FORWARD SHIFTING FALSE TARGET JAMMING FOR LINEAR FREQUENCY MODULATION RADARS

A Project report submitted in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY
IN
ELECTRONICS AND COMMUNICATION ENGINEERING

Submitted by

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PRAGNANAM BRAHMA
ANITS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES
(UGC AUTONOMOUS)
(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade*)
Sangivalasa, Bheemili Mandal, Visakhapatnam dist. (A.P)
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CERTIFICATE

This is to certify that the project report entitled **"Forward Shifting False Target Jamming for Linear Frequency Modulated Radars"** submitted by **A Yeswanth Sai (317126512002), B S P Sumanth (317126512004), G V K Viswanath (318126512L12), N Arun Teja (317126512042)** in partial fulfilment of the requirements for the award of the degree of **Bachelor of Technology** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

A method of frequency-shifting deceptive jamming is described in the paper on linear frequency modulated pulse compression radars. The method explores the different jammings caused by the two kinds of jamming signals, which are the single false target jamming and multiple false target jamming. A frequency shifting deceptive jamming linear frequency modulated (LFM) signal is transmitted which creates a false target to mislead the enemy radar. In the LFM signal a jamming frequency is added and transmitted with the original target signal which creates a false target. In all the previous methods, the false targets fall behind the true target so it is possible to detect the true target therefore in this paper a forward shifting jamming signal is used which transmits a jamming signal of frequency mismatching which creates a false target in earlier to the original target. It describes the mathematical expressions related to the jamming signals before and after the matched filtering and gives the relationship between the amount of frequency-shifting and the relative distance of the true targets and false targets. It also analyses the jamming energy loss occurred by frequency mismatching and gives theoretical support to the jammer when the jammer power is set. Lastly, the simulation results are given and the results verify the correctness of the theory.

LIST OF SYMBOLS

c	Speed of light
B	Bandwidth of signal
Pt	Pulse train
d	Pulse duration
μ	Frequency modulation slope
T	Pulse width
k	Attenuation constant
f_J	Jamming frequency of radar
Fs	Sampling frequency
u(t)	Radar signal
U(f)	Frequency spectrum
h(t)	Matched filter response
$s_t(t)$	Output target echo after matched filtering

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LIST OF ABBREVIATIONS

RADAR	Radio Active Detection and Ranging
SNR	Signal to Noise Ratio
LFM	Linear Frequency Modulation
DRFM	Digital Radio Frequency Memory
FFT	Fast Fourier Transform
FM	Frequency Modulation
AWGN	A White Gaussian Noise
PCR	Pulse Compression Radar
ECM	Electronic Countermeasures
PRF	Pulse Repetition Frequency
PRR	Pulse Repetition Rate
PRT	Pulse Repetition Time
AM	Amplitude Modulation
PRI	Pulse Repetition Interval
CW	Continuous Wave
RF	Radio Frequency
SAW	Surface Acoustic Wave
NLFM	Non Linear Frequency Modulation
MATLAB	MATrix LABoratory
LINPACK	
EISPACK	

CHAPTER 1

Introduction

CHAPTER 1

Introduction

In this chapter, a keen introduction regarding our project is given which justifies the solution to our problem posed, defines our project topic, and explains the aim, and scope of our work done. Thus, giving an entire overview of our project.

1.1 Aim and Scope

RADAR technology has firmly established itself as one of the primary tools across various fields of research and operational use. The use of radar technology in meteorology has evolved since its inception during World War II. RADAR plays an important role in almost both civil and military fields due to its all-weather, and day-night capacities superior to the other optical sensors. Whenever a RADAR transmits a signal it strikes the object and gets reflected known as an echo. A radar obtains information about a target by comparing the received echo signal with the transmitted signal. The availability of an echo signal indicates the presence of a reflecting target, but knowing a target is present is of little use by itself. Something more can also be known. A radar provides the location of the target as well as its presence. It can also provide information about the type of target. The availability of an echo signal indicates the presence of a reflecting the location of the target as well as its presence. It can also provide the delay between the transmission of the radar signal and the receipt of an echo is a radar. Here this is not acceptable in all cases due to security purposes. For example, in case of wars, if the enemy RADAR transmits a signal, they will receive an echo reflected by our spaceship or missiles, they will find the position of our missile and destroy it. So, in order to protect our target of interest from being detected by the enemy RADAR, we need to hide the target echo.

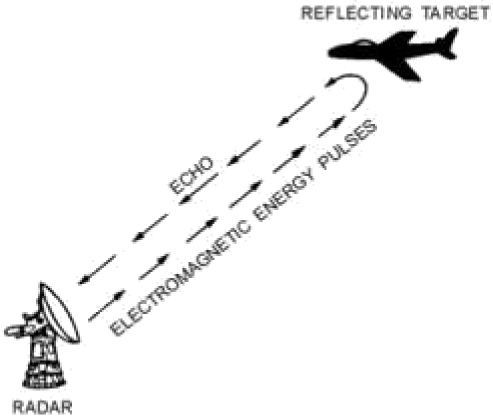


Figure 1.1 RADAR echo

1.2 Project Overview

RADAR plays an important role in almost both civil and military fields due to its all-weather, and day-night capacities superior to the other optical sensors. To protect the targets of interest (TOI) from being detected by the enemy RADAR, radar jamming techniques have been widely studied over the past few decades, including noise jamming and deception jamming. In deceptive jamming, it is mainly based on jamming in distance or in velocity which are based on DRFM. Using DRFM technology, the false targets that are created always lags behind the original target. So, it is possible for enemy radar to detect the original target signal. The method of Frequency Shift Jamming is a radar deception jamming technique proposed in 2009. This method is mainly based on jamming in distance. In this method a forward shifting false target is produced by using the frequency mismatching transmitted jammer. In this method, a jamming frequency f_J is added to the LFM radar modulating signal and which should be greater than zero $f_J>0$ to have forward shifting jamming.

The pulse compression technology has been extensively used in the modern radars as it decreases the pulse width to less than hundreds or thousands of microseconds which helps in improving the range resolution of the radar also. This technology gives high compression ratio which improves the signal to noise ratio and also helps to prevent jamming at the same time. So the pulse compression radars are difficult to jam. The three main jamming methods to linear frequency modulated pulse compression radars are noise blanket jamming, velocity deceptive jamming and distance deceptive jamming. The deceptive jammings are based on the technology of Digital Radio Frequency Memory(DRFM). With the increase in developments of DRFM technology, the jamming methods based on DRFM technology such as time delayed jamming based on DRFM, the distance-doppler multiple-false targets jamming based on DRFM and the combination jamming based on DRFM, etc. But the false targets generated in these methods always lags behind the true target which allows the radar to detect it easily. A method in which forward shifting false target is produced using the frequency mismatching transmitted jammer based on the LFM signal. Based on the group delay, the forward and backward shifting false targets produced by frequency shifting is explained.

In this method of forward shifting false target jamming two types of jamming signals are produced based on different frequency shifting rules and obtains the mathematical expressions for the two types of jamming signals after matched filtering. It also analyses the each jamming effect in detail. Firstly, the target echo passing through the matched filter is analysed and then it obtains the output equations after passing through the matched filtering. The simulation results are obtained from the single false target jamming and multiple false target jamming.

CHAPTER-2

RADAR

CHAPTER – 2

RADAR

2.1 Study about Basic Radar

RADAR is an electromagnetic system for the detection and location of reflecting objects such as aircraft, ships, spacecraft, vehicles, people, and the natural environment. It operates by radiating energy into space and detecting the echo signal reflected from an object or target. The reflected energy that is returned to the radar not only indicates the presence of a target, but by comparing the received echo signal with the signal that was transmitted, it’s location can be determined along with other target related information. Radar can perform its function at long or short distances and other conditions impervious to optical and infrared sensors.

RADAR is Radio Detecting And Ranging.

Radar is an electromagnetic system for the detection and location of reflecting objects such as aircraft, ships, vehicles, people and the natural environment. It can operate in darkness, haze, fog, rain, and snow. Its ability is to measure distance and position with high accuracy and in all weather, conditions is one of its most important attributes. The concepts from radar engineering can very well be used in satellites and microwave radio systems.

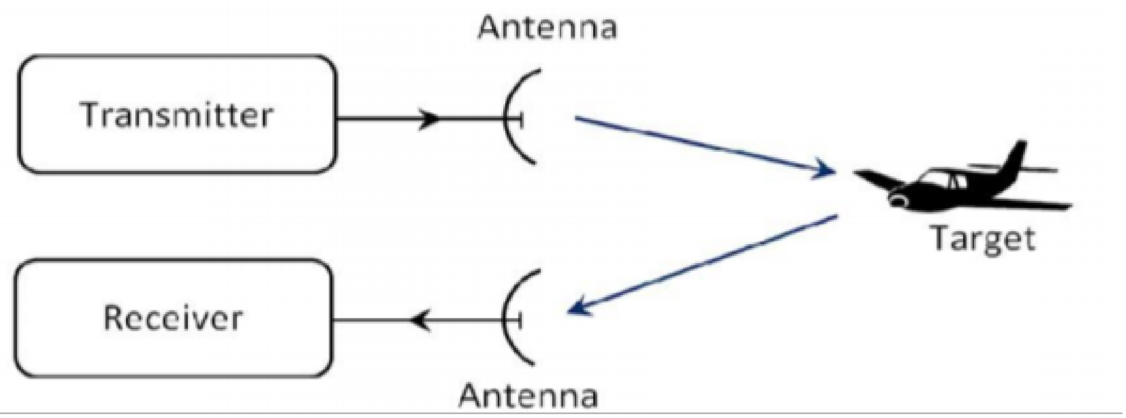


Figure 2.1 Elementary form of radar

A radar consists of a transmitter and receiver, each connected to a directional antenna. The transmitter radiates or transmits electromagnetic radiations generated by a magnetron oscillator. The receiver antenna collects the returned echo signal and delivers it to the receiver where it is processed to detect the presence of the target and to extract its relative velocity with respect to radar station if the target is moving. Pulse Repetition Frequency (PRF) or Pulse Repetition rate (PRR) is the number of pulses per unit time. These pulses are transmitted by a highly directional parabolic antenna at the target, which can reflect (echo) some of the energy back to the same antenna. The reflected energy is received, and time measurements are made, to determine the distance of the target.

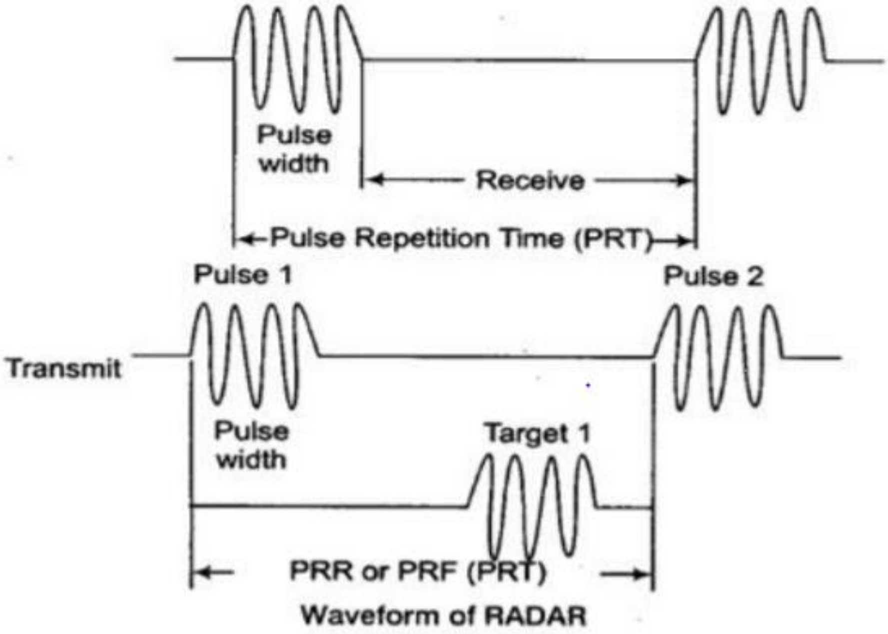


Figure 2.2: Waveforms of the RADAR

After the radar pulse has been transmitted, enough rest time must be allowed for the echo to return so as not to interfere with the next transmit pulse. Time difference between two successive pulses is called Pulse Repetition Time (PRT).

$$PRF = \frac{c}{2 * Unambiguous\ Range} = \frac{1}{PRT} \ldots(1)$$

$$PRT = \frac{2 * Unambiguous\ Range}{c}$$

2.2 Principle of RADAR

- The radar signal, usually a repetitive train of short pulses, is generated by the transmitter and radiated into space by the antenna.

- The duplexer acting as a switch permits a single antenna to be time-shared for both transmission and reception.

- Reflecting objects (targets) intercept and reradiate a portion of the radar signal, a small amount of which is returned in the direction of the radar.

- The returned echo signal is collected by the radar antenna and amplified by the receiver. If the output of the radar receiver is sufficiently large, detection of a target is said to occur.

- The range to a target is determined by time TR, it takes the radar signal to travel to the target and back i.e.,

$$R = \frac{cT_R}{2} \ldots(2)$$

- Once a signal is radiated into space by a radar by a radar, enough time elapse to allow all echo signals to return to the radar before the next pulse is transmitted. The maximum Unambiguous range is given by

$$R_{un} = \frac{cT_p}{2} = \frac{c}{2f_p}$$

2.3 Radar Range Equation

The radar range equation represents the physical dependence of the transmit power, which is the wave propagation up to the receiving of the echo signals Radar range equation is useful to know the range of the target theoretically

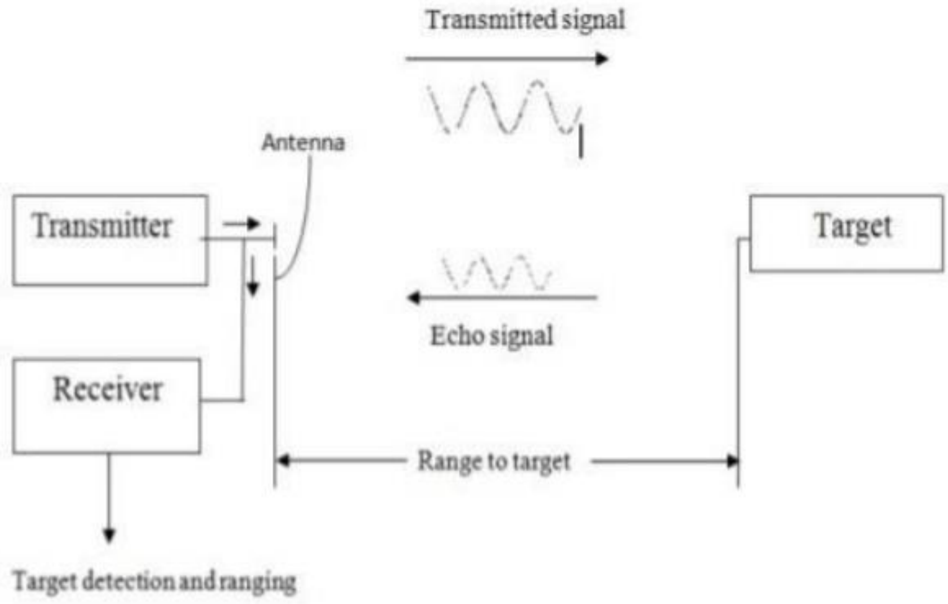


Figure 2.3: Radar range equation

We know that power density is nothing but the ratio of power and area. So, the power density, Pd at a distance, R from the Radar can be mathematically represented as

$$P_d = \frac{P_t}{4\pi R^2} \dots (3)$$

If the Gain of antenna of target is G, then power density is

$$P_d = \frac{P_t}{4\pi R^2} . G \dots (4)$$

Radar cross-section (σ) is a measure of how detectable an object is by radar. An object reflects a limited amount of radar energy back to the source. The factors that influence this include such as target's material type, size and at its angle.

If target area is σ then the power at target is,

$$P_d = \frac{P_t}{4\pi R^2} \cdot \boldsymbol{\sigma} \ldots (5)$$

The power density of reflected signal is,

$$P_d = \left[\frac{P_t G\boldsymbol{\sigma}}{4\pi R^2}\right]\frac{1}{4\pi R^2}$$

$$= \frac{P_t G\sigma}{[4\pi R^2]^2} \ldots (6)$$

For a pulsed radar, the peak power transmitted is usually much higher than the average power transmitted. The ratio of the average power to the peak power equals the duty cycle, which is the product of the pulse duration and the PRF.

The power received in all directions is Pr, then effective area (Ae) of antenna is expressed as

$$P_r = \frac{P_t G\sigma}{[4\pi R^2]^2} \cdot A_e \ \ldots (7)$$

$$S_{min} = \frac{P_t G\sigma A_e}{[4\pi]^2 (R_{max})^4} \ldots (8)$$

$$R_{max} = \left[\frac{P_t G\sigma A_e}{[4\pi]^2 . S_{min}}\right]^{\frac{1}{4}} \ldots (9)$$

Equation (9) represents the standard form of Radar range equation.

By using the above equation, we can find the maximum range of the target. For parabolic antenna

$$G = \frac{4\pi A_e}{\lambda^2}$$

then,

$$R_{max} = \left[\frac{P_t\left(\frac{4\pi A_e}{\lambda^2}\right)\sigma A_e}{[4\pi]^2 . S_{min}}\right]^{\frac{1}{4}}$$

$$R_{max} = \left[\frac{P_t (A_e)^2 \sigma}{4\pi\lambda^2 . S_{min}}\right]^{\frac{1}{4}} \dots (10)$$

Factors affecting the Radar Range

$$R\alpha[P_t]^{\frac{1}{4}}\alpha\left[\frac{1}{S_{min}}\right]^{\frac{1}{4}}\alpha\sqrt{A_e}\alpha\sqrt{G}$$

2.4 Limitations and Applications

2.4.1 Limitations of Radar Systems

1. Radars cannot resolve in detail like the human eye, especially at short distance.

2. Radars do not recognize the colour of the target.

3. Radars cannot identify internal aspects of the target.

2.4.2 Applications of Radar Systems

1. Civilian applications

2. Military applications
3. Remote Sensing
4. Ground Traffic Control
5. Air Traffic Control

CHAPTER 3

Pulse Repetition Frequency

CHAPTER 3

Pulse Repetition Frequency

3.1 What is PRF?

Pulse Repetition Frequency (PRF) of the radar system is the number of pulses that are transmitted per second. Radar systems radiate each pulse at the carrier frequency during transmit time (or Pulse Width PW), wait for returning echoes during listening or rest time, and then radiate the next pulse, as shown in the figure. The time between the beginning of one pulse and the start of the next pulse is called pulse-repetition time (PRT) and is equal to the reciprocal of PRF as follows:

$$\text{PRT} = \frac{1}{PRF}$$

The PRF is one of the defining characteristics of a radar system, which normally consists of a powerful transmitter and sensitive receiver connected to the same antenna. After producing a brief pulse of radio signal, the transmitter is turned off in order for the receiver units to hear the reflections of that signal off distant targets. Since the radio signal has to travel out to the target and back again, the required inter-pulse quiet period is a function of the radar's desired range. Longer periods are required for longer range signals, requiring lower PRFs. Conversely, higher PRFs produce shorter maximum ranges, but broadcast more pulses, and thus radio energy, in a given time. This creates stronger reflections that make detection easier. Radar systems must balance these two competing requirements.

3.2 Principle of PRF

A radar pulse train is a type of amplitude modulation of the radar frequency carrier wave, similar to how carrier waves are modulated in communication systems. In this case, the information signal is quite simple: a single pulse repeated at regular intervals.

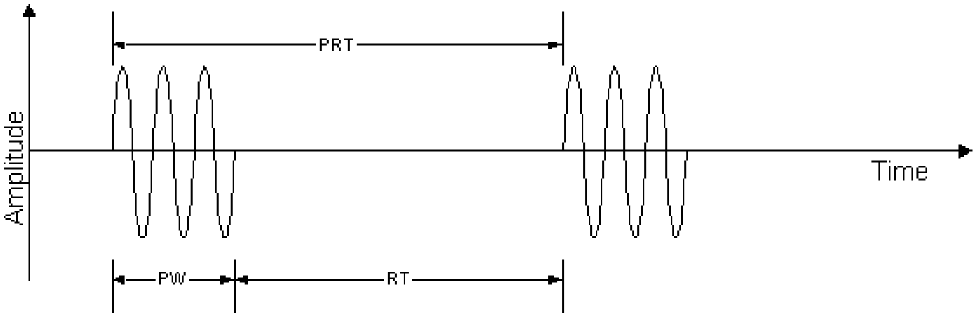


Figure 3.1 Pulse Repetition Frequency

PRF = pulse repetition frequency. PRF has units of time^{-1} and is commonly expressed in Hz (1 Hz = 1/s) or as pulses per second (pps). PRF is the number of pulses transmitted per second and is equal to the inverse of PRT. RF = radio frequency.

The reciprocal of PRF (or PRR) is called the pulse repetition time (*PRT*), pulse repetition interval (*PRI*), or inter-pulse period (*IPP*), which is the elapsed time from the beginning of one pulse to the beginning of the next pulse. The IPP term is normally used when referring to the quantity of PRT periods to be processed digitally. Each PRT having a fixed number of range gates, but not all of them being used. For example, the APY-1 radar used 128 IPP's with a fixed 50 range gates, producing 128 Doppler filters using an FFT. The different number of range gates on each of the five PRF's all being less than 50.

Within radar technology PRF is important since it determines the maximum target range ($R_{\max}$) and maximum Doppler velocity ($V_{\max}$) that can be accurately determined by the radar. Conversely, a high PRR/PRF can enhance target discrimination of nearer objects, such as a periscope or fast moving missile. This leads to use of low PRRs for search radar, and very high PRFs for fire control radars. Many dual-purpose and navigation radars—especially naval designs with variable PRRs—allow a skilled operator to adjust PRR to enhance and clarify the radar picture—for example in bad sea states where wave action generates false returns, and in general for less clutter, or perhaps a better return signal off a prominent landscape feature.

3.3 Range of PRF

The distance between Radar and target is called Range of the target or simply range, R. We know that Radar transmits a signal to the target and accordingly the target sends an echo signal to the Radar with the speed of light, C.

Let the time taken for the signal to travel from Radar to target and back to Radar be ‘T’. The two-way distance between the Radar and target will be 2R, since the distance between the Radar and the target is R.

Now, the following is the formula for Speed.

Speed=Distance/Time

⇒Distance=Speed×Time

$\Rightarrow 2R = C \times T$

$R = CT/2$

3.3.1 Different Ranges of PRF

a) Maximum Unambiguous Range

We know that Radar signals should be transmitted at every clock pulse. If we select a shorter duration between the two clock pulses, then the echo signal corresponding to present clock pulse will be received after the next clock pulse. Due to this, the range of the target seems to be smaller than the actual range.

So, we have to select the duration between the two clock pulses in such a way that the echo signal corresponding to present clock pulse will be received before the next clock pulse starts. Then, we will get the true range of the target and it is also called maximum unambiguous range of the target or simply, **maximum unambiguous range**.

Substitute, $R=R_{un}$ and $T=T_P$

$$R_{un}=CT_P/2$$

we will get the pulse repetition time, T_P as the reciprocal of pulse repetition frequency, f_P. Mathematically, it can be represented as

$$T_P=1/f_P$$

Substitute, Equation 1 in Equation 2.

$$R_{un}=C(1/f_P)/2$$

$$R_{un}=C2/f_P$$

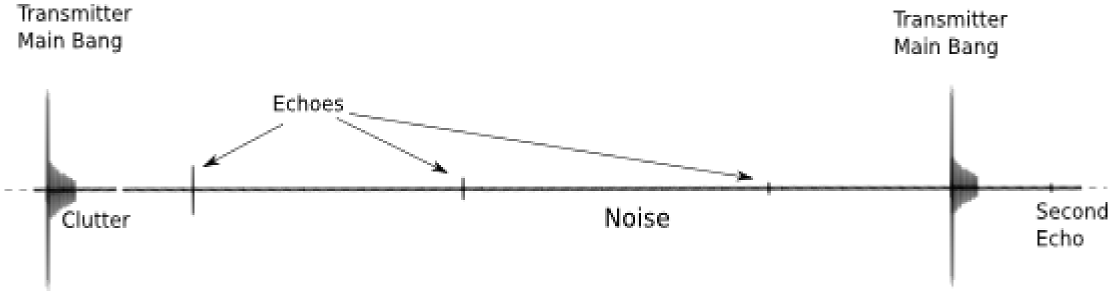


Figure 3.2 Maximum Unambiguous Range

b) Minimum Range

We will get the **minimum range** of the target, when we consider the time required for the echo signal to receive at Radar after the signal being transmitted from the Radar as pulse width. It is also called the shortest range of the target.

Substitute, R=Rmin and T=τ

$$R_{min}=C\tau/2$$

c) Range ambiguity

For accurate range determination a pulse must be transmitted and reflected before the next pulse is transmitted. This gives rise to the maximum unambiguous range limit.

The maximum range also defines a range ambiguity for all detected targets. Because of the periodic nature of pulsed radar systems, it is impossible for some radar system to determine the difference between targets separated by integer multiples of the maximum range using a single PRF. More sophisticated radar systems avoid this problem through the use of multiple PRFs either simultaneously on different frequencies or on a single frequency with a changing PRT.

The range ambiguity resolution process is used to identify true range when PRF is above this limit.

d) Low PRF

Systems using PRF below 3 kHz are considered low PRF because direct range can be measured to a distance of at least 50 km. Radar systems using low PRF typically produce unambiguous range.

Unambiguous Doppler processing becomes an increasing challenge due to coherency limitations as PRF falls below 3 kHz.

For example, an L-Band radar with 500 Hz pulse rate produces ambiguous velocity above 75 m/s (170 mile/hour), while detecting true range up to 300 km. This combination is appropriate for civilian aircraft radar and weather radar.

Low PRF radar have reduced sensitivity in the presence of low-velocity clutter that interfere with aircraft detection near terrain. Moving target indicator is generally required for acceptable performance near terrain, but this introduces radar scalloping issues that complicate the receiver. Low PRF radar intended for aircraft and spacecraft detection are heavily degraded by weather phenomenon, which cannot be compensated using moving target indicator.

e) Medium PRF

Range and velocity can both be identified using medium PRF, but neither one can be identified directly. Medium PRF is from 3 kHz to 30 kHz, which corresponds with radar range from 5 km to 50 km. This is the ambiguous range, which is much smaller than the maximum range. Range ambiguity resolution is used to determine true range in medium PRF radar.

Medium PRF is used with Pulse-Doppler radar, which is required for look-down/shoot-down capability in military systems. Doppler radar return is generally not ambiguous until velocity exceeds the speed of sound.

A technique called ambiguity resolution is required to identify true range and speed. Doppler signals fall between 1.5 kHz, and 15 kHz, which is audible, so audio signals from medium-PRF radar systems can be used for passive target classification.

For example, an L band radar system using a PRF of 10 kHz with a duty cycle of 3.3% can identify true range to a distance of 450 km (30 * C / 10,000 km/s). This is the **instrumented range**. Unambiguous velocity is 1,500 m/s (3,300 mile/hour).

The unambiguous velocity of an L-Band radar using a PRF of 10 kHz would be 1,500 m/s (3,300 mile/hour) (10,000 x C / (2 x 10^9)). True velocity can be found for objects moving under 45,000 m/s if the band pass filter admits the signal (1,500/0.033).

Medium PRF has unique radar scalloping issues that require redundant detection schemes.

f) High PRF

Systems using PRF above 30 kHz function better known as interrupted continuous-wave (ICW) radar because direct velocity can be measured up to 4.5 km/s at L band, but range resolution becomes more difficult.

High PRF is limited to systems that require close-in performance, like proximity fuses and law enforcement radar.

For example, if 30 samples are taken during the quiescent phase between transmit pulses using a 30 kHz PRF, then true range can be determined to a maximum of 150 km using 1 microsecond samples (30 x C / 30,000 km/s). Reflectors beyond this range might be detectable, but the true range cannot be identified.

It becomes increasingly difficult to take multiple samples between transmit pulses at these pulse frequencies, so range measurements are limited to short distances.

Taking all of the above characteristics into account means that certain constraints are placed on the radar designer. For example, a system with a 3 GHz carrier frequency and a pulse width of 1 µs will have a carrier period of approximately 333 ps. Each transmitted pulse will contain about 3000 carrier cycles and the velocity and range ambiguity values for such a system would be:

PRF	**Velocity Ambiguity**	**Range Ambiguity**
Low (2 kHz)	50 m/s	75 km
Medium (12 kHz)	300 m/s	12.5 km
High (200 kHz)	5000 m/s	750 m

Table 3.1 Velocity and Range Ambiguity values

3.4 Matched-Filter Receiver

A network whose frequency-response function maximizes the output peak-signal-to-mean-noise (power) ratio is called a matched filter. This criterion, or its equivalent, is used for the design of almost all radar receivers.

3.4.1 Matched Filter Frequency Response Function

The frequency-response function, denoted H (f), expresses the relative amplitude and phase of the output of a network with respect to the input when the input is a pure sinusoid. The magnitude $|H(f)|$ of the frequency-response function is the receiver amplitude passband characteristic. If the bandwidth of the receiver passband is wide compared with that occupied by the signal energy, extraneous noise is introduced by the excess bandwidth which lowers the output signal-to-noise ratio. On the other hand, if the receiver bandwidth is narrower than the bandwidth occupied by the signal, the noise energy is reduced along with a considerable part of the signal energy. The net result is again a lowered signal-to-noise ratio. Thus there is an optimum bandwidth at which the signal-to-noise ratio is a maximum. This is well known to the radar receiver designer. The rule of thumb quoted in pulse radar practice is that the receiver bandwidth B should be approximately equal to the reciprocal of the pulse width τ. This is a reasonable approximation for pulse radars with conventional superheterodyne receivers. It is not generally valid for other waveforms, however, and is mentioned to illustrate in a qualitative manner the effect of the receiver characteristic on signal-to-noise ratio. The exact specification of the optimum receiver characteristic involves the frequency-response function and the shape of the received waveform.

The receiver frequency-response function, is assumed to apply from the antenna terminals to the output of the IF amplifier. (The second detector and video portion of the well-designed radar super heterodyne receiver will have negligible effect on the output signal-to-noise ratio if the receiver is designed as a matched filter.) Narrow banding is most conveniently accomplished in the IF. The bandwidths of the RF and mixer stages of the normal super heterodyne receiver are usually large compared with the IF bandwidth.

Therefore, the frequency-response function of the portion of the receiver included between the antenna terminals to the output of the IF amplifier is taken to be that of the IF amplifier alone. Thus, we need only obtain the frequency-response function that maximizes the signal-to-noise ratio at the output of the IF. The IF amplifier may be considered as a filter with gain. The response of this filter as a function of frequency is the property of interest. For a received waveform s(t) with a given ratio of signal energy E to noise energy No (or noise power per hertz of bandwidth), North showed that the frequency-response function of the linear, time-invariant filter which maximizes the output peak-signal-to-mean-noise (power) ratio for a fixed input signal-tonoise (energy) ratio is

$$H(a) = GaS * (f)\exp(-j2\pi \mathrm{ft1})$$

Where $\mathrm{S(f)} = \int_{-\infty}^{\infty} s(t)\exp(-j2\pi \mathrm{ft})dt$ = voltage spectrum (Fourier transform) of input signal

S*(f) = Complex Conjugate of S (f)

t_1 = Fixed value of time at which signal is observed to be maximum

G_a= Constant equal to Maximum filter gain

The noise that accompanies the signal is assumed to be stationary and to have a uniform spectrum (white noise). It need not be gaussian. The filter whose frequency-response function is given by Eq. above has been called the North filter, the conjugate filter, or more usually the matched filter. It has also been called the Fourier transform criterion. It should not be confused with the circuit-theory concept of impedance matching, which maximizes the power transfer rather than the signal-to-noise ratio.

The frequency-response function of the matched filter is the conjugate of the spectrum of the received waveform except for the phase shift exp (- j2Πft1). This phase shift varies uniformly with frequency. Its effect is to cause a constant time delay. A time delay is necessary in the specification of the filter for reasons of physical realizability since there can be no output from the filter until the signal is applied. The frequency spectrum of the received signal may be written as an amplitude spectrum ׀S(f)׀) and a phase spectrum exp [- jφs (f)]. The matched- filter frequency-response function may similarly be written in terms of its amplitude and phase spectra ׀H (f) ׀ and exp [-jφm (f)]. Ignoring the constant Ga, Eq. above for the matched filter may then be written as

$$|H(f)|exp[-j\emptyset m(f)] = |S(f)|exp\{j[\emptyset 3(f) - 2\pi ft1]\}$$

or $$|H(f)| = |S(f)|$$

and $$\emptyset m(f) = -\emptyset 3(f) + 2\pi ft1$$

Thus, the amplitude spectrum of the matched filter is the same as the amplitude spectrum of the signal, but the phase spectrum of the matched filter is the negative of the phase spectrum of the signal plus a phase shift proportional to frequency.

The matched filter may also be specified by its impulse response h (t), which is the inverse Fourier transform of the frequency-response function.

$$h(t) = \int_{-\infty}^{\infty} H(f) \exp(2\pi ft)dt$$

Physically, the impulse response is the output of the filter as a function of time when the input is an impulse (delta function).

$$h(t) = Ga \int_{-\infty}^{\infty} S * (f) \exp[-j2\pi f(t1 - t)df$$

Since $S * (f) = S(-f)$, we have

$$h(t) = Ga \int_{-\infty}^{\infty} S(f) \exp[j2\pi f(t1 - t)]df = Gas(t1 - t)$$

A rather interesting result is that the impulse response of the matched filter is the image of the received waveform; that is, it is the same as the received signal run backward in time starting from the fixed time t1. Figure 1 shows a received waveform s (t) and the impulse response h (t) of its matched filter. The impulse response of the filter, if it is to be realizable, is not defined for t< 0. (One cannot have any response before the impulse is applied.) Therefore, we must always have t < t1. This is equivalent to the condition placed on the transfer function H (f) that there be a phase shift exp (-j2Πft1). However, for the sake of convenience, the impulse response of the matched filter is sometimes written simply as s (-t).

3.4.2 Derivation of Matched-Filter Frequency Response

Derivation of the matched-filter characteristic: The frequency-response function of the matched filter has been derived by a number of authors using either the calculus of variations or the Schwartz inequality. We shall derive the matched-filter frequency-response function using the Schwartz inequality.

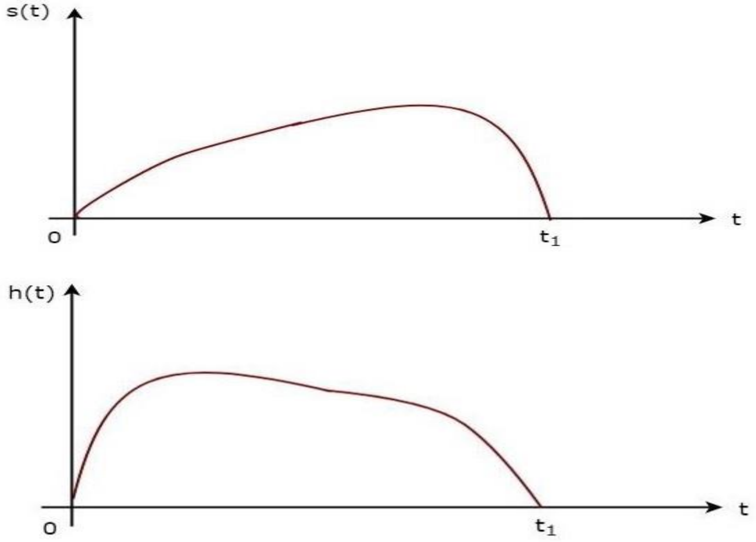


Figure 3.3 Graphs of received signal, s(t) and the impulse response, h(t)

The received signal, s(t) and the impulse response, h(t) of the matched filter corresponding to the signal, s(t) are shown in the above figures.

We wish to show that the frequency-response function of the linear, time-invariant filter which maximizes the output peak-signal-to-mean-noise ratio is

$$H(f) = GaS * (f)\exp(-j2\pi ft1)$$

when the input noise is stationary and white (uniform spectral density). The ratio we wish to maximize is

$$Rf = \frac{|s0(t)|^2}{N}\text{max}$$

where ǀso(t)ǀmax = maximum value of output signal voltage and N = mean noise power at receiver output. The ratio Rf is not quite the same as the signal-to-noise ratio which has been considered in the radar equation. The output voltage of a filter with frequency-response function H(f) is

$$|s0(t)| = \left|\int_{-\infty}^{\infty} S(f)H(f)\exp\left(j2\pi ft\right)dt\right|$$

where S(f) is the Fourier transform of the input (received) signal. The mean output noise power is

$$N = \frac{N\emptyset}{2}\int_{-\infty}^{\infty}|H(f)|^2 df$$

where No is the input noise power per unit bandwidth. The factor appears before the integral because the limits extend from - ∞ to +∞, whereas No is defined as the noise power per cycle of bandwidth over positive values only. Assuming that the maximum value of ǀso(t)ǀ 2 occurs at time t = t1, the ratio Rf becomes

$$Rf = \frac{\left|\int_{-\infty}^{\infty} S(f)H(f)\exp\left(j2\pi ft1\right)df\right|^2}{\frac{N\emptyset}{2}\int_{-\infty}^{\infty}|H(f)|^2 df}$$

Schwartz's inequality states that if P and Q are two complex functions, then

$$\int P * P\ dx \int Q * Q\ dx\ \geq |\int P * Q\ dx|^2$$

The equality sign applies when P = KQ, where k is a constant. Letting

$$P *= S(f)\exp(j2\pi ft1)\ and\ Q = H(f)$$

And recalling that

$$\int P * P\ dx = \int |P|^2$$

we get, on applying the Schwartz inequality to the numerator of Eq. earlier, we get

$$Rf \le \frac{\int_{-\infty}^{\infty}|H(f)|^2 df \int_{-\infty}^{\infty}|S(f)|^2 df}{\frac{N0}{2}\int_{-\infty}^{\infty}|H(f)|^2 df} = \frac{\int_{-\infty}^{\infty}|S(f)|^2 df}{\frac{N0}{2}}$$

From Parseval’s theorem,

$$\int_{-\infty}^{\infty}|S(f)|^2 df = \int_{-\infty}^{\infty} s^2\,(t)\,dt = signal\ energy = E$$

Therefore we have

$$Rf \le \frac{2E}{N0}$$

The frequency-response function which maximizes the peak-signal-to-mean-noise ratio Rf may be obtained by noting that the equality sign in Eq. applies when P = KQ, or

$$H(f) = GaS * (f)\exp\,(-j2\pi f t1)$$

where the constant k has been set equal to 1/Ga.

3.4.3 Correlation Receiver

The output of the matched filter is not a replica of the input signal. However, from the point of view of detecting signals in noise, preserving the shape of the signal is of no importance. If it is necessary to preserve the shape of the input pulse rather than maximize the output signal-to-noise ratio, some other criterion must be employed. The output of the matched filter may be shown to be proportional to the input signal cross correlated with a replica of the transmitted signal, except for the time delay t1. The cross correlation function R(t) of two signals y(λ) and s(λ), each of finite duration, is defined as

$$R(t) = \int_{\infty}^{-\infty} y(\lambda).\,\mathrm{s}(\lambda - \mathrm{t})\mathrm{d}\lambda$$

The output $y_0(t)$ of a filter with impulse response h(t) when the input is y_{in}(t) = s(t) + n(t) is

$$y_0(t) = \int_{\infty}^{-\infty} y_{in}(\lambda).\,\mathrm{h}(\lambda - \mathrm{t})\mathrm{d}\lambda$$

If the filter is a matched filter, then

h(λ) = s(t_1 - λ) and becomes

$$y_0(t) = \int_{\infty}^{-\infty} y_{in}(\lambda).\,\mathrm{s}(t_1 - \mathrm{t} + \lambda)\mathrm{d}\lambda$$

Thus, the matched filter forms the cross correlation between the received signal corrupted by noise and a replica of the transmitted signal. The replica of the transmitted signal is "built in” to the matched filter via the frequency-response function. If the input signal yin(t) were the same as the signal s(t) for which the matched filter was designed (that is, the noise is assumed negligible), the output would be the autocorrelation function. The autocorrelation function of a rectangular pulse of width τ is a triangle whose base is of width 2τ.

3.4.4 Approximation to the Matched Filter for a Rectangular Like Pulse

The early radar pioneers in the 1930s were not aware of the concept of the matched filter; yet they learned from experience how to maximize the output signal-to-noise ratio for the simple pulse waveforms that were used at that time. They found that if the receiver passband was too wide compared with the spectral bandwidth of the radar signal, extra noise was introduced (since noise power is proportional to bandwidth); and the signal-to-noise ratio was reduced. On the other hand, if the receiver bandwidth was too narrow, the noise was

reduced but so was the signal energy. Consequently, too narrow a bandwidth relative to the signal spectral width reduced the signal-to-noise ratio, and too wide a bandwidth also reduced the signal-to-noise ratio. Thus there was an optimum value of bandwidth relative to signal spectral width that maximized the signal-to-noise ratio. With rectangular-like pulses and conventional filter design, experience showed that the maximum signal-to-noise ratio occurred when the receiver bandwidth β was approximately equal to the reciprocal of the pulse width Ƭ, or when BT≈1.

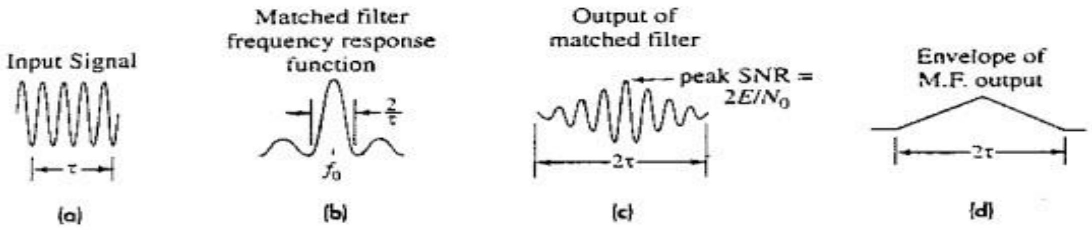


Figure 3.4 Matched Filter Outputs

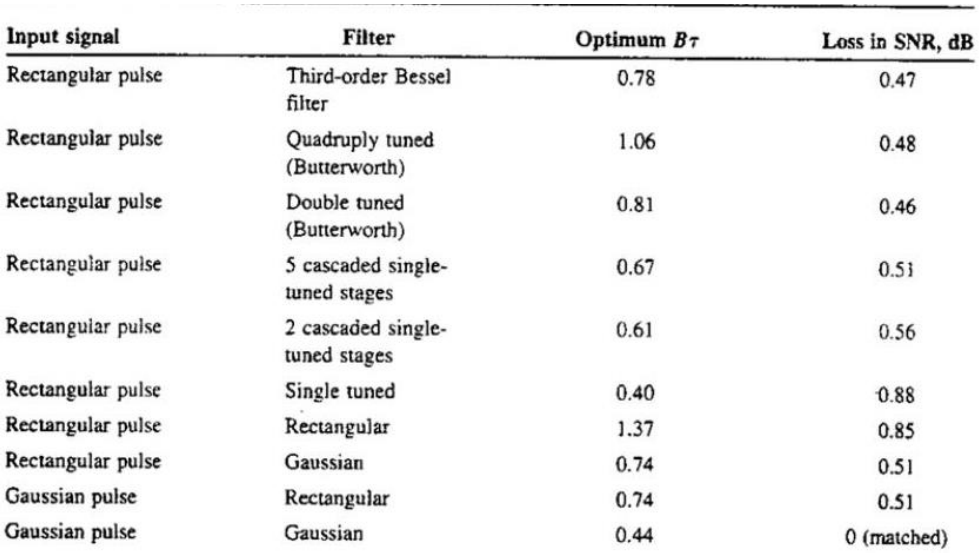
(a) Sketch of a perfectly rectangular pulse of sinewave of width Ƭ and frequency fo

(b) frequency response function of the matched filter, where H(f) = S*(f) = S(f)

(c) output of the matched filter

(d) envelope of matched-filter output.

In practice the matched filter cannot be perfectly implemented. There will usually be some loss in signal-to-noise ratio compared to that of a theoretically perfect matched fil ter. The measure of efficiency is taken as the peak-signal-to-mean-noise ratio from the nonmatched filter divided by the peak-signal-to-noise ratio (2E/No) obtained from a matched filter. Table lists values of BT that maximize the signal-to-noise ratio (SNR) for various combinations of hypothetical filters and pulse shapes. Note that the rectangular pulse assumed in Table is not a realistic waveform since it has zero rise time, which implies infinite bandwidth. Radar pulses are bandwidth limited, and the rise time is approximately 1/B. Also, several of the filters in Table are not likely to be used in practice. Nevertheless, Table is offered as an example of the performance of non-matched filters. The usual "rule of thumb" when no other information is available, is to assume that a practical approximation to a matched filter has B≈1 and a loss in SNR of about 0.5 dB.



Input signal	Filter	Optimum $B\tau$	Loss in SNR, dB
Rectangular pulse	Third-order Bessel filter	0.78	0.47
Rectangular pulse	Quadruply tuned (Butterworth)	1.06	0.48
Rectangular pulse	Double tuned (Butterworth)	0.81	0.46
Rectangular pulse	5 cascaded single-tuned stages	0.67	0.51
Rectangular pulse	2 cascaded single-tuned stages	0.61	0.56
Rectangular pulse	Single tuned	0.40	0.88
Rectangular pulse	Rectangular	1.37	0.85
Rectangular pulse	Gaussian	0.74	0.51
Gaussian pulse	Rectangular	0.74	0.51
Gaussian pulse	Gaussian	0.44	0 (matched)

Table 3.2 Efficiency of non-matched filter compared with Matched Filter

3.5 Detection Criteria

Detection of signals is equivalent to deciding whether the receiver output is due to noise alone or to signal plus noise. This is the type of decision made (probably subconsciously) by a human operator from the information presented on a radar display. When the detection process is carried out automatically by electronic means without the aid of an operator, the detection criterion must be carefully specified and built into the decision-making device.

The radar detection process was described in terms of threshold detection. If the envelope of the receiver output exceeds a pre-established threshold, a signal is said to be present. The threshold level divides the output into a region of no detection and a region of detection. The radar engineer selects the threshold that divides these two regions so as to achieve a specified probability of false alarm, which in turn is related to the average time between false alarms. The engineer then determines the other parameters of the radar needed to obtain the signal-to-noise ratio for the desired probability of detection**.**

3.5.1 Minimum Detectable Signal

If the echo signal has minimum power, detecting that signal by the Radar is known as minimum detectable signal. This means, Radar cannot detect the echo signal if that signal is having less power than that of minimum power.

In general, Radar receives the echo signal in addition with noise. If the threshold value is used for detecting the presence of the target from the received signal, then that detection is called threshold detection.

We have to select proper threshold value based on the strength of the signal to be detected.

- A high threshold value should be chosen when the strength of the signal to be detected is high so that it will eliminate the unwanted noise signal present in it.
- Similarly, a low threshold value should be chosen when the strength of the signal to be detected is low.

The following figure illustrates this concept −

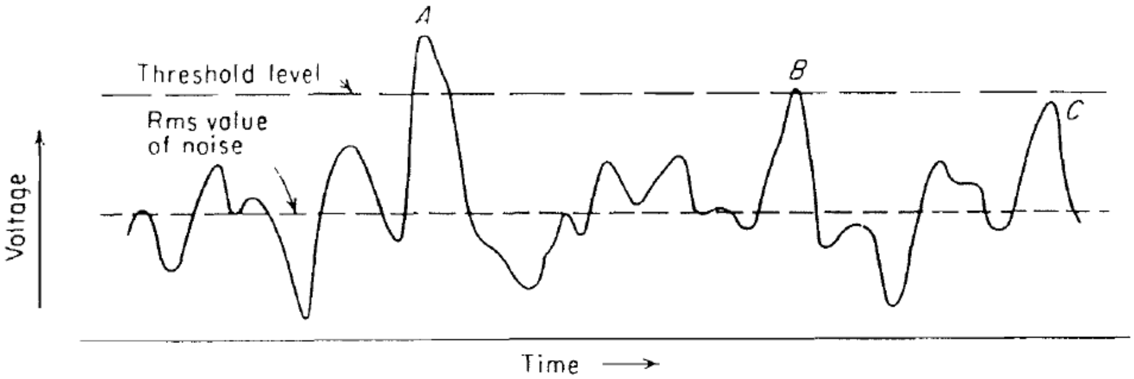


Figure 3.5 Typical envelope of tile radar receiver output as a function of time

A typical waveform of the Radar receiver is shown in the above figure. The x-axis and y-axis represent time and voltage respectively. The rms value of noise and threshold value are indicated with dotted lines in the above figure.

We have considered three points, A, B & C in above figure for identifying the valid detections and missing detections.

- The value of the signal at point A is greater than threshold value. Hence, it is a valid detection.
- The value of the signal at point B is equal to threshold value. Hence, it is a valid detection.
- Even though the value of the signal at point C is closer to threshold value, it is a missing detection. Because, the value of the signal at point C is less than threshold value.

So, the points, A & B are valid detections. Whereas, the point C is a missing detection.

3.5.2 Receiver Noise

If the receiver generates a noise component into the signal, which is received at the receiver, then that kind of noise is known as receiver noise. The receiver noise is an unwanted component; we should try to eliminate it with some precautions.

However, there exists one kind of noise that is known as the thermal noise. It occurs due to thermal motion of conduction electrons. Mathematically, we can write thermal noise power, Ni produced at receiver as

$$N_i = KT_0B_n$$

Where,

K is the Boltzmann's constant and it is equal to $1.38\times10-23$J/℃

T_0 is the absolute temperature and it is equal to 290°K

B_n is the receiver band width

3.5.3 Figure of Merit

The Figure of Merit, F is nothing but the ratio of input SNR, $(SNR)_i$ and output SNR, $(SNR)_o$. Mathematically, it can be represented as

$$F = (SNR)_i/(SNR)_o$$

$$\Rightarrow F = S_i/N_i/S_o/N_o$$

$$\Rightarrow F = N_o S_i / N_i S_o$$

$$\Rightarrow S_i = F N_i S_0 / N_0$$

Substitute, $N_i = FKT_0 B_n$ in above equation.

$$\Rightarrow S_i = FKT_0 B_n (S_o/N_o)_{min}$$

Input signal power will be having minimum value, when output SNR is having minimum value.

$$\Rightarrow S_{min} = FKT_0 B_n (S_o/N_o)_{min}$$

Substitute, the above Smin in the following standard form of Radar range equation.

$$\Rightarrow Rmax = \left[\frac{\mathrm{PtG\sigma Ae}}{(4\pi)^2 \mathrm{Smin}}\right]^{1/4}$$

$$\Rightarrow Rmax = \left[\frac{\mathrm{PtG\sigma Ae}}{(4\pi)^2 \mathrm{FKToBn}(\frac{S0}{N0})_{min}}\right]^{1/4}$$

From the above equation, we can conclude that the following conditions should be considered in order to get the range of the Radar as maximum.

- Peak power transmitted by the Radar, Pt should be high.
- Gain of the transmitting Antenna G should be high.
- Radar cross section of the target σ should be high.
- Effective aperture of the receiving Antenna Ae should be high.
- Figure of Merit F should be low.
- Receiver bandwidth Bn should be low.

CHAPTER 4

JAMMING

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JAMMING

4.1 Jamming

Radar jamming is a form of electronic countermeasures (ECM), designed to degrade the effectiveness of enemy radar systems. Usually, this is done by emitting radio signals at specific frequencies which impair the ability of radar systems to accurately detect and depict objects in the operational environment. This can generate "noise" in the radio spectrum which will confuse or mislead the enemy and affect their decision-making accordingly. Radar jamming and deception is a form of electronic countermeasures that intentionally sends out radio frequency signals to interfere with the operation of radar by saturating its receiver with noise or false information. Concepts that blanket the radar with signals so its display cannot be read are normally known as jamming, while systems that produce confusing or contradictory signals are known as deception, but it is also common for all such systems to be referred to as jamming.

4.2 Types of Jamming

There are two general classes of radar jamming, mechanical and electronic. Mechanical jamming entails reflecting enemy radio signals in various ways to provide false or misleading target signals to the radar operator. Electronic jamming works by transmitting additional radio signals towards enemy receivers, making it difficult to detect real target signals, or take advantage of known behaviours of automated systems like radar lock-on to confuse the system.

4.2.1 Mechanical Jamming

Mechanical jamming is caused by devices that reflect or rereflect radar energy back to the radar to produce false target returns on the operator's scope. Mechanical jamming devices include chaff, corner reflectors, and decoys.

- Chaff is made of different length metallic strips, which reflect different frequencies, to create a large area of false returns in which a real contact would be difficult to detect. Modern chaff is usually aluminum-coated glass fibers of various lengths. Their extremely low weight and small size allow them to form a dense, long-lasting cloud of interference. This cloud is only effective in the range cell that it occupies. The slow movement of the chaff (compared to a flying target) makes it easily discriminated, based on the lacking Doppler shift. Ships, on the other hand, can benefit greatly from a slow-moving chaff cloud. The cloud is released within the resolution cell of the ship and moves with the wind in one direction. The ship then escapes in another direction. The decoy (chaff cloud) should have a larger RCS than the target, so the radar tracks it.

- Corners reflectors have the same effect as chaff but are physically very different. Corner reflectors are many-sided objects that re-radiate radar energy mostly back toward its source. An aircraft cannot carry as many corner reflectors as it can chaff.

- Decoys are manoeuvrable flying objects that are intended to deceive a radar operator into believing that they are actually aircraft. They are especially dangerous because they can clutter up a radar with false targets making it easier for an attacker to get within weapons range and neutralize the radar. Corners reflectors can be fitted on decoys to make them appear larger than they are, thus furthering the illusion that a decoy is an actual aircraft. Some decoys have the capability to perform electronic jamming or drop chaff. Decoys also have a deliberately sacrificial purpose i.e. defenders may fire guided missiles at the decoys, thereby depleting limited stocks of expensive weaponry which might otherwise have been used against genuine targets.

4.2.2 Electronic jamming

Electronic jamming is a form of electronic warfare where jammers radiate interfering signals toward an enemy's radar, blocking the receiver with highly concentrated energy signals. The two main technique styles are noise techniques and repeater techniques. The three types of noise jamming are spot, sweep, and barrage.

- **Spot jamming** or spot noise occurs when a jammer focuses all of its power on a single frequency. This overwhelms the reflection of the original radar signal off the targets, the "skin return" or "skin reflection", making it impossible to pick out the target on the radar display. This technique is only useful against radars that broadcast on a single frequency, and can be countered by changing the frequency or other operational parameters like the pulse repetition frequency (PRF) so the jammer is no longer broadcasting on the same frequency or at the right times. While multiple jammers could possibly jam a range of frequencies, this would consume many resources and be of little effect against modern frequency agile radars that constantly change their broadcasts.

- **Sweep jamming** is a modification of spot jamming where the jammer's full power is shifted from one frequency to another. While this has the advantage of being able to jam multiple frequencies in quick succession, it does not affect them all at the same time, and thus limits the effectiveness of this type of jamming. Although, depending on the error checking in the device(s) this can render a wide range of devices effectively useless.

- **Barrage jamming** is a further modification of sweep jamming in which the jammer changes frequencies so rapidly it appears to be a constant radiator across its entire bandwidth. The advantage is that multiple frequencies can be jammed essentially simultaneously. The first effective barrage jammer was introduced as the carcinotron in the early 1950s, and was so effective it was believed that all long-range radar systems might be rendered useless. However, the jamming effect can be limited because this requires the jammer to spread its full power between these frequencies—the effectiveness against each frequency decreases with the number of frequencies covered. The creation of extremely powerful multifrequency radars like blue riband offset the effectiveness of the carcinotron.

- **Base jamming** is a new type of barrage jamming whereby one radar is jammed effectively at its source at all frequencies. However, all other radars continue working normally. • Pulse jamming produces noise pulses with period depending on radar mast rotation speed thus creating blocked sectors from directions other than the jammer, making it harder to discover the jammer location.

- **Cover pulse jamming** creates a short noise pulse when radar signal is received thus concealing any aircraft flying behind the jammer with a block of noise.

- Digital radio frequency, or DRFM jamming, or Repeater jamming is a repeater technique that manipulates received radar energy and retransmits it to change the return the radar sees. This technique can change the range the radar detects by changing the delay in transmission of pulses, the velocity the radar detects by changing the Doppler shift of the transmitted signal, or the angle to the plane by using AM techniques to transmit into the side lobes of the radar. Electronics, radio equipment, and antenna can cause DRFM jamming causing false targets, the signal must be timed after the received radar signal. By analysing received signal strength from side and back lobes and thus getting radar antennae radiation pattern, false targets can be created to directions other than one where the jammer is coming from. If each radar pulse is uniquely coded it is not possible to create targets in directions other than the direction of the jammer.

- Deceptive jamming uses techniques like "range gate pull-off" to break a radar lock.

- Blip enhancement deliberately makes some returns look larger on radar in order to hide their nature. This is used by escort ships to make them look as large as capital ships.

Figure 4.1 Protective/Standoff jamming

4.2.3 Radar range and burn-through range

The burn-through range is the distance from the radar at which the jamming is ineffective. When a target is within this range, the radar receives an adequate target skin return to track it. The burn through range is a function of the target RCS (radar cross section), jamming ERP (effective radiated power), the radars ERP and required J/S (for the jamming to be effective).

Inadvertent jamming

In some cases, jamming of either type may be caused by friendly sources. Inadvertent mechanical jamming is fairly common because it is indiscriminate and affects any nearby radars, hostile or not. Electronic jamming can also be inadvertently caused by friendly sources, usually powerful EW platforms operating within range of the affected radar.

4.3 Jamming Tactics

Three standard tactics are used:

4.3.1 Self-screening jammers

In this situation a unit carries jamming equipment for its own protection. This results in a trade-off between weight and space reserved for ECM equipment and that reserved for sensors, weapons and fuel. The trade-off is most critical in aircraft and least critical in ships. The self-screening method results in maintaining efficient jamming geometry between victim radar target and jammer because the jammer and victim radar are always along the same line.

4.3.2 Stand-off jammers

The jamming unit remains just outside the range of enemy weapons, providing screening for attacking units that actually penetrate enemy defences. Usually the jamming unit will have only that task, although it may be involved in command and control. The advantage of Stand-off jammers is that the jammer is safe from enemy home-on jamming weapons (a sub mode of nearly all RF homing weapons). The disadvantage of this geometry is that burn through occurs earlier on the attack units because the jammer must remain at very long range, while the attack units close the enemy to very short range.

4.3.3 Stand-forward jammers

The jamming unit is placed between enemy sensors and the attack units. While maintaining proper geometry between victim sensors, attack units, and the jammer is difficult, this method allows most efficient use of jamming power by reducing, spreading and attenuation losses. This situation is most dangerous for the jamming unit because he is a prime target for all weapons systems and well within the capabilities of Home-on-Jam and Anti-Radiation (ARM) weapons.

4.4 Deception

The other major type of active ECM is deception. In contrast to noise jamming, deception tries to mimic the radar echo so that the radar will respond as if it is receiving an echo from another aircraft or ship. For a radar to direct a fire control system correctly, it must accurately measure target range, bearing, and elevation. If either range or bearing is misrepresented without the operator's knowledge, the target's location will be incorrectly established. Deception ECM is generally accomplished by repeaters and transponders, and is sometimes also called repeater jamming.

Repeaters

The theory of repeater operation is basically simple. However, actual implementation requires sophisticated circuitry. Basically, the radar signal is received, delayed, amplified, modulated, and retransmitted back to the radar.

Transponders

The transponder differs slightly in that it plays back a stored replica of the radar signal after it is triggered by the radar. The transmitted signal is made to resemble the radar signal as closely as possible. Delay may be employed, but amplification is usually not used. The power requirements for a deception repeater are much lower than for a noise jammer, since the repeater emits its energy in pulses similar to the radar pulses. Its duty cycle is similar to that of the radar.

4.4.1 Range deception

If a repeater were to simply retransmit the received pulse as soon as it was received, it would reinforce the return echo and would help rather than frustrate the radar. But if the received pulse (as opposed to the echo that returns to the radar) could be briefly sorted and then transmitted a short time interval later, the radar would first receive the weak natural echo-return followed by an identical but stronger pulse. If a 20 repeater transmitted a series of time-displaced pulses, identical to the radar pulse, it could produce a series of spurious targets, each at different ranges.

In automatic tracking radars, the first step in the process of locking onto a target is for the operator to designate the specific target of interest by positioning the range tracking gate over the target video. Once this is done, the radar's receiver is, in effect, turned off until such time as an echo-return is expected at the approximate range of the designated target, thereby making allowance for the velocity of the target.

This allows the deception repeater to operate in the "range-gate" or trackbreaking mode. Initially, the repeater simply repeats back the received radar pulse without any delay, to allow for the radar's automatic gain control to adjust to the stronger signal, which it assumes to be the designated target. Then the deception repeater begins to introduce increasing amounts of time delay before retransmitting back the received radar pulse. Thus, the range-gate circuitry in the radar tracks the stronger pulse and gradually "walks off" from the true target range and makes the target appear to be at a greater range than it really is.

Similarly, the target can be made to appear at a closer range by delaying the received radar pulse long enough such that it can be retransmitted back prior to receiving the next radar pulse. Then the deception pulse will arrive at the radar before the real echo pulse, producing a false target at a closer range. This false target range information can cause significant aiming and guidance errors for antiaircraft guns and for missiles that require command guidance from ground-based radars.

The simplest remedy that the tracking radar can use is to have its operators switch to a manual mode of operation. This remedy is effective because a man watching a radar scope can see the cover pulse move away from the aircraft return, and he can therefore track the aircraft. Even though manual tracking will largely counter a repeater, manual tracking is never as smooth as automatic tracking. Thus, the weapon miss distance will increase and increase the probability of aircraft survival against non-nuclear defence weapons.

4.4.2 Angle Deception.

Radar and command control systems can be confused by causing the radar to generate incorrect target bearing and elevation information. For this to be successful, the deception device must cause the radar to indicate the presence of a target at some time other than when the radar is at the target's bearing and elevation. There are two primary methods of achieving this effect.

4.4.3 Side lobe angle deception.

First, the side lobes in the antenna radiation pattern must be evident to the ECM unit. A false target pulse is then transmitted while the ECM unit is at the azimuth of a side lobe of the victim radar. The radar circuitry is designed to register target angular position in the main lobe only, and therefore displays target video with an angular error equal to the angular displacement between the main lobe and the side lobe involved. This technique can be applied to any radar with ineffective side lobe suppression or cancellation. By combining this method with range deception, many false targets at different ranges and bearings can be generated, causing confusion over the entire search volume of the victim radar, with much less required average power than equivalent noise jamming.

4.4.4 Angle tracking circuit deception.

Mono-track radar, such as those employing Monopulse, Conical Scan, COSRO, LORO, and Track-While-Scan (TWS) or active tracking radars can be deceived by causing their angle sensitive circuitry to drive in some direction other than that which would correct the existing angular error at any given time. In doing so, the ECM unit will cause errors in solution of the fire control problem and thus induce considerable error and/or delay in weapons employment. Deception of angle- 22 tracking circuits sometimes involves specific equipment tailored to each angle tracking technique. For instance, the inverse conical scan (inverse gain) method is only effective against the conical-scan tracker and would not work with the others mentioned above. For all angle-tracking methods, the ECM unit must have knowledge of the scanning and tracking techniques employed by the victim radar. For the conical-scan and lobe-switching radar, this may be obtained by monitoring the radar with an ESM receiver. Monopulse, CORSO, LORO, TWS, and active tracking radars reveal nothing to an ESM operator concerning their tracking methodology. Therefore, good intelligence data is required to build deception devices and properly employ them against these systems. Briefly, two of the techniques that can be employed against all of these systems are:

4.4.5 Blinking

Noise or a sample of the victim radar pulse is amplified and retransmitted from various widely separated points on the ECM unit (or several closely spaced cooperating units) in a random fashion, causing enhancement of the usual movement (wander) of the point on the ECM unit that the radar tracks. For smooth tracking and accurate solution of the fire control problem, the radar should track the centroid of the target. The result of this technique is excessive tracking error. This excessive tracking error can be eliminated by using further techniques.

4.4.6 Cross eye (phase front distortion)

Two widely spaced locations on the ECM unit are selected (such as the nose and tail or two wingtips in the case of an aircraft) and interconnected transponders installed. Each of a pair of these locations normal to the direction of the victim radar receives the victim radar pulse and triggers the transponder on the opposite side of the unit, which then transmits a copy of the victim radar pulse with a 180o phase shift. The result is a reversal of the sign of the angular error measured at the victim radar. This causes the radar positioning mechanism to drive in the wrong direction. In the case of a TWS radar or active tracking radar, this technique can result in errors in 23 positioning tracking gates in azimuth and elevation; can prevent the establishment of a smooth track, or can cause problems in acquistion gate, tracking gate, and turn detection gate selection logic.

4.5 Continuous Wave Doppler and Pulsed Doppler Deception

CW Doppler and pulsed Doppler radars were developed to track high-speed, low-flying aircraft in the presence of ground clutter. The echo-return from these radars that enables the target to be tracked is the Doppler shift due to the target's velocity. The deception of the CW Doppler requires that the repeater retransmit the received CW signal with a spurious Doppler shift, gradually increasing its magnitude to cause velocity track breaking. This will not only cause errors in the fire control solution, but because of the velocity gate walk-off, it can result in loss of target tracking when the repeater is turned off. Deception of the pulsed Doppler radar is much the same. The repeater introduces a similar spurious Doppler shift when it retransmits the received pulses.

4.5.1 Stealth

For protective jamming, a small RCS of the protected aircraft improve the jamming efficiency (higher J/S). A lower RCS also reduce the "burn-through" range. Stealth technologies like radar-absorbent materials can be used to reduce the return of a target.

4.5.2 Interference

While not usually caused by the enemy, interference can greatly impede the ability of an operator to track. Interference occurs when two radars in relatively close proximity (how close they need to be depends on the power of the radars) are operating on the same frequency. This will cause "running rabbits", a visual phenomenon that can severely clutter up a radar display scope with useless data. Interference is not that common between ground radars, however, because they are not usually placed close enough together. It is more likely that some sort of airborne radar system is inadvertently causing the interference—especially when two or more countries are involved.

The interference between airborne radars referred to above can sometimes (usually) be eliminated by frequency-shifting the transmitter(s).

The other interference often experienced is between the aircraft's own electronic transmitters, i.e. transponders, being picked up by its radar. This interference is eliminated by suppressing the radar's reception for the duration of the transponder's transmission. Instead of "bright-light" rabbits across the display, one would observe very small black dots. Because the external radar causing the transponder to respond is generally not synchronised with your own radar (i.e. different PRFs [pulse repetition frequency]), these black dots appear randomly across the display and the operator sees through and around them.

The returning image may be much larger than the "dot" or "hole", as it has become known, anyway. Keeping the transponder's pulse widths very narrow and mode of operation (single pulse rather than multipulse) becomes a crucial factor. The external radar could, in theory, come from an aircraft flying alongside your own, or from space. Another factor often overlooked is to reduce the sensitivity of one's own transponder to external radars; i.e., ensure that the transponder's threshold is high. In this way it will only respond to nearby radars—which, after all, should be friendly. One should also reduce the power output of the transponder in like manner.

4.6 Scope of Jamming

Deception jamming systems are designed to inject false information into victim radar to deny critical information on target azimuth, range, velocity, or a combination of these parameters. To be effective, a deception jammer receives the victim radar signal, modifies this signal, and retransmits this altered signal back to the victim radar. Because these systems retransmit, or repeat, a replica of the victim's radar signal, deception jammers are known as repeater jammers. The retransmitted signal must match all victim radar signal characteristics including frequency, pulse repetition frequency (PRF), pulse repetition interval (PRI), pulse width, and scan rate. However, the deception jammer does not have to replicate the power of Victim radar system A deception jammer requires significantly less power than a noise jamming system. The deception jammer gains this advantage by using a waveform that is identical to the waveform the radar's receiver is specifically designed to process.

Therefore, the deception jammer can match its operating cycle to the operating cycle of the victim radar instead of using the 100% duty cycle required of a noise jammer. To be effective, a deception jammer's power requirements are dictated by the average power of radar rather than the peak power required for a noise jammer. In addition, since the jammer waveform looks identical to the radar's waveform, it is processed like a real return. The jamming signal is amplified by the victim radar receiver, which increases its effectiveness. The reduced power required for effective deception jamming is particularly significant when designing and building self-protection jamming systems for tactical aircraft that penetrate a dense threat environment.

Deception jamming systems can be smaller, lighter, and can jam more than one threat simultaneously. These characteristics give deception jammers a great advantage over noise jamming systems. Although deception jammers require less power; they are much more complex than noise jammers. Memory is the most critical element of any deception jammer. The memory element must store the signal characteristics of the victim radar and pass these parameters to the control circuitry for processing. This must be done almost instantaneously for every signal that will be jammed. Any delay in the memory loop diminishes the effectiveness of the deception technique. Using digital RF memory (DRFM) reduces the time delay and enhances deception jammer effectiveness.

Deception jamming employed in a self-protection role is designed to counter lethal radar systems. To be effective, deception jamming systems must be programmed with detailed and exact signal parameters for each lethal threat.The requirement for exact signal parameters increases the burden on electronic warfare support (ES) systems to provide and update threat information on operating frequency, PRF, PRI, power pulse width, scan rate, and other unique signal characteristics. Electronic intelligence (ELlNT) architecture is required to collect, update, and provide changes to deception jamming systems. In addition, intelligence and engineering information on exactly how a specific threat system acquires, tracks and engages a target is essential in identifying system weaknesses. Once a weakness has been identified, an effective deception jamming technique can be developed and programmed into a deception jammer. For example, if a particular radar system relies primarily on Doppler tracking, a Doppler deception technique will greatly reduce its effectiveness.

Threat system exploitation is the best source of detailed information on threat system capabilities and vulnerabilities. Effective deception jamming requires much more intelligence support than does noise jamming. Most self-protection jamming techniques employ some form of deception against a target tracking radar (TTR). The purpose of a TTR is to continuously update target range, azimuth, and velocity. Target parameters are fed to a fire control computer that computes a future impact point for a weapon based on these parameters and the characteristics of the weapon being employed. The fire control computer is constantly updating this predicted impact point based on changes in target parameters. Deception jamming is designed to take advantage of any weaknesses in either target tracking or impact point calculation to maximize the miss distance of the weapon or to prevent automatic tracking.

4.7 Digital Radio Frequency Memory

A DRFM system is designed to digitize an incoming RF input signal at a frequency and bandwidth necessary to adequately represent the signal, then reconstruct that RF signal when required. The most significant aspect of DRFM is that as a digital "duplicate" of the received signal, it is coherent with the source of the received signal. As opposed to analog 'memory loops', there is no signal degradation caused by continuously cycling the energy through a front-end amplifier which allows for greater range errors for reactive jamming and allows for predictive jamming. A DRFM system may modify the signal prior to retransmitting which can alter the signature of the false target; adjusting its apparent radar cross section, range, velocity, and angle. DRFMs present a significant obstacle for radar sensors.

The DRFM digitizes the received signal and stores a coherent copy in digital memory. As needed, the signal is replicated and retransmitted. Being a coherent representation of the original signal, the transmitting radar will not be able to distinguish it from other legitimate signals it receives and processes as targets. As the signal is stored in memory, it can be used to create false targets both behind (reactive jamming) and ahead of (predictive jamming) the target intended for protection. Slight variations in frequency can be made to create Doppler (velocity) errors in the victim receiver as well. DRFM can also be used to create distorted phase-fronts at the victim receive antenna which is essential for countering monopulse radar angular measurement techniques.

4.8 Single False Target Jamming

The jamming signal radar received is written as

$$u_j(t) = e^{j2\pi f_j t + j\pi\mu t^2} \qquad , |t|<\frac{T}{2}$$

where f_J is the modulating radar jamming frequency. When $f_J > 0$, it is forward shift jamming and when $f_J < 0$, it is backward shift jamming. We will mainly discuss forward shift jamming here.

The spectrum of the jamming is

$$U_j(f) = \frac{1}{\sqrt{\mu}} e^{-j\pi\frac{\left(f-f_j\right)^2}{\mu}+j\frac{\pi}{4}} \qquad , f_J - \frac{B}{2} < f < f_J + \frac{B}{2}$$

when $f_J > B$, there is no output for the matched filter, so no false target. When $f_J < B$, the output of the jamming after matched filtering is

$$s_j(t) = \frac{c}{\sqrt{\mu}}\left(B - f_J\right) \cdot sinc\left[\pi\left(B - f_J\right)\left(t - t_0 + \frac{f_J}{\mu}\right)\right] \cdot e^{j\pi f_J(t-t_0)}$$

The false target appears at $t = t_0 + \frac{f_J}{\mu}$, $\frac{cf_J}{2\mu}$ meters precede the true target and the maximum preceding distance is $\frac{cT}{2}$. When $f_J = 0$, $s_j(t)$ is the output of target echo after matched filtering. The radar receives the same jamming power and target echo, after matched filtering the relation between the maximum amplitude of the jamming signal and the target echo is

$$A_j = (1 - \frac{f_J}{B})A_t \ ,$$

where A_j is the maximum amplitude of the received jamming signal, A_t is the maximum amplitude of the target echo.

The loss in the jamming energy is caused by frequency mismatching. So to jam a radar efficiently, the power of the jamming signal must be higher than the power of target echo.

4.9 Multiple False Target Jamming

Single false target jamming can be easily identified by the radar. But if there are multiple false targets around the true target, then it is difficult for the radar to identify the true target among them. In order to produce the multiple false targets, we divide the pulse into smaller parts at first, and then different frequency is modulated on each smaller part. Initially make the assumption that the pulse is divided into N parts averagely, and take the initial modulated frequency as f_{J0}, the modulated frequency on each part is

$$f_{Jn} = f_{J0} + (n-1)\Delta f_J, \quad \text{n=1,2,3,…N}$$

where Δf_J is the difference of modulated frequency between two neighboured parts.

The jamming signal is

$$u_{jn}(t) = e^{j2\pi f_{Jn}t + j\pi\mu t^2}\ ,\quad t \in (-\frac{T}{2} + \frac{n-1}{N}T, -\frac{T}{2} + \frac{n}{N}T).$$

The jamming signal passes through the matched filter if the modulated frequency of the jamming signal is within $[f_{J0} - \frac{B}{2}, \frac{B}{2}]$. The frequency range of each false target is $\frac{B}{N} + \Delta f_J$, so the number of false targets is calculated as

$$N_{ft} = ceil(\frac{B - f_{J0}}{\mu \cdot \Delta T + \Delta f_J}),$$

where $\Delta T = \frac{T}{N}$, *ceil* means the nearest integer value.

The preceding distance of the false target compared to true target is

$$\Delta R = \frac{c f_{Jn}}{2\mu}\ .$$

The output of each part of jamming signal after matched filtering is calculated in two cases:

1) When $f_{Jn} \in [0, \frac{N-n}{N}B]$, $f \in \left[-\frac{B}{2} + f_{Jn} + \frac{n-1}{N}B, -\frac{B}{2} + f_{Jn} + \frac{n}{N}B\right]$, this part of the jamming signal can totally pass through the matched filter, so the jamming signal after matched filtering can be given by

$$s_{jn}(t) = \frac{c}{\sqrt{\mu}} \cdot \frac{B}{N} sinc[\frac{\pi B}{N}(t - t_0 + \frac{f_{Jn}}{\mu})] \cdot e^{j[2\pi\left(t - t_0 + \frac{f_{Jn}}{\mu}\right)\left(f_{Jn} + \frac{2n-N-1}{2N}B\right) - \frac{\pi {f_{Jn}}^2}{\mu}]}\ .$$

2) When $f_{Jn} \in [\frac{N-n}{N}B, \frac{N-n+1}{N}B]$, $f \in [-\frac{B}{2} + f_{Jn} + \frac{n-1}{N}B, -\frac{B}{2}]$, only parts of this part of the jamming signal can pass through the matched filter, the jamming signal after passing through the matched filter is

$$s_{jn}(t) = \frac{c}{\sqrt{\mu}}\left(B - f_{Jn} - \frac{n-1}{N}B\right) \cdot sinc[\pi\left(B - f_{Jn} - \frac{n-1}{N}B\right)\left(t - t_0 + \frac{f_{Jn}}{\mu}\right)] \cdot e^{j[\pi\left(t - t_0 + \frac{f_{Jn}}{\mu}\right)\left(f_{Jn} + \frac{n-1}{N}B\right) - \frac{\pi {f_{Jn}}^2}{\mu}]}\ .$$

Because of the frequency mismatching of the jamming signal, the amplitude of the first $N_{ft}-1$ false targets is $\frac{1}{N}$ times of the original target because of large mismatch in frequency.

CHAPTER 5

Pulse Compression Technique

CHAPTER 5

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5.1 What Is Pulse Compression?

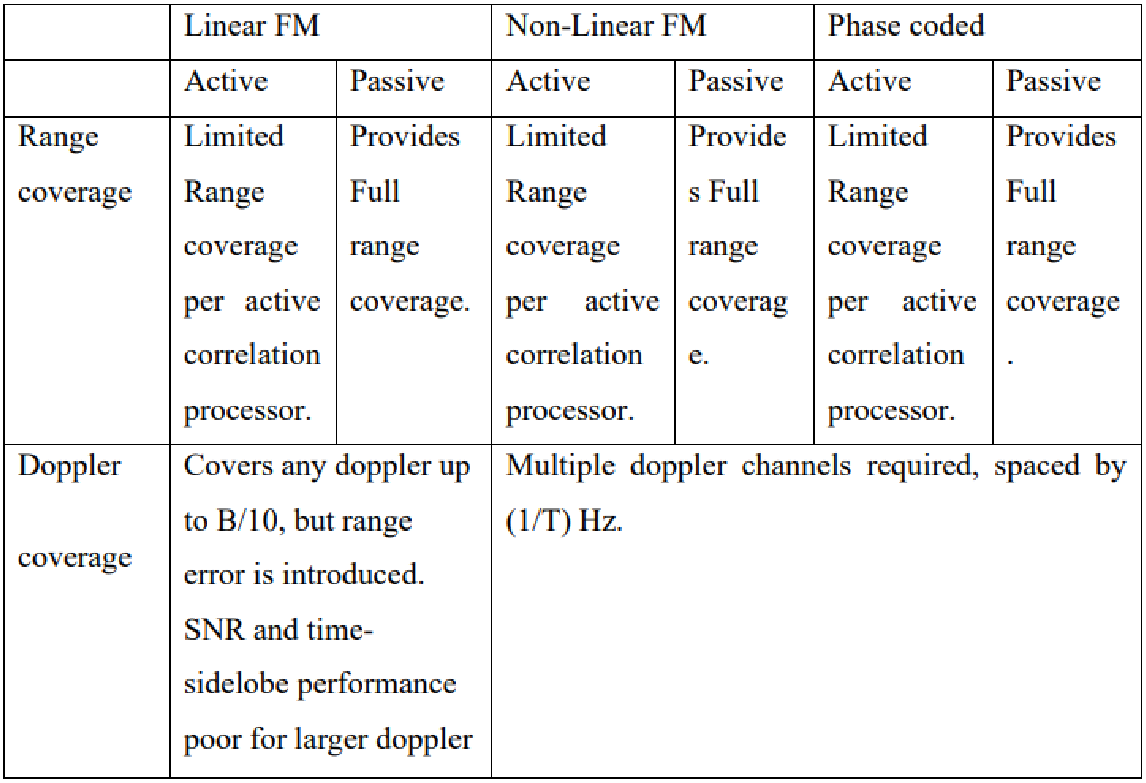
Pulse compression is a signal processing technique commonly used by radar, sonar and echography to increase the range resolution as well as the signal to noise ratio. This is achieved by modulating the transmitted pulse and then correlating the received signal with the transmitted pulse. Pulse compression involves the transmission of a long-coded pulse and the processing of the received echo to obtain a relatively narrow pulse. The increased detection capability of a long-pulse radar system is achieved while retaining the range resolution capability of a narrow-pulse system. Several advantages are obtained. Transmission of long pulses permits a more efficient use of the average power capability of the radar. Generation of high peak power signals is avoided. The average power of the radar may be increased without increasing the PRF and, hence, decreasing the radar's unambiguous range. An increased system resolving capability in doppler is also obtained as a result of the use of the long pulse. In addition, the radar is less vulnerable to interfering signals that differ from the coded transmitted signal. A long pulse may be generated from a narrow pulse. A narrow pulse contains many frequency components with a precise phase relationship between them. If the relative phases are changed by a phase distorting filter, the frequency components combine to produce a stretched, or expanded, pulse. This expanded pulse is the pulse that is transmitted. The received echo is processed in the receiver by a compression filter. The compression filter readjusts the relative phases of the frequency components so that a narrow or compressed pulse is again produced. The pulse compression ratio is the ratio of the width of the expanded pulse to that of the compressed pulse. The pulse compression ratio is also equal to the time band width product of the transmitted signal.

5.1.1 Factors affecting Pulse Compression System

The choice of a pulse compression system is dependent upon the type of waveform selected and the method of generation and processing. The primary factors influencing the selection of a particular waveform are usually the radar requirements of range coverage, doppler coverage, range and doppler sidelobe levels, waveform flexibility, interference rejection, and signal-to-noise ratio (SNR). The methods of implementation are divided into two general classes, active and passive, depending upon whether active or passive techniques are used for generation and processing. Active generation involves generating the waveform by phase or frequency modulation of a carrier without the occurrence of an actual time expansion. An example is digital phase control of a carrier. Passive generation involves exciting a device or network with a short pulse to produce a time-expanded coded waveform. An example is an expansion network composed of a surface-acoustic wave (SAW) delay structure. Active processing involves mixing delayed replicas of transmitted signal with received signal and is a correlation-processing approach. Passive processing involves use of compression network that is the conjugate of the expansion network and is a matched-filtering approach. Although combination of active and passive techniques may be used in same radar system, most systems employ same type for generation and processing; e.g., a passive system uses both passive generation and passive processing. The performance of common types of pulse compression systems is summarized. The systems are compared on the assumption that information is extracted by processing a single waveform as opposed to multiple-pulse processing. The symbols B and Tare used to denote, respectively, the bandwidth and the time duration of the transmitted waveform. Ripple loss refers to the SNR loss incurred in active systems because of the fluctuation or ripple in the SNR that occurs as a target moves from range cell to range cell. Clutter rejection performance of a single waveform is evaluated based on doppler response rather than range resolution; pulse compression provides a means for realizing increased range resolution and, hence, greater clutter rejection. In applications where an insufficient doppler frequency shift occurs, range resolution is the chief means for seeing a target in clutter.40

5.1.2 Pulse Compression Devices

Major advances are continually being made in the devices used in pulse compression radars. Significant advances are evident in the digital and SAW techniques. (a) Symmetrical (b) Non-Symmetrical Time. These two techniques allow the implementation of more exotic signal waveforms such as nonlinear FM. The digital approach has blossomed because of the many fold increase in the computational speed and also because of the size reduction and the speed increase of the memory units. SAW technology has expanded because of the invention of the inter digital transducer,3 which provides efficient transformation of an electrical signal into acoustic energy and vice versa. In spite of these advanced technologies, the most commonly used pulse compression waveforms are still the linear-FM and the phase-coded signals. Improved techniques have enhanced the processing of these "old standby" waveform



	Linear FM		Non-Linear FM		Phase coded	
	Active	Passive	Active	Passive	Active	Passive
Range coverage	Limited Range coverage per active correlation processor.	Provides Full range coverage.	Limited Range coverage per active correlation processor.	Provides Full range coverage.	Limited Range coverage per active correlation processor.	Provides Full range coverage .
Doppler coverage	Covers any doppler up to B/10, but range error is introduced. SNR and time-sidelobe performance poor for larger doppler		Multiple doppler channels required, spaced by (1/T) Hz.			

Range sidelobe level	Requires weighting to reduce the range sidelobes below (sinx)/x falloff.		Good range sidelobes possible with no weightlifting. Sidelobes determined by waveform design.		Good range sidelobes $N^{-(\frac{1}{2})}$ for an Nelement code.	
Waveform flexibility	BW and pulse width can be varied	Limited to one BW and pulse width per compression network.	BW and pulse width can be varied	Limited to one BW and pulse width per compres-sion network.	Bandwidth, pulse width, and code can be varied	
Interferen-ce Rejection	Poor clutter rejection		Fair clutter rejection		Fair clutter rejection	
SNR	Reduced by weight-lifting and by ripple loss versus range	Reduced by weight-lifting	Reduced by ripple loss versus range	No SNR loss	Reduced by ripple loss versus range	No SNR loss

Table 5.1 Summary of performance of various pulse compression implementation

5.2 Why Pulse Compression?

Pulse compression allows a radar to utilize a long pulse to achieve a large radiated energy, but with the range resolution of a short pulse of wide bandwidth. It achieves this by modulating the long pulse of width T to obtain bandwidth B >> 1/T. The received signal is passed through a matched filter to produce a compressed pulse of width 1/B. The pulse compression ratio, which is the duration of the long pulse divided by the duration of the short (compressed) pulse, is equal to BT. Frequency and phase modulations have both been used for pulse compression. Amplitude modulation could also be employed, in principle, but it is seldom found in practical pulse compression systems. Nowadays, Radars are commonly used in Air Traffic Control System. It requires a good presence of target location and good target resolution. Good range resolution can be achieved with a shorter pulse.

But on the other hand, shorter pulses require more peak power. The shorter the pulse gets; more energy is required to pack the pulse by increasing the peak power. Introduction of high peak power makes the design of transmitters and receivers difficult since the components used in the entire system must be able to withstand the peak power. In order to overcome this problem, convert the short duration pulse into a longer pulse. Increasing the length of the pulse results in reduction in the peak power of it, but it reduces range resolution To preserve the range resolution, modulation is to be incorporated to increase the bandwidth of the long pulse (transmitting pulse). This used technique is called the Pulse Compression Technique (PCT) and is used widely in Radar applications where high peak power undesirable. Pulse-compression radar is the practical implementation of a matched-filter system. The reflected radar signal is corrupted by additive white Gaussian noise (AWGN) from the transmission channel. The probability of detection is related to signal-to-noise ratio (SNR) rather than exact shape of the signal received. Hence it needs to maximize the SNR rather than preserving the shape of the signal. A matched filter is a linear filter whose impulse response is determined for a signal in such way that the output of the filter gives maximum SNR when the signal along with AWGN is passed through the filter. In the radar receiver, Pulse compression filter is used to increase the bandwidth of radar pulses and are compressed in the time domain, resulting in a range resolution which is finer than that associated with an uncoded pulse. There are several methods of pulse compression that have been used in the past.

Pulse Compression is one of the important signal processing technique which is used in radar systems to reduce the peak power of radar pulse by the usage of long especially modulated pulses in order to sacrificing the range resolution associated with a shorter pulse. Fig 1 illustrates two pulses having same energy with different pulse width and peak power. Longer pulse is employed at transmitter side and at radar receiver the matched filter output results in short pulse signals with improved SNR during pulse compression procedure. This pulse compression is widely used in the radars to get higher detection ranges due to increasing the transmitted energy and realization of high range resolution. The advantages of larger range detection ability of long pulse and better range resolution ability of short pulse are achieved by Pulse Compression techniques are used in Radar systems. In pulse we can use different types of modulations, such as linear/ non-linear frequency modulation signals (chirp modulation) or discrete phase code modulation.

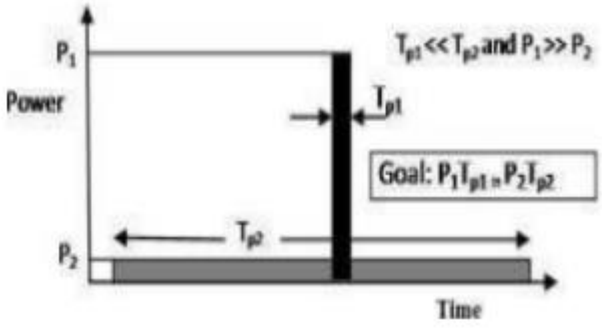


Figure 5.1 Transmitter and Receiver ultimate signal

For range resolution, the bandwidth of the pulse is taken into account but not necessarily the duration of the pulse. ρ = τc/2 = c/2B (1) where ρ=range resolution; τ=pulse duration; c=speed of light; B=signal bandwidth.

5.3 Algorithm

The algorithm for pulse compression in radar involves mainly two steps, first of all generation of Linear Frequency Modulation waveform followed by Matched Filtering. The flow chart which describes the algorithm for pulse compression in radar involves mainly two steps, first of all generation of Linear Frequency Modulation waveform followed by Matched Filtering. The flow chart which describes the whole work is shown below

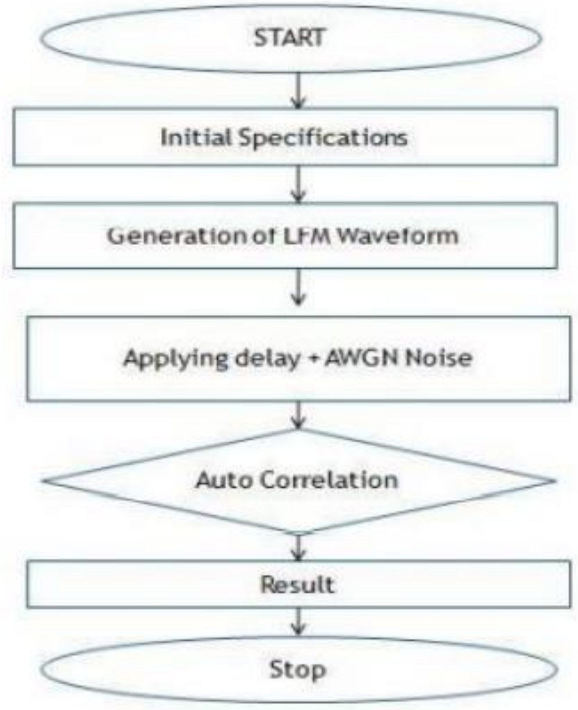


Figure 5.2 Flowchart of the work

An LFM signal is a frequency modulated waveform in which carrier frequency varies linearly with time, over a specific period.

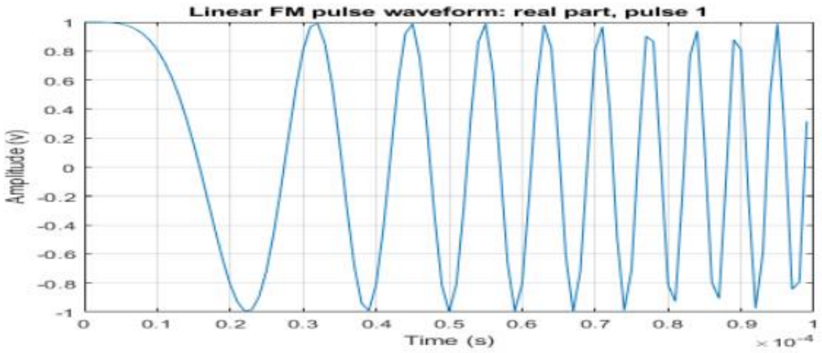


Figure 5.3 LFM signal

This is one of the oldest and frequently used waveforms. It finds application in CW and pulsed radars. Since an LFM waveform is constant amplitude signal, it makes sure that the amplifier works efficiently. Also, this waveform spreads the energy widely in frequency domain.

5.4 What Is an LFM Signal?

The process of compressing a wide pulse into a narrow pulse is known as pulse compression. It requires that the signal has characteristic of large time width and band width product, and LFM signal, which is obtained by nonlinear phase modulation, is a typical signal with large time width and band width product. An LFM pulse is one in which the "instantaneous frequency" changes linearly over the duration of the pulse. By "instantaneous frequency" I mean the rate of change of phase. Over its τ=500µs duration, a pulse with "bandwidth" B=50kHz and center frequency fc=150kHz would be defined by

$$f(t)=A\cos(\theta(t)) = A\cos(2\pi(fc-B/2)t+\pi(B/\tau)t2+\theta0)$$

Taking the derivative of phase with respect to time, we have

$$\partial\theta(t)/\partial t=2\pi(fc-B/2) + 2\pi(B/\tau)t$$

We can see that this sweeps from $2\pi(fc-B/2)$ to $2\pi(fc+B/2)$ over the duration of the pulse. An LFM pulse provides better range resolution than an unmodulated pulse of the same duration.

5.4.1 How to Create Linear FM Pulse Waveforms

To create a linear FM pulse waveform, use phased LFM waveform. You can customize certain characteristics of the waveform, including:

- Sample rate
- Duration of a single pulse46
- Pulse repetition frequency
- Sweep bandwidth
- Sweep direction (up or down), corresponding to increasing and decreasing instantaneous frequency
- Envelope, which describes the amplitude modulation of the pulse waveform. The envelope can be rectangular or Gaussian.
- The Gaussian envelope is a(t)=e −t2/τ2 t≥0 Number of samples or pulses in each vector that represents the waveform

5.4.2 Linear frequency modulated waveform:

LFM waveform commonly known as linear chirps are the most commonly used waveform in radar systems as it can be easily generated, have good range resolution and more doppler tolerant than NLFM. A linear FM chirp has a linear time frequency description as its frequency varies linearly over the pulse duration of the signal. In case of LFM frequency increases (up chirp) or decreases (down chirp) linearly with time. Following figure shows the time frequency characteristics of the signal. Fig 1 depicts the frequency versus time characteristics of a linear FM chirp.

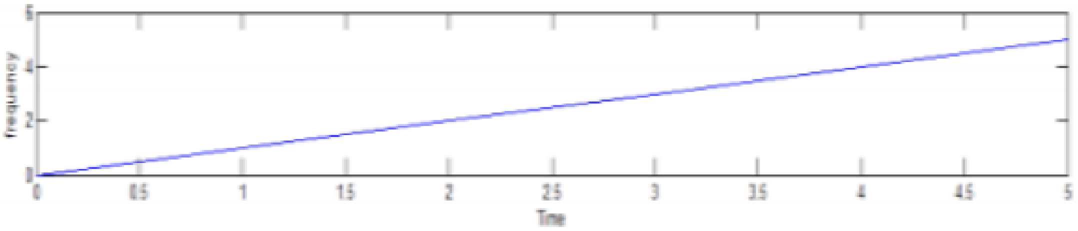


Figure 5.4 Time versus Frequency plot of linear chirp

5.5 Non-Linear Frequency Modulation (NLFM) waveform

NLFM is considered to be capable of achieving fine resolution, good SNR, low cost and high-quality interference mitigation. NLFM is having superior detection rate characteristics and is more precise in range determination than LFM 47. In case of NLFM, it is observed that the time frequency characteristic is nonlinear in nature.

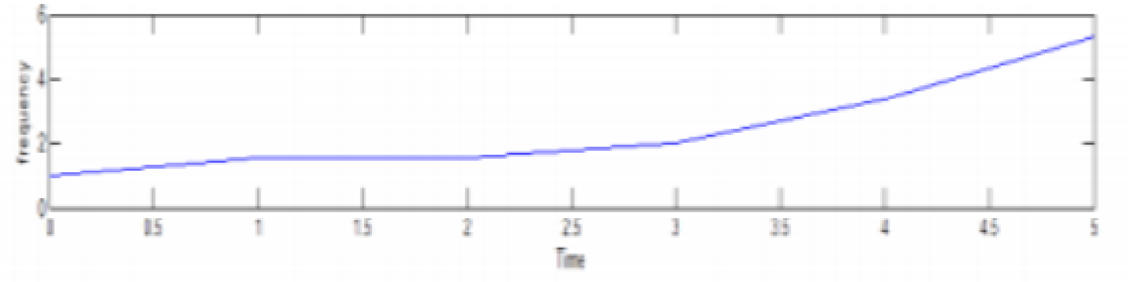


Figure 5.5 Time versus Frequency plot of Non-linear chirp

5.6 Phase-Coded Waveforms

Phase-coded waveforms differ from FM waveforms in that the pulse is subdivided into a number of sub pulses. The sub pulses are of equal duration, and each has a particular phase. The phase of each sub pulse is selected in accordance with a given code sequence. The most widely used phase-coded waveform employs two phases and is called binary, or bi phase, coding. The binary code consists of a sequence of either Os and Is or +Is and —Is. The phase of the transmitted signal alternates between 0° and 180° in accordance with the sequence of elements, 0’s and 1’s or +1’s and -1’s, in the phase code, as shown in Fig. 10.8. Since the transmitted frequency is not usually a multiple of the reciprocal of the sub pulse width, the coded signal is generally discontinuous at the phase-reversal points. Upon reception, the compressed pulse is obtained by either matched filtering or correlation processing. The width of the compressed pulse at the half amplitude point is nominally equal to the sub pulse width. The range resolution is hence proportional to the time duration of one element of the code. The compression ratio is equal to the number of sub pulses in the waveform, i.e., the number of elements in the code.

5.7 Advantage of Pulse Compression

Pulse compression allows us to use a reduced transmitter power and still achieve the desired range resolution. The costs of applying pulse compression include: – added transmitter and receiver complexity – must contend with time 48 sidelobes. The advantages generally outweigh the disadvantages so pulse compression is used widely.

5.7.1 Advantages of LFM Pulse Compression

LFM is easy to implement in hardware - even more so if you can use stretch (de-chirp) processing. It has been the most popular type of pulse compression. Good range resolution which is a function of bandwidth. Autocorrelation (matched filter output) has good side-lobe levels. The LFM spectrum is "nice" given its sharp band edges. This make it more robust to signal processing chains with lots of filtering. LFM is Doppler tolerant. This means that the matched-filter output (think SNR) is robust to Doppler shifts from the return signal.

5.7.2 Disadvantages of LFM Pulse Compression

LFM exhibits range-doppler coupling. A doppler shift will shift the peak of the matched filter output to a different delay (range). Jamming signals can be produced by relatively easy by so called “sweepers”.

CHAPTER 6

Results and Discussions

CHAPTER 6

Results and Discussions

In this chapter, simulation is carried out for generation of false targets using frequency shifting jamming for linear frequency modulated pulse compression radars. The plots for single false target jamming and multiple false target jamming are present in this chapter. The output after matched filtering is also presented in this chapter. From the final results it is depicted that the enemy radar is deceived using the frequency shift jamming by generating the false targets so that the enemy radar cannot identify the true target.

6.1 LFM Signal

A LFM radar waveform is generated such that it has good signal detection capability as that of longer pulse and good resolution as that of shorter pulse. Assume radar signal u(t) is an LFM signal, with pulse width is T, band width B, and frequency spectrum U(f). It can be expressed as

$$u(t)=e^{j\pi\mu t^2}\ ,\ |t|<\frac{T}{2}$$

When BT>>1, the frequency spectrum of the transmitting signal is given by,

$$U(f)=\frac{1}{\sqrt{\mu}}e^{-j\pi\frac{f^2}{\mu}+j\frac{\pi}{4}},\quad -\frac{B}{2}<f<\frac{B}{2}$$

where μ is the frequency modulation slope and $\mu=\frac{B}{T}$

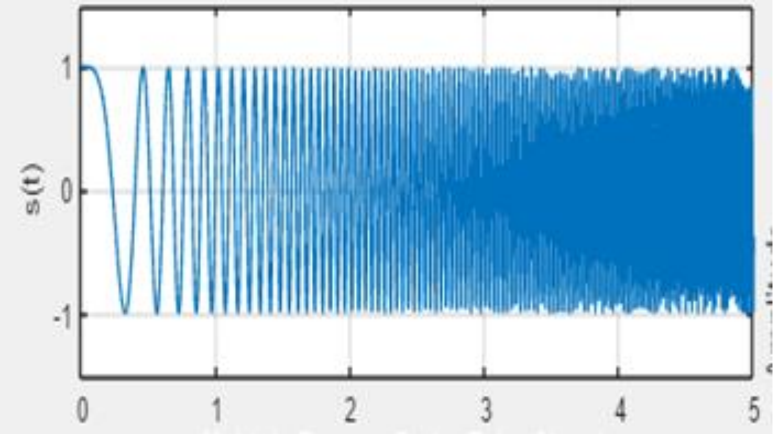


Figure 6.1: LFM radar Signal

6.2 Output after Matched Filtering

The target echo output after matched filtering is,

$$s_t(t) = u(t)*h(t)$$

or

$$s_t(t) = IFFT\{FFT[u(t)].FFT[h(t)]\}.$$

From the above, output is obtained by convolution and through FFT. Usually the efficiency of FFT is high, so FFT is used in this simulation.

After solving the above equation, we obtain

$$s_t(t) = \int_{-\infty}^{\infty} U(f)H(f)e^{j2\pi ft}df$$

$$= \frac{c}{\sqrt{\mu}} B\cdot \text{sin}c[\pi B(t\text{-}t_0)].$$

The target appears at t=t_0, and the target echo after matched filtering is correlated to the slope of frequency modulation, signal bandwidth, the amplitude of matched filter and the time delay.

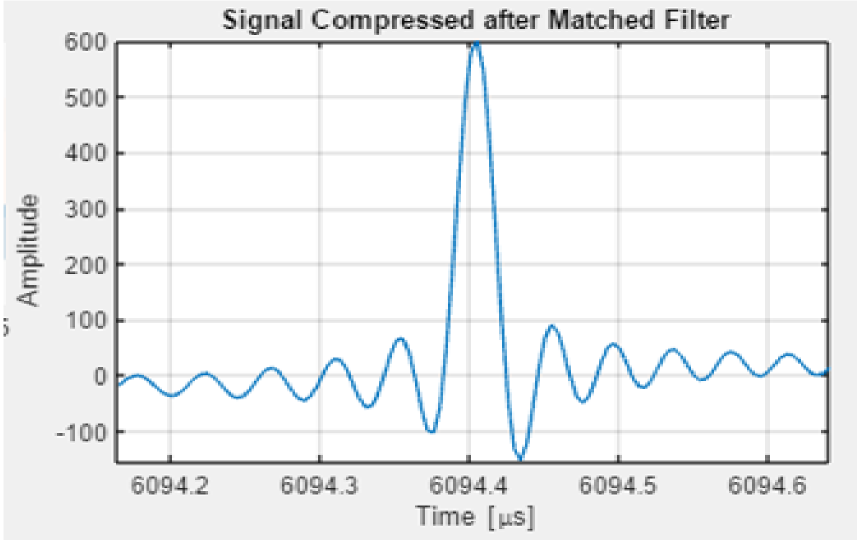


Figure 6.2 : Output of matched filter.

6.3 Single False Target Jamming

The bandwidth of the jammer is 61MHz. The Single false target jamming is shown in Figure 6.3. It can be observed that the false target precede the true target. The radar will receive the false target signal earlier than the true target which confuses the enemy radar. Also, the amplitude of the true target is less than the false target . The jamming is done in amplitude and in time delay to mislead the enemy radar.

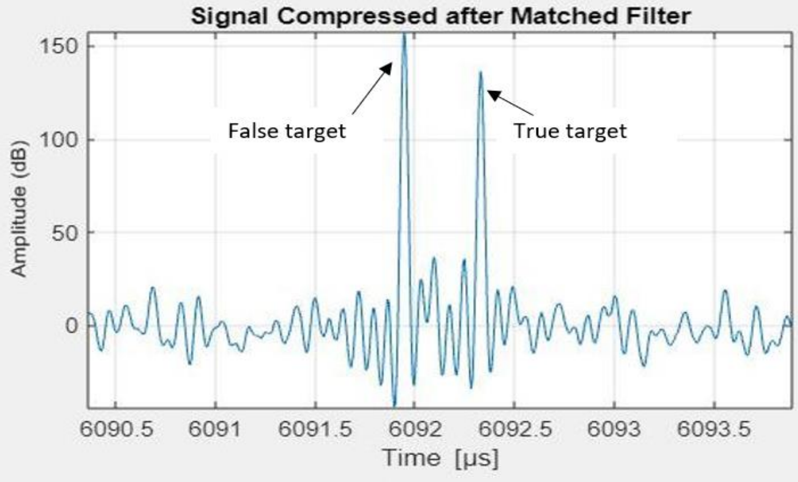
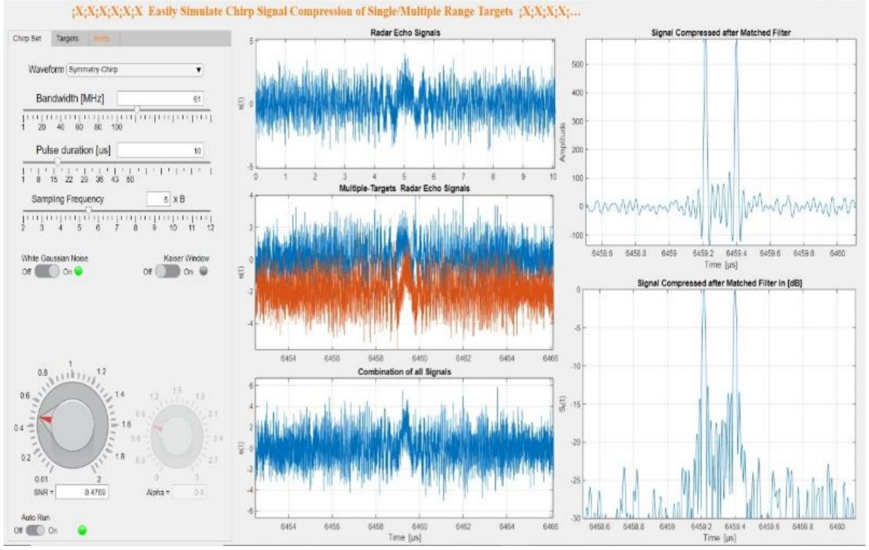


Figure 6.3 Single False Target Jamming

The above results Figure 6.3 are generated using matlab simulator as shown in figure 6.4.



Waveform Symmetry Chirp

Bandwidth [MHz] 61

Pulse duration [us] 10

Sampling Frequency 5 x B

White Gaussian Noise Off On

Kaiser Window Off On

SNR = 0.4769

Alpha = 0.8

Auto Run Off On

Figure 6.4 Result of single false target using simulator.

6.4 Multiple-false Target Jamming

Single false target jamming can be easily identified by the radar. But if there are multiple false targets around the true target, then it is difficult for the radar to identify the true target among them. The figure 6.4 shows the multiple-false target jamming.

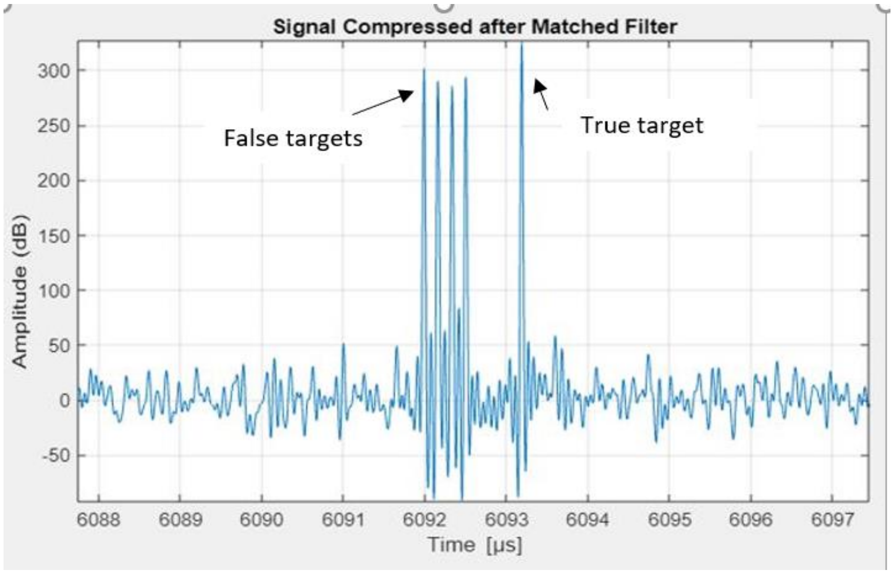
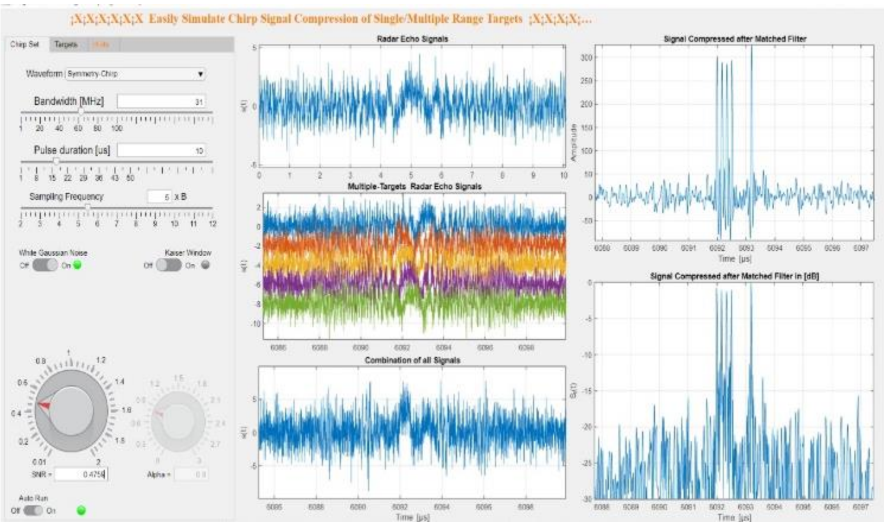


Figure 6.5 Multiple-false target jamming

Multiple number of false targets are generated around the true target and are in earlier to the true target .They are generated using forward shifting jamming with different f_J values. But it can be observed that the amplitude of the false targets is reduced than true target as there is a lot of energy loss due to multiple jamming signals. Even the amplitudes are less for false targets , as created a many false targets before true target which can mislead the true target.

The above results in Figure 6.5 is generated using matlab simulator as shown in figure 6.6.



Waveform Symmetry-Chirp

Bandwidth [MHz] 31

Pulse duration [us] 10

Sampling Frequency 5 x B

SNR = 0.4758

Alpha = 0.8

Figure 6.6 Result of Multiple-false target using simulator.

CHAPTER 7

Software Implementation

CHAPTER 7

Software Implementation

MATLAB is widely used in all areas of applied mathematics, in education and research at universities, and in the industry. MATLAB stands for MATrix LABoratory and the software is built up around vectors and matrices. This makes the software particularly useful for linear algebra, but MATLAB is also a great tool for solving algebraic and differential equations and for numerical integration. MATLAB has powerful graphic tools and can produce nice pictures in both 2D and 3D. It is also a programming language and is one of the easiest programming languages for writing mathematical programs. MATLAB also has some toolboxes useful for signal processing, image processing, optimization, etc.

7.1 Introduction

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. MATLAB stands for matrix laboratory and was written originally to provide easy access to matrix software developed by LINPACK (linear system package) and EISPACK (Eigen system package) projects. MATLAB is therefore built on a foundation of sophisticated matrix software in which the basic element is an array that does not require pre dimensioning which to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of time.

MATLAB features a family of applications specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow learning and applying specialized technology. These are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available to include signal processing, control system, neural networks, fuzzy logic, wavelets, simulation, and many others. Typical uses of MATLAB include Math and computation, Algorithm development, Data acquisition, Modelling, simulation, prototyping, Data analysis, exploration, visualization, Scientific and engineering graphics, Application development, including graphical user interface building.

7.2 Basic Building Blocks of MATLAB

The basic building block of MATLAB is MATRIX. The fundamental data type is the array. Vectors, scalars, real matrices, and complex matrix are handled as a specific class of this basic data type. The built-in functions are optimized for vector operations. No dimension statements are required for vectors or arrays.

7.2.1 MATLAB Window

The MATLAB works based on five windows: Command window, Workspace window, Current directory window, Command history window, Editor Window, Graphics window, and Online-help window.

7.2.1.1 Command Window

The command window is where the user types MATLAB commands and expressions at the prompt (>>) and where the output of those commands is displayed. It is opened when the application program is launched. All commands including user-written programs are typed in this window at MATLAB prompt for execution.

7.2.1.2 Work Space Window

MATLAB defines the workspace as the set of variables that the user created in a work session. The workspace browser shows these variables and some information about them. Double-clicking on a variable in the workspace browser launches the Array Editor, which can be used to obtain information.

7.2.1.3 Current Directory Window

The current Directory tab shows the contents of the current directory, whose path is shown in the current directory window. For example, in the windows operating system, the path might be as follows: C:\MATLAB Work, indicating that directory "work" is a subdirectory of the main directory "MATLAB"; which is installed in drive C. Clicking on the arrow in the current directory window shows a list of recently used paths. MATLAB uses a search path to find M-files and other MATLAB related files. Any file nun in MATLAB must reside in the current directory or in a directory that is on the search path.

7.2.1.4 Command History Window

History Window contains a record of the commands a user has entered in the command window, including both current and previous MATLAB sessions. Previously entered MATLAB commands can be selected and re-executed from the command history window by right-clicking on a command or sequence commands. This is useful to select various options in addition to executing the commands and is a useful feature when experimenting with various commands in a work session.

7.2.1.5 Editor Window

The MATLAB editor is both a text editor specialized for creating M-files and a graphical MATLAB debugger. The editor can appear in a window by itself, or it can be a sub-window in the desktop. In this window, one can write, edit, create and save programs in files called M-files.

MATLAB editor window has numerous pull-down menus for tasks such as saving, viewing, and debugging files. Because it performs some simple checks and also uses color to differentiate between various elements of code, this text editor is recommended as the tool of choice for writing and editing M-functions.

7.3 MATLAB Files

MATLAB has three types of files for storing information. They are M-files and MAT-files.

7.3.1 M-Files

These are standard ASCII text files with 'm' extension to the file name and creating own matrices using M-files, which are text files containing MATLAB code. MATLAB editor or another text editor is used to create a file containing the same statements which are typed at the MATLAB command line and save the file under a name that ends in .m. There are two types of M-files:

1. Script Files

It is an M-file with a set of MATLAB commands in it and is executed by typing the name of the file on the command line. These files work on global variables currently present in that environment.

2. Function Files

A function file is also an M-file except that the variables in a function file are all local. This type of file begins with a function definition line.

7.3.2 MAT-Files

These are binary data files with .mat extension to the file that is created by MATLAB when the data is saved. The data are written in a special format that only MATLAB can read. These are located in MATLAB with the 'load' command.

7.4 Some Basic Commands:

Pwd	: Print working directory
Demo	: Demonstrates what is possible in Matlab

Who : Lists all of the variables in your Matlab workspace?

Whose : List the variables and describes their matrix size

Clear : Erases variables and functions from memory

clear x : Erases the matrix 'x' from your workspace

close : By itself, closes the current figure window

figure : Creates an empty figure window

xlabel(‘ ‘) : Allows you to label x-axis

ylabel(‘ ‘) : Allows you to label y-axis

title(‘ ‘) : Allows you to give title for plot

A semicolon “;” at the end of a MATLAB statement suppresses printing of results. Use **Up arrow** and **Down arrow** to edit previous commands you entered in Command Window.

Insert “%” before the statement that you want to use it as comment; the statement will appear in green color.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in and fraction of the time.

The name MATLAB stands for Matrix laboratory, MATLAB features a family of applications solutions called toolboxes. Toolboxes are comprehensive collections of MATLAB(M-files) that extend the MATLAB environment to solve particular classes of problem. It is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science. MATLAB is the tool of choice for high-productivity research, development, and analysis.

MATLAB's support for object-oriented programming includes classes, inheritance, virtual dispatch, packages, pass-by value semantics, and pass-by reference semantics. A wrappers function it created allowing MATLAB data types to be passed and returned.

7.5 The MATLAB language

Versions such as R2009, R2010, R2012, R2013, R2015 R2017 are available in both ‘a’ and ‘b’ versions. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both “programming in the small” to rapidly create quick and dirty throw-away programs, and “programming in the large" to create complete large and complex application programs.

7.6 MATLAB program control

MATLAB is also a programming language. Like other computer programming languages, MATLAB has some decision-making structures include for loops, while loops, and if-else-end constructions. Control flow structures are often used in script M-files and function M-files.

By creating a file with the extension .m, we can easily write and run programs. We do notneed to compile the program since MATLAB is an interpretative (not compiled) language. MATLAB has thousands of functions, and you can add your own using M-files. MATLAB provides several tools that can be used to control the flow of a program.

7.7 Types of Functions

MATLAB offers several different types of functions to use in your programming.

7.7.1 Anonymous Functions

An anonymous function is a simple form of the MATLAB function that is defined within a single MATLAB statement. It consists of a single MATLAB expression and any number of input and output arguments. You can define an anonymous function right at the MATLAB command line, or within a function or script. This gives you a quick means of creating simple functions without having to create a file for them each time.

7.7.2 Primary and Sub functions

Any function that is not anonymous must be defined within a file. Each such function file contains a required primary function that appears first, and any number of sub functions that may follow the primary. Primary functions have a wider scope than sub functions That is, primary functions can be called from outside of the file that defines them (e.g., from the MATLAB command line or from functions in other files) while sub functions cannot. Sub functions are visible only to the primary function and other sub functions within their own file.

7.8 Plotting in MATLAB

MATLAB provides a variety of functions for displaying vector data as line functions for annotating and that produce basic line plots. These functions differ in the way they scale the accepts input in the form of vectors or matrices and automatically scales the axes to accommodate the data. The mesh and surf commands create 3-D surface plots of matrix data. Surface object properties provide additional control over the visual appearance of the surface and also the edge line styles, vertex markers, face colouring, lighting, characteristics can also be specified.

7.8.1 Basic Plot Commands

plot(x, y)	: create a Cartesian plot of vectors x & y
plot(y)	: creates a plot of y vs, the numerical values of the elements in vector
semilogx(x, y)	: plot log(x) vs y
semiology(x, y)	: plot x vs log(y)
loglog(x, y)	: plot log(x) vs log(y)
polar(theta, r)	: creates a polar plot of the vectors r theta where theta is in radians
bar(x)	: creates a bar graph of the vector x (Note also the command stairs(x))
bar(x, y)	: create a bar graph of the elements of the vector y, locating

the bars

Plot description:

grid : create a grid on the graphics plot

title(‘text’) : places a title at top of graphics plot

xlabel(‘text’) : writes ‘text’ below the x-axis of a plot

ylabel(‘text’) : writes ‘text’ below the x-axis of a plot

7.9 Data Types in MATLAB

By default, MATLAB stores most data in array of class double. The data in these arrays is stored as double precision (64-bit) floating-point numbers. All MATLAB functions and capabilities work with these arrays.

For images stored in one of the graphics file formats supported by MATLAB, however, this data representation is not always ideal. The number of pixels in such an image may be very large, for example, a 1000-by-1000 image has a million pixels. Since each pixel is represented by at least one array clement, this image would require about 8 megabytes of memory if it were stored as class double. To reduce memory requirements, MATLAB supports storing image data in arrays of class uint8 and uint16. The data in these arrays is stored as 8-bit or 16-bit unsigned integer. These arrays require one eighth or one-fourth much memory as data in double arrays.

7.10 Applications of MATLAB

- Data Exploration, Acquisition, Analysing & Visualization
- Engineering drawing and Scientific graphics
- Analysing of algorithmic designing and development
- Mathematical functions and Computational functions
- Simulating problems prototyping and modelling
- Application development programming using GUI building environment

CHAPTER 8

Conclusion and Future Work

CHAPTER 8

Conclusion and Future Work

A method of Forward shifting false target jamming for a LFM radar signal is effective in a single false target and multiple-false target jamming. To jam the enemy radar transmitted a jamming signal with forward shifting jamming frequency of single and multiple jamming signals. By changing the frequency-shifting rule, it can produce forward shifting and backward shifting multiple-false targets jamming which is effective to jam the LFM pulse compression radars. To jam the enemy's radar successfully, we should choose the different frequency modulation method of the jamming signal according to the concrete warfare state. The simulation results shows that the multiple- false target jamming is more better to deceive the enemy radar compared to single false target jamming. In future work, the amplitude of multiple-false targets can be increased by increasing the jamming energy and the true target echo can be cancelled using active echo cancellation which makes the enemy radar impossible to detect the target.

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