Transequatorial Propagation of V.H.F. Signals

A Study of North-South V.H.F. Propagation Based on the work of F9BG, G4LX, ZC4IP, ZC4WR and ZE2JV

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In 1947 a form of long-distance propagation of 50-Mc. signals hitherto unknown was discovered when XE1KE began working Argentine stations on 50 Mc. in the afternoon and evening hours. In recent years this transequatorial propagation has received much attention in scientific as well as amateur circles. Detailed here are the results of a remarkable series of observations by competent v.h.f. enthusiasts bearing on this as yet little-understood phenomenon.

During the years since the end of World War II increasing use of the 50-Mc. band by amateurs in areas adjacent to the tropics has revealed the existence of radio propagation in the v.h.f. region, up to at least 80 Mc., that cannot be explained by conventional theories. Peculiarities of the earth's magnetic equator,[1] about which this mode of propagation occurs, give Southern Rhodesia a most favorable position from which to observe *TE* effects. For this reason study of transequatorial propagation was chosen as a project for the International Geophysical Year.

Commercial and other use of the 30-80-Mc. portion of the spectrum is mainly restricted to short-range "groundwave" services, such as television broadcasting and mobile communication. Results of amateur observations indicate, however, that for the areas of the world where *TE* propagation is encountered it represents an opportunity for long-distance communication having a high degree of reliability for certain hours and seasons.

In general, the *TE* path is between areas on either side of the geomagnetic equator [1] and 1500 to 2500 miles away from it. It is effective during the hours of darkness, and on frequencies up to 1.5 times the observed daytime maximum usable frequency for *F*-layer propagation. Optimum propagation conditions occur at the time of the equinox, between points in the same longitude, located about 2000 miles from the geomagnetic equator.

The *TE* mode may be usable between locations where the direct line between the two stations cuts the geomagnetic equator at an angle as low as 45 degrees, and beyond the distance limits mentioned above, but moving away from the most favorable spots causes both the reliability and the maximum usable frequency to drop off. The quality of the modulation on a *TE*-propagated signal is often distorted by a characteristic flutter fading. The signal is good enough for communication purposes, but the mode is unlikely to be of value for broadcasting or television. The transmitter power required to produce an intelligible signal is small. A few watts of r.f. in a vertical quarter-wave aerial may induce a signal of one microvolt or more in a similar aerial located 4000 miles away in the opposite *TE* zone.

Transequatorial propagation is by no means limited to the hours of darkness. At the peak of solar activity, daytime signals above 50 Mc. were weak and infrequent at Salisbury, but in 1959, probably due to decreased ionization at the lower levels, signals from the *TE* area around the Mediterranean have been received at ZE2JV very regularly, and at great strength on frequencies up to 56 Mc., throughout the day.

Examination of Fig. 1 shows that the geomagnetic equator traverses Africa in an arc approximately centered on Victoria Falls, and having a radius of about 2000 miles. The effect of this curvature is to give places in southern Africa lying within the *TE* belt an abnormally large zone into which *TE* propagation takes place, and from which interference and noise can be received.

The density of ionization is affected by the angle of the sun. Across Africa the geomagnetic equator lies well to the north of the geographical equator. Hence Southern Rhodesia and its neighbors experience *TE* propagation effects together with a higher density of ionization than is generally experienced elsewhere.

* Salisbury, Southern Rhodesia.

[1] Southworth, "A Look Back and Ahead at PRP," *QST*, June, 1959, page 48.

The Experimental Program

An automatically keyed c.w. transmitter delivering 60 watts to a 4-element array has been in operation from the author's location in Salisbury, Southern Rhodesia, since September, 1957. Its transmissions on 50.04 Mc. have been received with varying degrees of consistency in Poona, Bahrein, Israel, Cyprus, Libya, Switzerland, Morocco, France, Portugal, Madeira Islands, England and North America. Two-way contacts were made with all of these countries where operation on 50 Mc. is permitted. Crossband work was done with the others, 50–28 Mc.

Jean Garat, F9BG, Toulon, France, George Barrett, ZC4IP, and R. A. Whiting, ZC4WR, Limassol, Cyprus, accurately recorded the time of arrival, variations in signal strength, and peculiarities of the propagation of these signals throughout the evening, over long periods. It was found impractical to record the time of closure of the propagation path, it being in the early morning hours ordinarily. Gordon Spencer, G4LX, Newcastle, England, undertook similar thorough observation of the 50-Mc. signals, though he received them for much shorter periods and with considerably reduced regularity. From February 1959 on, L. S. Cole, ZS6IG, Johannesburg, South Africa, transmitted twice each evening, for regular observation on Cyprus. Regular reception of European television signals in Salisbury was of interest, but multiple use of the same frequencies, especially 48.25, 49.75 and 53.25 Mc., was confusing.

An estimate of the m.u.f. was made regularly in Salisbury by tuning a receiver over the range of 30 to 75 Mc. Television signals and harmonics of commercial stations in southern Europe and the Middle East countries were sufficient for reasonable accuracy. It is probable that the m.u.f. actually rose above 75 Mc. many times. However, resonant beam antennas are necessary for effective reception at these frequencies, and for practical reasons these were limited to the amateur bands at 28, 50, 72 and 144 Mc. From March through May, 1958, F9BG made three transmissions nightly on 72.025 Mc. His signal was never positively identified in Salisbury, but this may have been due to strong interference on this frequency from Beirut, Lebanon.

ZC4WR, who conducted the experimental work on the characteristics of *TE*, developed a technique for photographing the received signal, as displayed on an oscilloscope. The receiver was operated without a.v.c., and the signal voltage was taken from the a.m. diode detector and fed to the oscilloscope amplifier. Though the technique was later improved, the pictures were taken with a time-base duration of 0.08 to 0.1 second. First exposures were 0.1 second at f.2. Pulses of 0.03 and 0.02 second were transmitted, and photographs were made of signals received during various kinds of propagation. Normal 28-Mc. signals were also photographed for comparison purposes.

As the directional properties of the antennas appeared to vary from day to day, and even from hour to hour, tests were made to determine the degree of scatter, and to investigate possible correlations between this and the percentage of flutter, and extensions of the *TE* zone. The Yagi array at ZE2JV was aimed first north, then east and then south, while signal levels and characteristics were recorded at Cyprus. The tabulated observations showed very marked differences in both scatter and degree of signal flutter, but there was no significant correlation between the two. The strength of signals received in Cyprus from Johannesburg was found to vary directly with the degree of scatter. The scatter indication was also high when the ZE2JV signal was heard in England by *TE*, and when direct contact was possible on 50 Mc. between Salisbury and Kenya-Uganda.

An attempt was made to determine the effect of vertical directivity. The 4-element Yagi (low-angle radiator) was compared with a half-wave dipole mounted ¾ wavelength above ground (high-angle radiator). These tests showed a fairly constant gain of about 6 db. for the Yagi, but the percentage of flutter was always higher with the dipole.

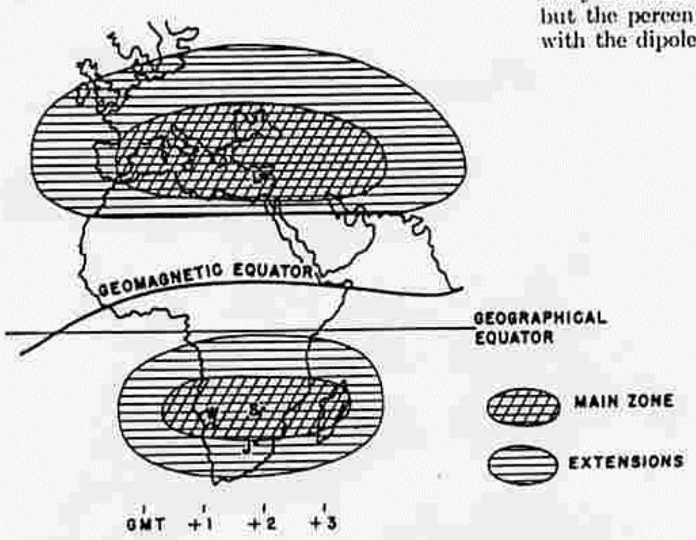


Fig. 1—Northern and southern *TE* zones, as indicated by amateur experience. The curve in the Geomagnetic Equator as it crosses Africa appears to have a focussing effect on *TE* propagation. The cities of Windhoek, Salisbury, Limassol and Johannesburg are indicated by their initial letters.

Results

Extent of Zones: The northern and southern *TE* zones, as indicated by our observations, are shown in Fig. 1. The extent of the northern zone is based on reports of reception of the 50-Mc. transmissions made from ZE2JV, and from reception of television and other signals in the v.h.f. range at Salisbury. The southern zone outlines are based on the reception of amateur 50-Mc. signals in Limassol, Cyprus. At frequencies higher than the 50-Mc. band, the zones are more limited in geographical extent, but extensions at lower frequencies were of no significance.

To avoid complication of the results by the possibility of confusion between normal F_2 and *TE* propagation, no account has been taken of the reception of signals lower in frequency than 50 Mc. Reports from England showed that our 50-Mc. signals were received there frequently for two brief evening periods, 1700 to 1715 GMT, usually showing a "clean" signal, and 1900 to 1930, always showing flutter fading that is characteristic of *TE* propagation. (*Local time in* Southern Rhodesia is GMT plus two hours.)

The 1700-to-1715 period was discounted, as F_2 propagation may have been responsible, but F_2 propagation during the later period appeared unlikely. Tests on 52.5 Mc. in the other direction bore this out. Transmissions on this frequency by G4LX were received in Salisbury (though very weakly) in the later period, but only one 5-second burst was heard during the 1700 to 1715 period in three months of testing.

There are some 500 television stations in Europe and the Middle East. With the majority of them in the 40-to-70-Mc. range there is no way of telling with any degree of certainty the origin of the mass of TV signals received at Salisbury in this frequency band. It was assumed, for example, that a very strong video signal on 49.75 Mc., heard from 1000 to 2200 daily for 6 months of the year, and less consistently the rest of the year, was from Odessa. Published data indicated that all Russian stations used this frequency (video 49.75 Mc., audio 56.25 Mc.), but an Odessa amateur told us that the video of that station had been shifted to 97 Mc., and that the only Russian video on 49.75 Mc. after early 1959 was the 100-kw. station in Moscow. If this information is accurate, the reception of strong signals on this frequency consistently is of considerable significance.

A graph of the m.u.f. as observed at 1830 GMT for an entire year is given in Fig. 3. Typical m.u.f. for the evenings of April, 1958, is shown in Fig. 4.

Extensions of the southern zone over Africa were observable with greater accuracy, since they were based on the reception of amateur signals in Cyprus. The geographical location and power limitations of these stations are, of course, readily ascertained, but it is by no means certain that a 100-kw. TV signal comes by direct path. Test transmissions from Jinji, Uganda, beamed at Cyprus, were not received there, but Uganda

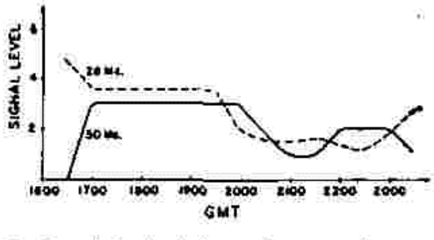


Fig. 2—Signal levels during a long evening contact, October 18, 1957. ZC4IP, Limassol, Cyprus, was on 28 Mc. and ZE2JV, Salisbury, Southern Rhodesia, on 50 Mc.

stations have been heard in Cyprus when they were beamed south, into the region where backscatter can carry them back north across the equator. Test transmissions from Johannesburg showed clearly that this city is at or just outside the main *TE* zone.

It would appear that Newcastle, England, is situated near the northern limit of *TE*, and that Capetown, South Africa, is near the southern limit. From this it would appear to be possible that reception of TV from the north of England on 48.75 Mc. in Capetown is the longest "one-hop" propagation that has been experienced.

Seasonal Effects: The principal effects of the position of the sun are discussed later, but it may be mentioned here that there tend to be more frequent and longer extensions to the south in the southern summer, and to the north in the

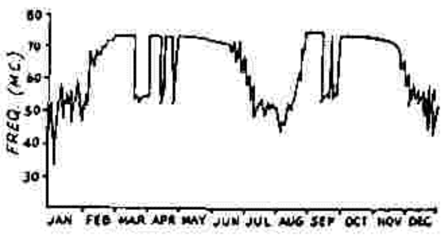


Fig. 3—Maximum usable frequency at Salisbury, Southern Rhodesia, at 1830 GMT. Two major *TE* seasons are clearly indicated.

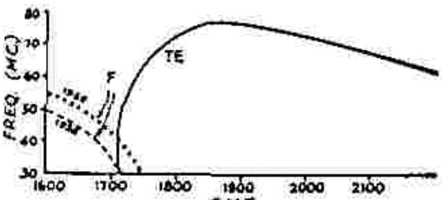


Fig. 4—Hourly curve of the m.u.f. as observed by ZE2JV in April, 1958. F_2-layer curves for 1958 and 1959 are given at the left.

northern summer. These are most noticeable a month or so each side of the respective solstice. The line joining locations most favorably situated with respect to each other appears to veer away from the line of longitude between an equinox and a solstice. This can possibly be explained by a tendency for conditions to be optimum when the time of sunset approximates. Thus, from Southern Rhodesia there is an extension to the east in the southern winter, and to the west in summer.

Scatter and seasonal extensions of the *TE* zone do not appear to be entirely independent. The longest scatter extensions to the north take place in the northern summer, and vice versa.

Extension of the range by other forms of propagation was experienced in February and November to North America (northwest) and in May to Japan (northeast). In order that this may occur at 50 Mc. the m.u.f. at the point of the second reflection must be high enough to propagate the wave at the angle at which it was propagated by *TE*. These openings were of a sporadic nature, but they seemed to occur 48 to 60 hours after an outburst of fairly high sunspot activity. The distance was always in the region of 8000 miles. No east-west DX was worked, except by back-scatter or tropospheric propagation.

Reliability

September–November, 1957: Although the equipment used by ZC4IP for this period was not as good as that employed subsequently, and his antenna was merely an indoor dipole in a built-up area of Limassol, he received signals from ZE2JV on 50 Mc. 58 evenings out of 63 on which tests were made. Frequently conditions were good enough for duplex telephony, using 50 and 28 Mc. An attempt to determine the time of closure of the path was made on the night of October 18–19, but it was abandoned at 0135 local time, with both bands still open. Communication had been maintained crossband since 1830. Fig. 2 shows the signal levels on both bands during this 5-hour contact.

March–July, 1958 F9BG, Toulon, had cooperated in many tests since September, 1957. From September to November he received the ZE2JV 50-Mc. transmissions less regularly, and for shorter periods, than they were received at Cyprus. In March, 1958, he erected a 3-element Yagi on the top of a building overlooking the Mediterranean, and thereafter failed to hear the transmissions on only four evenings, testing 4 or 5 evenings each week. Many of the transmissions were received with considerable strength.

Though commercial transmissions on 70 to 71 Mc. from Cyprus and f.m. and other signals up to 74 Mc. were frequently received at Salisbury in March and April, the 72-Mc. transmissions of F9BG were never positively identified.

September, 1958: G4LX, Newcastle, England, reported reception of the ZE2JV tests several times in May, 1958. In the fall he had permission for operation on 52.5 Mc. He made tests every evening in September, and at noontime (at the midpoint) on Sundays only. The evening tests were received at Salisbury 3 evenings out of 29 tried in September, though European television interference made reception very difficult. G4LX, on the other hand, heard ZE2JV 15 evenings out of 29 tried, and heard noontime tests on 2 out of 4 tries.

September–December, 1958: ZC4WR, also of Limassol, Cyprus, listened to the 50-Mc. tests in 1957. He was then using a single 6J6 converter and a vertical wire of random length. Even so, he heard the 50-Mc. signals every day in October that tests were made by ZE2JV (all but two days). In 1958 he erected a 4-element Yagi on the top of a block of flats, 100 feet above ground, and employed a crystal-controlled converter of modern design. The signal levels during October and November, 1957, and September and October, 1958, are shown graphically in Fig. 5.

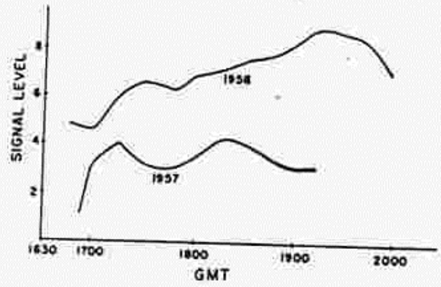
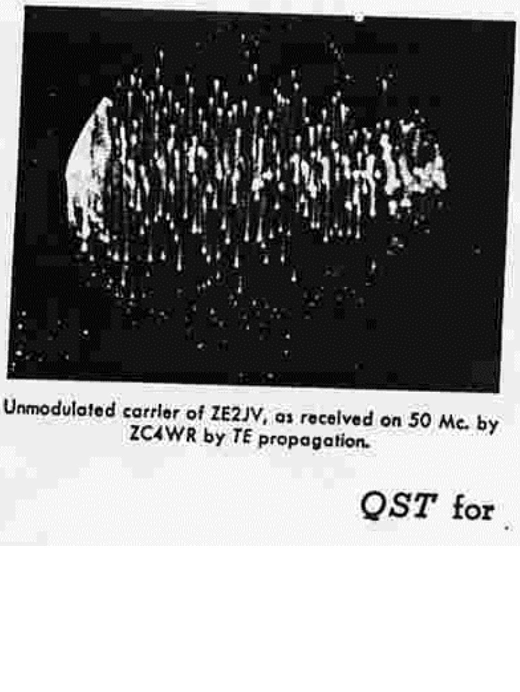


Fig. 5—Average 50-Mc. signal level of ZE2JV, as observed by ZC4WR during 20 days in October and November, 1957, and September and October, 1958. Higher levels in 1958 were due in part to improved equipment at the Cyprus end.

Looking at TE Signals

The first photograph shows an unmodulated signal from ZE2JV as received on Cyprus. This and subsequent photographs were made with an exposure of .08 second at f.4, from a short-persistance cathode-ray tube. The time base was truly one-shot, in that opening the camera shutter triggered the time base, which gave a single sweep. Fly-back could not occur until the shutter was closed. Examination of *TE* signals is still in progress, but it seems safe to assume that the received energy consists of components arriving so that they differ in phase or frequency. Oscillograms of this nature do not appear continuously, but rather at five times per second, or thereabouts, at irregular intervals. The rest of the time the carrier is relatively "clean."



Unmodulated carrier of ZE2JV, as received on 50 Mc. by ZC4WR by *TE* propagation.

Flutter is usually of a complex nature. Phase distortion can make amplitude modulation unintelligible, and amplitude variations can "key" a signal so that even the slowest code is difficult to copy. These effects can appear simultaneously, each in varying degrees, but extremes of flutter are experienced only with simple antennas. Never, when low-angle antenna systems have been in use at both ends, has the degree of flutter been sufficient to destroy intelligibility. A.m. signals appear to be demodulated. More speech clipping than would normally be tolerated, and modulation depth in excess of 100 per cent (with suitable precautions to prevent carrier splitting) are helpful under conditions of severe flutter.

Flutter is not an essential feature of *TE* propagation, though it is normally present in the late evening. It may appear over the whole band of *TE*-propagated signals, or only over a segment of it. Generally signals within a few kilocycles of the m.u.f. show little or no flutter.

Types of Evening Propagation

Most evenings showed propagation similar to that of the early-evening part of Fig. 2. The 50-Mc. signal appeared about 1900 local time (1700 GMT), building up to moderate strength with only minor variations. Flutter fade was present after about the first hour, and beam tests would show a moderate degree of scatter. Fig. 6 shows an average of three such evenings in September and October, 1958.

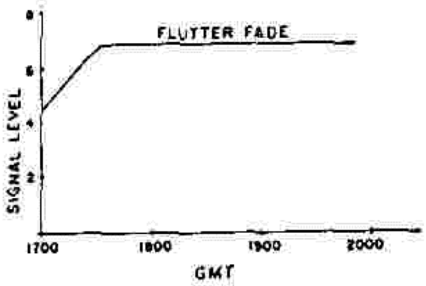


Fig. 6—Average of three typical evenings of *TE* propagation. Signal levels build up to moderate levels around 1900 local time, and thereafter show only minor variations. *TE* flutter appears after the first hour.

On abnormal evenings following high daytime m.u.f., signals of *F*-type characteristics may last as late as 2100 local time. When this happens, the fadeout affects all frequencies from 28 to 56 Mc. simultaneously. Fadeout is not necessarily rapid, and signals from high-powered TV stations (at the high end of the range) may last for 30 minutes after weaker signals have faded out. *TE* propagation has not been observed after these occurrences, but this is not proof that it did not occur later at night. No flutter appeared on these signals, but beam tests indicate that the degree of scatter may be very high.

More frequently *F*-type signals would not appear until late afternoon, and in these cases fadeout occurred earlier in the evening, to be followed by the return of a signal showing *TE* characteristics, but with exceptional strength. Fig. 7 shows a graph of signal strengths on two such evenings. Photographs of the received signals show the characteristics of *F* and *TE* propagation.

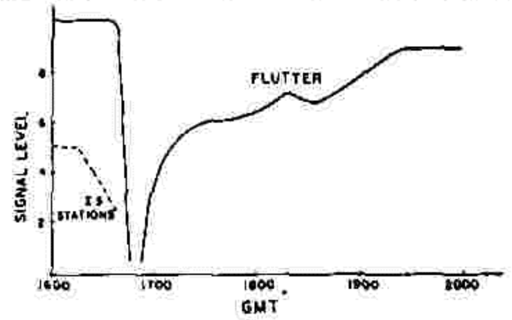


Fig. 7—Both *F* and *TE* propagation appear in this graph for September 26 and October 7, 1958. Solid line is the ZE2JV signal. Farther south ZS signals are shown in broken line at the left.

Still another type, Fig. 8, shows no fadeout in the period of transition from *F* to *TE*. Photographs made of this (not reproduced here) show a mixture of the two types of propagation.

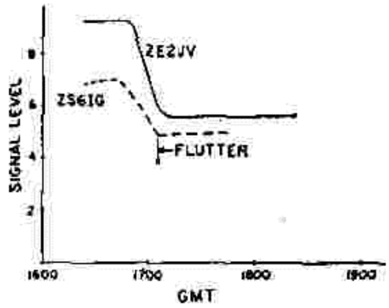


Fig. 8—Gradual transition from *F* to *TE* reception at ZC4WR, September 18, 1958. ZS6IG, Johannesburg, South Africa, is shown in dashed line.

There were few evenings when propagation was not in one of the categories described above. Ionospheric storms apparently had little effect. Disturbed conditions are of two types, as shown in Figs. 9 and 10. Of the two, the first occurred more often, and was probably due to late-persisting ionization in the lower levels. The second shows sporadic signals observed, and it would appear that late-evening *F*-type signals were being cut off by sporadic-*E*.

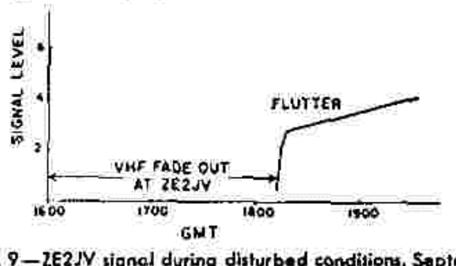


Fig. 9—ZE2JV signal during disturbed conditions, September 9. The v.h.f. range was devoid of signals from the north at ZE2JV, between 1800 and 2000 local time.

Noise Levels

Noise measurements made in Salisbury show the level to be high through the *TE* seasons,

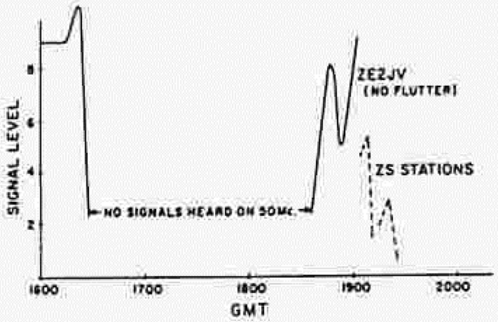


Fig. 10—Another type of disturbed conditions, September 30, showed the ZE2JV signal hitting a high level in the early evening at Cyprus, followed by a 2-hour fadeout and subsequent *TE* propagation from ZE and ZS.

There is a marked drop in midsummer and midwinter, when receiving on frequencies above the m.u.f. At these times the noise level is comparable with that experienced in temperate zones. Noise level during the *TE* seasons stays high through the day, and often does not appear to vary with propagation conditions. It does vary directly with the degree of scatter, however.

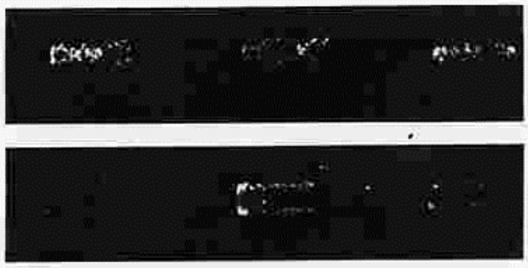
Observations on Cyprus were quite different. There the noise level rose with propagation conditions. A belt of severe thunderstorms across the Rhodesias gave an S-unit increase in noise level at the Cyprus end of the path. Apparent contradictions in these noise observations can be explained by two factors: The *TE* zone as seen from Salisbury is larger, and the geomagnetic equator crosses Africa well to the north of the geographical equator.

The tropical convergence zone can be considered as a vast noise generator. This zone remaining approximately in the subsolar region is substantially in the southern *TE* belt. North of the geographical equator (Kenya-Uganda, from where 50-Mc. signals scatter back into Rhodesia with great strength) desert conditions are rapidly approached. Noise from the tropical convergence zone can, therefore, be received in Cyprus only by *TE* propagation, whereas in Rhodesia noise from the zone can be received by direct scatter and back-scatter propagation. This is consistent with the fact that noise is received throughout the day up to the highest frequency reached by *TE* propagation.

Echoes

Occasionally echoes indicating a 1/6-second delay appear on *TE* signals. Unfortunately, these have not yet been photographed. Such echoes were prevalent on the 40-Mc. signals of Sputnik I as it travelled over the *TE* zones during the evening.

The delay suggests that these echoes may be circumterrestrial. It is difficult to imagine how this can happen when east-west work within the *TE* belts has not been possible. (IGY beacon stations in South America, just below 50 Mc., were never received.) Unconfirmed evidence has suggested that signals may be propagated to east and west by beaming a powerful signal away from the equator. If, as seems likely, ionization at the lower levels is the main barrier to east-west work, it would appear possible for such propagation to take place.



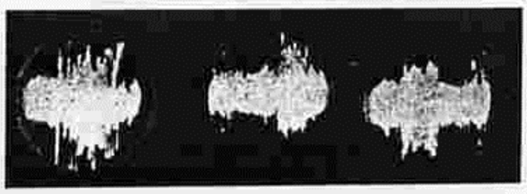
Periods of unmodulated carrier showing the complex fading pattern of *TE* propagation (upper three examples) in comparison with the steadier F_2 signal in the lower row.

Echoes of even longer delay have been reported.

Back-Scatter

Contacts on 50 Mc. with Kenya and Uganda were commonplace in the evening hours. Signals usually had *TE* characteristics, but when these East African stations work farther south into Johannesburg and Windhoek their signals are often without flutter. Such contacts took place only when the indication of scatter was high.

Back-scatter from other Rhodesian amateurs is common on 28 Mc. when both stations beam north. Signals are the flutter type, but remarkably constant day and night. The level is just sufficient for readability on a.m. with 100-watt stations. Back-scatter is not so consistent on 50 Mc., but the lower level of activity, lower power, and frequent interference from DX television are limiting factors.



50-Mc. pulses from ZE2JV, recorded when flutter was relatively severe and beam tests showed a high degree of scatter.

A portable station on a 5,200-foot elevation near Umtali provided round-the-clock communication on 50 Mc. with Salisbury, a 160-mile path. During the evening its back-scatter signal from the north was of good strength. The same transmitter working from the town itself was never heard, despite numerous tests.

Only once was a sporadic-*E* signal heard on 50 Mc. This was from Windhoek, Southwest Africa. Lack of sporadic-*E* signals otherwise is in part due to low activity, as there are few stations within the usual range for this type of propagation.

Split pulses from ZE2JV recorded during October, 1958. Such pulses appeared only occasionally, in a string of normal ones. Breaks in the continuity of the signal in this way occasionally make keyed signals difficult to copy.

Conclusions

For purposes of this account, *TE* propagation is definited as v.h.f. propagation between points on opposite sides of the geomagnetic equator, and at least 1000 miles from it, without intermediate reflection from the surface of the earth. It will be noted that the term "*TE* scatter" is avoided. This term is thought unsuitable, as scatter appears to play a part only in certain circumstances.

The differences in signal characteristics at various times might suggest entirely different modes of propagation, but the writer feels that the mode is substantially similar for each type mentioned, and that all are merely variations of the same basic mode. The regions of the ionosphere between the temperate zones and the geomagnetic equator have been said to exhibit a tilt, and would appear to be regions of flux and turbulence. A wave transmitted toward the geomagnetic equator, striking the tilted ionosphere, could be projected forward to take a similar deflection at the region of tilt on the other side of the geomagnetic equator before being returned to earth. This low angle of strike at both points would enable higher frequencies to be propagated by the F_2-layer than would normally be possible.

There would appear to be no reason why a signal so propagated should have characteristics widely different from those propagated in the normal manner. However, a wave reflected from a moving medium will show a frequency shift (Doppler effect) and should the ionosphere in these regions be turbulent it would seem likely that characteristics similar to those observed would be imparted to the signal.

The effect of lower-level ionization in the *E* and *D* regions appears to be the controlling factor, in daytime, of the maximum usable frequency. Late persistence of lower-level ionization may delay the appearance of *TE*, and sporadic-*E* may occasionally obstruct propagation. The possibility of propagation from the top of lower-level ionization in the subsolar region is not entirely rejected as a possible explanation for long-persisting *F*-type propagation. Duct propagation conceivably could support circumterrestrial propagation around the equator.

All types of propagation observed exhibit certain features in common. The zone into which signals propagate remains substantially the same irrespective of the type of propagation (two-hop propagation excluded.) All types of propagation are observed over a wide band of frequencies. Scatter readings do not vary with different types of propagation observed on the Salisbury-Cyprus path.

Carrier photographs show that the types of propagation tend to mix, even when this is not apparent in listening to the received signals.

The possibility of propagation outside the F_2-layer is discounted by the similarity of conditions over the range from 18 to 72 Mc.

Pulse tests and carrier photography, and the lack of connection between scatter tests and the degree of flutter, indicate that the flutter is caused by the state of the ionosphere at the regions of refraction. The presence of identical flutter on signals from East Africa, and the sharp directivity of beams on this path, confirm this opinion.

Acknowledgments

The help and information supplied by the Propagation Research Project of The American Radio Relay League was responsible for the beginning, and to a large degree, the continuation of this project across the African continent. The willing cooperation of amateurs in many countries, who supplied data upon which this account is based, and the work of R. A. Whiting, ZC4WR, who played a major part in the experiments, are gratefully acknowledged. QST