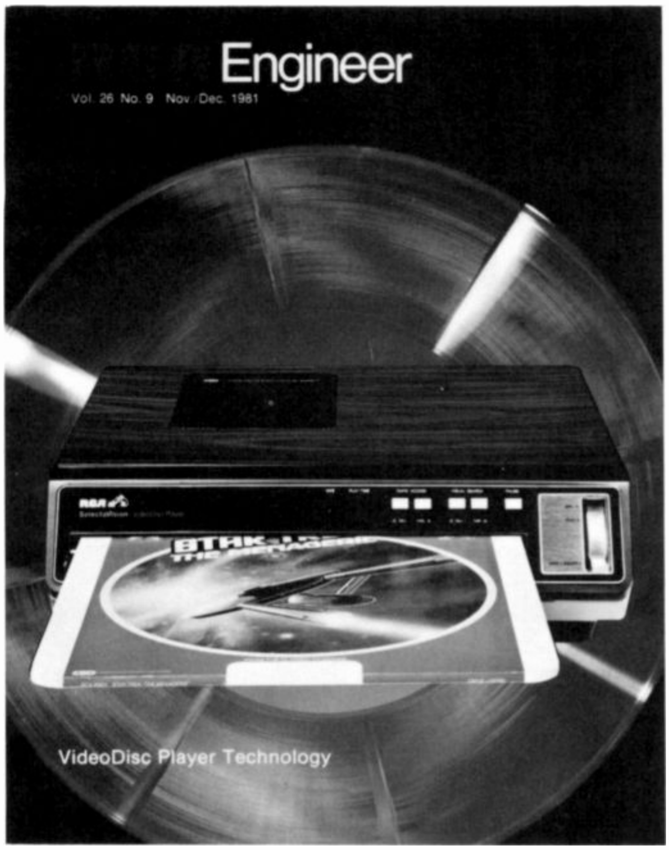
RCA Engineer

Vol. 26 No. 9 Nov./Dec. 1981

VideoDisc Player Technology

Cover design by Louise Carr



On the cover: The "SelectaVision" SFT100W VideoDisc player, shown in the foreground, is the primary subject of this issue. The Jan./Feb. 1982 issue of the *RCA Engineer* will describe disc technology in detail.

These timely information packages on the capacitance electronic disc "CED" system are made available to engineers throughout RCA because

- the engineers and scientists who developed the product *made* time to document their work, and because
- we had assistance from Nelson Crooks, "SelectaVision" Operations' Technical Liaison, who orchestrated and expedited this difficult publications project.

Nelson and these engineers make the well-worn maxim, "If you want a job done, give it to a busy person," seem newly written.

RCA Engineer

A technical journal published by
RCA Research and Engineering
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Cherry Hill, NJ 08358
TACNET: 222-4254 (609-338-4254)

•To disseminate to RCA engineers technical information of professional value •To publish in an appropriate manner important technical developments at RCA, and the role of the engineer •To serve as a medium of interchange of technical information between various groups at RCA •To create a community of engineering interest within the company by stressing the interrelated nature of all technical contributions •To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field •To provide a convenient means by which the RCA engineer may review his professional work before associates and engineering management •To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

J.J. Brandinger

RCA's "CED" "SelectaVision" VideoDisc

The RCA "SelectaVision" "CED" VideoDisc System is a miracle in new technology. This miracle is best characterized by the discs on which are recorded the equivalent of 200-billion information elements representing two hours of color television programming.

With the March 22, 1981 introduction of the "CED" VideoDisc system, RCA launched another new industry. This breakthrough will forever change our lives.

The ability to see and hear what we want when we want it, gives each of us new freedoms of choice. Each of us can become the discriminating connoisseur of what entertainment we will watch, how we will be educated and what messages will inspire us. Adventure, science fiction, comedy, mysteries, drama, sports, information, and inspiration are literally as close and as immediate as we desire.

I am personally proud of the team at Rockville Road and Bloomington where we have assembled some of the best minds from many other RCA divisions and elsewhere to create technical and manufacturing skill centers second to none. To support these efforts, our research laboratories in Princeton, New Jersey have provided key inventions and developments. In addition, Consumer Electronics melded their unique skills with ours to create a viable product, and Bloomington has converted the engineered product into a manufacturable, saleable player. I would also be remiss if I did not acknowledge the support of the Record Division with their unique disc packaging skills. If I seem proud of our team's effort — I am. I want to personally thank each of you who has participated for your commitment and dedication, which has successfully fulfilled the promise made two years ago when we told the world that we would introduce our system in the first quarter of 1981.

It is indeed exciting to be where history is in the making. We who are in the VideoDisc Operations are working as a team to introduce and develop the best products and services for people the world over. We are moving forward into the future, growing, evolving, and creating. There are, virtually, no limits to our potential for the future, for we here at RCA are truly a "Tradition on the Move."

Jay J. Brandinger

J.J. Brandinger
Division Vice-President and General Manager
"SelectaVision" VideoDisc Operations

RCA Engineer

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system overview

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the player's mechanical design

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the player's electrical design

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regulatory considerations

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player quality assurance

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general interest

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departments

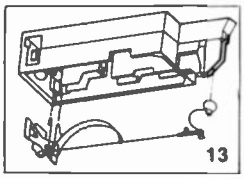
in this issue...

VideoDisc player technology

- *"[Members of the team] faced many alternative, undeveloped paths. They would need to push the state-of-the-art in new technologies, just to get started."*

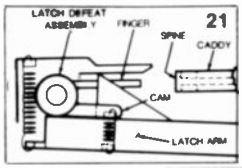
- *"This paper provides an overview of the entire system, to help the reader to understand how each of the detailed papers relates to others."*

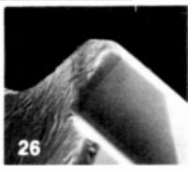
- *"The 'CED' system parameters have been carefully chosen to ensure that the player can be manufactured at a cost that will make it available to the mass consumer market."*



- *"The user was to provide operating forces where possible; thus, the player became more mechanical in nature."*

- *"The cartridge is the first critical building block in reproducing a TV picture from recorded signals in a VideoDisc."*





- *"Included in the VideoDisc signal retrieval system are the pickup housing assembly and associated support circuitry of the PW500 control board as well as the pickup-housing drive motor and gear assembly."*

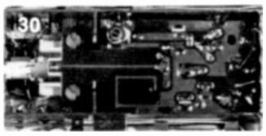
- *"The purpose of the nonlinear aperture corrector (NLAC), which is the first circuit to process the signal emerging from the arm, is to reduce this (nonlinear) distortion."*

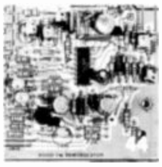
- *"The device was specifically designed for application in the VideoDisc player and.. it efficiently replaces extensive discrete circuits."*

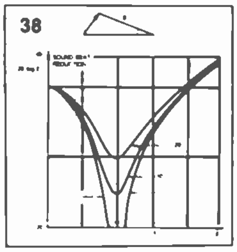
- *"The use of a lower chrominance-subcarrier frequency 'buried' in the luminance frequency band requires that comb-filter techniques be applied...."*

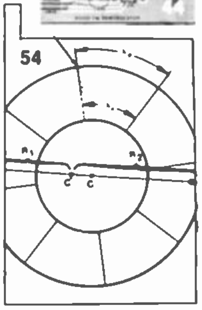
- *"...we found that it was practical to implement a large portion of the circuitry required for these functions on one integrated circuit, the video-converter IC."*

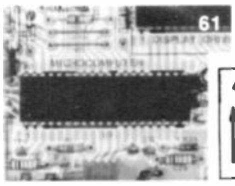
- *"The digital control system, from stylus location via DAXI code to stylus control via adaptive kicking, represents a significant new direction in the design of a home entertainment product."*

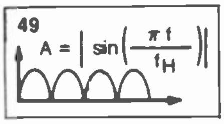






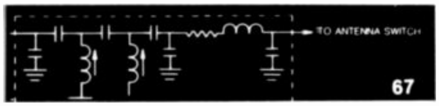






- *"In order to interface the VideoDisc player with the TV receiver, the composite video and audio signals are modulated on an RF carrier."*

- *"Radio frequency interference and safety were prime concerns for the player's designers."*



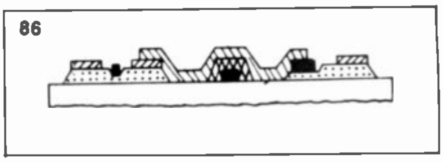
70 *RFI design considerations*

- *"The purpose of systems such as MACS is to provide manufacturing management with information that will aid in improving the manufacturing process."*

- *"Everyone participating in the VideoDisc program wants to deliver to the consumers a player of outstanding quality."*

- *"We used these high-speed switching properties of the GaAs FETs to develop low-power, medium-speed, medium-scale integrated circuits."*

- *"Several applications became apparent, but the most interesting and least costly to me was the idea of transmitting international Morse code using a microprocessor."*



in future issues...

disc technology, manufacturing engineering

J.K. Clemens | E.O. Keizer

The early days of the "CED" system

"In 1960, a new concept for signal readout was proposed. . . ." Since then, the 1973 "February player," shown here, was just one step on the road to a marketable product.

Abstract: *The authors present the problems faced by the VideoDisc engineering team, giving the milestones on the path to market introduction of the system. This paper shows how the technology of the "CED" system evolved to its present form.*

Before 1965

In the 1950s, fresh from helping launch color TV, some people at RCA Laboratories turned to the challenge of home video recording. In 1956, they demonstrated to RCA's Board Chairman, General Sarnoff, an experimental "hear-see" player that used magnetic tape. Magnetic tape appeared to be well-suited for home recording and playback of off-the-air programs. Since it could be erased and used again, its initial cost could be spread over a number of programs, making the cost per program quite reasonable. For prerecorded programs, however, the total cost per program — for the materials plus the recording process, plus the program content — seemed to be too high for mass acceptance. Thus, there appeared to be a need for a less costly way to deliver prerecorded video programs to homes, programs that could be selected by a consumer and viewed at any time.

During 1953, RCA Laboratories began a small effort to look into extending audio phonograph technology to video storage and playback. Disc material and replication costs both would be significantly less than for videotape. However, recordings would require much smaller signal elements than audio recordings, signals with smallest dimensions of less than one micrometer — about the same as a wavelength of visible light — and it was not clear that they could be made and reproduced. A report following this and other work concluded that plastic discs with such small signal elements probably could be pressed, but no practical means then existed for recording or for recovering signals from such small signal elements.

In 1960, however, a new concept for signal readout was proposed. By electronically sensing variations between the disc and the edge of a thin conducting film on a special stylus, very small signal elements theoretically could be detected. With this concept it appeared that the player as well as the disc could be cost effective.

In 1964, RCA Laboratories organized a four-man team to develop a home video disc playback system. The system would:

- Produce a high quality picture on a home TV set.
- Be capable of high quality sound reproduction.
- Use low-cost, long-play program discs.
- Use a low-cost player.

The team, at the outset, decided that a player cost of not more than half the cost of a home videotape recorder would meet the "low-cost" requirement for the player.

In spite of the earlier work, members of the team knew they had a Herculean task before them. They faced many alternate, undeveloped paths. They would need to push the state-of-the-art in new technologies, just to get started. They could get bogged down easily by following too many paths, the wrong paths or by meeting enormous difficulty with a critical path. Colleagues understood the problems. About 90 percent of them thought the project never would succeed. Even later, after some initial progress had been shown, one colleague offered to "eat his hat" if the system worked.

The team undertook a two-step program to test and develop the basic signal recovery method; and then, based on the signal recovery, develop technology to implement a basic full-scale system, continuously improving the signal channel and its use.

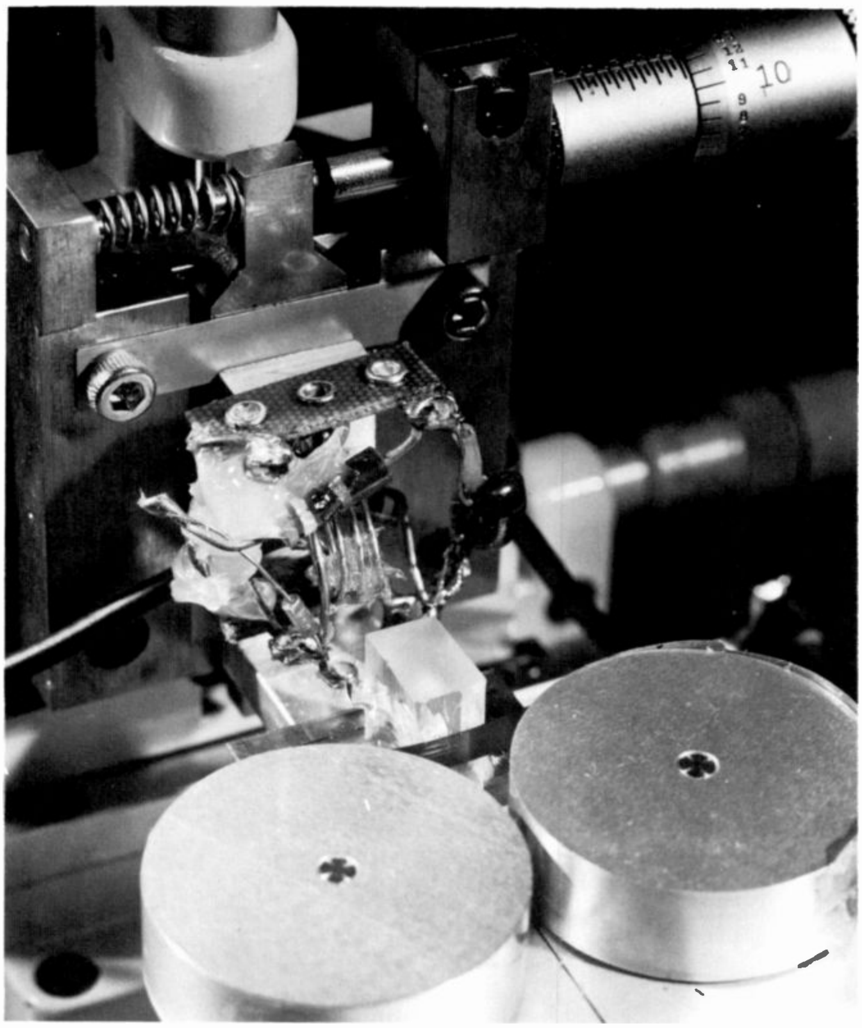
Gradually involving more people, this program lasted for about five years (1965-1970). Much of it was "blind" because individual parts of the system couldn't be tested until the full system had been implemented.

1965-1971

Tests of the basic readout method paced the entire project because the form of implementation of all parts of the system depended on the results. Difficulty with attempts to test readout with small signal elements led to tests with model styli and disc signal elements scaled up from proposed sizes by a factor of 10,000.

These tests gave definitive results. Along with concurrent theoretical analysis, they showed that best results would be obtained with a single-electrode stylus configuration and with dielectric-coated conductive discs. They confirmed that the capacitance readout technique with a conductive

Reprint RE-26-9-1
Final manuscript received Sept 8, 1981



Tiny Tester. Embossed with a microscopic signal pattern, a metallized Mylar tape moves back-and-forth across a stationary "stylus" to test capacitive pickup in this 1967 setup. To make the "stamper" for embossing the Mylar, the electron beam of a scanning electron microscope exposed a line pattern in a "resist coating" on a half-inch diameter metal substrate. After chemical development of the resist, the resulting contour pattern served as a mask during an r.f. sputtering process by which corresponding contours were formed in the substrate itself, which then was used as the "stamper."

disc should have enough resolution and sensitivity to recover a prerecorded video signal.

Following the initial tests, the researchers concentrated on developing real-scale technologies so a complete system could be tested. During the late 1960s, they developed:

1. A method of recording spiral grooves with fine pitches of thousands of turns per inch.
2. Optical, mechanical, and electron beam techniques for recording signal elements as short as 1 millionth of a meter (1/25,000th of an inch) in a disc master.
3. Signal systems for providing TV picture and sound signals at uniform, slowed-down rates, precisely synchronized for either mechanical or electron-beam recording of a disc master.
4. Methods for making metal stampers and plastic discs from the masters.
5. Processes for putting conducting, insulating, and lubricating coatings on the discs.
6. Technology for fabricating new, composite types of styli, with tips 10 times smaller than tips on audio styli.
7. Ultra-sensitive circuitry to detect capacitance variations.
8. Player mechanisms that include accurate tracking of the fine-pitched groove.
9. Player signal systems that reprocessed the signals recovered from full-color pictures and high quality sound.

In 1970, the system produced its first pictures — barely recognizable monochrome pictures that took 200 times as long to record as to play back. In 1971, it produced better ones and even fairly good color pictures by the end of the year.

The 1971 system used a disc the same size as an audio record, but with much finer grooves. The discs were coated with conducting, insulating and lubricating films. They were played back using the capacitive pickup technique, with electroded sapphire styli. The discs were made from either electron beam or electro-mechanical recordings.

As developed, the capacitive pickup technique could detect sub-micrometer-sized signal elements. Resolution was limited only by the thickness of the electrode along the groove and the distance between the edge of the electrode and the recorded signal elements. Resolution did not change significantly with wear. The stylus body could wear, but the electrode edge dimension along the groove remained nearly constant. The high resolution of the pickup relative to other pickup types permitted use of lower player turntable rotation speed, which translated into longer play time for a given groove pitch.

The signal encoding system used an FM carrier for the video information and separate FM carriers for the audio information, the video and audio carriers being combined to form a single information track. A buried-subcarrier color-multiplexing system was devised. Using comb-filter technology, it placed the color signal in the same frequency band as the luminance signal. This allowed use of a lower frequency for the video FM carrier, which increased playing time.

By 1971, a number of systems using alternate technologies had become known. As they were recognized, they were carefully assessed, often by an extensive building and testing effort. Ultimately, RCA decided that the capacitive pickup system, now known as the "CED" system, would provide the lowest-cost, longest playing time of any known system, and would best meet its guidelines for a home prerecorded video player.

1971-1976

High priority product development followed the system decision. Additional people were assigned to the research teams in Princeton and the small supporting-type efforts at Indianapolis in the Record Division and Consumer Electronics Division soon became substantial co-efforts.

Recording technology

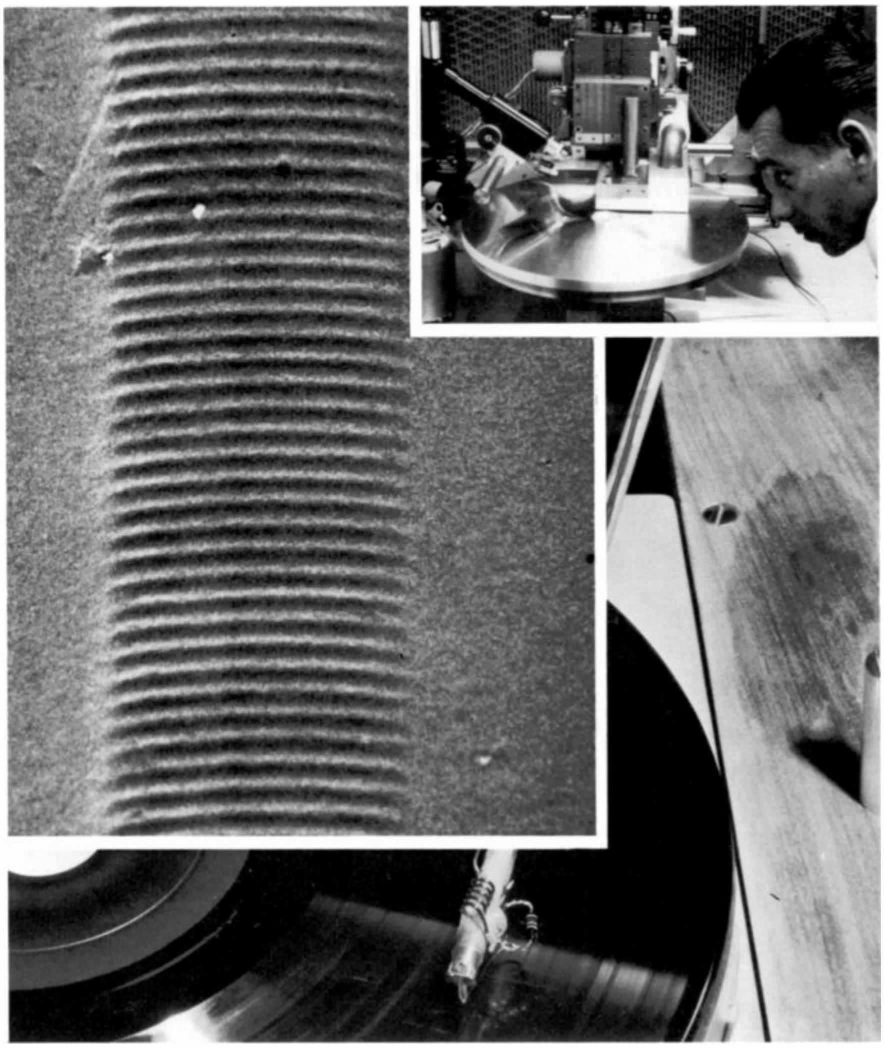
In one of the larger team efforts, the following years saw step-by-step improvements in electron beam mastering speed. The speed doubled every seven months until 450 rpm real-time recording was achieved in 1974.

During the same period, a small but persistent effort was continued on electromechanical recording. In 1974, tests showed that copper could be cut more smoothly than lacquer, and with less loss of high frequencies. This, and development of increasingly smaller piezoelectric cutterheads, led to a few experimental real-time electromechanical recordings being made in 1976.

In the mid-1970s, using the latest laser technology, optical mastering was explored vigorously. From the beginning, it achieved real-time recording speed. However, there were technical difficulties in obtaining the optical resolution to make 0.25-μm signal elements and in avoiding undesired standing wave patterns caused by optical reflections from the bottom of the grooves.

Disc pressing methods

Throughout the early stages of the project, all test discs had been pressed by compression molding, the standard production technique for 12-inch diameter audio discs. For VideoDiscs, with their shallower grooves, injection molding had several possible advantages. Thus, in 1973, injection molding was chosen for production. The first injection press was installed in the RCA Rockville Road plant in July, 1975.



Making Tracks. Developed from a commercial jigbore, the precision disc lathe shown at the upper right proved to be of great use throughout the project. Normally equipped for machining ultrasmooth surfaces on 14-inch diameter substrates, it easily was adaptable for other uses, including slow-speed optical recording of test signals. Equipped with high quality optics, a high-pressure mercury vapor lamp, and a mechanical light-beam chopper, it generated a circular track of high resolution test signal contours with wavelengths as short as 0.6 μm. These patterns were replicated in metal and used in an audio record press to make vinyl records. At the upper left a scanning electron microscope photo shows the surface of such a pressed disc, with a segment of a full turn of signal pattern that had been pressed into the disc. After the disc was coated a capacitive pickup of the type shown at the bottom of the composite figure retreived the signal. In the first such recording, a handling slip caused a deep scratch that cut right across the signal path. Suprisingly, the pickup with its long, lightweight tone arm was not derailed by the scratch and successful pickup of a 4-MHz signal was achieved at a turntable speed of 360 rpm.

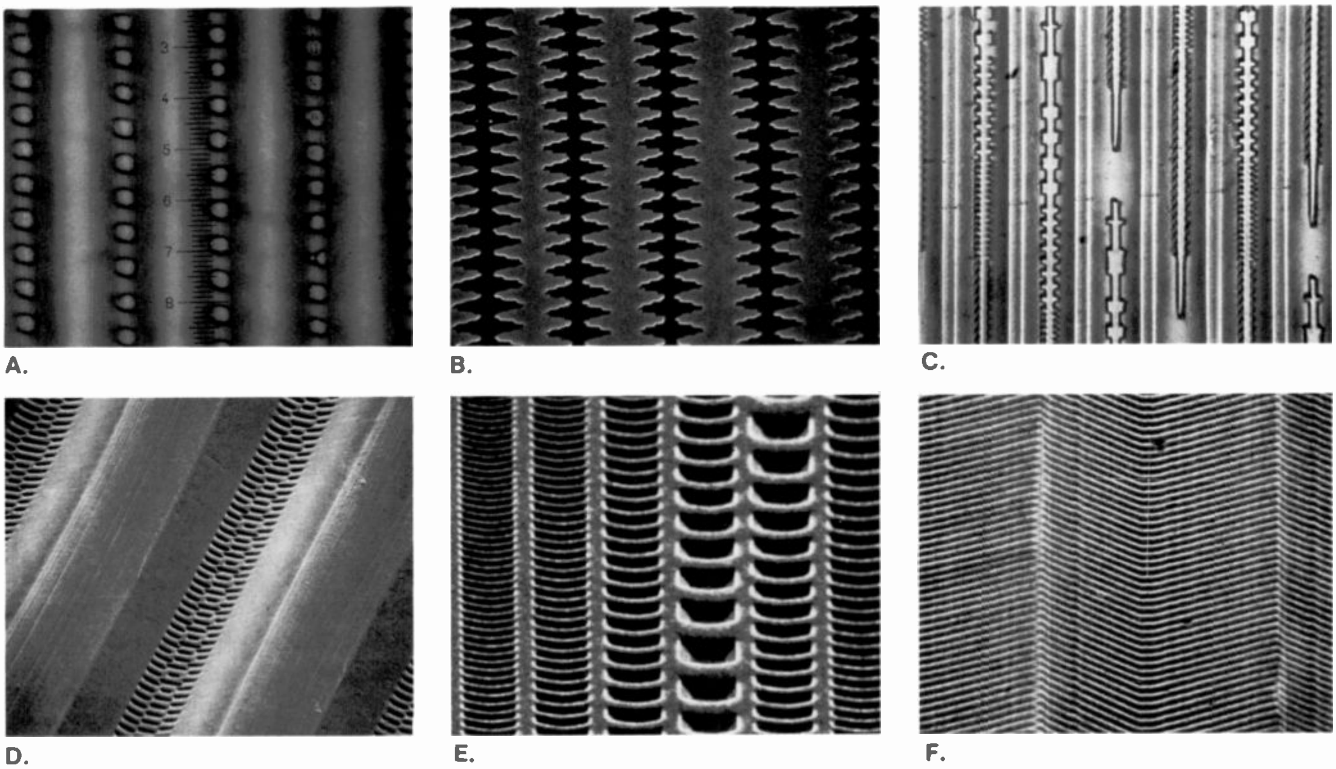
Disc coating processes

In 1971, discs were made by first pressing them from a standard vinyl compound, then coating them in sequence — with a thin metal layer to provide conductivity, with a thin durable dielectric layer, and finally with a lubricant layer to prolong the life of the stylus and disc. Evaporated aluminum, used initially, proved too grainy. Evaporated gold produced better pictures, but was too expensive. In 1972, evaporated or sputter-deposited copper replaced the gold. By 1975, however, it was confirmed, as

Patterns, patterns

The array of signal patterns, shown in Figs. A-F, illustrates the shifting focus of the project. In the early stages, patterns such as (A) and (B) served to test the signal pickup technique. The progress in recording technology permitted flexibility in the types of patterns that could be generated, as well as ability to generate them in full-sized grooved masters. Patterns such as (C) and (D) supported the concurrent investigation of alternative signal modulation schemes for the VideoDisc system; frequency modulation was the winner. Patterns (E) and (F) illustrate electron-beam and electromechanically generated patterns, respectively.

Although high-power optical microscopes were very useful in inspection of signal patterns, scanning electron microscopes provided the greater resolving power and depth of focus needed for evaluation of micrometer-sized contours. It was fortunate, then, that scanning electron microscopes became available commercially just in time to be used in the development of VideoDisc technology. The demand for their use was such that several of them were purchased for, and used full-time, on the VideoDisc project.



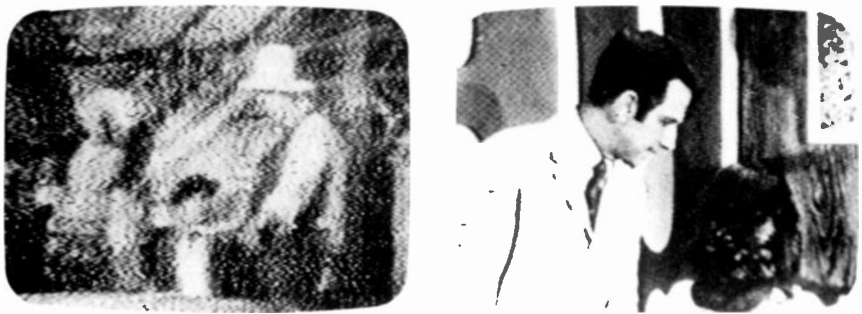
Patterns Patterns. A. Pattern produced in 1967 on the ridges of a smooth groove nickel stamper by optical exposure through a thin resist coating. The "signal elements" were then built up on the stamper by electroplating through the exposed areas after chemical development had removed the resist from those areas. **B.** Variable-width signal pattern produced in a scanning electron microscope by scanning the beam from side-to-side. **C.** Modulated variable-width pattern produced in 1970 in the first full-scale electron beam recorder. **D.** Electron-beam generated signal pattern used in 1971 to test a balanced amplitude-modulation signal system. **E.** Electron-beam generated sweep frequency pattern used in 1972 system tests. **F.** Electromechanically generated pattern. Note V-shaped groove used once choice was made to use electromechanical recording for production mastering.

feared, that under certain conditions, the copper would corrode in spite of being coated with a dielectric. With considerable effort, a copper-inconel bimetal sandwich conductive layer was developed that passed all corrosion tests.

In early disc-coating experiments, coatings were applied layer by layer, one side at a time, in individual bell-jar setups. Soon it was clear that coating of discs this way would be a bottleneck in production. To coat discs economically, a highly automated process was needed. After engineering studies with an outside firm showed such an "Autocoater" was feasible, it was ordered in 1974. During 1976, Indianapolis teams pressed some 240,000 experimental discs and coated about 120,000 of them.

Dust and environmental problems

In 1976, using 25 players from an engineering pilot run and discs with durable coatings, Indianapolis conducted a private "field test." This test uncovered field problems sufficient to cause an intensive reassessment of production readiness. After exposure to dust, high humidity, and high temperature, the dust bonded to the



A.

B.

Early recording progress.

A is a photograph of a picture reproduced in October 1970 on a TV screen while playing a disc made from an electromechanical recording. **B** shows the progress made by April 1971 (electron-beam recording). Whether made by electromechanical or by electron beam techniques, early recordings were time-consuming. At first, each minute of play time required several hours of recording time. To supply signals at the slow rate, special signal generating and processing equipment was developed. A flying-spot scanner provided high quality signals from 35-mm film at rates slowed down by factors in the range of 20 to 400. Later, a video slow-down processor, developed for the video disc project by RCA's Missile and Surface Radar Division in Moorestown, New Jersey, was used for recording rates slowed down by factors of 5 to 20. These were not needed for electron beam recording after 1974. For production electromechanical recording, a two-to-one slowdown was chosen; a third type of slow-down equipment was then developed for this rate.

Eugene Keizer, now Staff Scientist in the VideoDisc Systems Research Laboratories at Princeton, New Jersey, joined RCA in 1940. Since then he has worked in several areas, principally radar, FM and television receivers, television display systems and prerecorded video disc systems. As the responsible group head, he led the video disc research team during its early years, 1964-1971, and continued to be responsible for research in the video disc mastering and pickup areas until 1979. In 1979 he became associated with RCA "SelectaVision" VideoDisc Operations at Indianapolis, returning to RCA Laboratories in 1980.

He has sixty patents, an Achievement Award for receiver circuit work, David Sarnoff Awards for color TV work and for video disc work, and an Eduard Rhein Award for video disc work.

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Jon Clemens is Director, VideoDisc Systems Research Laboratory. He joined RCA Laboratories in Princeton, New Jersey, after receiving a Ph.D. in Electrical Engineering from M.I.T. During the years 1965 through 1970, he worked on various approaches to video disc systems and conceived the capacitive pickup video disc system used by RCA today. During the next years, his work included all aspects of system development. In 1975, he was appointed Head, Signal System Research, with the primary responsibility for developing the VideoDisc signal system for both mastering and player design. He has received three RCA Laboratories Outstanding Achievement Awards, the Eduard Rhein Prize, and the David Sarnoff Award for his contributions to the "CED" VideoDisc system.

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discs, creating a plethora of defects that caused severe stylus mistracking, even stylus breakage, as well as episodes of signal loss due to debris under the stylus.

Later in 1976, intensive work began on a protective sleeve or "caddy" for the disc. A disc would always be in its caddy except when automatically extracted for play within a dust-protected player compartment. In laboratory tests, caddies protected discs even against prolonged exposure to wind-driven dust.

1976-1979

The 1976 reassessment dealt with the whole system, with particular emphasis on manufacturing costs and product reliability, and important system decisions were made. Electron-beam recordings were made with a nearly doubled groove density, extending the playing time to two hours per disc. Studies had shown that 90 percent of all feature-length movies could be contained on one such disc. The economic advantage was compelling and the finer groove pitch (of nearly 10,000 turns per inch) became the "standard." However, since it cost less and could produce recorded masters with less noise and fewer defects, electromechanical recording was selected as the production recording method.

The narrowed groove required a smaller tip on the stylus, making it more likely to break or wear out. Sapphire styli, for which elegant technology had been developed, were replaced by diamond styli. The main benefit of the switch was the much greater resistance to breakage of diamond styli.

In January, 1977, the first successful discs using conductive compound were pressed. With good dispersal of tiny, 300-A diameter, carbon particles throughout the vinyl, discs with adequate conductivity characteristics could be pressed. The signal-to-noise of signals recovered from these discs was within a few dB of that from coated discs. The main advantage of the conductive disc resulted from the elimination of all coatings except the lubricant. The need for the expensive Autocoater was thus eliminated. However, the carbon-loaded vinyl was too stiff to be

State-of-the-art in 1976 at the RCA "SelectaVision" VideoDisc facility in Indianapolis. A. A pre-grooved master is mounted in an electron-beam recorder for mastering. **B.** Finished discs are stacked by a mechanical arm after leaving the coater, where metal, dielectric and lubricant layers were automatically deposited on the surface of the discs. **C.** A bank of pencil-like devices holds sapphire rods that are being shaped into stylus tips. RCA was growing its own supply of sapphire rods at the time. **D.** An automated tester screens finished discs in one of several methods of playback performance evaluation, which also included field tests with engineering model players.

injection molded, so pressing again was done by compression molding.

Beginning in the early 1970s, many succeeding generations of experimental players were built — several hundred players in all. Each generation came from intensive engineering efforts to make the player better, simpler, easier to use, and more reliable than its predecessors. By the late 1970s, when home videotape recorders were being marketed nationally by RCA, it was clear by comparison that VideoDisc players could be built with far fewer parts, especially fewer critical parts, and should cost only about half as much to build.

By the end of 1978, RCA had made arrangements for a varied and extensive catalog of programs to record. In January 1979, after more than a decade of homework, RCA announced its plans to make "SelectaVision" VideoDiscs and Players and market them on a nationwide basis starting early in 1981. Two years is a very, very short time for gearing up to large-scale production and distribution of an entirely new product. The ensuing effort was even more intense than earlier ones — some of the results are described in the companion articles in this and the next issue of the *RCA Engineer*.

The development of the "CED" system was characterized by the dedicated efforts of many people both technical and nontechnical, both management and non-management. Throughout the years the authors have had an exciting and rewarding time working with them and wish to express appreciation to all who have helped bring the system to fruition.

Bibliography

Readers who wish to delve further into the development of the "CED" system may also refer to the March, 1978, issue of *RCA Review*, Vol. 39, No. 1, which is devoted entirely to the RCA "SelectaVision" VideoDisc System.

H.N. Crooks

Introduced to the American market in March 1981, RCA's best technology for a major consumer electronics product is in...

The RCA "SelectaVision" VideoDisc System

Fig. 1. The VideoDisc is 12 inches in diameter and 70-mils thick. The TV signal is recorded in a spiral groove—10,000 grooves per inch—about 40 times as many as on an audio-LP record. The disc material is made electrically conductive by the addition of 15 percent of finely divided carbon. In playback, the disc rotates at 450 revolutions per minute.

This issue of the *RCA Engineer* and the issue to follow contain papers describing various aspects of RCA's recently introduced "SelectaVision" VideoDisc System. Each paper describes a specific part of the system and an effort has been made to eliminate nonessential duplication of information. This paper provides an overview of the entire system to help the reader to understand how each of the detailed papers relates to others.

As described in the paper by Keizer and Clemens (page 4), the VideoDisc program has been underway at RCA for about sixteen years. The system that has evolved from this work has resulted from many trade-offs including technical, marketing, and economic considerations. The system, introduced to the American market in March 1981, is RCA's best estimate of what will be the basis for a major consumer electronics product.

The disc

The VideoDisc System comprises a flat circular plastic disc, 12 inches in diameter, as shown in Fig. 1, upon which television signals are recorded in a spiral groove. Although similar in appearance to an audio LP disc, the details of the recorded information are quite different. For example, there are nearly 10,000 grooves per inch of radius, which is about 40 times that of an audio disc. Information is recorded as vertical undulations of a V-shaped cross-section groove, as shown in Fig. 2. These undulations are about 1500-times smaller in amplitude and 15-times smaller in wavelength than those on an audio disc. Because of the very small dimensions of the information elements on the disc and in order to protect the surface from dust, fingerprints and other contaminants, we have chosen to encase the disc in a plastic cover, or caddy, as shown in Fig. 3. The disc is kept there at all times except when it is being played in a player.

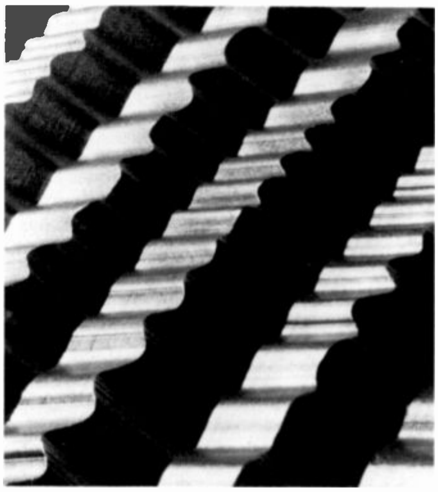

Fig. 2. Photograph of a model of the VideoDisc surface. Center-to-center spacing of the grooves is 2.5 micrometers. Information is recorded as frequency-modulated vertical undulations in the bottom of the V-shaped groove. On playback, the frequency varies from 4.3 to 6.3 MHz.

Fig. 3. VideoDisc caddy. Because of the very small dimensions of the recorded information, the disc is kept in a protective plastic sleeve, or caddy, at all times except when being played in a player. The plastic frame surrounding the disc, called a spine, serves to move the disc into and out of the protective sleeve when the disc is inserted into and retrieved from a player.

Reprint RE-26-9-2
Final manuscript received Sept. 11, 1981

Recording and pressing

In the recording operation, television signals read from a magnetic tape are encoded into two FM signals, one for video and one for audio, which are added together to provide a composite signal that is used to drive a recording cutterhead. The cutterhead, fitted with a super-sharp diamond cutting stylus, cuts the undulating V-shaped groove in a copper-coated aluminum substrate. To increase reliability, the recording operation is done at half the real-time rate, that is, two hours are required to record a one-hour program. The end result of the recording operation is a copper-plated disc containing the same topographic signal pattern as desired in a finished disc.

To press the signal patterns into a plastic disc, a negative of the pattern recorded in the copper substrate is required. This negative is provided by electroforming nickel on the copper. As in the audio recording industry, we call this negative a "master." When the master is heated and pressed into hot vinyl, the topographic pattern of the copper substrate is reproduced in the vinyl surface. If the master is cooled before being removed from the vinyl, the pattern is retained permanently in the vinyl.

Because only a limited number of discs can be pressed from a set of metal negatives (one for each side), we normally make positive metal copies, called "mothers," from the masters by nickel electroforming, and from these positive mothers, we make negative replicas by nickel electroforming, which we call "stampers." The stampers are then used for pressing discs. The reason for using the master-mother-stamper sequence is to enable a greater number of discs to be made from one recording operation. At each stage of the process several electroformed copies of the earlier part can be made. The fan-out is such that a large number of stampers result from one recording operation.

The vinyl compound from which the discs are pressed is especially formulated for the VideoDisc. It includes finely dispersed carbon to make it conductive and various additives to aid in the molding operation. After the discs are pressed in a multiton automatic record press, they are washed and then covered with a thin film of oil to provide lubrication and long playback life of both stylus and disc.

Playback

In playback, information is retrieved from the topographic signal patterns pressed into the vinyl through the use of a capacitive stylus, giving rise to the system descriptor "Capacitance Electronic Disc" or "CED." The capacitive stylus consists of a pointed diamond, the end of which is shaped to fit the grooves on the disc, and a thin metal electrode affixed to one surface, as shown in Fig. 4. The foot of the stylus that rides in the groove is long enough to cover several of the longest recorded wavelengths. As a result, the stylus rides on the crests of the waves pressed into the grooves and, ideally at least, suffers no high-frequency motion either vertically or horizontally as the disc is played. As a consequence, the disc surface rises and falls under the stylus electrode, giving rise to a stylus-disc capacitance variation which can be calculated to be about 1 x 10^{-16} farads, or one ten-thousandth of a picofarad, peak to peak. This very small change in capacitance constitutes the disc readout signal.

The stylus-disc capacitance is made part of a resonant circuit with a resonant frequency of about 910 MHz, as shown schematically in Fig. 5. This circuit is excited with a signal from a 915-MHz oscillator. As can be seen in the figure, the 915-MHz signal falls at about the half-amplitude point on the resonance curve. As the stylus-disc capacitance changes, the frequency of the resonance peak also changes, causing a change in the response of the resonant circuit to the 915-MHz oscillator signal. As a result, the 915 MHz passed through the stylus' resonant circuit is amplitude modulated by the capacitance variation. Demodulation with a diode detector recovers the modulating signal from the amplitude-modulated wave. This signal rises and falls as the disc surface rises and falls under the stylus and thus reproduces the signal that drove the cutterhead during recording. The video and audio signals are recovered from the composite FM signals by FM demodulators, compensation for disc defects is applied to the signals, and the signals are then converted to NTSC format (U.S. television standard) to drive television sets on either channel 3 or 4.

A disc is played by inserting the caddy (containing the disc) into a slot on the front of the player (Fig. 6),

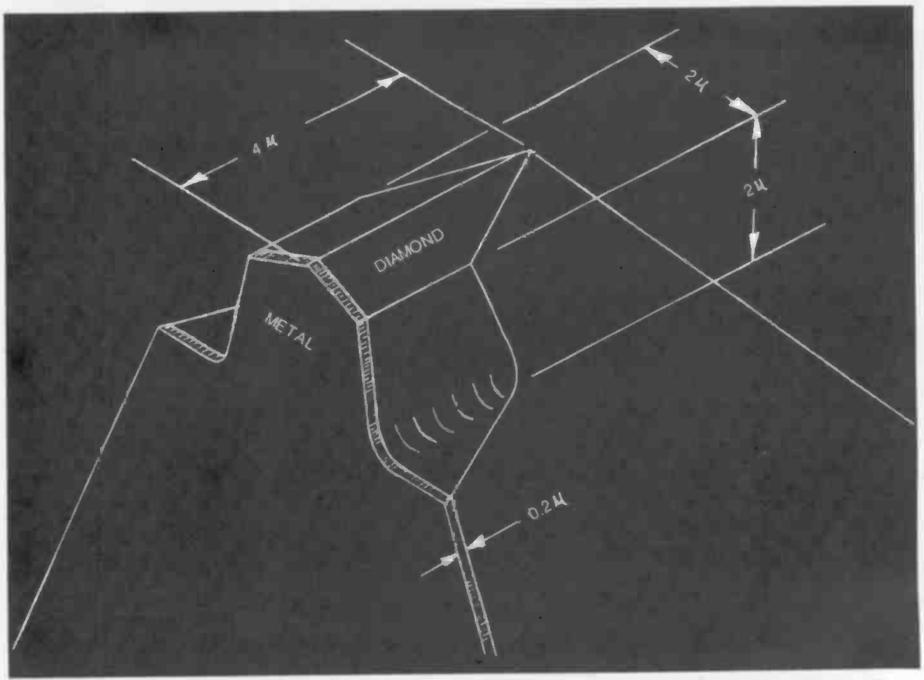

Fig. 4. The stylus is made of diamond with a thin metal electrode on one face. The end of the stylus is shaped to fit the groove and long enough to cover several of the longest recorded waves. The sides are cut away to provide a "keel-lapped" shape which gives long-play life as the end of the stylus is worn away. The end of the metal electrode is one plate of a capacitor, the disc is the other plate, which varies in value as the disc is played and provides the read-out signal.

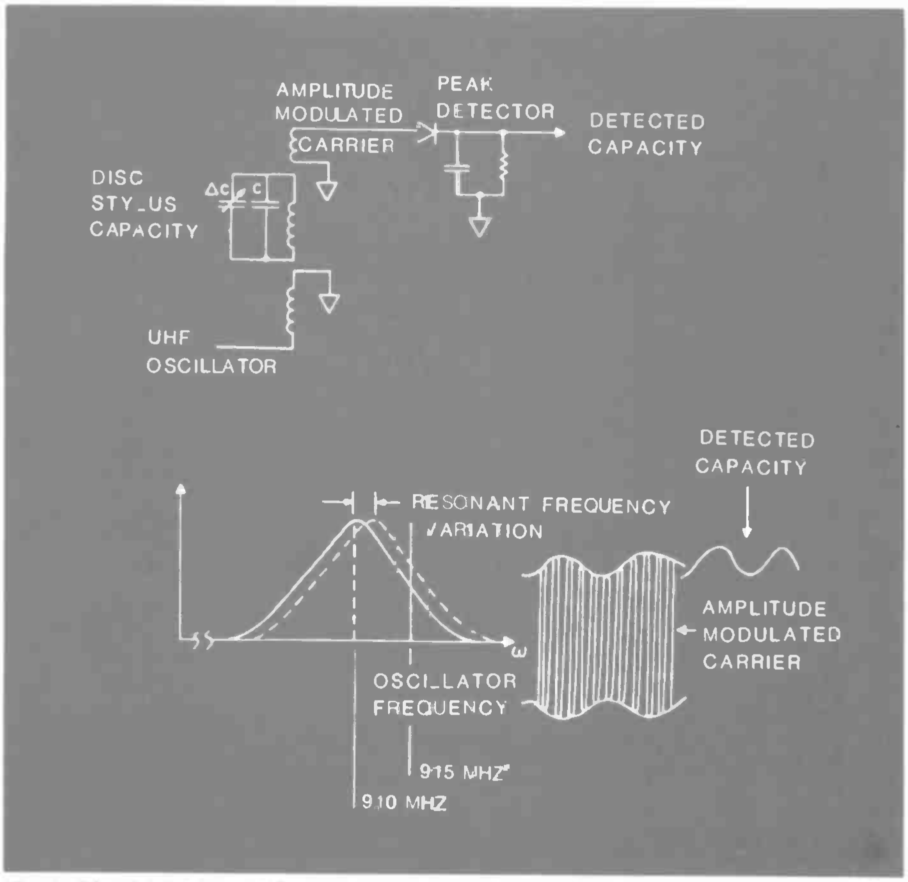

Fig.5. Disc-stylus capacitance is made part of a circuit resonant at ~910 MHz. As the capacitance changes, the resonant frequency changes, giving rise to a variation in the response of the circuit to a 915-MHz signal and providing amplitude modulation of this signal. The modulation is stripped off by a diode detector to provide a voltage that rises and falls as the disc surface rises and falls under the stylus.

removing the caddy, and then throwing the function lever to the PLAY position. At the conclusion of play, the disc is retrieved by throwing the function lever to LOAD/UNLOAD and reinserting the caddy into the player. When the caddy is withdrawn, it brings the disc with it, locked inside the protective cover.

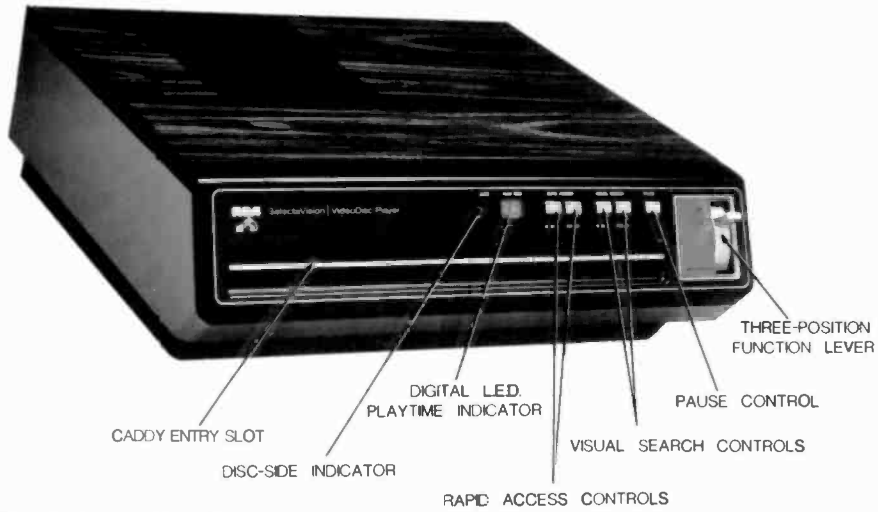

Fig. 6. VideoDisc Player SFT-100. The controls and indicators on the VideoDisc player make it simple enough that even a child can operate it.

Other features

Mechanisms and circuits in the player provide for the disc's removal and retrieval, indicate which side of the disc is uppermost in the player, rotate the disc at the proper speed (450 rpm), use time-base correction to correct for non-centered disc conditions, and use locked-groove correction to counter the effects of unavoidable disc defects. LED playing-time indicators, together with controls for rapid (150-times normal advance speed), visual search (16-times normal advance speed), and pause (for program interruption) are also included. The player measures 17-inches-wide, 15½-inches deep, and 5¾-inches high, weighs 20 pounds, and draws 35 watts from the power line.

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VideoDisc player design — an overview

Fig. 1.

The VideoDisc is the most exciting consumer electronics development since color TV. Hundreds of engineers and scientists within the RCA Corporation have been working during the last decade to perfect the Capacitance Electronic Disc "CED" system for the playback of high quality video information. This article is a very general overview of the introductory player with more technical details of the design contained in the other papers in this issue. Much of the information contained herein was first presented at Electro/81 and then at the IEEE 1981 Spring Conference on Consumer Electronics.

History

Before examining the details of the first production player, it might be interesting to quickly review some of the key development steps in the evolution of the player design (Fig. 1).

1973. The first model that had multiple engineering samples was built. Known by the engineering personnel as "the February player," it was the first to use 900-MHz arm electronics and had a playing time of 20 minutes per side using discs with 4,000 grooves per inch.

1975. A second engineering model (EM-2) was built in 1975 and had automatic push buttons to replace the manual controls in the first model. The EM-2 featured a line-locked turntable, velocity-error correction, and defect correction. Playing time had been increased to 30 minutes per side using discs having 5,500 grooves per inch.

1976. The EM-3 was the first player to use a cartridge close to the final form. This family of players was built in quantity using soft tooling.

1977. A design release for hard tooling was completed, and 35 players were built and designated as the SDT250. Players, up to this point, were operated with discs that were manually placed on the turntable by opening a lid on the player, much like manual audio turntables. By this time it had become obvious that the disc could not survive without protection, and the newly developed concept of a caddy allowed the disc to be handled in the player without exposing the disc to damage.

1978. A modified player, designated the SDT200, accepted a disc with a caddy. Playing time had been increased to one hour per side, and a diamond stylus was developed for improved life to replace the sapphire stylus used previously.

The cost and complexity of the SDT200 required one more design iteration to shrink the size mechanically and to reduce the electrical parts count by designing several custom integrated circuits. This program was accelerated in January of 1979 with the decision to go to market, and resulted in product delivery on schedule on

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Reprint RE-26-9-3
Final manuscript received August 19, 1981.

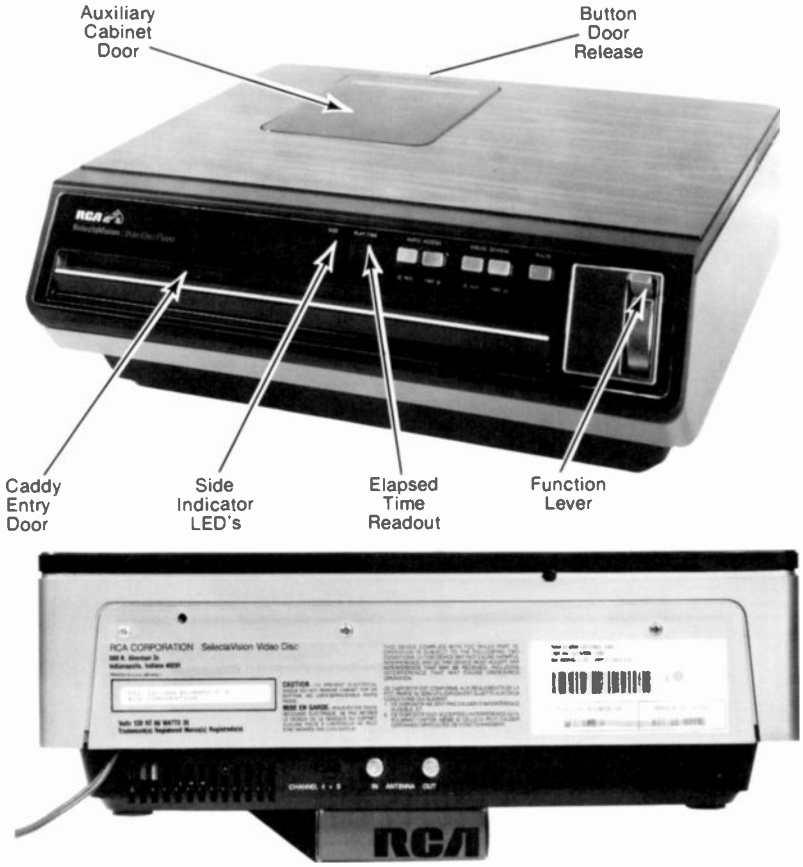


Fig. 2. The front-panel user interface features stylus-cartridge access locations. Rear-panel antenna-lookup locations are shown.

March 22, 1981. There were three primary design goals for consumer use: affordability, simplicity of operation, and reliability.

The RCA "SelectaVision" VideoDisc player, shown in Fig. 2, is a compact instrument measuring 17-inches wide, 5¾-inches high and 15½-inches deep. Its weight is 20 pounds and power consumption is less than 35 watts.

Installation of the player by the consumer is easy — rear-panel connections provide AC power, an antenna output connects to the TV receiver, and an antenna input provides signals to the TV when the player is not in use. A channel switch on the rear allows the user to select channel 3 or channel 4 for viewing VideoDisc programs.

To play a VideoDisc, the function lever is placed in the LOAD/UNLOAD position, which opens the caddy entry door. A VideoDisc, contained within its protective caddy, is inserted into the front-loading slot and pushed to the rear until fully seated within the player. The empty caddy is then withdrawn, leaving the disc in the player and the caddy jacket available for reference during play.

After moving the function lever to PLAY, the program will appear in approximately six seconds on channel 3 or 4, as selected by the viewer using the player's rear-panel switch. When viewing is completed, the function lever is returned to the LOAD/UNLOAD position, the empty caddy is reinserted into the player to recover the disc, and the process is repeated to play the second side or to view another disc. Returning the function lever to the OFF position will remove power and reconnect the external antenna input through the player's antenna output to the TV receiver.

Other front-panel controls provide user convenience during viewing. PAUSE provides muted audio and video until either the button is depressed again or one of the other customer controls is activated. Visual search, forward and reverse, allows visual searching of the disc program at approximately 16-times real time with the sound muted. Rapid access, forward and reverse, allows the user to quickly move across the disc at approximately 150 times normal speed with picture and sound muted, thus allowing any portion of a one-hour disc to be accessed in less than 30 seconds. Visual indicators on the player's front panel provide the disc playing time in minutes, referenced from start of play. Side identification is also provided for the disc being played.

Capacitance pickup

The RCA player uses capacitance pickup techniques to recover signals from a conductive disc. The audio and video FM carriers are cut as vertical modulation in a 140-degree groove (Fig. 3). Groove density is just under 10,000 grooves per inch, which allows one hour per side of playing time.

A mechanical stylus, whose length is several times the shortest wavelength of the signal elements, rides along the crests of the carrier (Fig. 4). An electrode is deposited on the trailing edge of the stylus. As the disc rotates, varia-

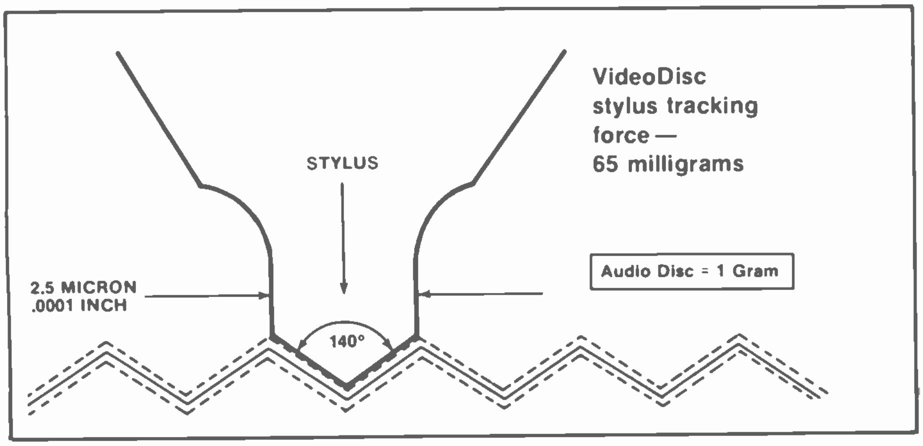


Fig. 3. Disc, groove, and stylus geometry is shown at approximately 10,000 magnification. Tracking force of the VideoDisc stylus is 15-times less than that of an audio system.

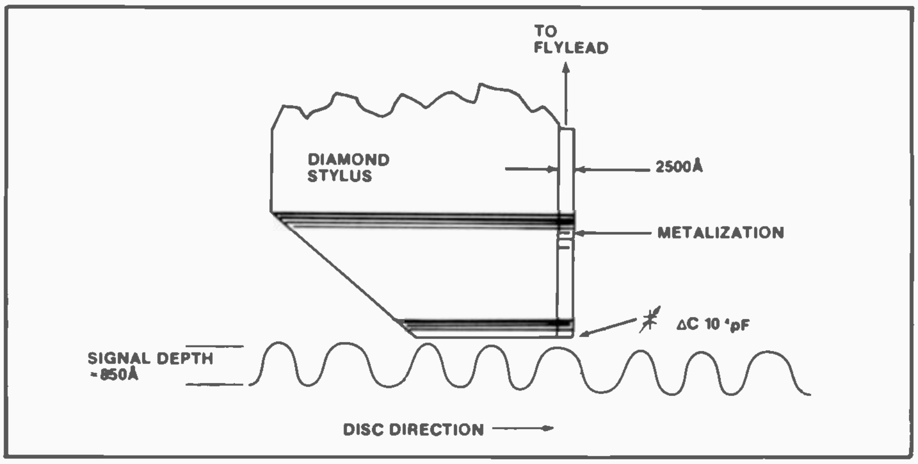


Fig. 4. Enlarged side view of the diamond-stylus/disc interface. Details of the metallization and signal depth are also shown. The signal generation, ΔC, is only 10^{-4} pF.

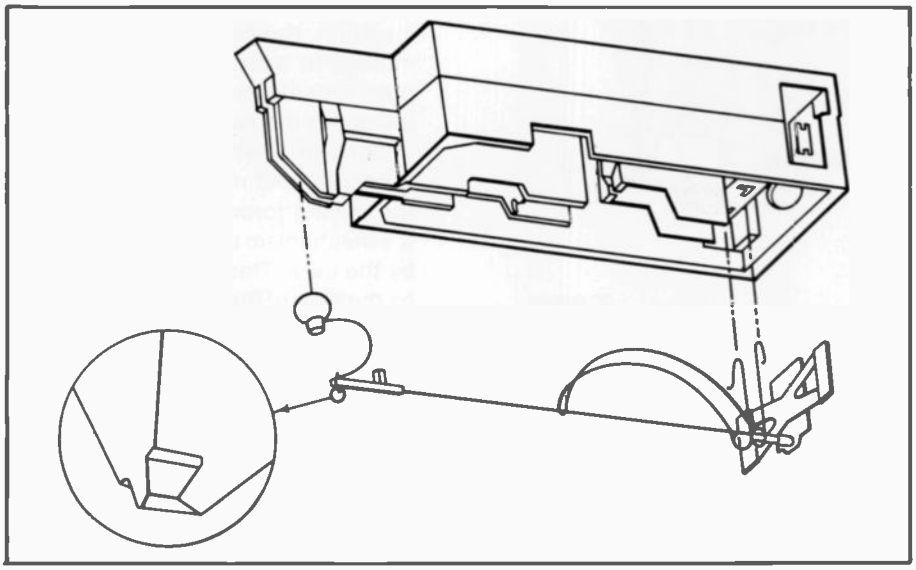


Fig. 5. The stylus cartridge is composed of the diamond stylus, the flylead, the tipholder, the aluminum tube, the arm-stretcher coupler, and a clamp spring. This assembly is user-replaceable.

Fig. 6. The VideoDisc caddy is the key element providing protection for the disc from environmental and handling-induced damage. Program information is provided on the front and rear faces.

tion in the distance from the bottom of the stylus electrode to the disc surface changes the stylus/disc capacitance at the FM-carrier rate.

Stylus cartridge

The stylus cartridge (Fig. 5) fits within an arm assembly that is mounted over the turntable and is driven radially by a DC motor across the disc from the outside to the inside.

The stylus is mounted on a small plastic tip holder attached to the end of a three-inch aluminum tube. Controlled tracking force is provided by a beryllium-copper flylead, which also provides the electrical connection of the stylus electrode to the electronics located within the arm assembly. The rear of the aluminum tube is connected through a compliant rubber member to a flat metal plate that is magnetically latched to the arm-stretcher transducer in the arm assembly. The arm-stretcher transducer imparts tangential motion to the stylus. This motion partially corrects for time-base errors that are encountered during playback. Signal retrieval and groove skipping are sensitive to side forces exerted on the groove wall by the stylus. These forces are minimized by the arm servo and a very accurate stylus-centering adjustment.

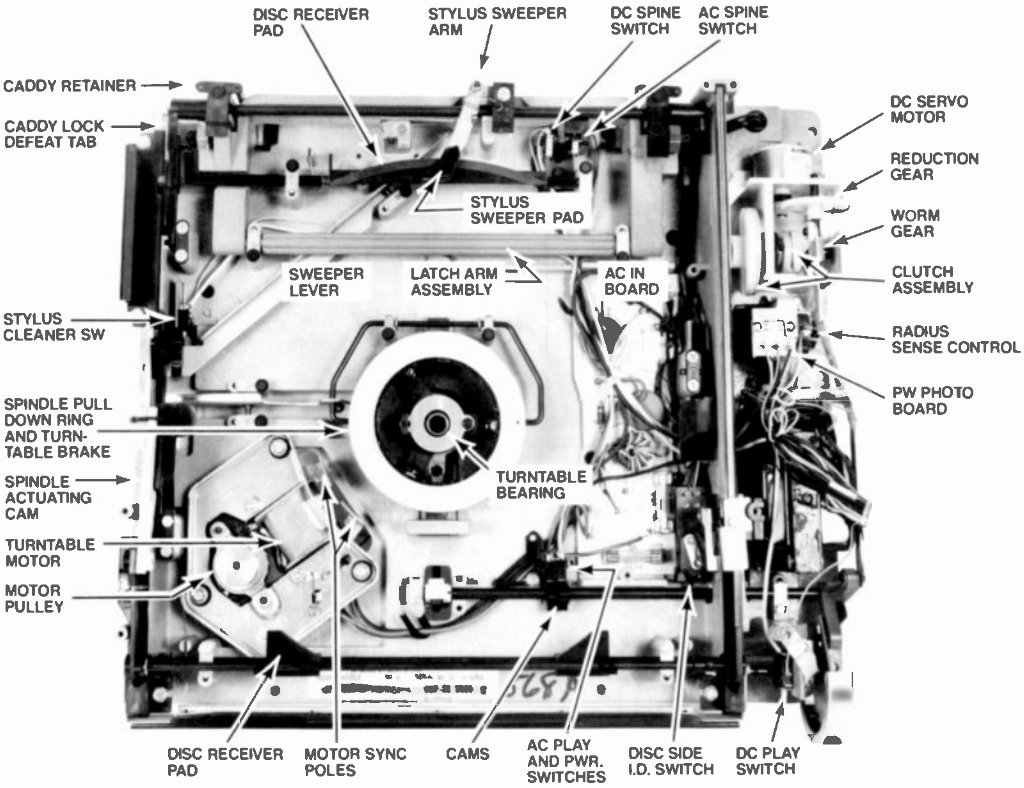
A small permanent skipper magnet is located on the plastic tip holder. Stylus skipper coils, located on each side of the stylus inside the arm assembly, produce magnetic fields that impart a force on the skipper magnet that moves the stylus in controlled groove-to-groove motion radially across the disc.

The stylus cartridge assembly is designed for simple consumer replacement and is accessible through a door in the top of the cabinet (Fig. 2).

VideoDisc caddy

The RCA VideoDisc caddy (Fig. 6) is a component of the "CED" system allowing fulfillment of several basic design goals. First, the caddy provides a convenient means for handling and storing the VideoDisc while protecting the disc from dust, debris and other damage which might impair playback. Secondly, the caddy design makes possible a relatively simple mechanical player interface to the disc.

Contained within the caddy is a plastic spine that surrounds and captures the disc during insertion into the player. The spine has visual side identification molded into the front face with side reference always maintained between the disc and spine. A molded-in key at the front edge of the spine provides a means for mechanically identifying, within the player, the side being played. At the outer front edge, locking tabs retain the spine, thus holding the disc inside the caddy when it is not inside the player.



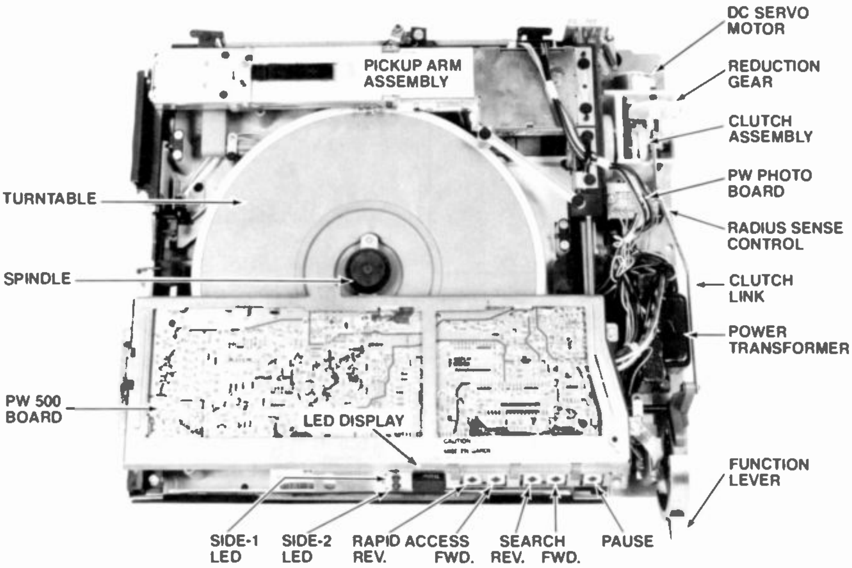


Fig. 7. Top view of the VideoDisc player with the cabinet shell removed. The upper view also shows the control board (PW500), turntable, and pickup-arm assembly removed (for clarity).

Mechanism

The mechanical design of the player involves approximately 300 uniquely tooled items. Extensive use of molded plastic parts in the mechanism both minimize weight and, on a number of parts, achieve the needed precision tolerances that are inherent in injection molding.

The player is a compact mechanism built around a structural foam injection-molded centerplate. The mechanism incorporates a number of disc- and spine-handling systems to accurately position the disc during operation. The pickup arm assembly is mounted above the disc at the rear of the centerplate and moves on a carriage driven by a bidirectional DC motor and gear reduction assembly. The turntable is driven by an AC motor and rotates within two bearing assemblies. The electronics are attached to the centerplate above and below the mechanism.

For ease in manufacturing, only the player's signal processing circuit board and three other parts attach to the bottom of the centerplate. All others are topside, mounted and serviceable (Fig. 7).

The centerplate foam-molding process was chosen for its ability to produce parts with closely repeatable dimensional accuracy combined with favorable thermal stress characteristics. In addition to providing molded-in rails that control the vertical and lateral motion of the caddy during insertion, the centerplate provides molded-in references and attachment points for all components in the player including the cabinet.

Consistent with the end goals of simplicity and minimum cost, most of the driving forces needed to interface the mechanism to the disc are provided by the user. This is partially illustrated by the view of the function lever linkage (Fig. 8). Manual operation of the function lever engages/disengages the arm servo clutch, opens/closes the caddy-entry door, raises/lowers the turntable, and connects/disconnects the antenna switch. In addition, AC and DC mechanism position switches are activated in the correct sequence to ensure proper switching of the electronics.

Other moving components of the mechanism that are activated during caddy insertion include spindle pull down, spine latching, pushback of the arm assembly to the start position, side-identification switching, arming of the stylus sweeper, and activation of spine-sensing switches to prevent operation unless a disc is present.

Two major portions of the mechanical assembly deal with handling of the caddy, disc and spine, both during insertion and extraction and during the transition modes of LOAD-to-PLAY and PLAY-to-UNLOAD. Varying forces, speeds and caddy-entry attitudes are carefully considered. First the front, side and rear receiver pads are designed to accurately maintain the vertical location of the spine and disc while the turntable spindle controls the lateral position. The spine remains in a fixed postion while the

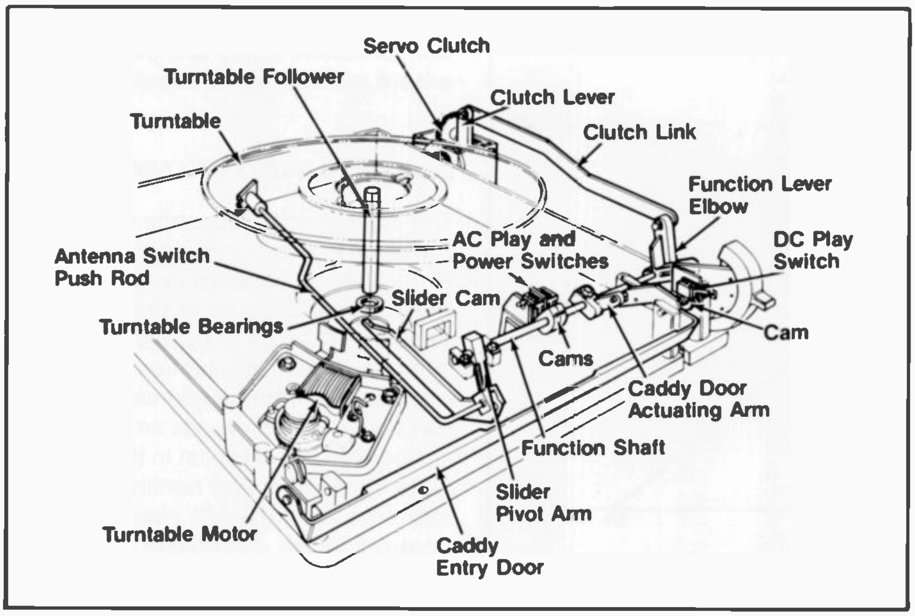


Fig. 8. The activation force of the mechanism and disc interface is provided by the user. The function lever as well as the major components are illustrated.

turntable raises the disc to the PLAY position. This allows the arm assembly to be vertically fixed and placed into the initial start position during caddy insertion.

The second handling system consists of the defeat tabs, the latch arm and the caddy retainer, controlling the spine latching and unlatching. Synchronous engagement of each element in this system was a complicating factor in its design, but recognized to be needed to avoid failure modes associated with only partial caddy insertion and extraction by the user.

Turntable drive

In the RCA player, the rotational speed is 450 rpm. With a 60-Hz vertical field rate, there are eight fields per revolution with sync aligned radially on the disc. The constant angular velocity system does not require a complex turntable servo control, and results in minimal picture disruption as the stylus is moved from groove to groove.

A two-pole, shaded-pole synchronous AC motor drives the turntable via a silicone rubber belt. A small squirrel cage fan mounted to the bottom motor shaft provides cooling to the motor and electronics. Accurate dimensional control of the turntable pulley, turntable-drive step diameter and belt length ensure a free running speed of 450 ± 2 rpm. Precise speed control is then achieved by coupling the stray AC motor flux through two magnetic poles to a 16-pole magnetic strip located within the interior diameter of the turntable drive step. This magnetic synchronization has sufficient torque to ensure that the turntable runs at 450 rpm ± powerline frequency tolerance. This operation is illustrated in Fig. 9.

VideoDisc signals

The video information recorded on the RCA VideoDisc is a frequency-modulated 5-MHz video carrier (Fig. 10). Sync tip causes the carrier to deviate to 4.3 MHz, peak white causes the carrier to deviate to 6.3 MHz, and black level corresponds to zero deviation. The video information bandwidth of 3 MHz results in FM-modulation sidebands that extend from 2 MHz to 9.3 MHz.

In order to limit the video spectrum to less than 3 MHz, the chrominance subcarrier is at 1.53 MHz. This composite video signal is referred to as a buried-subcarrier signal.

Audio information on the VideoDisc is contained in a second carrier at 716 kHz. which is frequency modulated with a deviation of ± 50 kHz.

To optimize signal-to-noise ratio, both audio and video signals are pre-emphasized in recording. Complementary de-emphasis is provided during playback.

Arm electronics

The electronics that interface with the stylus are contained within the arm assembly. The resonator circuit contains the 915-MHz capacitance detection electronics. Inputs from the signal processing circuits drive the arm-stretcher transducer as part of the time-base correction function. Stylus skipper coils are located on each side of the cartridge and are pulsed by the control electronics when groove skipping is desired. The stylus lifter is a

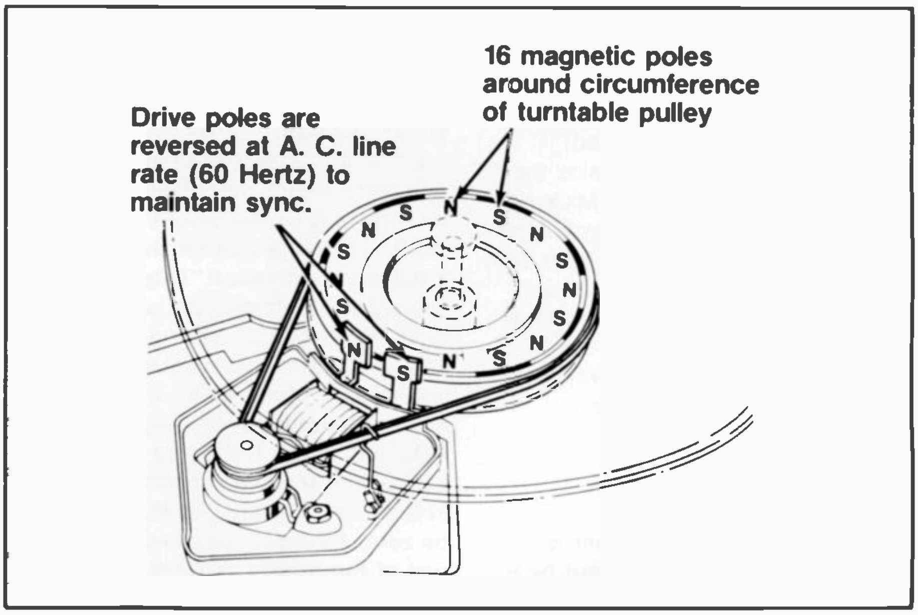


Fig. 9. The major drive components in the disc rotating system. Included are the AC motor, compliant rubber belt, drive poles, and magnetic strip.

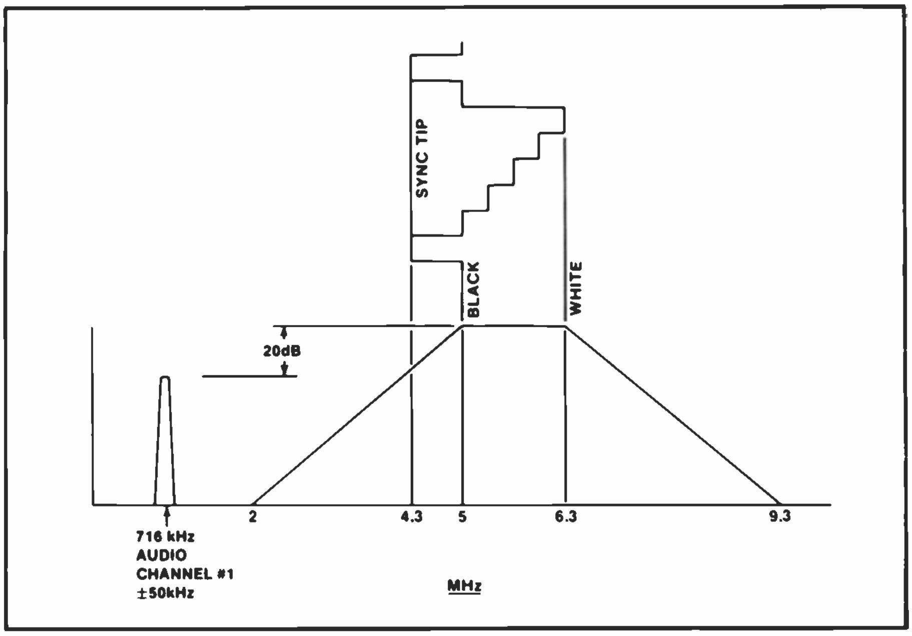


Fig. 10. "CED" VideoDisc signals. The audio FM carrier is centered at 716 kHz, and the video carrier varies from 4.3 MHz to 6.3 MHz.

small solenoid that causes the stylus to be raised within the arm housing when the disc is not being played.

Capacitance detection

The FM carriers modulate the stylus/disc capacitor, which terminates a resonant line tuned to approximately 907 MHz. When a fixed 915-MHz oscillator is loosely coupled into this tuned circuit, the changing capacitance between the stylus and disc varies the tuned-circuit's center frequency and causes amplitude modulation of the 915-MHz signal at the FM-carrier rate. Envelope detection of the 915-MHz signal provides recovery of the original FM-modulated signals on the disc.

The detected output contains the video FM carrier, the audio FM carrier, and a 260-kHz arm servo signal. The preamplifier raises the signal level from a few millivolts to several hundred millivolts. AFT circuits ensure stable operation of the detector at the specified point on the 907-MHz tuned-circuit selectivity characteristic.

Audio demodulation

The 716-kHz FM audio carrier is separated from the arm output by a bandpass filter and then amplified, limited, and demodulated within the audio demodulator IC.

The recovered audio is then fed through a squelch switch and amplifier. To minimize ticks and pops, a track-and-hold circuit is activated by a defect detector whenever a carrier dropout occurs. Audio is muted during visual search, rapid access, pause, and load functions.

Pickup arm servo system

The maximum lateral force exerted on the stylus by the groove ($\simeq$23 mg) is inadequate to pull the pickup arm assembly along with the stylus. A bidirectional DC motor, through a gear reduction assembly, drives the arm across the disc under control of a servo that matches the arm-drive rate to the stylus position.

Equal and opposite-phase 260-kHz-rate capacitance modulation of varactor diodes is coupled from sensors on either side of the stylus to the flylead in a balanced operation. This capacitance information is detected along with the disc information. The 260-kHz signal is separated from the arm output signal with a bandpass amplifier and is synchronously detected. When the stylus is in the center of the servo sensors, the 260-kHz signal recovered by the stylus will be zero. As the stylus moves closer to one of the pickup sensors, a 260-kHz error signal of a particular phase will be detected. This error voltage is used to drive the arm servo motor to reduce the error signal to zero. This maintains the correct relative stylus-arm position to ensure optimum stylus tracking.

Baseband video recovery

The additive low-frequency audio FM carrier on the disc causes a modulation of the spacing between the stylus and video signal. Because of the unsymmetrical fields at the stylus/disc interface, phase modulation of the video carrier at the audio carrier rate can occur, which causes an objectionable 716-kHz beat in the picture if not eliminated. The nonlinear aperture correction (NLAC) circuit introduces phase modulation of the video carrier by the sound carrier, which cancels modulation introduced at the stylus/disc interface. Any residual 716-kHz component in the demodulated video output is synchronously detected and used to adjust the amplitude of the cancelling signal.

The FM video carrier from the NLAC circuit is demodulated in the video demodulator IC and passed through a squelch switch that blanks the video whenever the stylus is not on the disc. Defect detection is accomplished by sensing carrier irregularities, producing a defect-gate signal used to control the defect corrector.

Comb filter and defect correction

Demodulated video is supplied to the CCD comb-filter and defect-corrector IC. A CCD 1-H delay line is utilized in a comb filter to separate the interleaved luminance and buried-subcarrier chrominance information. When a defect is detected, the 1-H delayed signal from the delay line is recirculated to produce defect-free video.

Vertical detail information is extracted from the combed chroma signal by low-pass filtering and added to the combed luminance signal.

Video conversion

The luminance signal is de-emphasized in the video converter IC and added to regenerated 3.58-MHz chroma to create a standard NTSC composite video signal. Inverted low-

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level luminance is added to cancel high-frequency noise before being fed to the RF modulator.

NTSC standard 3.58-MHz chroma is produced by mixing the combed 1.53-MHz chroma with the output of a 5.11-MHz voltage-controlled crystal oscillator (VCXO). A gated phase detector compares the up-converted 3.58-MHz burst signal to a 3.58-MHz crystal reference oscillator, producing a phase-error signal that controls the VCXO. This signal is also used to control the arm-stretcher transducer in the arm assembly, which drives the stylus tangentially along the groove in a direction to reduce time-base errors.

RF modulator

The RF modulator contains a 4.5-MHz oscillator that is FM modulated by the audio signal. The regenerated NTSC video and the 4.5-MHz FM audio modulate a VHF oscillator producing an RF signal on channel 3 or channel 4.

Control system

A microcomputer IC controls overall operation of the player. In response to inputs from the user controls and signals read from the disc, it operates the stylus lifter, the stylus skipper, and the pickup arm servo, and also provides status information on an LED display.

The signal read from the disc is a 77-bit digital auxiliary information (DAXI) code that provides field and band number identification. The DAXI code is recorded on line 17 of each vertical field, in a NRZ (Non-Return-to-Zero) format synchronized with the 1.53-MHz chroma.

The data is detected, stored, and checked for errors by a DAXI buffer IC. On command, it is shifted into the control system microcomputer IC. The field number is converted within the control system microcomputer to a playing time in minutes and is displayed on the instrument's front panel. The field numbers are also checked to verify that they are progressing in the proper sequence.

Occasionally the stylus may encounter a disc defect or debris within the disc groove that will cause the stylus to jump to a previously played groove. If the defect is severe enough, this could actually become a repetitious or locked-groove condition. When the field number sequence indicates that a groove is being replayed, the stylus skipper is activated to move the stylus forward past the defect.

When the visual search feature is activated by the user with one of the player front panel buttons, the control system microcomputer again outputs pulses to the stylus skipper coils. The pulse is applied so that a nominal skip of two grooves occurs during the vertical interval where it is not visible in the picture. This provides approximately 16-times real-time motion in the picture.

When it is desirable to move more rapidly, the user activates one of the rapid-access buttons, causing the microcomputer to lift the stylus and move the arm at approximately 150-times real time. Since the DAXI information is not available in this mode, an opto-interrupter coupled to the arm assembly provides pulses to the microcomputer. These pulses are used to update the instrument's front-panel display.

If the pause button is pressed during the play of a disc, the microcomputer raises the stylus, and stops the arm drive. The end of the disc program is recognized from the decoded band number, which also causes the stylus to be raised, and the arm drive to be disabled.

Summary

A general description of the key mechanical and electronic systems within the RCA "SelectaVision" player has been presented. The "CED" system parameters have been carefully chosen to ensure that the player can be manufactured at a cost that will make it available to the mass consumer market. The player is designed to be easy for the average consumer to operate, with features that will be useful in the playback of all video program material.

C.F. Coleman|L.M. Hughes|L.R. Caswell

VideoDisc player mechanical design considerations

Innovative mechanical design protects the VideoDisc player from damage and makes it easy to use.

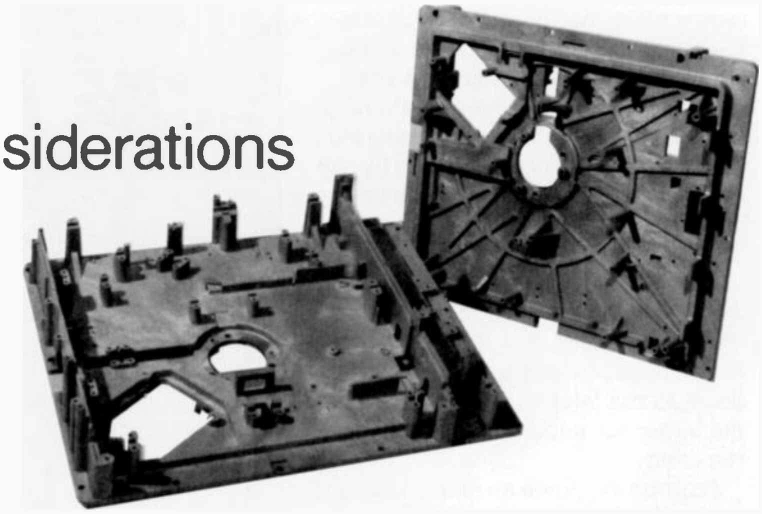

Fig. 1. Structural foam centerplate is a multifunctional mounting base for the VideoDisc player.

Abstract: *This article discusses the mechanical design considerations given to the player as an instrument and describes some of the individual mechanisms within the player. Plastic materials selection and processing considerations are also discussed.*

The VideoDisc player is partially a mechanical instrument by definition of the task it must perform. The primary design goals for consumer use were affordability, simplicity of operation, and reliability. The user was to provide operating forces where possible; thus, the player became more mechanical in nature.

Mechanism: centerplate

The player is built around a structural foam injection-molded part called a centerplate, shown in Fig. 1.

The centerplate provides molded-in references and attachment points for all components in the player, including the cabinet. It also provides molded-in rails that control the vertical and lateral motion of the caddy during insertion. Since all components have a common mounting plate, dimensional tolerances between related assemblies are minimized. With the exception of the main signal board and three mechanical components, all of the player parts and assemblies are assembled from the top. The centerplate divides the player into two compartments, isolating the major heat-generating source from the disc.

The drawing describing this part is 3-feet wide, 17½-feet long and contains approximately 1200 dimensions, but only 30 are considered critical. A general tolerance of 0.001 inch per inch of span applies to most dimensions. The main requirements of the centerplate are that it be lightweight, rigid, dimensionally stable at temperatures up to 150° F, flat, flame retardant, and that it withstand repeated insertions of self-tapping screws. Polycarbonate structural foam having a high strength-to-weight ratio, a deflection temperature of 280° under a 66 PSI load, a U.L. 94VO flammability rating, and a low molded-in stress, as compared to standard-injection molding, satisfies these requirements.

Mechanism: caddy loading and unloading

The very nature of the caddy dictated some of the disc handling requirements — to extract the spine and disc from the caddy and to load them back into the caddy at end of play. The mechanism had to align the disc and spine with the turntable and spindle so that the disc could be raised to the play position, centered on the turntable, and be lowered back into the spine for reloading into the caddy. The mechanism is shown in Fig. 2.

The caddy loading and unloading mechanism consists of two components — a defeat device and an arm assembly — that latch into two recesses in the spine. The mechanism is designed so that, unless both sides of the spine are latched, the spine will remain in the caddy assembly. The mechanism is molded of foam polyester to give it the stiffness required. A small radius at the top of the latching ramp compensates for the small amount of flex present in the assembly.

The defeat assembly contains fingers that enter the caddy to unlock the spine and has cams that unlatch the spine from the latch arm upon insertion of an empty caddy. The polycarbonate finger and cam combination is insert-molded onto each end of a steel shaft. Since the latching and unlatching mechanism is duplicated on each side of the player and since each side is rigidly tied to the other, both sides operate when only one side is activated by the caddy. This design allows operation with a broken caddy.

Operation of caddy loading and unloading mechanism (Fig. 3).

Position #1 The mechanism is shown in the unloaded position. The latch arm is pulled against the round portion of the defeat assembly and the cam is pulled against the latch arm. This aligns the finger so that it can enter the caddy.

Position #2 Upon insertion of a loaded caddy, the finger enters the

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Reprint RE-26-9-4
Final manuscript received Sept. 15, 1981.

caddy and unlatches the spine. The caddy depresses the latch arm and the ramp enters the recess in the spine, thus locking it into the player. A leaf spring holds the spine against the ramps to maintain proper positioning with respect to the turntable centerline. The latch arm being held down by the spine exerts a downward force on the cam and finger, which is still held inside the caddy.

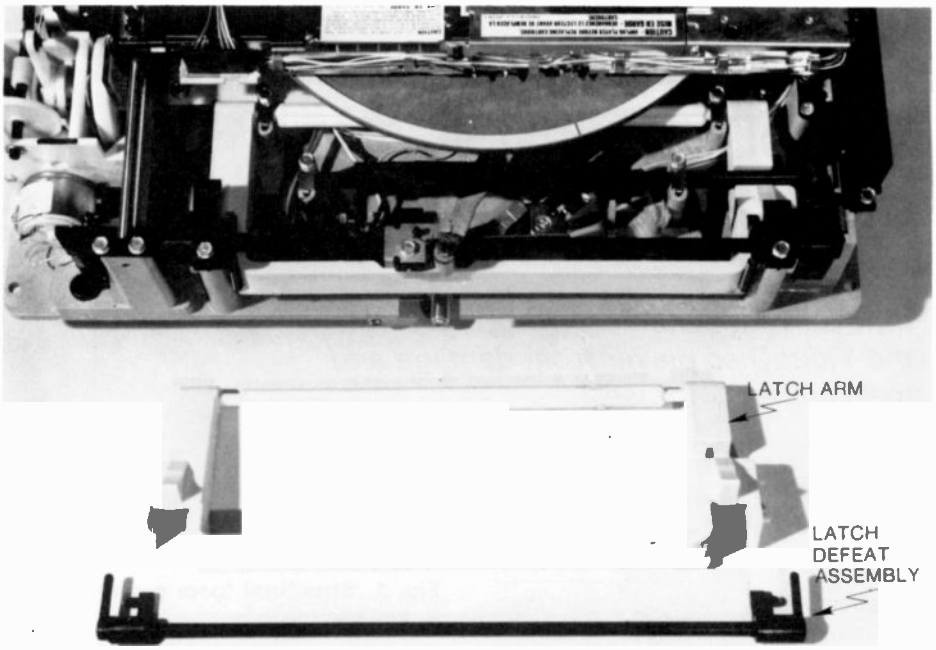

Fig. 2. Caddy loading and unloading functions remove the disc from the caddy for playing and reload disc into caddy after play.

Position #3 When the caddy is withdrawn, the spine and disc remain inside the player. The finger is freed from the caddy and the cam is pulled down to the latch arm. This positions the finger for reloading the spine into the caddy.

Position #4 When an empty caddy is inserted, it forces the finger down as it rides on top of it. The cam forces the latch arm down and the spine is released. The leaf springs force the spine back into the caddy and it becomes latched inside again. Withdrawal of the caddy removes the spine and disc from the player. The mechanism then returns to Position 1.

The guide rails are provided so the caddy assembly is guided into the latched position. As the cover is withdrawn, receiver pads spring up to maintain the disc within and at the same level as the now-latched spine. This level and relationship is maintained during the load mode of the player so that the spine and disc can be reinserted into an empty caddy. The receiver pads activate individually as the jacket is withdrawn, and support the disc on its outer bead without touching the play area. All receiver pads retract sufficiently to clear the label. The occasional warped spine cannot cause improper loading because the spine hold-down is provided.

The turntable is a smaller diameter than the disc and, unlike other horizontally moving parts, travels vertically within the receiver pads. These components are shown in Fig. 4.

The bearings are affixed to the centerplate, and below the bottom bearing is a linear cam that the thrust sphere of the turntable shaft rests upon. The cam is mechanically linked to the function lever. Shifting from load to play thereby raises the turntable to play position.

Shifting from play to load drops a disc spinning at 450 r/min onto the receiver pads and within the spine. The turntable proceeds downward to a level below the caddy insertion plane, but the spindle remains within the disc to assure stabilization during disc deceleration, which is accomplished by a friction pad attached to the rear receiver. The spindle is subsequently cam-activated by the caddy during insertion.

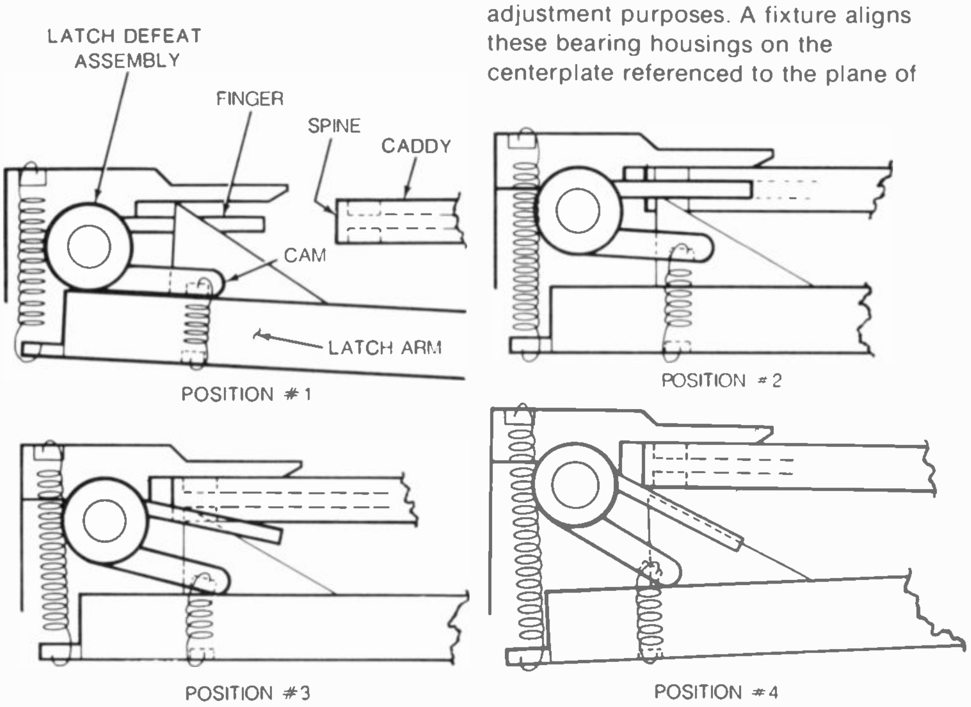

Fig. 3. Operation of caddy loading and unloading is accomplished using mechanical logic rather than a sequencing mechanism.

The tracking of a stylus in a minute disc groove puts heavy demands upon the accuracy of the system. The turntable itself is a foam-molded part which assures flatness and dimensional stability. The turntable shaft is induction-heated and fixture-inserted into the turntable to achieve squareness and vertical runout.

The self-centering, service-replaceable bearings are mounted in two housings and are allowed to move laterally with respect to each other for adjustment purposes. A fixture aligns these bearing housings on the centerplate referenced to the plane of

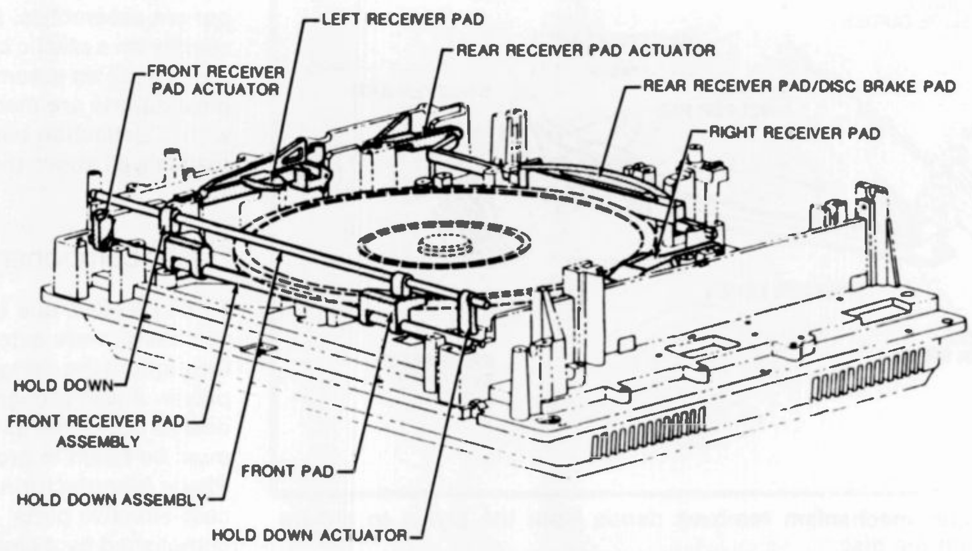

Fig. 4. Turntable and receiver pads set critical levels for play and for disc loading and unloading.

the arm travel and the spine latch.

The spindle must center the disc within 0.005 TIR to the center of rotation of the turntable. This was accomplished, firstly, by insert-molding of the spindle assembly and, secondly, by accurate machining of spindle and turntable shafts.

Disc side identification is accomplished by a switch whose activation is sensitive to the edge of an identifying notch in the spine (Fig. 5).

Stylus cleaning is accomplished with a sweeper pad as the full caddy is removed from the player. The mechanism is shown in Fig. 6. This occurs because the empty caddy returns the arm housing to set-down, which then pushes the sweeper arm to a cocked position. The extraction activates a switch and cam, which then lowers the stylus onto the sweeper pad and activates the sweeper arm through the remainder of the cleaning cycle.

Player cooling

One design specification states that the player must operate in an ambient temperature range of 59° F to 90° F. Within this range, the temperature rise at the disc surface shall not exceed 14° F. Critical electronic parts must operate below their maximum design temperature for long life and reliability.

A blower wheel attached to the bottom of the turntable motor shaft (Fig. 7) provides adequate cooling. Air inlets were located in the bottom player compartment to avoid depositing dust and other contaminants in the top disc compartment. Inlets were also located to direct air flow to the hottest components.

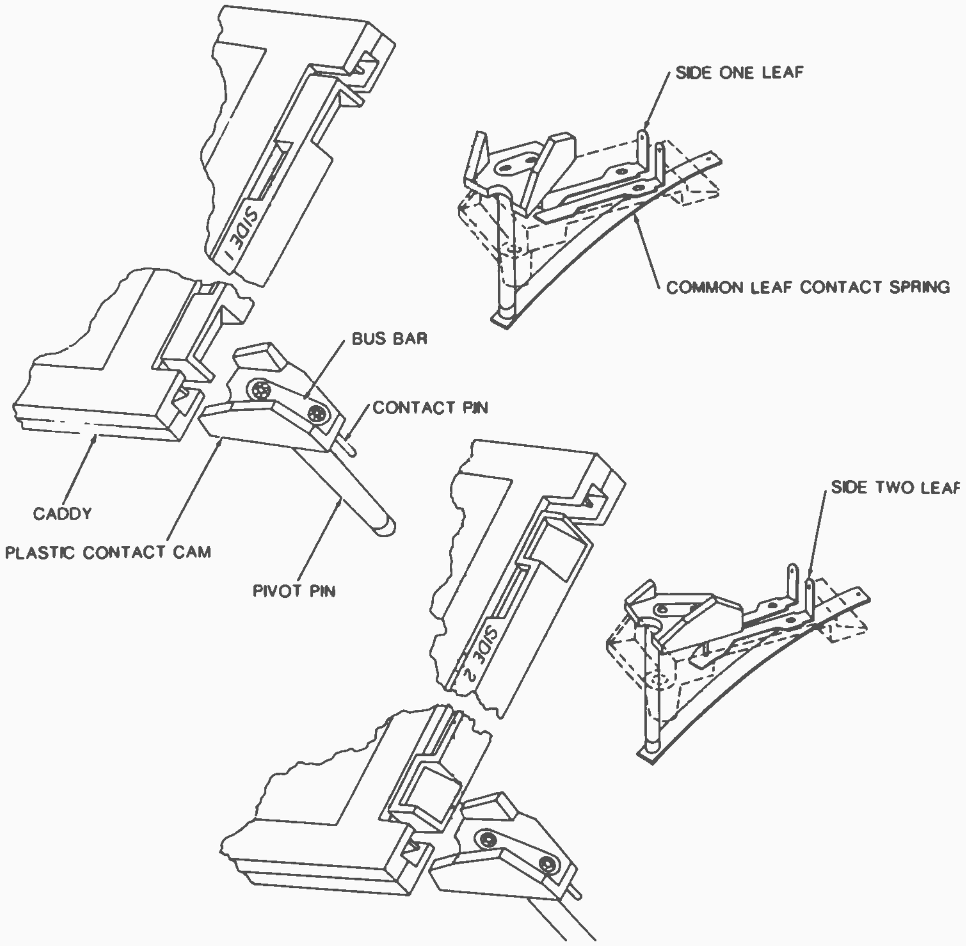

Fig. 5. Side identification switch indicates to the operator which side of the disc is being played.

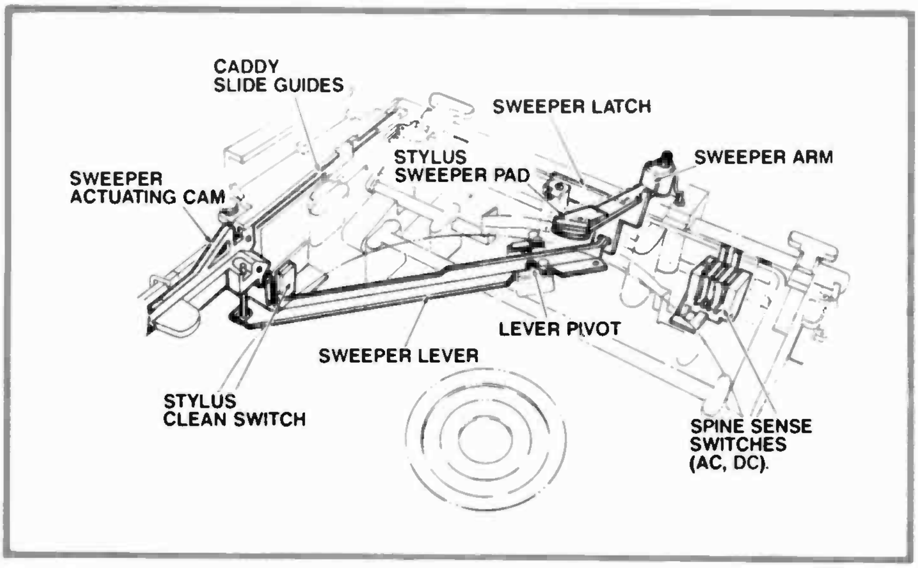

Fig. 6. Stylus-cleaner mechanism removes debris from the stylus to ensure intimate contact with the disc.

Player packing

A player must survive the trip from the factory to the customer's home. The player is designed to withstand drop and vibration tests described in RCA Procedure ENG202. The final packing components are shown in Fig. 8.

The player is enclosed by top and bottom polystyrene foam trays and is covered by thin sheets of polyurethane foam to protect the cabinet finish during vibration. The polyethylene foam piece is assembled through a cartridge access door to secure the pickup arm and turntable.

The packaged player is vibrated for 30 minutes on a vibration table that simulates the motion of a truck. It is then rotated 90° about its vertical axis and vibrated another 30 minutes. Next, the package is dropped 24 inches on five sides, an edge, and a corner. Engineering drops are made from 30 inches to determine weak design areas and establish a safety factor. The package is also subjected to the same drop series at a height of 18 inches after being cooled to -10° F.

Player storage

The player is designed to withstand storage at temperature extremes of -10° F to 150° F. Storage problems were avoided by allowing for differences in coefficients of expansion and contraction of dissimilar component assemblies. An aluminum overlay on a plastic crystal is an example of such an assembly. Also, critical plastic parts are made of materials whose deflection temperature under load is well above the 150° F extreme.

Plastic component development

Since plastics, due to their functional versatility, were extensively used throughout the design of the VideoDisc player, it was recognized early in the design cycle that extraordinary steps must be taken in order to provide Player Manufacturing with quality cost-effective parts. This was accomplished by a close coordination of Design Engineer, Tooling/Materials Engineer, Purchasing and the vendor.

Materials Engineering guided the materials specifications. Function, cost and safety were the three prime requisites.

After completion of the functional design and initial material identification, the in-house tooling engineer integrated the part with proper tooling and molding requirements. This included complete mold-cavity fills with varying section thicknesses, non-entrapment of air in the cavity, and proper ejection of sections without introducing distortions. The component part was then detailed to reflect these considerations.

When the first prototype of fabricated components was assembled and design evaluation completed, the actual molding design commenced. The tooling design considered part shrinkage, glass fiber orientation, gate location, knockout pin location, parting line, draft angles, and factors affecting physical properties. Experience showed that all of the above items were interrelated — seemingly insignificant changes in the part or mold geometry might significantly affect the part. It was decided to completely prototype mold the entire VideoDisc player. Several techniques were tested and used after the conception of the part and before hard tool production. Aluminum soft tooling was found to be the most powerful way to examine injection molded parts. Soft tooling was an important bridge between prototype and hard tooling. In critical parts such as the turntable,

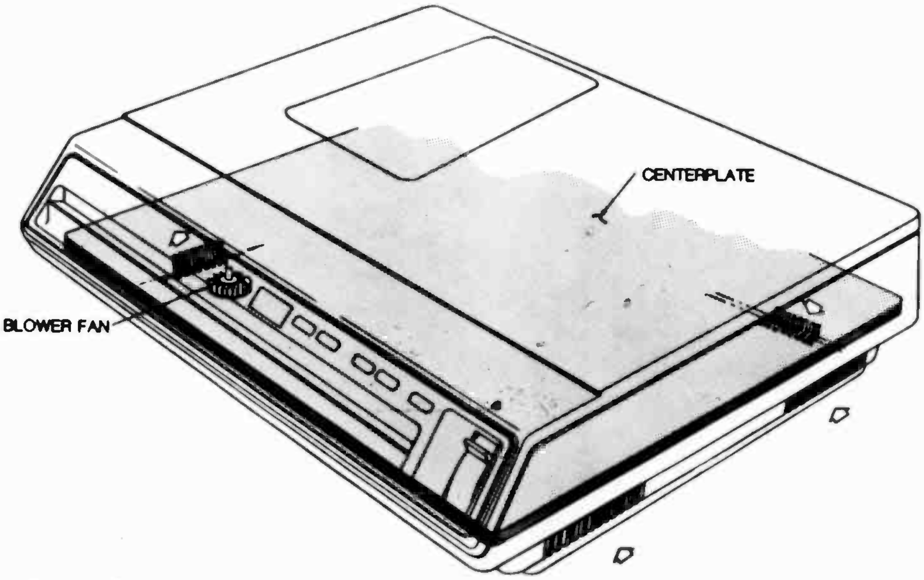

Fig. 7. Air flow through the player cools critical components.

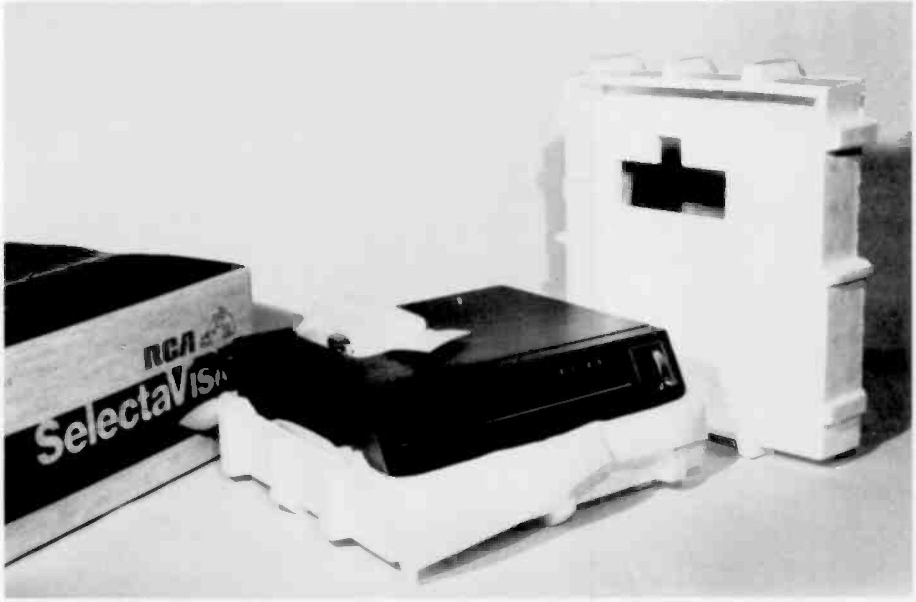

Fig. 8. **Player packing components** protect the player during shipping from factory to consumer's home.

water lines were included. Analysis during the soft tooling phase related to areas such as shrink relative to gate function, runner systems and gates involved in system balance of multiple cavity tools, resin flow, press size, and vents. Approximately 85 soft tools were designed, fabricated and used to produce the several prototype and engineering pilot runs of the SFT100 VideoDisc player.

The extensive information gained was then transferred to the part and tool vendor. In many cases, the part vendor experimented with the original soft tools in order to satisfy his own concerns. In all cases, a very close working relationship with all parties was attempted.

During the hard tooling phase, Engineering requested copies of all tool designs. The soft tooling experience could then be used to predict the results of any part geometry changes. In addition, last minute changes could be rapidly implemented since the intimate details of the mold were known. An example of this would be the intrusion of a newly added detail into a water cavity. These problems were avoided early on. Of the approximately 70 hard tools that were designed and fabricated, only three caused initial start-up problems. These problems, however, were corrected in a reasonable amount of time.

Left to right, authors Coleman, Hughes, and Caswell

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Lyle Caswell joined RCA in 1978 as Design Engineer, Player Engineering Group. He is responsible for tool design of the plastic parts for the player — prototype as well as production tooling.

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C.F. Hackett|B.K. Taylor

The VideoDisc groove-riding stylus cartridge

The stylus cartridge is an ingenious combination of human, electrical, mechanical and material engineering that meets demanding requirements on the microscopic and macroscopic levels.

Abstract: *The authors describe requirements of the RCA VideoDisc cartridge. The VDC-3 Stylus Cartridge is given as a means to satisfy these requirements. A detailed description of each part or assembly is provided. Since mass is an "enemy" in the dynamic assembly, the minute dimensions and forces are conveyed to the reader in laymen's terms. The actual diamond stylus and its production control are treated in depth.*

The function

The "SelectaVision" VideoDisc System requires a capacitive sensing element in continual intimate contact with a spiral groove of the plastic disc. The sensing element must maintain, on a micro level, the intimate groove contact with spacing that is less than a wavelength of visible light. Concurrently, on the macro level, the entire groove and sensing element must experience excursions approximately 500 times that, in both lateral and vertical directions. In order to compensate for these excursions, and for other reasons, means must be included to move the sensing element in an analog manner both down a groove and across grooves. A final requirement is that the customer be able to replace the sensing element without adjustment; that is, the cartridges must be player interchangeable.

The pickup means

Figure 1 is an exploded view of the RCA VideoDisc signal pickup means, a VDC-3 Stylus Cartridge. It contains a variety of materials configured in a unique manner, assembled with mass production methods. The assembly uses only three types of fasteners: adhesives, solder, and one rivet. There are three precision plastic moldings. A stamped flat mylar sheet is provided as a customer handle to be grasped during replacement procedures. A rubber assembly is used that comprises two rubber types, an aluminum tube, and soft-iron plate. Two springs are used. One is a wire form, while the other is a photo-etched conductive flat spring. A gold-plated tubular rivet serves as an electrical contact and reference point. The tiny skipper magnet, which responds to fields from small electromagnets in the player, provides a means for control of the lateral position of the diamond stylus so that it can be made to jump one or more grooves in either forward or reverse direction. The last item, the diamond stylus, encompasses a vast amount of technology in both its microscopic shaping and its conductive coating (the capacitive sensing element). Due to its importance, the latter part of this article will deal with it in depth.

The plastic moldings

The largest plastic part, of course, is the case. This is a protective housing for the entire pickup arm and stylus. It must protect during manufacture, handling, shipment, and installation. When installed, it establishes the global reference for the stylus with three basic points. These reference points are triangularly spaced with two widely separated points at the rear and a central point at the front. The lateral case referencing is supplied by two walls at the front and a groove at the rear. The two holes in the top are used during machine handling for stylus micro-faceting. Later, the flat mylar customer handle fits into these holes.

An expandable socket receives the plastic cartridge ball. The ball-socket affords an infinite combination of three-axes rotation for the upper termination of the conductive spring, the flylead. This is the factory adjustment that determines the exact lateral and vertical forces that the stylus will exert on the disc's groove walls.

The third plastic part is the stylus holder. It mounts the diamond to the

Reprint 26-9-5
Final manuscript received June 25, 1981

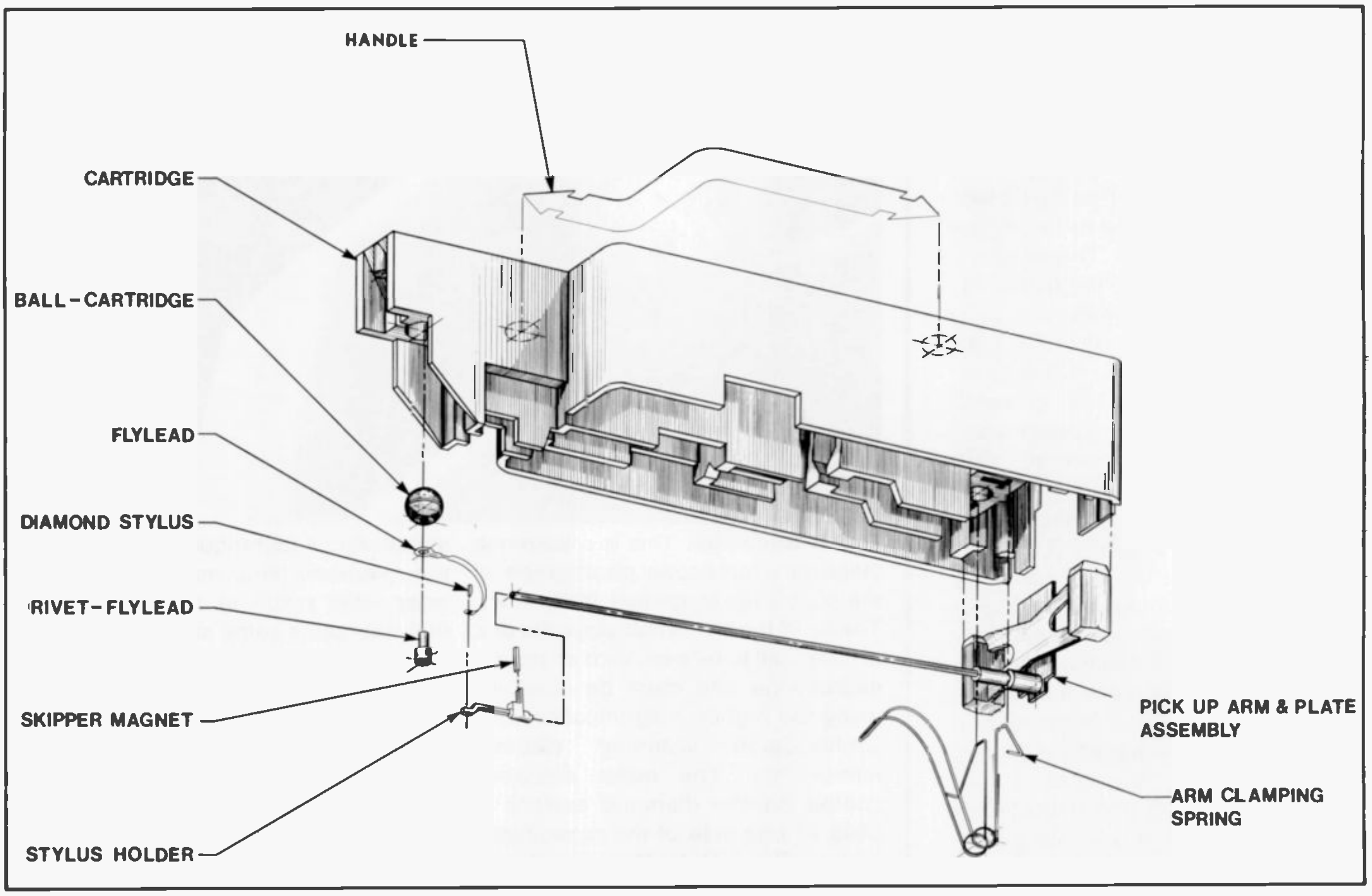

Fig. 1. Cartridge Assembly (exploded view). In the cartridge assembly, the case is simply pressed onto the previously assembled ball, pickup arm assembly, and stretched suspension. The arm clamping spring is pushed in to retain the stylus in a protected position. Ball adjustment within its socket provides the final positioning of the stylus tip, as dictated by the flylead orientation. This "force and bias adjustment" determines the nominal stylus-groove wall forces. After micro-machining the keel shape onto the stylus tip, the handle is inserted to complete the assembly, ready for electrical test.

pickup arm, terminates the lower end of the flylead, provides electrical and mechanical isolation, and mounts the skipper magnet.

The rubber assembly

The pickup arm and plate assembly uses two rubber types to bond the aluminum pickup-arm tube to the soft iron latch plate and provide a convenient means of attachment within the case. The rubber compound and shape was designed to damp pickup arm vibrations, minimize lateral, vertical, and rotational forces, while maintaining axial stiffness. Any lateral and vertical stiffness here can adversely affect the stylus-groove wall forces as the stylus follows a non-planar and non-circular groove. The axial rotational forces must be controlled for precise groove "skipping." As the stylus rides over occasional microscopic imperfections in the groove, sharp impulses are imparted to the pickup arm system. The rubber quickly damps out the resultant vibrations.

The aluminum pickup arm itself is a hollow tube with wall thickness less than half that of a common human hair. This material configuration has a very high strength-to-mass ratio. When the cartridge is installed in a player, the soft-iron latch plate is magnetically coupled to the axial transducer. Player electronics drives the transducer, which imparts axial movement to the pickup arm and finally results in stylus motion along the groove. This pushing and pulling of the stylus within a groove occurs many times during each disc revolution. The entire motion is transmitted through the rubber on its way to the stylus.

Another rubber suspension maintains registration of the pickup arm assembly within the cartridge case before installation into a player. It is molded to the latch plate at its center and stretched taut into cartridge pockets.

The springs

The aforementioned flylead spring is a critical electromechanical member. Beryllium copper was chosen for its electrical conductivity and high mechanical yield strength and elastic modulus. This member is the electrical link from the stylus electrode to player electronics. It also provides the mechanical spring force of the stylus-groove-wall tracking force. This force is roughly one-tenth that of a high quality audio stylus. It would take ten of these springs stacked one upon another to equal the thickness of a U.S. dollar bill. The basic "C" shape and part configuration was chosen to fulfill the electrical and mechanical restraints.

The cartridge clamp spring is a wireform that restrains the pickup arm within the case prior to player installation. It is easily inserted into an assembled cartridge and yet easily released by a player.

The rivet

The only rivet in the cartridge is the electromechanical link of the flylead to the player electronics. The flylead is first soldered to it and then is mechanically staked into the cartridge ball. The gold coating assures a low-resistance electrical contact. This contact provides the front elevation reference for the entire cartridge.

The magnet

The skipper magnet is bonded into the stylus holder such that, in the player, it is situated between two air-core coils. When the coils are activated by a current, the electromagnetic field interacts with the skipper magnet to exert a lateral force on the dynamic stylus. The magnet is then a means to pull the stylus out of a given groove, on command. The player electronics issues these commands for, in response to customer activated controls, forward and reverse visual scans in addition to automatically clearing occasional repeating grooves.

The stylus

The stylus capacitance pickup is achieved by a metal coating on the diamond trailing surface. This metal coating, that is, the electrode, is about 2000-angstroms thick. The metal is coated onto the diamond surface using vacuum deposition. The diamond final tip geometry (Figs. 2 and 3) is machined after the electrode is applied. The resulting keel geometry includes a shoe that resembles a boat prow that plows debris out of the disc groove ahead of the electrode.

The diamond shoe is long enough to cover several of the longest disc-recorded wavelengths and thus rides smoothly on the crests formed by these signals. The recorded signals below the stylus are transferred to the stylus as capacitance variations. As the stylus tip plays the disc surface, diamond and metal are eroded away at a very slow rate, which results in a very long stylus wear life. In order to achieve wear of the metal film without chipping or flaking, the metal film properties must be controlled in a very precise manner.

In order to control the metal film precisely, a number of quality control tests are performed. These include control of the metal thickness, resistivity, adhesion to the diamond, contamination particle size and density, and the metal film elemental makeup and contamination. Surface particle contamination is controlled by optical microscopy such that the probability of a contaminating particle being anywhere on the tip is less than 0.2 percent. Metal thickness, which affects signal pickup, is controlled to within ± 25 percent by a metal etching technique and use of an interferometer. Resistivity is monitored for consisten-

The flylead spring design

Second only to the stylus itself, the flylead is critical to the functioning of the stylus cartridge system. This thin (five VideoDisc-grooves thick) photo-etched flat metal spring is deflected into a unique "C" shape to force the stylus into the grooves. The orientation of the upper end of the flylead is the only assembly adjustment within the cartridge. The vertical and lateral spring rate of the stylus tip is largely determined by the flylead. Its stiffness is an order of magnitude greater than the other compliant member, the rubber tailpost coupling the aluminum tube to the magnetic latch plate. The flylead length is critical in that it is a section of an electrically self-resonant conductor at 915 MHz.

Extensive computer studies led to the design of the flylead with compliant sections near each end. This was a significant stylus tracking improvement in that it allowed a three-times reduction in side force produced by a given lateral displacement. It thus is more compliant laterally and yet still supplies the vertical force required within the fixed electrical length restraint.

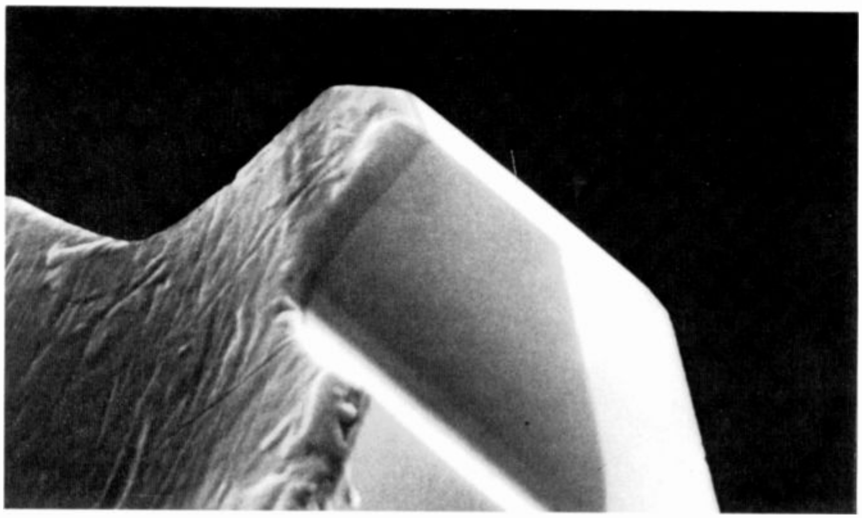

Fig. 2. Stylus tip. This is a scanning electron microscope photograph of the stylus tip magnified 9000 times. The tip of the stylus that plays the disc is too small to be seen with an optical microscope and must be observed using the higher magnification of a sophisticated scanning electron microscope. The metal electrode coated on the diamond surface is used as one side of the capacitance pickup of the VideoDisc signal with the conductive disc used as the second side. Sophisticated metallurgical techniques ensure that the diamond and metal electrode wear rates result in an equilibrium that maintains some stepback of the electrode from the diamond tip (the stylus shown here has not yet played a disc, thus, no stepback is apparent). If the electrode is flush to the diamond, noise can be introduced to the system. On the contrary, if the metal electrode is stepped back from the diamond excessively, loss of signal will occur.

cy using a four-point probe technique. Four contacts are made to the metal surface. Current flows through the outside two contacts and the resulting voltage drop between the two inner contacts is measured. The resulting sheet resistance for the film can then be calculated. Adhesion of the metal to the diamond surface is measured by a "scratch test" technique. The metal film is scratched away from the diamond with another diamond. Only a "clean" scratch without metal flaking is allowed; that is, no bare diamond should be visible except at the contact line.

Relative film thicknesses and elemental constituents of the electrode are measured by an electron microprobe technique. The metal is bombarded by high energy electrons. The numbers and energies of the resulting x-rays are measured to determine a relative metal thickness and the elements present. The ion microprobe technique uses high energy ions to sputter off secondary ions from the surface of the sample. The secondary ions are collected and analyzed by a mass spectrometer to determine the elements present. Since this technique is used to essentially bore through the sample, the elements present and relative concentrations can be determined as a function of depth into the sample. The important parameters monitored with these techniques include oxygen and nitrogen contamination levels.

Conclusion

The "SelectaVision" VideoDisc system places a myriad of demands upon the stylus cartridge. The cartridge is the first critical building block in reproducing a TV picture from recorded signals in a VideoDisc. As an electrical capacitor, the edge electrode is of foremost importance. The mechanical framework constitutes and maintains the intimate electrode-groove dynamic relationship. The various materials ensure reliability and a degree of environmental immunity for the functions. The human factor is considered because, after prolonged usage, the customer may want to replace the stylus, without adjustment. The VDC-3 groove-riding stylus cartridge represents a significant achievement.

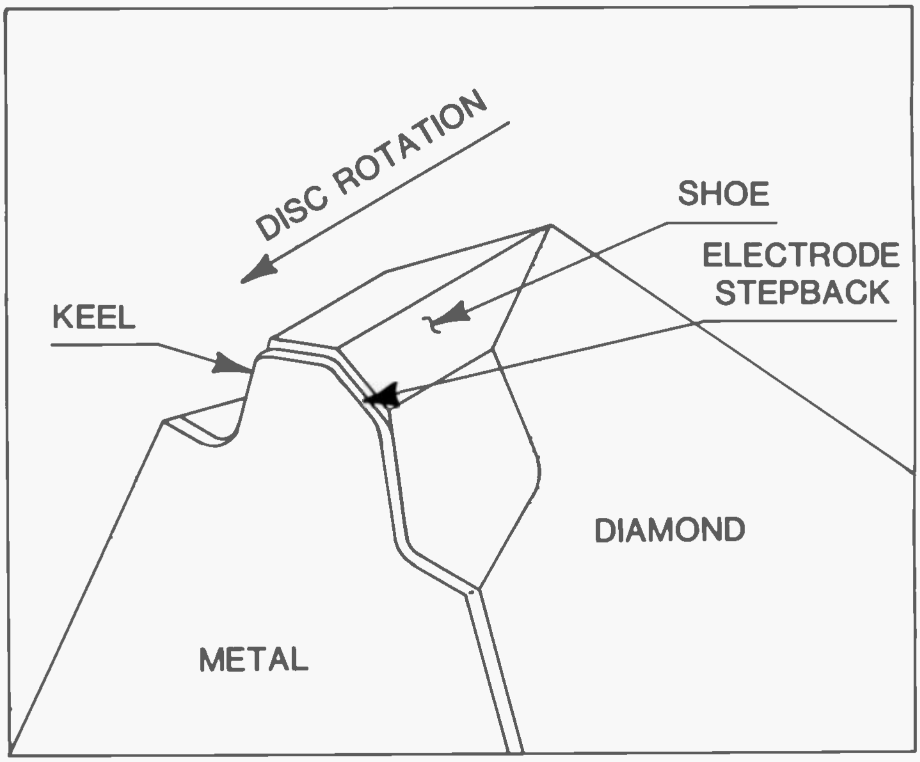

Fig. 3. Stylus tip. This inverted view of the stylus tip shows the shoe that rides in the disc groove. The boat-prow shape of the shoe plows debris out of the disc grooves. The trailing metal coating is the capacitance pickup means.

Charles Hackett joined RCA as a Member Engineering Staff, "SelectaVision" VideoDisc Operations at Indianapolis in the spring of 1979. His responsibilities within the Stylus Cartridge Design group are mainly the diamond tip configuration and metallization specification. His additional tasks have been to analyze stylus failure and to understand stylus/disc interface problems.

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The VideoDisc signal retrieval system

Complex, interrelated systems convert the information on the disc into a useable electrical signal from which audio, video, and control information can be culled.

Abstract: *Included in the VideoDisc signal retrieval system are the pickup housing assembly and associated support circuitry on the PW500 control board as well as the pickup housing drive motor and gear assembly. The tasks of this system involve positioning the stylus in the proper groove and transporting it radially as the disc is played, providing correction for time-base errors and tracking defects, providing for controlled groove skipping for special effects, and converting the stylus-to-disc capacity variations into electrical signals that can be processed to recover the recorded information.*

Mechanical description of the pickup housing assembly

The VDH-3 pickup housing assembly provides the means to accurately locate and house the stylus cartridge in relationship to the player turntable. It also contains the electronics (stripline resonator/oscillator and preamplifier) for the initial processing and generation of the signal that the stylus generates in conjunction with the disc.

The stylus lifter, transducer (armstretcher), skipper coils, servo sensors, radiation shielding, cartridge cover, caddy pushback mechanism, drive-gear rack and the mounting/drive bracket are included in this assembly.

VDH-3 pickup housing assembly

Figure 1 shows the relative locations of the components of this assembly. This assembly is composed of various materials and processes selected with manufacture, reliability, serviceability, and performance as the uppermost considerations.

Due to stringent FCC emission requirements, the stripline resonator/oscillator is factory aligned and is not field serviceable. The stylus lifter, transducer, preamplifier, pushback mechanism and drive-gear rack are field serviceable. The pickup housing assembly is replaced as a unit if the other service is required.

To maintain the critical perpendicularity-parallelism parameters between the cartridge and the disc, these adjustments are also made at the factory and are not field serviceable. The assembled pickup housing is placed in a fixture, simulating the mechanism mounting points. The adjustments are made by means of an eccentric roller and the adjustable mounting bracket. The pickup housing assembly is then mated to any player mechanism that has had the turntable located by "fixturing" to the same common mechanism mounting points. The final height relationship between the pickup housing assembly and the disc (turntable) is achieved by vertical adjustment of the player turntable. A field-service gauge is available to maintain this height during mechanism service.

Housing

The housing is a thin-wall zinc die casting—underplated with copper for conductivity. A cadmium overplate protects the copper from oxidation and provides adequate solderability. The housing is configured to provide separate shielded areas for the stripline resonator/oscillator, preamplifier and stylus cartridge. FCC spurious harmonic emission requirements dictate the use of feed-through capacitors and close-fitting shields over the electronics and cartridge areas.

Resonator board

The resonator board is held in the housing at the cartridge end by a molded plastic support. The material for this block was chosen for its dielectric properties. The resonator board is soldered directly to the housing casting at critical grounding points. The resonator board/support assembly is fixtured to the casting during assembly and then becomes one of the reference points for housing alignment on the player.

Cartridge area

The integrity of the height location of the stylus cartridge in the housing is assured by close dimensional control of the height relationship between the mating contact rivet on the resonator board/support assembly and the two rear-cartridge mounting surfaces in the pickup housing. The contact end of the stylus cartridge is received by close-fitting vertical surfaces on the previously "fixtured" resonator support, while the rear of the cartridge is received by a locating rail in the housing casting. By this method, the lateral and the front-to-back location of the stylus cartridge to the housing is maintained.

Transducer

The locating rail also holds the transducer in a side-to-side relationship with the

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Reprint RE-26-9-6
Final manuscript received Sept 9, 1981

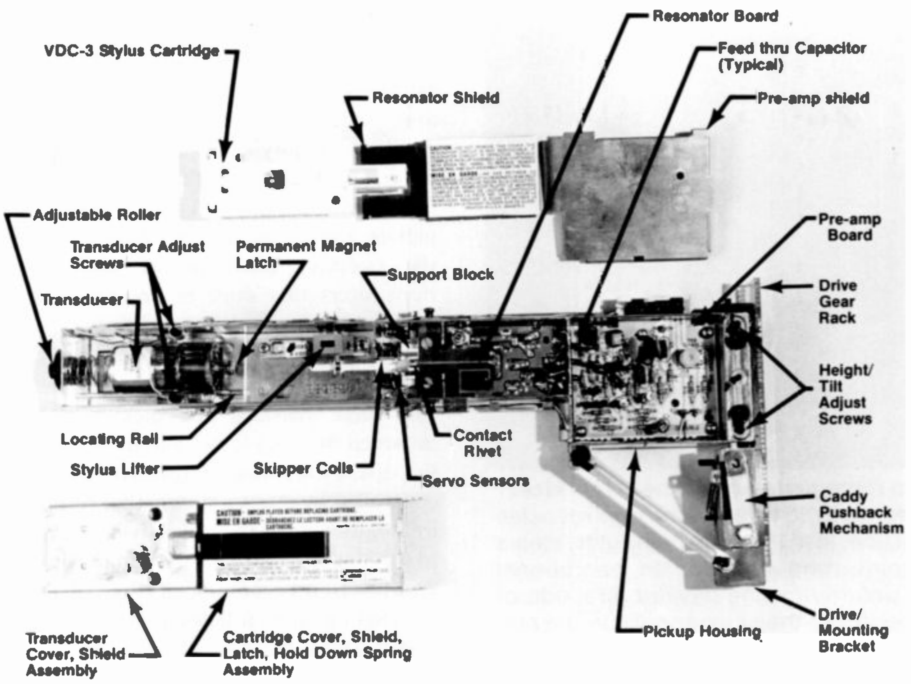

Fig. 1. The pickup housing assembly, Model VDH-3. The pickup housing assembly measures 14-inches long by 1-inch high by 6-inches wide at the driven end, and weighs 1.5 pounds. The functions of this assembly, while similar to a conventional audio tone arm, are varied and complex. In addition to housing the stylus cartridge and providing the proper reference planes between the cartridge and the disc as on a conventional audio tone arm, this assembly houses: the mechanism for time-base error correction; the coils used for locked groove correction and visual search; the mechanism used for stylus lifting and set down; the electronics for initial signal retrieval and processing; the mechanism for return to start of play by the caddy; and the drive-gear rack for powering the housing assembly during play.

cartridge. The transducer is held against the locating rail by a bias spring between the pickup housing and the transducer body. Since the transducer must be free to move fore and aft, this spring cancels any excessive "play" between the rail and the transducer. The transducer is held against the rear of the cartridge by a coil spring exerting a nominal 1-lb. force. This force ensures that the cartridge properly contacts the resonator support.

The transducer vertical movement in the housing is limited by the adjustment of two ball-ended self-locking screws, lightly bearing on opposite side flanges of the transducer housing. A stamped steel cover over the transducer also serves as a receiver for the cartridge cover latch. A beryllium-copper shield under this cover aids in RFI suppression.

The transducer corrects time-base errors caused by vertical and lateral runout of the disc. It is a linear actuator that extends or retracts the stylus arm to maintain a constant groove velocity. This device consists of a stationary magnet structure with a moving coil. The coil is mounted on a pair of silicone rubber diaphragms. The diaphragms determine the natural resonance of the device. A permanent magnet latch attached to the coil connects the linear actuator to the stylus-arm plate.

The transducers are tested during assembly for resonant frequency, sensitivity at resonance, sensitivity at 7.5 Hz, and smooth response (phase lag) up to 2.5 kHz.

Cartridge cover

The stamped steel cartridge cover, when closed and latched, applies a spring force downward and toward the resonator block. The cartridge cover, when closed, also releases the stylus handling/shipping clamp spring by means of an integral tab formed in the cover. A beryllium-copper shield attached to the underside of the cover further contains RFI by spring contact along the top edges of the housing casting. The cartridge cover, when opened, uncouples the transducer from the cartridge by use of a connecting wire-form link for easy cartridge replacement.

Stylus lifter

The function of the stylus lifter is to lower and raise the stylus from the disc as required by the player mechanism for pause, start of play, end of play, stylus cleaning, and rapid search.

This device consists of a stationary coil, and a moving magnet attached to a spring lever that acts on the stylus pickup arm tube. In the up position, the magnet is held inside the coil by the spring lever. Upon application of the proper voltage, the magnet is repelled from the coil at a linear rate, allowing the stylus to descend. This set-down rate is determined by the spring rate of the lever and the applied voltage. The stylus lifter is tested, during assembly to the pickup housing, for smoothness of operation and full downward excursion.

Skipper coils

The skipper coils are used to apply the proper lateral influence to the skipper magnet located on the stylus arm tube to clear malfunctions that may occur because of minute disc defects. The skipper coils are also used for forward and reverse visual scanning.

This device is composed of two small air-core coils in the pickup housing, mounted on either side of the aforementioned permanent magnet on the arm tube. The operational signal is received from the player electronics and provides a typical displacement of two grooves per pulse.

Servo sensors

The servo sensors consist of two varactor resistor devices located at the nose of the resonator mounting block. When the stylus cartridge is installed, the stylus flylead is located between opposing leads on these devices. Differences in capacitance between each of these sensors and the cartridge flylead are detected and compared. This allows the entire pickup housing assembly to be displaced, as required, to maintain the true electrical and mechanical centers of the stylus. Spacing and attitude of the sensor leads in relationship to the cartridge flylead are critical. Therefore, this assembly is "fixtured" to ensure accuracy.

Electromechanical control systems

Stylus lifter

Current through the stylus-lifter solenoid is controlled by the system microprocessor

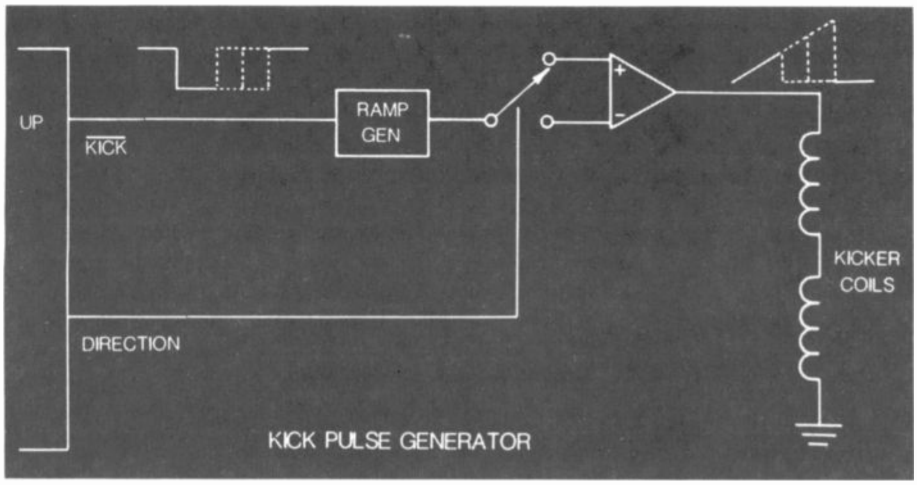

Fig. 2. The triangular pulse is produced by a ramp generator in the stylus kicker circuit. The amplitude of the pulse is dependent on the width of the control pulse from the microcomputer. A direction control line, also from the computer, steers the pulse into either the inverting or noninverting input of an operational amplifier, to produce a pulse of the proper polarity for the desired direction of stylus movement. A high-current buffer stage drives the skipper coils in the arm assembly.

and two mechanism switches. In the play mode, a control line from the processor causes the lifter circuit to raise and lower the stylus at controlled rates. Careful studies have shown that a rate that is too fast or too slow can result in damage to the disc or stylus. In addition, during caddy withdrawal, the stylus is lowered onto a special pad for cleaning by a mechanism switch. Another switch provides reverse current through the coil in the load mode, to assist the spring in holding the stylus up inside the arm through the mechanical shocks of the pushback operation.

Groove skipping system

Any defect or particle of foreign material on the disc surface that causes the stylus to skip outward to a previously played groove can cause a small segment of the disc to be repeated indefinitely if no corrective action is taken. When such a condition occurs on an audio phonograph, the listener must normally move the arm ahead manually. Because of the microscopic size of the VideoDisc grooves, defects large enough to cause skipping are more likely to occur. It is highly desirable to have a means available to clear defects automatically. The stylus skipping system is the primary means for correcting such tracking defects.

The system control microcomputer monitors the field identification number, which is recorded along with the video and audio information during the vertical interval. A skip, either forward or reverse, can immediately be detected by a change in the field number sequence. When a reverse skip is detected, the processor generates a stylus kick pulse that is shaped by the kicker circuits and fed to the coils in the pickup housing assembly (Fig. 2). These coils act on a small magnet on the stylus arm and cause a forward kick of two grooves, which moves the stylus to the groove beyond the defect. The entire process occurs in less than a thirtieth of a second and is normally imperceptible to the viewer.

The current pulse delivered to the skipper coils is roughly triangular and has an energy content determined by the microcomputer, which controls the width of the pulse. This control capability enables the system to compensate for several variables that affect the number of grooves skipped by the stylus. The computer can also generate reverse skips of one or two grooves for special effects such as a "groove-repeat" mode or visual search.

The dynamics of the stylus skip are quite complex and dependent upon a surprising number of interacting forces. The basic mechanism involves a rotation of the stylus assembly about the diamond tip during the slow rise time of the pulse that moves the center of mass of the stylus assembly to a position over the target groove. A sudden reversal of the torque then causes the stylus to snap back to a vertical position. This movement is resisted by the inertia of the stylus assembly. As a result, the rotation is primarily about the center of mass and the tip is pulled from the original groove and ends up below the center of mass in the target groove.

Pickup housing servo system

The pickup arm on an audio turntable is normally mounted on a low-friction pivot and guided across the disc by the force exerted on the stylus by the groove walls. In the VideoDisc player, this is not practical for several reasons. For example, the pickup arm is considerably heavier due to the circuitry and various mechanical transducers that must be present, the requirements for stylus tracking are much more exacting, and the side force available from the groove walls is extremely small. For these reasons, the pickup arm is mounted on a guide rail and driven across the disc by its own motor. The motor is controlled by a servo system that responds to the position of the stylus flylead relative to the pickup housing, such that the proper arm position is maintained (Fig. 3). Thus, the pickup arm follows the stylus as it moves across the disc.

Constraints on the Servo System. The VDC3 stylus/cartridge has an upper limit of about a 0.5 mg/mil spring constant laterally as the stylus is displaced from its relaxed (zero side force) position. Under ideal conditions the stylus could operate at about 30 mils off center, but registration errors between the relaxed flylead position and the arm-housing centerline reduce the practical range to about ± 20 mils.

Since the arm servo is not fast enough to follow disc TIR, which occurs at a 7.5-Hz rate, the centering performance must be such that the stylus remains within 20 mils of the arm centerline while experiencing a side-to-side movement of about 10 mils p-p. Thus, the average error should not exceed 15 mils (0.015 inch) under any operating conditions.

Control and Drive Circuitry. Any displacement of the stylus flylead from the arm centerline is detected by the stylus position-sensing system (see box), which produces a DC voltage proportional to the positioning error. This error signal is first passed through a low-pass filter that is essentially an integrator.

This provides a very high loop gain at DC and forces the average error to be extremely small. Since the slew rate of the integrator is slow, a clamp is included to hold the output near its nominal value when the loop is opened by the lifting of the stylus. This allows a fast recovery when the loop is closed again.

The integrator output is then fed to a bridge-type amplifier that drives the DC permanent-magnet motor. For reasons to be discussed later, only one side of the bridge is active in any player mode and the

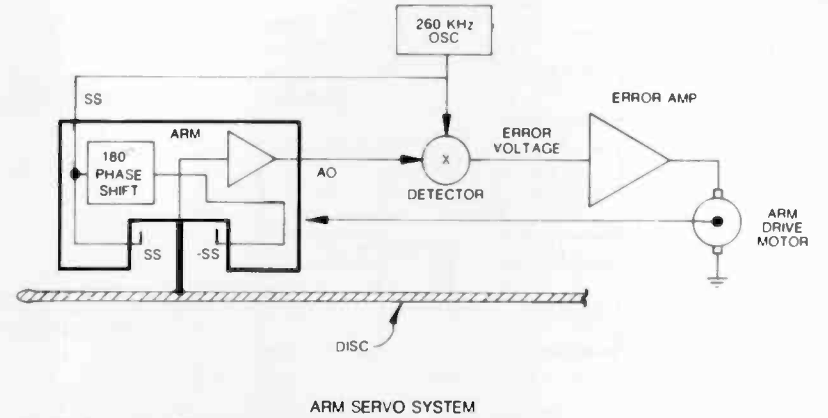

Fig. 3. Stylus position sensing.

The basic input to the servo system is an error signal that relates the position of the stylus flylead to the centerline of the arm. This position is detected by two sensors, on either side of the flylead, that are capacitively coupled to the flylead and coupled to ground by varactors. The capacitance of the varactors is modulated at a 260-kHz rate, but in opposite polarities. Thus, a capacitive load on the flylead is established. This load is parallel with the disc-to-stylus capacity, and is detected by the pickup circuitry as an additional signal component.

When the flylead is electrically equidistant from the two sensors, the 260-kHz variations cancel out. As it moves away from this electrical center, a 260-kHz component appears on the arm output having the polarity of the nearest sensor and an amplitude related to the distance from the electrical center. Synchronous detection of this signal by the original 260-kHz source produces a DC error signal proportional to the distance from electrical center. This sensing system is quite linear and has a transfer gain of about 50 mV/mil.

The use of opposing sensors tends to cancel out most of the temperature variations and provide a very stable electrical center. The tolerances involved in setting the electrical center to a point matching the mechanical centerline of the arm, however, can lead to an error of ± 10 mils.

other is essentially a low-impedance ground. Transistors on the noninverting inputs to the bridge amplifiers "turn off" the outputs. In any motor-stop mode, both amplifiers aare turned off to provide dynamic braking. Another switching transistor is active whenever the stylus is raised and causes either side of the bridge which is not disabled to produce maximum voltage for rapid access. These switches are controlled by the microcomputer.

Another control line, the defect exit line, is used by the processor in the play mode if a disc defect is encountered that is so severe that normal kicking will not work. A low voltage on this line causes the servo to move the arm housing forward until a large enough side force is available to force the stylus to kick through the defect.

Performance and Stability Considerations. A fully linear bidirectional servo system could provide very accurate centering and even correct for TIR by moving the pickup arm back and forth at a 7.5-Hz rate in response to the position-error signal. Unfortunately, this would require a reduction-gear assembly with very tightly controlled backlash and a high-performance motor. Both are unnecessarily expensive in this application. The compliant flylead and groove guidance of the stylus allow proper operation as long as the average position of the stylus is within 10 mils of the electrical center of the arm.

The gear-reduction assembly used is constructed of low-cost plastic parts and can have backlash that is much larger than the distances involved in arm positioning. If the motor were allowed to run in both directions, this would cause a nonlinear variation in loop gain that would make stability difficult to achieve. Consequently, the motor is limited to movement in one direction at a time.

The position error signal normally has a TIR-induced 7.5-Hz component that is much larger than the DC error. As a result of the one-directional motor drive, this AC component is effectively rectified and motor conduction occurs only during some portion of the positive half cycle of the error signal. This process results in a nonlinear gain factor that is dependent on the amount of TIR in a given disc and turntable combination. The induced loop-gain variation can be as much as 18 dB. Maximum gain occurs with minimum TIR. Fortunately, the allowable positioning error can be larger when TIR is very small. Therefore, in this maximum gain condition, the loop is allowed to become slightly unstable. Because of the one-directional drive, the instability takes the form of a start-stop operation of the motor at about a 1-Hz rate and the peak-to-peak error produced is much less than the normal TIR error.

The gear backlash comes into play when the direction of movement is reversed. The worst case is a change from normal play to visual search reverse. The stylus is kicked in a reverse direction at 16 times normal speed but the arm housing cannot follow it until the motor has unwound the backlash. This results in a temporary positioning error which, if it exceeds 10 mils, can result in a momentary jerkiness in the search performance. In the current design, the maximum reversing error is held to about 4 mils. This represents the worst-case positioning error of the system.

Arm-stretcher transducer

Operation of the time-base correction system is discussed in detail in another article (see page 64). The transducer serves to move the stylus tangentially along the groove to compensate for errors in the relative disc-to-stylus velocity caused by TIR, warp, and vibration. The transducer is essentially a permanent magnet loudspeaker movement that is mechanically adapted for coupling to the stylus assembly.

Limitations. The transducer characteristics are not the limiting factors in the bandwidth of the time-base correction system. Other factors limit this to about 200 Hz. The main limitation imposed by the transducer is a maximum excursion of about 20 mils p-p. This excursion is adequate for use in this player.

Signal recovery circuits

The approach of converting the small change in capacity (10^{-4}pF) at the stylus and disc interface to a corresponding change of frequency resonance has proved to be an efficient and practical means of signal detection. This approach was chosen for implementation in the VideoDisc player.

Figure 4 is a block diagram of the signal retrieval system built into the pickup arm housing. The circuits designed to perform the indicated functions are constructed on two printed circuit boards. The separate boards and functions are as noted by the dashed lines. These circuit boards have

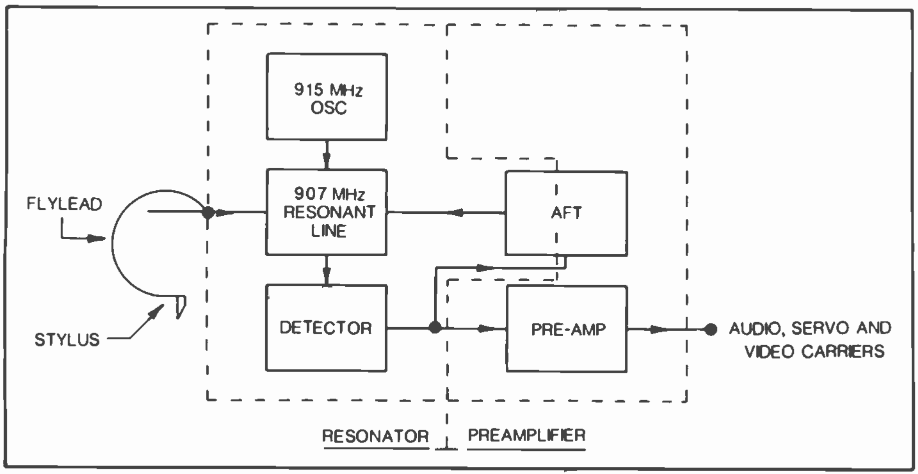

Fig. 4. The signal retrieval system. The system converts 10^{-4} pF changes in capacitance to corresponding changes in frequency resonance.

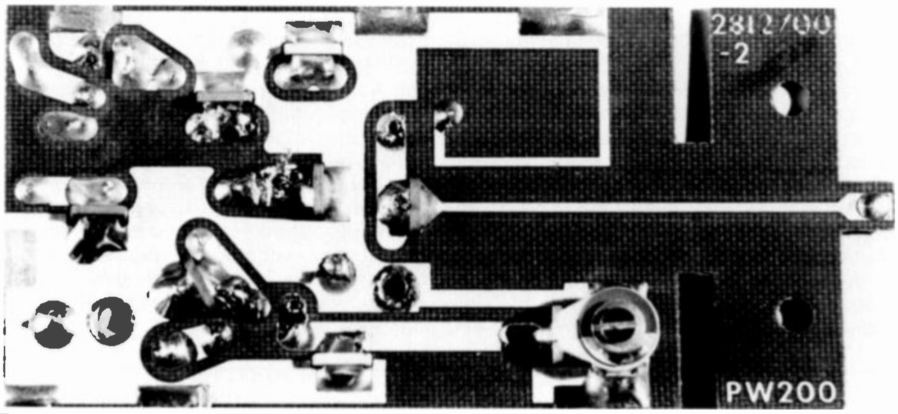

Fig. 5. Resonator board, copper view. Circuits designed to perform the resonator and preamplifier functions, indicated in the signal retrieval system block diagram, are constructed on two printed-circuit boards.

been dubbed the Resonator and the Preamplifier and will be referred to as such in the following discussions.

Resonator

The resonator circuit board contains the functions, 915-MHz oscillator, 907-MHz resonant circuit, part of AFT (automatic frequency tuning) and detector. The circuit is printed on one-sided copper glass-filled Teflon 0.031-inch board. The choice of material will be discussed later. Board size is 1.4 in. by 2.9 in. Printed circuit board design and construction was chosen for the well-known reasons relative to any circuit but the essential accuracy and repeatability required for stripline parameters were paramount in the choice. Furthermore, these essentials can be maintained in mass production processes. The completed board is tested and then installed in a partitioned cavity in the arm housing by soldering to strategic points on the copper pattern. Figure 5 is a photo of the copper side of a completed board. Figure 6 is a schematic of the circuit.

Resonant line and detector

The concept of a capacitance, with a fixed and variable component, existing at the stylus electrode and disc interface, is well-developed and documented. The small variable component is consistent with the signals encoded in the disc. The conversion technique used in the VDH-3 pickup assembly evolved from development work formulating a high-frequency, high-Q resonant circuit as an effective means for converting ΔC to ΔV. Further development work resulted in the stripline resonant circuit used in the VDH-3 resonator circuit.

The mechanism of conversion is slope detection. Detection is achieved by using the off-resonance slope characteristics of a resonant circuit. The transmission line plus cartridge flylead, varactor diode and stylus electrode capacity in combination make up a resonant circuit at approximately 907 MHz. The small change in capacitance (10^{-4} pF) at the stylus electrode due to interaction with the disc-encoded signal elements cause a shift in resonance at the encoded signal rate. Energy from a fixed 915-MHz oscillator is coupled via the resonant circuit to a detector loop. The characteristics of the resonant circuit and the operating point on the universal resonance curve determine the proportional energy coupled to a detector diode. The sensitivity of the resonance to ΔC transforms a change in energy to the detector at the signal rate. Figure 7 is a representation of ΔC-to-ΔV conversions.

A filter in the detector output stores the peak value of the 915-MHz voltage to the detector. This value corresponds to an operating point on the resonant curve and is used to provide control information to an automated frequency tuning circuit that will be discussed later. Also present at the detector output, are the desired signal components. They are much lower in frequency than the 915-MHz switching frequency and are passed as an output. Figure 4 exaggerates the amplitude relations of the 915-MHz frequency and the signal components. The DC term, resulting from rectification and filtering of 915 MHz, is:

$$V_D = V_p \beta \qquad (1)$$

where V_p is peak voltage at resonance and β is a factor depending on the point of operation off resonance. These are 3.3 volts and 0.52 respectively in the design, yielding a V_D of 1.72 volts. The signal term involves the parameters of the circuit and system that must be optimized within constraints to maximize output level and response. The choice of parameters and constraints will be discussed later. The signal at the detector in terms of the foregoing is:

$$V_{SD} = \left(\frac{Q}{2}\right)\left(\frac{\Delta C}{C}\right) V_p \ \alpha \qquad (2)$$

where Q = Freq./3dB B.W., V_p is peak voltage at resonance, α is a proportional constant depending on the operating point off resonance and equals 0.43 in the design, C is fixed or stray capacitance of electrode and flylead, ΔC is the previously mentioned principal element in conversion. For the circuit as designed, these particulars are typically: Q = 55, ΔC = 1 x 10^{-4} pF, C = 0.5 pF, V_p = 3.3 volts, α = 0.43. From these, a recovered signal V_{SD} at the detector output typically equals 7.8 mV peak-to-peak. This signal plus the DC level are present at the detector load.

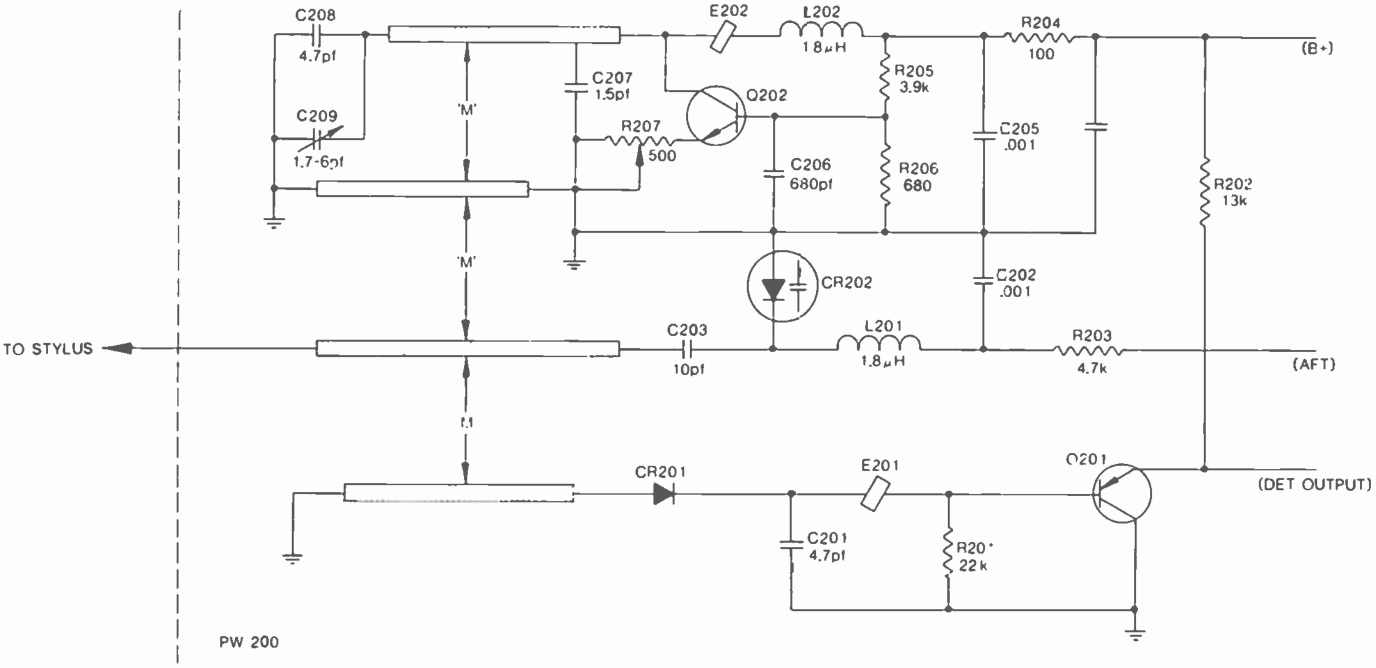

Fig. 6. Resonator schematic. Energy from a fixed 915-MHz oscillator is coupled, via the resonant circuit, to detector loop. The sensitivity of the resonance change in capacitance transforms a change in energy to the detector at the signal rate.

Referring to the Fig. 6 schematic, an emitter follower provides isolation and a low driving source from the detector-to-resonator output (preamp input).

The detector diode is a Schottky-barrier diode, selected for the low noise and good detection sensitivity it offers. The part is specified for a low-leakage current and reverse-bias capacity to minimize degradation of Q for the resonant system.

915-MHz oscillator

The 915-MHz source to provide excitation for the resonant line is constructed on the same printed circuit board. With reference to the Fig. 6 schematic, the oscillator circuit is Q202 and associated components. The transistor is a silicon epitaxial device commonly used in UHF tuners. Circuit configuration is common base with the tuned circuit in the collector. A stripline with capacitance end load is the 915-MHz resonant circuit. Part of the capacitance is variable to adjust the oscillator precisely to 915 MHz.

An intermediate stripline loop is tightly coupled to the oscillator stripline but loosely coupled to the resonant line and detector. This loop is primarily a means to get energy from the oscillator to the resonant line, necessitated by the practical layout of the overall copper pattern. Only a small part of the oscillator power is required at the stylus capacitance, therefore, the afforded loose coupling minimizes the effect of the resonant line on the oscillator stability and noise.

Resonator adjustments

The only factory adjustments to the resonator are two in the oscillator circuit. Variable resistor R207 in the emitter of Q202 sets the power in the oscillator as measured at the detector output by obtaining desired peak voltage (V_p) while sweeping the resonant line around 915 MHz. Variable capacitor C209 accurately adjusts the oscillator frequency to 915 MHz. These adjustments are factory set and not field serviceable to ensure compliance with certification requirements.

Varactor diode CR202 in the resonant line circuit is an automatic control means of adjusting to a constant operating point on the resonance curve (V_d). A change in diode capacitance and a consequent change in resonance become controlled parameters as established by the AFT amplifier on the preamplifier circuit.

Preamplifier

The preamplifier circuit board contains three functions: signal amplification;

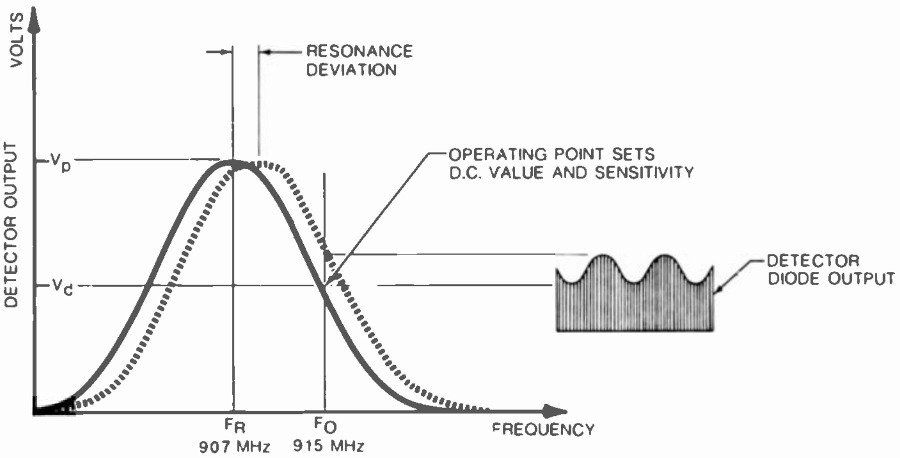

Fig. 7. ΔC-to- ΔV conversion.

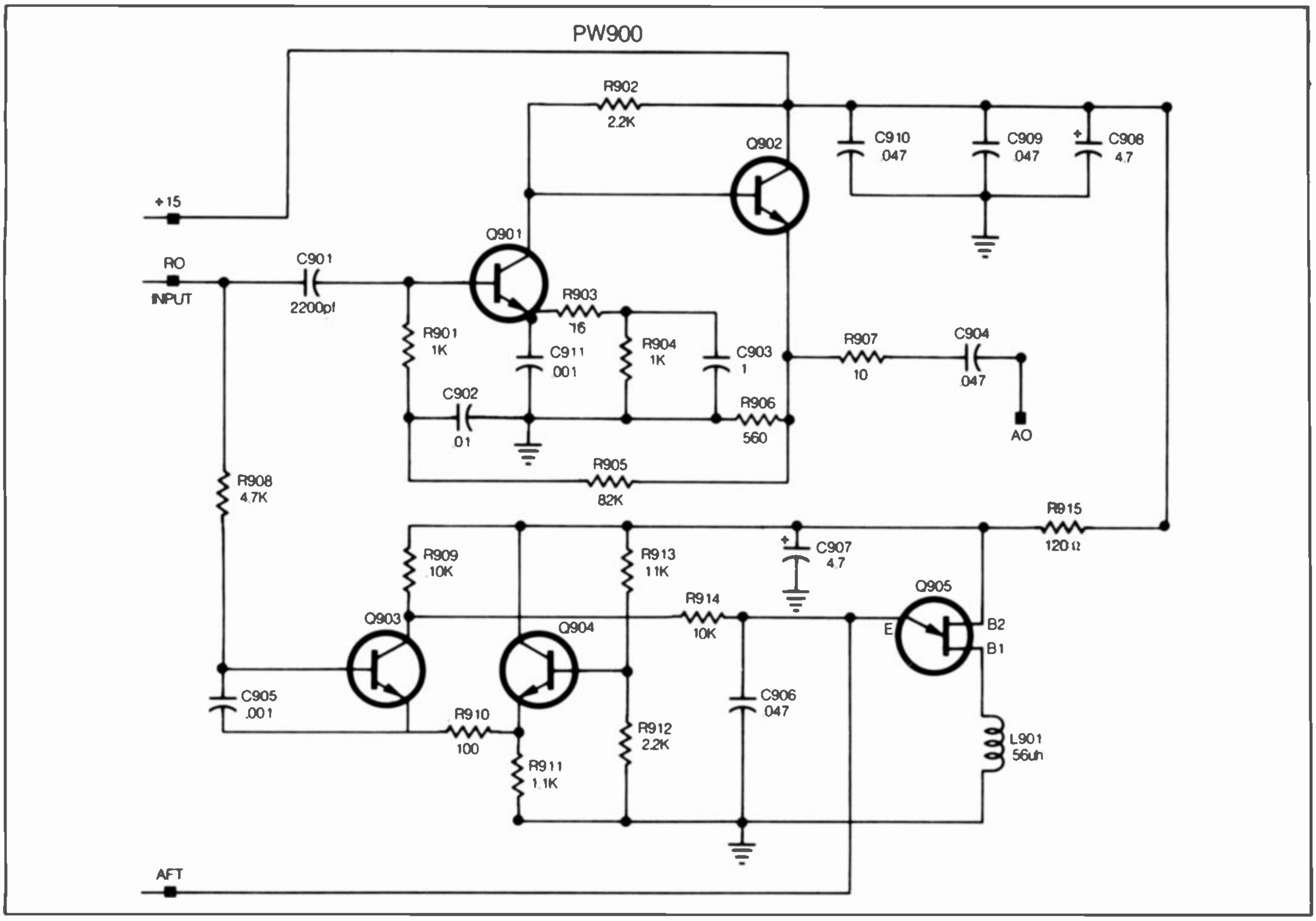

Fig. 8. Preamplifier and AFT circuit.

automatic frequency tuning; and the tuning search oscillator. The circuit is printed on a 2.3-by-2.8-inch conventional glass-filled epoxy printed circuit board. Figure 8 is a schematic of the circuitry on the board.

The signal amplification path is rather straightforward. Transistors Q901 and Q902 amplify the AC output of the detector and provide a low impedance drive source to the connecting signal processing electronics. Voltage gain is 37 ± 1 dB.

The AFT circuit consists of Q903 and Q904 and the associated components. The input signal is principally the DC component of the detector output. The desired level of this component is set by resistor ratio to the base of Q904. Error voltage from the desired level is amplified, filtered and fed to the varactor diode by the resonator AFT connection. The connected circuit forms a closed loop to maintain the desired operating point off resonance (1.72 volts as previously mentioned). This AFT action compensates for reasonable resonator circuit component tolerances but significantly compensates for the stylus cartridge parameters that affect resonance; for example, flylead length, flylead and/or stylus fixed capacitance to disc, flylead position in arm housing, and so on. The closed-loop response also passes low-frequency components caused by variations of these parameters that may occur at rates related to rotational speed due to disc warp and runout.

The tuning search oscillator is somewhat related to the AFT in that it enables the circuit to recognize the corresponding point on the opposite side of the resonant curve that would yield 1.72 volts at the detector. This point lies on an opposite slope of the curve (Fig. 7), which yields an error voltage to the varactor in a relation that essentially opens the loop. This corresponds to an increasing voltage at the emitter of the Q905 unijunction transistor. When the voltage reaches the turn-on point of Q905, C906 at the emitter is discharged to ground. The low or ground potential to the varactor adjusts the resonant circuit to a low frequency and sets the conditions for the proper slope and operating point to be detected as C906 charges through R909, R914 and the AFT loop again becomes closed. The relaxation oscillator mode of the entire AFT circuit will continue until the entire resonant circuit can be properly adjusted. The search mode of the circuit sweeps a resonant window somewhat greater than the approximate 50-MHz window over which the AFT can accurately control the resonant circuit. Forcing a high reference voltage at the base of Q904 will cause a continuous sweeping, and is in fact, the method used to obtain a peak injection from the oscillator by factory adjustment.

Design options and constraints

The foregoing has related to the circuitry as designed for the VDH-3 pickup housing to achieve a conversion of ΔC at the stylus electrode to a useable signal at the output. Regardless of construction, lumped element or stripline, the ultimate goal is to maximize practical performance within the realistic constraints. A cursory examination of equation (2), $V_{SD} = Q/2\Delta C/C\,V_p\alpha$ suggests the parameter options and constraints. The ΔC is a constraint with practical limitations that can be achieved by the stylus- and disc-encoded signal properties. C, fixed capacitance, also has limitations. V_p must be constrained to a value that will ensure oscillator frequency components do not provide excessive energy to the stylus electrode to cause destruction. A proportional constant α must be selected to compensate for nonlinearities in the overall system so as to provide an overall response with minimum distortion. It must be selected in accordance with Q. The problem resolves to obtaining the highest Q possible along with a proportional constant that will provide a high output-signal level while maintaining adequate undistorted signal bandwidth of approximately 10 MHz.

In the case of a stripline construction, it can be shown that this resolves to a choice of characteristic impedance, Z_0, of the transmission line and corresponding angular length for resonance. The cartridge flylead is a large part of this length. A flylead design providing adequate spring rate and compliance to properly track the disc grooves resulted in a Z_0 of approximately 300 ohms. Total transmission line (flylead plus stripline)with this Z_0 proved to meet the performance requirements. To achieve consistency in production, Z_0 and angular length must be predictable. Printed copper patterns definitely can be consistent, but the printed circuit board material's 1-GHz properties become very significant in maintaining Z_0 and angular length. The relative dielectric constant and dielectric losses (loss tangent) become very important. Glass-filled teflon boards (with 2.5 ± .05 and 0.002 dielectrics, respectively) adequately meet the requirements as opposed to the more economical conventional glass-filled epoxy material which proved to be inadequate and inconsistent at 1 GHz.

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Performance of recovery circuits

Using a signal injector cartridge, the completed VDH-3 signal recovery system has a noise floor of typically −69 dB relative to 1 volt peak-to-peak in a 30-KHz bandwidth over a 3-dB response to at least 10 MHz. Intermodulation products are −60 dB or better (sidebands of sound carrier on video carrier). Performance from a carbon-loaded test disc and typical stylus provides approximately 700 mV peak-to-peak output of video FM carrier with approximately 48-dB C/N in a 30-kHz bandwidth.

J.J. Gibson|F.B. Lang|G.D. Pyles

Nonlinear aperture correction in the RCA VideoDisc player

What is it and why is it needed?

Nonlinear aperture correction (NLAC) is needed to reduce nonlinear distortion — sound beats, for example — generated at the disc-stylus interface.

Abstract: *The capacitance pickup system has nonlinear properties. One consequence is phase modulation of the video FM carrier by the sound carrier, resulting in "sound beats" in the picture. The mechanism of sound-beat generation and the principle for sound-beat correction in the player are discussed. The NLAC (nonlinear aperture correction) circuit used in the player for sound-beat reduction is described. With the help of a feedback-control circuit, the NLAC is adapted to minimize the sound beats.*

The capacitive stylus used in the RCA VideoDisc player can resolve a recorded signal having a wavelength shorter than the wavelength of light. This remarkable resolution, which enables the player to read discs with an enormous information packing density, is obtained because the electrode is very thin and because it rides very close to the surface of the disc. Figure 1 is an idealized illustration (to scale) of a profile cut through the stylus and recorded video carrier. It shows that the wavelength of the carrier may be as short as 5000 Å (0.5 μm), that the peak-to-peak amplitude of the carrier is about 850 Å, and that the distance from the electrode to the crests of the carrier is typically 200 Å. The electrode, which is supported on one side by the diamond stylus, has a thickness that tapers off from about 2000 Å to become very thin at its closest point to the disc.

Nonlinear distortion and the NLAC

The system operates by detecting the variations in the capacitance between the electrode and the conductive disc. The detection system yields an output signal, from the "arm," that is proportional to these capacitance variations. However, because the electrode rides so close to the relief pattern recorded in the surface of the disc, the capacitance does not vary in proportion to the depth of the recorded pattern. This is quite obvious, if the stylus-disc capacitance is simply modeled as a plane-parallel capacitor that has a capacitance inversely proportional to the height of the electrode above the disc surface. For this case, it is clear that when the electrode rides close to the crests of the recorded relief signal the relative variations in this height are large and as a consequence the response is very nonlinear. In reality, the response of the stylus is more complex but nevertheless nonlinear, thereby generating nonlinear distortion products, which appear in the output from the arm. The purpose of the nonlinear aperture corrector (NLAC), which is the first circuit to process the signal emerging from the arm, is to reduce this distortion.

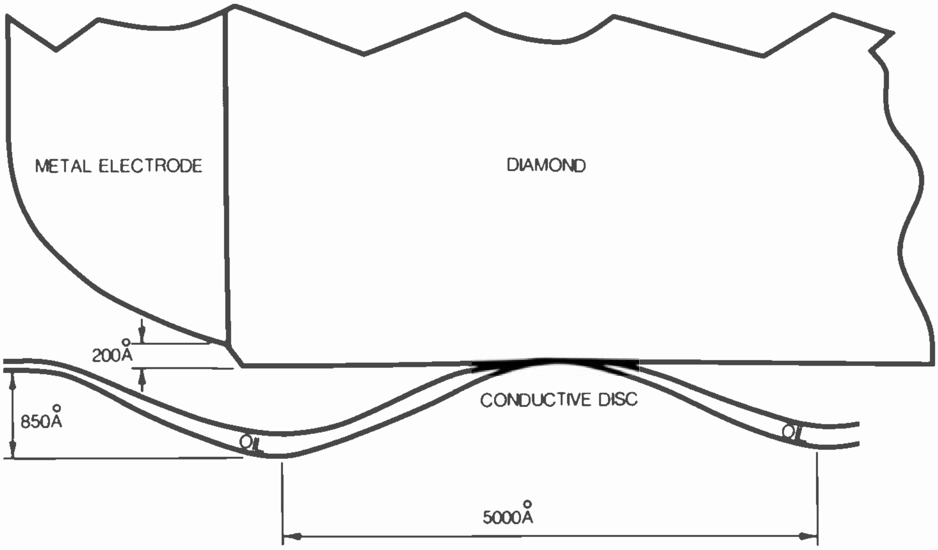

Fig. 1. Profile of stylus and disc along a groove. Recorded video carrier is shown with its shortest wavelength.

Reprint RE-26-9-7
Final manuscript received Aug 10, 1981

Sound beats

A particularly disturbing distortion is "sound beats" in the picture, which appear when the 716-kHz sound carrier inadvertently appears in the video signal. To explain how sound beats are caused by the nonlinear response of the capacitive stylus, it is necessary to describe the signal recorded along the grooves of the disc. This signal consists of the sum of two sinewave carriers that are frequency modulated, one by the video signal and the other by the audio signal. When they are unmodulated, the nominal frequency of the video carrier is $f_c \cong 5$ MHz and the nominal frequency of the audio carrier is $f_a \cong 716$ kHz. A signal consisting of unmodulated carriers recorded in a groove of the rotating disc, as seen right under the electrode of the stylus, can be expressed as

$$s = C \cos c + A \cos a, \qquad (1)$$

where $2C$ is the peak-to-peak amplitude (about 850Å) of the video carrier, $2A$ is the peak-to-peak amplitude of the audio carrier (about 80 Å), and $c = 2\pi f_c t + c_0$ and $a = 2\pi f_a t$ are the instantaneous phases of the video and audio carriers, respectively. At a tracking radius of three inches, which is almost at the inner radius of the disc that rotates at 450 rpm, the tracking velocity is v = 3.6 m/s. The wavelength of the video carrier is $\lambda_c = v/f_c$ = 0.72 μm (7200 Å), and the wavelength of the sound carrier is $\lambda_a = v/f_a = 5$ μm. Thus, even at the inner radius, the wavelength of the sound carrier is much larger than the resolving aperture of the stylus. The stylus, therefore, sees the sound carrier as a slowly varying bias added to the video carrier.

Figure 2 illustrates the video carrier under the stylus for two extreme levels of the sound carrier, that is, a sound-carrier crest and a sound-carrier valley. The vertical scale is greatly amplified. At the sound crest, the capacitance variations caused by the video carrier will be stronger than in the sound valley. This results in an amplitude modulation of the video carrier by the sound carrier, a harmless distortion *per se* since the video carrier later will be limited before FM detection. A more serious distortion is a phase modulation of the video carrier by the sound carrier caused by the fact that the diamond on one side of the electrode has a larger dielectric constant than the air on the other side. As a consequence, the electric field energy is concentrated on the diamond side causing the aperture response to be unsymmetrical. The asymmetry of this aperture depends on the height of the stylus above the disc. Overall, the effect is very much as if the stylus is reading the information on the disc "at an angle."

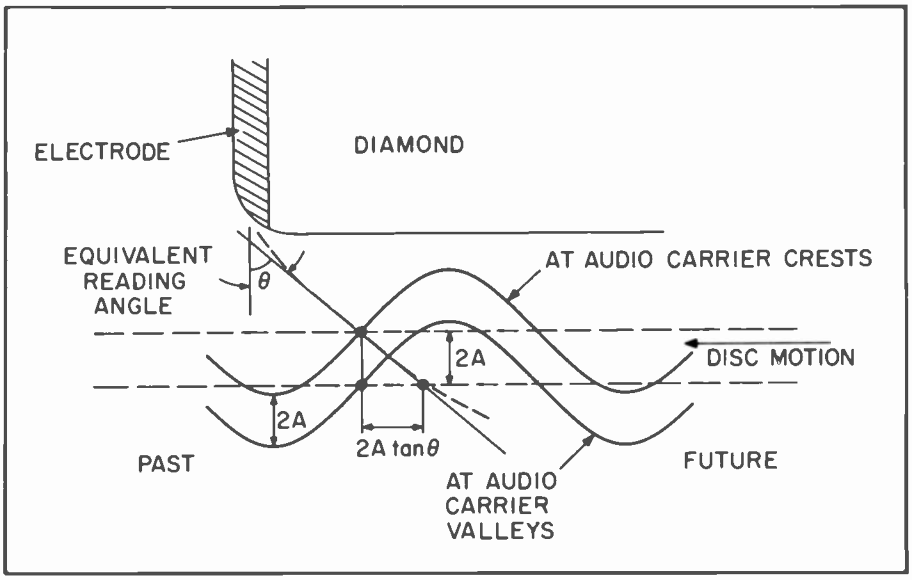

Fig. 2. Heuristic explanation of sound beats. Electric field energy concentrated on the diamond side of the electrode causes an effect very much as if the stylus were reading the disc at an angle, causing a delay modulation of the video carrier by the sound carrier.

As can be seen from Fig. 2, the effect of such "angle-reading" is to delay the video carrier at the audio crests and advance it in the audio valleys. The instantaneous phase of the video carrier leaving the arm is therefore not "c" as it should be, but $c + b \cos a$, where b is the amplitude of the disturbing phase modulation in radians. It can be seen from Fig. 2 that for a given "reading angle" θ the peak-to-peak delay variation is $2A \tan \theta$. Consequently, the amplitude of the phase deviation of the disturbance is

$$b = 2\pi\, kA/\lambda_c, \qquad (2)$$

where $k = \tan \theta$ is the tangent of the equivalent reading angle θ, λ_c is the wavelength of the video carrier, and A is the amplitude of the audio carrier.

The instantaneous frequency deviation of the disturbance is $1/2\pi$ multiplied by the time derivative of the instantaneous phase deviation, that is

$$-bf_a \sin a. \qquad (3)$$

Relative to some nominal frequency deviation D, the amplitude of the disturbing frequency deviation (the sound beats) is

$$bf_a/D = 2\pi\, kA\, f_a/D\lambda_c. \qquad (4)$$

For k = 3, $2A$ = 80 Å, λ_c = 7200 Å, f_a = 0.715 MHz, and D = 1 MHz, the relative sound-beat level is 8 percent or −22 dB, which is typically the sound-beat level obtained on the inner playing radius without an NLAC. At this level, the sound beats in the picture are quite visible and disturbing.

Sound-beat reduction in the NLAC circuit

In the stylus, the nonlinear process that generates the sound beats acts as a phase modulator operating with a single input delivering a signal s consisting of the sum of two carriers. The NLAC is also such an "additive" phase modulator, modulating the video carrier with the audio carrier to cause a phase deviation that tends to cancel the phase deviation, $b \cos a$, generated by the stylus. In principle, the NLAC works as follows.

Assume a perfect stylus-arm system yielding an output signal qs, where s is the recorded signal and q is the arm sensitivity in mV/Å. The video carrier is phase shifted by 90° while the audio carrier is phase shifted by an angle $\alpha \leqslant 90°$. The video carrier is also attenuated with respect to the sound carrier by a factor of $r^2 < 1$. The resulting signal is squared to yield a signal

$$p\,[(qC/r) \sin c + qAr \cos (a + \alpha)]^2 \qquad (5)$$

where p is a constant of dimension $(\mathrm{mV})^{-1}$. This signal has d.c. terms and second harmonics of the video and audio carriers, but the important term is the intermodulation product $2pq^2AC \sin c \cos (a + \alpha)$. If r is sufficiently large to make the second harmonic of the video carrier negligible, this intermodulation product is the only signal of concern in the video band. This intermodulation product is added to the video carrier $qC \cos c$. If the $2pqA$ term is much less than one, the resulting signal is a phase-modulated video carrier:

$$qC \cos [c - 2pq\, A \cos (a + \alpha)]. \quad (6)$$

Sound-beat cancellation theoretically occurs when $\alpha = 0$ and $2pq\, A = b$, that is, when the constant p is

$$p = p_0 = \pi k / q\, \lambda_c. \quad (7)$$

The fact that α is quite predictable, and theoretically zero, greatly simplifies the design of the NLAC. It is also noted that p_0, a parameter which controls the amplitude of the phase deviation to be generated by the NLAC, is theoretically independent of the recorded video-carrier amplitude C as well as the recorded audio-carrier amplitude A. It is only dependent on the wavelength λ_c of the video carrier, which is proportional to the track radius on the disc, and on the ratio q/k, which primarily depends on the gain of the capacitance-detection system in the arm and on the geometry of the stylus and its position relative to the recorded relief signal. These simple properties of α and p suggest that fairly good sound-beat cancellation can be obtained if these parameters are preset to fixed values, as they are in a so-called "fixed NLAC," and that very good cancellation can be obtained if α is fixed while p is adaptively varied for best cancellation, as it is in the so-called "adaptive NLAC," which is used in the player.

In practice, α cannot be predicted perfectly, partly because the stylus is more complex than its theoretical model and partly because sound beats are generated by other mechanisms in the VideoDisc system, for example, in the recording process and in the FM demodulator. In the fixed NLAC, the imperfection of the cancellation is caused primarily by an incorrect gain setting whereby $g = p/p_0 \neq 1$. Figure 3 shows that sound-beat reduction has magnitude $E = (1 + g^2 - 2g \cos \alpha)^{1/2}$ of a vector obtained by vectorial subtraction of a vector $ge^{i\alpha}$ from the unit vector. Figure 3 also shows the sound-beat reduction, 20 log E, in decibels as a function of the gain g with the phase error α as a parameter. It is seen that if the phase error is less than 10°, an adaptive NLAC can reduce the sound beats by more than 15 dB. Numerous tests of fixed NLACs—at different radii, different discs and different styli—showed that worst case sound beats could be reduced from −22 dB to about −30 dB, which was considered marginal. The adaptive NLAC reduces the sound beats to be less than −37 dB.

The NLAC circuit

The NLAC circuit is a phase modulator where both the modulating and carrier signals come in as one input. This input is the arm-output signal, which contains the 716-kHz sound carrier that becomes the "modulating signal" and the 4.3- to 6.3-MHz video carrier that is the "carrier" to be phase modulated. The phase-modulation technique is the one frequently used to generate narrowband FM, where a balanced modulator generates sidebands that are added to the carrier in quadrature.

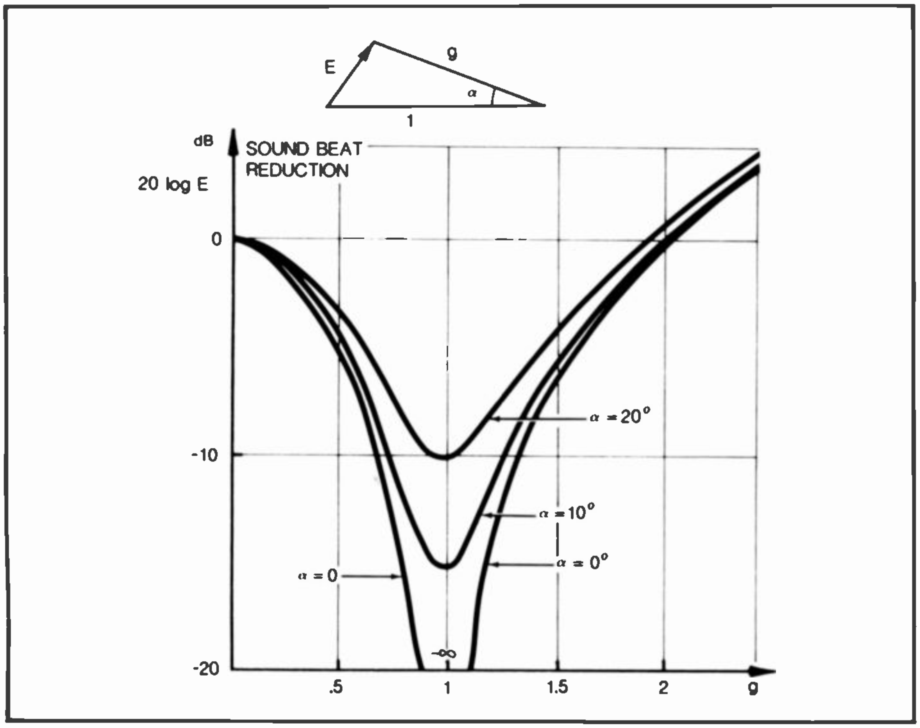

Fig. 3. Sound-beat reduction. It can be described as a function of errors in the gain g and phase α of the compensating signal.

Figure 4 shows the NLAC circuit with the components grouped by function. The input network performs four tasks: attenuation, trapping, sound-carrier phase control, and video-carrier integration. R_1 and R_2 attenuate the input so that the diodes in the modulator section will be operated over only a small portion of their I-V curve. L_1 and C_1 together with the source resistance provided by R_1 and R_2 form a series-resonant trap at 260 kHz. This trap is necessary to prevent the arm-tracking servo signal from reaching the balanced modulator and phase modulating the video carrier at a 260-kHz rate. L_1, C_1 and C_2 become parallel resonant near the sound-carrier frequency. The "Q" of the network is very low so the sound-carrier amplitude is relatively insensitive to the actual resonant frequency. The network's parallel resonance, which is set by the value of C_2, is critical because of its effect on the sound-carrier phase. The reason that the phase is so important is that the modulator section uses the sound carrier to generate sidebands on the video carrier. It is these sidebands that cancel the sound-beat sidebands and proper phase is needed for good cancellation.* At video-carrier frequencies, well above resonance, the reactance of C_2 dominates and the input network becomes an integrator. Consequently, the video-carrier portion of the input will have a decreasing amplitude response and lagging phase with increasing frequency. This compensates for the increasing amplitude and leading phase of the 90° phase shifter, C_6, which is used to add the video carrier in quadrature to the sidebands generated by the modulator section.

C_3, R_3 and R_4 form a high-pass filter with a 72-kHz cutoff to reject low-frequency

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*Two sinusoidal signals will cancel each other completely if they have equal amplitudes and are 180° out of phase. If either input's amplitude changes 10 percent, or if either input's phase shifts by 5.7°, the resulting partial cancellation will have a residual that is 20 dB below the original input-signal amplitudes. The parallel resonance of the NLAC input network would have to shift downward by 52.7 kHz in order to shift the phase of the sound carrier 5.7°. However, in order to change the sound carrier amplitude by 10 percent, resonance would have to shift downward by 131 kHz or approximately 2.5 times further.

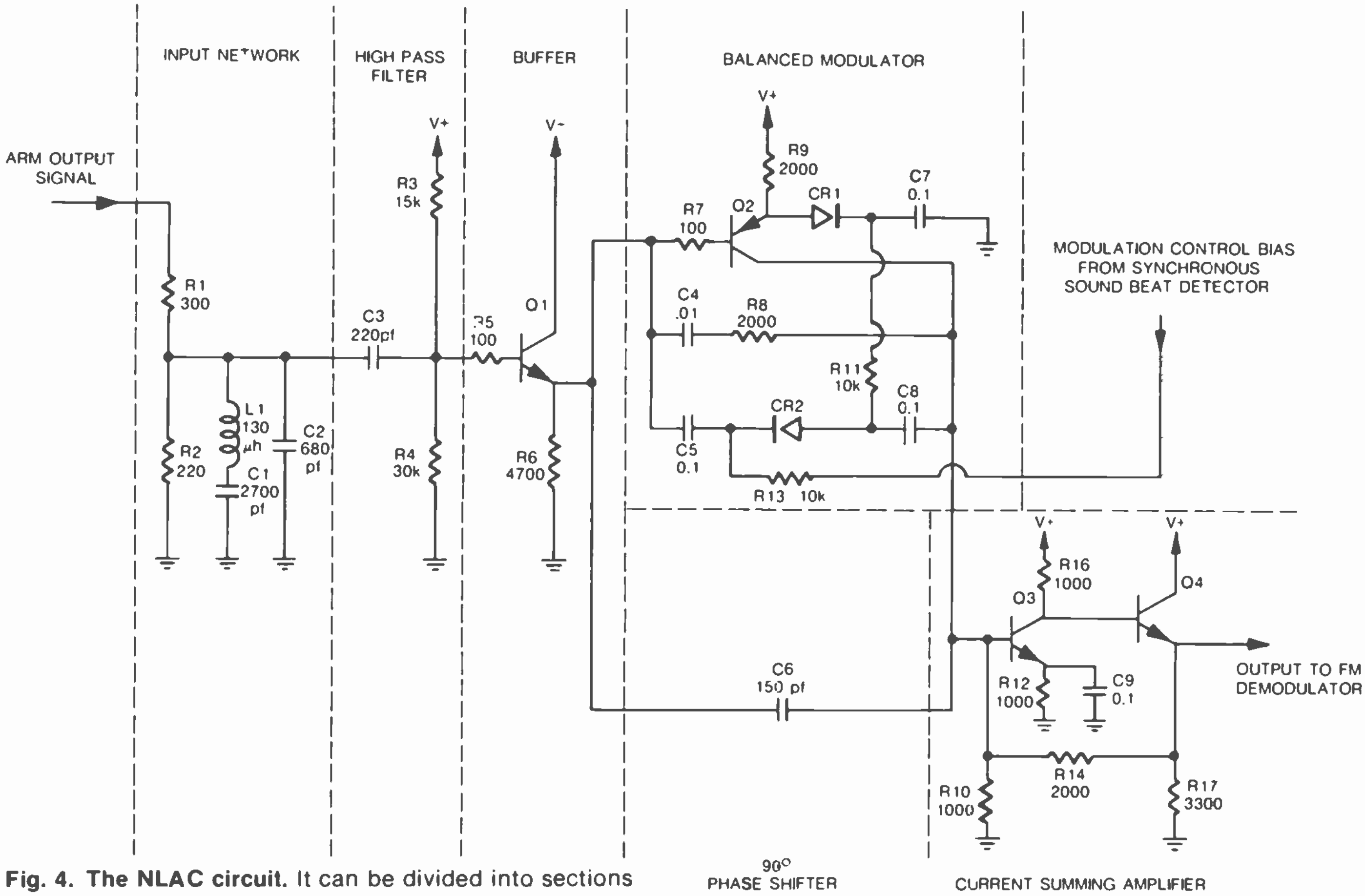

Fig. 4. The NLAC circuit. It can be divided into sections that have six distinct functions.

noise that could generate video-carrier sideband noise if allowed into the modulator. The buffer stage — Q_1, R_5 and R_6 — provides a high-impedance load for the input network and high-pass filter, and a low driving impedance for the modulator and 90° phase-shifter sections that follow.

The modulator and phase-shifter sections are connected in parallel. These sections are driven from a low impedance or voltage source and are terminated by the low input impedance of the summing amplifier feedback pair, Q_3 and Q_4. The summing amplifier converts the sum of its input currents to an output voltage. The operation of the phase shifter is straightforward; the current through capacitor C_6 is the differential of the voltage across it. The main signal, which is the video carrier, and all its sidebands including the sound-beat sidebands, go via this path and are phase-shifted 90°. This is the quadrature function required to give the NLAC circuit its phase-modulator characteristic.

The balanced modulator section can be thought of as three parallel current paths, two conductances and one transconductance. Diode CR_2 is the first path, a nonlinear conductance, with C_5 and C_8 providing signal coupling and bias network isolation. Transistor Q_2 is the second path, a nonlinear transconductance which is a function of the conductance seen by its emitter, CR_1 in parallel with R_9. The third path is R_8 with coupling capacitor C_4. A positive-going signal voltage from buffer Q_1 causes the current in CR_2 to decrease and the current in CR_1 to increase. As a result, CR_2's conductance decreases while CR_1's increases. This effect is the nonlinearity that provides modulation. A component of Q_2's collector current is the inverse of CR_1's current so it tends to cancel the signal coming through CR_2. In fact, if CR_1 and CR_2 were linear devices, the signal current through the two paths would cancel completely. This is the feature that makes the modulator balanced and only the products of the input signals appear at its output, not the original signals themselves. Resistor R_8 adds a linear signal current to cancel the linear component of Q_2's collector current due to resistor R_9 in the emitter circuit. If R_9 were replaced by a high-impedance current source, C_4 and R_8 would not be necessary. Resistors R_{11}, R_{13} and capacitors C_5, C_7, C_8 provide a.c. signal isolation between the diodes while allowing them to be biased with the same d.c. current.

The balanced modulator mixes the sound and video carriers, thereby generating sidebands that are 716-kHz above and below the video carrier. As a result of the input network's "phase processing," these sidebands are exactly 180° out of phase with the sound-beat sidebands that are also arriving at the input node of the summing amplifier via C_6. If the amplitude of the sidebands generated in the modulator are equal to the sound-beat sideband amplitudes, cancellation will occur and the sound beat will be removed from the signal. Modulator-generated sideband amplitude is a function of diode conductance, which, in turn, is a function of diode-bias current. This provides a means of controlling the NLAC so that it can cancel a wide range of sound-beat amplitudes.

Adaptive NLAC circuit

Adaptive control of the bias current to the modulator diodes is achieved in the player's NLAC control circuit. The sound-beat variations from the outside to the inside radius of the disc, as well as differences between styli, are sensed and

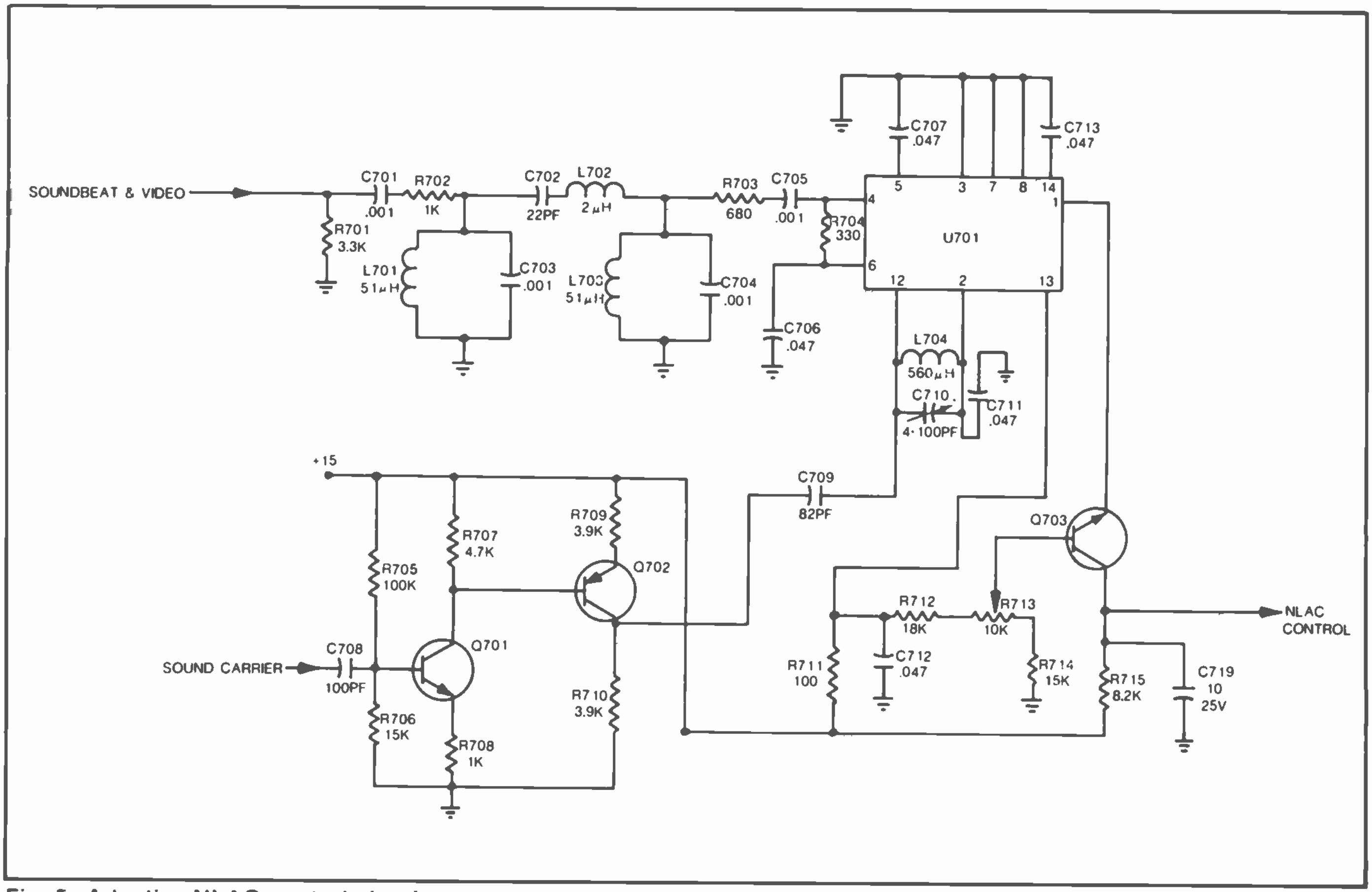

Fig. 5. Adaptive NLAC control circuit.

the modulator-generated sideband amplitudes adjusted to optimize reduction. Figure 5 is a schematic of the adaptive control circuit.

IC *U*701 is a synchronous detector. The two inputs to the detector are the sound carrier and the sound-beat component present in the demodulated video from the video FM demodulator. The filtered sound carrier from the "pickup arm" composite signal is used as the reference-signal input to the synchronous detector. A similar filter separates the sound-beat component from the video and inputs it to the synchronous detector via an amplifier circuit in *U*701. The synchronous detector is sensitive to amplitude and phase relations between the sound beat and the reference sound carrier. A phase-shift network between pins 12 and 2 sets the relative phase to optimize this sensitivity. Video-frequency components that fall within the pass band of the sound-beat filter are not synchronous with the reference carrier, therefore, error voltages due to these components are small. The sound-beat component is synchronous with the reference, hence, the amplitude variations result in a significant error signal at the detector output, particularly as the closed-loop action of the adaptive control with the modulator adjusts to minimize or null the sound beat. Low-pass filters *C*713 and *C*719 in the output of the detector and the error voltage amplifier remove the spurious components caused by video and average the synchronous sound-beat error voltage to a principally d.c. control voltage for modulator diodes CR_1 and CR_2.

The closed-loop action of the control circuit, in connection with the modulator, is as follows, starting with the condition of two inputs (sound beat and sound carrier) applied to the adaptive control circuit, as would be the case when the stylus drops onto the disc. The synchronous detector sees the two required inputs. An output error signal will develop, the amplitude primarily dependent on sound-beat amplitude relative to the reference sound carrier. Phase (negative or positive going) is dependent on what is causing the beat component nonlinear behavior from the disc or modulator action. Assume the condition is caused by a beat component from disc. This corresponds to a negative-going error voltage at the synchronous detector output (pin 1 of *U*701). The error is amplified and level translated at the *Q*703 collector. This error signal is in the direction to cause an increase in the current of CR_1 and CR_2, effecting an increase in modulator action. The consequent increase in out-of-phase, modulator-generated sidebands adds to the stylus-generated sidebands in the NLAC, as previously explained, to cause a decreasing sound beat. The continuing closed-loop action proceeds until the error signal becomes zero, signifying that the modulator-generated sidebands equal the sidebands from the disc signal. At this point, the sound beat is at a minimum. The closed-loop control of adaptive circuit on the NLAC will continue to track out variations to keep the system running optimally.

Acknowledgments

Many people have contributed to the development of the NLAC circuit. In particular, we want to acknowledge contributions to the design and testing of the circuit by M.D. Ross. J.K. Clemens and R.C. Palmer have greatly contributed to the understanding of sound beats, and D.L. Jose, K.A. Pitts, E.P. Cecelski, and J. Rustman extensively tested the NLAC circuit.

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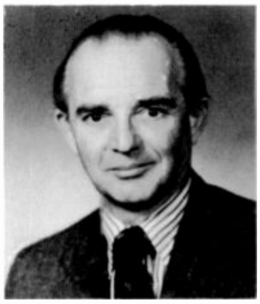

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G.D. Pyles | B.J. Yorkanis

VideoDisc's video and audio demodulation, defect detection, and squelch control

One custom-developed IC in the VideoDisc player does the job of several discrete circuits.

Abstract: *The demodulation circuits for video and audio FM carriers on the signal processing board use a custom-developed integrated circuit in the VideoDisc player. The integrated circuit contains all of the functional blocks for phase-locked-loop (PLL) demodulation and signal amplification for further processing by other circuits in the system. Also, several other functions unique to the VideoDisc system are designed on the IC. Defect detection, recovery of carrier recognition, squelch, and squelch logic are performed by the device.*

Video and audio signals for the VideoDisc player are recovered via appropriate demodulation of FM carriers. The integrated circuit designed to perform the demodulation also performs several other functions essential to the performance of the VideoDisc player. Detection of defects in the FM carrier, defect-pulse generation, carrier recognition, squelch logic, and baseband-signal amplification are all achieved by one 16-pin IC and peripheral components (Fig. 1). The device was specifically designed for application in the VideoDisc player and, as such, it efficiently replaces extensive discrete circuits.

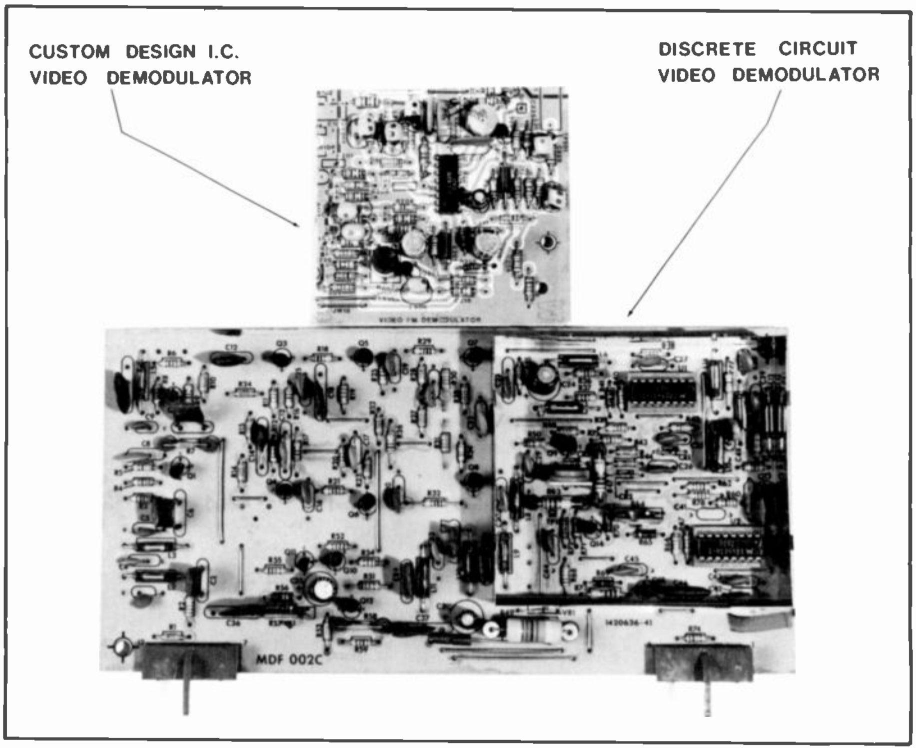


Fig. 1. Custom IC and discrete circuit equivalent for video demodulation. A custom-designed integrated circuit for the VideoDisc player performs the extensive tasks required for video and audio signal recovery. Significant reduction in size and complexity along with substantial cost reduction make the IC a vital part of the VideoDisc player.

Audio and video baseband signals are recorded on the disc as FM modulation of carriers at 716 kHz (mono) and approximately 5 MHz, respectively. The audio channel is rather straightforward — 716-kHz carrier, maximum deviation ± 50 kHz, audio bandwidth of 20Hz to 15 kHz with $75\mu s$ pre-emphasis. The video channel is more complex in description — sync tip (−40 IRE) is 4.3 MHz, blanking (0 IRE) is 4.87 MHz, black level (7.5 IRE) is 5.0 MHz, white level (100 IRE) is 6.3 MHz, and video bandwidth is 3 MHz with luminance pre-emphasis (maximum of 21 dB at 3 MHz). Deviation clip levels are 3.9 and 6.9 MHz (−66, + 144 IRE). Figure 2 is a spectrum representation of these signal and parameter specifications.

Despite the gross differences between the video and audio signals, the custom-designed integrated circuit for use in the VideoDisc player satisfactorily fulfills both applications.

Demodulator

The principle of demodulation for both video and audio signals is a phase-locked loop (PLL). Figure 3 shows the functional

Reprint RE-26-9-8
Final manuscript received Aug 12, 1981

blocks as connected in the IC and to the external circuits to perform as a demodulator. The same configuration applies to both video and audio signals with only external components adjusted to appropriately agree with the FM signal parameters and the modulation information, video or audio. The phase detector and voltage-controlled oscillator are fundamental in this PLL demodulator. With the addition of an external loop filter, these two functions in a closed-loop system provide a demodulated output response, namely,

$$H(j\omega) = \frac{K_0 K_d F(j\omega)}{j\omega + K_0 K_d F(j\omega)} \qquad (1)$$

where $H(j\omega)$ is the closed-loop output response, $F(j\omega)$ is the loop-filter response, K_0 is the voltage-controlled-oscillator (VCO) conversion gain and K_d is the phase-detector conversion gain. The latter two are significant constants determined by circuits designed internally in the IC. The design intricacies are beyond the scope of this article but a general description of performance properties enhancing application in the VideoDisc player is appropriate.

The phase detector is a multiplier type. A doubly balanced construction provides good cancellation of the two input signals (FM signal and VCO reference) in the output. This is especially important in the video demodulation application where the upper baseband signal is close to the carrier frequency. The conversion gain (K_d) is designed to avoid saturation but adequate to combine with the VCO conversion gain (K_0) to give an overall loop gain sufficient for design optimization in both applications.

The VCO is a RC-type multivibrator noted for good linearity of voltage-to-frequency conversion and having a wide dynamic range. Again, this is particularly important in the video demodulator application — refer to Fig. 2 and note the required tracking range. The VCO center frequency is set by adjustment of an external timing capacitor. The rate of voltage change (dV/dt) across the capacitor, which determines the conse-

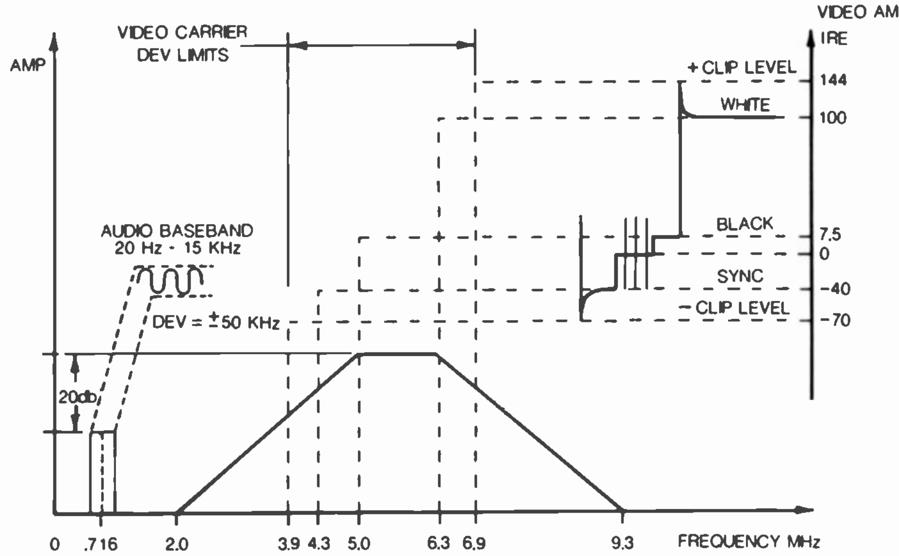


Fig. 2. Frequency spectrum. The signals recovered from the disc contain frequencies extending to nearly 10 MHz. Selective filters input the appropriate FM carriers and sidebands to the video and audio PLL demodulators to recover the baseband information. Note the wide tracking required by the video demodulator due to large overshoots caused by pre-emphasis. These extreme deviations are limited in the modulation process to a maximum change of 3 MHz.

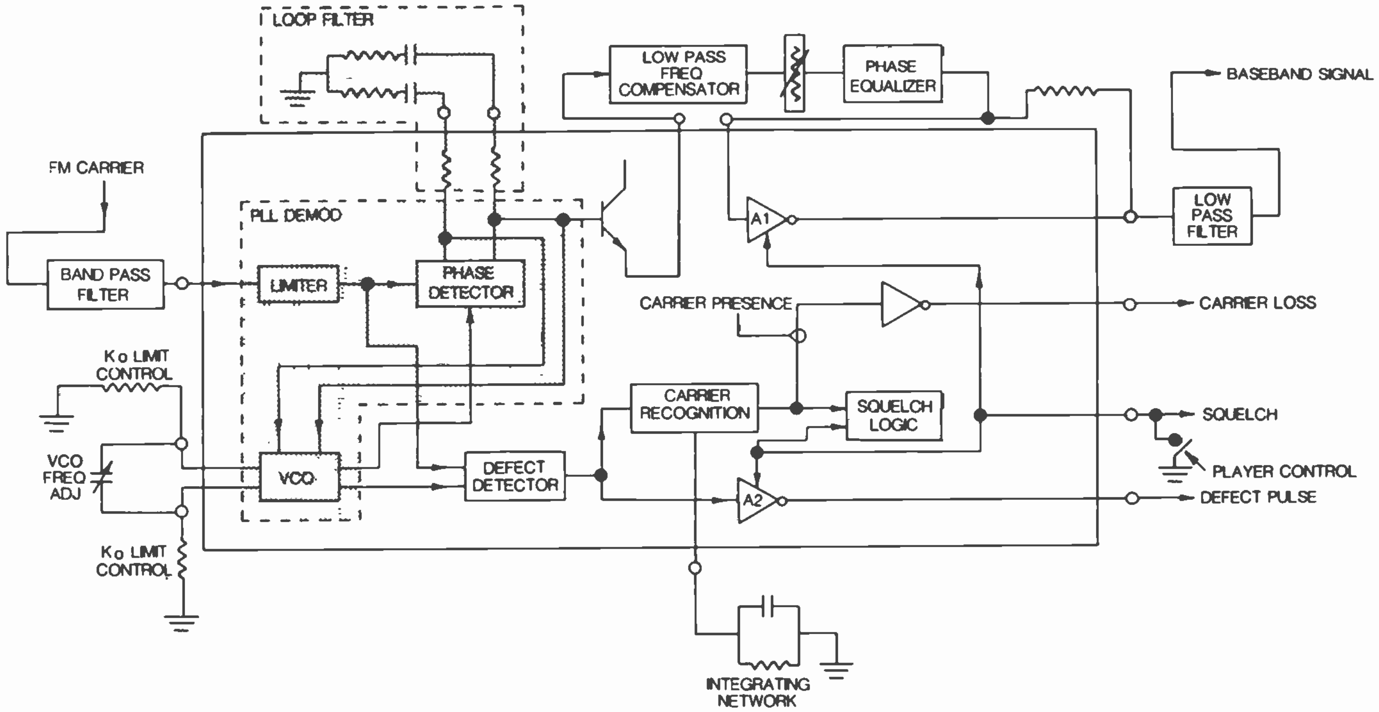


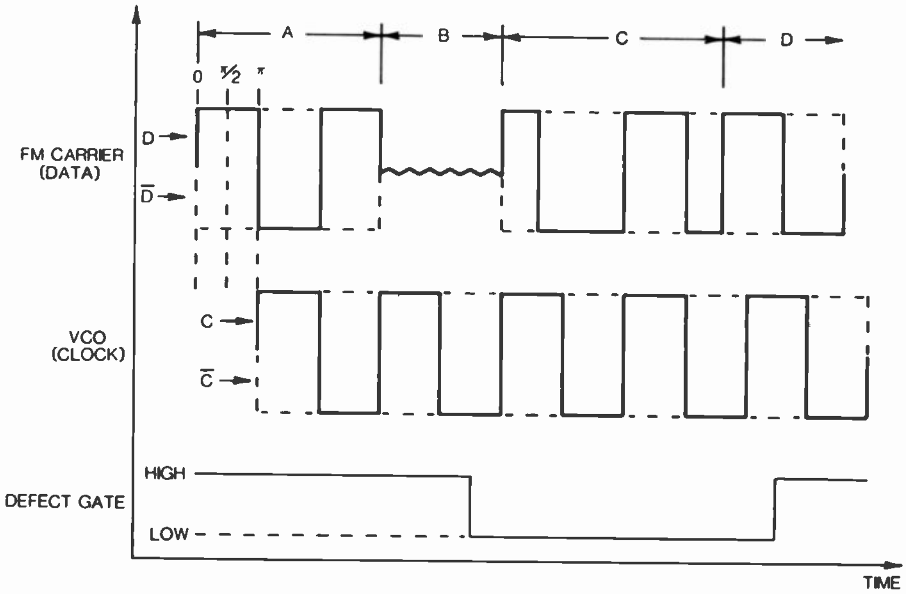
Fig. 3. Functional block diagram of the custom-designed IC used as video and audio demodulators in the VideoDisc player.

quent frequency, relates to the current in the capacitor as

$$I_c = C_c \frac{dV_c}{dt} \qquad (2)$$

where the current, I_c, is controlled by current sources in the multivibrator. The sources are controlled by error voltage from the phase-detector output. The steering of the current by the phase-detector output results in instantaneous frequency control of the VCO to track the input frequency.

The integrated PLL demodulator also has a limiter circuit that precedes the input of the phase detector. The pre-filtered FM carrier typically may vary 20 dB in level, but with adequate C/N to provide a good picture or sound. The limiter serves as a gain block with constant level output compensating for the variations, and it provides a constant level input to the phase detector, resulting in a constant phase-detector conversion gain and good AM rejection.



FUNCTIONAL TABLE		
CASE	INPUT RELATION	DEFECT GATE
1.	$\Delta\phi = > 0 < \pi$	HIGH (NO)
2.	$\Delta\phi = \leq 0$	LOW (YES)
3.	$\Delta\phi = \geq \pi$	LOW (YES)
4.	D = 0; C = X	LOW (YES)

Fig. 4. Defect detection. Signal input conditions, *A* and *D*, are normal input-phase ($\Delta\phi$) relations between VCO and input signal. Case 1 shows the functional response of no defect gate. Condition *B*, Case 4, is a loss of input signal — note that a defect gate is generated. Condition *C* goes through relations of Case 2 and 3 after signal is recovered, holding the defect-gate low. Note the input half-cycle (*D* and $\bar{D}$) is read for each half-cycle of clock (*C* and $\bar{C}$). A generated defect starts one clock half-cycle late, but this is compensated for by group delay in baseband phase-corrector circuits.

In summary, the fundamental operation of demodulation is as follows. The preselected FM carrier inputs to the IC PLL demodulator. A gain-block limiter enhances performance by accepting a large dynamic range of input levels. A doubly balanced phase detector and a voltage-controlled oscillator with wide dynamic range, connected in a closed loop, track the input signal via control of current sources in the multivibrator oscillator that have a linear sensitivity to the averaged phase-detector output error signal. The instantaneous phase error between input signal and VCO is the demodulated output signal. Addition of an external loop filter to the loop gain constants K_0 and K_d provides design flexibility to optimize the PLL response for both video and audio applications.

Defect detection

Similar to the disturbance or interference experienced in a radio or TV receiver, signals from the VideoDisc sometimes exhibit disruptions or distortions in the FM carriers to the demodulation circuits. Unless corrected, the abnormalities, termed defects, result in undesired disturbances in video and/or audio. The VideoDisc player incorporates circuits to detect and correct for defects in video and audio. The correction to video is covered in another article in this issue (see page 54). The audio correction will be covered in this article along with the means for defect detection.

The defect-detection circuit, as part of the IC performing demodulation, is dependent on the performance characteristics of the PLL demodulator. Reference to Fig. 3 shows the two inputs to the defect detector to be the same as those to the phase detector — the limited FM signal and the VCO. The defect-detection mode is essentially monitoring these two inputs to validate that they indeed have the correct relation to demodulate as coherent video or audio information. If not, a defect-gate pulse is generated to enable corrective circuits.

One of the criteria for defect recognition is based on the signal relations in the operation of a PLL demodulator using a phase detector as previously described. The input-output relationship of the phase detector

$$E_0 = K \cos(\phi_2 - \phi_1) \qquad (3)$$

shows the output E_0 to be zero with the input relations at 90° and increasing negatively or positively for differences greater than or less than 90°, respectively. In other words, the PLL closed loop maintains a phase lock with the two signals in quadrature at zero error voltage and will maintain lock with an increasing error voltage ± 90° from quadrature. Beyond these extremes, the loop will lose lock and fail to perform properly as a demodulator. The defect-detection circuit is designed to recognize these two extremes and generate a defect-gate pulse upon recognition. Restated, if the input signal exceeds deviation limits or a rate of deviation to cause the PLL to lose lock, a defect-gate pulse is generated.

A second condition causing defect-pulse generation is momentary loss of the input signal. The limiter output is essentially zero with only the VCO signal present at the defect detector, resulting in a defect-gate pulse for this momentary loss. This response holds true for losses as short as one-half cycle of the input frequency.

A third condition causing defect-pulse generation is excessive noise present on the carrier, that is, a poor carrier-to-noise (C/N) ratio. This condition causes a failure mode in the same manner as the first case in that the noise is randomly phase additive to the carrier, and hence causes random excursions that exceed the ± 90° degrees relation.

Figure 4 is a graphical presentation and functional response table of the defect-detection circuit as described. The input relations between the VCO and input signal are read in a time-serial manner. Any exceptions to the relation (positive input when the VCO goes positive) result in a defect-gate pulse output.

Audio defect correction

As mentioned, the VideoDisc player incorporates circuits to reduce audio disturbances caused by signal input conditions. These are not part of the demodulator IC but depend on its derived pulse to accomplish correction. The amplified demodulated output is passed through a track-and-hold circuit, which gates off when a defect pulse appears. The gated state causes the output audio to remain at the level prior to disruption. Although this breaks the coherence momentarily, it is normally not detected in complex waveforms. The small discrepancy is much less noticeable than the large outputs of defects that normally exceed signals greater than 100-percent modulation amplitudes. This track-and-hold technique is very effective in reducing "tick-and-pop" disturbances, especially noted during low-modulation passages.

Squelch logic and recovery of carrier recognition

One of the operational conditions of the player is to blank the TV screen and mute audio when the player lever is in the PAUSE or LOAD position, or during initial turn on, and maintain this condition until the lever is returned to PLAY and a good picture and audio are recovered.

This squelched state acts on the amplifiers in the demodulator IC to reduce the gain to zero. The amplifiers are particularly designed to reduce gain with a minimum change in DC quiescent level present in the video or audio signal. The overall result is that the operating quiescent level is maintained, but demodulated output (principally noise) is blocked to avoid spurious inputs to the video or audio processing circuits that follow. Secondly, the defect-gate pulse is inhibited to avoid a recirculating substitution mode. Thirdly, the video conversion and time-base correction system uses squelch to precondition its servo loop for rapid acquisition.

The state of squelch (true, logic 1 as low; false, logic 0 as high) is determined by logic circuitry from two inputs — carrier recognition and the player's function-control switch. The squelch output port serves as a bidirectional data port. When the player-control switch is closed, this switch closure acts as an input to the squelch-logic circuit to hold its output at a low level. When the switch is open, it allows the output of the squelch logic to be passed to squelch circuitry. Carrier recognition necessary for the logic function is developed by integrating the pulses at the defect-detector output. A high rate exists for no carrier, but this rate becomes low or essentially zero for a good carrier. An external network integrates the pulses and sets a threshold for the rate below which carrier recognition is established. Based on the foregoing, the explanation of the squelch and not-squelch response is as follows.

Assuming a condition of play, the logic circuit and memory are set in a condition to respond only to the simultaneous presence (logical product) of forced squelch (switch closure) and loss of carrier. Squelch is begun by a user operation that closes a control switch and pulls squelch low. Simultaneously, the stylus lifts from the disc, causing loss of carrier. The flip-flop sets and conditions the logic circuit to now respond only to the inclusive logical sum of two variables — recovery of carrier and squelch. The latter (squelch) is read as false, due to the previously set condition of the flip-flop.

Return to play requires a user command, which releases the control switch that initiates squelch. With the opening of this switch, the stylus drops to the disc but squelch is maintained by the latched state that has been set by the flip-flop. This latched state inputs to the logic circuit as squelch being false (logic 0, high). Carrier is recovered when the stylus contacts the disc, hence the logic sees carrier recognition as true. This changes the output state to "not squelch" and play resumes. This resets the flip-flop and conditions the memory and logic circuits to respond only to the logical product of forced squelch and loss of carrier.

Design considerations

The design considerations for the demodulators logically had to start with the modulation characteristics of the FM signals, stated earlier. Secondly, the C/N ratio of the signals from the disc had to be considered and they are reasonably predictable. These two fundamental considerations suggest an appropriate noise bandwidth for the demodulation loop. In both cases, video and audio, this becomes

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the determining factor establishing the loop-tracking performance, S/N ratio, and loop response best suited for the application. Optimization of each of these required compromises yielding the overall best performance for each application. We designed each demodulator within constraints by selection of loop-gain constants (VCO and phase detector) and the PLL loop filter.

The video demodulator was chosen to be a first-order loop due to the wide tracking requirements (recall that encoded signal clip levels are 3.9 to 6.0 MHz) and large baseband bandwidth (3 MHz). The gain constants, as designed in the IC, are adjusted down by external resistors (see Fig. 3, K_0 limit control) to give tracking performance slightly greater than deviation requirements, but limited to a range that will enhance defect detection — recall that defect detection results when the loop fails to track. Also, a good S/N ratio and response were achieved by this loop.

The audio demodulator was chosen to be a second-order type-two loop. Within the modulation parameters and input signal C/N ratio constraints, this type of demodulation loop allowed a choice of loop-filter design, in combination with the conversion gain, yielding a minimally compromised performance.

VideoDisc System articles are in the line up for...

The *RCA Review* September 1981 issue

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The Principles and Quality of the Buried-Subcarrier Encoding and Decoding System and Its Application to the RCA VideoDisc System
D.H. Pritchard, J.K. Clemens, and M.D. Ross

The Influence of Carrier-to-Noise Ratio and Stylus Life on the RCA VideoDisc System Parameters
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Computer Simulation of Horizontal Transient Response of the NTSC
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N.J. Kiser|E.F. Lambert
D.H. Pritchard|D.J. Sauer

CCD comb-filter and defect-corrector system for VideoDisc application

IC design advances minimized the external circuitry — and the cost — required for this crucial signal-processing job.

Abstract: *The use of the "buried-subcarrier" signal in the "SelectaVision" VideoDisc system requires that the luminance and chrominance components of the signal be processed for subsequent translation to standard NTSC format. The necessary processing of luminance and chrominance can only be accomplished through the use of comb-filter techniques. By taking advantage of recent developments in the application of charge-coupled device (CCD) technology to comb filters in television receivers, a cost-effective integrated-circuit approach to the VideoDisc comb filter was made possible. This comb-filter implementation also provides a 1-H delayed signal suitable for correction of picture drop-outs caused by small defects in the disc.*

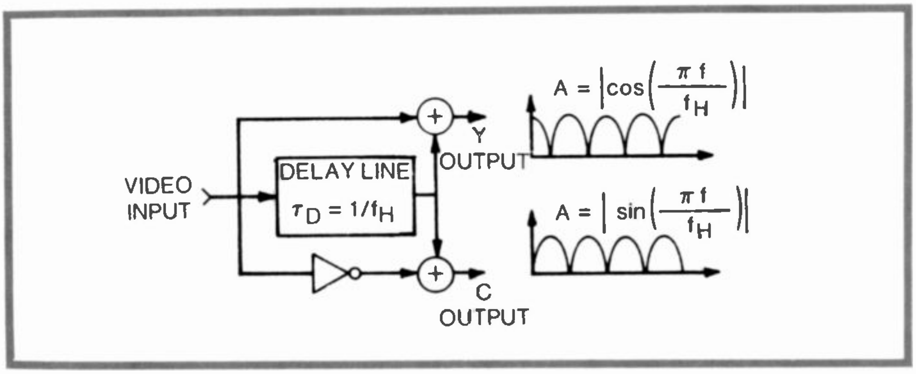

Fig. 1. Basic comb-filter circuit. The resulting amplitude responses for luminance (Y) and chrominance (C) outputs are shown on the right.

To conserve bandwidth, maximize playing time, and minimize beat and interference effects, the "buried-subcarrier" signal-encoding technique was developed for the "SelectaVision" VideoDisc system. This signal format is very similar to the standard NTSC format, except that it uses a chrominance-subcarrier frequency of 1.53 MHz instead of 3.58 MHz. The use of a lower chrominance-subcarrier frequency "buried" in the luminance frequency band requires that comb-filter techniques be applied to encode and subsequently to decode the luminance and chrominance components so that the signal can be translated to standard NTSC format.

The comb filter

Since a comb filter was required in the VideoDisc player, it became necessary to develop a cost-effective implementation. Figure 1 shows the basic elements of a comb filter with a single delay line suitable for separating luminance and chrominance components of a video signal. Although the concepts of comb filters have been well known for many years, technology has not been available to allow a cost-effective, highly reliable implementation in IC format, of a comb filter for video signal processing (that is, one with the necessary 63.5-μs delay). Fortunately, at the time that the introductory VideoDisc player was being developed, RCA was making advances in the application of charge-coupled device (CCD) technology to comb filters in television receivers. This approach is particularly attractive since it allows a complete 1-H comb filter to be implemented in a single integrated circuit. In addition, the availability of a 1-H delayed signal allows for correction of signal drop-outs caused by small defects in the disc that are detected in the FM demodulator.

Reprint RE-26-9-9
Final manuscript received Aug. 19, 1981

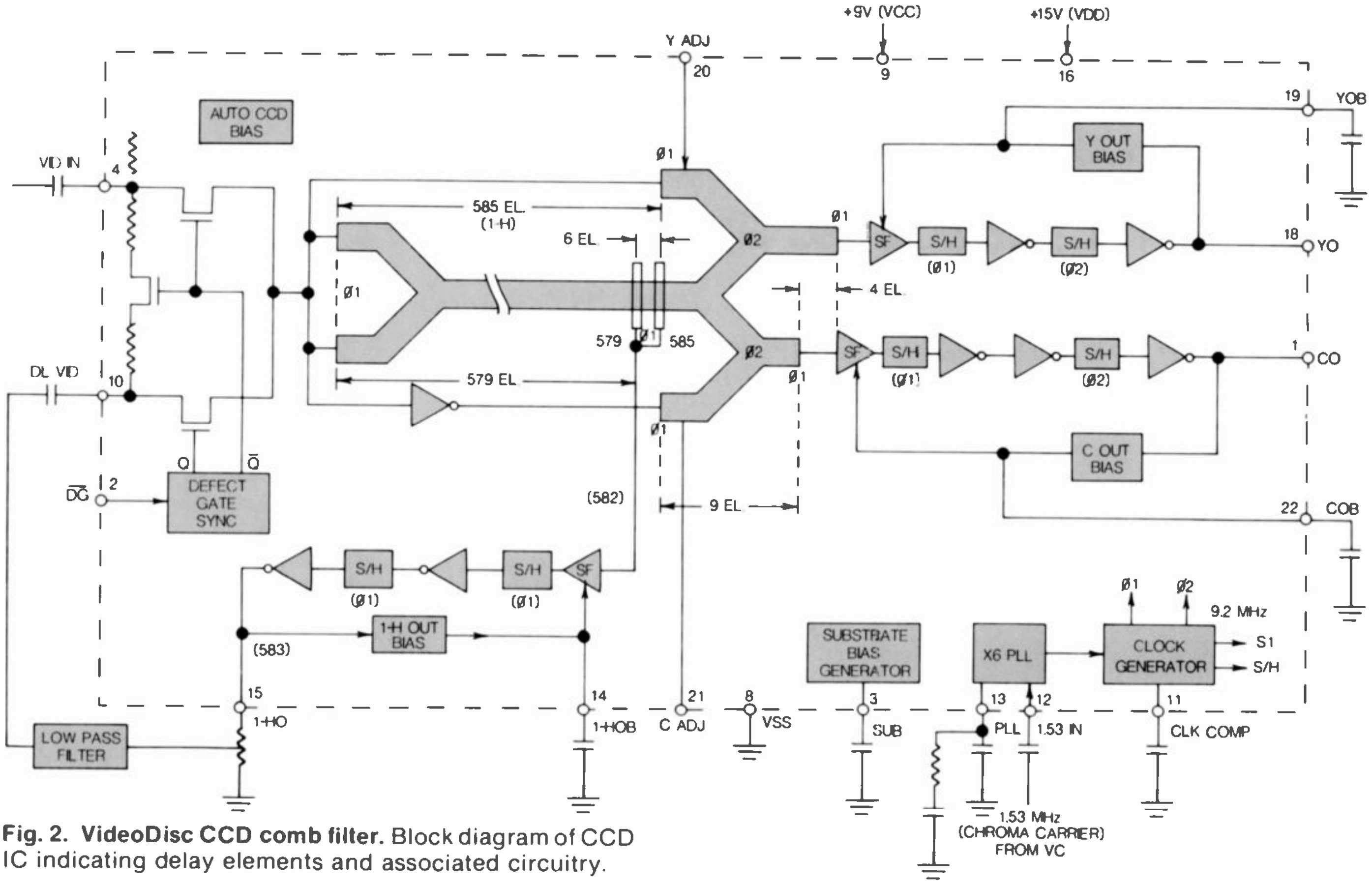

Fig. 2. VideoDisc CCD comb filter. Block diagram of CCD IC indicating delay elements and associated circuitry.

RCA developed an advanced *n*-channel process that combines high-performance buried-channel CCDs with linear and digital NMOS circuits. This process makes it possible to include all of the support circuits needed to operate a 1-H CCD delay (such as clock drivers and video amplifiers) on a single low-cost chip that is suitable for consumer electronics. The major features of the VideoDisc Comb Filter/Defect Corrector IC are as follows:

- Combines a buried-channel CCD delay line with analog and digital NMOS circuits.
- Double-poly *n*-channel self-aligned gate process.
- On-chip "times-6" clock-multiplier phase-locked loop (PLL).
- 585-stage 1-H CCD delay line for 9.2-MHz clock frequency (6 x 1.53 MHz).
- Transfer inefficiency of approximately 2 x 10 [illegible] per transfer.
- On-chip clock drivers.
- Self-adjusting CCD input and output biasing circuits.
- On-chip substrate bias generator (−5 volts).
- 1-H tap with phase inversion at 1.53 MHz to provide a signal suitable for defect correction.
- On-chip input switch to choose either incoming video or 1-H delayed video by external "on" trigger.

The comb-filter IC's functions

A block diagram of the VideoDisc CCD comb-filter IC is shown in Fig. 2. A single 1.53-MHz reference sinewave input (0.5 V p-p) is required to lock the times-6 PLL multiplier, which in turn provides a 9.2-MHz output to drive the on-chip clock generator. The PLL employs a digital phase comparator with an external two-pole *RC* loop filter designed to minimize 1/*f* noise components generated by the MOS transistors in the comparator's voltage-controlled oscillator (VCO). The clock-generator circuitry includes a two-phase CCD clock driver and clock phase comparator feedback circuit to maintain a 50-percent clock-duty cycle for optimum charge-transfer efficiency. The clock-driver circuitry used in this IC is very similar to comparable circuits developed for the CCD comb-filter IC used in some RCA ColorTrak TV receivers.[1] The comb-filter IC operates from two power supplies: $V_{CC} = 9$ V and $V_{DD} = 15$ V. V_{CC} supplies the times-6 PLL and clock-driver output circuitry, and V_{DD} supplies the clock-generator logic circuitry and video output amplifiers on the chip. In addition, a −5-V substrate bias is developed on-chip by a capacitive inverter operating at 9.2 MHz. The purpose of the substrate bias is to: (1) increase parasitic field-transistor thresholds, (2) lower junction-depletion capacitance to increase circuit speed, and (3) avoid nonlinear MOS threshold characteristics in the video output amplifiers.

The comb-filter function is implemented directly on-chip by using a unique CCD-channel configuration. Highly accurate signal addition is accomplished by merging two CCD channels together. The luminance comb is formed by adding signals from a short delay line and a long delay line (Fig. 2). The difference in delay between the short and long lines is 585 elements, which is exactly 1-H. The chroma comb is formed in a similar manner, except that an additional unity-gain inverter is used before the chroma short-line input. To provide separate 1-H delayed signals for the Y and C adders, the signal charge is split equally into two channels at the output of the long line. At the input of the long line, two separate inputs followed by channel merging are used to provide optimum tracking to the short-line inputs.

The video output amplifiers used on this IC have improved performance compared to the earlier TV comb-filter IC design.[1,2] The output signal-to-sampling-clock-noise ratio has been improved by about 10 dB by using a double sample-and-hold configuration operating from opposite-phase clocks. In addition, a novel switched-capacitor differential amplifier is used to set the video amplifier's DC operating point. This differential amplifier provides high DC gain without saturating on video or clock components and only requires a single external capacitor for loop compensation.

The on-chip video input switch that is used for defect substitution is controlled by a TTL level-defect gate-input signal (DG). Video switching transients that could occur during substitution are minimized by synchronizing the DG input signal to the on-chip clocks with a D-type flip-flop so that the switching transients at the input only occur between the CCD input-sampling windows.

External circuitry minimized

Minimization of external circuitry associated with defect substitution was accomplished through innovative design of the 1-H tap on the delay line. Before the 1-H delayed signal from the delay line can be used to substitute for signal drop-outs (that is, defect correction), the 1.53-MHz chrominance must be phase inverted to match the chroma phase on the present line. To do this, the outputs from two taps on the CCD delay line at elements 579 and 585 are summed to form a transversal filter with the amplitude and phase response, as shown in Fig. 3. This configuration creates a "comb-shaped" filter. The delay between the two taps is as follows:

- Time delay = (6 elements) (1/9.2 MHz)
  = (6 elements)(208.6 ns per element)
  = 651.9 ns.
- Frequency of second response peak
  = 1 time delay = 1/(651.9 ns)
  = 1.53 MHz.

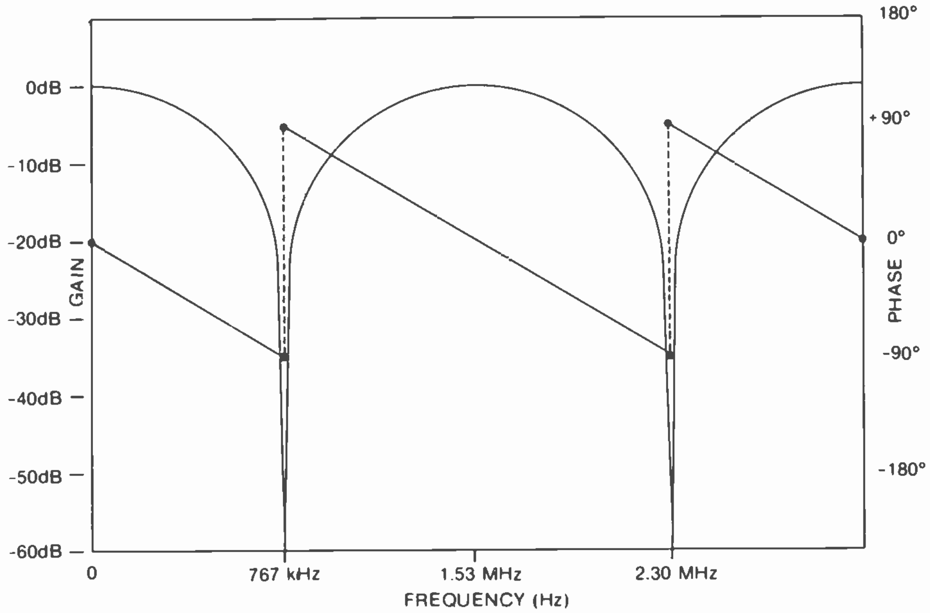

Fig. 3. The amplitude and phase response of the 1-H output, gives the necessary 180-degree phase inversion at the chrominance subcarrier. This phase relationship is required to substitute "previous" line video for defects occurring on the "present" line.

As indicated in Fig. 3, the phase response during the second lobe of the filter is reversed 180° relative to the previous lobe, which accomplishes the desired chrominance-signal phase inversion. Thus, with no external circuitry, the 1-H delayed signal is put into the proper phase relationship with the present line of video so that defect substitution is possible. The amplitude response is somewhat compromised by this technique, but since defects are fleeting phenomena of relatively short duration, the overall response turns out to be quite satisfactory for the application.

Applications and performance

At this point, it is appropriate to comment on some application requirements and the performance of the CCD Comb Filter, Defect Corrector. The combing performance of the device, when adjusted for optimal combing at 1.53 MHz, yields comb-null depths of more than 23 dB at the passband edges. This level of combing performance provides very acceptable separation of luminance and chrominance signal components. Since the CCD is effectively a sampled data system, the frequency response of the signal channels has a (sin x)/x rolloff characteristic with the first zero occurring at the clock frequency. At 3 MHz, this only contributes about 2.0 dB of rolloff. Some additional losses in the CCD are attributed to the transfer inefficiency.

Another characteristic of the device that had to be carefully taken into account in the application is the relatively large amount of clock signal that appears on all outputs and the power-supply inputs. The clock drivers on the chip must supply fairly large amounts of current in order to achieve the necessary clock-signal rise times on all of the clocking gates of the CCD. This results in spikes of heavy supply-current drain especially from the 9-V (V_{CC}) supply. As a result, the device tends to radiate a broad spectrum of radio frequencies at the clock rate and its harmonics. In the VideoDisc player, this problem is dealt with by judiciously shielding the IC and filtering the power-supply leads and all of the signal outputs.

Figure 4 is a block diagram representing the external signal-processing filters associated with the Comb Filter/Defect Corrector in the VideoDisc player. The luminance low-pass filter is a fifth-order 0.1-dB Chebyshev filter with a 3-dB down point of 3.5 MHz. This results in suppression of 9.2-MHz clock components by more than 50 dB while passing full bandwidth luminance information. A third-order 0.5-dB Chebyshev low-pass filter with the same corner frequency is used in the chrominance channel to provide an initial 30 dB of attenuation of clock components. This filter then feeds three other networks.

The first network is the chrominance-bandpass filter, which is a first-order filter with a center frequency of about 1.45 MHz. The center frequency is chosen lower than the buried-subcarrier frequency so that a uniform passband results after the chroma

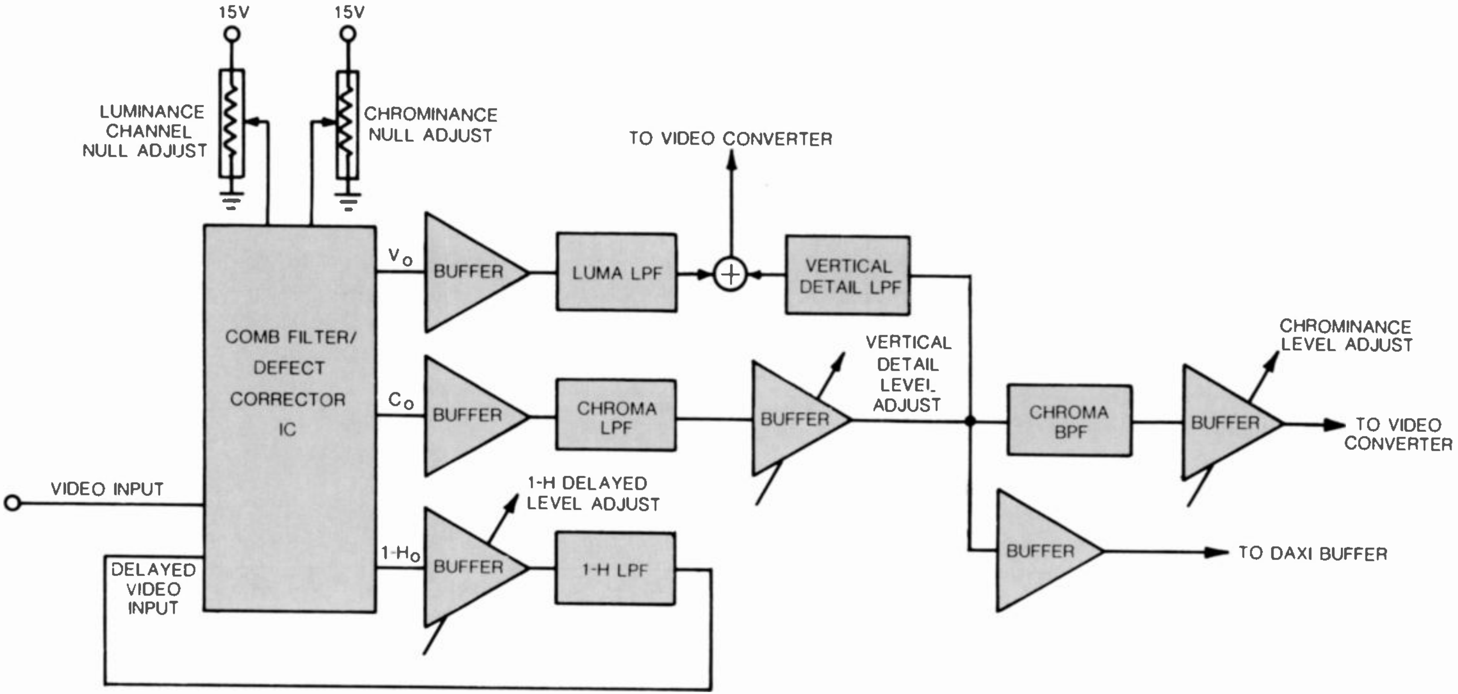

Fig. 4. Block diagram of external circuitry associated with the signal ouputs.

signal is translated to 3.58 MHz and bandpass-filtered in the video converter circuit (Fig. 4).

The second network fed by the chrominance low-pass filter is the vertical detail low-pass filter. To successfully separate chrominance-signal information from the luminance-signal information, the combed frequency range could simply be limited to approximately 500 kHz on either side of the buried subcarrier, thereby leaving the low frequencies uncombed. If, however, luminance combing is accomplished down to zero frequency (as is the case with the CCD comb filter), one-half of the vertical resolution is removed. The low-frequency combed output of the chrominance channel consists of exactly the vertical detail content that was removed from the luminance signal. An advantage can be realized by reinserting this vertical content into the luminance channel to restore the vertical resolution. The vertical detail low-pass filter is here for expressly this purpose. The filter was synthesized to have a passband of about 500 kHz, a notch at 1.53 MHz, and a constant delay in the passband of 500 ns. The delay was chosen so that the signals from the luminance filter and the vertical detail filter would arrive at their respective outputs at the same time for proper signal summation.

The final network connected to the chrominance low-pass filter is a buffer circuit that sends the combed chrominance signal to the Digital Information Buffer IC. Since the special digital control information (DAXI) contained on the disc consists of a 1.53-MHz pulse stream, the combed-chrominance output is the ideal point to tap the video signal path for the digital signal.

One more filter is required to complete the signal processing associated with the Comb Filter Defect Corrector circuitry. A low-pass filter is placed between the 1-H delayed output and the 1-H delayed input to filter out clock components on the signal and to add the necessary amount of delay for proper signal time coincidence between the delayed line of video and the incoming line.

Figure 4 also shows all of the factory adjustments required in the Comb Filter/Defect Corrector circuitry. The luminance and chrominance channels must be independently adjusted for optimal combing performance and the levels must be separately adjusted on the vertical detail, chrominance, and 1-H delayed signals. Thus, through innovative IC design and careful design of the external circuitry, only five adjustments are required to achieve optimum performance from this important functional block of the VideoDisc player.

Summary

In summary, a self-contained CCD Comb Filter Defect Corrector IC has been developed for use in the RCA "SelectaVision" VideoDisc player. The device effectively separates the luminance and chrominance components of the buried-subcarrier VideoDisc signal and also provides defect correction for enhanced player performance. Design advances in the IC help to minimize the amount of external circuitry required, and thereby minimize the cost of implementing this crucial signal-processing function in the VideoDisc system.

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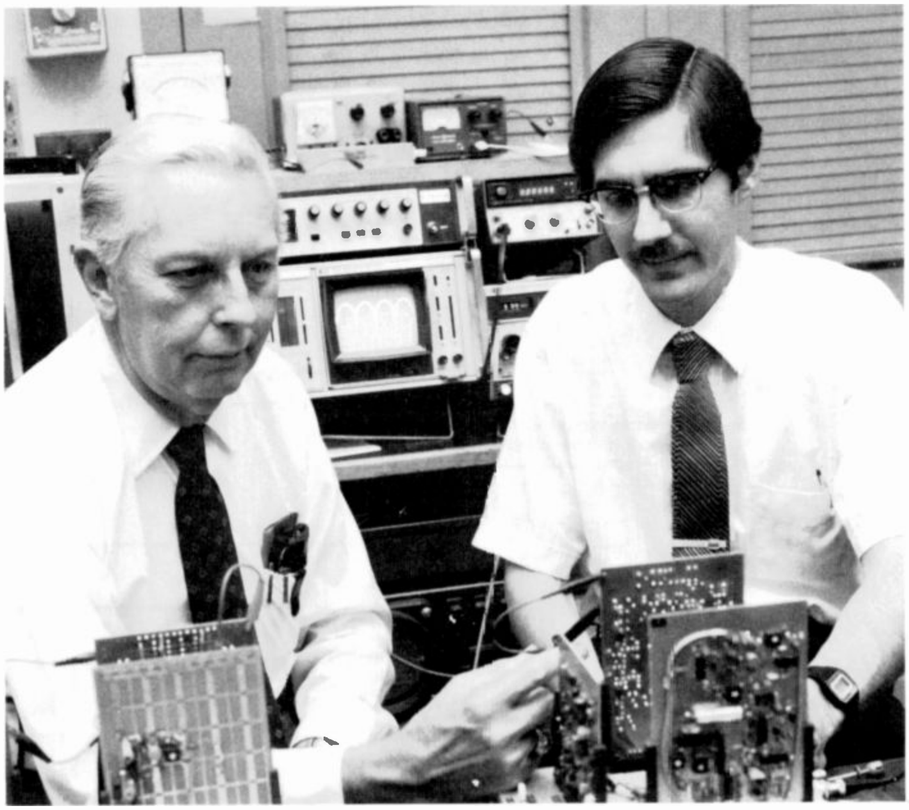

Authors Pritchard (left) and Sauer (right).

Donald Sauer joined RCA, Electromagnetic and Aviation Systems Division, in Van Nuys, California, in 1969. He was responsible for state-of-the-art circuit designs for audio amplifiers, power supplies, and encoding/decoding devices using universal logic arrays. In 1973, he began working on charge-coupled digital memory devices intended for the replacement of rotating magnetic drums, and successfully designed and demonstrated experimental 4K-bit and 16K-bit CCD memories.

In 1974, Mr. Sauer transferred to RCA Laboratories, Princeton, New Jersey, as a Member of Technical Staff. He continued working on CCD technology and has been responsible for the design, layout, and characterization of charge-coupled devices for imaging, memory, and signal-processing applications. Mr. Sauer has received two RCA Laboratories Outstanding Achievement Awards for his work on CCD delay-line techniques for video signal processing. In 1981, Mr. Sauer received the David Sarnoff Award "For the development and implementation of a CCD comb-filter integrated circuit in Color TV receivers."

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Video conversion and time-base correction in the VideoDisc player

Abstract: *The authors give a technical discussion of the processing required in the VideoDisc player to convert the recovered buried-subcarrier-encoded signal with its time-base errors to the NTSC signal with sufficiently reduced time-base errors.*

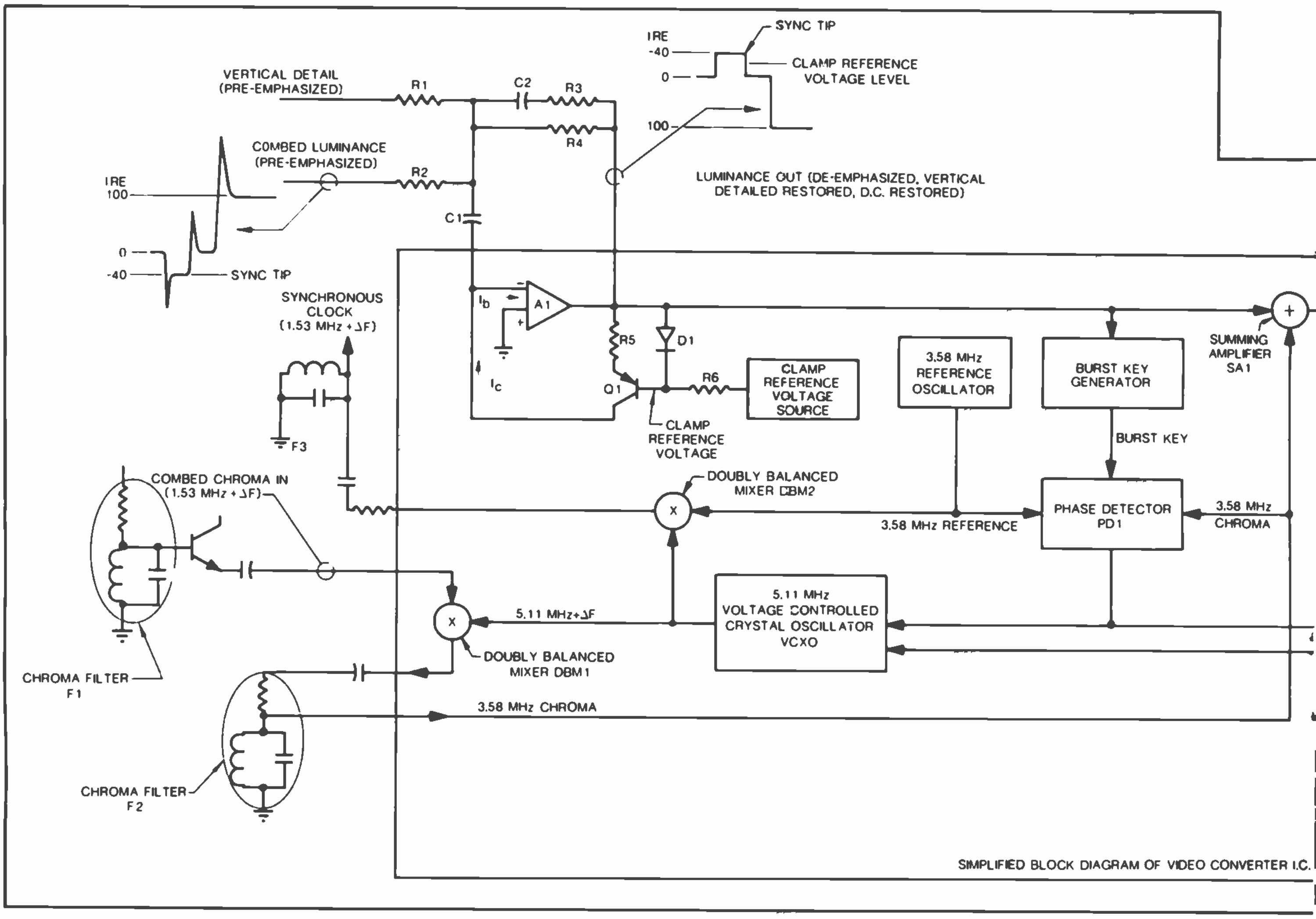
Reprint RE-26-9-10
Final manuscript received Aug. 10, 1981.

Although video conversion and time-base correction could be treated as independent subjects, we found that it was practical to implement a large portion of the circuitry required for these functions on one integrated circuit, the video-converter IC. Some functional blocks are actually shared between video conversion and time-base correction. For example, the doubly balanced mixer used in translation of chroma from 1.53 MHz to 3.58 MHz, which is a video conversion function, is also an error-summing point for the time-base-correction loops. In the discussion that follows, we will begin with the simpler video-conversion functions and then proceed through the more complex time-base-correction functions.

Video conversion

Video conversion is necessary due to the way in which the video signal is encoded on the disc (see box, "Video signal encoding"). Video conversion really begins with the separation of the buried-subcarrier chroma from the luminance, discussed in the paper on the comb filter and defect correction (page 49). Then the remaining video conversion process includes the following functions:

- Summation of the vertical detail and



SIMPLIFIED BLOCK DIAGRAM OF VIDEO CONVERTER I.C.

combed luminance signals to achieve the complete luminance signal.

- Removal of the *RC* pre-emphasis from the luminance signal (de-emphasis).
- Translation of the 1.53-MHz buried-subcarrier chroma (with static and dynamic time-base error) to the stabilized 3.58-MHz chroma required for the NTSC system.
- Bandpass filtering of the chroma signal.
- Summation of the 3.58-MHz chroma and complete luminance signals to form the video signal.
- DC restoration of the video signal.

These functions are achieved using the video-converter IC and associated discrete components (Fig. 1).

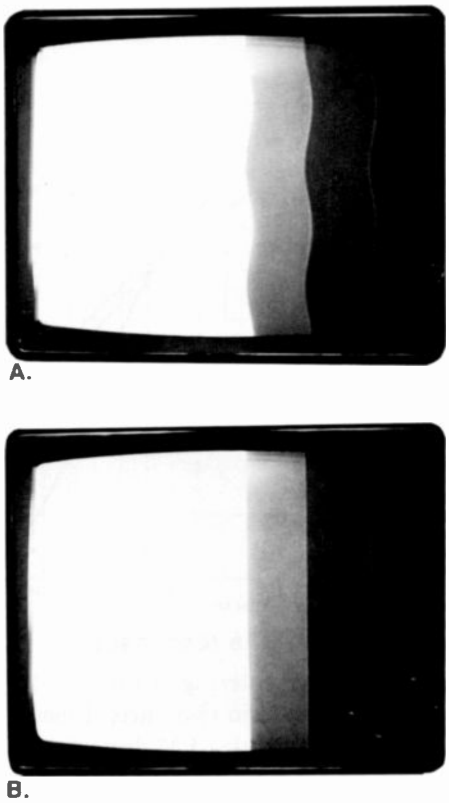
Static time-base error and correction

The turntable rotation is synchronous with power-line frequency and, thus, the recovered video and audio have the power-line frequency error. If left uncorrected, an error of only 0.03 percent could cause loss of color on some TV receivers. The chroma-correction circuitry (Fig. 1) phase locks the translated chroma to a stable 3.58-MHz crystal-controlled reference oscillator, and thus removes this static frequency error from chroma. The design assures color-subcarrier correction for power-line frequency error up to ±0.1 percent. Luminance and audio are not corrected for this error.

Dynamic time-base error and correction

The dynamic time-base error is the undesirable frequency modulation of signals recovered from the disc, caused by changes in the relative velocity between the disc groove and stylus tip. This relative velocity fluctuates due to non-ideal centering of the disc groove about its rotational axis (Fig. 3), warps, surface imperfections of the disc, and vibrations. For the most part, these disturbances occur at the disc rotational frequency of 7.5 Hz (7.5 revolutions per second) and its harmonics. These disturbances result in a frequency modulation as high as 0.1 percent at 7.5 Hz.

The magnitude of the disturbance decreases significantly at higher harmonics. This modulation, if uncorrected, would cause large side-to-side movement of the picture on a typical TV receiver. The



Before and after. Time-base error causes the distorted display shown in photo A. Photo B shows the same signal with time-base error removed.

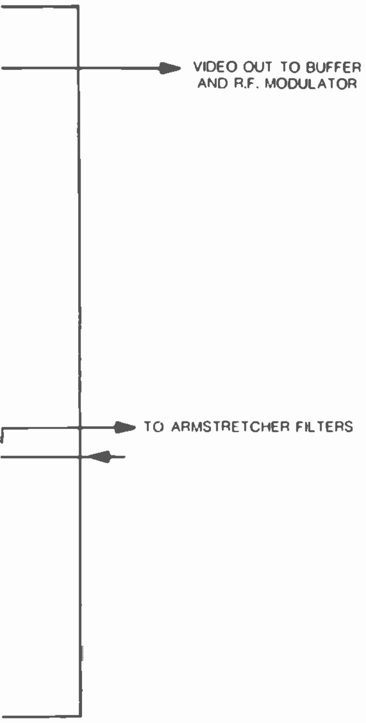


Fig. 1. Video conversion.

The amplifier A_1 is connected in an operational configuration to achieve a low-impedance summing junction for the combed luminance and vertical detail signals. The *RC* de-emphasis is accomplished with the feedback network R_3, R_4, and C_2. Thus, the inverted, amplified, and de-emphasized luminance signal, with vertical detail restored, appears at the amplifier output.

DC restoration is achieved at the amplifier A_1 also. When sync at A_1 output goes more positive than the clamp reference at Q_1 base, clamp current I_c flows into C_1, clamping the amplifier output and setting a charge on capacitor C_1. During the time between sync pulses, the charge is removed by the bias current I_b into A_1. Noise pulses at A_1 output going more positive than sync would cause restoration to the peak-noise pulses. Diode D_1 and resistors R_5 and R_6 limit the clamp current on those noise pulses that go more positive than sync tip, so that restoration to noise-pulse peaks does not occur.

Chroma translation is achieved by mixing the 1.53-MHz chroma signal with the output of the 5.11-MHz VCXO at the doubly balanced mixer DBM_1. The resulting 6.64-MHz sideband is removed and the 3.58-MHz chroma is selected by the filter F_2. The 3.58-MHz chroma is amplified and summed with the luminance at summing amplifier SA_1.

The desired chroma bandpass is achieved by the combination of filters F_1, F_2, and the linear phase de-emphasis network discussed under "Video and Audio Demodulation." Figure 2 shows how the de-emphasis network response and F_1 response translate and add to F_2 response to achieve the desired chroma-bandpass response.

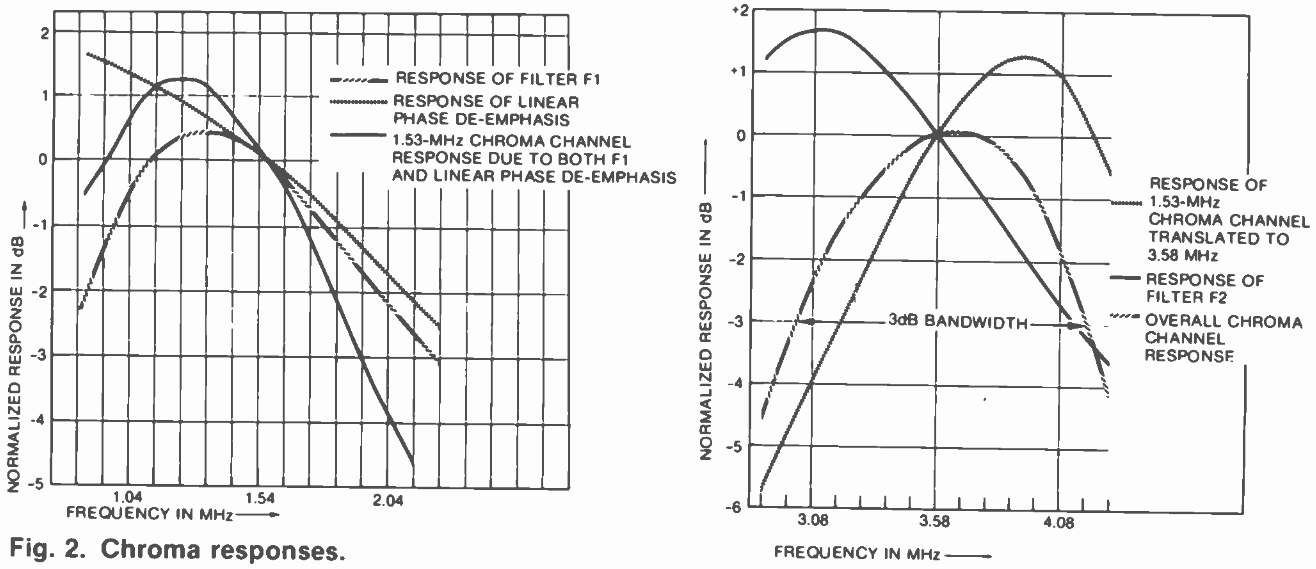


Fig. 2. Chroma responses.

2A Chroma filtering at the 1.53-MHz subcarrier frequency occurs in two parts. Linear phase de-emphasis occurs in the video FM demodulator circuitry causing a response with attenuation in decibels equal to the square of frequency in megahertz. This response is shown with the response of filter F_1. The sum of these gives the VideoDisc player response to the 1.53-MHz chroma shown.

2B The overall chroma response includes the response of the 1.53-MHz chroma processing, translated to 3.58 MHz by doubly balanced mixer DBM_1, and the response of filter F_2. The figure shows these two responses added to achieve the overall chroma-channel response, which typically results in a chroma bandwidth slightly greater than ± 500 kHz as shown.

modulation at 7.5 Hz has to be reduced about 25 dB to reduce this effect to the threshold of visibility in luminance. Since only a few degrees of color-subcarrier phase shift cause noticeable hue shift, the modulation of the color subcarrier has to be reduced about 70 dB.

The complex frequency-domain block diagram (Fig. 4) shows how the time-base correction is achieved in two parts. The arm-stretcher transfer function, plotted in Fig. 5A, relates the frequency error after arm-stretcher correction $F_{EA}(s)$ to the frequency disturbance $F_D(s)$. This is the only correction required by the audio and luminance signals. The chroma receives the additional correction of the color-correction loop. The color-loop transfer function, plotted in Fig. 5B, relates the frequency error after color-loop corrections $F_{EC}(s)$ to the frequency error after arm-stretcher correction $F_{EA}(s)$. The total color correction is the sum of corrections of the arm-stretcher and color-correction loops shown in Fig. 5C.

Video signal encoding

The video signal is encoded in the buried-subcarrier[1] format, which means that the combed chroma is placed within the combed luminance band at a color-subcarrier frequency of 1.53 MHz. This is done to reduce the bandwidth required in recording the signal on the disc, and to allow increased playing time.[2]

In addition, the luminance signal is pre-emphasized to improve the luminance signal-to-noise ratio. This means that the high-frequency components of the luminance are recorded at higher-than-normal amplitude. The pre-emphasis is performed in two parts. First, the *RC* pre-emphasis[2] boosts the high frequencies at a rate of 6 dB per octave between 249 kHz and 995 kHz; and second, the linear phase pre-emphasis boosts the higher luminance frequencies by a number of decibels equal to the square of the frequency in megahertz.

The arm-stretcher loop's bandwidth must be limited on the high-frequency side to prevent instability due to delays and spurious resonances. About 100 μs of delay results from a compliant coupling between the transducer and stylus tip. About 32 μs of delay results from the comb filter that is in the loop but not shown in Fig. 4.

As shown in Fig. 5, the arm-stretcher correction is from about 2 Hz to 200 Hz. The response of the loop is shaped to provide the most error reduction (minimum error transfer) at 7.5 Hz, shown as f_1. The null in error transfer at 60 Hz is due to the transducer resonance, shown as f_2.

It may be seen from Fig. 4 that the arm-stretcher loop gain varies inversely as the chroma wavelength λ_c. Figure 3 shows that the wavelength of a recorded signal decreases by a factor of two from the outside groove to the inside groove, and, thus, if the electronic gain were left unchanged from outside to inside, the total loop gain and correction would be boosted about 6 dB at the inside groove. To run the

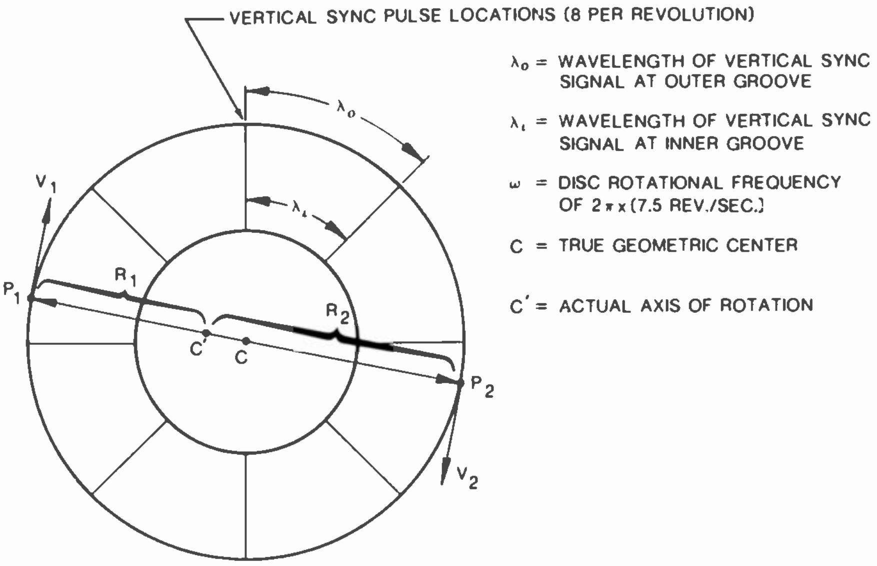


Fig. 3. Dynamic time-base error and arm-stretcher correction.

The simplest cause of dynamic time-base error is improper centering of the disc due to tolerances in the player and disc, illustrated by the displacement of the axis of rotation C' from the geometric center C. If the stylus were stationary at point P_1, it would see vertical sync pulses (or any other signal elements of interest) come by at a velocity given by $V_1 = \omega R_1$. But if it were stationary at point P_2, it would see the sync pulses come by at a greater velocity given by $V_2 = \omega R_2$ (since R_2 is greater than R_1). This results in undesirable velocity modulation $\Delta V \sin \omega t$, which can be expressed as equivalent frequency modulation given by $\Delta f = (\Delta V \sin \omega t) / \lambda$.

The arm stretcher corrects this undesirable moduation by causing stylus motion forward and backward along the groove to keep the relative velocity, between sync pulses and the stylus, constant. In other words, if the velocity of the stylus is the same as the velocity modulation of the sync pulses, then the velocity modulation will be removed from the recovered signal.

This figure can be used to demonstrate the −6-dB change in gain of the arm-stretcher transducer from the inside groove to the outside groove of the disc. Consider the stylus to be in the inside groove with a motion $\Delta V \sin \omega t$ caused by the transducer-drive voltage. This motion would correct frequency modulation of $(\Delta V \sin \omega t) \div \lambda_i = \Delta f_i$. If the stylus now moves to the outside groove with the same drive voltage to the transducer, then the frequency modulation would become $(\Delta V \sin \omega t) \div \lambda_o = \Delta f_o$. Since the wavelength λ_o is twice λ_i, only half as much frequency modulation could be corrected.

loop at constant gain and constant phase margin, an adjustable gain stage of gain kR modifies the transducer drive as a function of playing radius R so that the arm-stretcher loop gain is constant for any radius.

Synchronous clock

Because power-line frequency variation causes uncorrected, static-frequency error in the recovered video signal, a continuous clock with the same frequency error is needed for two purposes: to clock the charge-coupled device (CCD) at a rate that makes its delay match the horizontal sync period of the recovered video signal, and to synchronously clock the digital auxiliary information (DAXI) data bits into the DAXI buffer. Consider that the power-line frequency is in error such that the 1.53-MHz color burst is actually at 1.53 MHz + ΔF, where ΔF is the frequency error. A continuous (restored) color subcarrier of the same frequency is needed for the clock. From Fig. 1, it is seen that this clock is derived by mixing the VCXO output at a frequency of 5.11 MHz + ΔF with the stable 3.58-MHz reference oscillator at DBM_2. The difference frequency, selected by filter F_3, is the desired synchronous clock at a frequency of 1.53 MHz + ΔF.

Color-correction loop

The color-correction loop (Fig. 4) consists of the following: phase detector PD_1, voltage-controlled crystal oscillator VCXO, and a summation point that is the doubly balanced mixer DBM_1. These components form a phase-locked loop that develops an error-signal voltage $E_E(s)$ proportional to the phase error $\phi_{IE}(s)$ of the 3.58-MHz chroma burst (when referenced to the phase of the 3.58-MHz reference oscillator ϕ_R). This error voltage $E_E(s)$ adjusts the VCXO frequency $F_{CC}(s)$ in the direction to reduce the frequency error $F_{EA}(s)$ to the value $F_{EC}(s)$. Because the phase detector includes a sample-and-hold function for sampling only burst, a delay is introduced that limits the stable bandwidth. We chose the loop constants that made the bandwidth as wide as possible without sacrificing stability.

This loop develops the error signal $E_E(s)$ used to drive the transducer-drive electronics $H_D(s)$. The color loop acts as a frequency discriminator (below 3 kHz) providing an error signal $E_E(s)$ proportional to the frequency error after arm-stretcher correction $F_{EA}(s)$.

Arm-stretcher time-base correction loop

The arm-stretcher loop consists of the color-correction loop (used as a frequency error $F_{EA}(s)$ to voltage $E_E(s)$ converter), drive electronics $H_D(s)$, transducer $H_T(s)$, and the stylus riding in the disc groove. The frequency-error signal $E_E(s)$, modified by the drive electronics, drives the transducer with a voltage proportional to frequency error $F_{EA}(s)$ to cause stylus motion along the groove in the direction to reduce the frequency error.

The arm-stretcher loop must be limited in bandwidth to disturbances above DC, because it cannot move the stylus continuously around the disc to compensate for turntable-speed errors. The active low-

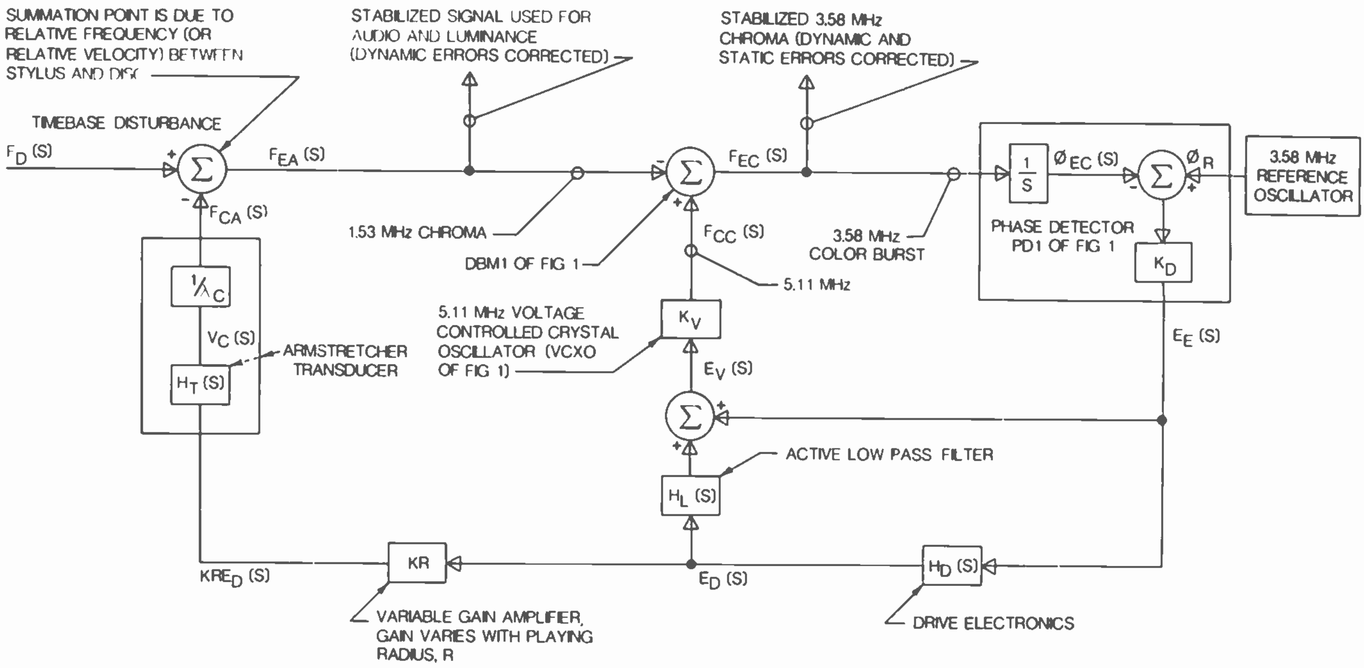


Fig. 4. Time-base-correction system.

The diagram shows the nested servo loops comprising the time-base correction system. At the left is the frequency-disturbance input $F_D(s)$, which is a frequency modulation of the disc time-base. At the first summing junction a frequency correction signal $F_{CA}(s)$, due to the stylus motion caused by the arm-stretcher, subtracts from the frequency disturbance leaving a frequency error, after arm-stretcher correction, of $F_{EA}(s)$. This signal is the stabilized signal used for audio and luminance.

Near the center, a second summing junction receives as its disturbance input the frequency error after arm-stretcher correction $F_{EA}(s)$ and a frequency -correction signal $F_{CC}(s)$ from the VCXO. This summing junction outputs the difference, leaving a frequency error after color correction of $F_{EC}(s)$. This is the stabilized signal used for chroma.

Signal symbol list

$E_D(s)$	Transducer-drive voltage (before variable gain block)
$E_E(s)$	Error voltage from phase detector
$E_V(s)$	VCXO drive voltage
$F_{CA}(s)$	Frequency correction due to arm-stretcher
$F_{CC}(s)$	Frequency correction due to color-correction loop
$F_D(s)$	Frequency disturbance (time-base error)
$F_{EA}(s)$	Frequency error after arm-stretcher correction
$F_{EC}(s)$	Frequency error after color-correction loop
K	A constant associated with the variable gain amplifier
R	The playing radius (distance from center hole to stylus)
$V_C(s)$	Velocity correction due to arm-stretcher
$\phi_E(s)$	Phase error after color-correction loop
ϕ_R	Reference phase from 3.58-MHz reference oscillator

pass filter $H_L(s)$ increases the gain of the color-correction loop at DC, so that the VCXO does the correction at DC with very little DC appearing in the transducer-drive signal.

The synchronous clock, in addition to tracking the static error of the recovered video signal, tracks the dynamic error that remains after arm-stretcher correction. This can be seen from Fig. 4 at DBM$_1$, where it is shown that the correction signal from the VCXO, $F_{CC}(s)$, tracks the frequency error of the 1.53-MHz color burst $F_{EA}(s)$ within a small error $F_{EC}(s)$. Since the 1.53-MHz synchronous clock is derived from the VCXO output, it tracks the dynamic error of the color burst with the same small error.

Acquisition considerations

The dead-zone amplifier, which is necessary to guarantee that the color-correction phase-locked loop acquires lock, is shown in Fig. 6. The IC Pin 24 has a voltage E_{24}, which in the normal in-lock condition, is equal to the phase-detector output E_{PD}, and the feedback-limit voltage $E_L = 0$. This occurs because the VCXO DC control voltage E_{VX} is within the ±0.7-V thresholds of the dead-zone amplifier. The DC control voltage E_{VX} is essentially equal to the DC part of the VCXO-control voltage E_V because, for the in-lock condition, the gain of the active low-pass filter

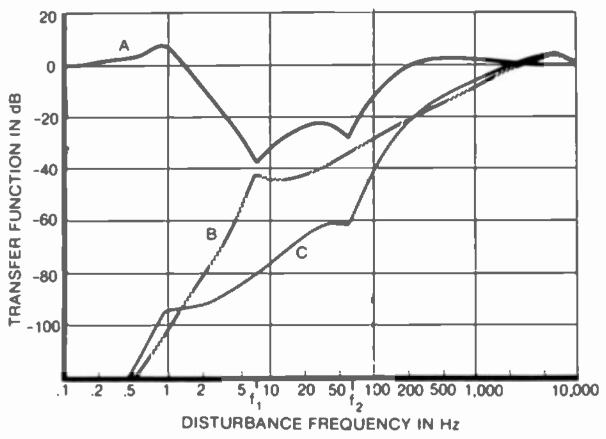


Fig. 5. Time-base-correction system transfer functions.

A. Arm-stretcher closed-loop transfer function,

$$20 \log \frac{F_{EA}(s)}{F_D(s)}$$

B. Color-correction-loop closed-loop transfer function,

$$20 \log \frac{F_{EC}(s)}{F_{EA}(s)}$$

C. Total color correction,

$$20 \log \frac{F_{FC}(s)}{F_D(s)}$$

causes E_{24} to be much less than E_{18}. For a given frequency offset ΔF of the 1.53-MHz color burst, $E_{18} = \Delta F / K_V$. The design allows for ΔF of 1.53 kHz with K_V within the ± 0.7-V thresholds of the dead-zone amplifier.

Should the loop be allowed to lose lock (for example, if the stylus were removed during play of a disc), the phase detector would develop only a small offset voltage. This voltage would be greatly amplified by the transducer-drive electronics. H_D and the active low-pass filter H_L which, without the dead-zone amp, would cause E_{18} to be very large, driving the 5.11-MHz voltage-controlled oscillator beyond the pull in range of the loop (or even beyond the dynamic range of the oscillator).

When the DC control voltage E_{18} exceeds ± 0.7 V, a feed-back-limiter error voltage E_L is developed, which feeds through the drive electronics and active low-pass filter to regulate E_{18} at the appropriate threshold (± 0.7 V). This voltage

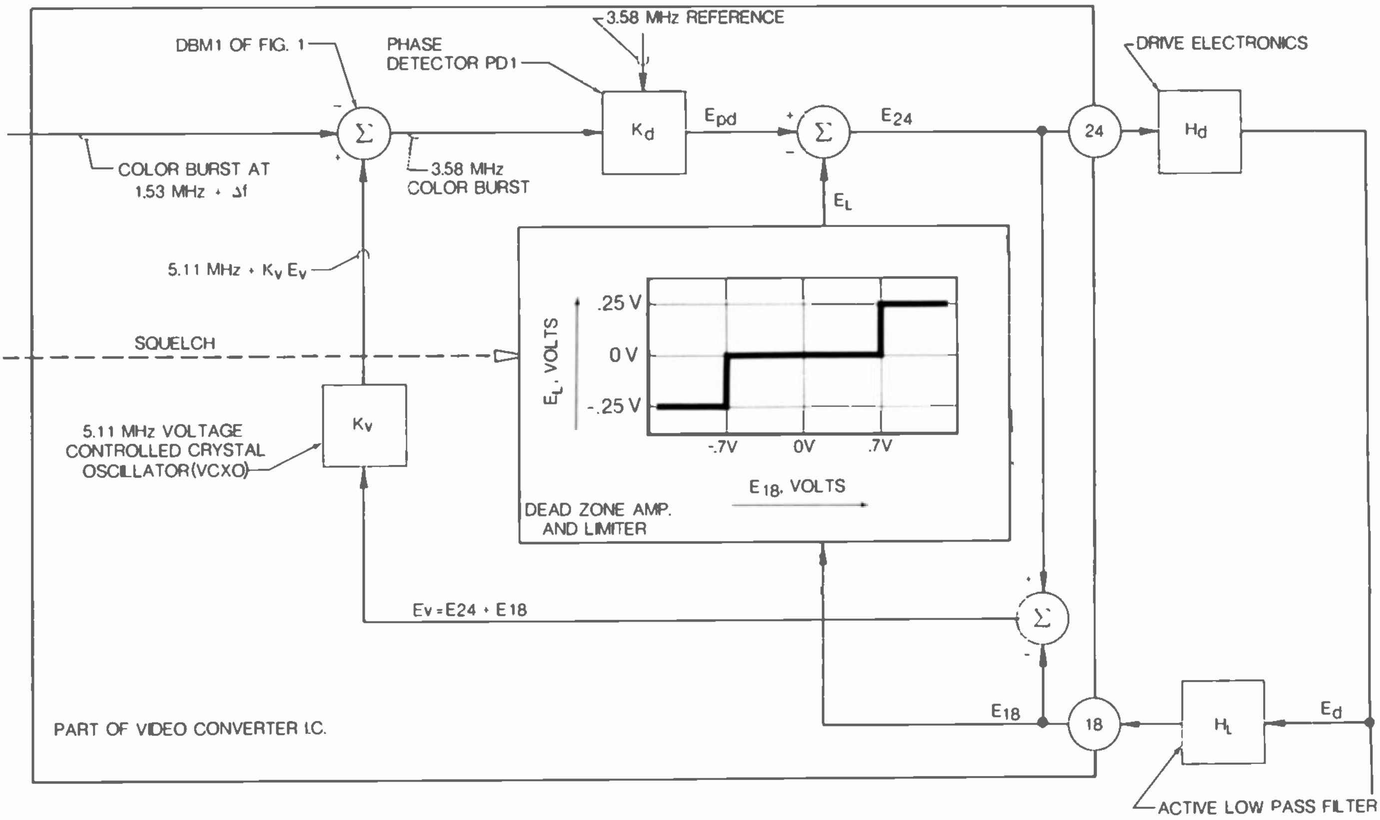


Fig. 6. The color-correction loop with dead-zone amplifier and limiter.

The dead-zone amplifier, required for acquisition, is shown in the not-squelched mode. In the squelched mode, the dead zone is narrowed from the ± 0.7 V shown to ± 0 V so that the circuit becomes an amplifier. All voltages shown are normalized to their nominal values.

keeps the VCXO within 2100 Hz of nominal. When this is added to as much as a 1500-Hz error in the 1.53-MHz color burst, the loop is still within its acquisition range so that lock can be achieved when the 1.53-MHz color burst reappears.

Note in Fig. 6 that the feedback-limiter error voltage E_L from the dead-zone amp is itself limited to ±0.25 V. This is chosen within the ±1.5-V dynamic range of the phase-detector output E_{PD} so that the in-lock phase detector can track through any noise disturbance that might erroneously activate the dead-zone amplifier.

One additional function achieved with the dead-zone amplifier is the centering of the voltages E_D and E_{IR} from the transducer-drive electronics and the active low-pass filter when the player is in the squelch mode. If this were not done, a significant delay would be required to slew these voltages to their proper operating points when signal was received in the play mode. This centering is achieved by changing the limits of the deadzone amp from ±0.7 V to ±0 V during the squelch, forcing regulation of E_{IR} to its nominal value, and thus E_D to its nominal value, also.

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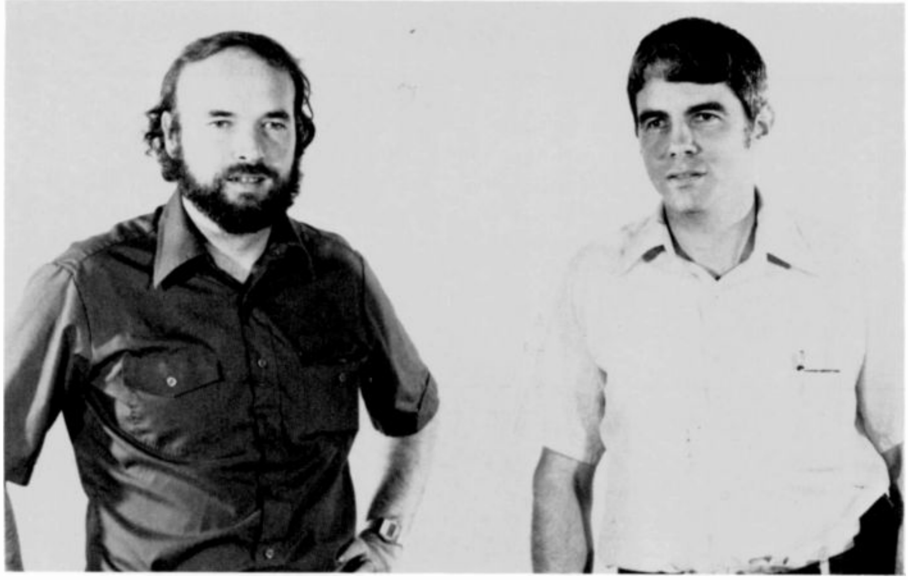

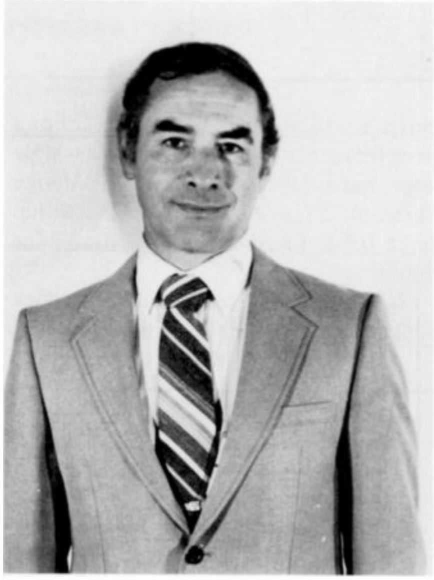

Kevin Kelleher received a BSEE from Iowa State in 1973 and joined Motorola in Schaumburg, Illinois. His reponsibilities included design of CCTV cameras and control equipment. He joined the RCA VideoDisc project in 1979 after receiving his MSEE from the Illinois Institute of Technology. His major responsibility is design of player electromechanical control systems.

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Jim Wilber joined the New Products Department in Indianapolis in 1966. He served three years in the U.S. Coast Guard doing power distribution and lighting design, and returned to RCA's New Products Department in 1971. He began development of the VideoDisc player electronics at that time and continued with player electronics design when "SelectaVision" VideoDisc Operations was formed. His major responsibilities have been color correction and power supply, although he has at times contributed in other areas of the player electronics.

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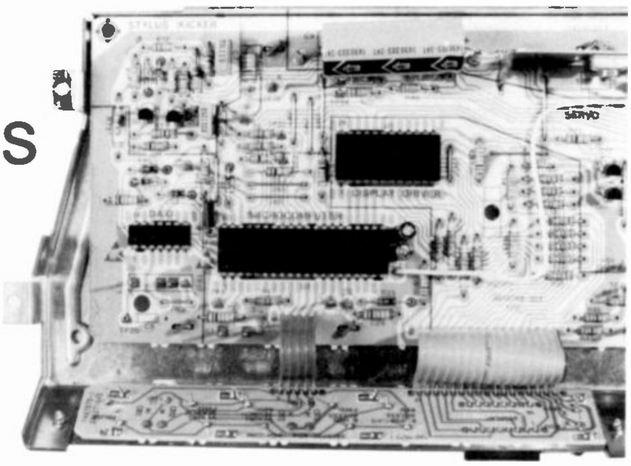
V.W. Fisher|C.M. Wine|C.B. Dieterich

The VideoDisc player's digital control system

How does it work?



Looks can be deceiving! These words ring true when one observes the VideoDisc player for the first time. The straightforward operation of the customer controls and the apparent simplicity of operation give no hint of the sophisticated microcomputer system that monitors every action occurring in the player.

Abstract: *The control system has evolved from discrete logic and a few simple switches to a sophisticated microcomputer-based control system, which oversees every function of the player. This article will briefly explain the operation and interaction of the main elements of the digital control system now used in the SFT100 W VideoDisc player.*

The "SelectaVision" VideoDisc player's control system represents a new dimension in control of disc play. To show just how different the system is, compare it to a regular audio-record player.

One could imagine an audio-record player with an LED display that flashed the letter "L" before you put on a record, played the record to the end, and then picked up the needle and flashed the letter "E." One might even imagine a system where minutes of play time were shown on the LED display.

But audio record-players suffer from several unfortunate control problems. First, they have no way of getting out of locked grooves — there is no positive method of detecting when the needle is "stuck." To prevent stuck grooves, the audio-record pickup cartridge must track with higher tracking force. Audio-record manufacturing must have tight quality control specifications to prevent locked grooves. Another problem arises because the start and end of play is specified by a mechanical location. If a record is out of tolerance, the setdown may cause an abrupt start of the music — and the record player's stylus may never be picked up at the end of play. The VideoDisc player performs tasks similar to this conceptual record player, but it does so in a totally new way.

The VideoDisc control system approaches the problem of disc playback from a new direction. Enhanced features are provided thanks to two new components. The first is the stylus kicker, a small magnet on the stylus cantilever that can lift the stylus tip from a groove and push it ahead one groove or back one groove (several microns). This allows ac-

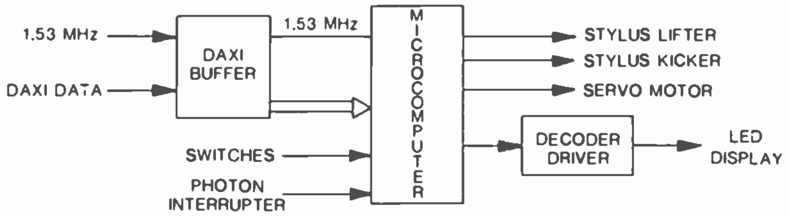
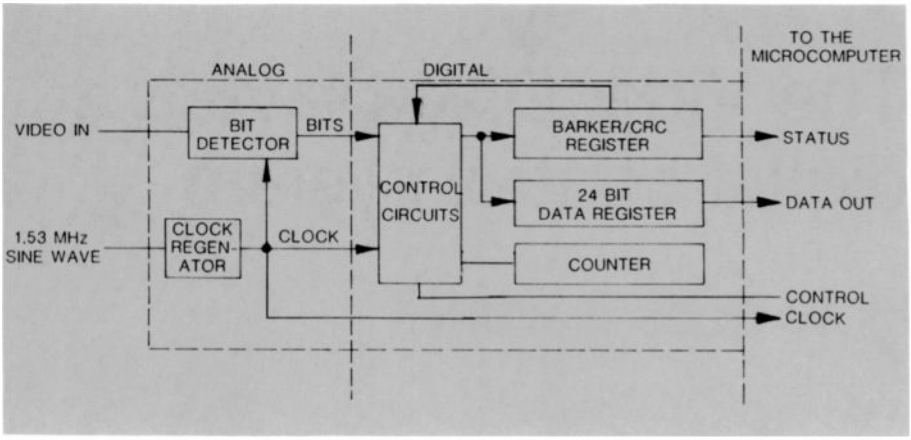


Fig. 1. Digital control system. The principal parts of the control system are shown above. The system comprises three custom integrated circuits with the microcomputer as the main control element. The stylus-lifter signal is used to lift or lower the stylus. The stylus-kicker signal energizes a kicker coil that kicks the stylus forward or backward several microns. The servo-motor signal actuates a motor that moves the stylus carriage backward and forward. The switch inputs include the rapid access, visual search, pause, and load functions. The photon interrupter consists of a light beam that is interrupted by the arm every time the arm moves a distance equal to one minute. The resultant signal is sent to the microcomputer.

Reprint RE-26-9-11
Final manuscript received Oct. 23, 1981

DAXI buffer integrated circuit



The DAXI is a custom IC designed especially for the VideoDisc player. The IC's analog circuits, the bit detector and clock regenerator, make use of the CMOS linear operating region to convert small analog signals to logic level outputs. The digital circuits are mostly shift registers and counters.

A single integrated circuit provides the interfacing between the VideoDisc's analog signals and the microprocessor. The DAXI buffer includes: a bit detector, a clock generator for the microcomputer, a correlator for detecting the start code, error-detection circuitry and storage for the 24 bits used in the current VideoDisc player. As shown on this page, the DAXI buffer IC can be separated into two parts. The analog interface circuits comprise the bit detector and clock regenerator, while the digital signal processing circuits include the start-code detector, the error detection, the timing, and the storage.

The analog interface circuits (see the figure on the facing page) make use of the CMOS linear operating region. The microcomputer clock generator uses a CMOS inverter with a feedback resistor as an AC-coupled amplifier/limiter. The 1.53-MHz sinewave from the player's chroma processing circuitry is amplified to provide the time base for the microcomputer and the buffer IC. Bit detection is performed by an integrate-and-dump circuit composed of an inverter and transmission gate. When the transmission gate is short-circuited, the capacitor is charged to the inverter's threshold voltage. When the transmission gate is an open circuit, charge may be accumulated or withdrawn depending on the instantaneous video-input voltage. If the charge remaining after the integration is greater than the original threshold level, the bit is judged logic one and if it is less than threshold, it is judged logic zero. Biasing is provided by using "vertical detail" video — the difference output of the player's video comb filter. This signal has no DC component at all and the average level is logic zero. To compensate for this, a bias current I_b is continuously withdrawn from the circuit. This current makes the threshold lie about midway between logic zero and logic one.

The remainder of the DAXI buffer IC consists of two shift registers, a counter, and other control circuitry. The first shift register searches the output of the bit detector for the Barker sequence. When this is found,

curate control of stylus position. The second component is called the digital auxiliary information (DAXI) circuit. It is a communication link that informs the player of the precise location of the stylus on the disc. The combination of stylus control (by the kicker) and position sensing (from the DAXI) leads to all the advantages of feedback control.

Closing the feedback loop with a microcomputer allowed us to include several features not otherwise possible, such as locked-groove correction, quick start-up and smooth visual search.

The control system

The control system consists of three custom-integrated circuits: the DAXI buffer, the microcomputer, and the decoder driver (Fig. 1). The 1.53-MHz sinewave, which is phase-locked to the buried-subcarrier burst recorded on the disc, is the system clock for the DAXI buffer and the microcomputer. A communication link from the recorded disc to the control system is provided by the 77-bit DAXI signal embedded within the video signal. The DAXI information identifies each video field on the disc and is used by the microcomputer to precisely locate the stylus position on the disc. The DAXI buffer IC detects the 77-bit DAXI code, performs error checking and stores the last 24 bits of the code word.

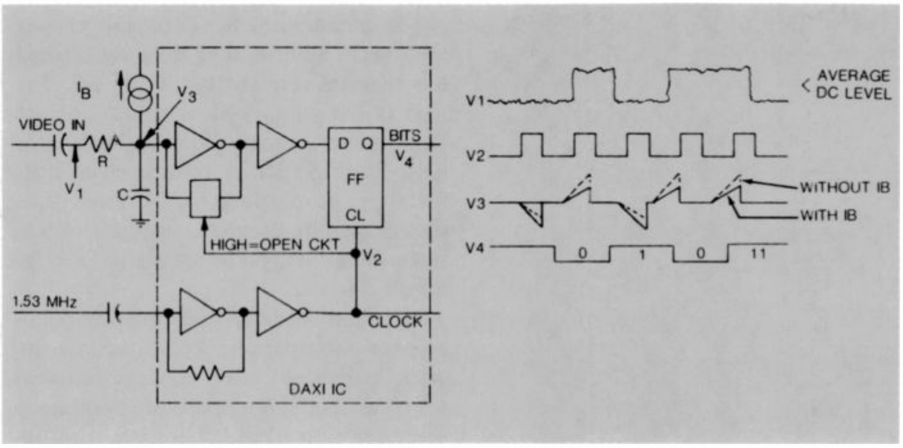
A 3870 single-chip 8-bit microcomputer responds to the DAXI code and various switch inputs, and thereby controls the movement of the stylus. The microcomputer also controls the information sent to the LED display and other player circuits.

A decoder driver decodes the outputs from the microcomputer and drives a low-current, high-brightness LED display.

The digital control system is connected to an array of sensors and manipulators. A micro switch indicates the position of the player's function lever. A "photon-interrupter" code wheel measures relative arm-carriage motion. Arm-carriage motion is controlled by an arm-drive DC motor under microprocessor supervision. The stylus position can be controlled by the stylus-kicker circuits described above.

The digital auxiliary information code (DAXI)

The design of a digital data link from disc to player presents an unusual array of design criteria. The system's primary purpose is to associate a unique number with each of the "CED" VideoDisc's 216,000 video fields on one side of the disc. The player need not read every field's number but it must never read a number incorrectly. The coding system has to be easily decodable, implementable entirely in CMOS, and must have a minimum number of connections to the analog processing circuitry in the player. The data link should also provide space for program-band information to allow the segmentation of



Analog interface circuits include a clock regenerator and a bit detector. The clock regenerator is a limiter-amplifier implemented in CMOS. The bit detector averages sections of the input waveform to produce a logic output by integrating and dumping charge. When the clock, V_2, is low, the transmission gate, TG, sets the voltage on capacitor C to CMOS logic threshold voltage. When V_2 is high, charge is added or taken from C. The integration of this charge flow changes voltage V_3 away from threshold. The offset from threshold is amplified and applied to the D-input of flip-flop FF, which stores the logic level when V goes low. Because the video-input signal is vertical detail, the average signal voltage is very near to the logic-zero voltage. This causes very little current flow through resistor R during logic-zero bits. To equalize current flows for the two logic levels, a bias current I_B is added.

digital feedback is added, which switches the register's function from a synchronization detector to a CRC check register. The bit-detector output is also shifted into the other 24-bit shift register for the duration of the DAXI signal. After the seventy-seventh DAXI bit has been shifted in the CRC, the check register can judge if the data is error-free and the 24-bit shift register will contain the last 24 bits of DAXI data — the field and band numbers. These data are now ready to be read-in by the microcomputer.

programming recorded on a disc side as well as space for other auxiliary information to be defined. These data do not need the absolute reliability of the field number, so error correction should be available if we wish to make a "best guess" at the cost of allowing some incorrect data output. While the decoder must be as simple as possible and allow for wide variations in component tolerances, the same restriction does not apply to the encoder. The encoder, which resides in the disc mastering studio, may have hundreds of extra logic gates if this saves one flip-flop in the player's decoder.

The digital auxiliary information coding system meets these design criteria. "CED" player interfacing has been simplified to require no adjustments or close-tolerance parts and only one all-CMOS IC to interface a microcomputer to the player's analog signals.

Early studies[1] had shown that the "CED" VideoDisc video format could store digital data at 3 Mb/s and play it back at a lower than 0.1 percent error rate. This data rate corresponds to about 160 bits per horizontal line, assuming that horizontal sync and color burst are left undisturbed. The unique identification of every field in a 60-minute disc requires only 18 bits. The digital data rate could therefore be considerably less than 3 Mb/s and still allow storage of the field number and a lot more data on a single horizontal line in the video signal's vertical blanking interval.

The VideoDisc player produces its own 1.53-MHz sinewave, which is phase-locked to the buried subcarrier burst recorded on the disc. Data which is recorded at 1.53 Mb/s using non-return-to-zero (NRZ) waveforms can be digitally sampled at precise times, eliminating the need for self-clocking waveforms, such as Miller codes. Use of a 1.53-MHz clock allows transmission of the 77-bit DAXI code in 50.2 μs. The DAXI code (Fig. 2) includes a large amount of redundancy and still has 27 bits for use in future products.

The DAXI code is divided into five sections: synchronization, error detection, auxiliary information, video field numbers, and band numbers. The usual method of locating a signal recorded in the vertical interval of a video field uses the vertical synchronization pulse and a line selector. Video test signals such as VIRS and VITS are often located in this way. The VideoDisc player does not contain circuitry to locate vertical sync, so the player control system obtains synchronization from a 13-bit Barker[2] sequence, which takes up the first 13 DAXI bits. This 4.7-μs-long bit stream is "borrowed" from radar technology, where it has been used to reduce the interfering effects of impulse noise and to improve signal detection reliability. The player control system attains synchronization by looking for an exact match to this pattern in the detected data stream. The Barker sequence has another advantage — it produces a waveform that is not normally found in video. Because of this, the DAXI code need not be separated from video before synchronization. This simplifies detection by allowing the player to continuously scan the entire video signal for the Barker sequence.

The DAXI code includes error protection for the 64 bits following the Barker[2] sequence. The most common error-protection system in use today is the "parity check." A parity check is one bit, added to the end of a bit stream, that is chosen to produce an odd (or even) number of ones in the entire bit stream. The parity bit does not produce or change the existing data stream, just the final addition of the bit stream is modified to give even or odd parity. Any single error will be detected

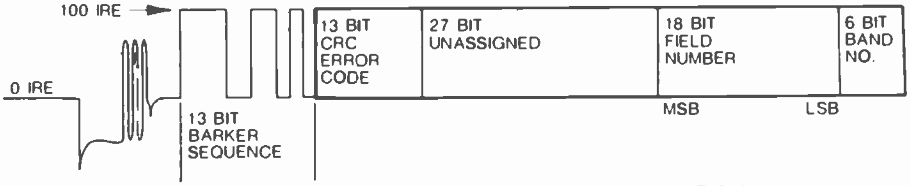


Fig. 2. DAXI code. This line drawing graphically describes the DAXI 77-bit stream as it would appear on Line 17. The 13-bit Barker sequence is transmitted first, and the least significant bit of the band number is transmitted last. The clock rate of each bit is 1.53-MHz.

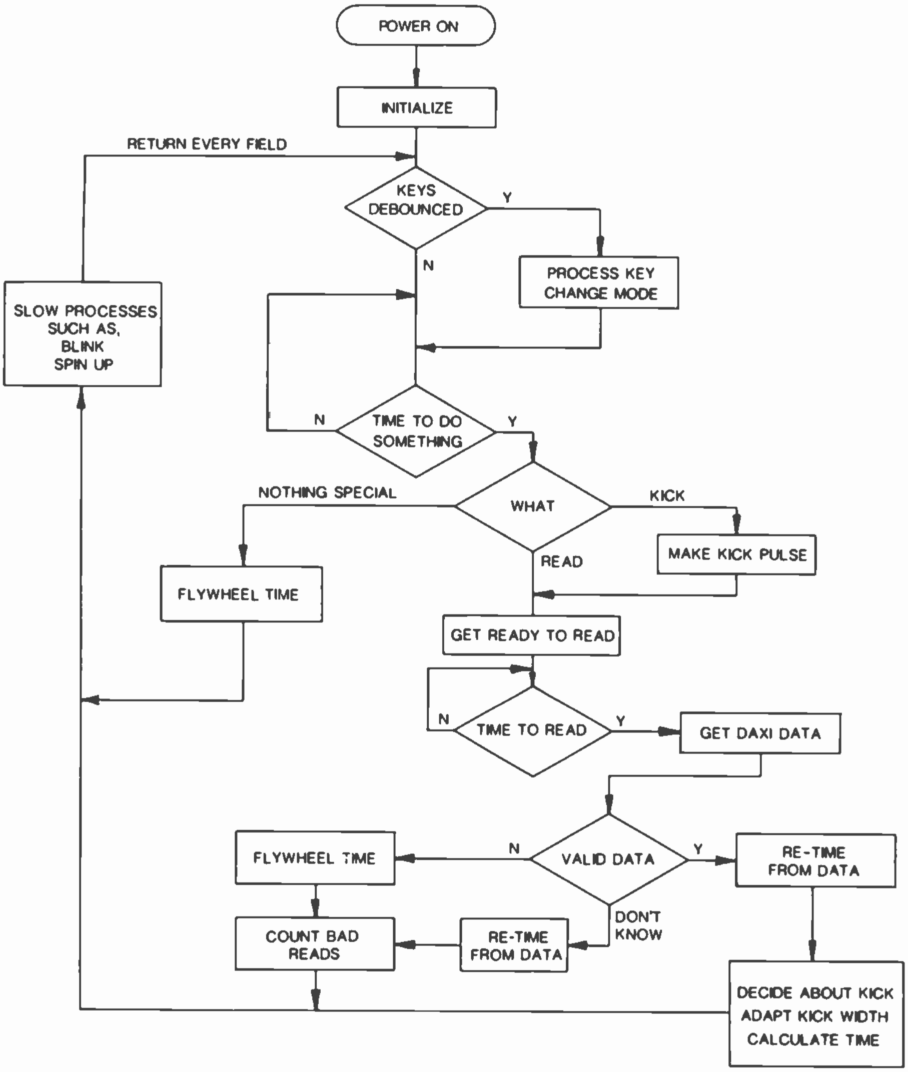


Fig. 3. Microcomputer flowchart briefly describes the functions performed by the microcomputer software.

because the parity bit will have the wrong value. The same error protection could also be provided by inserting the parity bit at the beginning of the bit stream rather than the end. This is uncommon because it complicates the encoder just to save a few gates in the decoder.

The DAXI error-protection system is more powerful than the simple parity check. It employs 13 parity bits in a cyclic redundancy check (CRC). One parity bit is capable of detecting every single-bit error and one-half (0.5) of all errors. The 13-bit CRC is capable of detecting every error that affects 13 or fewer adjacent bits and all but $(0.5)^{13}$ or 99.987 percent of all possible errors. CRC bits are usually placed at the end of a bit stream to simplify the encoding hardware. The DAXI code includes the CRC bits at the beginning of the bit stream because, since there will only be a few VideoDisc mastering studios compared with millions of VideoDisc players, every effort has been made to simplify player circuitry even at the cost of a more complex encoder.

Errors caused by microscopic defects on the disc tend to affect only one or two microseconds of signal, producing a burst of bit errors four or five bits long. The CRC code will detect the presence of up to two burst errors in a DAXI code. The player circuitry is wired to perform this type of error detection. With a different decoder, the CRC bits could be used to locate and correct any single burst affecting six or fewer bits. This error correction capability is not presently implemented because any reduction in the discard rate (percent data that is correctable but not used) increases the false alarm rate (data distorted beyond correction which looks as if it is another correctable codeword). The error protection works so well that in over two years and thousands of players, no known false alarms have occurred.

The remaining 51 bits of the DAXI code are data. The first 27 of these are unused bits that are reserved for future use. The next 18 bits are the field number, a binary number that uniquely identifies each video field. The VideoDisc is recorded with eight fields per revolution, so the three least significant bits provide a method of distinguishing the eight wedge-shaped sectors on the disc.

The final six DAXI bits provide band-number information. Audio records are often recorded with several musical selections per side — these are commonly separated into bands of grooves with unrecorded spaces between them. The greater density of grooves in the "CED" system along with the closed environment of the VideoDisc player would make the visual location of program bands impractical. Digital band location provides up to sixty-two program bands per side.

Microcomputer

The SFT100 player uses a microcomputer with internal ROM to manage control system processes. Some of these processes are straightforward and could easily be performed without a microcomputer. For example, when the function lever is in "LOAD" position, the LED display shows the letter "L" also; when the function level is moved from "LOAD" to "PLAY", the microcomputer waits six seconds before lowering the pickup stylus. Either of these tasks could have been implemented more cheaply with wired circuitry.

We use a microcomputer because some tasks — such as time display, adaptive kicking and locked-groove correction — cannot be implemented with simple hardware. Once we have included a microprocessor in a system, other processes can be included at practically no cost. In our final design, the microcomputer was given control of: the stylus lifter, stylus kicker, arm servo, DAXI buffer, LED display, and audio mute line.

Microcomputer programming

The microcomputer program is a conglomeration of routines and subroutines carefully fit into two kilobytes of read-only memory. The variety and complexity of the tasks implemented in software preclude a description in this paper; instead we shall mention a few of the programming highlights.

Microcomputer functions

- *Calculates minutes and seconds played.*
- *Displays the minutes played.*
- *Corrects for locked grooves.*
- *Maintains a two-groove kick during visual search by changing the width of the kick pulse sent to the kicker coils.*
- *Generates a signal to lift the stylus when required.*
- *Stores the current band number.*
- *Stores the previous field number.*
- *Controls the servo motor during the rapid-access mode, to move the stylus carriage to the proper position.*

The microcomputer operates in five basic modes: LOAD, SPINUP, PAUSE, PLAY, and RAPID ACCESS. LOAD and PAUSE are similar in that the microcomputer keeps the stylus up, while displaying a flashing "L" or "P" on the display. SPINUP mode is entered after LOAD. It is simply a waiting routine that counts out six seconds before lowering the stylus.

PLAY is the most complex mode. The program structure in the play mode was dictated by the need to read DAXI codes from the disc 60 times per second.

In every field, a new DAXI code arrives and the microcomputer must be ready to catch it. There are exactly 195/2 times 525/2 cycles of the clock in one video field. Therefore, the microcomputer's internal timer can be set into a mode in which its free-running period is very nearly one field. The error in the timer rate is 0.025 percent. Whenever a DAXI code is read, the time at which the next code is expected is calculated and stored in the scratch-pad RAM. All processing takes place quickly enough to be completed well before the next DAXI code is expected. The microcomputer then can loop, waiting for the timer to indicate that a new DAXI code is due soon. A few hundred microseconds before the code is due, the microcomputer puts the DAXI buffer IC in its "get-data" mode. If the data arrives when expected, the next time is recalculated from the arrival time. If the data has not come in a few hundred microseconds after the expected time, the DAXI buffer is turned off and the next arrival time is calculated from the previously stored value. The worst-case tolerances are such that many more than 16 codes can be missed before the read window drifts away from the correct time. After 16 bad reads, timing is reacquired through an interrupt process.

The primary job the microcomputer must do during PLAY is to prevent the "locked-groove" phenomenon, whereby a defect forces the stylus back, and one or more revolutions later, the stylus hits the same defect. To do this task, the DAXI information is used. The DAXI codes indicate the current field. An expected field is maintained by incrementing a value every sixtieth of a second. If the current field matches the expected field, no action is required. If the current field is greater than the expected field, the expected field is changed to the actual value. If the current field is a lower number than expected, the stylus has been moved back. The microcomputer emits a kick pulse to advance the stylus by two grooves. Depending upon the severity of the defect, several kicks may be needed to advance the stylus past the disturbance. As a result of various manufacturing tolerances, the width of kick pulse required to move the stylus two grooves cannot be predicted. The microcomputer knows where the stylus was before and after emitting a kick pulse and, therefore, adapts the width of future kick pulses to produce exactly the desired two-groove effect.

The visual search function, at 16-times normal speed, is obtained by kicking the stylus in the user-selected direction by two grooves every field. The kick pulse is delayed to the bottom of the field to minimize the visibility of the effects of the groove change.

There are two special bands encoded in the DAXI information on the disc. Band 63 (all 6 bits are ones) means end of play. When the microcomputer reads this band number, it picks up the stylus, stops playing and displays a blinking "E" on the LED display. This is simple enough to do, but there are interesting complications that arise if the user then presses some buttons. It is reasonable to take no action if the user tries to visual-search forward or to rapid-access forward. It is less obvious what to do for exception cases such as: the user, having reached the end of play, starts a rapid-reverse access and then suddenly switches to rapid access in the forward direction. For all of the imaginable exception cases, we have tried to do what would seem most natural without risking any harm to the disc or player. The other special band is Band 0. Mechanical tolerances leave a possible uncertainty about where the stylus is first put down. This uncertainty may be more than a minute. A user would not like to start the play process and then wait a minute before the picture appears. The "set-down" band is encoded with Band 0. The microcomputer, upon recognizing this band, kicks the stylus ahead at the visual search rate to make the picture show up within five seconds of stylus set down.

Another important function of the microcomputer in PLAY mode is the

Choice of the microcomputer

Whenever a computer is selected for a task, the question arises: "Why did they pick that one and not brand R, brand I, or brand N?" The microcomputer used is a 3870 single-chip machine with 2 kbytes of ROM, 64 bytes of RAM, 32 I/O pins and an internal 8-bit timer. It was selected because it has a proven record (it was used in the Auto-Programmer TV set), it was available from many sources, and it had more than enough capability for the job as initially envisioned. By the time the product was completed, essentially all of the microcomputer resources were used.

The final program yielded over 2,000 bytes of object code and a 59-page, 4,2000-line listing.

calculation and display of play time. The field numbers in the DAXI code start at 0 at the beginning of the disc. Minutes of play are obtained by dividing the field number by 3600. Actually, tens of minutes is calculated by dividing the field by 36,000, and then the units figured out by dividing the remainder by 3600. In the RAPID ACCESS mode, the microcomputer lifts the stylus and commands the arm-servo motor to move the arm at full speed in the appropriate direction. In this mode, there is no DAXI input. An optical interrupter input is debounced and produces one transition (positive or negative) for each minute's worth of arm movement. The previously calculated value of play-time minutes is incremented (or decremented), and displayed.

Conclusion

The digital control system, from stylus location via DAXI code to stylus control via adaptive kicking, represents a significant new direction in the design of a home entertainment product. Our first model, the SFT100W player, represents a restrained implementation of such a control system. We at "SelectaVision" VideoDisc Operations, Indianapolis, and at RCA Laboratories, Princeton, have only begun to exploit the many features possible using the VideoDisc control system.

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2. Van Trees, Harry L., *Detection Estimation and Modulation Theory, Part III*, John Wiley and Sons, p. 315 (1971)

Bill Fisher joined RCA in 1979 as Member of Engineering Staff, "SelectaVision" VideoDisc Operations, Indianapolis. He has worked on the digital control system now used in the SFT-100 VideoDisc player.

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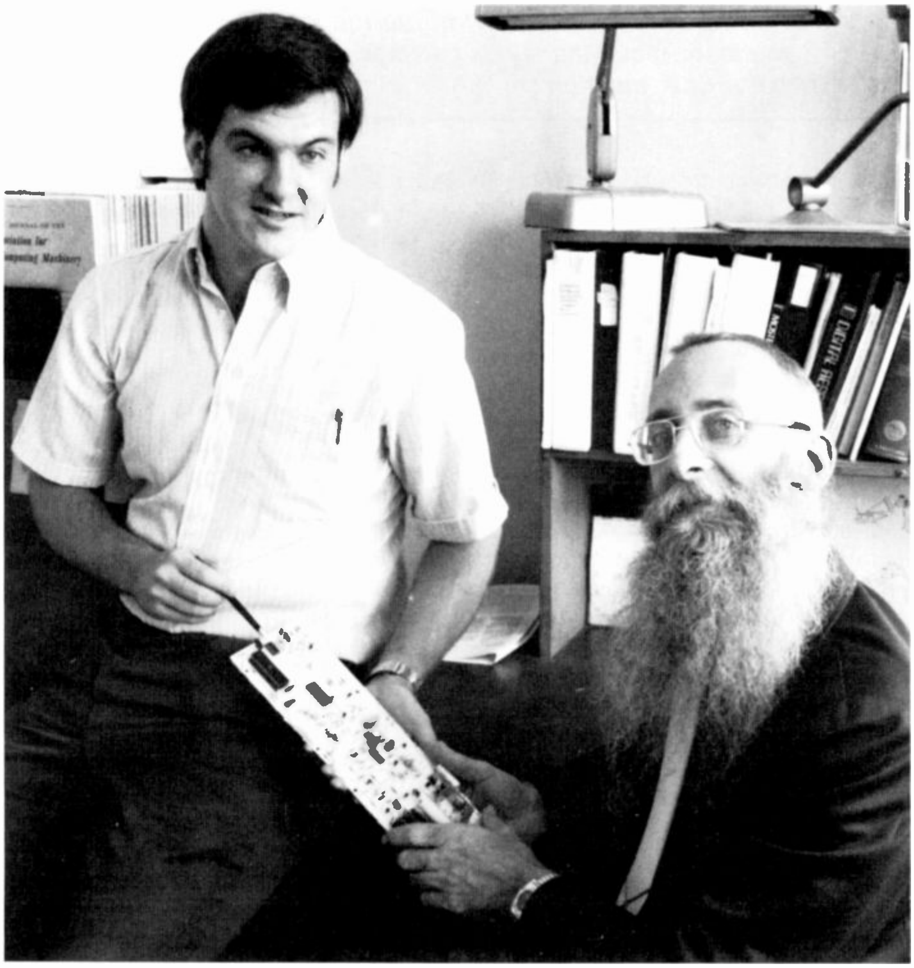

Charles Dieterich, currently Member of Technical Staff, joined the technical staff at the Princeton Labs in 1978 after completion of a Cooperative Master's Degree program with M.I.T. He has worked on flat television displays and comb filters in addition to his more recent work with VideoDisc audio and digital control systems. He holds one patent and received a 1979 RCA Laboratories Achievement Award for work on the VideoDisc player control.

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Charles Wine, since coming to RCA Laboratories from CCNY in 1959, has been involved in work in a wide variety of projects. He has 26 patents and has received 5 RCA Laboratories Achievement Awards. He was also part of the team that was honored by the 1980 David Sarnoff award for outstanding achievement for the ChanneLock TV tuning system. He is now a Fellow of Technical Staff at the David Sarnoff research center, working in the area of advanced consumer products.

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R.S. Batra

RF modulation in the VideoDisc player

The system requirements and the design approach for the RF modulator in the VideoDisc player ensured a high quality RF signal that met FCC regulations.

Abstract: *This article describes the system requirements and the design approach for the RF modulator used in the VideoDisc player.*

In order to interface the VideoDisc player with the TV receiver, the composite video and audio signals are modulated on an RF carrier. A simplified block diagram shown in Fig. 1. describes the operation of the modulator section.

The audio signal from the audio demodulator frequency modulates the 4.5-MHz sound oscillator. This signal, along with the video signal amplitude, modulates either the channel-3 or channel-4 oscillator. The resultant modulated RF carrier is passed through the filters and applied to the antenna switch assembly. The switch, which is operated by the player function lever, connects either the player's RF output signal or the external antenna signal to the player's RF output connector, which in turn is connected to the TV receiver.

System requirements

To ensure that the RF signal is of high quality, the RF modulator must meet the following performance criteria:

- Stable RF carrier frequencies within ±50 kHz over a range of temperature and power-supply variations.
- Stable sound-subcarrier frequency within ±5 kHz.

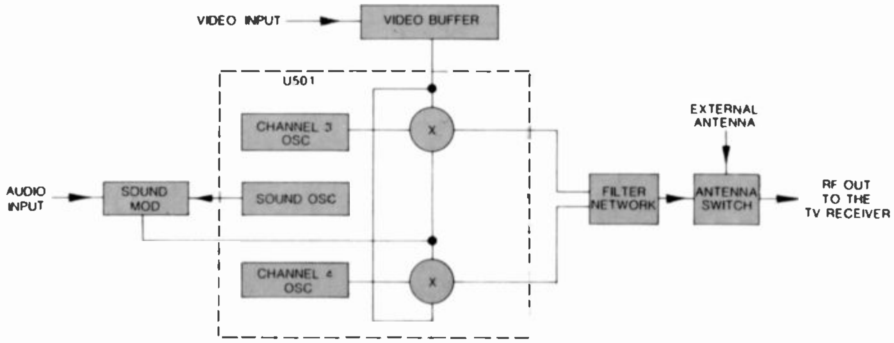

Fig. 1. Block diagram of the modulator section. The composite video signal — combined with the FM 4.5-MHz sound signal — modulates either the channel-3 or the channel-4 video carrier. This RF signal is connected to the TV receiver after it is passed through a filter network and an antenna-transfer switch.

- Linear modulator, with intermodulation and other beat products to be at least 48 dB lower than the video carrier.
- High carrier suppression.
- Customer-selected operation on either channel 3 or channel 4.
- Compliance with the FCC regulations, which demanded: RF output not to exceed 3 mVrms into 75 Ω; sound carrier to be at least 13 dB below video carrier; out-of-band signals at greater than 3 MHz from the channel edge should be at least 30 dB down from 3 mVrms into 75 Ω; and antenna switch isolation with RF signal on the antenna input jack to be no greater than 3 μv into 75 Ω.

RF oscillators

An integrated circuit is used for oscillator and modulator functions. Figure 2 shows the simplified circuit for the RF oscillators. Positive feedback is achieved by cross-coupling the collectors of the differential

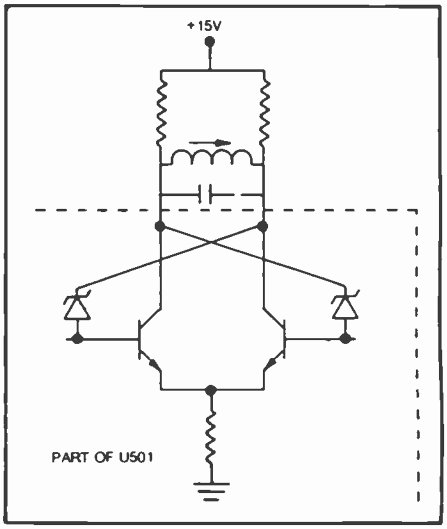

Fig. 2. Basic oscillator circuit. The frequency of oscillation is determined by the parallel tank.

Reprint RE-26-9-12
Final manuscript received Sept. 8, 1981.

amplifier to the bases. The oscillator frequency is defined by the parallel tank, which in the case of channel 3, is resonant at 61.25 MHz, and for channel 4 is resonant at 67.25 MHz. The peak-to-peak oscillator amplitude is determined by the load resistors, which also set the Q. An optimum value of Q will be high enough for the frequency stability criterion and will also satisfy the output requirement.

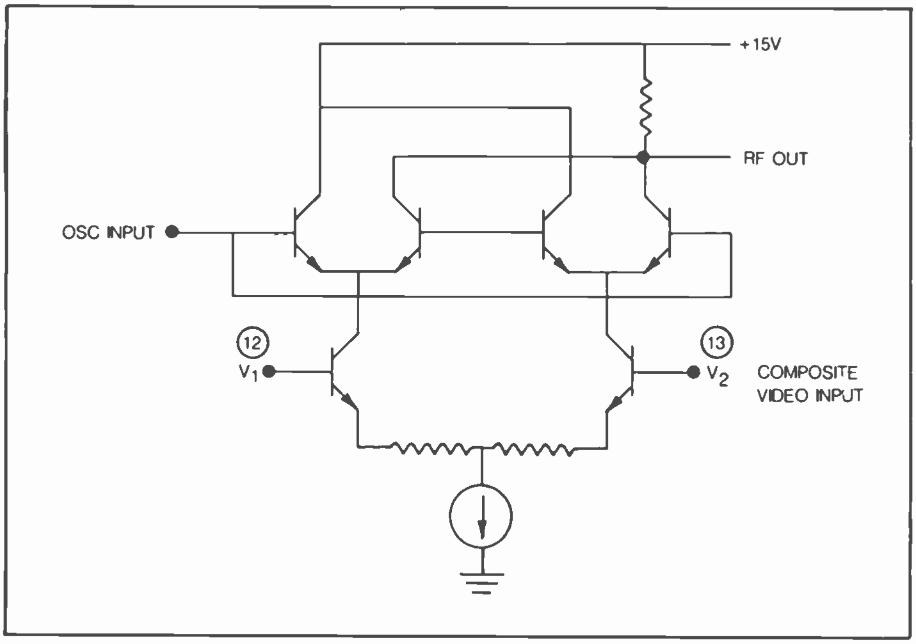

Fig. 3. Basic modulator circuit. A double-balanced modulator is used to modulate the RF carrier with the composite video signal.

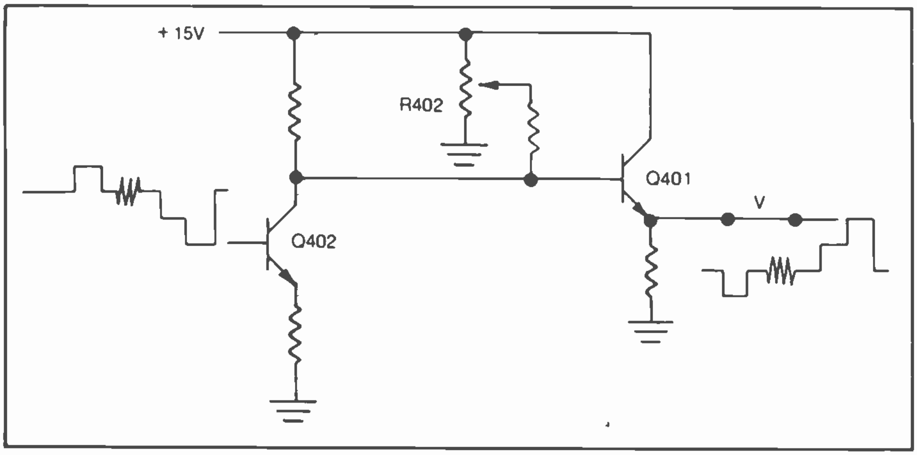

Fig. 4. Video buffer stage. *R402* provides a means for adjusting the video modulation depth by changing the DC voltage of the video signal.

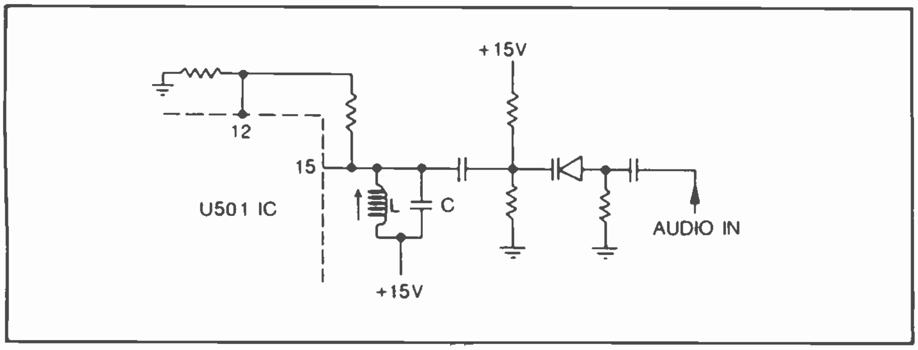

Fig. 5. Sound modulation. The 4.5-MHz oscillator is frequency modulated with the audio signal by using a varactor diode.

RF modulator

Figure 3 shows the conventional doubly balanced mixer used for the modulator. Output of this modulator is proportional to the product of the oscillator input signal and the offset voltage $V_1 - V_2$. V_1 is the DC reference, while V_2 is the video input voltage from the emitter-follower *Q*401, as shown in Fig. 4. Composite video is applied to the base of *Q*402, which is an inverting amplifier stage. *R*402 changes the DC voltage of the collector, which in turn is connected to the base of *Q*401. V_2, the output of the emitter follower *Q*401, is the composite video signal with negative-going sync. This signal is applied to Pin 13 of *U*501. V_1 (Pin 12) and V_2 (Pin 13) are so adjusted that the maximum offset and hence the maximum RF output occurs at sync peaks. At peak white, the offset voltage approaches the balance condition, giving the lowest RF output. In production, the modulation depth is controlled so as not to exceed the NTSC broadcast standard of 90 percent.

DC switching of the channels is accomplished by switching the supply voltage to the load resistors of the oscillator tank circuits. This, in addition to turning the oscillator off, cuts the current source to the modulator. Thus, at one given time, only one oscillator/modulator combination is turned on.

Sound modulation

The 4.5-MHz sound oscillator is similar to the RF oscillators with the difference that the tank circuit is connected between +15 V and one output of the differential amplifier. This oscillator is frequency modulated by the audio signal from the audio demodulator by using a varactor diode, as shown in Fig. 5. The frequency deviation is set to ±25 kHz by adjusting the audio input level to the varactor diode. The modulated subcarrier is connected to Pin 12 of IC *U*501. The AC voltage at Pin 12 determines the sound RF carrier level, while the DC voltage at this pin, as explained earlier, is used to set video modulation depth.

Filter network

Output of channel 3 is passed through a bridged-T trap and a bandpass filter (Fig. 6). The trap is of medium high Q and is

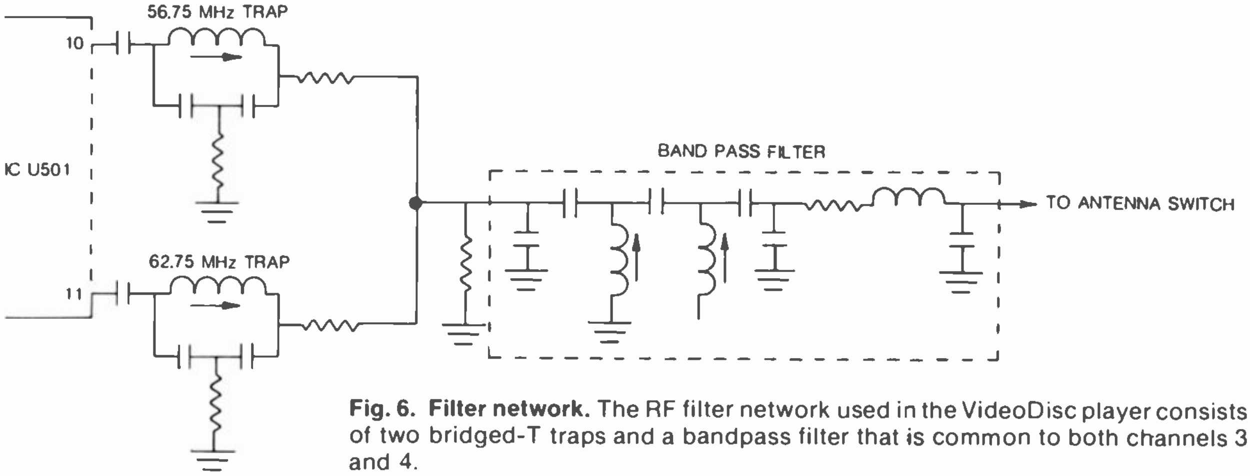

Fig. 6. Filter network. The RF filter network used in the VideoDisc player consists of two bridged-T traps and a bandpass filter that is common to both channels 3 and 4.

adjusted to give a minimum of 20-dB attenuation at 56.75 MHz, which is the lower sideband of the sound subcarrier. Since the sound carrier is already 15-dB lower than the video carrier, total attenuation achieved is greater than 35 dB, thus giving more than 5-dB margin to the FCC limit of 30 dB.

The bandpass filter response is very nearly flat to within ±0.5 dB for frequencies between 60 MHz to 72 MHz, as shown in Fig. 7. The need for the bandpass is to filter out the baseband signals and the channel harmonics caused by the RF modulator.

Channel-4 output (pin 11) is passed through a bridged-T network similar to the one used for the channel-3 section, with the difference that it is adjusted to trap out the 62.75 MHz, the lower sideband of the sound subcarrier for channel 4. The output is passed through the bandpass filter before being connected to the antenna switch. Figure 8 shows the channel-4 filter response. The insertion loss of the filter network is approximately 20 dB, giving an RF output of 2 mVrms that is well within the FCC limits.

Antenna switch

The antenna switch is made of two standard DPDT switches, mechanically linked and electrically connected to act as a high-isolation SPDT switch. The switches are mechanically linked to the player function lever. In the OFF position, the external antenna is connected to the RF output connector of the player. In LOAD and PLAY positions, the antenna is isolated from the RF output connector by at least 60 dB, while the RF modulator output is connected to the RF output connector.

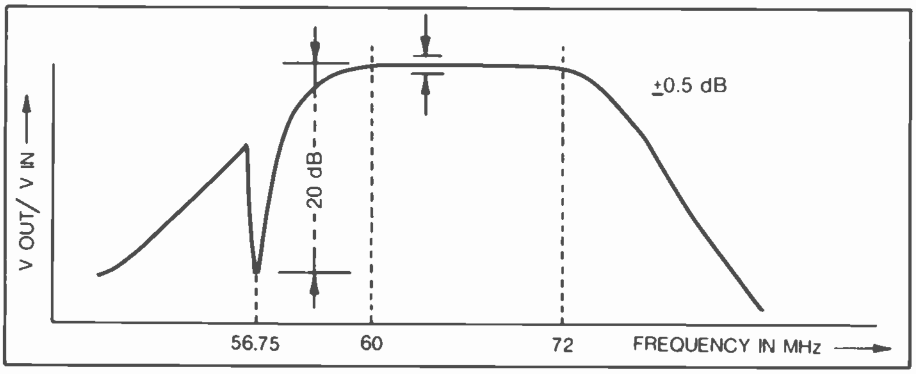

Fig. 7. Channel-3 filter-network response. A minimum of 35-dB attenuation is achieved at 56.75 MHz, the lower sideband of the sound subcarrier of channel 3.

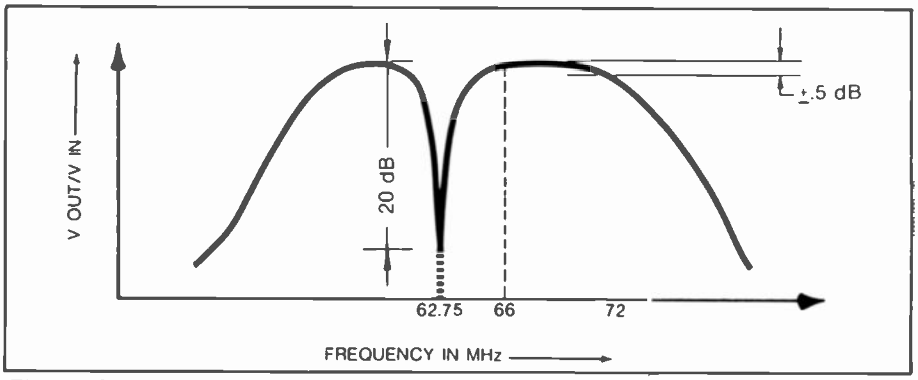

Fig. 8. Channel-4 filter-network response. A minimum of 35-dB attenuation is achieved at 62.75 MHz, the lower sideband of the sound subcarrier of channel 4.

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Regulatory considerations in player design

Radio frequency interference and safety were prime concerns for the player's designers.

Abstract: *Player Engineering is responsible for designing the SFT100W to comply with all relevant regulatory requirements, and for securing all necessary regulatory approvals. For video disc players, these regulations fall into two categories: radio frequency interference (RFI) and safety. RFI requirements are established by the Federal Communications Commission (FCC). Safety requirements are established by Underwriters Laboratories (UL), the Canadian Standards Association (CSA), and RCA Product Safety.*

Radio frequency interference (RFI) and product safety were two important considerations in the design of the SFT100W "SelectaVision" VideoDisc Player. Meeting the Federal Communications Commission (FCC) requirements for RFI performance involved construction of an RFI measurements facility, as well as considerable design effort in reducing the player's RF emissions. Safety considerations were factored into the design from the player's conception, and were regularly reviewed with RCA Product Safety as the design developed.

Radio Frequency Interference (RFI)

The RFI regulations for video disc players are contained in Part 15 of the FCC Rules and Regulations. These regulations are intended to prevent various users of the RF spectrum from interfering with one another. Other devices governed by this part include radio and TV receivers, low-power communication devices, and computing devices.

Until September, 1979, the FCC classified the "SelectaVision" VideoDisc Player as a Class I TV Device and a Field Disturbance Sensor. At that time, the FCC proposed to amend Part 15 by abolishing the Class I TV Device classification and creating a new classification, the TV Interface Device. As will be shown later in this article, this proposal had a major impact on the SFT100W.

A Class I TV Device is an electronic device which produces an RF carrier that is modulated by a video signal and is intended to be fed into the antenna input terminals of a television receiver. This classification includes video cassette recorders, TV games, and video disc players.

The FCC defines a Field Disturbance Sensor as any device that creates an electromagnetic field and detects changes in that field due to movement of objects within the field. This classification was originally created to regulate intrusion alarms and theft detection devices. However, by definition, it also applies to the 915-MHz pickup system in the "SelectaVision" VideoDisc Player. This system creates a 915-MHz field in the area between the stylus tip and the grooves of the disc. As the disc spins, variations in the depth of the groove create a change in the relative height of the stylus electrode above the disc. This change in height creates a change in the electromagnetic field, which is detected by the pickup circuitry.

TV Interface Device

The TV Interface Device was created in a Notice of Proposed Rule Making (NPRM) in FCC General Docket 79-244 (adopted September 18, 1979). This NPRM resulted primarily from a petition filed by RCA Corporation in 1977, requesting the FCC to amend the Class I TV Device Rules. RCA filed this petition because it was anticipated that the "SelectaVision" VideoDisc Player would be difficult to market under the existing Class I TV Device rules for two reasons:

1. Class I TV Devices are required to be type approved under the FCC Equipment Authorization Program (Table I). RCA proposed certification as a substitute procedure.
2. No provision is made in the Class I TV Device rules for other types of devices (such as a Field Disturbance Sensor) to be included within the Class I TV Device package.

The proposed TV Interface Device rules addressed both of the RCA concerns. Under the proposed rules, video disc players are now permitted to be certificated rather than type approved. This is significant because, under the type-approval process, the manufacturer is obligated to make no design changes to the approved device without first obtaining FCC reapproval. This reapproval may or may not involve retesting, depending on the Commission's perception of the nature of the change. Under the certification procedure, the manufacturer provides measurement data, taken on an FCC-approved measurement site, to the Commission. The

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Reprint RE-26-9-13
Final manuscript received Sept. 8, 1981

Table I. FCC Equipment Authorization Program. The FCC Equipment Authorization Program contains four procedures by which various types of equipment receive FCC approval. The SFT100W was approved under the certification procedure. For certification, "permissive changes" include any changes which do not degrade RFI performance.

Procedure	*Test Requirements*	*Applicability*	*Example Devices*
Type Approval	Based on FCC testing of sample unit(s) at FCC laboratory.	Applies to all subsequent units that are identical to tested sample.	Class I TV Device Ultrasonic Equipment Medical Diathermy Equipment
Type Acceptance	Based on test data supplied by applicant.	Applies to all subsequent units that are identical to tested sample except for permissive changes.	Land Mobile Transmitter Broadcast Transmitter
Certification	Based on test data supplied by applicant.	Applies to all subsequent units that are identical to tested sample except for permissive changes.	TV Interface Device (proposed) Field Disturbance Sensor Radio/TV Receiver Home Computing Device
Verification	Manufacturer responsible for verifying compliance. Submission of data or samples to FCC generally not required.	Applies to all subsequent units that conform with tested sample.	Hand-held Calculator Digital Watch Commercial Computing Device

Table II. Summary of RFI limits. TV Interface Device requirements are contained in (proposed) Subpart H of Part 15 of the FCC Rules and Regulations. Field Disturbance Sensor requirements are contained in Subpart F of Part 15. In practice, Field Disturbance Sensor measurements are made at a distance of 3 m, and the results extrapolated to 30 m by assuming an inverse linear relationship between field strength and distance.

	TV Interface Device	
RF Carrier Output Signal Level	Visual	3000 μV at 75Ω
	Aural	At least 13 dB below visual
RF Output Terminal Conducted Interference		95 μV at 75Ω
Antenna Transfer Switch Isolation		3 μV at 75Ω
Field Strength of Emissions	30 - 88 MHz	100 μV/m at 3m
	88 - 216 MHz	150 μV/m at 3m
	216 - 1000 MHz	200 μV/m at 3m
Power Line Conducted Interference	450 kHz - 30 MHz	250 μV
	Field Disturbance Sensor	
Field Strength of Emissions		
Fundamental	915 ± 13 MHz	50,000 μV/m at 30m
Harmonics	1 - 10 GHz	160 μV/m at 30m
Spurious	1 - 10 GHz	15 μV/m at 30m

manufacturer may make design changes under the permissive-change rules without notifying the Commission, provided that the manufacturer verifies that no degradation in RFI performance results. The certification procedure places the burden of responsibility on the manufacturer to maintain compliance, but affords him much greater flexibility to make changes. This flexibility proved to be very crucial in bringing the SFT100W to market on time. Many design changes had to be made in the early stages of production. These changes could not have been made under the type-approval procedures without jeopardizing production schedules.

The proposed TV Interface Device rules also allow for the combining of various types of regulated devices, which may be used to generate the video signal, into a single package. Furthermore, the proposed rules allow that when a TV Interface Device is contained in a package which also contains other regulated devices, the entire package must meet the field strength of emissions limits of each individual device, with the exception that where an overlap in requirements occur, the device with the greatest allowable level of field strength governs. This provision allows the VideoDisc player to emit higher RF levels at 915 MHz, where the Field Disturbance Sensor rules apply, than would otherwise be allowed for a TV Interface Device alone.

In addition to emission limits, the proposed TV Interface Device rules contain a limit on RF interference voltages which can be injected onto the AC power line. The proposed rules also contain specifications on signal levels and interference levels allowable on the RF cable which attaches to the TV receiver. These rules are designed to maintain compatibility with NTSC TV receivers. Finally, a limit is placed on the signal level that the RF modulator can inject onto the antenna input terminals of the player. This limit is intended to prevent the player from becoming a miniature TV transmitter through the customer's TV antenna.

The RFI limits for TV Interface Devices and Field Disturbance Sensors are summarized in Table II.

RFI design considerations

The chief sources of emissions in the 30- to 1000-MHz region are the RF modulator, CCD comb filter, DC servo motor, and 915-MHz oscillator. The RF-modulator and comb-filter emissions are controlled using metal shields, ferrite beads, RF bypass capacitors, and careful considerations of printed circuit layouts. DC motor emissions are primarily controlled by RF bypass capacitors internal to the motor.

The harmonic emissions of the 915-MHz oscillator are controlled by shields, ferrite beads, feedthrough capacitors, and adjustment of the layout of the resonator printed circuit board. The fundamental emission falls far below the FCC limit without any special design effort.

The limits on the RF emissions on the modulator terminals were met by using filters and by careful attention to layout (see RF modulator design article, page 67).

The emissions on the AC power cord are controlled by a toroidal line choke. Both leads of the AC power line are wound on a toroidal ferrite core. The leads are connected in a start-start, finish-finish configuration to supress common-mode signals.

RFI measurements facility

The certification process by which the SFT100W was approved requires the submission of RFI data taken on an approved test site. The RCA facility located at the Rockville Road plant consists of three parts:

1. An enclosed screen room for line-conducted RFI voltage and RF modulator output measurements.
2. A 3-m open-field site for measuring field strength of emissions from 30 to 1000 MHz.
3. A large indoor room for measuring field strength of emissions from 1 to 10 GHz.

Line-conducted RFI voltage is measured using a Line Impedance Stabilization Network (LISN). The LISN provides a standard termination for the device under test as well as a means of coupling the RFI signal to the measurement device. A spectrum analyzer is used to measure line-conducted RFI voltages as well as RF modulator output characteristics.

The open-field site is built on a platform raised approximately two feet above ground level. The platform is 6 m wide by 9 m long and is covered with galvanized steel sheets to provide a constant ground surface. The measurement antenna (either a half-wave dipole or biconical antenna) is attached to a mechanical "monkey" which can be raised and lowered on the antenna mast over a height of 1 to 4 m above the metal ground plane. The device under test is located on a turntable 3 m from the antenna. Both the antenna height and turntable rotation are motor driven and remotely controlled from within the measurements house, which is located adjacent to the platform. This house contains the measurement instrumentation, which consists of a spectrum analyzer and a Field Strength Meter.

Spurious and harmonic emissions from 1 to 10 GHz were originally measured on the open-field site. However, several implementation problems made this difficult, and an alternate location was desired. A large indoor room (4.5 m by 12 m) inside the plant was transformed into a measurement site. Because horn antennas with high directivity are primarily used, reflections from the walls, ceiling, and floor are many decibels below the primary-path emissions and are not significant. Microwave absorbing material is used to cover two metal structures (a steel door and girder) located behind the device under test. A microwave spectrum analyzer is used to measure the field strength of emissions from 1 to 10 GHz.

Steps in the approval cycle

Player Engineering worked closely with the Washington, D.C. office of the RCA Frequency Bureau during all steps in the approval process. The Frequency Bureau provided guidance in the preparation of all required documentation, and submitted the documentation to the Commission.

The first step in the approval process was to receive a waiver from the Commission to allow the SFT100W to be certificated under the proposed TV Interface Device rules. As previously noted, these rules were proposed in September of 1979; however, as of July, 1981, they have not been formally approved by the Commission. Therefore, to avoid the complications of the existing Class I TV Device rules, a waiver was required. A request for a waiver was filed by the RCA Frequency Bureau in May, 1980, and was granted by the Commission in June of that year.

The next step was to receive approval for the measurement site. Details of the site, including a list of equipment, photographs, and site attenuation measurements, were submitted to the FCC. Approval of the site was granted in August of 1980.

The final step was submission of the data on the player itself. In addition to the RFI data, the FCC requires that photographs, circuit descriptions, and other details be submitted. Because of an FCC policy of making comparative measurements on all new types of devices, a sample player was requested by the Commission and provided by RCA. The Grant of Certification for the SFT100W was issued by the Commission on September 26, 1980.

Safety

RCA's policy states that "all products made or sold by the company shall conform to the highest practical standards of safety and shall comply with all applicable safety requirements." For the SFT100W VideoDisc Player, these requirements are established by Underwriters Laboratories (UL) and RCA Product Safety. In addition, since the player is intended to be marketed in Canada, the requirements of the Canadian Standards Association (CSA) must be met.

The basic UL safety requirements for video disc players are contained in UL-1409, "Standard for Low-Voltage Video Products Without Cathode-Ray-Tube Displays." This standard is supplemented by other standards which cover many of the individual components used in the player. These documents contain construction, performance, and test requirements necessary to insure that the product will not likely become a personal injury, shock, fire, or casualty hazard.

CSA requirements are contained in CSA Standard C22.2 No. 1-M1981, "Radio, Television, and Electronic Apparatus."

RCA Product Safety requirements are documented on various RCA drawings, guidelines, and internal standards. These requirements generally are structured along the same lines as those of UL and

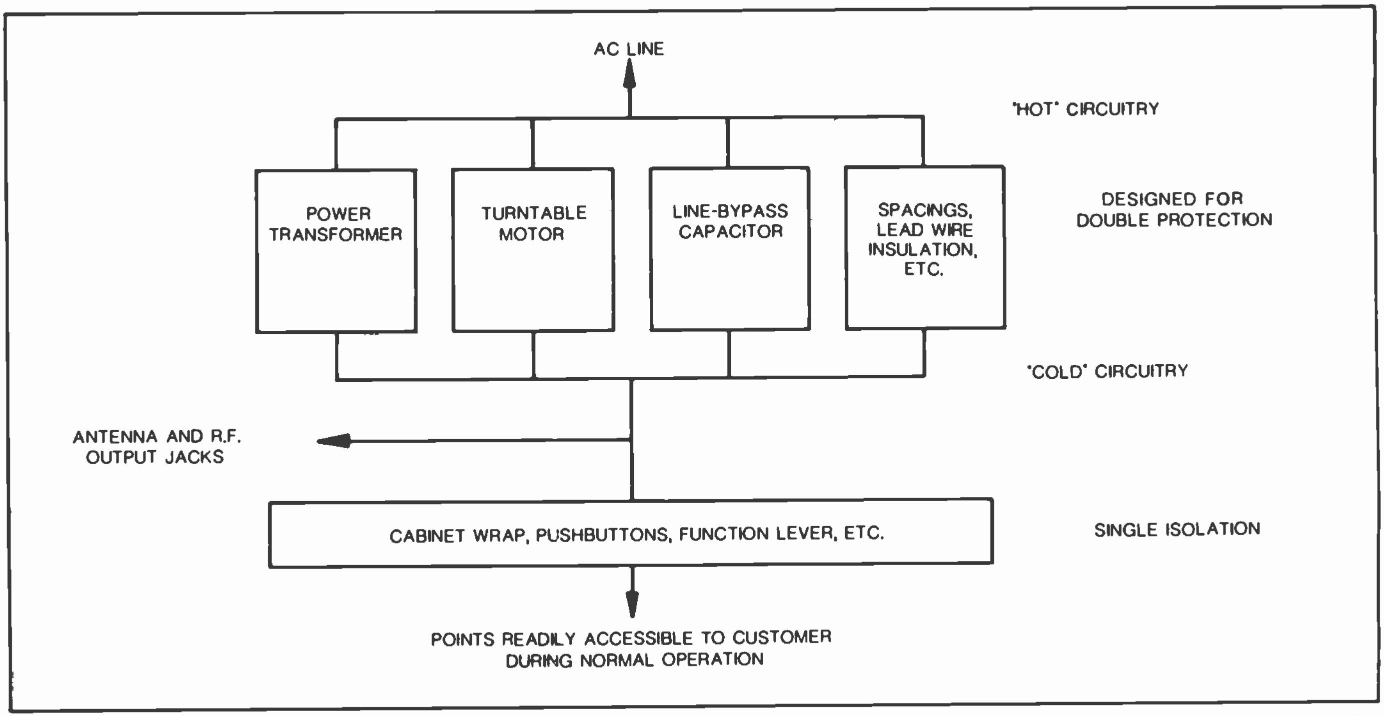

Fig. 1. Block diagram of SFT100W safety system for protection from electrical shock. The SFT100W provides two levels of protection against electrical shock. The first level has been designed for double protection (see text) between "hot" and "cold" circuits. The second level provides a single isolation barrier between points readily accessible to the customer during normal operation and the "cold" circuitry. This second level is intended primarily to reduce the possibility of electrical shock in the event that a device connected to the player (via the RF jacks) becomes a shock hazard.

CSA. However, in many cases, the RCA requirements are more stringent.

Safety aspects of the product design

There are many aspects of the SFT100W which were influenced by safety considerations. Only some of the major concerns will be mentioned here.

The safety system of the SFT100W, as it pertains to shock hazards, is illustrated in Fig. 1. All circuits on the secondary of the power transformer are "cold" (no shock hazard). One of the decisions made early in the development of the SFT100W was to design all line-isolating components and interfaces to UL's double-protection requirements. These requirements are specified in Section 38 of UL1410, "Standard for Television Receivers and Video Products." As such, double protection is not required for a video disc player, and the SFT100W is not qualified by UL for double protection. However, the double protection features have been designed into the SFT100W.

Additional shock hazards within a product may exist if the customer can gain access to "hot" components. To test for accessibility, UL has developed a three-jointed finger probe and a set of coin probes. These are designed to simulate a person's finger and a person holding a coin between two fingers, respectively. CSA has its own version of the finger probe which has only one joint but is smaller in diameter than the UL probe.

All openings in the player cabinet, such as ventilation slots, must be small enough so that access to "hot" circuits cannot be made with these probes. The stylus access opening in the cabinet top posed special difficulties because it is large enough for an entire hand to enter. Special covers were designed for the AC spine-sense switch and the AC-input printed circuit board to prevent customer access of "hot" components through the stylus access opening.

UL requires that all polymeric parts that exceed a minimum size requirement be constructed of a UL-recognized material which meets one of several flammability classifications. The exact classification required depends on the use and location of the part. In the SFT100W, there are over 70 polymeric parts that must be properly documented with respect to material content. This documentation consists of two notes on the part drawing, one which specifies the material flammability requirement and another which specifies the approved materials.

Steps in the approval cycle

Both UL and CSA require that a sample of the product be submitted for testing before approval is granted. Additional samples of components which are likely to fail during testing, including fuses, limiting resistors, and power transistors, are supplied upon request. A complete set of circuit schematics is required. UL also requires a list of all polymeric parts and the name of the material from which they are constructed. Approval times range from 3 to 6 months, depending somewhat on how similar the device is to a previously approved device. Since the SFT100W was the first of its kind, UL and CSA approvals both took approximately 6 months.

Both UL and CSA use a follow-up service that consists of unannounced inspections of the manufacturing plant. These inspections occur at least four times a year. The inspectors check to see that the product being built is equivalent to the sample previously tested. Processes related to safety are inspected. Components that must be approved are inspected to insure that they are properly marked as being UL recognized and/or CSA certified. The dielectric withstand test is inspected.

RCA Product Safety is kept abreast of the product design all through the design cycle. Sample players from each engineering build are sent to Product Safety for evaluation. Product Safety and Design Engineering work closely together during the design phase to insure that the final product meets RCA safety requirements. Formal RCA safety approvals are given via two documents, the Product Safety Start (authorization for production start and factory hold) and Product Safety Release (authorization for shipping release).

Acknowledgments

The author would like to acknowledge the contributions of:

J.D. Elliott, Manager of Engineering, RCA Inc., Prescott, Ontario, Canada, for his help with CSA submissions.

F.E. Korzekwa, UL Coordinator, RCA Consumer Electronics, for his help with UL submissions and in preparing this article.

E.E. Thomas, Manager of the Washington, D.C., office of the RCA Frequency Bureau, for his help with FCC submissions and in preparing this article.

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MACS: A computer-based system for manufacturing analysis of VideoDisc player production

As the VideoDisc players go through the manufacturing process, MACS collects and analyzes data from the numerous test stations, so that production quality can be monitored in real time.

Abstract: *MACS (Manufacturing Analysis and Control System) is a computer-based information system used for manufacturing analysis of VideoDisc player production in real time, for the timely detection of problems and trends. To accomplish this, a minicomputer, located at the RCA facility in Bloomington, Indiana, automatically collects production test data from a large number of test stations, processes the data and generates a variety of reports on yields, failure patterns and other information of interest to manufacturing management. This system was developed by a team composed of personnel from four RCA locations: Consumer Electronics, Indianapolis, Indiana; Consumer Electronics manufacturing facility, Bloomington, Indiana; David Sarnoff Research Center, Princeton, New Jersey; and VideoDisc Operations, Indianapolis, Indiana.*

In March 1981, RCA introduced to the United States a new consumer product — the VideoDisc system. To accomplish such a nationwide introduction, RCA started production of the discs and the players several months earlier. The player, produced at the RCA manufacturing facility in Bloomington, Indiana, requires the fabrication and test of many subassemblies prior to its integration and test. To successfully manage such a large and complex manufacturing operation, particularly during a new product start-up, a means of obtaining up-to-the-minute manufacturing information must be provided so that the managers can quickly identify and solve assembly-line anomalies. MACS (Manufacturing Analysis and Control System) is the system used to provide this information in nearly real time. A prototype of this system, called DARTS[1], had previously been developed to provide similar information for the TV-chassis manufacturing facility in Bloomington.

MACS is a minicomputer-based system that collects data from a myriad of test stations. It reduces the data so that useful information can be provided in timely fashion. These reports contain such information as production summaries, test-station yields, failure patterns, and most-frequent repairs. As shown in Fig. 1, data is collected by MACS from two kinds of sources: automatic test equipment (ATE) and bar-code readers at the manual test stations. A large number of automatic test stations are used for the alignment and test of the player's circuit boards. Each ATE transmits test data to the MACS computer automatically. Each transmission of test data includes an identifying number for the unit under test; this number is provided to the ATE by a bar-code reader. There are also many manual test stations at which other circuit boards, the arm, and the players are tested. Near each of these test stations is a bar-code reader, through which an operator can transmit test codes and identifying numbers to MACS. In addition, these bar-code readers are used to transmit repair information to MACS. All information relating to a given unit is collected in the computer's data base and can be retrieved during the generation of the required reports.

Data collection

As previously mentioned, MACS collects data from two kinds of sources: the automatic test equipment (ATE)[2] and the bar-code readers at the manual test stations.

Automatic test equipment (ATE)

MACS collects ATE data by constantly "listening" to all ATE stations (Fig. 2) simultaneously. Each ATE is connected directly to the MACS computer through a 20-mA current-loop line operating at 9600 baud.

The computer has buffered communication controllers to allow simultaneous data reception. This method was necessary to prevent loss of production data, since the ATEs cannot afford to wait for MACS.

During the ATE test cycle, the operator is requested by the ATE to enter the unit's identifying number. To ensure the entry of the serial number, the ATE will not release the unit under test until the identifying number is entered. The operator uses a hand-held bar-code reader to make the entry. The identifying number and the

Reprint RE-26-9-14
Final manuscript received Aug. 31, 1981

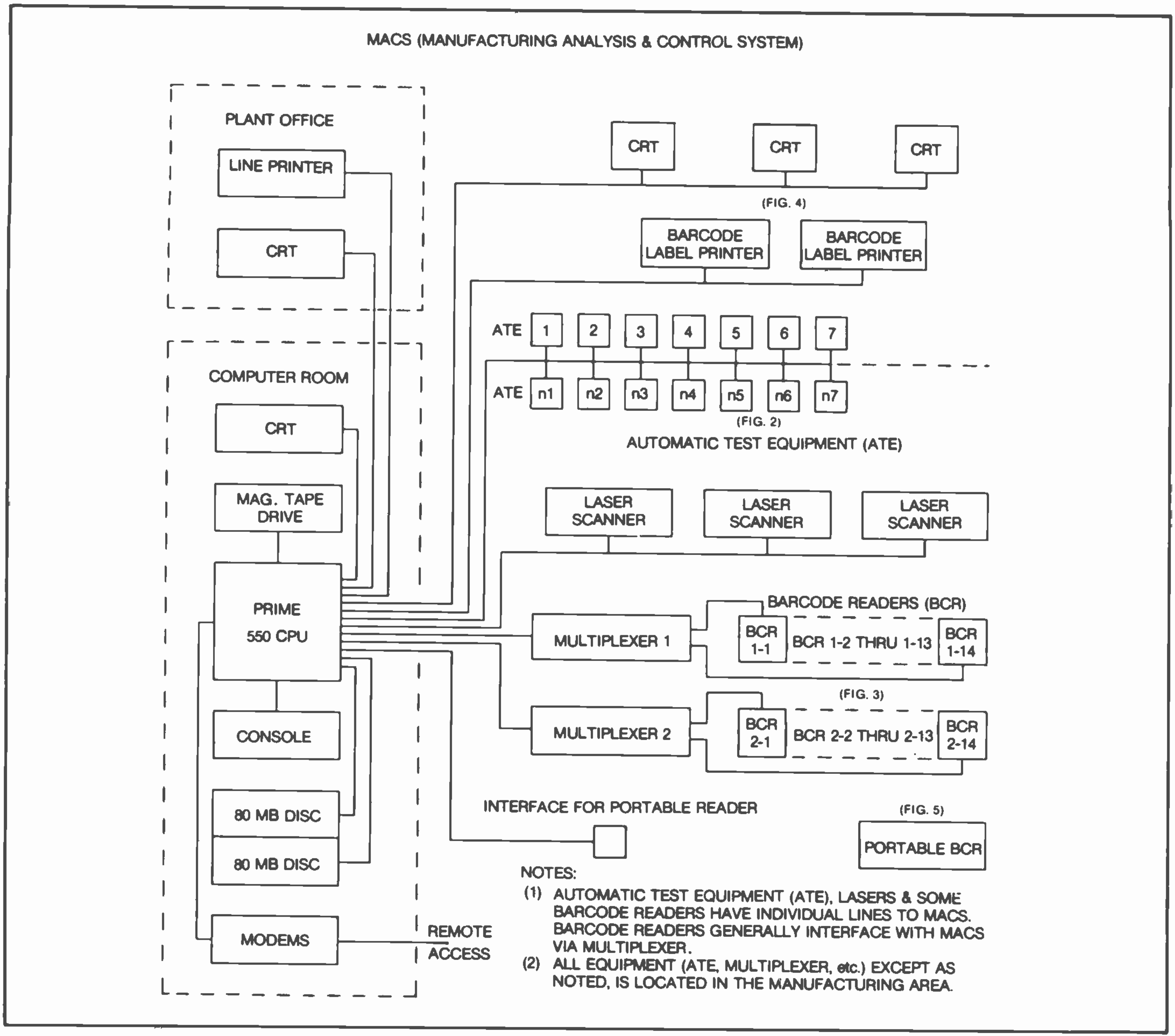

Fig. 1. MACS system block diagram. The heart of the MACS system is a Prime 550 Minicomputer with 160-million bytes of disk storage. Each of the automatic test equipment (ATE) units automatically transmits test data to the computer. Operators use the bar-code readers to transmit other test and repair information. The CRT terminals, located in various places, are used for system operations, as well as to control the label printers, and to obtain reports.

results of the test are transmitted to MACS at the conclusion of each test cycle.

Each time an ATE is turned on, it transmits its unique identity, and the test limits and procedures with which it is operating. MACS stores this information to be used for report generation. Thus, MACS can relate test results to a specific tester configuration.

The Test Technology Department of Consumer Electronics (designers and builders of the ATE systems) developed the ATE software to communicate with MACS.

Manual data collection

Bar-code readers (Fig. 3) are used to transmit test data to the computer from the many (approximately 30) manual test stations positioned throughout the manufacturing area, and they are used to transmit all repair information for both manually tested and automatically tested assemblies. Bar-code readers were chosen to transmit this data, rather than other devices (for example, CRTs), to ensure accuracy of the data and to minimize data-collection labor.

Bar-code readers are connected to the MACS computer via multiplexers. Data transmission is in an asynchronous bit serial mode via a 20-mA current loop; data is in ASCII format. The data rate between the multiplexer and the computer is 4800 baud; the data rate between the bar-code readers and the multiplexer is 2400 baud.

Each bar-code reader can perform multiple functions, including: lot pass; test pass; test failure; and repair information. The computer determines the function to be performed by examining the first message (after unit ID) transmitted, and it then

Lessons We Learned

- The user *must* be involved in making system decisions. If the user is not involved, the project will fail. But even if the user is involved in early decisions, design changes must be expected after the use of the system begins.
- In a manufacturing environment, direct labor applied to data collection *must* be minimized and justified.
- A team of people from different locations can be used efficiently to develop a complex system if a team spirit and a unified goal prevails.
- The system design is dynamic and will continue to grow as the user becomes more involved. The system designers must realize that their work is never complete, even after system start-up.
- Documentation, training, and system simplicity are essential if the developers ever wish to transfer responsibility for maintenance of the system.

Fig. 2. Automated test equipment. This automated tester is one of several that align and test the major printed-circuit boards of the VideoDisc player. It transmits the test results directly to MACS.

prompts accordingly. The computer prompts the bar-code-reader operators, step-by-step, through the data-entry process. By this prompting, such information as "unit ID," or "test code," is requested from the operator. Generally, the operator enters the required information using a bar-code reader; other information, such as "operator number" or "part legend," is entered by keyboard. The operator selects the desired test codes or repair codes from a book that contains a series of bar codes, corresponding numbers, and descriptions. There is such a book near each bar-code reader, and its contents are appropriate for the station.

All bar codes (for example, unit ID, test codes, and repair codes) are of the 14-digit, 2-of-5 interleaved type.[3] The bar code for the player unit ID includes model-number information as well as date code, assembly line, plant, and serialization data. The bar code for each subassembly unit ID contains the unique descriptor designating the subassembly (for example, the arm, signal board, control board, and so on) as well as a serialization.

Some data is transmitted to the computer using laser scanners. They are used to record the serial numbers of players that have passed all testing and are being moved along the assembly line to the packing area. Laser scanners were installed to help minimize data-collection labor.

Portable bar-code readers are used to collect data at the shipping dock (Fig. 4). They record the serial numbers of all packed players being sent to the warehouse. Portable units are used so that the operator can move to the skids of players. Data stored in the portable bar-code readers (serial numbers of several hundred players can be stored) can be transmitted to the computer at a later time.

Two label printers (Fig. 5) are located in the VideoDisc player-manufacturing area, and they are driven by the MACS computer. The label printers are used to print all bar-code tags, including player serial-

Fig. 3. Bar-code reader. This bar-code reader is one of several located on the manufacturing line. It is used to transmit instrument serial numbers, test codes, and repair information via bar code to the computer. It transmits part legends and operator numbers via keyboard.

Fig. 4. Portable bar-code reader. The operator is using a portable bar-code reader to record the serial numbers of completed players being shipped to the warehouse. The information is stored in the reader memory (a maximum of about 500 fourteen-digit numbers can be stored). The reader will later be connected to the computer interface so that the stored information can be transferred to the computer data base.

Sorting It Out: D & DB & DBM & DBMS

DBMS is the common acronym for data-base-management system. Each successive word in this phrase implies additional functionality. In the simplest case, data may be manipulated by a program to produce useful information. By organizing data into a structured data base, applications can more readily take advantage of the relationship between data items. If the data base is structured according to a data model, then a general-purpose data-base manager can be used to interface applications to the data base. At a minimum, reliability is improved when access to the data base is controlled by such a consistent and debugged interface.

The full potential of data management is achieved by use of a data-base-management system. A good DBMS will include the facilities necessary to define the data-base structure, allow substantial data/program independence, provide for concurrent access, maintain consistency and integrity, assure data security, and aid in data-base backup and recovery.

The three most important data models on which DBMSs have been based are: hierarchical, network, and relational.[5] *A network model is used for MACS. A network DBMS provides additional flexibility in data structure compared to hierarchical systems. And for large data bases, systems based on the relational model have yet to achieve the necessary efficiency.*

The data-base-management system used for MACS is Prime Computer's DBMS. It is based on the 1971 proposal of the Data Base Task Group of CODASYL (the Conference on Data Systems Languages, the same organization that defined COBOL)[6]*. Other implementations of CODASYL-compatible data-base-management systems used within RCA include Cullinane Corporation's IDMS (on IBM computers) and Univac's DMS1100.*

Fig. 5. Label printer and CRT terminal. This label printer, which is driven by the computer, is one of two located in the manufacturing area. It is used to print instrument multi-part labels, subassembly-ID tickets, and test-and-repair code charts. All of these tickets and charts contain bar codes, corresponding numbers, and other information. The CRT terminal is used to transmit the required parameters of the tickets and charts to the computer, and it can be used for systems operations as well as for displaying reports.

number tags, subassembly tags, test-code charts, and repair-code charts. CRT terminals (Fig. 5), located on the manufacturing floor, are used to control these printers as well as to access MACS reports and to perform system functions.

Data storage

Data-base management

All MACS data is stored, updated, retrieved, and maintained under control of a vendor-supplied data-base-management system. This decision was the cornerstone of the overall system architecture. It allows a highly organized, but flexible, data structure; it permits significant data program independence; and it provides the facilities necessary for data integrity, concurrent access control, and data-base security.

The data-base-management system used in MACS is of the CODASYL-compatible network data model type (see box, Sorting It Out, page 78). In this data model, the structure of the entire data base is defined by a schema and is usually described by a schema diagram (Fig. 6). The rectangles represent data-record types and the arrows represent relationships between records, called sets. A set defines a one-to-many relationship between an occurrence of the record type at the tail of the arrow, and zero or more occurrences of the record type at the head of the arrow.

Data-base structure

The actual MACS schema consists of more than 30 record types and more than 40 set relationships. Figure 6 is a simplified version of this schema that includes its most important data structures. An explanation of this schema diagram will help to clarify the notions of record and set.

Starting from the top left, the diagram shows a "product" record type: an occurrence of this record type will exist for each product (final product or subassembly) being produced in the factory. For each product, a set relationship defines all the "parts" that comprise that product (note the one-to-many relationship). Similarly, each product type is connected to every unit of that product that is manufactured (the "serialized units"). And finally, all "manufacturing lines" that assemble each product are identified.

Moving to the right half of the schema diagram, you see the "plant" record. Each plant consists of a number of manufacturing lines and also identifies every "tester type" that may be used in the factory. (Indirectly, the manufacturing-line records can be used to determine which products are produced at which plants.) For each tester type, the collection of "test limits" that have ever been used in production are identified. Each active "test station" is connected to the unique manufacturing line to which it belongs and to the current test limits.

The heart of the data structure consists of the "serialized-unit," "reject-repair," and "pass" records. For each piece of product, the history of its progress through the various test positions is identified either as a "pass," or as a "reject" and subsequent "repair." In the case of a reject-repair, the repaired part and the "troubleshooter" are identified. In both cases, the reject, repair, and pass actions are date-time stamped, collected into "date-time windows," and connected to the particular test station that performed the test.

Data-base maintenance

In addition to the programs that update the data base on the basis of incoming transactions and those that report on its contents, a number of data-base utilities exist to maintain the data base. Among these are a number of vendor-supplied utilities for data-base backup and restoration, data-base consistency checking, and other administrative aids.

Two MACS-specific editors — the factory and the product editors — were developed to maintain two relatively static portions of the data base. The factory editor is used to define and revise those portions of the data base that describe the layout of the factory: the manufacturing lines, the testers, and their parameters. The product editor is used similarly for the products and their parts. Both of these editors are interactive, using multiple-choice menus and "fill-in-the-blanks" formats.

A data-base purge routine is used periodically, as the data base fills, to delete accumulated detail data for the finished product. Summary information for some of this data is maintained.

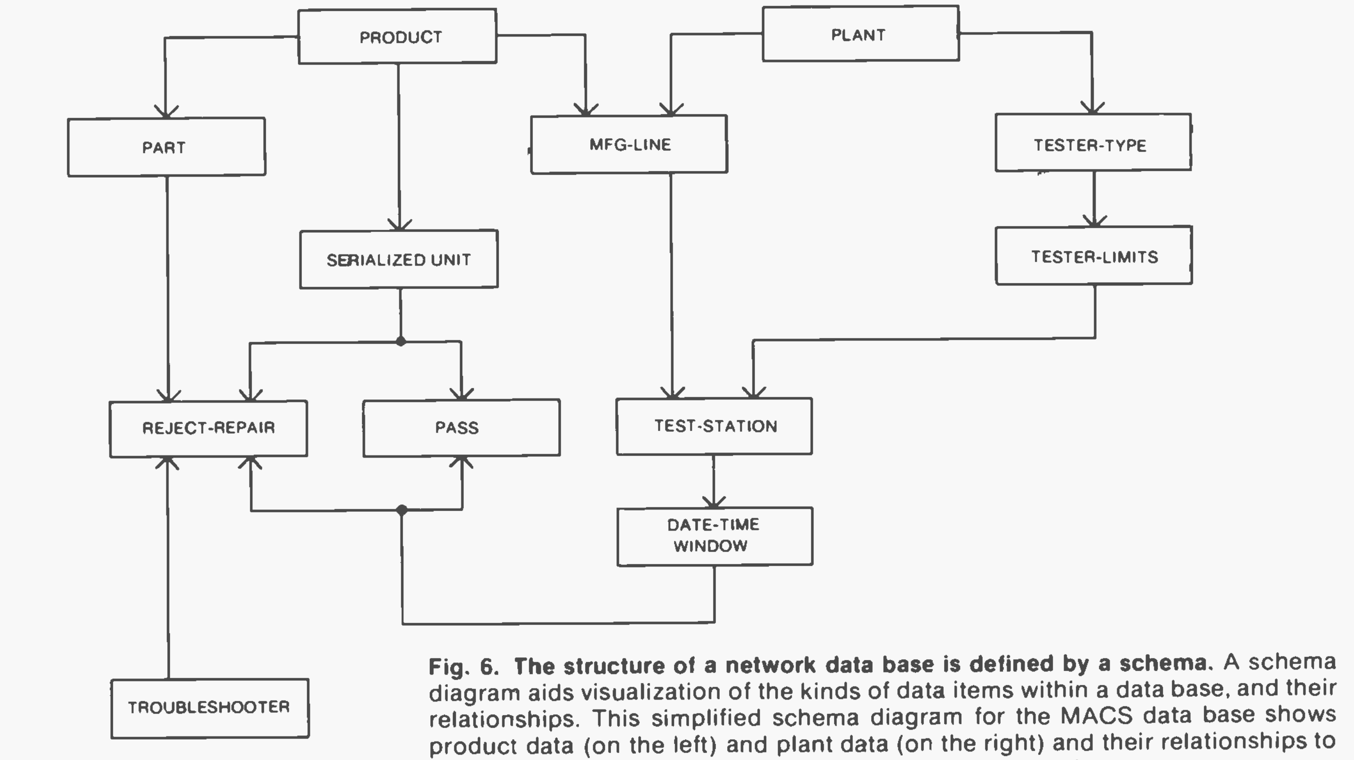

Fig. 6. The structure of a network data base is defined by a schema. A schema diagram aids visualization of the kinds of data items within a data base, and their relationships. This simplified schema diagram for the MACS data base shows product data (on the left) and plant data (on the right) and their relationships to serialized units of product as they pass through test stations.

Reports

MACS has over 40 reports available to all levels of management. These reports give information about product, components, process, equipment, and people. These reports are summarized in the box, Description of Reports, page 80.

Reports may be generated on a schedule that can be altered by the user or by special request. The user must specify the name of the report from a menu, the time period that the report should include, and the schedule on which it should be generated (hourly, every 4 hours, end of shift, or only once). To request a report, the user follows a fully prompted set of instructions.

As each report is generated, it is kept on file until it is updated. This file can be accessed from any remote location on a phone line at 1200 baud. This phone connection is protected by a security-code system similar to that of a time-sharing network. A user with proper code clearance can access 37 of the reports on either video terminal or printer at his remote locations. A remote user cannot request a special report or change the schedule of reports. To do either, he must contact the system operator.

Description of Reports

The summary report (Fig. 7) gives a list of the pass, fail, and yield percentages for each of the nine major production areas that comprise the VideoDisc player assembly process.

The repair reports (Fig. 8) consist of two parts, one for component repairs and one for workmanship repairs. In each part, the repair codes are shown across the top as headers to columns. Down the page, the components associated with the repair are listed. The components are sorted, with those most frequently repaired at the top.

The unit-history report shows a complete history of each entry to the data base for the unit specified.

The commodity reports give the pass, fail, and yield by hour for each test station on each assembly line for all the major subassemblies in the VideoDisc player.

The failure-pattern report provides a list of the 20 most frequent test rejects by station, the corresponding repairs, and the retest results.

The station-yield report shows a summary of pass and fail for each active test station.

The shipping report gives a serialized listing of every player shipped to the warehouse from the production area during the requested time interval.

The top-ten reports present the most frequent occurrences of failures in the plant, at ATEs or at manual test stations. These reports also show where the failures occurred, by test station.

The EMS-guide reports tell the repair operators the most frequently effective repairs for a specific test-failure symptom. This report is based on recent history of successful repairs in the data base.

Other reports are available showing efficiency of repair operations.

Computer system

MACS system development, begun in January 1980, was performed by a team of personnel from four RCA locations (see box, Team, page 82), and it provided some interesting lessons during the project (see box, Lessons, page 77). The development was accomplished using a Prime 550 computer located at VideoDisc Operations headquarters in Indianapolis; team members at the RCA Laboratories in Princeton accessed the computer by telephone.

Design considerations

The architecture of MACS—hardware and software—was driven by three major considerations: system performance, development schedule, and flexibility and expandability. The critical performance requirements included the ability to handle uncontrolled communication from the ATE minicomputers (arbitrary bit streams at 9600 bits per second, perhaps simultaneously), and an average transaction rate of more than one per second. To meet manufacturing commitments with adequate safety margin, only four months were available for software development.

Finally, since MACS was to be a part of a new manufacturing process, it would have to be able to respond to the evolving needs of this process. Furthermore, success of MACS in its initial application would likely result in its being applied to future manufacturing situations, with different specific needs. Indeed, the features of expandability and flexibility became essential after commencement of the evaluation period in September 1980. Thereafter, many new capabilities were incorporated, such as: remote communications; automatic counting; and many new reports.

These considerations led to the following criteria for computer-vendor selection: minimum custom software to be written; a general-purpose data-base-management system, preferably with CODASYL-compatible network architecture; large address space with minimum addressing overhead (32-bit architecture); intelligent asynchronous I/O (not character interrupt); and an effective software development environment. Our evaluation resulted in the selection of a Prime Computer system.

Hardware

MACS operates on a Prime 550 minicomputer with 1.25 megabytes of main memory. Two 80-Mb disks provide storage for the data base and MACS software. A magnetic tape unit is used for data-base

```
TITLE: PLAYER PRODUCTION SUMMARY

GENERATION DATE: SEPT XX, 1980 TIME: 16:04:13
REPORT PERIOD:
  START DATE: SEPT XX, 1980 TIME: 07:00
STOP DATE: SEPT XX, 1980 TIME: 16:00

                       CURRENT PRODUCT                     ALL PRODUCT
                     PASS    FAIL   YIELD              PASS    FAIL   YIELD
ACINBD   TOTAL        480                               480
  ACINBD LINE 5       480      0     100                480      0     100

ARM   TOTAL           106                               278
  ARM LINE 1          106      8      93                278     15      95

BURNIN   TOTAL         37                                69
  POST BURN-IN 1       37      2      95                 69      2      97
  POST BURN-IN 2        0      0       0                  0      0       0

CTRLBD   TOTAL        205                               491
  CTRLBD LINE 4       205     13      94                491     26      95

NLACBD   TOTAL        491                               491
  NLACBD LINE 5       491     15      97                491     10      98

PLAYER   TOTAL       1430                              1770
  INST LINE 1         540     40      93                760     50      94
  INST LINE 2         890     80      92               1010    100      91

PREAMP   TOTAL        585                               585
  PREAMP LINE 5       585      6      98                585     36      94

RES BD   TOTAL        426                               446
  RES BD LINE 5       426     18      95                446     18      96

SGNLBD   TOTAL        168                               464
  SGNLBD LINE 1       168     15      92                464     24      95

SHIP   TOTAL           43                                72
  SHIPPING DOCK        43      0     100                 72      0     100
```

Fig. 7. Player production summary. This is a typical report available from MACS. It provides information about production counts, failure rates, and process yields.

```
TITLE: INSTRUMENT REPAIR REPORT (ALL PRODUCT)

GENERATION DATE: SEPT XX, 1980 TIME: 16:21:07
REPORT PERIOD:
  START DATE: SEPT XX, 1980 TIME: 07:00
  STOP DATE: SEPT XX, 1980 TIME: 16:00

LINE: INST LINE 1     FAILURE GROUP: WORKMANSHIP                 E  M
                                      X  L        D  R        P  A  A
                        M  W  P  N  X  D  S  W  A  E  O  L  W  D  D
PART            TOTAL   P  P  S  S  S  S  H  W  M  V  E  D  W  J  J

C3215             4     0  0  0  0  0  0  0  0  0  0  0  0  0  4  0
PLAYBACK          3     0  0  0  0  0  0  0  0  0  0  0  0  0  0  3
B/PB ASY          3     0  0  0  0  0  0  0  0  0  0  0  0  0  0  3
WIRE              1     0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
SIGNALBD          1     0  0  0  0  0  0  0  0  0  0  0  0  0  0  1
R3202             1     0  0  0  0  0  0  0  0  0  0  0  0  0  1  0

LINE  INST LINE 1      FAILURE GROUP: COMPONENT
                                                           O
                                 S                         T
                        O     S  L     I  C  O        A  D  H
                        P  O  H  U  W  N  L  E  L  D  E  E
PART            TOTAL   N  V  C  G  K  T  N  C  O  D  F  R

SWPLATCH          6     0  0  0  0  0  0  0  0  0  0  6  0
PHOTONBD          3     0  0  0  0  0  0  0  0  0  0  3  0
SWPSWTCH          2     0  0  0  0  0  0  0  0  0  0  2  0
TURNTABL          1     0  0  0  0  0  0  0  0  0  0  1  0
TT MOTOR          1     0  0  0  0  0  0  0  0  0  0  1  0
SCREW             1     0  0  0  0  0  0  0  0  0  0  1  0
S3                1     0  0  0  0  0  0  0  0  0  0  1  0
FNCLEVER          1     0  0  0  0  0  0  0  0  0  0  1  0
CARTRDGE          1     0  0  0  0  1  0  0  0  0  0  0  0
ARM               1     0  0  0  0  0  0  0  0  0  0  1  0

    42% WORKMANSHIP DEFECTS
    58% COMPONENT DEFECTS
```

Fig. 8. Instrument repair report. This report provides repair-analysis information showing repair location and required repair action, for example, replacement of a missing part (MP), wrong part (WP), open part (OPN), or off value (OV). It also displays the percentage of component and workmanship problems.

backup and for software updates. Asynchronous communication controllers connect to the ATE minicomputers, bar-code readers and their multiplexers, CRTs, and bar-code printers. A system console terminal and line printer, used for reporting, complete the hardware configuration.

Software

MACS is built on the vendor-supplied PRIMOS operating system, and is written entirely in FLECS[4], a FORTRAN preprocessor that provides structured control features. The highly efficient task-exchange mechanism and shared-program facilities offered by PRIMOS led to a software architecture based on a large number of independent concurrent tasks, each dedicated to a relatively small and specialized function. For example, communication with each ATE minicomputer is handled by a separate task; all such tasks share an identical code, and only one copy of this code exists in memory.

Communication between tasks at different levels, for example between an ATE handler and an associated data-base update task, is accomplished by message queues. These queues are global to the sending and receiving tasks, but are not accessible to other "foreign" tasks. Storage for the queues is dynamically assigned.

An event scheduler and a master timer initiate the constantly executing tasks at system startup, and control other time-of-day-driven events. An event editor is used to define the master time table. Reporting programs are single-streamed by a batch monitor. This improves performance by eliminating data-base contention by multiple requestors. System security is aided by a facility that constrains certain terminals to execute only a very limited subset of system functions.

Future directions

The purpose of systems such as MACS is to provide manufacturing management with information that will aid in improving the manufacturing process. MACS has made the first steps toward this goal: rapid and accurate data collection, reduction, and reporting. The next steps include more efficient, accurate and reliable data entry, more sophisticated analysis, and improved information presentation. Efforts are underway both at the Laboratories and at Consumer Electronics to address these issues: configurable input stations to minimize the direct labor associated with data entry and reduce the possibility of operator error; query systems for *ad hoc* data-base inquiries and analyses; statistical analysis and control techniques; and graphical displays for better user interfacing.

MACS has proven its abilities in meeting the evolving needs of VideoDisc player manufacturing, and will be used as the prototype for larger manufacturing information systems. To meet the requirements of those systems, a number of distributed-processing approaches are being explored which may improve reliability, integrity and performance. Some of these approaches are: distributed mass-data buffers, to avoid data loss in case of central processor failure; coaxial-cable-based data-communications systems for higher speed and more reliable data collection; computer networking for integration with divisional information systems; and back-end data-base hardware for improved performance.

Acknowledgments

We wish to thank the members of our team who, through their contributions, spirit, and dedication, were instrumental to the success of this project:

- R. Atkins, R. Fein, J. Grayson, L. Turpin, D. Ward (Consumer Electronics Div.);
- S. Golin, D. Piper, T. Stiller (RCA Laboratories);
- E. Curtis, S. Williams (Consumer Electronics manufacturing facility); and
- E. Bennett, D. Gray (VideoDisc Operations).

Moreover, we wish to thank the members of management at each of the four RCA locations who supported and guided us during the development and evaluation phases of this project.

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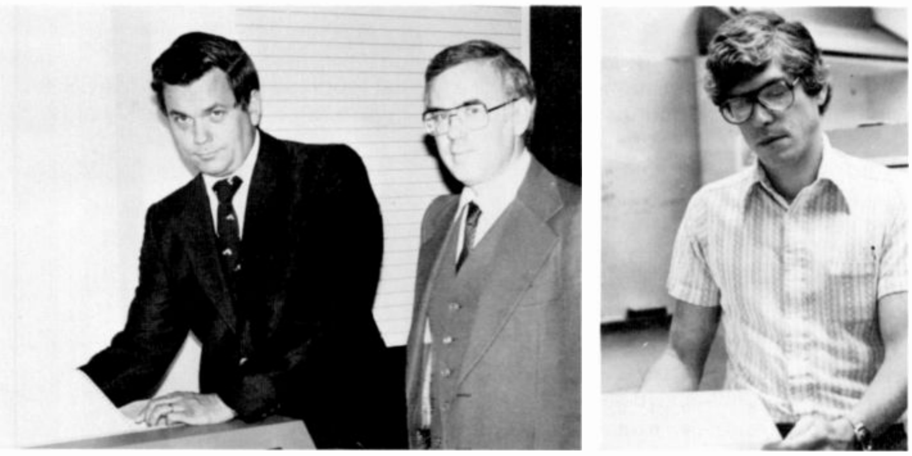
System Developed by Team

The MACS computer system was developed by a team composed of personnel from four RCA locations: Consumer Electronics, Indianapolis; Consumer Electronics manufacturing facility, Bloomington; RCA Laboratories, Princeton; and VideoDisc Operations, Indianapolis.

The team concept was used to quickly provide the talents needed to develop the system and to ensure that the user was involved in system decisions. The team performed a myriad of interrelated tasks including: system specification; software system design and development; user requirement definition; bar-code system definition; system installation; project management; training; and documentation.

The team spirit and the use of the development computer has continued during the writing of this paper. Each of the authors has used this computer to record and edit his part of the original draft. Storing the text in the computer made it easy for the authors to obtain copies of each other's work in spite of each being located in a different RCA location.



Authors (left to right) Limberg, D'Arcy, and Korenjak.

Jim D'Arcy, an electrical engineer at VideoDisc Operations, is currently assigned to the Disc Engineering activity as a Manufacturing Methods Engineer. He has worked on such projects as the MACS computer system and the signal system for the Player Technology Center. Prior to joining VideoDisc Operations in August 1979, he worked at RCA Astro-Electronics, Princeton, for 16 years on such projects as the Shuttle CCTV system, the Landsat Satellite high-resolution TV cameras, and the Dielectric Tape Camera. Joining RCA in 1959, he worked in the Broadcast Division, Camden, for four years on such projects as the CCTV system for the Nuclear Ship Savannah.

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F.T. Scearce

Product assurance for the VideoDisc player

Product Assurance uses mathematical modeling to evaluate player reliability in advance of production, and then puts selected manufactured players through a rigorous gauntlet of tests in advance of shipping.

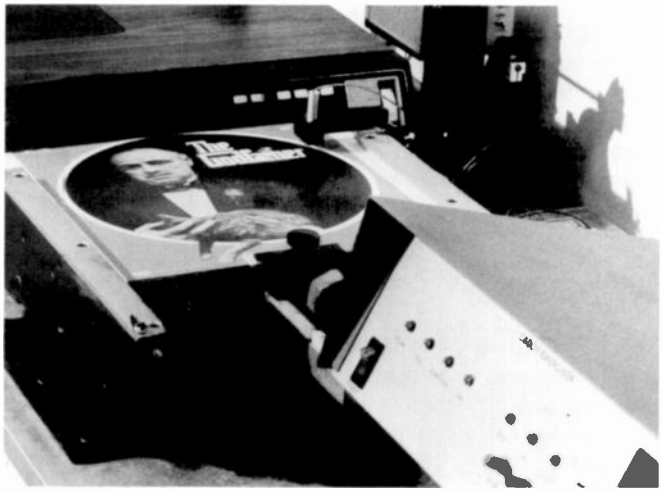

Fig. 1. Caddy exerciser for player life-test cycling.

Abstract: *The Product Assurance department's role in the introduction of the player to the consumer market has been to ensure that the quality of the player exceeds that of any previously introduced consumer electrical/mechanical system. Product Assurance conducted a rigorous reliability program on early models, and followed through with the acceptance testing and life testing of samples from each day's production for distribution. Following the release of the player, field-service reports were evaluated to determine the effectiveness of the quality program.*

Everyone participating in the VideoDisc program wants to deliver to the consumers a player of outstanding quality. The Product Assurance department has assisted these participants in producing a quality product.

Product Assurance has performed this assistance in the following ways:

- Performed player-stress tests
- Performed player- and component-life tests
- Produced a reliability model with its projection of the player reliability
- Performed tests to ensure compliance with regulatory agencies
- Obtained approvals from regulatory agencies and Underwriters Laboratories
- Controlled player and manufacturing compliance with corporate safety requirements
- Performed materials evaluation
- Assisted in establishing a quality-control program
- Performed vendor-quality surveys and ratings
- Assisted in rectifying vendor-quality problems
- Performed engineering-approval testing of all integrated-circuits from vendors
- Performed part-failure analysis
- Performed acceptance testing of all manufactured player lots
- Provided field-service support through analysis of field problems, in conjunction with design engineering.

Reliability

Player reliability was evaluated through a mathematical reliability model for the system and through extended life and stress testing. The player-reliability model was developed to predict the expected service calls per 100 players during the first three and twelve months of player use by the consumer. Table 1 gives the principal aspects of the mathematical model. The numbers used in the mathematical model were developed using data from one or more of the following sources:

- Voltage, current and temperature measurements made on a VideoDisc player.
- Demonstrated failure rates for passive electrical components experienced in television field failures.
- Demonstrated failure rates for similar mechanical and electromechanical components experienced in VCR field failures.
- MIL-HDBK-217G "Reliability Prediction of Electronic Equipment."
- RADC-TR-74 "Non-electronic Reliability Handbook."
- RADC-TR-73-248 "Dormancy & Power On-Off Cycling Effects on Electronic Equipment & Part Reliability."

The initial voltage, current and temperature measurements made on early engineering model players were subsequently refined as the engineering and factory pilot players were built. Temperature measurements made in one of the early engineering models and their assessment in the reliability model showed that the player's internal ambient temperature would need to be reduced in order for several integrated circuits to have satisfactory expected life. Consequently, a small fan was added to the turntable motor.

Results from stress testing of the early engineering and pilot player models were used to understand player deficiences and to make necessary changes to the player's design. Stress tests performed on the player were:

- Temperature cycling tests
- Resonance vibration (search and dwell) tests
- Drop-and-shake shipping tests
- User error-and-abuse tests
- Electrostatic discharge tests
- Electrical transient (antenna and line) tests
- Thermal shock tests

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Final manuscript received Aug. 10, 1981

- Temperature-step stress tests
- Voltage-step stress tests

Pilot players were life tested for 3000 playing hours. Portions of the player's mechanical system have been life cycled up to 40,000 times. Figure 1 shows one of the caddy exercisers used for extended life cycling of the player.

Vendor quality

Suppliers of parts and materials must have quality standards that are up to the quality level of the player design and its manufacturing processes if a quality product is to be produced.

Before a vendor's component or material is used, his manufacturing facility is given a quality survey and quality rating as to his ability to produce a product at an acceptable quality level. The elements of the vendor-quality survey are:

- Quality organization
- Quality documents/reports
- Test-equipment calibration and gauge control
- Receiving/incoming inspection
- In-process control
- Final acceptance/shipment
- Configuration control
- Reliability test program
- Facility conditions

The vendor is given a rating for each of these quality-survey elements, and the sum of these ratings determines the vendor's acceptability.

During production, problems frequently develop with vendor materials and components. Product Assurance works with engineering, manufacturing, and purchasing to determine the nature of the problem, and then these groups work with the vendor to establish corrective action. It is frequently necessary to make trips to the vendor to correct a quality problem.

Consumer acceptance laboratory

The Consumer Acceptance Laboratory (CAL) is one of the most important parts of Product Assurance's role to ensure that the consumer will receive a quality product. CAL is set up to evaluate players using a check to determine if all performance functions operate properly. In this functional test, the player is connected to a

Table I. Mathematical reliability models.

System Reliability Model

$$\lambda_T = (\lambda_1 t_1)\,100 + (\lambda_2 t_2)\,100$$

Where:

λ_T = Total number of service calls per 100 players (over 3 or 12 months).

λ_1 = Active failure rate for player ("Power On").

t_1 = Time for "Power On" (over 3 or 12 months).

λ_2 = Dormancy failure rate ("Power Off").

t_2 = Time for "Power Off" (over 3 or 12 months).

Integrated Circuit Reliability Model

IC active failure rate =

$$(\lambda_a \pi_T \pi_Q) + (\lambda_b \pi_T \pi_Q \pi_E) + (\lambda_c \pi_T \pi_Q \pi_E) + (\lambda_d \pi_Q) + (\lambda_e \pi_Q \pi_E) + (\lambda_f \pi_T \pi_Q \pi_E) + (\lambda_g \pi_Q) + (\lambda_h \pi_Q)$$

Where:

λ_a = Failure rate due to oxide-layer failures.

λ_b = Failure rate due to faulty bonds.

λ_c = Failure rate due to metallization failures.

λ_d = Failure rate due to faulty diffusion.

λ_e = Failure rate due to foreign materials.

λ_f = Failure rate due to die-header bonding problems.

λ_g = Failure rate due to surface defects.

λ_h = Failure rate due to crystal imperfections.

π_Q = Quality factor.

π_E = Environmental application factor.

π_T = Temperature factor.

Discrete Semiconductor Reliability Models

- Transistors (*pnp* or *npn*) and Silicon Diodes
  $$\lambda_T = \lambda_b (\pi_E \pi_A \pi_Q \pi_R \pi_{S2} \pi_C)$$
- Voltage Regulator and Voltage Reference (Zener) Diodes
  $$\lambda_T = \lambda_b (\pi_E \pi_A \pi_Q)$$

Where:

λ_T = Total failure rate

λ_b = Base failure rate (temperature versus electrical stress).

π_E = Environmental application factor.

π_A = Application factor.

π_Q = Quality factor.

π_R = Power rating or current rating for diodes.

π_{S2} = Voltage rating.

π_C = Complexity factor or contact construction for diodes.

Fig. 2. Consumer Acceptance Laboratory (CAL) tests being performed on part of the player sample taken from the daily production.

color television set, a disc is inserted into the player and all player operations are tested for performance as if in the typical consumer's home. The CAL functional test is shown being performed on several players in Fig. 2.

CAL determines the releasibility of each day's production of players. Player samples are taken throughout the production day after the players have been sealed in their carton and prepared for delivery to the warehouse. The day's production is held from being delivered to the warehouse until CAL has completed the testing of its sample of players. The players are released for delivery to the warehouse if they meet CAL's acceptance criteria. If the players sampled from a production line do not meet CAL's acceptance, then the players from that production line must be retested by the manufacturing department and the defective players must be repaired. CAL takes a new sample from this retested lot, and this retested lot must meet CAL's acceptance criteria before it is allowed to be delivered to the warehouse.

A portion of each CAL sample is given a simulated shipping test, before the cartons are opened and the players are functionally tested. The simulated shipping test consists of a shake-and-drop test. The players that have been tested this way must also pass the same functional test-acceptance criteria as the other CAL samples.

Following the CAL functional acceptance test, a significant number of players from the CAL sample are put on life testing for the equivalent of the time that a consumer would be expected to use the player over its first three months. These players are operated continuously and, once a day, they are given the initial CAL functional test. This life test provides an ongoing audit of the players to uncover any defects that could develop after a number of operating hours.

Field support

The true quality of the players is understood if we know how the players are performing in the consumer's environment. Product Assurance, therefore, collects field information for appropriate evaluation. The principal sources of information from the field on the VideoDisc player performance are:

- Warranty-service invoices
- Parts returned under warranty
- Warranty registrations
- Field-service-engineer reports

The warranty-service invoices provide information on the nature of the player problem, any part failures, days in use, and the manufacturing date from the serial number. Analysis of returned parts can help to identify possible part problems, application problems or environmental problems. Warranty registrations, in conjunction with warranty service invoices, can be used to establish the player reliability in the field on the basis of service calls per 100 players over the warranty period. The assessment of player reliability in the field can be compared to the original player-reliability-model projection made during the design phase, and also compared to the player life-test results for determining the effectiveness of the reliability model, the CAL functional test and the life test. The field-service engineers provide the most rapid access to field problems — especially those of a repeating nature. The field-service-engineering reports can frequently lead to corrective action long before a reoccurring problem can be recognized through the warranty-invoice system.

Product Assurance works with Engineering and with Field Service Support to decide whether special field Service Bulletins are needed as more information about player performance becomes known through field information, parts analysis, and CAL testing. These Service Bulletins are sent out to assist the field-service technicians in their diagnosis of field failures and special service requirements.

Product Assurance informs people at RCA Distributor and Special Products (D&SP), Deptford, New Jersey, of expected failure rates for the parts in the player. These failure projections are based on failures experienced during CAL tests — both the initial tests and life tests. This information helps D&SP to project their flow of parts to the distributors. Also, D&SP is alerted to potential part demand increases that are caused by a reoccurring field problem identified early by the field-service-engineer reports.

Frank Scearce joined "SelectaVision" VideoDisc Operations in 1979 as a Senior Member of Engineering Staff in the Product Assurance Department in Indianapolis, Indiana. He started with RCA in 1958 at Astro-Electronics in Princeton, New Jersey. He has managed the Integration and Test Groups for the TIROS, SATCOM, Atmospheric Explorer and Dynamic Explorer spacecraft programs. He is currently the Manager of Player Product Assurance for VideoDisc.

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Technology development for gigabit-rate GaAs integrated circuits

Using a few medium-scale integrated circuits, the authors show that multigigabit-rate logic applications are a demonstrated reality.

Abstract: *This paper gives an overview of GaAs MSI circuit applications, characterizing the advantages of GaAs, detailing the fabrication and application requirements, and reviewing experimental results of circuits made at RCA.*

Multigigabit-rate logic capability for real-time signal processing is rapidly becoming a major requirement for modern strategic and tactical military systems. There are vital needs for digital integrated circuits operating at data rates of 1 to 10 Gb/s for application in radar, electronic warfare, and communication systems of the 1980s. The need for such circuits to operate in hostile radiation environments is also becoming critical. GaAs MSI circuits have the potential for fulfilling these stringent requirements.

The principal requirements of the IC technology in the development of ultra-high-speed, medium- or large-scale integrated circuits are: high speed (that is, low propagation delay); low dynamic switching energy (that is, speed-power product); and high process yield. In the past two decades, impressive progress has been made in silicon (Si) ICs. Propagation delays of about 64 ps and 200 ps have been reported[1,2] in NMOS and CMOS/SOS, respectively. These improved performance results in Si IC technology were obtained mainly by improvements in fine-line lithography and clever fabrication techniques. However, these impressive results have not been translated into circuit performance. Although propagation delays obtained from ring-oscillator measurements (with fan-in = 1 and fan-out = 1) are impressive, rise-and-fall times may limit clock rates in Si ICs. One way to circumvent this problem is to replace Si with another semiconductor, one having superior electronic properties, such as gallium arsenide (GaAs). The electronic properties of GaAs that are superior to those of Si are: its very high, low-field electron mobility, which results in smaller series resistance in the devices; the low electric field for velocity saturation (7 to 10 kV/cm for GaAs versus 20 kV/cm for Si), which results in lower operating bias; and its excellent semi-insulating property of the substrate, which makes possible interconnections between circuits with minimum losses. Recent work on GaAs FETs showed[3-5] that voltage gain-bandwidth products of 15 to 18 GHz and propagation delays of the order of 34 to 150 ps are feasible. We used these high-speed switching properties of the GaAs FETs to develop low-power, medium-speed, medium-scale integrated circuits. Our program goals were: to develop GaAs-based technology with micrometer-sized geometries; and to design and fabricate MSI circuits to operate at gigahertz clock rates.

Technology development[6,7]

A cross-section of an IC is shown in Fig. 1. The IC consists of a MESFET (metal semiconductor field-effect transistor),

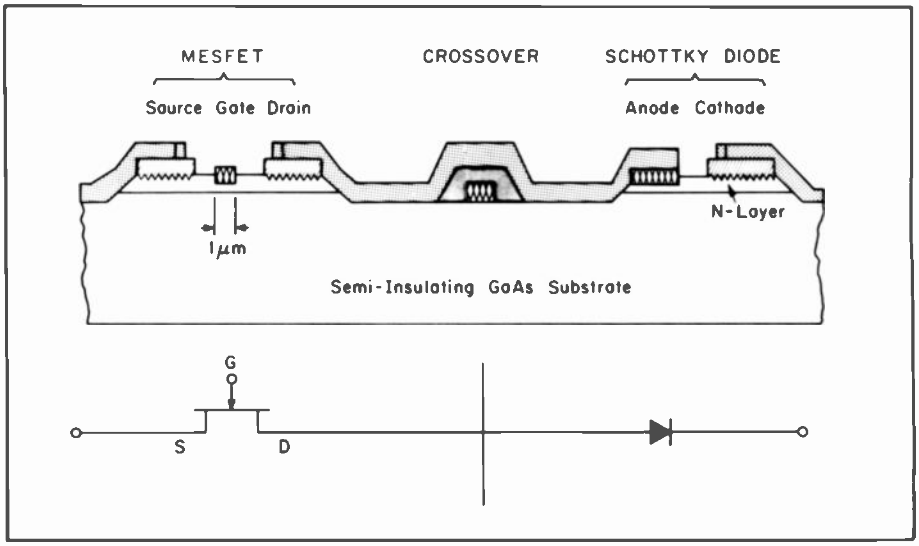


Fig. 1. GaAs IC cross section. A MESFET and a Schottky diode are the active devices. Interconnections with two-level metal lines and dielectric isolation layer for crossovers are also shown.

Reprint RE-26-9-16
Final manuscript received July 28, 1981

Depletion-mode GaAs FET logic families

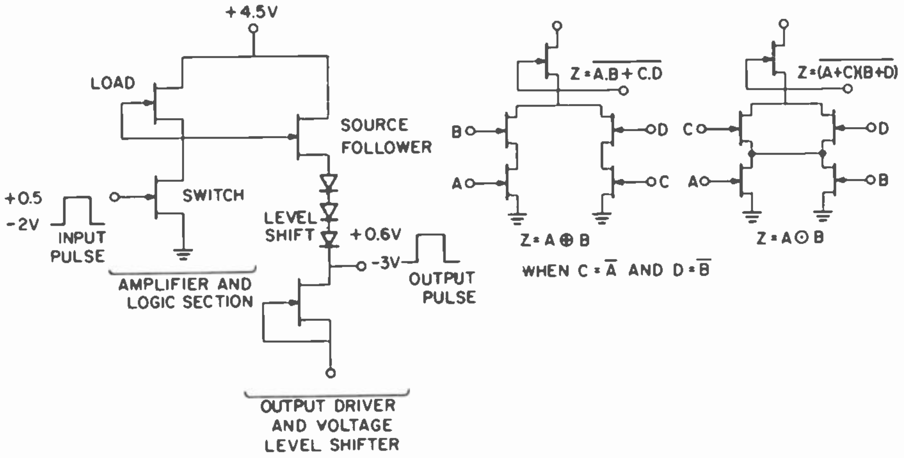


Fig. (a). Buffered-FET logic (BFL) or transistor-transistor logic (TTL) gates.

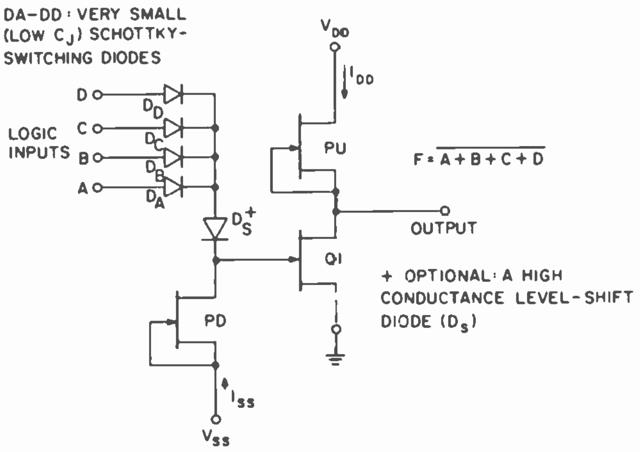


Fig. (b). Schottky-diode FET logic (SDFL) gate.

The two logic families commonly referred to that use depletion-mode MESFETs are: buffered-FET logic (BFL) or transistor-transistor logic (TTL); and Schottky-diode FET logic (SDFL). Each of these has its own merits.

Buffered-FET logic. A basic inverter and several logic functions (NAND, NOR) are shown in Fig. (a). A negative gate voltage is required to turn off an *n*-channel D-MESFET. But the output voltage produced at the drain is positive and must be dc-level-shifted so that the output logic levels are compatible with the input levels. This is accomplished by the three level-shifting diodes in the source-follower output stage of the logic gate. Since the diodes are in the source-follower section, which is conducting all the time, the power dissipation is relatively higher. But, the availability of NAND/NOR gates makes it possible to implement complicated logic functions such as EXCLUSIVE-OR and INCLUSIVE-OR with one gate delay. Also, the fastest circuit performance reported to date used BFL architecture. The level-shifting diodes require the same doping profiles as the MESFETs. Therefore, BFL circuits can be fabricated with a process similar to that used for conventional GaAs microwave FETs.

Schottky-diode FET logic. A four-input SDFL NOR gate is schematically shown in Fig. (b). In this approach the logic function and the level shifting is performed in the diodes. Gain and inversion are provided in the MESFET output stage. As the level shifting is done at the input stage where the current is low, substantial power economy is achieved in SDFL circuits. Typically, 1-μm by 2-μm diodes are used for the logic and 3-μm by 3-μm diodes for the level shifting. The small size of these diodes requires special doping profiles, different from those used for MESFETs. The active layers have to be produced by selective ion implants only — epitaxial growth techniques are not suitable. Relatively low-power dissipation in SDFL circuits leads to denser circuits. Fan-out is limited to three, and buffering is needed for higher fan-out.

Even though these two approaches are different from the viewpoint of circuit design, there is no significant difference in the technologies involved. One can readily switch from one approach to the other if desired. At present we are developing the technology for BFL circuits.

Schottky-barrier-diode active elements, and two-level metal interconnections. Uniformity of device characteristics, isolation layers with good dielectric properties, and micrometer-sized geometry control are the key factors in the technology development for IC fabrication. The need for thin active layers (0.1 to 0.25 μm) with good electrical properties (for example, high electron mobility, freedom from interface traps, and so on) on semi-insulating substrates need not be overemphasized for realizing operating ICs.

A process schedule developed for the fabrication of GaAs ICs is illustrated in Fig. 2. The starting wafers for IC processing have a thin (0.4- to 0.6-μm) active layer, with from 0.8 to 1.0×10^{1} cm^{-3} carrier density on the semi-insulating substrates. The active *n*-layers are produced by epitaxial growth or ion-implantation and annealing. The majority of the wafers processed in our program were epitaxially grown, although several ion-implanted wafers were also processed recently. There are eight critical steps in GaAs IC fabrication and these are briefly discussed below.

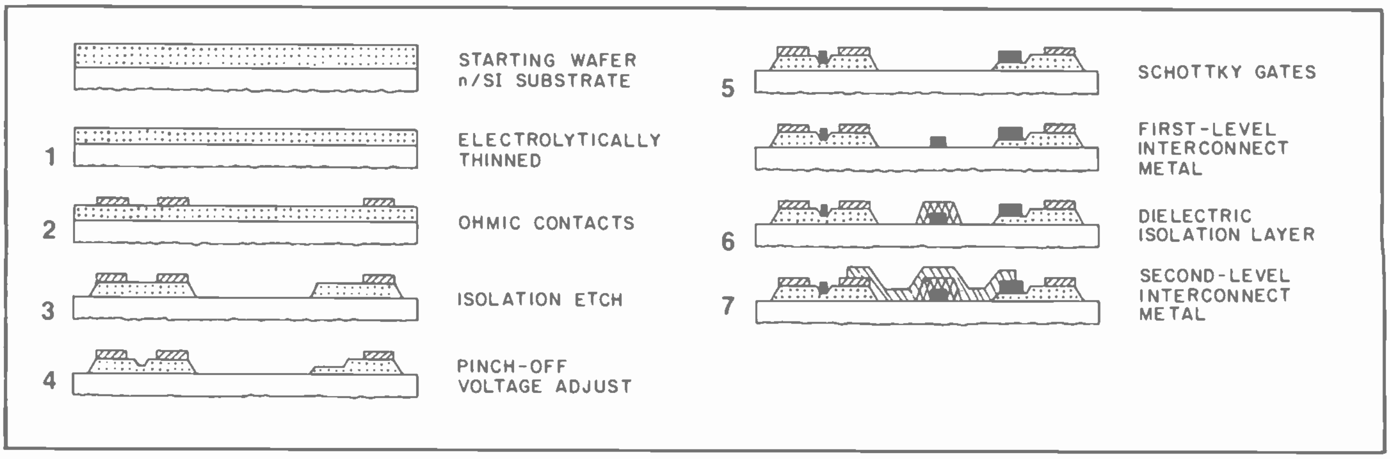


Fig. 2. Process schedule for IC fabrication. It takes seven masking steps to complete the IC.

1. *Electrolytic Thinning*. Unacceptable variations in doping density and thickness can exist in "as-received" wafers. These wafers are, therefore, electrolytically thinned by anodic oxidation and oxide stripping.[3] This is a self-limiting process that stops when the active-layer thickness reaches the maximum breakdown thickness corresponding to the local doping density in any region. Thus, a uniform doping-density-thickness product (*nt*) across the wafer is realized. In the range of doping densities of interest (8×10^{16} to 1.0×10^{17} cm^{-3}), the variation in *nt* of electrolytically thinned wafers is less than 10 percent.

2. *Ohmic Contacts*. We are using the Au:Ge/Ni/Au system to make ohmic contacts onto the *n*-layers. These metals are sequentially evaporated onto the wafer. Metal lift-off or the ion-etching technique was used to delineate ohmic contact regions. The metals are then sintered at 420 to 450°C for one minute to obtain good ohmic contacts. The specific contact resistance is typically 2×10^{-5} to 2×10^{-6} ohm cm^2. For the 10-μm by 10-μm contacts on the IC, the ion-etching process yielded much smoother surfaces than metal lift-off.

3. *Device Isolation*. Device isolation is achieved by mesa etching. Due to a low power-dissipation requirement, the smallest width of the MESFET used is 7.5 μm. Chemical etching techniques are not suitable for defining such small devices. Therefore, ion etching is used for mesa isolation. The etch rate for GaAs is about 600 Å/min. The end point of the etching is determined by measuring either the surface breakdown or the mesa-to-mesa breakdown.

4. *Pinch-Off Voltage Adjustment*. The *nt* product realized using this technique is about 4×10^{12} cm^{-2} in the desired range of carrier concentration. This results in a channel pinch-off voltage of 10 to 18 V, which is too high. We have developed a procedure to monitor the open-channel current in test devices on the wafer and selectively etch the channel until the final current is a specific fraction of the open-channel current. This procedure makes possible the adjustment of the pinch-off voltage for logic-array FETs to between 1.5 and 2.5 V and for comparator FETs in the A/D circuit to between 5 and 6 V.

5. *Schottky Barriers*. Schottky barriers are used in both FET gates and level-shifting diodes. We are using either Ti/Pt/Au or Ti/Pd/Au metallization for Schottky barriers. For FETs, we are using

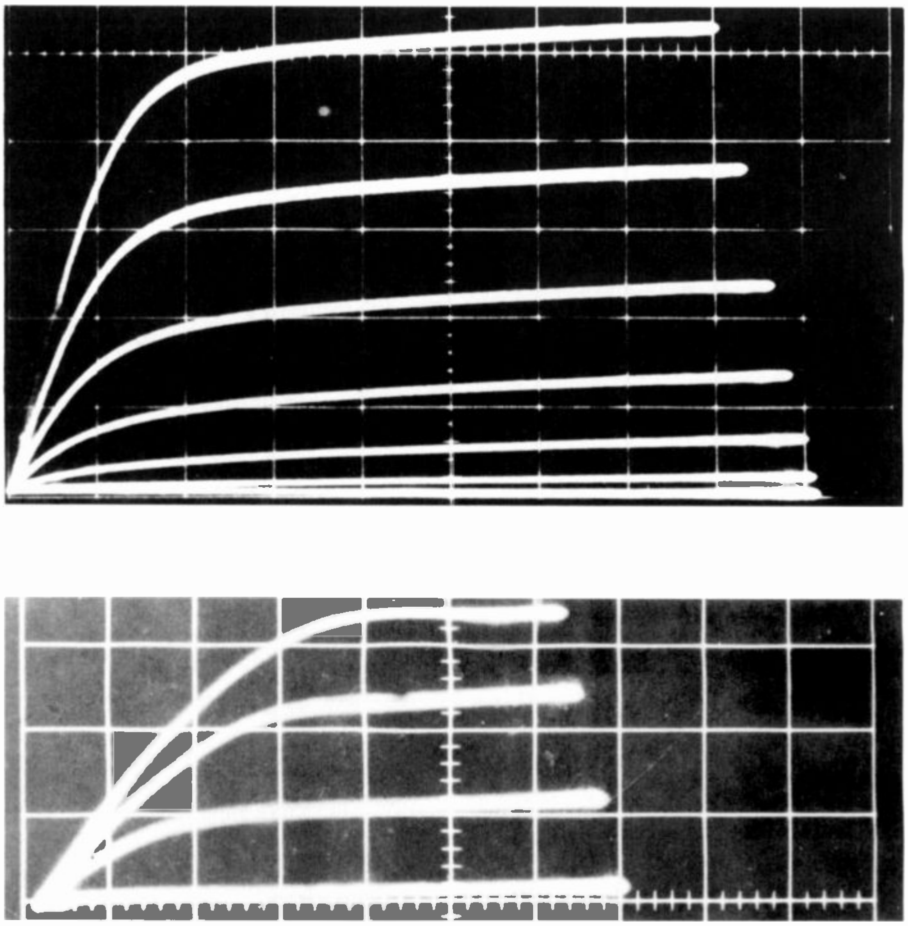


Fig. 3. Current-Voltage characteristics of test FETs. The plots show: **(a)** recessed gate device; **(b)** uniform channel device. Vertical is 0.2 mA/div.; and horizontal is 0.5 V/div.; 0.5 V/step.

a recessed-gate structure. This reduces the channel resistance between the source-gate and gate-drain regions. Also, this geometry decreases the high electric field in the gate-drain region. The gate regions are defined by means of optical photolithographic techniques. While monitoring the FET channel currents, the gate regions are etched by means of a touch-up chemical etch. For the level-shifting diodes, the regions under the Schottky contacts may or may not be recessed. Ti/Pt/Au is evaporated with an electron-gun system. Direct lift-off using photoresist is employed to define Schottky-barrier gates. To ensure the continuity of metal across the mesa edges, a total metal thickness of 3000 to 4000 Å was used.

The *I-V* characteristics measured on discrete test FETs are shown in Fig. 3. The current-saturation voltage (V_{DSAT}) is about 1.2 V for the recessed-gate structure and 2.0 V for the planar structure.

6. *Dielectric-Isolation Layers*. Two-level metal interconnections are required for GaAs ICs. Dielectric layers are used for isolation in defining the crossovers. In the early program phase, we used plasma-deposited Si_3N_4 as the isolation layer. The composition of the Si_3N_4 varied from run to run, and thus the etch rates were different. This variance resulted in severe undercutting of the isolation islands, making it difficult to define small Si_3N_4 islands for crossovers. The step coverage of the Si_3N_4 on mesa edges was poor. It appears that this is an inherent problem, and silicon oxynitride must be used to obtain better step coverage. Therefore, we investigated polyimide as an alternative. Dupont PI-2555 polyimide with 3 : 1 dilution by weight in pyrrolydinone was found to be excellent for isolation layers on GaAs ICs. This polyimide requires low-temperature curing (~200°C) and can be patterned by either oxygen plasma or chemical etching. Both these processes are compatible with our GaAs IC-fabrication process. The smallest isolation islands defined in this program are of the order of 7.5 μm by 10.0 μm.

7. *Interconnections*. Two-level metal interconnections are required to complete the GaAs ICs. In order to carry the desired currents, particularly in the bias lines, a metal thickness of about 0.7 to 1.0 μm should be used. The minimum width of the interconnect (signal) lines is 3 μm. Defining thick interconnect metal lines using contact printing and lift-off was difficult. Procedures were developed using a 1.5- to 1.7-μm-thick photoresist and chlorobenzene soak for defining the interconnect pattern. Ti/Pd/Au or Ti/Pt/Au metal systems are used for interconnections.

Figure 4 shows a typical two-level interconnect pattern with a polyimide isolation. The first-level metal line is about 3.0 μm wide.

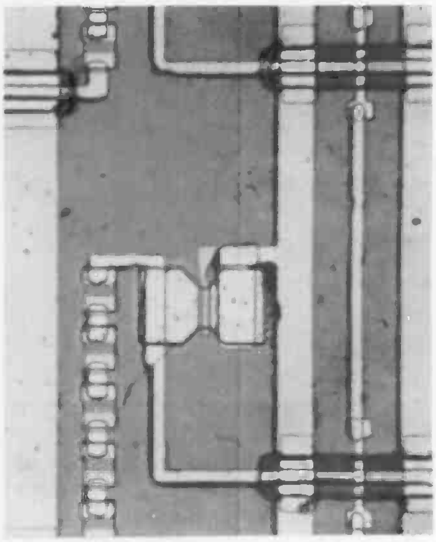
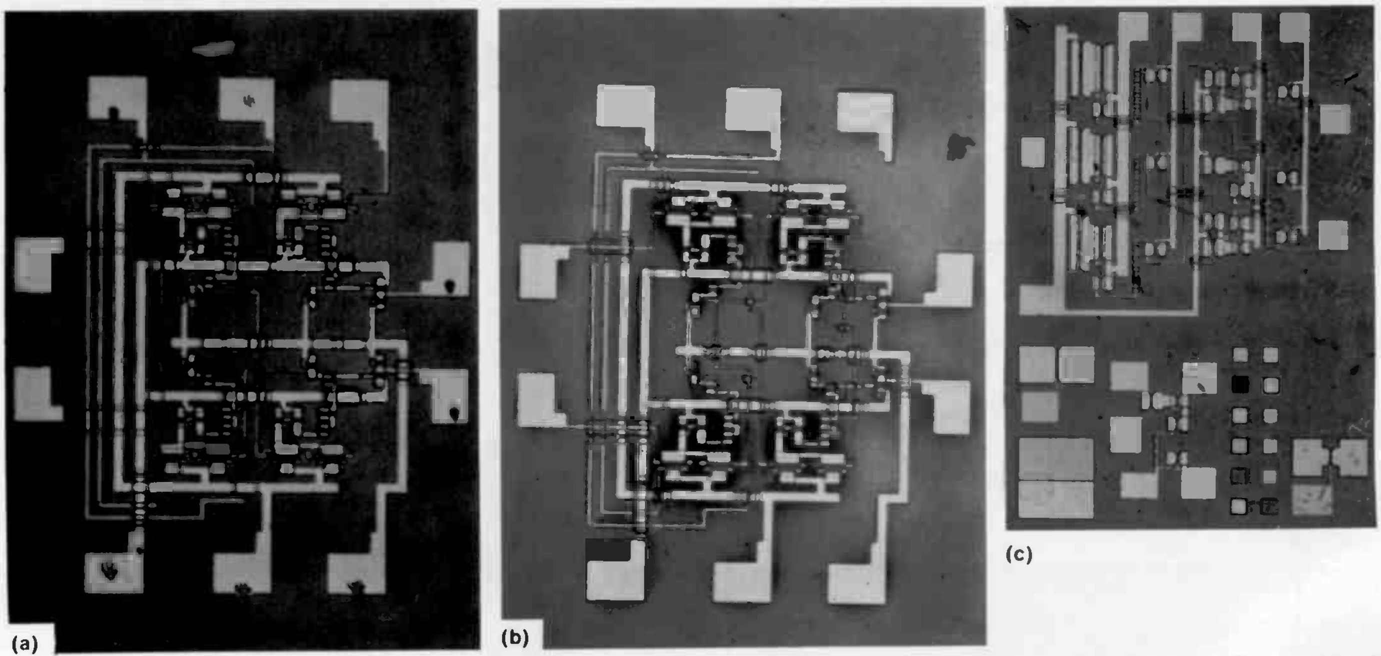


Fig. 4. Photomicrograph of a two-level interconnect pattern. Polyimide dielectric layer used for isolating the crossovers. The width of the smallest line is 3.0 μm. Polyimide islands as small as 7.5 to 10 μm were used.

8. *GaAs Integrated Circuits*. We have fabricated three types of ICs: ring oscillators; type-D or R-S master/slave flip-flops; and 2-bit analog-to-digital converters. Figure 5 shows photomicrographs of the three types of GaAs ICs fabricated. The chip size is 0.65 mm by 0.450 mm for the logic arrays and 1.3 mm by 1.0 mm for the A/D converter. 1.0-μm gate-length FETs are used in the A/D IC and 1.5-μm gate-length dual-gate FETs are used in the ring oscillator and type-D flip-flop ICs. The width of the smallest (constant current load) FET is 7.5 μm.



(a)

(b)

(c)

Fig. 5. Photomicrographs of GaAs ICs. (a) Ring oscillator—fan-in = 2, fan-out = 2; **(b)** D-type master/slave flip-flop; and **(c)** 2-bit A/D converter. The 1.0-μm gate-length devices are used in A/D and the 1.5-μm gate-length devices are used in ring oscillators and flip-flops.

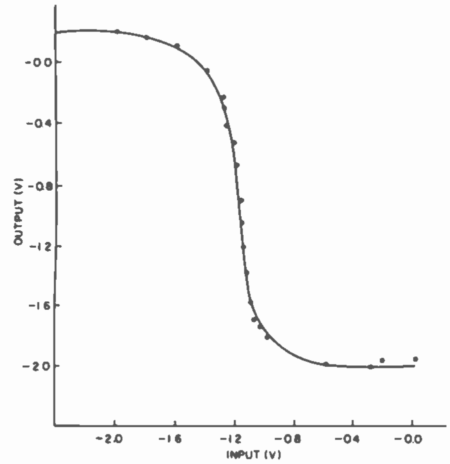


Fig. 6. DC-transfer characteristics of an inverter. The noise margins for both LOW and HIGH are about 1.0 V.

Experimental results

Inverters. Test inverters fabricated on the IC's were evaluated up to 950 MHz. Figure 6 is a typical dc-transfer characteristic of an inverter. The noise margins for logic LOW and HIGH are approximately 0.5 to 1.0 V. The response of the inverter for a 950-MHz sinewave input is shown in Fig. 7.

Ring Oscillators. Ring-oscillator circuits are used to determine the propagation delay and dc dissipation per logic gate. Many of the results reported in the literature are for a fan-out of one. In practical circuits, a fan-out of two or more is desired. We, therefore, used a ring-oscillator circuit with a fan-in of two and a fan-out of two in our experiments. The ring-oscillator output frequency was measured on a spectrum analyzer and also identified by use of a frequency meter. Propagation delays between 170 and 210 ps were obtained from these measurements, and the corresponding power dissipation was 7.0 to 9.5 mW. The delay-dissipation product is 1.4 to 1.6 pJ. It is important to note that 1.5-μm gate-length FETs were used in these circuits and also that the second gates of the dual-gate MESFETs were connected to form the ring. These results are plotted on the propagation-delay and power-dissipation chart shown in Fig. 8. Our results (marked with an asterisk) are in good agreement with published data on GaAs (TTL or BFL) circuits. Based on these results, we can confidently project a 100- to 120-ps delay when 1.0-μm gate-length devices are used.

R-S Flip-Flops. These flip-flops have been externally connected as divide-by-two or divide-by-four circuits. The input-output waveforms of these divide circuits are shown in Fig. 9. The divide-by-four circuit operated satisfactorily up to an input frequency of 280 MHz. The parasitics due to the bonding pads and output measuring probe were limiting the performance. We are trying to improve our probe system to facilitate measurements into the GHz region.

A/D Converters. The two-bit A/D converter was tested with input pulses as small as 0.5- to 0.8-ns wide. Such an input pulse corresponds to the sample-and-hold pulse which the comparators see. The response of the A/D (that is, comparators and coding logic) to a pulse input is shown in Fig. 10. The IC works satisfactorily at a 1.0-GHz sampling rate. However, the resolution of this type of A/D is limited to 3 or 4 bits.

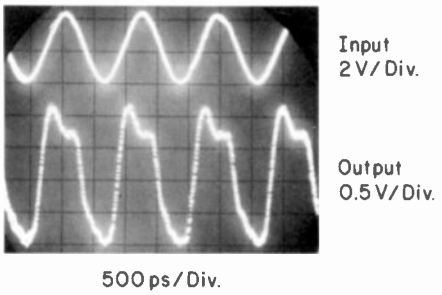


Fig. 7. Response of an inverter to a 950-MHz sinewave input signal. Sharpening of the rise and fall times can be seen in the output pulse.

Conclusions

GaAs MSI technology has been developed. Several types of IC's were fabricated and evaluated. The potential of GaAs-based integrated circuits for multigigabit-rate

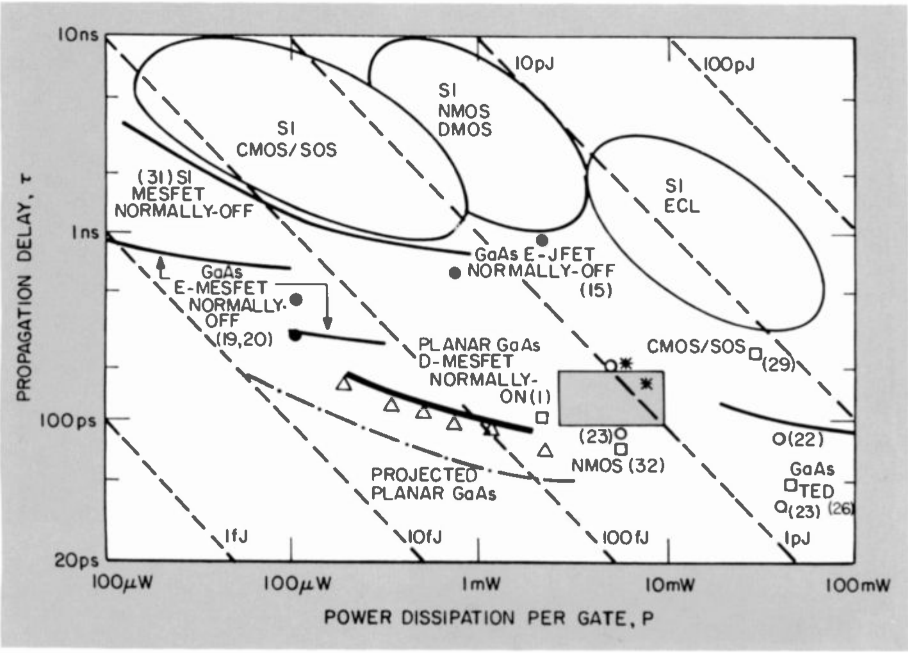


Fig. 8. Speed-power performance chart for various IC technologies. Published data on GaAs BFL devices are shown by the box. Our experimental results are shown by an asterisk.

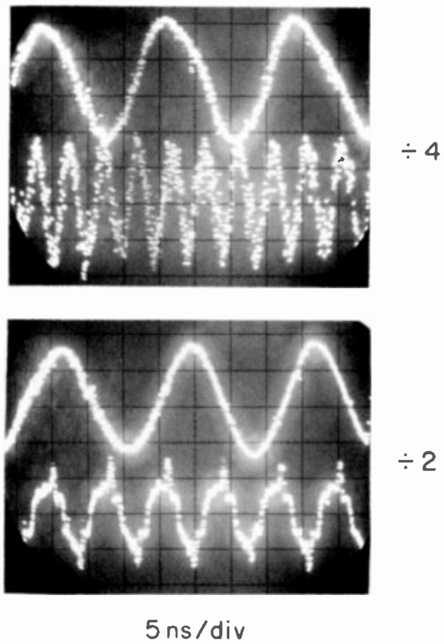


Fig. 9. Performance of divide-by-two and divide-by-four circuits. D-flip-flops were externally interconnected to form divide circuits. Divide-by-four circuits operated at 280 MHz. Parasitics due to external bonding connections, and reflections at discontinuities in the probe station limited the test frequency range.

logic applications has been demonstrated. A viable, cost-effective MSI/LSI technology for system applications seems certainly feasible. For example, prescalers, pseudorandom code generators, programmable delay lines, and A/D converters operating at 1.0-GHz clock rates are a few of the MSI circuits that can be implemented with our present technology.

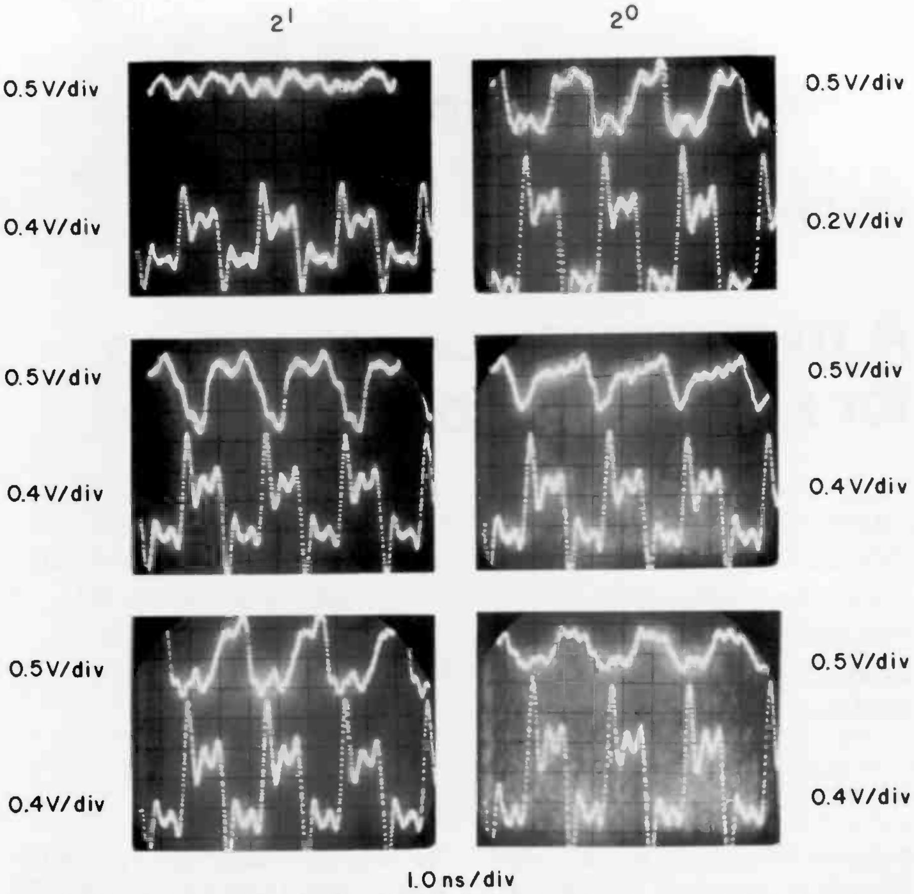


Fig. 10. Performance of the 2-bit A/D converter. The input signal amplitude is varied to demonstrate the thresholding of the first, second, and third comparator. The 2-bit binary-coded output corresponds to the analog input signal. This A/D was tested with an input signal of 0.5- to 0.8-ns width.

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Authors (left to right) Upadhyayula, Matarese, and Smith.

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Mr. Matarese has been granted one patent and another is pending. He has also been author and coauthor of several papers.

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on the job/off the job

J.W. Safian

A microprocessor application for amateur radio

Learning how microprocessors work is one challenge. Practical application of the theory is another. This author chose to consolidate his newly acquired knowledge by designing a microprocessor system for his ham radio operation that transmits Morse code uniformly and accurately.

I became interested in amateur radio through an electronics shop teacher while attending high school. I remember listening in fascination to the "dits" and "dahs" coming from the school-owned receiver. Amateur radio is still appealing because it offers hands-on experiences in designing and troubleshooting electronic equipment and provides the means to communicate directly with those who share similar interests.

I recently took a course in microprocessors to help me understand and design computer equipment for use in manufacturing. In addition, I purchased a small development system to perform lab experiments. When the course was completed, I

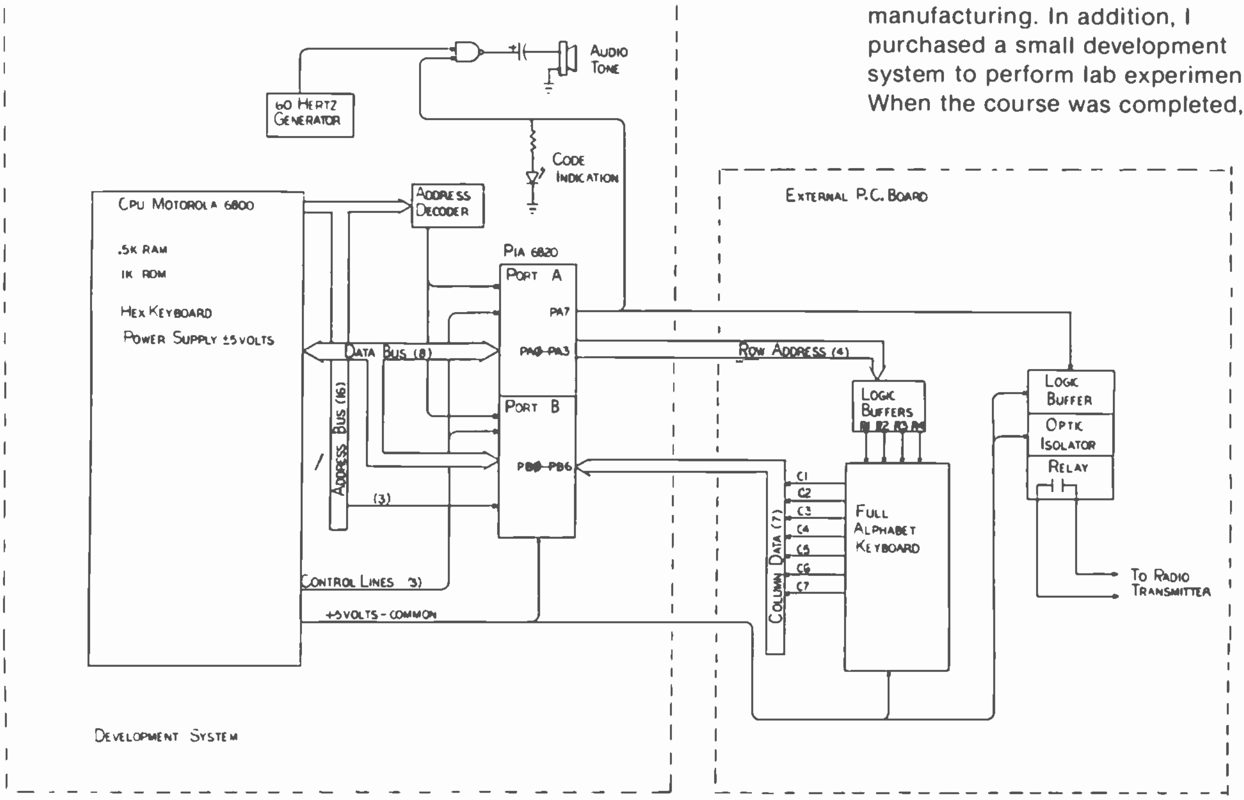

Fig. 1. This block diagram shows how the basic microprocessor system is interfaced to an external keyboard and driver circuit. Memory-mapped I/O is used in the development system.

Reprint RE-26-9-17
Final manuscript received Dec. 19, 1980

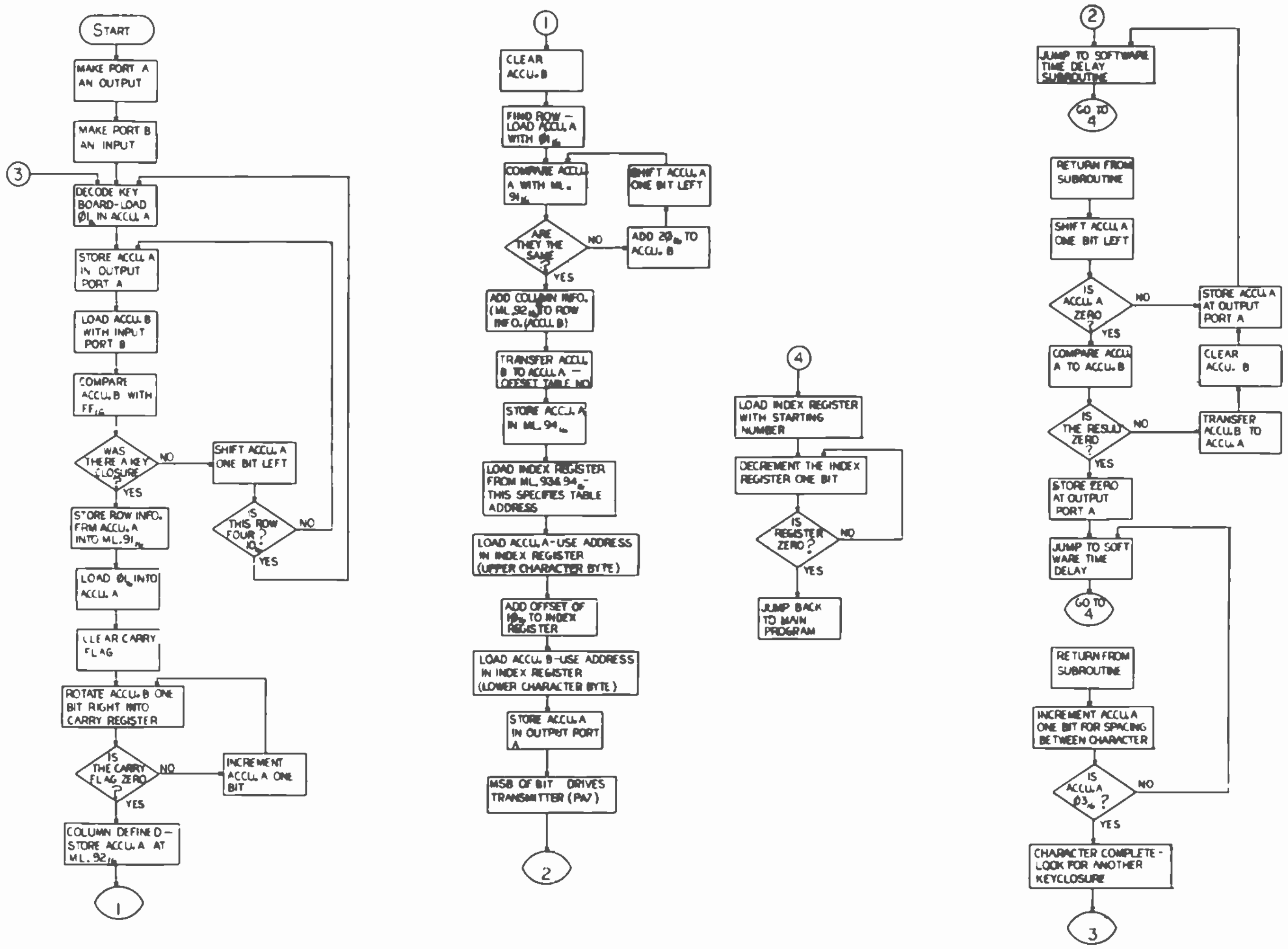

Fig. 2. Software flow diagram. The first and second column shows how a key closure is decoded and masked. Finding a closure, the row and masked bytes are software manipulated so that an address is formed which points to a memory location, which specifies the character information. The third column is a software time delay that controls the speed of the bit transmission. The final column shows how the character bytes are used to key the transmitter by shifting the information between accumulators A and B, and Port A.

faced the problem of how to utilize the equipment. Having both a technical background and interest in amateur radio, it seemed natural to incorporate the microprocessor into a design which could be used with my ham gear.

Several applications became apparent, but the most interesting and least costly to me was the idea of transmitting international Morse code using a microprocessor. In this way, code would be sent uniformly and more accurately. The task of transmitting a character would be accomplished by interfacing a typewriter keyboard to the input of the microprocessor. When the radio operator depressed any letter on the keyboard, the Morse-code equivalent output from the microprocessor would key the radio transmitter.

System development and description

I divided the design into several phases in order to develop the software and the keyboard interfacing in gradual steps. The interfacing of the output to the transmitter was left for the final phase. The design progressed from a system that had a 2 x 2 keyboard matrix to the present system that has a 4 x 7 keyboard. This task took four main revisions. The main program uses 126 words of memory while the alphabet lookup table uses 52 words of memory. Figure 1 is a block diagram of the present system. Note that an audio tone and a visual indicator allow the dits and dahs to be both heard and seen when a character is keyed.

To understand the software-hardware interrelationship, refer to Fig. 2, which is the software flow diagram, and to Fig. 3, which is the hardware interface diagram. To begin, the PIA 6820 must be software initialized. The program makes Port A an output and Port B an input. The first portion of the program is dedicated to decoding the keyboard. A "01" is stored at Port A. This takes row one to a low state. If there is a key closure, one of the bits at Port B will go from a high to a low state. The program will detect the transition and branch from the decoding portion of the program.

If no closure is detected, a "02" is stored in Port A. This takes row two to a low state. The same process takes place as in row one and continues until all four rows have been tested. If there is no key closure after the fourth row is

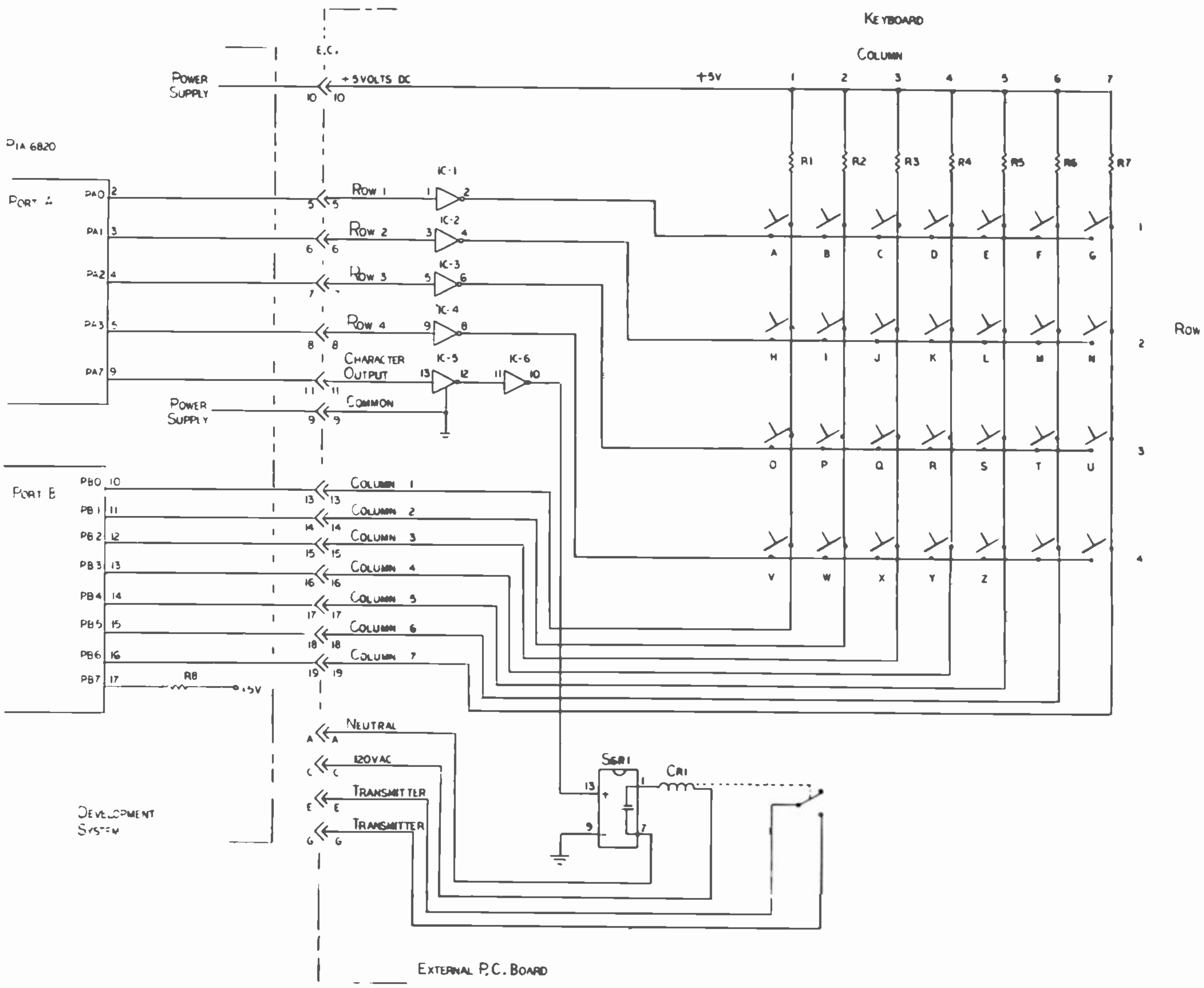

Fig. 3. This schematic diagram shows the hardware interconnections between the PIA 6820 and the 4 x 7 keyboard. One 7404 hex buffer, a solid state relay, a control relay, and 28 single-pull-single-throw push buttons were used.

tested, row one is taken low again. This process is repeated until a key closure is found. When that happens, the row number, which was in Port A, is stored at memory location 91 for future use.

The task of the next portion of the program is to retrieve the proper digital information from the table in memory that corresponds to the key that was depressed. This retrieval task is accomplished by taking the number in accumulator B which specified the column that was selected and rotating the accumulator to the right until a low level is found. Every time the byte is rotated once, accumulator A is incremented by one. When zero is found, the number in accumulator A is stored in memory location 92. Accumulator B is cleared, and the row information which was stored in memory location 91 is compared to accumulator A. Accumulator B will be incremented by 20 until both the memory location and accumulator A numbers are the same. When this occurs, accumulator B and memory location 92 are added together. This forms an offset address from which the full address will be created. The offset address is stored at memory location 94.

The next step is to load the index register from memory locations 93 and 94. These locations together will point to the character address in the table. The upper byte of the selected character is loaded into accumulator A using the address in the index register. The character's lower byte is loaded into accumulator B by adding "10" to the index register and using that address as the memory address for that byte.

The purpose of the final portion of the program is to take the character information which resides in accumulators A and B and shift it to Port A. The upper byte is loaded into Port A from accumulator A. Immediately the most significant bit appears at PA7. Figure 3 shows how this bit drives the transmitter through SSR1 and CR1. A software time delay subroutine is used to control the time duration that the bit appears at the output line PA7. This effectively controls the speed of bit transmission. When the delay ends, the byte in accumulator A is shifted one bit, and stored at Port A. The next bit appears at PA7.

This process continues until all bits are shifted out of accumulator A and loaded into Port A. Immediately after accumulator A is zero, the lower byte is transferred to accumulator A and accumulator B is set to zero. The lower byte is loaded into Port A. The previously mentioned process is repeated until all bits are shifted out of accumulator A. When both accumulators contain zeros, then the character has been transmitted, and after a time delay at the end of the character, the program jumps back to scan the keyboard for another key closure.

Summary

This system has been used on the air with very good results. Fellow hams comment most frequently on code uniformity. At present, only letters can be sent with the existing keyboard. To make the system more flexible, there are several improvements which are recommended:

1. Add a thumb-wheel switch so that the transmission speed can be varied externally.
2. Develop a larger keyboard to include the alphabet, several punctuation marks, and numbers.

In this application, a Motorola 6800 was used although other microcomputers could be utilized. The additional cost of the hardware was sixty dollars. The development system's cost was under two hundred dollars.

Readers interested in this accessory can get detailed schematics, program listings, and wiring diagrams from the author.

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Design Advances in a Very Portable Color Camera—IEEE, Washington, D.C. (9/17/81)

M.R. Johns (retired)|M.A. Ralston
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Laboratories

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Missile and Surface Radar

F.J. Buckley

Software Quality Assurance—Lecturer, ASQC Energy System Division Annual Conference, Phoenix, Ariz. (/22/81)

F.J. Buckley

Software QA Standard—A Status Report—IEEE Software Engineering Standards Applications Workshop, San Francisco, Calif., *Proceedings* (9/81)

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IEEE Software Quality Assurance Seminar, Instructor, Dallas, Texas (9/14/81)

W.T. Patton

Phased Array Alignment with Planar Near-Field Scanning or Determining Element Excitation from Planar Near-Field Data—1981 Symposium on Antenna Applications, Univ. of Illinois, published in the Symposium *Digest* (9/23-25/81)

T.M. Shelton

Testing of Properties for Soldered Leadless Chip Carrier Assemblies—*IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, Vol. CHMT-4, No. 2 (6/81)

S.A. Steele|W.J. Paterson

Ada Implementation on the Nebula ISA: Ada/Nebula Compatibility—1981 EIA Data and Configuration Management Workshop, Orlando, Fla. (9/21-25/81)

S.A. Steele

Software/Firmware Productivity Quality and Standards—IEEE Software Engineering Standards Application Workshop, San Francisco, Calif. (8/19/81)

Solid State Division

A. Blicher (retired)

Field-Effect and Bipolar Power Transistor Physics (Book)—Academic Press (6/81)

Engineering News and Highlights

Joseph T. Threston to head Naval Systems Department

Joseph T. Threston has been appointed Division Vice-President of the Naval Systems Department of RCA's Missile and Surface Radar business unit.

Mr. Threston, appointed by Division Vice-President and General Manager, **William V. Goodwin,** succeeds **Lawrence J. Schipper,** who was promoted to head RCA's Government Communications Systems unit.

Mr. Threston is responsible for the management, development, integration, and test of the U.S. Navy's AEGIS Ship Combat System and for the definition phase of the new Guided Missile Destroyer project, as well as other government programs. His department also is responsible for developing and producing the AEGIS Weapon System, the core of the Combat System.

Since 1979, Mr. Threston had been Manager of System Engineering and Test for the AEGIS Weapon System. Between 1959, when he joined RCA, and 1968, Mr. Threston participated in or directed system studies for ballistic missile defense, shipboard instrumentation radar, test-range instrumentation, and land/sea-based anti-air warfare systems.

Since 1968, Mr. Threston has held several management positions within the AEGIS program, primarily in system engineering.

Mr. Threston graduated from Villanova University in 1957 with a bachelor's degree in mechanical engineering. In 1959, he received a master's degree in mechanical engineering from the University of Southern California.

Before coming to RCA, Mr. Threston worked for Hughes Aircraft and participated in the development of the Falcon missile.

Staff Announcements

Thornton F. Bradshaw, Chairman of the Board and Chief Executive Officer, announces that **Herbert S. Schlosser,** Executive Vice-President, in addition to his current responsibilities for "SelectaVision" VideoDiscs, will assume responsibility for the RCA Records Division.

Mr. Schlosser will continue as President, RCA International Audio-Visuals, Inc., the RCA subsidiary company involved with the Columbia Pictures joint venture, and as President, RCA Cable, Inc., the RCA subsidiary company involved with the RCTV joint venture.

Consumer Electronics Division

Larry A. Cochran, Director, Signal Systems and Components, announces his organization as follows: **Roger W. Fitch,** Manager, Component Engineering; **Jack S. Fuhrer,** Manager, Signal Processing; **Ronald R. Norley,** Manager, Taiwan Coordination and Competitive Analysis; and **Robert P. Parker,** Manager, Television Tuning Systems.

James A. McDonald, Director, Display Systems Engineering, announces the appointment of **David E. Laux** as Manager, Advanced Yoke Development.

Robert P. Parker, Manager, Television Tuning Systems, announces his organization as follows: **David J. Carlson,** Manager, RF Processing.

Globcom

Joe T. Swaim, Vice-President, Engineering, announces his organization as follows: **John P. Shields,** Manager, System Planning; **Alexander Avanessians,** Manager, Customer Engineering; **Leo A. Tita,** Manager, Engineering Administration; **Solomon J. Nahum,** Manager, Construction and Installation; **Richard H. Roth,** Director, Computer Programs (KCC); **Anthony J. Falco,** Manager, Central Office Engineering; and **Joel A. Spanier,** Administrator, Project Control.

Laboratories

Arthur Kaiman, Director, Advanced Systems Research Laboratory, announces the appointment of **Ted N. Altman** as Head, Microsystems Research Group.

Fred Sterzer, Director, Microwave Technology Center, RCA Laboratories, announces the appointment of **Barry S. Perlman** as Manager, Computer-aided Design and Testing.

Picture Tube Division

Carmen A. Catanese, Director, Picture Tube Systems Research Laboratory, announces the appointment of **David L. Staebler** as Head, Kinescope Systems Research Group.

Solid State Division

Heshmat Khajezadeh, Director, Bipolar and MOS Logic IC Operations, announces his organization as follows: **Stephen C. Ahrens,** Manager, Product Engineering Bipolar and MOS Logic; **Richard E. Davey,** Manager, Manufacturing, Findlay; **James L. Dunkley,** Manager, Engineering Bipolar and MOS Logic; **John R. Kowalak,** Administrator, Bipolar and MOS Logic; and **Arthur M. Liebschutz,** Manager, Product Marketing Bipolar and MOS Logic.

Joseph J. Fabula, Manager, Production Engineering, Solid State Technology Center, announces the appointment of **Charles D. Mulford** as Manager, Equipment and Facilities, Solid State Technology Center

Donald J. Ransom, Manager, Product Safety, Quality & Reliability, announces the appointment of **Jorge Davin** as Manager, Tube Processing — Quality and Reliability Assurance.

Professional activities

Automated Systems Engineers Head Chapter Activities

Automated Systems is well represented in the Boston Section of the IEEE. For the 1981/1982 operational year, **Norm Laschever** is Vice-Chairman and **Roger Plaisted** is the IEEE Chairman of the Education Chapter. **Jack Anderson** is the IEEE Membership Coordinator for Automated Systems.

Blicher writes about power transistors

Adolph Blicher, formerly with the Solid State Technology Center, has published *Field-Effect and Bipolar Power Transistor Physics.* The retiree's book, from Academic Press, is available from the author and through bookstores. The book covers: general considerations, bipolar power transistors, and field-effect power transistors. It assumes a general knowledge of small signal transistor operation theory and partial differential equations.

RCA scientist receives international award

Dalton H. Pritchard, Fellow of Technical Staff, RCA Laboratories, has been honored by the Edward Rhein Foundation of West Germany for his contributions to improved television picture sharpness and quality.

Mr. Pritchard was the only American among the nine co-receipients of the Rhein Prize 1980 — the most prestigious and richly endowed award for research in the consumer audio-visual field.

He was honored for numerous contributions in the field of video techniques and particularly as a leader in the RCA development of the Dynamic Detail Processor incorporated in RCA ColorTrak TV receivers. The device employs a charge-coupled device (CCD) in an advanced integrated circuit. The RCA processor, through optimization of horizontal and vertical sharpness, produces a clear and sharp picture free of dot crawl and cross color associated with conventional color receivers. See page 49 in this issue for CCD IC applications in the RCA VideoDisc System.

Most of Mr. Pritchard's 35-year career with RCA has been devoted to research in color television systems and devices. He has received nine RCA Laboratories Outstanding Achievement Awards for his research in television and related areas. This work included the planning and testing of systems and circuits proposed for adoption by the National Television System Committee (NTSC). The author of numerous technical papers, he has been granted 36 U.S. Patents, with several others pending. In 1975, Mr. Pritchard was appointed a Fellow of the Technical Staff of RCA Laboratories.

In 1977, he received the Vladimir Zworykin Award of the Institute of Electrical and Electronics Engineers for "significant contributions to color television technology." Recently, he was a member of a team receiving RCA's highest technical honor, the David Sarnoff Award for Outstanding Technical Achievement, for "the development and implementation of a CCD comb filter integrated circuit in color TV receivers."

Symposium on VLSI

Walter F. Kosonocky was the Chairman and **Maureen Czarnecki** the Symposium Administrator of the 1981 Symposium on VLSI Technology sponsored by the IEEE Electron Devices Society and the Japan Society of Applied Physics. The Symposium was held on September 9 to 11, 1981 at Maui Surf, Maui, Hawaii. Kosonocky is Fellow of Technical Staff, IC Technology Research; and Czarnecki is Senior Secretary, RCA Laboratories. The Symposium participants included 147 from the United States, 65 from Japan, and 3 from Europe.

Dr. Hillier honored

James Hillier, retired Executive Vice-President and Chief Scientist of RCA, was honored at an official reception by the Brant Historical Society and the Brant County Museum, Brantford, Ontario, on September 19, 1981.

The reception marked the opening of a new display entitled "Smaller than a Grain of Sand: The History and Development of the Electron Microscope." The central item on display is an early production model of an RCA electron microscope donated to the Museum by the University of Toronto's Department of Physics.

Dr. Hillier is best known for his contributions to the development of the electron microscope. He was elected to the Inventors Hall of Fame in 1980 for this development.

RCA NASCOM engineer honored

Ed Mellen, a senior member of RCA Service Company's NASCOM engineering team, headquartered in Riverdale, Maryland, was honored on September 2 by the Washington Telecommunications Society for his contributions during the past 40 years to the development of the nation's telecommunications industry. Among his many achievements were design and development of automatic and semiautomatic teletypewriter switching systems and a 10-year plan for U.S. Air Force communications. During his initial association with RCA, which spanned the 1950s, he developed the specifications for network transport of operating signals from neutral to polar for the Airways and Air Communications Service and wrote the military exhibit for the worldwide Quick Fix program. He was a consulting engineer prior to joining RCA's NASCOM project in 1973. Since joining RCA's NASCOM organization, Mr. Mellen has devoted his efforts to updating NASA's global communications capabilities. He conducted a study of expansion capabilities applied to network switching and has prepared a user's guide for the tracking and data-relay satellite ground system, which is due to become operational in 1982.

Automated Systems Professional Recognition dinner

On June 25, 1981, Automated Systems held the fourteenth annual Professional Recognition dinner at Anthony's Pier 4 Restaurant, Boston, Massachusetts to honor their people for achievements in professional activities. These achievements include papers published and presented, patents awarded, and Engineering Excellence Awards. The people honored have exemplified the outstanding individual efforts required to continue successful operations in Burlington. **William C. Hittinger,** Executive Vice-President, presented to **Dr. Harry Woll,** RCA Staff Vice-President and Chief Engineer, his twentieth patent award for "Patching Tape for Diffractive Subtractive Filter Viewgraphs."

Globcom engineer publishes book

Data Transmission Analysis, Design, Applications, a McGraw-Hill book co-authored by **Dogan A. Tugal,** Principal Member, Engineering Staff, RCA Global Communications, is available from the author and at bookstores nationwide. Together with Osman Tugal, a Staff Engineer at GTE Satellite Corporation, the RCA engineer aims at concisely, yet thoroughly, explaining data communications for engineers, managers, and others in data communications.

Edelman wins author prize

"Managers, Computer Systems, and Productivity," an article written by **Franz Edelman** and published in the September 1981 *MIS Quarterly,* is the first-place-winning article chosen in the Society for Management Information Systems Award Paper competition.

Gary W. Dickson, Senior Editor of the *MIS Quarterly,* cites the article as one of few demonstrating the cost/benefit relationship of a systems application. He writes that "Edelman not only does this, but provides us with documentation of an application affecting large numbers of employees of a large corporation, RCA."

Before entering the consulting field and joining Index System, Inc., Dr. Edelman spent over thirty years at RCA Corporation, where he rose to the position of corporate staff vice-president for business systems and analysis, with responsibilities for company-wide computer applications and business analysis. Dr. Edelman retired from RCA in 1977.

Professional society activities from RCA Laboratories

Douglas F. Dixon is IEEE Chairman, and **Rebecca T. Mercuri** is Treasurer of the Princeton Chapter of the ACM/IEEE Computer Society.

Ronald E. Enstrom, Display Processing and Manufacturing Research Laboratory, has been elected to a two-year term as Chairman of the Electronics Division of the Electrochemical Society. The 2500-member Electronics Division sponsors Spring and Fall symposia on the growth, processing, technology and science of silicon and other materials for electronic device applications.

Thomas T. Hitch received the Technical Achievement Award of the International Society for Hybrid Microelectronics, "for his studies of the relationship between phase morphology and conduction and adhesion mechanisms of thin and thick films on ceramic and porcelain-enameled-steel substrates." The Award is given in recognition of technical contributions that have been made to the hybrid microelectronics industry.

K.W. Hang, A.N. Prabhu, and **A. Sussman** were Principal Investigators and **L.S. Onyshkevyck** was Project Leader on work reported in their award-winning article, "RCA Porcelain Coated Steel Substrate and Compatible Thick Film Ink Systems for Electronic Applications." The "Award of Excellence" for this entry in the 1981 Top Twenty awards competition was presented by the editors of *Materials Engineering.*

Dorothy M. Hoffman has been appointed to a 3-year term on the Committee for Public Policy, an advisory committee of the American Institute of Physics.

Frederick J. Tams, III, is the publicity chairman of the Delaware Valley Chapter of the American Vacuum Society.

Joseph Zelez is the chairman of the Delaware Valley Chapter of the Optical Society of America and vice-chairman of the Delaware Valley Chapter of American Vacuum Society.

John L. Vossen has been elected to a 3-year term on the Governing Board of the American Institute of Physics

technical excellence

Technical Excellence Committee formed at "SelectaVision" VideoDisc Operations

First members of "SelectaVision" VideoDisc Operations' Technical Excellence Committee, seated (left to right): Nelson Crooks, Jim D'Arcy, John Amery, Ned Kiser, Ron Tilford, and Mary Voelker (who is filling the unexpired term of Barry Stevens). Standing (left to right): Tom Strauss, Charlie Weaver, Mike Mindel, Waldo Feldmeyer, John Kowalchik, Dick Castle, and Dick Marks.

In December, 1980, a Technical Excellence Committee was chartered at "SelectaVision" VideoDisc Operations to further technical and professional growth at "SelectaVision" and to encourage and recognize outstanding technical performance among "SelectaVision" technical personnel.

Eleven members of the technical community (see photo) were appointed by their respective managers to serve on the committee for prescribed terms. Officers were elected (**Jim D'Arcy,** Chairman; **John Kowalchik,** Vice-Chairman; and **Charlie Weaver,** Secretary/Treasurer) for eight-month terms. Then the committee, commencing operations on January 1, 1981, began to formulate plans for its various activities. On January 19, 1981, a Technical Excellence Kick-Off Dinner was held at a nearby restaurant for the technical community; **Mr. William C. Hittinger,** RCA Executive Vice-President, was the keynote speaker, and **Dr. Jay J. Brandinger,** who had initiated formation of the committee, reiterated his enthusiastic support of the committee's purpose.

On April 13, the first Technical lecture (VideoDisc Systems by **J. Clemens,** RCA Labs) was presented. On June 23, the first technical excellence award was presented. Notice of the first two awards will appear in the next issue of the *RCA Engineer.* Since then, the technical lecture series has continued with lectures from within and outside VideoDisc; plans for the fall education series have been finalized; and the first of a series of dinner lectures is being finalized.

On August 24, with the first eight-month term nearing completion, the second election of officers was held. Those elected were: **John Kowalchik**, Chairman; **Ned Kiser**, Vice-Chairman; and **Waldo Feldmeyer**, Secretary/Treasurer. Currently, the other members of the committee are: **John Amery; John Bowen; Jim D'Arcy; Mike Mindel; Ron Tilford; Mary Voelker; Charlie Weaver; Don Wierschke; Dick Marks** (I.R. Liaison); and **Nelson Crooks** (Management Liaison).

Automated Systems announces Technical Excellence Awards

A team of engineers at Automated Systems received the Technical Excellence Team Award for their work on Wing Automation Graphics.

The significant achievement by this team of hardware and software engineers resulted in the successful development and demonstration of an automation of the flight-planning phase for a tactical mission. The team designed, assembled, integrated, and tested an intelligence subsystem that contained a microcomputer, two cathode-ray tubes and a color-graphics generator. In addition to the hardware, 8500 lines of source code were written integrated and tested. The team demonstrated a high degree of technical excellence by applying theoretical and practical understanding of Automated Data Processing and its integration with display hardware.

The team's enthusiasm and dedication to their tasks meant that all milestones were met on schedule, even though difficult problems had to be solved. The problems included:

- The ability to superimpose digital graphics over an analog presentation.
- The ability to access files automatically and perform computations without operator intervention.
- The ability to identify the manual tasks involved in mission planning, in order to implement the correct automated methods.

Automated Systems also recently announced a Technical Excellence Award given to **George E. Miller** for his Wake Homing Torpedo Study.


Mr. Armstrong receives his First Patent Plaque for work done on "Engine Fault Diagnosis."


Left to right: A. Hospidor, George Miller, and D.M. Priestley.


Left to right: M.E. Spencer, D.M. Priestley (Chief Engineer), M. McCuller, P.W. Westcott, D.F. Dion, A. Hospidor (Vice-President and General Manager), C.J. McLarney, and R.S. Fishman.

Mr. Miller is Senior Engineering Scientist. His contributions were commendable in both the writing of the winning proposal and the resulting study contract.

The contract ran a short eight months. Mr. Miller was the principal investigator, and in this brief period, he devised methodologies to explore and evaluate a wide range of concepts and technologies.

The evaluation measures ranged across the full spectrum of analyses, that is, probability of effectiveness, reliability, false alarm rates, system response time, and unit production costs. The study results are highly regarded by the Navy and a follow-on phase is being planned.

Mountaintop Technical Excellence Award

The Mountaintop Technical Excellence Award is designed to recognize and reward members of the technical community who have consistently exhibited qualities of initiative, leadership, technical competence, attitude, and follow-up. The Technical Excellence Committee has reviewed candidates at the request and recommendation of fellow technical staff members and is proud to announce that **Bill Hepp** and **Ken McDowell** are recipients of the Mountaintop Technical Excellence Award for September, 1981. The committee will honor these recipients at a luncheon and also at an annual dinner.


Hepp


McDowell

Second Quarter 1981 Consumer Electronics Technical Excellence Awards

Dr. D.J. Donahue, Division Vice-President, Operations, has notified the following people of their selection by the Technical Excellence Committee for receipt of Quarterly Awards:

Back row (left to right): W. Speer, B. Rooks, V. Rage, J. Lufkin, J. Keeth. Front row: H. Becker, J. Nicholson, S. Naimpally, S. Mehta, R. Lancaster, B. Gries, P. Filliman. Not pictured: L. Leonhardt.

Bobby Rooks. Leadership and essential contribution in controlling and solving the soldering problems in Juarez on the CTC107/108/110 chassis.

Voldemars Rage. The successful design and implementation of a new cost reduced concept of clamping ferrite cores for 110° yoke manufacture.

Sai Naimpally. Significant state-of-the-art advances in the practical application of computer-aided circuit design to television transient response.

John Nicholson. Development, documentation, and implementation of a "universal chassis" system employed on XL100 and ColorTrak I family (CTC107, 108, 110, 120).

Paul Filliman. Successful and innovative design and layout of an advanced integrated circuit for color TV application.

Walt Speer. The development of a new series of cable connectors to eliminate factory and field contact reliability problems by their ability to tolerate distorted pins.

Larry Leonhardt. Major picture tube socket design improvements, virtually eliminating separation of housing from terminals, deformed contacts and retention problems.

Jim Keeth/Bob Gries. Development and implementation of a high-speed spectrum analyzer for use with the VideoDisc ATE system.

John Lufkin. The design and implementation of a diagnostics system for ATE maintenance purposes.

Robert Lancaster. The upgrading of RCA's mechanical design evaluation procedures with a quantitative, computer-aided approach leading to improved quality and product reliability.

Shirish Mehta/Hollis Becker. Improvements in CE's approach to materials analysis, selection and process control. Of particular significance is the solution of a serious dial drive reliability problem.

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How to use this index

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**A technical journal published by
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Bldg 204-2, Cherry Hill, NJ 08358
Forwarding and return postage guaranteed

EM MUSSELMANN LCTT
PO BOX 9
STRASBURG
PA 17579

**Printed in the U.S.A.
Form No. RE-26-9**