Defence School of
Aeronautical Engineering

Aerosystems Engineer & Management Training School

Academic Principles Organisation

FT4

AVIONICS PART 2 PHASE 3
Radar

BOOK 3
Radar Transmitters & Receivers

WARNING

These course notes are produced solely for the purpose of training. They are not subject to formal amendment action after issue and they must NOT be used for operating and maintaining the equipment described. Operation and maintenance of equipment is governed by the limitations and procedures laid down in the authorized publications and manuals which must be complied with for these purposes.

RADAR TRANSMITTERS & RECEIVERS

OBJECTIVES

T.O.s – 42.1, 42.2, 42.3, 42.13

E.O **S92-01** Describe Aircraft Radar Fundamentals

KLP Ref: **S92-01- 04** Describe the principles and techniques of Radar Transmission

KLP Ref: **S92-01- 06** Describe the principles and techniques of Radar Reception

CONTENTS

Notes:

AIRBORNE RADAR TRANSMITTERS

Introduction

1. Although radar operates over a range of frequency bands in general airborne radars generate RF energy in the microwave region of the EM spectrum i.e. Upper UHF, SHF and Lower EHF bands

2. However there are several different ways of transmitting the microwave energy at these frequencies. The main forms of radar transmission being:

a. Pulsed.

b. Pure CW (Doppler).

c. Frequency Modulated CW (FMCW).

d. Pulsed Doppler: *(covered in Radar Techniques book4*)

i. Interrupted CW (ICW).

ii. Frequency Modulated Interrupted CW (FMICW).

Radar Transmitter Types

3. Radar transmitters operate over a wide range of frequency and power ranges and vary considerably in their design. The two main types of radar transmitters being:

a. High Power Oscillator (HPO) transmitters.

b. Master Oscillator Power Amplifier (MOPA) transmitters.

High Power Oscillator (HPO) Transmitter

4. Refer to Figure 1.

a. That the arrangement of the HPO type transmitter is different to a basic radio TX in that the RF osc is at the end of the transmitter chain.

b. The RF osc in a HPO is usually a Magnetron.

c. The HPO TX is normally used for Pulsed radar type transmission.

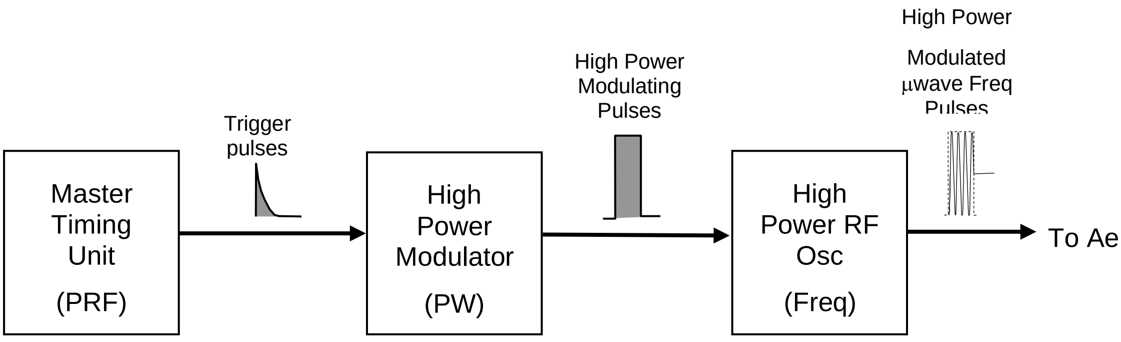


Figure 1 – High Power Oscillator Transmitter

High Power Oscillator (HPO) Transmitter Block Functions

5. Refer to Figure 1.

a. **Master Timing Unit (MTU):**

i. The MTU governs the Pulse Repetition Frequency (**PRF)**

ii. It does this by controlling the number of pulses transmitted every second to the High Power Modulator, trigger it “on”.

b. **High Power Modulator (Mod):**

i. The Modulator controls the Pulse Width (**PW)** of the system.

ii. When triggered by the MTU (at the PRF) the High Power Modulator generates the rectangular pulses of specific width, which are used to modulate the RF Oscillator switching it “on” and “off”.

c. **High Power RF Oscillator:**

i. The High power RF oscillator (Magnetron) determines value of the **RF Frequency** transmitted.

ii. When modulated by the High Power Modulator, It converts the rectangular pulses into bursts of High Power RF energy.

6. There are many different types of modulators the can be used in radar transmitters. The choice of modulator depends on many factors including;

a. The output power needed,

b. The type of RF oscillator used i.e. magnetron, klystron etc.

c. The precision of the pulse shape and width (PW).

7. One of the most common types of high power modulator used with HPO transmitters is the Pulse Forming Network (PFN).

Pulse Forming Network (PFN) High Power Modulator

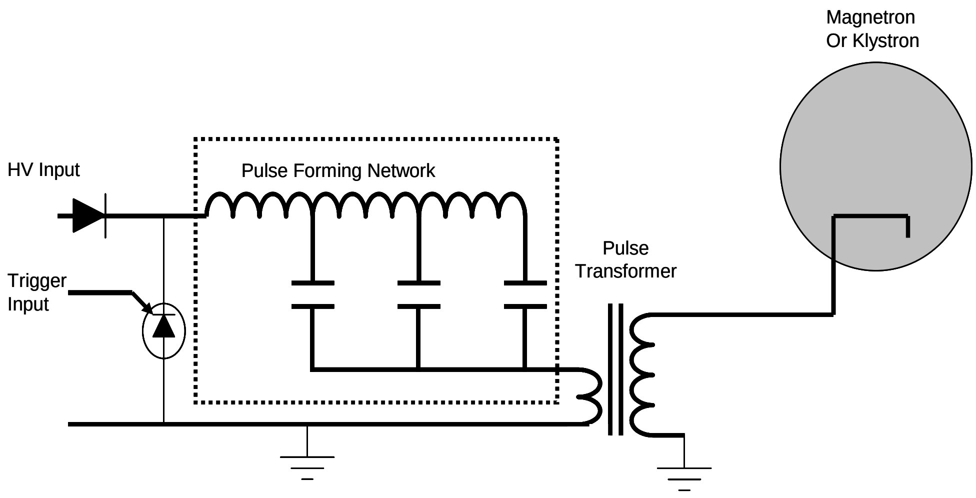


Figure 2 Pulse Forming Network (PFN) High Power Modulator

8. The PFN consists of a number (n) of L and C-sections in series similar to a piece of transmission line.

9. It has a "Characteristic Impedance" value $Z_O = \sqrt{(L \div C)}$

Modulating Pulses Formed by the PFN

10. The Pulse Width (PW) is equal to the discharge time (t) of the PFN which is determined by the formula $t = 2n\sqrt{(LC)}$ seconds

11. In between the TX firing, the PFN modulator charges up to the EHT voltage (kV).

12. On discharging the PFN forms a modulating pulse which is:

a. Large in amplitude - High Power

b. Rectangular, well - shaped, steep sided.

c. Precise in width = $2n\sqrt{(LC)}$ seconds

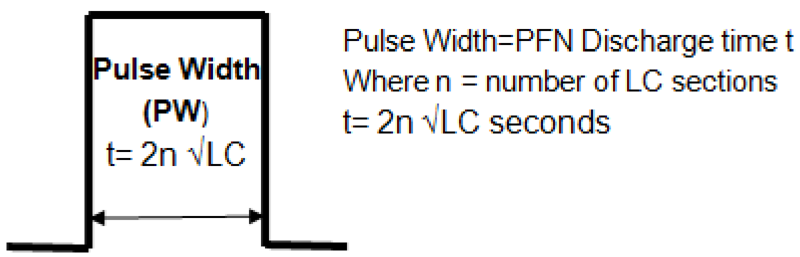


Figure 3 – PFN Modulating Pulse

Worked Example for PFN calculation

13. **Given:** For a PFN:

a. Number of LC sections n = 10

b. Value of Inductance L = 5μH (5×10^{-6})

c. Value of Capacitance C = 500pF (500×10^{-12})

Question: For the PFN in para 10a Calculate the:

a. Characteristic Impedance (Zo)

b. Pulse Width (PW) of the modulating output pulse

Answers:

a. $Z_O = \sqrt{(L \div C)}\ \Omega$

$= \sqrt{(5 \times 10^{-6} \div 500 \times 10^{-12})}$

$= \sqrt{10 \times 10^{3}}$

$\mathbf{Z_O = \underline{\underline{100}}\Omega}$

b. PW = 2n $\sqrt{(L \times C)}$ seconds

$= 2 \times 10\sqrt{(5 \times 10^{-6} \times 500 \times 10^{-12})}$

$= 20\sqrt{(2.5 \times 10^{-15})}$

$= 20\times (50 \times 10^{-9})$

$= 1\times 10^{-6}$ or

PW = 1μ second

Master Oscillator Power Amplifier (MOPA) Transmitter

14. Refer to Figure 4.

a. That the arrangement of the MOPA is similar to air communications transmitters in that the RF oscillator is at or near the beginning of the transmitter chain.

b. The MOPA can be used for both Pulsed and CW radar.

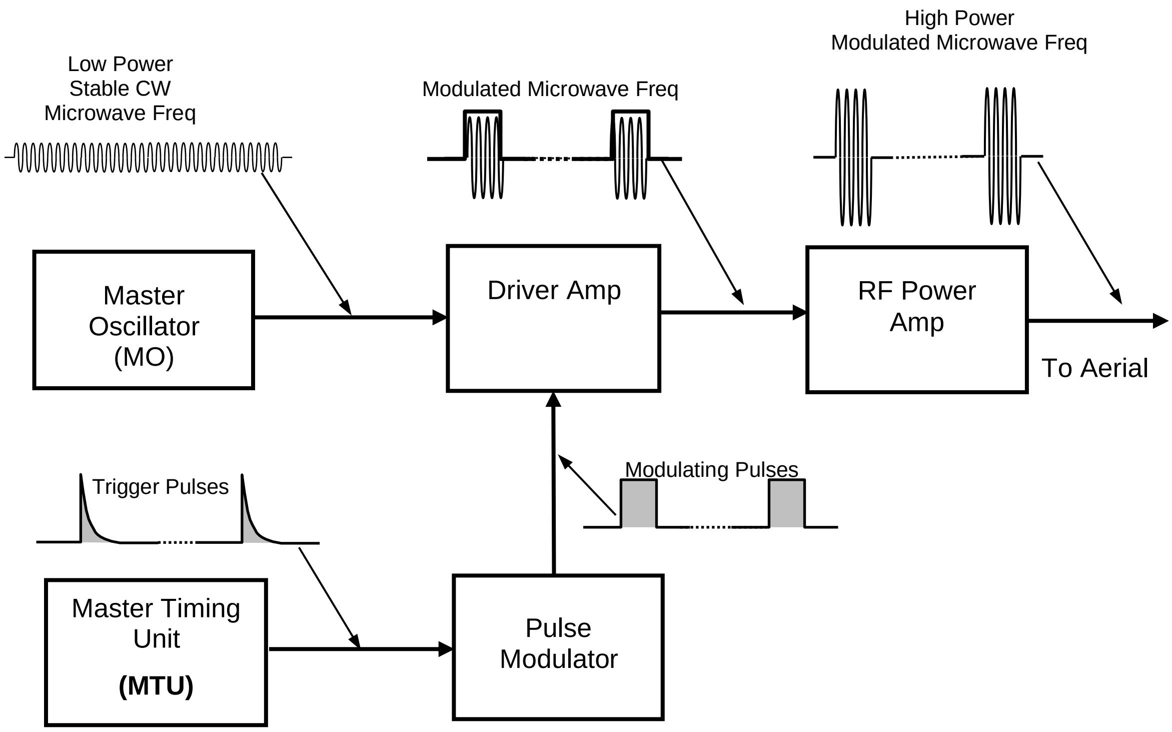


Figure 4 – Basic MOPA Transmitter

Master Oscillator Power Amplifier (MOPA) Block Functions

15. Refer to Figure 4.

16. **Master Oscillator (MO)**: Controls the transmitters RF output in the form of a low power, stable, CW microwave frequency.

a. Low power stable CW microwave oscillator, devices could include:

i. Resonant Cavity Oscillator.

ii. Gunn diode (semi-conductor).

b. To maintain frequency stability the MO:

i. Runs continuously and direct modulation is avoided.

ii. Normally runs at low power.

17. **Driver Amp**:

a. Pulse modulation of the low power CW microwave frequency and increased amplification takes place at this stage, avoiding the use of a high power modulator.

b. Devices that could be used are:

i. Double Cavity Klystron.

ii. TWT.

18. **Master Timing Unit (MTU)** – triggers the Pulse Modulator at the required Pulse Repetition Frequency (PRF).

19. **Pulse Modulator**

a. Controls the Pulse Width (**PW)** of the system by switching the Driver Amp “on” and “off” for fixed periods of time when triggered by the MTU (at the PRF).

b. Need only be a low power device to modulate the Driver amp.

20. **RF Power Amp**:

a. The output of the Driver Amp would be insufficient for achieving the range needed.

b. The RF power amp raises the output level to that required by the system.

c. Devices that could be used are:

i. Double or Multi-Cavity Klystron.

ii. High power TWT.

Advantages of a basic MOPA over a HPO

21. Only a low power modulator is needed because it does not have to provide the high power required to feed a single stage transmitter.

22. Frequency stability is much better.

23. Phase coherence between pulses is much easier to achieve.

AIRBORNE RADAR SUPERHETERODYNE RECEIVERS

Introduction

1. The function of the radar receiver is to process the target echo signals in the presence of noise, interference and clutter. It must separate wanted signals from clutter, and amplify those wanted signals to a level where target information can be displayed.

2. In general the majority of pulsed radar receivers are quite similar to airborne radio superheterodyne receivers though there are some differences.

3. The basic requirements of the airborne radio superheterodyne receiver is to obtain adequate signal amplification and constant selectivity over a wide tuning range by converting all incoming radio-frequency signals to a fixed (generally lower) radio frequency the IF at which high amplification and good selectivity can be obtained. Following this the audio signal can then be recovered and by detecting it and applying final power amplification.

4. Radar receivers for pulsed radar used for airborne interception (AI) have to be able to cope with a very wide range in the strength of returning signals.

5. For example it could be that the amplitude of the echo return from a target 50 miles away could be in picovolts (10^{-12} volts) compared with millivolts (10^{-3} volts) from a target 1 mile away.

6. Therefore for an AI pulsed radar it is quite likely that the features of the returning rectangular echo pulses could be:

   a. Extremely small (i.e. $10^{-9}/10^{-12}$ nano/pico volts).

   b. Very narrow (nano seconds)

   c. Well shaped (steep sided with square edges)

7. Perfect square or rectangular waveforms are made up of an infinite number of odd harmonic waveforms.

8. To process such pulses with minimal distortion, radar superheterodyne receivers need to have:

   a. Low Noise Factor (N/F)

   b. Extremely high gain.

   c. Very Wide Band Width (B/W)

Radar Superheterodyne RX - with Automatic Frequency Control (AFC)

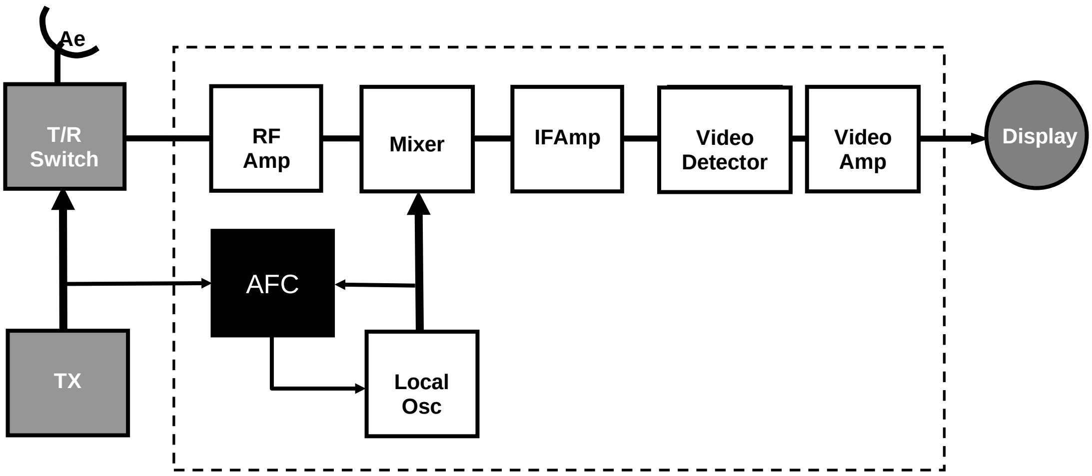


Figure 1 - A Typical Pulsed Radar Superheterodyne Receiver with (AFC)

Radio Frequency (RF) Amplifier Stage

9. The RF amplifier has two main functions:

a. It provides a small amount of gain to the signal, enough so that it can be dealt with by the mixer stage.

b. It lowers the noise factor (NF= S/N in ÷ S/N out) of the whole receiver, allowing the processing of extremely small signals. This in turn could lead to a reduction in transmitter power and/or the antenna size.

10. Low noise devices that could be used as RF amplifiers include: Travelling Wave Tubes (TWTs) and Semi-conductor devices called GaAs FETs, which are field effect transistors (FET) made from Gallium Arsenide (GaAs).

11. Unlike the Air Communications analogue superheterodyne receiver the RF amplifier in radar superheterodyne receivers is not tuned with LO. This is because it is not just looking for one specific frequency but has to accept a wide B/W of frequencies necessary to preserve the pulse shape.

Mixer Stage

12. This stage mixes together the RF frequencies of the received echo pulse and LO frequency to produce the wanted intermediate frequency (IF). The microwave frequencies (GHz) of the RF echo pulses are converted to a lower intermediate frequency (IF), typically somewhere between 30MHz and 90MHz.

Balanced Mixing

13. If the local oscillator (LO) is a noisy device such as a reflex klystron, it will introduce large amounts of noise that reduces the signal-to-noise ratio of the receiver therefore decreasing the effective range of the radar.

14. By using balanced mixer circuits the noise produced by the local oscillator (LO) can be cancelled.

Local Oscillator (LO) Stage

15. The function of the local oscillator (LO) is to provide a continuous low amplitude frequency input to the mixer that when mixed with the received echo signal produces the intermediate frequency (IF).

16. HPO transmitters usually have a Magnetron RF oscillator, which can be frequency unstable. To compensate for this electronically tuneable local oscillators are used (e.g. reflex klystron or Gunn Diode device), which can vary their output frequency.

Automatic Frequency Control (AFC).

17. (Refer figure 1) The purpose of the automatic frequency control (AFC) is to maintain a constant IF from the mixer stage, it does this by monitoring the TX frequency and adjusting the LO frequency to the correct output

18. Any frequency drift of the transmitter output has to be mirrored by the local oscillator frequency.

a. If the transmitter frequency increases by 50 KHz, then the AFC causes the local oscillator to increase its frequency by 50 KHz maintaining the IF.

b. If the transmitter frequency decreases by 40 KHz, then the AFC causes the local oscillator to decrease its frequency by 40 KHz maintaining the IF.

Intermediate Frequency (IF) Amplifier Stage

19. The main requirements of the radar IF amplifier are:

   a. Provide the majority of the receivers gain typically in the order of millions.

   b. Have a very wide bandwidth (B/W) to preserve the square pulse shape.

   c. Be very stable, preventing any tendency to oscillate.

20. Radar echo pulses are generally square or rectangular waveforms that are made up of an infinite number of odd harmonic waveforms. To preserve the pulse shape and avoid distortion, the IF amplifier bandwidth (BW) must be related to the pulse width (PW) of the transmitted pulse, as shown below.

21. Bandwidth (BW) and pulse width (PW) are inversely proportional.

$$\textbf{Band Width (BW)} = \frac{\mathbf{1}}{\textbf{Pulse Width (PW)}}$$

Therefore a 1μs pulse would need a receiver with a bandwidth of:

$$BW = \frac{1}{\mathbf{1 \times 10^{-6}}}$$

$$BW = \frac{1 \times 10^{6}}{\cancel{\mathbf{1 \times 10^{-6}}}}$$

$$\underline{\underline{BW = 1\ MHz}}$$

Therefore the narrower the pulse width (PW) the wider the receiver BW has to be.

22. For an amplifier the Gain and B/W product (G x B/W) is a constant, if B/W is increased the Gain must decrease. However the radar IF amplifier stage requires both very high gain and wide bandwidth (B/W).

23. The bandwidth of pulse radar receivers is far wider for analogue communication receivers and many different techniques have been developed to produce the required combination of very high gain and wide bandwidth (B/W). One such technique is called "Stagger-Tuning".

Staggered-Tuning

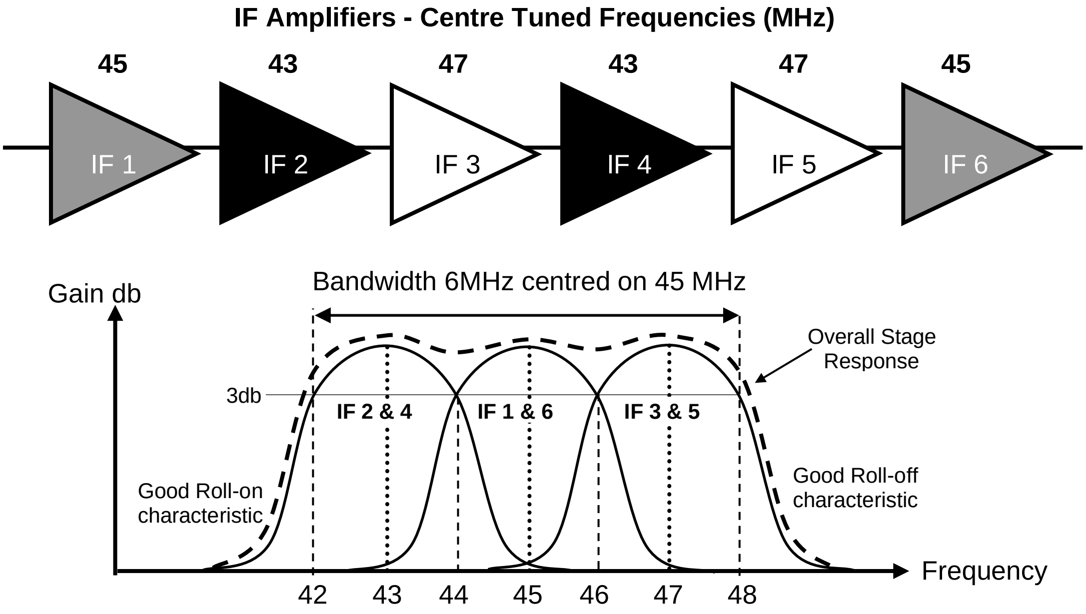


Figure 2 – Typical "Stagger Tuned" IF Amplifier Stage

24. Refer Figure 2.

a. Each of the IF amplifiers within the IF stage has to provide very high gain but with a relatively narrow bandwidth of about 2MHz.

b. If these IF amplifiers were all tuned to the same centre frequency say 45MHz, their narrow (2MHz) bandwidth would distort the pulse shape.

c. To ensure that the IF stage provides both the very high gain required and preserves the pulse shape, the overall bandwidth of the IF stage can be increased by staggering (offsetting) the centre tuned frequencies of the individual IF amplifiers above and below the wanted IF frequency.

d. In this example the required IF is 45MHz:

i. IF amplifiers 1 & 6 are tuned to the required IF of 45MHz,

ii. IF amplifiers 2 & 4 are tuned lower to 43MHz

iii. IF amplifiers 3 & 5 are tuned higher to 47MHz,

e. Stagger tuning the IF amplifiers has increased the overall IF stage bandwidth to 6MHz but is still centred on the wanted IF of 45MHz.

25. Because the IF stage uses several very high gain amplifiers in series they can become unstable with a tendency to oscillate, this can be prevented by:

a. Adequate decoupling of the stages.

b. Careful screening of components.

c. The use of small amounts of negative feedback.

d. Good circuit design.

Video Detector (Demodulator) Stage

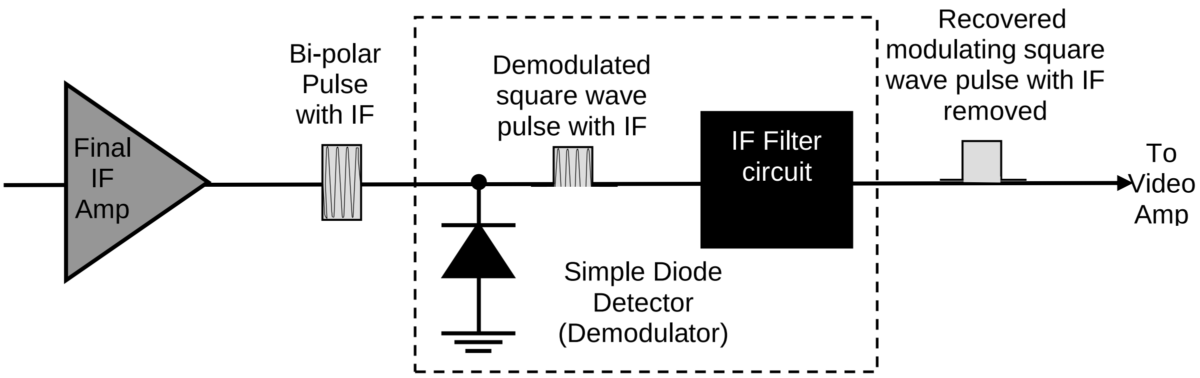


Figure 3 – Simple Diode Detector and IF Filter

26. (Refer to figure 3). The function of the video detector is to demodulate the bi-polar pulse output of the IF amplifier to recover the original modulating square wave pulse shape, though it will be much smaller in amplitude.

27. A simple diode can be used as the detector by removing the positive or negative half of the bi-polar pulse.

28. The pulse now passes through filter circuits to remove the unwanted IF carrier ripple frequency before is fed to the video amplifier.

Video Amplifier Stage

29. The function of the video amplifier is to provide sufficient gain to the pulse waveform to drive the display or indicator.

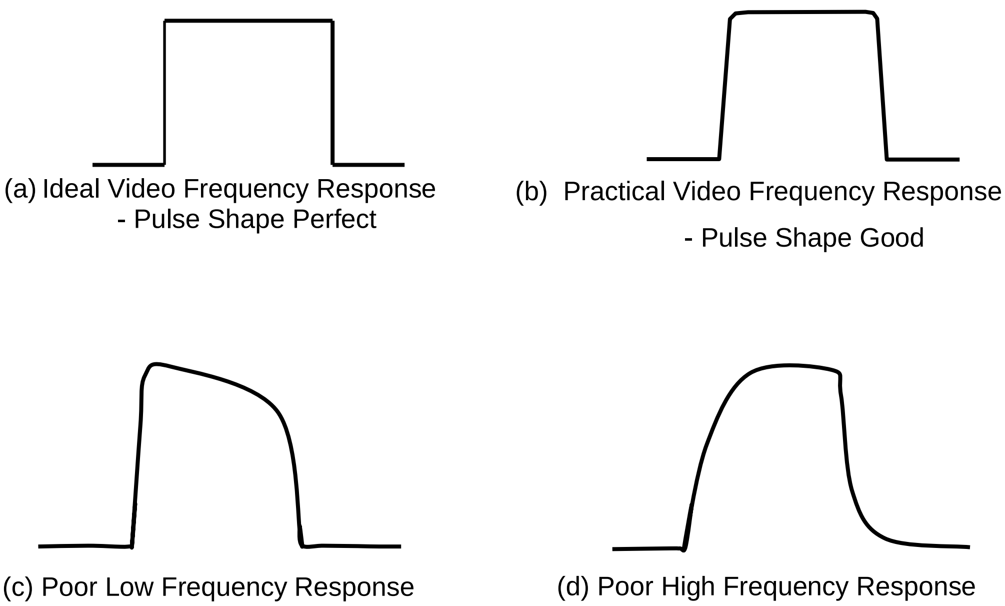
30. To accurately represent target range information on the display the pulse waveform must not be distorted and have a steep leading edge (refer figure 4a).

31. The video amplifier therefore has to be a wide bandwidth amplifier so that it amplifies equally all the odd harmonic frequencies components that make up a square wave pulse, typically in a range from 100 Hz up to 2 MHz or for very narrow pulses up to 6MHz.

32. Figures 4a & 4b below illustrate a perfect and good practical pulse shape with almost equal amplification of the square wave frequencies components.

33. Figures 4c & 4d illustrate distortion of the pulse shape in the video amplifier due to unequal amplification of the square wave frequency components.

34. Although very difficult to achieve these problems can be overcome by the use of frequency compensation circuits.



(a) Ideal Video Frequency Response - Pulse Shape Perfect

(b) Practical Video Frequency Response - Pulse Shape Good

(c) Poor Low Frequency Response - Pulse Shape Distorted

(d) Poor High Frequency Response - Pulse Shape Distorted

Figure 4 – Video Amplifier Frequency Response

NOISE AND CLUTTER REDUCTION TECHNIQUES

Introduction

34. For even the most basic radar receiver to function adequately it must be able to detect and process the returning echo signals in the presence of noise and clutter so that the target information can be displayed and used.

35. **Noise** is due to **random** variations in the signal that originate either externally or more likely internally within the receiver itself from its electronic components.

36. **Clutter** on pulse radar is due to unwanted reflections or echoes from natural and man-made objects such as ground, clouds and rain or buildings and makes it difficult to identify targets on the display. Clutter returns produce **fairly constant** effects on the radar display unlike noise, which is random.

37. If clutter objects are very close to the radar they can saturate or paralyse the receiver such that it cannot detect even large target returns until the effect has dissipated and the receiver returns to normal operation.

Techniques for Removing Clutter

38. To reduce clutter, the following are examples of processing techniques that could be used:

a. Fast Time Constant (FTC)

b. Swept Gain or Sensitivity Time Control (STC).

c. Logarithmic IF amplifier

Fast Time Constant (FTC)

39. **'Short CR Time' Differentiating Circuit.** (Refer Figure 5).

a. If the input is a narrow pulse, with a duration similar to the CR time constant of the circuit, then the output pulse shape is much less affected.

b. If the input is a long pulse, with a duration much greater than the CR time constant of the circuit, then the output pulse shape will be greatly affected. Having one small positive pip at the leading edge of the pulse, a negative pip at the trailing edge of the pulse.

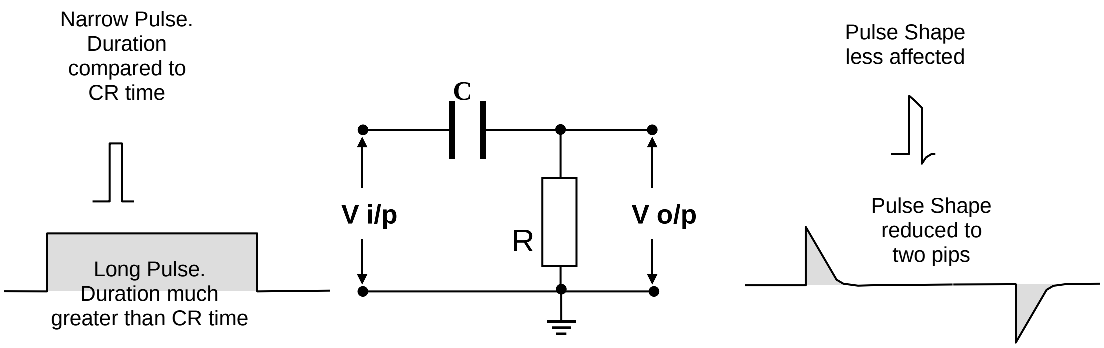


Figure 5 – Short CR Time Differentiating Circuit

40. **Fast Time Constant (FTC)**. Figure 6 shows how the Fast Time Constant (FTC) technique reduces clutter by means of a Short CR Time Differentiating Circuit.

a. Due to the amount of reflected energy present, clutter pulses may be considered to be 'long pulses'.

b. Individual target returns will have a short duration are much less affected by the FTC.

c. A further improvement to the clutter removal is achieved by using a Negative limiting Diode after the FTC circuit. This removes any negative blips from the trailing edge of the clutter pulse.

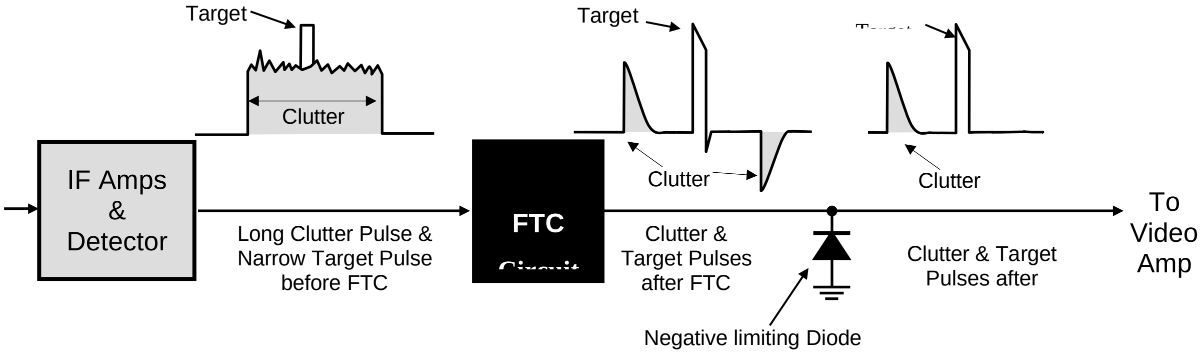


Figure 6 - Fast Time Constant (FTC) Clutter Reduction

Swept Gain or Sensitivity Time Control (STC)

41. At short ranges radar will detect many strong returns such as the ground directly below the aircraft that will increase the clutter on the display and may even mask close range targets.

42. Swept Gain or Sensitivity Time Control (STC) would reduce the receiver gain to reduce near ground clutter and as the range increases the gain would be increased so weaker distant targets are seen clearer.

43. Figure 7 shows a typical Swept Gain/STC waveform in relation to the transmitted pulse. As the transmitter fires, the Swept Gain/STC circuit decreases the receiver gain to minimum, at the end of the transmitted pulse the gain is gradually increased to the maximum at some pre-determined range from the radar e.g. 20 nm.

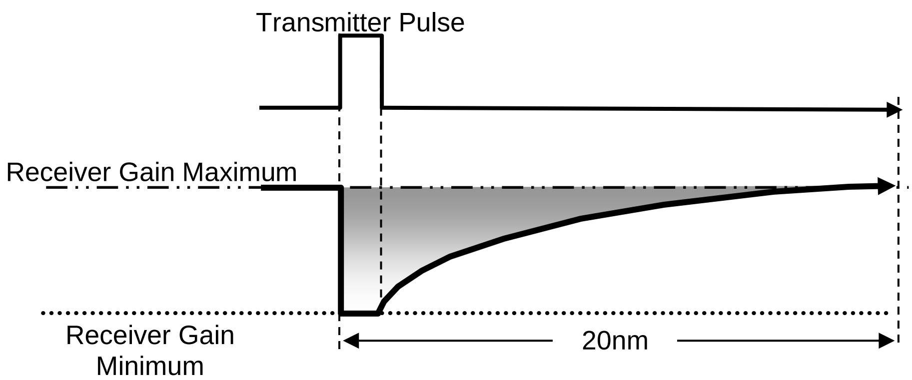


Figure 7 – Swept Gain or Sensitivity Time Control (STC)

Logarithmic IF amplifier

44. The Swept Gain or STC technique has its limitations:

a. If the amount of clutter is not the same on all bearings the Swept Gain setting must be a compromise good on some parts of the sweep poor on others.

b. Therefore to keep the performance at its best the operator must constantly adjust the swept gain settings, which is not practical.

45. The Logarithmic IF amplifier receiver acts as an ideal swept gain system:

a. The Log IF Amp element reduces short-term clutter as effectively as an ‘automatically adjusting’ swept gain system.

b. The addition of a Fast Time Constant (FTC) circuit reduces any long-term clutter.

46. The Logarithmic IF amplifier behaves as Lin-Log amp (a linear and Logarithmic amplifier) this means that:

a. For extremely small signals e.g. echoes from long range it acts as a linear amplifier providing maximum gain.

b. For large signals e.g. echoes from short range it acts as a Logarithmic amplifier providing little gain.

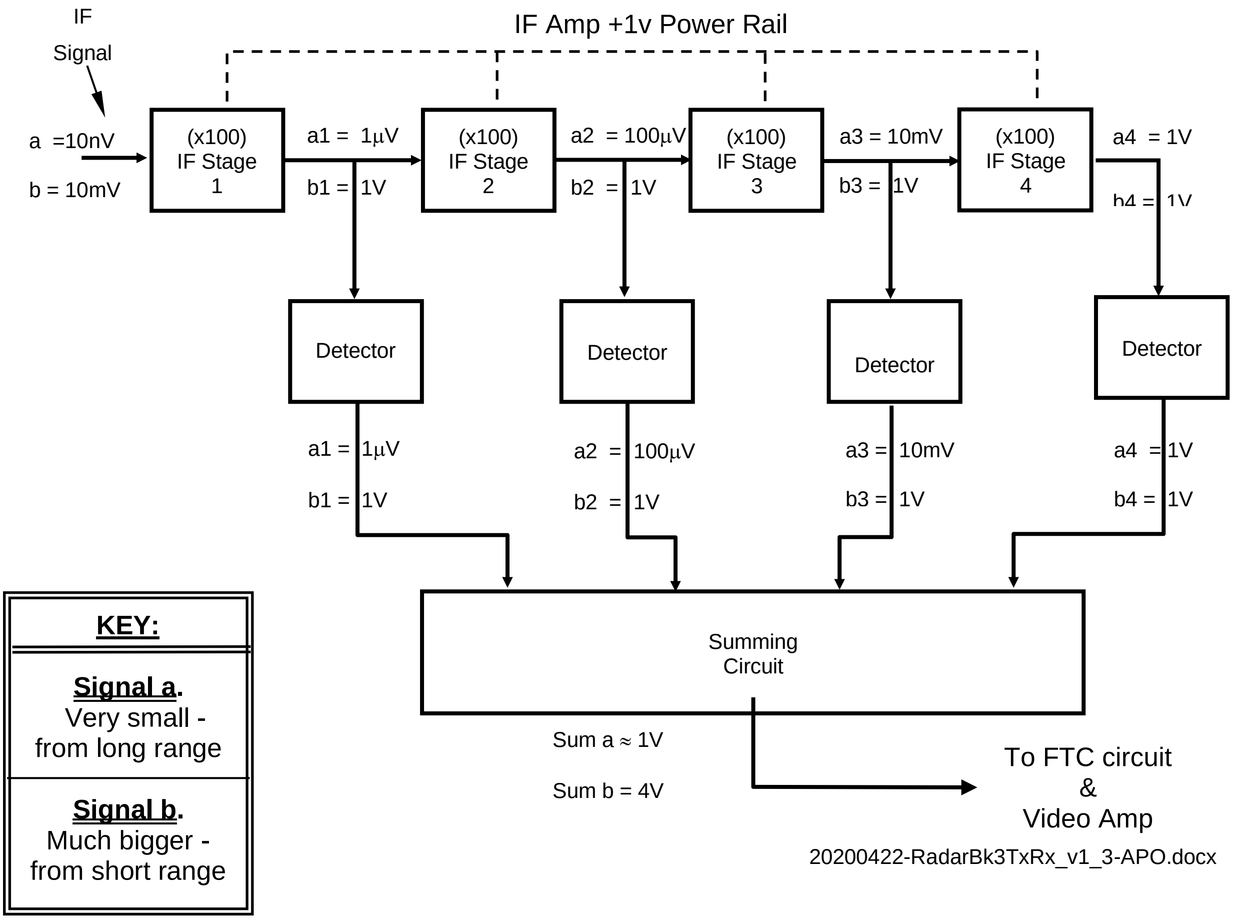


Figure 8 - Logarithmic IF Amp

Worked Example: Logarithmic IF amplifier

47. (refer figure 8)

a. **Given:** Each of the three stages of the log amp has a gain of 100 and the maximum output voltage of each stage is 1volt (the supply voltage).

b. Determine the output from the summing circuit (to the nearest volt) for the following inputs:

i. Input (**a**) = 10nV = $(1/100)^4$. A very small signal from long range.

ii. Input (**b**) = 10mV = $(1/100)^1$. A much bigger signal from short range.

c. Answers: the output voltage sum for inputs (to the nearest volt):

i. Output (**a**) = 1V

ii. Output (**b**) = 4V

48. It can be seen that from paragraph 47b above that:

a. Input signal (b) is bigger than Input signal (a) by a power of 4

b. Output sum (b) however is only 4 times bigger than the Output sum (a).

c. A logarithmic relationship is said to exist between input and output over the given input range.

Noise Reduction Techniques

49. There are many different techniques used to reduce noise.

50. They vary in complexity some require modification of the existing IF and detector stages others a completely different type of IF stage:

51. Two common methods are:

a. Matched Filter Noise Reduction.

b. Adaptive Noise Reduction.

Matched Filter Noise Reduction

52. Provides the maximum Signal/Noise ratio (S/N) under given conditions.

53. Refer figure 9a & 9b. The IF stage act as a filter to pass the signal and reject the noise.

54. The Band Width of the filter must be carefully matched to the required signal:

a. Too wide and excess noise is received – gives poor S/N.

b. Too narrow and signal energy is lost– gives poor S/N.

55. The matched filter operates at the optimum Band Width where S/N is maximum, this occurs when the filter Band Width is equal to 1/Pulse Width (P/W) i.e. if P/W = 1μs the Band Width = 1MHz

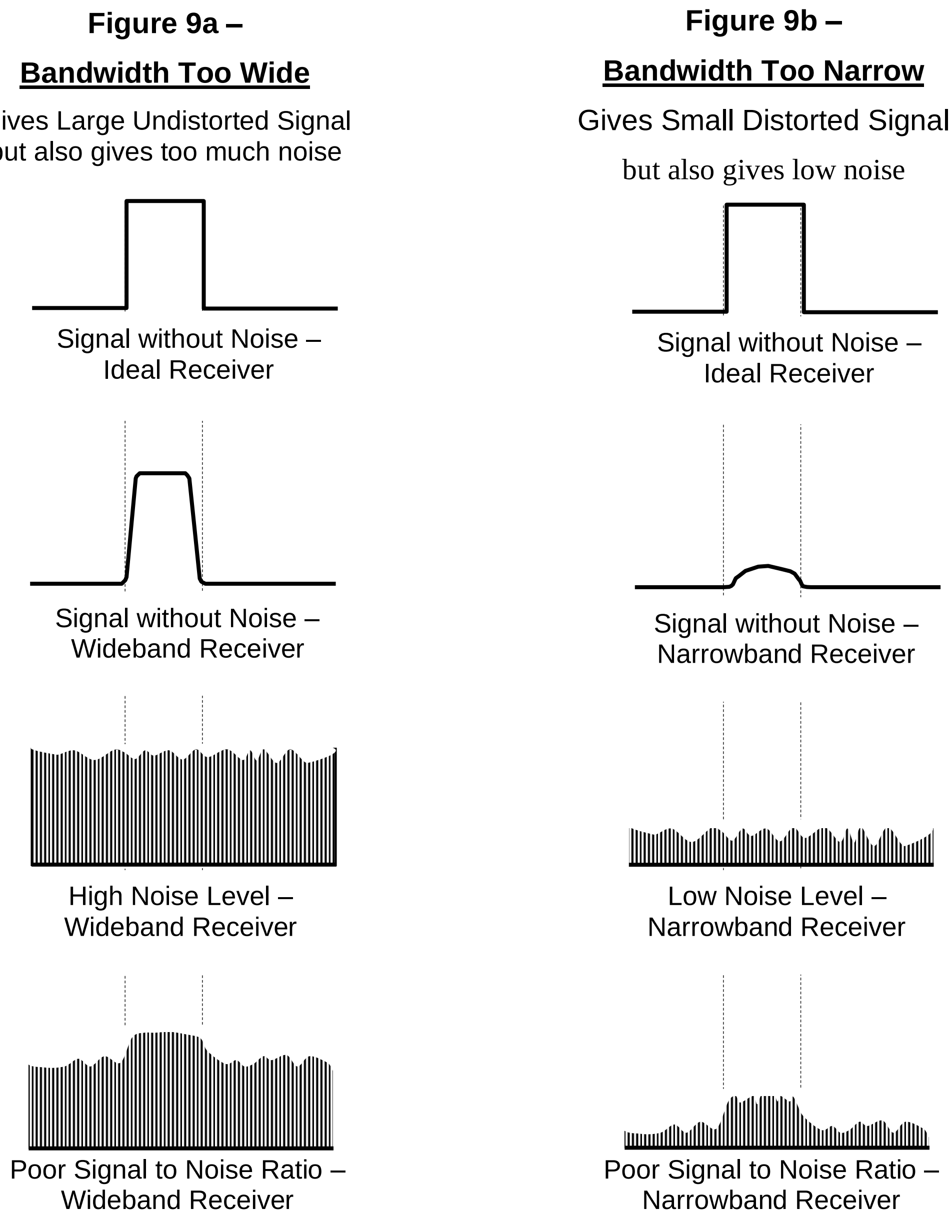


Figure 9 – The Need to Match Receiver Bandwidth to Noise and Signal

Adaptive Circuit Techniques

56. Adaptive circuits make evaluations of input parameters and automatically change circuit parameters to either correct errors or adapt to new conditions. In effect, the circuit could be said to learn and this almost always involves feedback and/or comparison with reference values.

57. The adaptive noise reduction circuit in figure 10 is needed to maintain the ability of the radar to see targets against a certain set level of background noise, which if it was to go above a certain level then the noise could eventually mask targets.

58. Slowly changing noise levels are be dealt with by adjusting a variable gain stage of the IF amplifier, which is arranged so that Low Pass Filter does not respond to sudden changes that could be a target pulse. In radar, adaptive circuits are used to reduce the false alarm rate (i.e. stop noise being treated as targets) and improve performance in noisy environments.

59. This is dealt with by adjusting a variable gain stage in the IF amplifier. The Low Pass Filter only let the noise element of the signal through modifies the amount of gain relative to the amount of noise detected compared to the set noise reference level, but does not respond to sudden changes that could be a target pulse.

60. In radar, adaptive circuits can be used to reduce the false alarm rate (i.e. stop noise being treated as targets) and improve target detection performance in noisy environments.

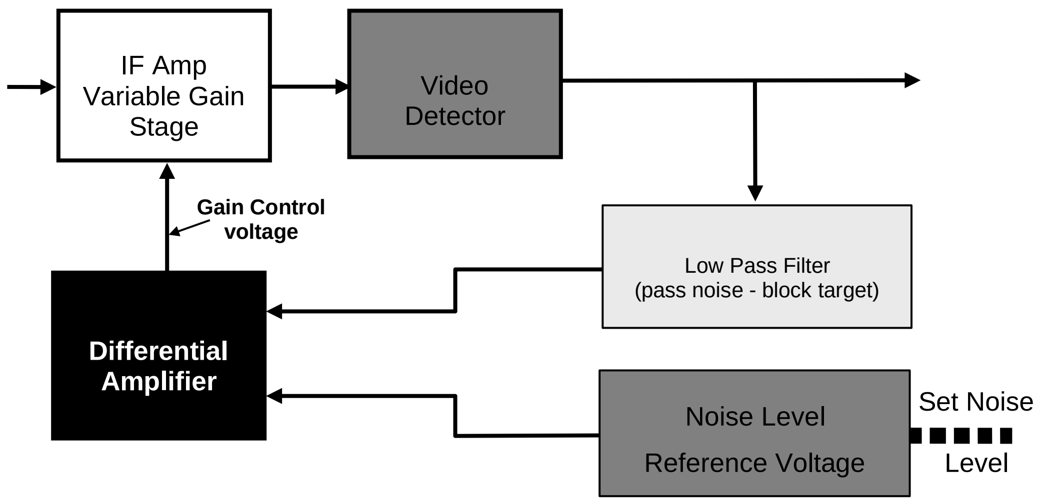


Figure 10 - Adaptive Noise Reduction