Radar Systems - Paul A. Lynn
SUMMARY

1 Introduction
1.1 Historical Notes

Early work in radar used continuous-wave (SW) transmissions. These relied upon interference between a transmitted wave and the doppler-shifted signal recieved from a moving target. Detection of aircraft was first achieved in the USA in 1930.

CW can detect the presence, and direction if radio betam is narrow enough.
THEY CANNOT PROVIDE RANGE INFORMATION.

This can be overcome by modulating the CW - to from a train of pulses. The time taken for echoes to return to the receiver is then a direct measure of target range.

These are radar systems - ‘Radio Detection and Ranging’.

Before the Second Wolrd War, radio frequencies between 5-200MHz were used in radar. Equipment used was modified from radio broadcasting and reception.
Microwaves are far more desirable - as accurate location of a target requires a narrow radio beam.

THis is only possible if the antenna aperture is much greater than the radio wavelength lambda. At 200MHz (lambda = 1.5m) a very large antenna is needed.
Problems with - expense, steering difficulty, heavy wind loading. Unsuitable for ships and aircraft.

The development of the cavity magnetron by Randell and Boot in 1940 allowed transmission of 1kW power at 10cm wavelength - microwave radar was feasible.

Radar applications -
air traffic control
meteorology
speed traps
measurement of insect swarms and crop growth

1.2 Types of radar system

1.2.1 Transmission waveforms

4 categories

1) CONTINUOUS-WAVE (CW) radar
problem with ‘breakthrough’ where transmission is picked up by receiver and receiver can’t detect echoes from stationary targets - even if separate antennas are used for transmission and reception. Receiver has to rely upon the doppler effect to detect moving targets instead.

A small portion of the transmitter output is mixed with the received signal. The doppler, or difference, FREQUENCY is then extracted.

Doppler frequency is given by - $f_d=2v_r/\text{lambda}=2v_rf_o/c$

v_r = target velocity relative to radar - or the *radial velocity*
f_0 = transmitter frequency
c = velocity of radio waves ($3x10^8$ ms^{-1})

Homodyne detection - where transmission and received signals are directly mixed
Heterodyne detection - incoming signals are first converted to an Intermediate Frequency. - advantage - reduced noise.

applications - short-range with limited power, eg. radar speed traps.
Increased power - can't shield receiver from transmitter power output

2) FREQUENCY-MODULATED CONTINUOUS-WAVE (FM-CW) radar

Modulation of CW wave - wither **triangular or sinusoidal** modulation. The difference frequency or **beat frequency** is measured between instantaneous transmitter frequency and the frequency of a received echo, it is possible to infer the range of the target.

Triangular modulation- carrier frequency is changed linearly over time.

Suppose rate of change over a half-cycle of modulation is df_o/dt.
Echo from a target at range R (go and return path=2R) experiences time delay: $T_0=2R/c$. If target is stationary and there is no doppler shift - beat frequency is :

$f_r=T_o(df_o/dt) = 2R(df_0/dt)/c$

For a moving target there is an additional doppler shift imposed on f_r.
If transmitter frequency is instanteously increasing, net beat frequency due to an approaching target is (f_r-f_d) - for a receding target it is (f_r+f_d). Reverse these for transmitter frequency instanteously decreasing.

Average the net beat frequency over a complete modulation period, the beat frequency due to target range alone may be found. Thus

$f_r=0.5\{(f_r-f_d)+(f_r+f_d)\}$

There is ambiguity over interpretation of net beat frequency in an FM-CW radar. A given frequency may be produced either by a fast target at close range, or a by a slow target at far range.

The latter is normally designed for. This is where the range component f_r is much larger than the doppler component f_d. - application - radio altimeter used in aircraft.

3) PULSE RADAR

Transmitter sends out a train of short radio-frequency pulses. Target range is found by measuring the time for echoes to return to the receiver.

Major advantage - transmitter is off most of the time - more time to listen for returning echos without transmitter interference. Same antenna is used for reception and tranmission.

Reference diagram 1 below.
Pulse modulator turns on and off the transmitter
Transmitter output is fed to the antenna via a duplexer - protects receiver from excess of transmitter breakthrough. As soon as pulse transmission finishes, duplexer connects antenna to receiver.
Returning echos are first processed by a high-quality, low-noise amplifier.
Then converted to IF by mixing with output of local oscillator - using heterodyning.
At IF do further amplifying, bandlimitation to reduce system noise.
Received signal is then detected to produce a video waveform
Then final amplification and processing -> drives display - Plan Position Indicator. provides a bird's eye view.

Two important parameters are :

1) Pulse Repetition Frequency (PRF)
   Should be as high as possible - to avoid second-time-around echos. when echo is not detected in correct reception phase. This is another ambiguity problem in relation to the FM-CW radar.
2) Pulse Length
   Choice of pulse length is compromise between :
   1) very short pulse - good range resolution
      - allows accurate measurement of short ranges
   2) too short - detection becomes very difficult.

   practical pulse lengths - 0.1 to 5 microseconds.

   Note the USE OF PULSE COMPRESSION.
   where a much longer, coded pulse is transmitted - and echo's are sharpened in receiver using signal processing techniques.

Doppler shift effect is also very important.
Doppler info is not continuously available, as in CW systems.
Makes the info harder to extract from the received echoes.

The MOVING TARGET INDICATION (MTI) method has been developed for discrimination in favour of aircraft and other moving targets.

4) Pulse Doppler Radar - similar to MTI pulse radar. MTI Uses a PRF low enough to avoid second-time-around echoes. But problem with velocity ambiguity and to the occurence of *blind speeds*. THese are particular values of radial velocity at which targets tend to become invisible.

Pulse doppler achieves the opposite compromise by - using a higher PRF - however is susceptible to range ambiguity.

1.2.2 Operating frequencies

50cm produce negligible weather echoes
3cm cause evere ones
Consequence of the phenomenon of *Rayleigh Scattering* - where visibility of small water droplets to a radar is inversely proportional to the fourth power of the wavelength.

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Most pratical radars operate at wavelengths between 1 and 50cm.