FMCW Radar:

CW Radar with Frequency Modulation

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Lecture 22-23

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Introduction

- CW Radar limitations
    - Cannot measure distance
    - Most developers realized that modulating the frequency will allow distance to be calculated.

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- FMCW Radar is a low cost technique, often used in shorter range applications.
- Applications include,
    - altimetry for aircraft landing,
    - speed guns,
    - laboratory test instruments,
    - education, runway debris monitoring,
    - avalanche detection,
    - volcano eruption onset and many more“
- The technology is simple to fabricate but requires care to obtain high accuracy.
- The technique has the same conceptual basis as pulse compression and high resolution"

- Frequency Modulated Continuous Wave (FMCW)
- Chirp pulse compression …
- FMCW-Radar with classic sawtooth or triangle shaped frequency shift (Chirp-radar);
- FSK-FMCW (frequency shift keying FMCW);
- SFMCW (Stepped FMCW) for interferometric measurements;
- FMiCW (Interrupted FMCW) for better isolation between transmitter and receiver PMCW (phase modulated CW) with pseudorandom codes.

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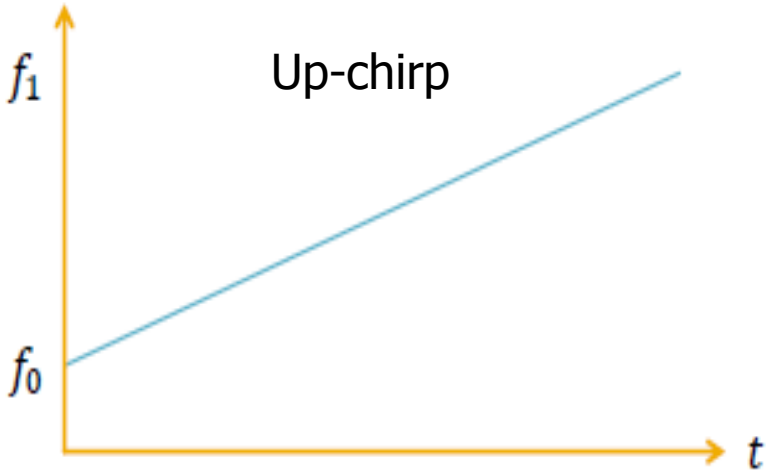
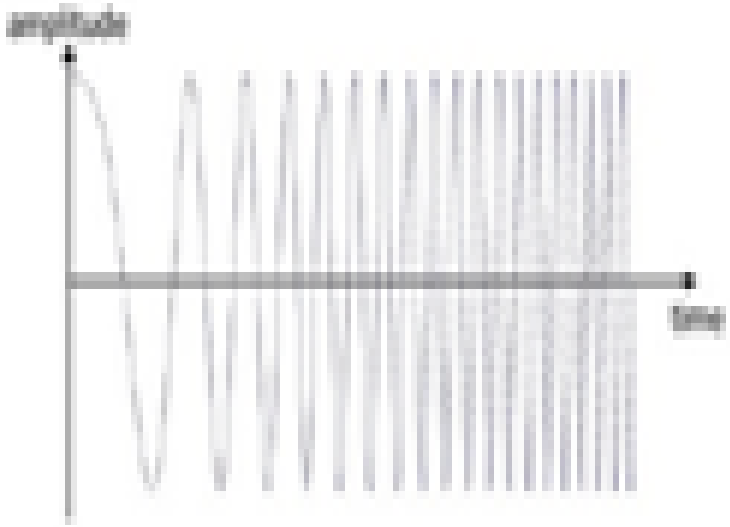
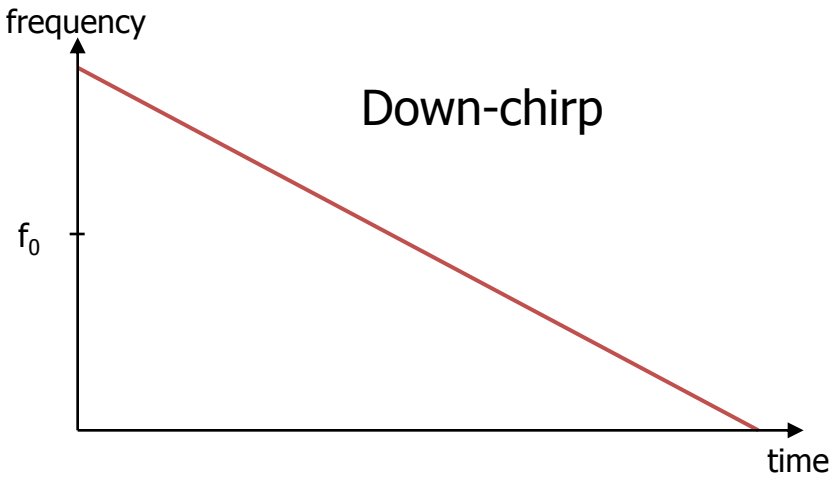
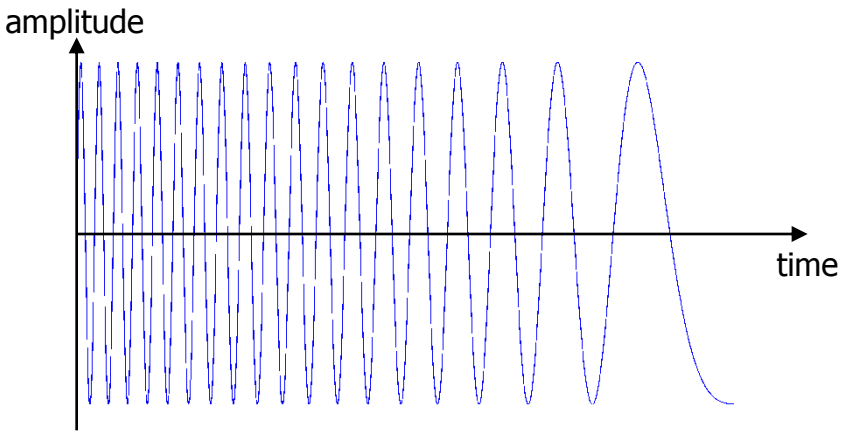


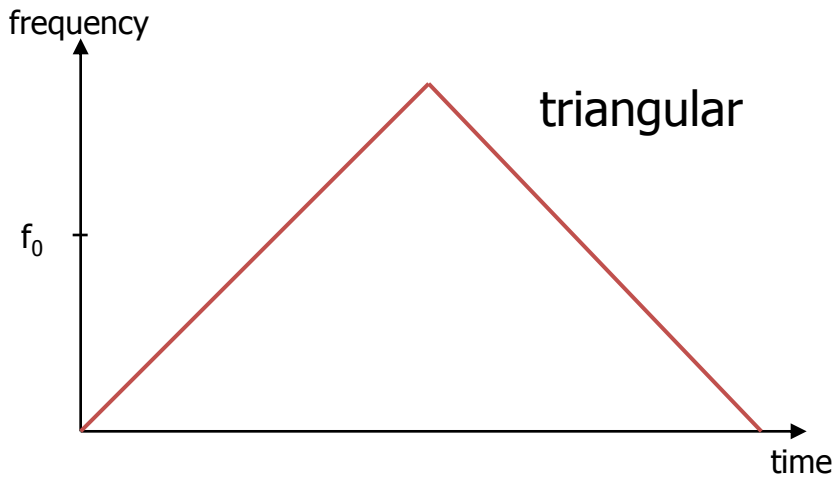


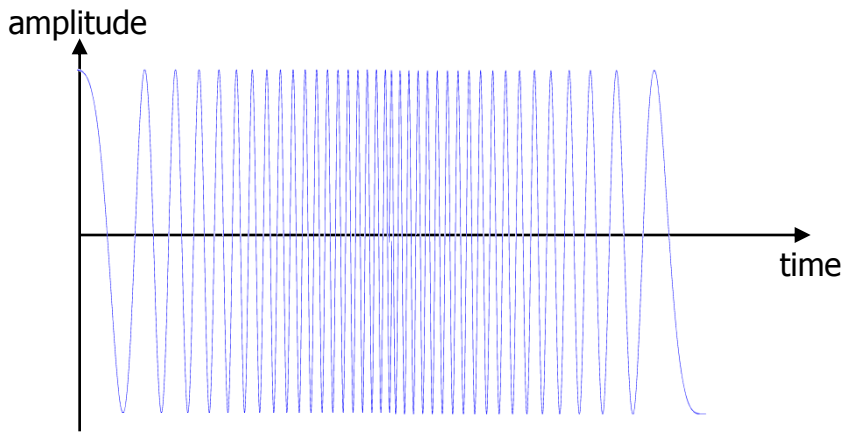
$$f' = \frac{f_1 - f_0}{T_{\mathrm{mod}}} = \frac{B_{sweep}}{T_s} = \frac{sweepBW}{sweeptime}$$





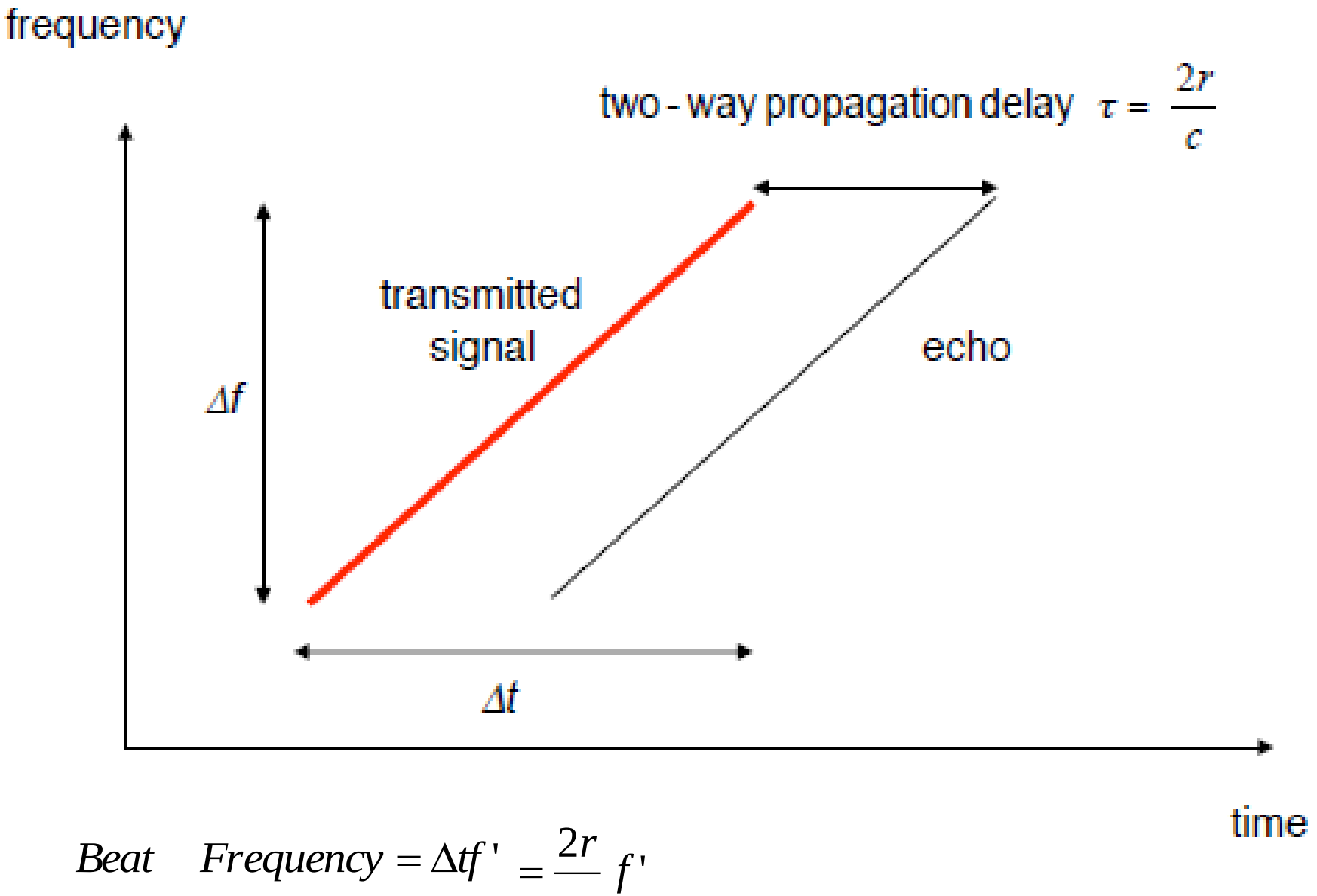
A radar transmitting a continuous carrier modulated by a periodic function such as **a sinusoid or saw tooth wave** to provide range data (IEEE Std. 686-2008).





FMCW Radar: Principle

Stationary Target



$$Beat \quad Frequency = \Delta t f' = \frac{2r}{c} f'$$

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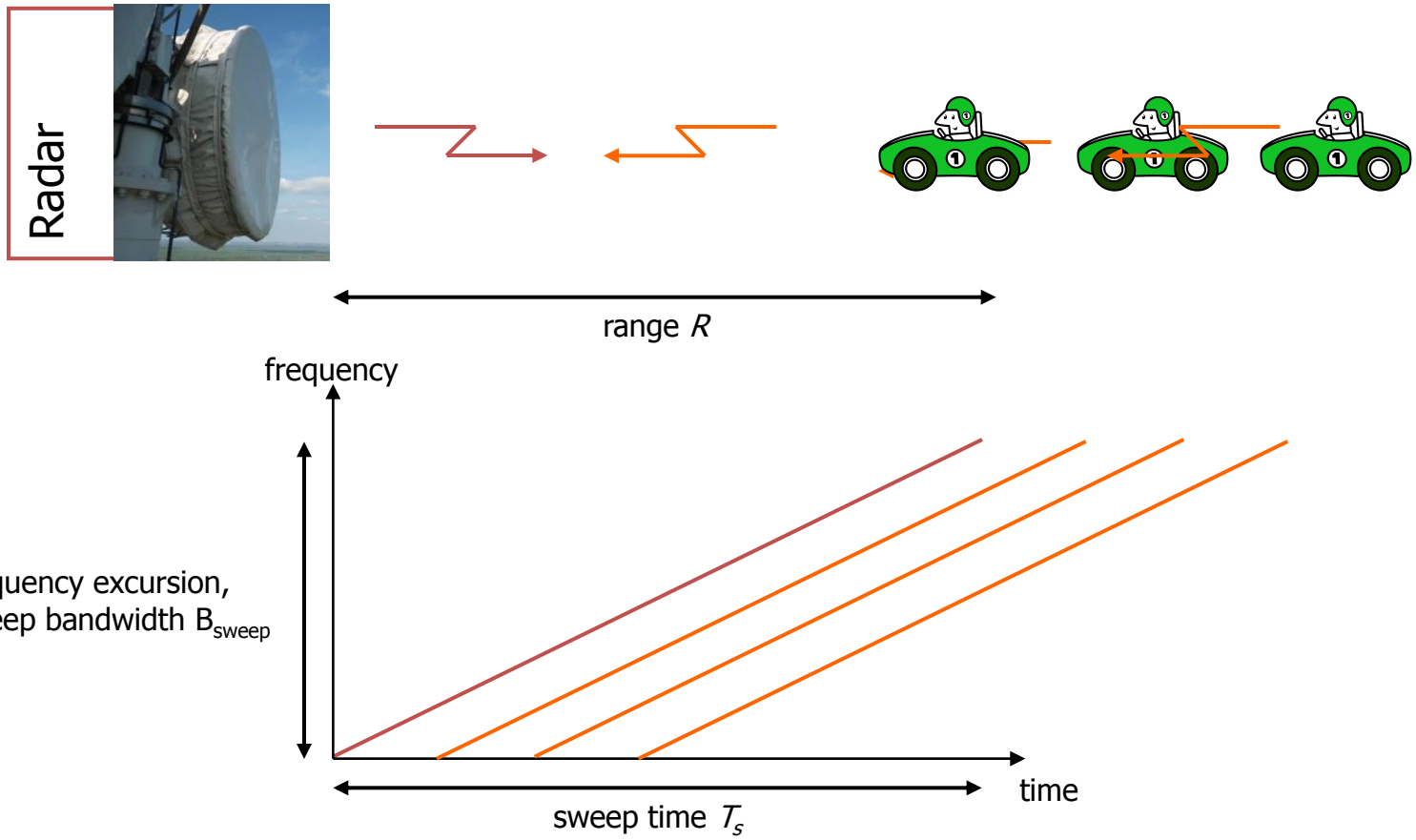
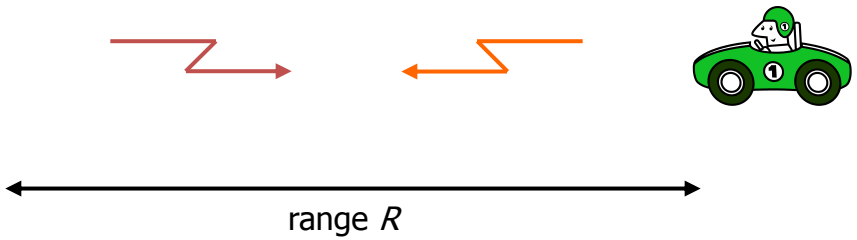
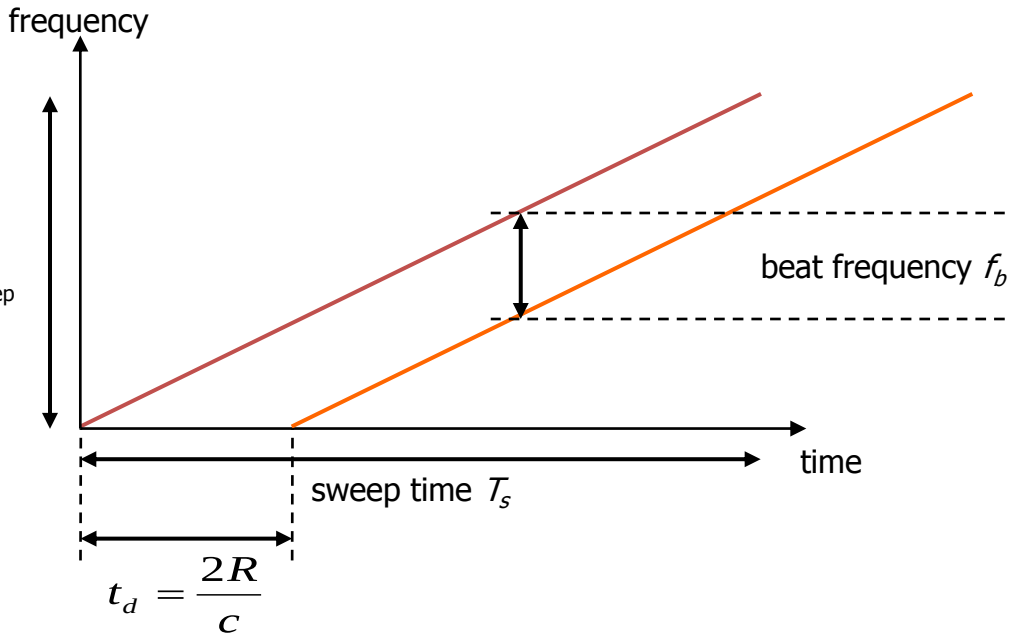

Radar
range R
frequency
frequency excursion,
sweep bandwidth B_{sweep}
time
sweep time T_s

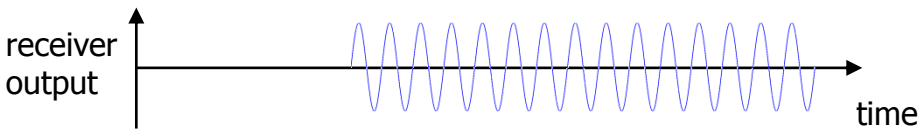
Beat Frequency and Range

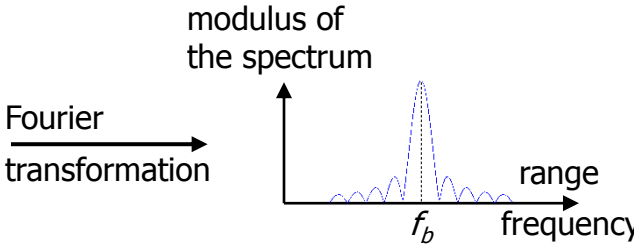




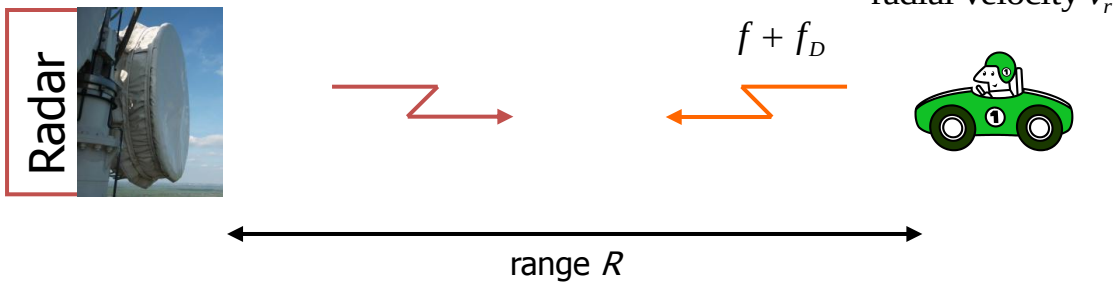
$$\frac{t_d}{T_s} = \frac{f_b}{B_{sweep}}$$

$$R = \frac{cT_s f_b}{2B_{sweep}}$$





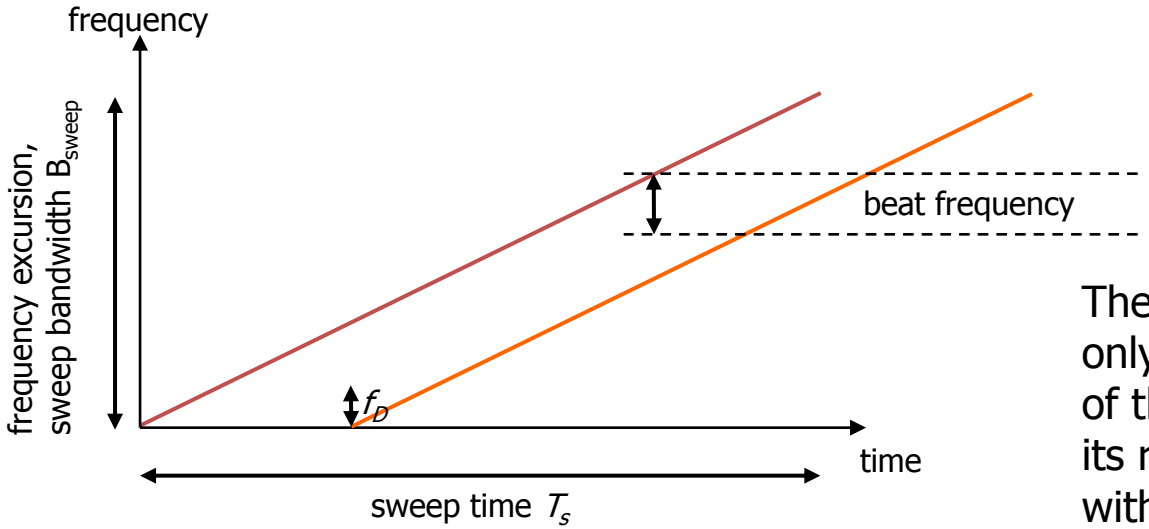
Moving single target



A moving target induces a Doppler frequency shift

$$f_D = \frac{2v_r}{\lambda}$$

with the radar wavelength λ.



The beat frequency is not only related to the range of the target, but also to its relative radial velocity with respect to the radar.

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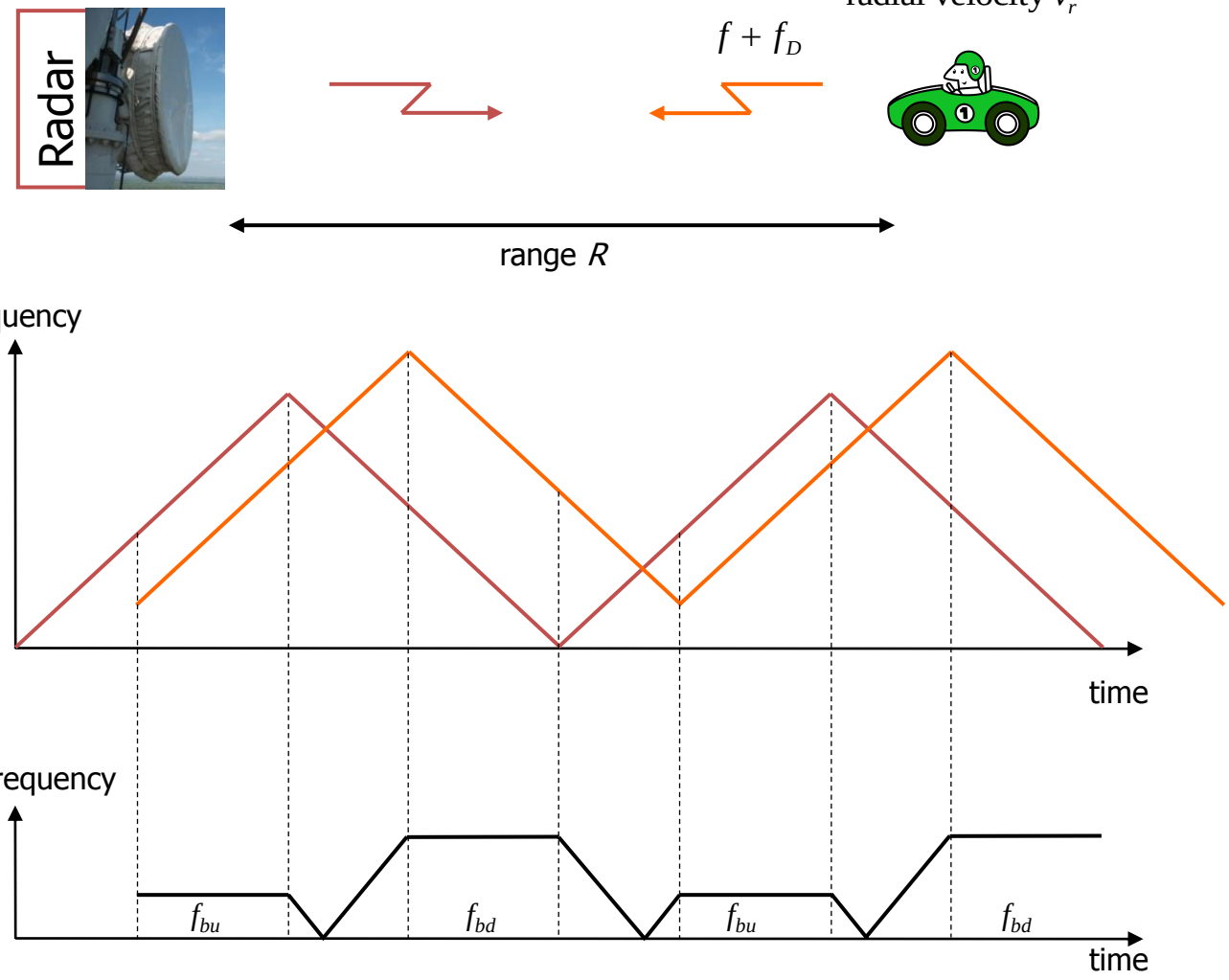
Moving single target



Beat frequency components due to range and Doppler frequency shift:

$$f_b = \frac{B_{sweep}}{T_s} \cdot \frac{2R}{c}$$

$$f_D = \frac{2v_r}{\lambda}$$

that are superimposed as

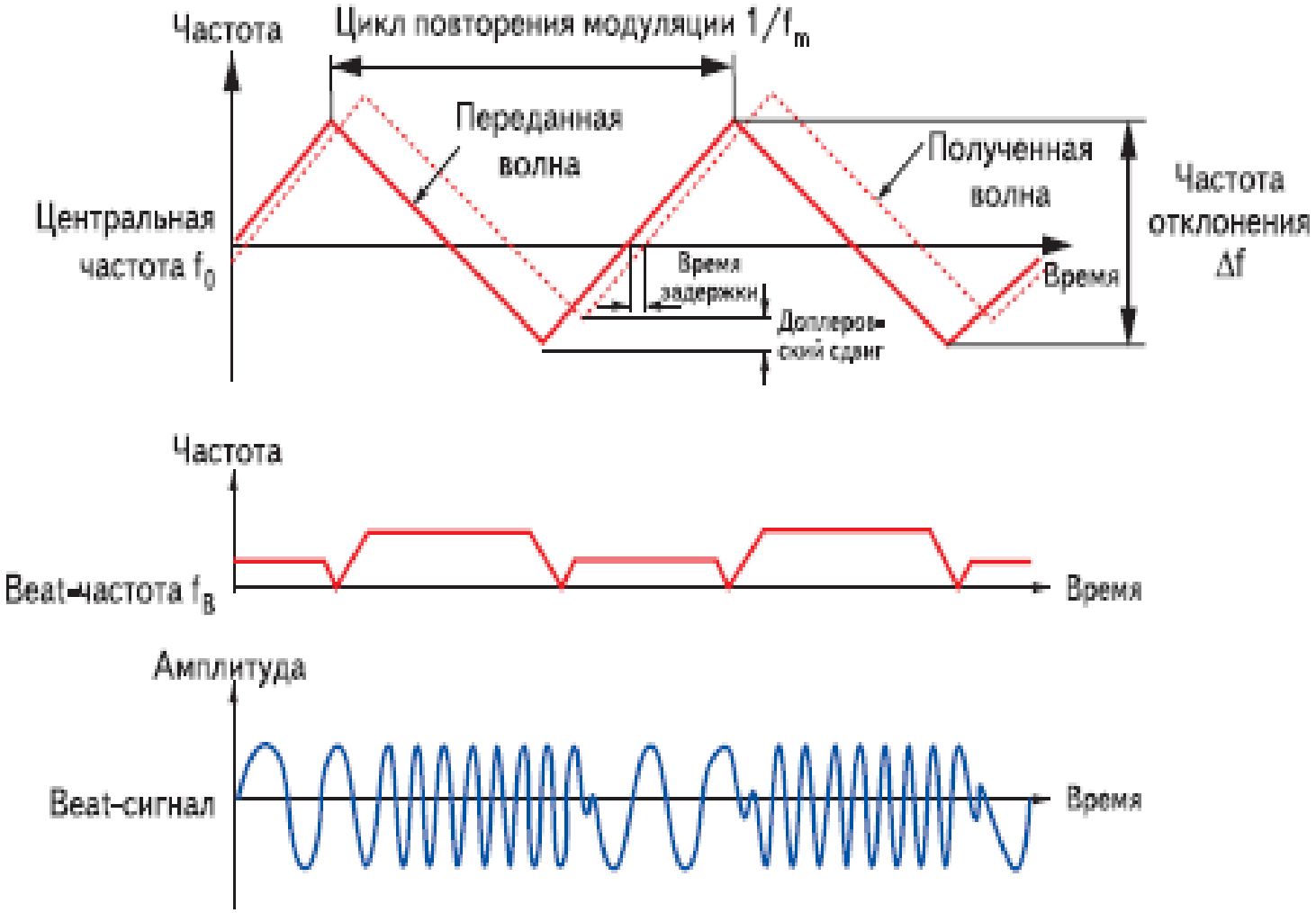
$$f_{bu} = f_b - f_d$$

$$f_{bd} = f_b + f_d$$

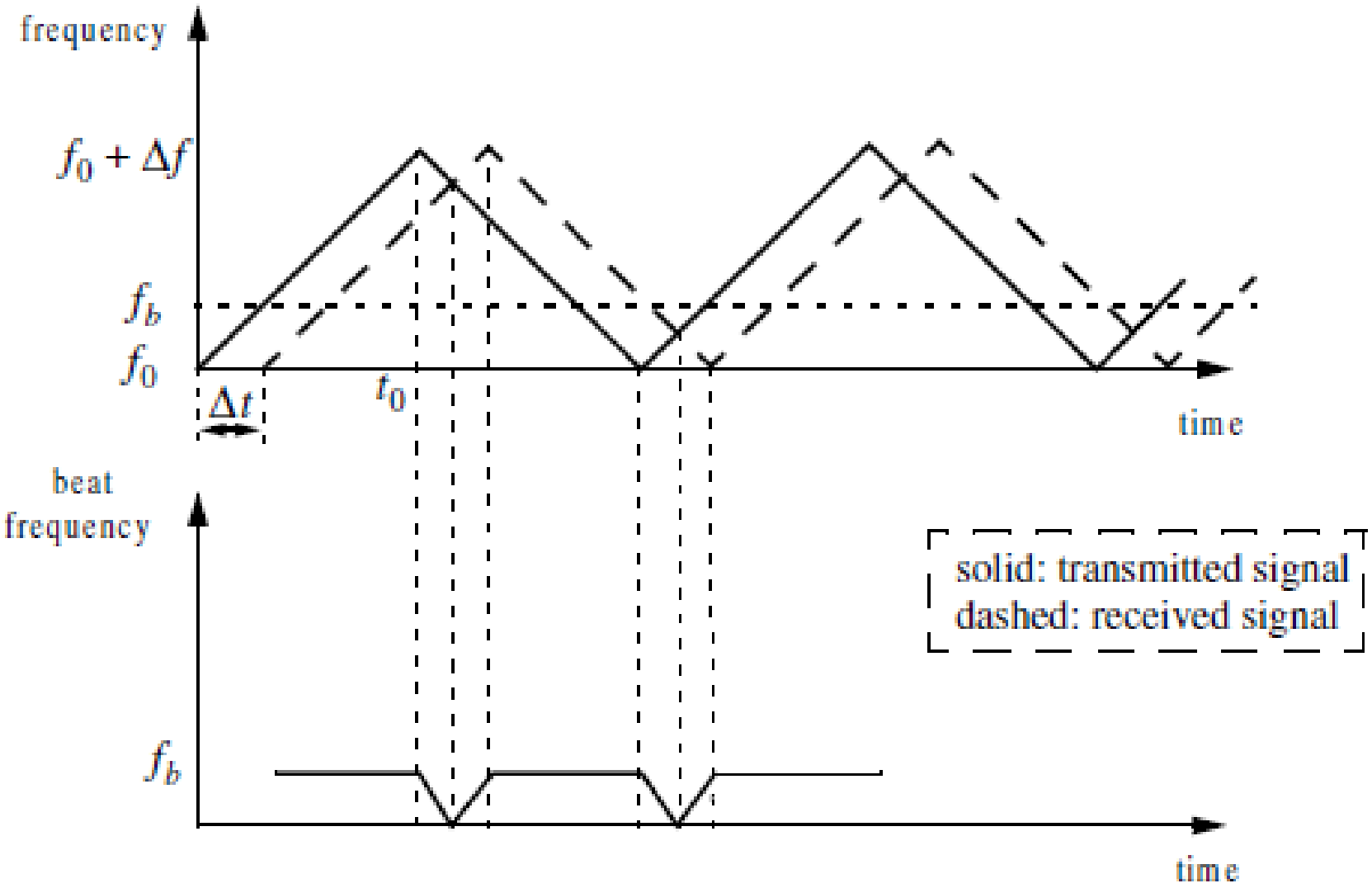
so range and radial velocity can be obtained as

$$R = \frac{cT_s}{4B_{sweep}}\left(f_{bd} + f_{bu}\right)$$

$$v_r = \frac{\lambda}{4}\left(f_{bd} - f_{bu}\right)$$

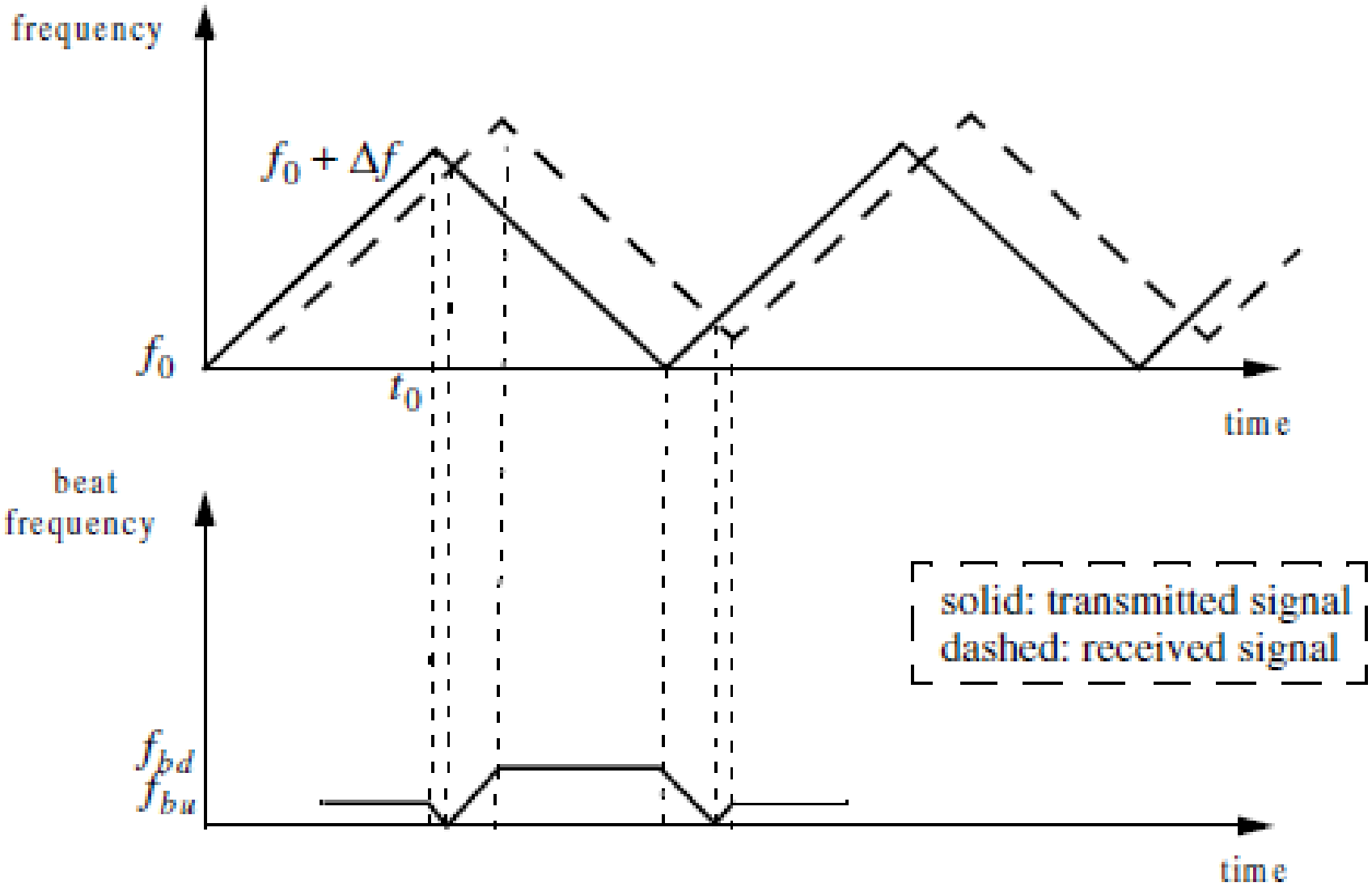

Частота
Цикл повторения модуляции $1/f_m$
Переданная волна
Полученная волна
Центральная частота f_0
Время задержки
Доплеровский сдвиг
Время
Частота отклонения Δf
Частота
Beat-частота f_B
Время
Амплитуда
Beat-сигнал
Время

Triangular type modulation For Stationary Target



Transmitted and received triangular LFM signals and beat frequency for stationary target

Moving Target [Non-stationary Target]



Transmitted and received LFM signals and beat frequency, for a moving target.

Why FMCW for concealed Weapon Detection

- 94 GHz radar
- reasonable penetration for certain materials (thickness)
- High accuracy
- Resistance for outdoor and indoor use
- Could be used for imaging or non-imaging
- Low emitted power – no health concern
- Can be remotely deployed

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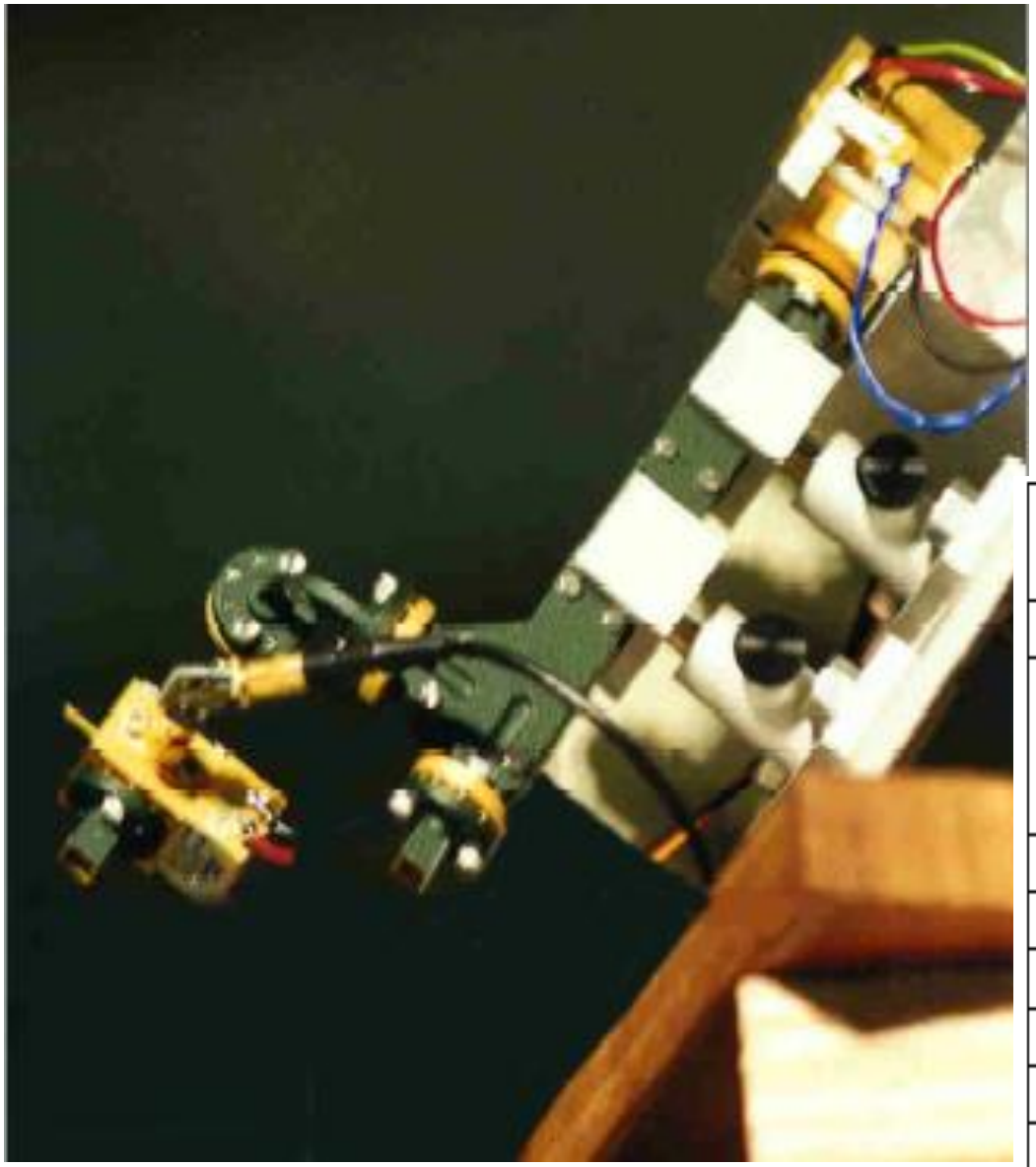
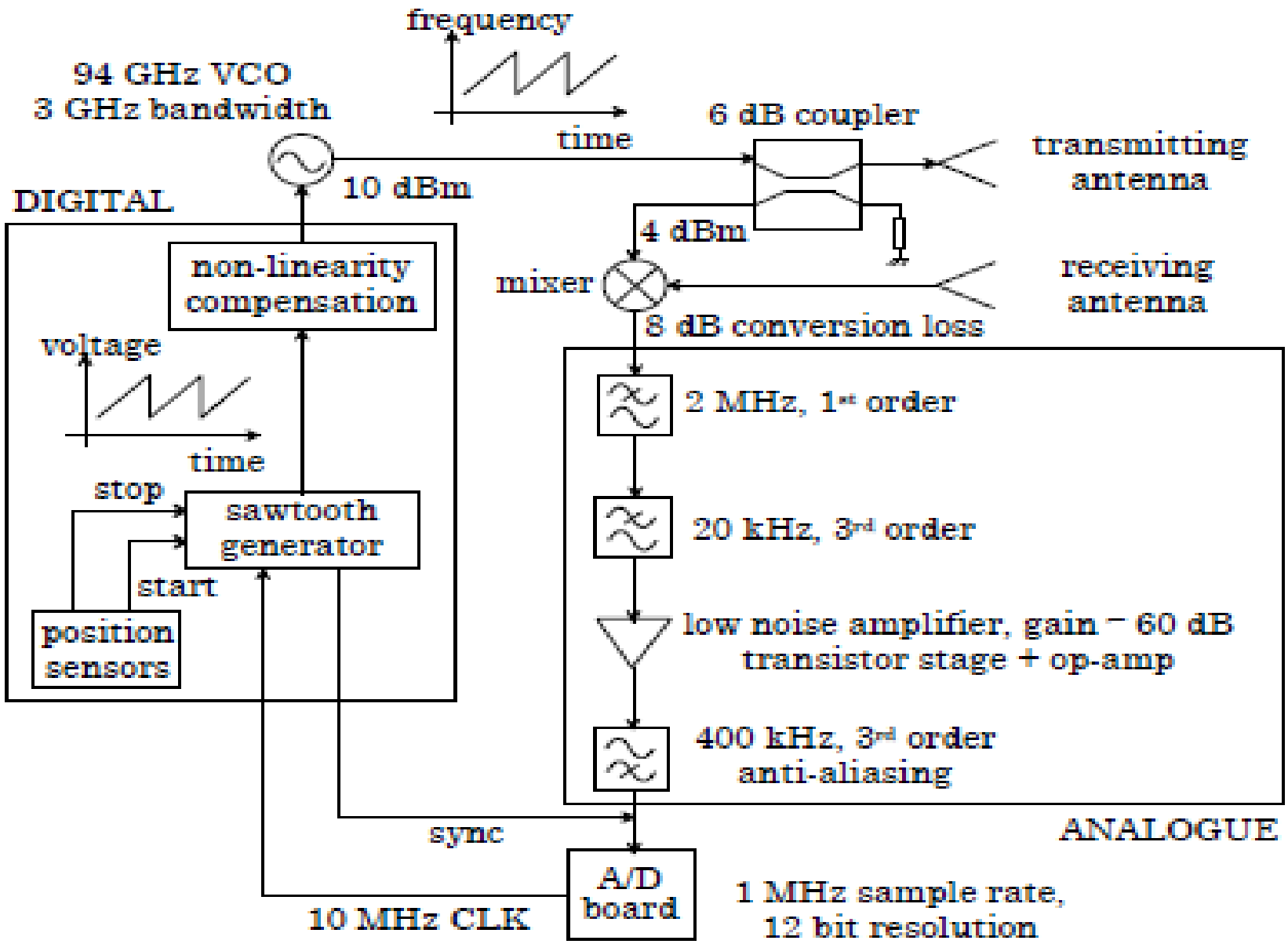
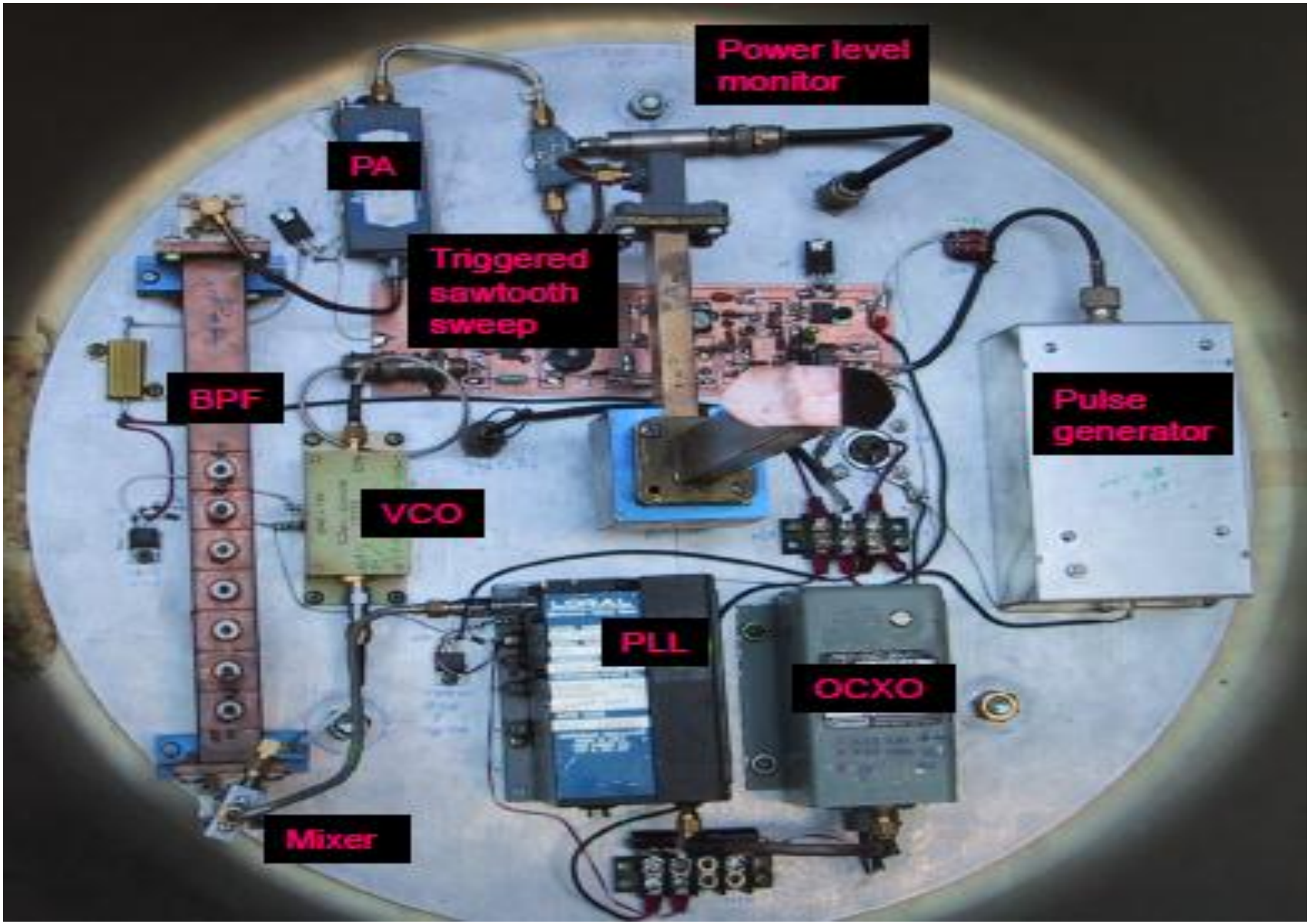


Centre frequency Radar wavelength	94 GHz 3.2 mm
Sweep bandwidth	3 GHz
Sweep duration Pulse Repetition Frequency	1.6 or 0.4 ms 625 or 2500 Hz
Transmit power	10 mW
Antenna size	7 mm x 5 mm
Antenna beamwidth	32° E- & H-plane
Antenna gain	15 dBi
Resolution	ΔR: 5 cm, Δx:1 cm
SNR at 3 m range	22.5 dB


frequency
94 GHz VCO
3 GHz bandwidth
time
6 dB coupler
transmitting antenna
10 dBm
DIGITAL
4 dBm
non-linearity compensation
mixer
receiving antenna
8 dB conversion loss
voltage
time
2 MHz, 1st order
stop
sawtooth generator
20 kHz, 3rd order
start
low noise amplifier, gain ~ 60 dB
transistor stage + op-amp
position sensors
400 kHz, 3rd order
anti-aliasing
ANALOGUE
sync
A/D board
1 MHz sample rate,
12 bit resolution
10 MHz CLK

Radar Transmitter



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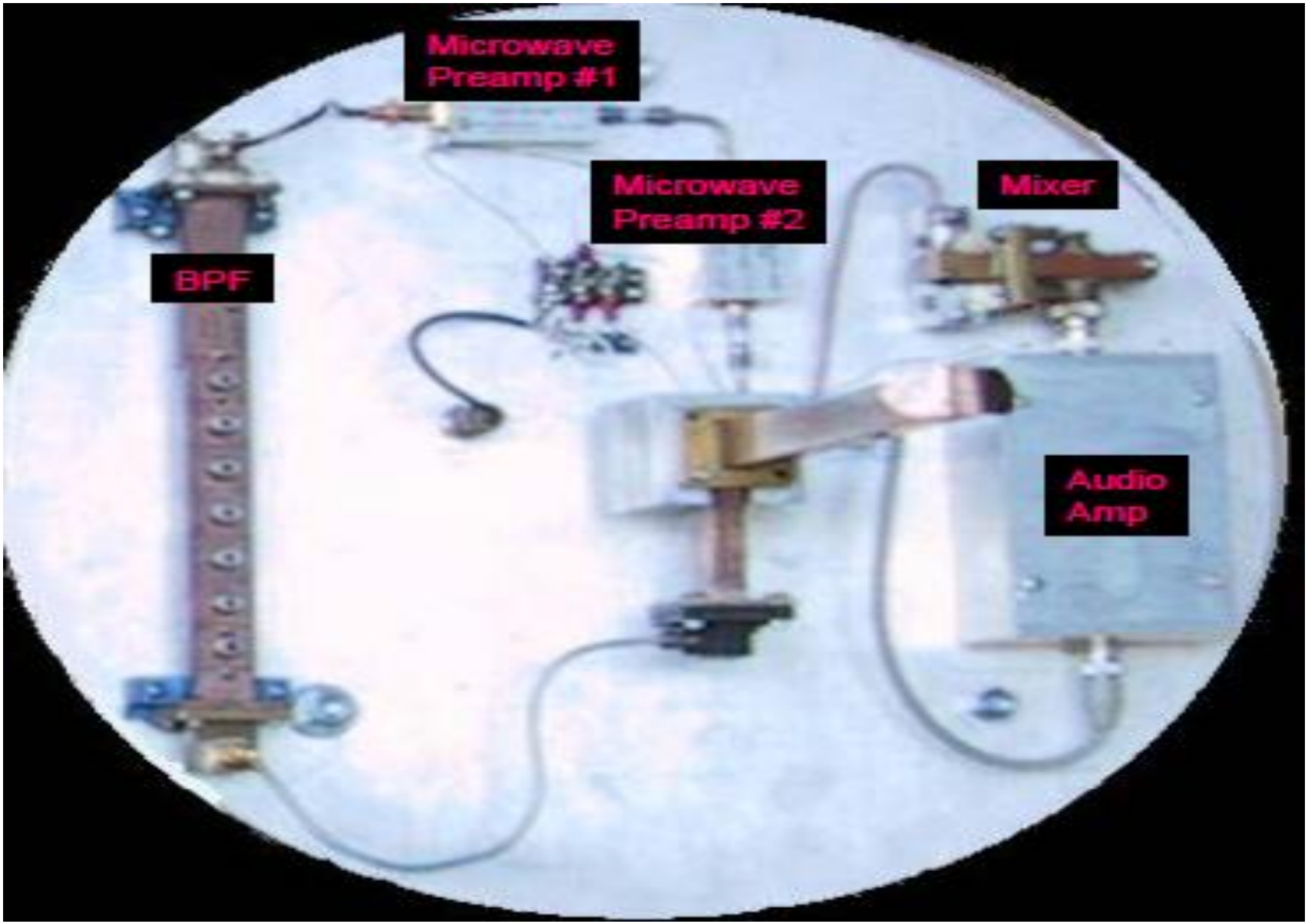
Radar Receiver



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Summary and Conclusion

- The advantages of FM-CW Radar are:
    - (1) low cost
    - (2) good sensitivity
    - (3) high spatial resolution
    - (4) high reliability
    - (5) portability
    - (6) simplicity
    - (7) safety
- FM-CW radar is capable of producing range-resolved velocities.
- FM-CW radar has limited range.

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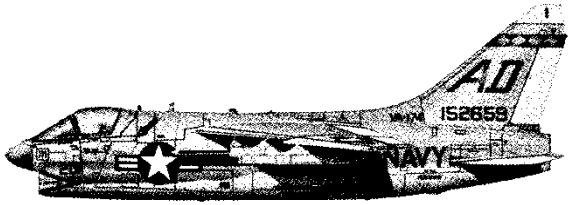

Transmission

Echo

Wasted Echo