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Performance Analysis of Radar for Effective Air Traffic Control System

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ABSTRACT

Air Traffic Control (ATC) radar propagation with a short pulse duration lacks the capability of long range detection of targets. Thus, pulse compression techniques can be used in the system to provide the benefits of large range detection capability of long duration pulse and high range resolution capability of short duration pulse especially for solid state radar transmitter with low peak power. In these techniques, a long duration pulse is used which is phase modulated before transmission and the received signal is passed through a matched filter to compress the energy into a short pulse in other to achieve high signal-to-noise ratio (SNR). In this work, pulse compression matched filter model was developed in which the output is the autocorrelation function (ACF) of a modulated signal associated with range side lobes along with the main lobe which is used to maximise the signal-to-noise ratio as shown in the simulation result using MATLAB software. With the implementation of this model, radar system in Port Harcourt can be made to detect targets beyond 256nm.

Keywords: Air traffic control, Pulse compression, Signal-to-noise ratio, Matched filter, Range detection, Radar system performance, MATLAB.

1.0 INTRODUCTION

Air traffic control (ATC) is a service provided by ground-based controllers who direct aircraft on the ground through controlled airspace, and can provide advisory services to aircraft in non-controlled airspace. The primary purpose of ATC worldwide is to prevent collisions, organize and expedite the flow of traffic, and provide information and other support for pilots with the use of radar system. Radar is an object detection system which uses radio waves to determine the range, altitude, direction, or speed of objects. It can be used to detect aircraft, ships, spacecraft, guided missiles, motor vehicles, weather formations, and terrain. The radar dish or antenna transmits pulses of radio waves or microwaves which is reflected at the target object. The object returns a tiny part of the wave's energy to a dish or antenna which is processed and displayed to be used by the Air Traffic Controllers to locate the target airplane through careful analysis of the signal (Shrader, W.W., 1973).

The day-to-day problems faced by the air traffic controllers are primarily related to weather and the volume of air traffic demand placed on the radar system. Each landing aircraft must touch down, slow, and exit the runway before the next crosses the approach end of the runway. Air traffic control errors generally occur when the separation (either vertical or horizontal) between airborne aircraft falls below the minimum prescribed separation set or during period of intense activity, when controllers tend to relax and overlook the presence of traffic and conditions that lead to loss of minimum separation. Beyond runway capacity issues, weather is a major factor in traffic capacity. Rain, ice, snow on the runway cause landing aircraft to take longer to slow and exit, thus reducing the safe arrival rate and requiring more space between landing aircraft (Meril I. Skolnik, 2001).

One of the greatest challenges being faced today by pilots in Nigeria airspace is effective communication with the air traffic controllers on ground especially at long range owing to the short range of the radar system of about 256nm together with its inability to detect reply signals at heavy precipitation as a result of narrow pulse width of 0.8μs.

This research work was carried out to present a mathematical model of pulse compression matched filter capable of accumulating the energy of large pulse into a short pulse without sacrificing its range resolution in other to increase its sensitivity, maximize the output signal-to-noise ratio and improve radar target detection of aircraft farther than 256nm. The paper also included the analysis and the simulated result of the matched filter as an autocorrelation of the modulated input signal.

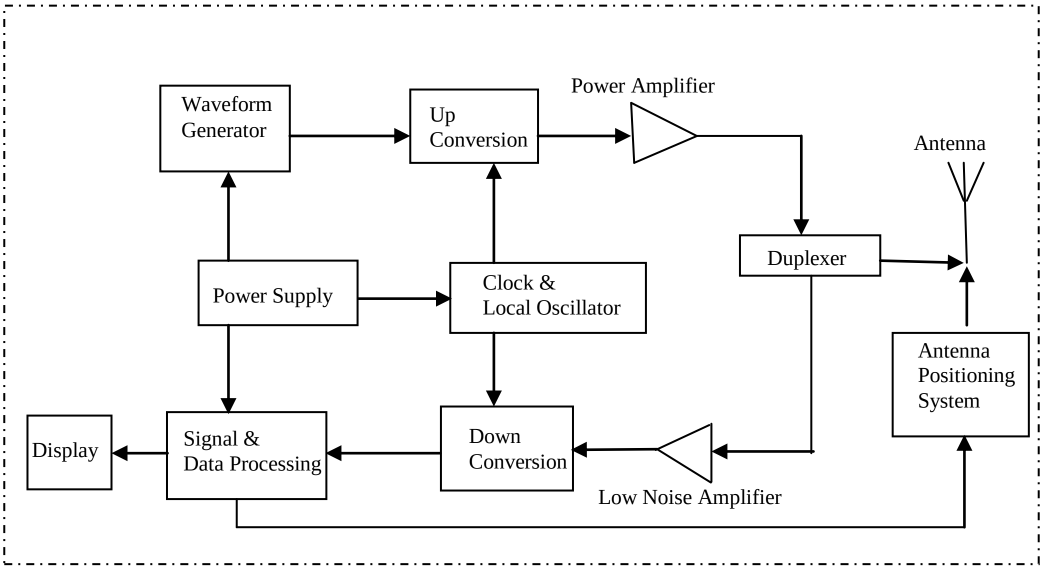


Figure 1.0 Radar system schematic

Radar systems are very complex electronic, electromagnetic and mechanical systems. They are composed of many different subsystems, which themselves are composed of many different components. There is a great diversity in the design of radar systems based on purpose, but the fundamental operation and main set of subsystems is the same. Some of the subsystems and important components that are found in typical portable monostatic pulsed ground surveillance radar systems are shown in the figure 1.0(Varshney Lar, 2002).

1.1 THE RADAR EQUATION

Consider radar with an omnidirectional antenna (one that radiates energy equally in all directions).

$$P_d = \frac{\text{Peak transmitted power}}{\text{Area of a sphere}} \left(\frac{W}{m^2}\right) \quad \text{---------} (1)$$

Since these kinds of antennas have a spherical radiation pattern which can be defined as the peak power density, P_d (Power per unit area) at any point in space as:

The power density at range R away from the radar (assuming a lossless propagation medium) is:

$$P_d = \frac{P_t}{4\pi R^2} \quad \text{---------}(2)$$

Where P_t is the peak transmitted power and $4\pi R^2$ is the surface area of a sphere of radius R. Radar systems utilize directional antennas in order to increase the power density in a certain direction. Directional antenna gain G and the antenna effective aperture A_e are related by:

$$A_e = \frac{G\lambda^2}{4\pi} \qquad \text{----------- (3)}$$

Where λ is the wavelength of the signal. The relationship between the antenna's effective apertures A_e and the physical aperture A is.

$$A_e = \rho A \qquad \text{-----------(4)}$$

$$0 < \rho < 1$$

ρ is referred to as the aperture efficiency and good antennas require $\rho \longrightarrow 1$. In this work, A and A_e are assumed to be the same including antennas gain in the transmitting and receiving modes. In practice $\rho \longrightarrow 0.7$ is widely accepted.

The power density at a distance R away from radar using a directive antenna of gain G is then given by:

$$P_d = \frac{P_t G}{4\pi R^2} \qquad \text{-----------(5)}$$

When the radar radiated energy impinges on a target, the induced surface currents on that target radiate electromagnetic energy in all directions. The amount of the radiated energy is proportional to the target size, orientation, physical shape, and material, which are all lumped together in one target-specific parameter called the radar cross section (RCS) and is denoted by σ.

The radar cross section is defined as the ratio of the power reflected back to the radar to the power density incident on the target,

$$\sigma = \frac{P_r\,(m^2)}{P_d} \qquad \text{------------- (6)}$$

Where P_r is the power reflected from the target. Thus, the total power delivered to the radar signal processor by the antenna is:

$$P_{dr} = \frac{P_t G \sigma A_e}{(4\pi R^2)^2} \qquad \text{----------- (7)}$$

Substituting the value of Ae from Eq (3) into Eq (7) yields

$$P_{dr} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \qquad \text{-------------- (8)}$$

Let S_{min} denote the minimum detectable signal power. It follows that the maximum radar range R_{max} is

$$R_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}}\right)^{1/4} \qquad \text{-------------- (9)}$$

Eq (9) suggests that in order to double the radar maximum range, one must increase the peak transmitted power (P_t) Sixteen times; or equivalently increase the effective aperture four times.

In practice situations, the returned signals received by the radar will be corrupted with noise, which introduces unwanted voltages at all radar frequencies. Noise is random in nature and can be described by its Power Spectral Density (PSD) function. The noise power N is a function of the radar operating bandwidth B. More precisely

$$N = \text{Noise (PSD)} \times B \qquad \text{-----------(10)}$$

The input noise power to a lossless antenna is

$$N_i = K T_e B \qquad \text{---------- (11)}$$

Where $K = 1.38 \times 10^{-23}$ joule per degree kelvin is boltzman's constant.

T_e = 290 degree kelvin is the effective noise temperature.

It is always desirable that the minimum detectable signal (S_{min}) be greater than the noise power. The fidelity of a radar receiver is normally described by a figure of merit called the noise figure F. The noise figure is defined:

$$F = \frac{(SNR)_i}{(SNR)_o} = \frac{S_i/N_i}{S_o/N_o} \qquad \text{------------- (12)}$$

$(SNR)_i$ and $(SNR)_o$ are respectively the signal to Noise ratios (SNR) at the input and output of the receiver. S_i is the input signal power, N_i is the input noise power, S_o and N_o are respectively the output signal and noise power (Barton, 1988).

Substituting Eq. (11) into Eq. (12) and rearranging terms yield:

$$S_i = KT_eBF(SNR)_o \qquad \text{---------- (13)}$$

Thus, the minimum detectable signal power can be written as:

$$S_i = KT_eBF(SNR)_{omin} \qquad \text{------------ (14)}$$

The radar detection threshold is set equal to the minimum output SNR, $(SNR)_{omin}$.

Substituting Eq (14) into Eq (9) gives:

$$R_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 KT_e BF(SNR)_{omin}}\right)^{1/4} \qquad \text{---------- (15)}$$

Or equivalently

$$(SNR)_{omin} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 KT_e BFR^4} \qquad \text{---------- (16)}$$

Radar losses denoted as L reduces the overall (SNR) and hence

$$(SNR)_{omin} = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 KT_e BFLR^4} \quad \text{---------- (17)}$$

Though it may take different forms, Eq. (17) is what is widely known as the radar equation. It is a common practice to perform calculations associated with the radar equation using decibels (dB) arithmetic (Bassem, R. and Mahafza, 2000).

1.2 DETECTION RANGE OF RADAR SYSTEM

The radar equation can be modified to compute the maximum detection range required to achieve a certain $(SNR)_{omin}$ for a given pulse width. If $B = 1/\tau$

Where:

B is the bandwidth

τ – pulse width of the transmitted signal

Thus:

$$R_{max} = \left(\frac{P_t G^2 \lambda^2 \sigma \tau}{(4\pi)^3 KT_e FL(SNR)_{omin}}\right)^{1/4} \text{----------(18)}$$

1.3 DESIGN SPECIFICATIONS FOR THE RADAR SYSTEM

The design parameters of the L-band radar system is as presented below:

Band: L

Frequency band (F): 1 ~ 2GHz

Wavelength range (λ): 15 ~ 30cm

Transmitting peak power (P_t): 2570W

Transmitting average power (P_{avg}):25.70W

Pulse repetition time (PRT): 1000μs

Pulse repetition frequency (PRF): 1000pulses per second

Pulse width (P_w): 10μs

Duty cycle (DC): 0.01

Radar target cross section (σ): 1.0m^2

Table 1.0: Antenna and Receiver Parameter Values

Antenna Parameters	Value	Radar Receiver Parameters	Value
Width:	7.3m	Noise figure (F):	3dB
Height:	4.3m	Boltzman's constant (K):	1.38×10^{-23} J/^{0}K
Rotating clearance:	8.7m	Effective noise temperature (K):	290^{0}K
Horizontal beamwidth (Θ):	2.4^0	Probability of detection (P_d):	80% and above
Vertical beamwidth (Φ):	4.0^0	Probability of false alarm rate (P_f):	1.0×10^{-6}
Directional gain (G_{dir}):	36.4dB	Minimum signal-to-noise ratio $(SNR)_{omin}$	13dB
Scan rate:	6rpm		

The distance beyond which a target can no longer be detected and correctly processed can be determined with the use of maximum range (R_{max}) radar equation. The criterion for detection is simply that the received power, P_r must exceed the minimum, S_{min}. Since the received power decreases with range, the maximum detection range will occur when the received power is equal to the minimum detectable signal of the radar receiver i.e. $P_r = S_{min}$ (Blake, L. M., 1991).

Table 2.0: MDS vs pulse width at a specified noise figure and SNR.

Pulse Width (μs)	Bandwidth (KHz)	Noise Figure(dB)	KT_e (W)	SNR (dB)	R_{max} (nm)	MDS (dB)	MDS (dBm)
0.8	1250	3.0	4.0×10^{-21}	13	293	-127	-97
2.0	500	3.0	4.0×10^{-21}	13	359	-131	-101
5.0	200	3.0	4.0×10^{-21}	13	464	-135	-105
10.0	100	3.0	4.0×10^{-21}	13	552	-138	-108

From the radar equation, it can be observed that the ability of radar to detect targets can be improved when there is an increase in pulse width. Figure 1.1 shows a typical plot generated by using MATLAB program listed in Appendix A with 2.0μs, 5.0μs and 10.0μs input values of the pulse width.

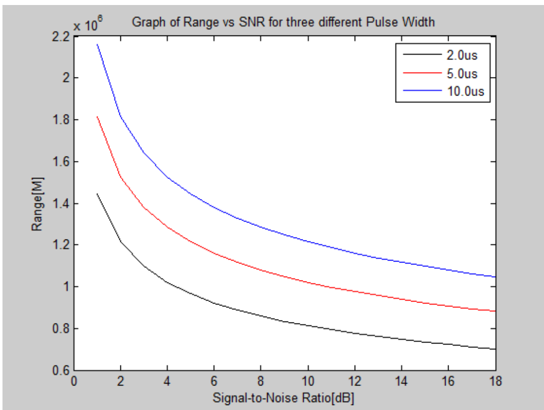


Figure 1.1: Graph of Range against SNR with three different pulse width

The required signal-to-noise ratio (SNR) at the receiver is determined by the design goal of P_d and P_{fa}, as well as the detection scheme implemented at the receiver. The relation between P_d, P_{fa} and SNR can be best represented by a receiver operating characteristics (ROC) curve shown in figure 1.2.

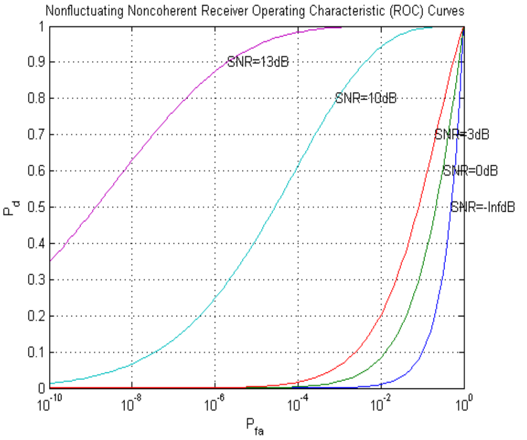


Figure 1.2: P_d vs P_{fa} varying pulse SNR (Masanoni Shinriki and Hironori Susaki, 2008**).**

Wider pulses can effectively increase radar's sensitivity to weak atmospheric events and enhance its ability to penetrate heavy precipitation. Sensitivity in a radar receiver is normally taken as the minimum input signal (S_{min}) required to produce a desired output signal having a specified signal-to-noise ratio (SNR) which is usually stated in dBm.

Table 3.0: Values of Sensitivity in Accordance With Increase in Range and Pulse Width

THE VALUES OF SENSITIVITY IN dBm				
RANGE (KM)	PULSE WIDTH (µs)			
	0.8	2.0	5.0	10.0
1.0	-27.47	-23.49	-19.51	-16.50
5.0	-95.43	-91.45	-87.47	-84.46
200	-119.51	-115.53	-111.55	-108.54
1000	-147.47	-143.49	-139.51	-136.50

From the MATLAB simulation in figure 1.3, it is obvious that the sensitivity of radar is reduced when there is an increase in the transmitted pulse width which limits its performance. Consequently, if the radar transmitter can increase its PRF and its receiver performs integration over time via pulse compression technique, an increase in PRF or pulse width can permit the receiver to "pull" coherent signals out of the noise thus reducing S/N_{min} thereby increasing the detection range.

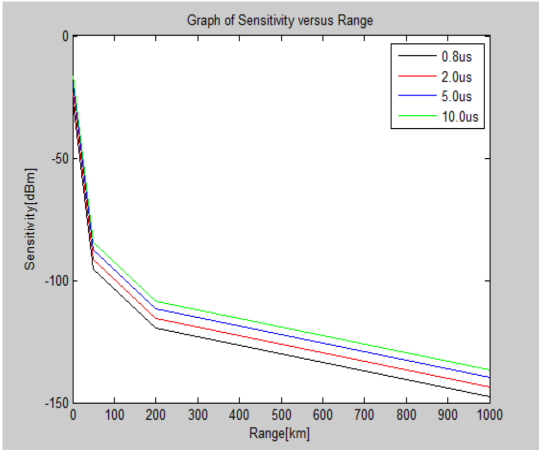


Figure 1.3: Graph of Sensitivity against Range

1.4 PULSE COMPRESSION IN RADAR SYSTEM

To get the advantages of larger range detection ability of long pulse and better range resolution ability of short pulse, pulse compression techniques are used in radar systems to obtain high energy and simultaneously achieve the resolution of a short pulse by internal modulation of the long pulse. This technique can increase signal bandwidth through frequency or phase coding. The received echo is processed in the receiver matched filter to produce a short pulse with duration 1/B, where B is bandwidth of compressed pulse. This technique is of interest when the radar is not able to generate enough required power as found in solid state radar transmitter. So, a concise summary for pulse compression is gathering two opposite benefits "High Range Resolution" and "high detection probability" concurrently. It can be stated that "radar pulse compression" is a substitute for "short pulse radar"

The maximum detection range depends upon the strength of the received echo. To get high strength reflected echo, the transmitted pulse should have more energy for long distance transmission since it gets attenuated during the course of transmission. The energy content in the pulse is proportional to the duration as well as the peak power of the pulse. The product of peak power and duration of the pulse gives an estimate of the energy of the signal (E_t). Where

$E_t = P_t \times \tau$ ---------------- (19)

A low peak power pulse with long pulse duration provides the same energy as achieved in case of high peak power and short duration pulse. Shorter duration pulses achieve better range resolution.

The range resolution, $S_x = \frac{C_o}{2B}$ ------- (20)

Where B is the bandwidth of the pulse and C_o is the speed of electromagnetic waves.

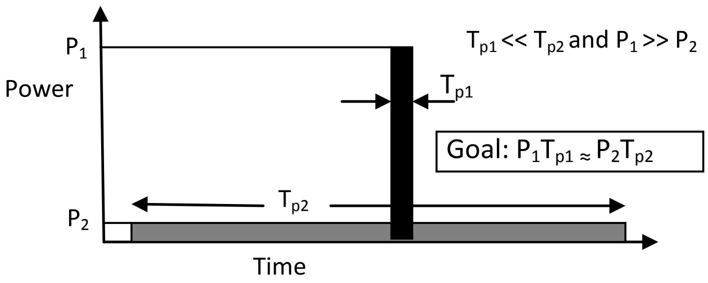


Figure 1.4 illustrates two pulses having same energy with different pulse width and peak power

In pulse compression technique, a pulse having long duration and low peak power is modulated either in frequency or phase before transmission and the received signal is passed through a filter to accumulate the energy in a short pulse. The pulse compression ratio (PCR) is defined as

$$PCR = \frac{\text{width of the pulse before compression}}{\text{width of the pulse after compression}} \text{--- (21)}$$

The block diagram of a pulse compression radar system is shown in Figure 1.5. The transmitted pulse is either frequency or phase modulated to increase the bandwidth. Trans-receiver (TR) is a switching unit which regulates the function of the antenna as a transmitting and receiving device. The pulse compression filter is usually a matched filter whose frequency response matches with the spectrum of the transmitted waveform. The filter performs a correlation between the transmitted and the received pulses. The received pulses with similar characteristics to the transmitted pulses are picked up by the matched filter whereas other received signals are comparatively ignored by the receiver (Vansi Krishma M, 2011).

1.5 MATCHED FILTER MODEL

Pulse compression matched filter is a part of the receiver network system that is specifically designed to maximize the output of the signal-to-noise ratio. This is achieved through its frequency response function denoted by H(f). It expresses the relative amplitude and phase of a network with respect to the input when the signal is a pure sinusoid.

In radar applications, the reflected signal is used to determine the existence of the target. The reflected signal is corrupted by additive white Gaussian noise (AWGN). The probability of detection is related to signal-to-noise ratio (SNR) rather than exact shape of the signal received. Hence, it is required to maximize the SNR rather than preserving the shape of the signal. A filter which maximizes the output SNR is called matched filter. A matched filter is a linear filter whose impulse response is determined for a signal in such way that the output of the filter yields maximum SNR when the signal along with AWGN is passed through the filter. An input signal s(t) along with AWGN is given as input to the matched filter as shown in Figure 3.12.

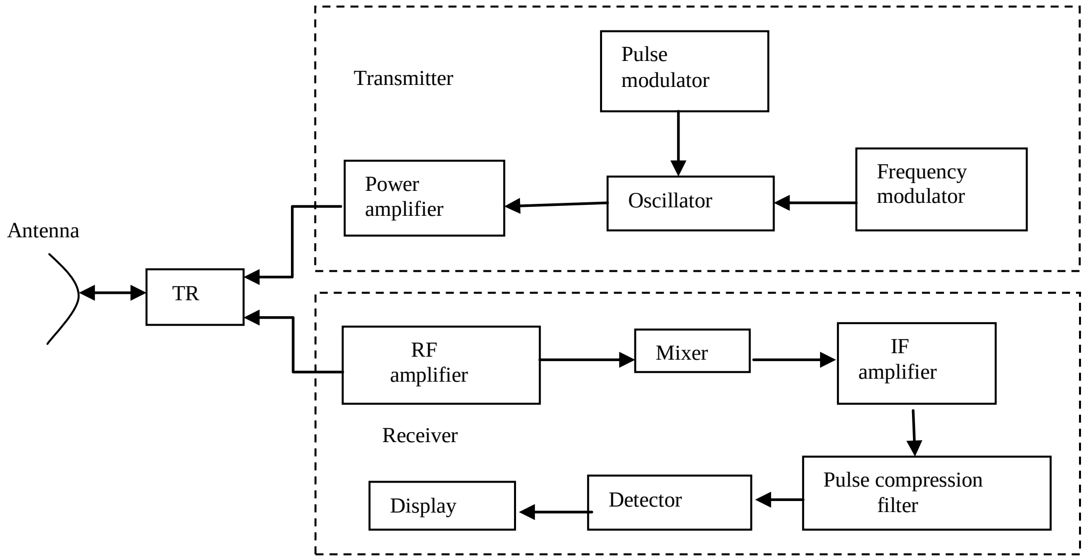


Figure 1.5: Block diagram of a pulse compression radar system

Let $N_o/2$ be the two sided power spectral density (PSD) of AWGN. We are required to find out the impulse response h(t) or the frequency response H(f) (Fourier transform of h(t)) that yields maximum SNR at a predetermined delay t_o

In other words, h(t) or H(f) is determined to maximize the output SNR which is given by

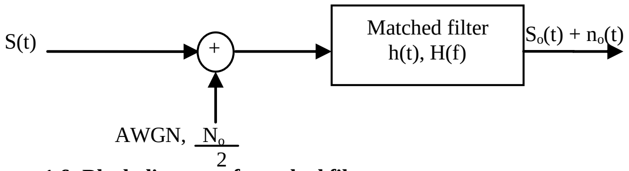


Figure 1.6: Block diagram of matched filter.

$$\left(\frac{SP}{NP}\right)_{out} = \frac{|S_o(t_o)|^2}{\overline{N_o{}^2(t)}} \quad \text{-----------} \quad (22)$$

Where SP is the signal power, NP is the output noise power, $S_o(t_o)$ is the value of the output signal So(t) at $t = t_o$ and $\overline{N_o{}^2(t)}$ is the mean square value of the noise.

If S(f) is the fourier transform of S(t), then $S_o(t)$ is obtain as

$$S_o(t) = \int_{-\infty}^{\infty} H(f)\, S(f) e^{j2\pi ft_o}\, df \quad \text{--------} \ (23)$$

The value of $S_o(t)$ at $t = t_o$ is

$$S_o(t_o) = \int H(f)\, S(f) e^{j2\pi ft_o} df \quad \text{-----} \ (24)$$

The mean square value $\overline{N_o{}^2(t)}$ of the noise is evaluated as

$$\overline{N_o{}^2(t)} = \frac{N_o}{2} \int_{-\infty}^{\infty} |H(f)|^2 df \quad \text{---------} \ (25)$$

Substituting equ (24) and equ (25) into equ (22)

$$\left(\frac{SP}{NP}\right)_{out} = \frac{\left|\int_{-\infty}^{\infty} H(f)\, S(f) e^{j2\pi ft_o}\, df\right|^2}{\frac{N_o}{2}\int_{-\infty}^{\infty} |H(f)|^2 df} \quad \text{---------} \ (26)$$

Using Schwartz inequality, the numerator of equ (26) can be written as

$$\left|\int_{-\infty}^{\infty} H(f)\, S(f) e^{j2\pi ft_o}\, df\right|^2 \leq \int_{-\infty}^{\infty} |H(f)|^2 df \int_{-\infty}^{\infty} \left|S(f) e^{j2\pi ft_o}\right|^2 df \quad \text{-------}(27)$$

In equ (27), the equality holds good if

$$H(f) = K_1\left[S(f) e^{j2\pi ft_o} df\right]^* = K_1 S^*(f) e^{-j2\pi ft_o} \quad \text{----------} \ (28)$$

Where K_1 is an arbitrary constant and * stands for complex conjugate. Using the equality sign of equ (27) which corresponds to maximum output SNR in equ (26)

$$\left(\frac{SP}{NP}\right)_{out} = \frac{\int_{-\infty}^{\infty} |S(f)|^2 df}{\frac{N_O}{2}} = \frac{2E}{N_O} \quad \text{---------} \ (29)$$

Where E is the energy of the infinite time signal and defined as

$$E = \int_{-\infty}^{\infty} |S(t)|^2 dt = \int_{-\infty}^{\infty} |S(f)|^2 df \quad \text{-------}(30)$$

From equ(29), it is obvious that the maximum SNR is a function of the energy of the signal but not the shape. Taking inverse Fourier Transform of equ(30), the impulse response of matched filter is obtained as

$h(t) = K_1 S^*(t_o - t)$ ------------ (31)

From equ (31), it is clear that the impulse response of matched filter is a delayed mirror image of the conjugate of the input signal from equ (24) and equ (28).

The output at $t = t_o$ is given as

$$S_o(t_o) = K_1 \int_{-\infty} S(f) S^*(f) e^{-j2\pi f t o} e^{j2\pi f t o} df$$
$$= K_1 \int_{-\infty}^{\infty} |S(f)|^2 df$$
$$= K_1 E \text{ -------------- } (32)$$

Equ (32) states that regardless of the type of waveform, at the predefined delay $t = t_o$, the output is the energy of the wave form for $K_1 = 1$. The output of the matched filter is evaluated as

$S_o(t) = S(t) \otimes h(t)$ -------------- (33)

Where $\otimes$ denotes the linear convolution operation

$$= \int_{-\infty}^{\infty} S(\tau)\, h(t-\tau) d\tau$$
$$= \int_{-\infty}^{\infty} S(\tau) K_1 S^*(\tau - t + t_o) d\tau \quad = K_1 = 1, t_o =$$
$$0 \int_{-\infty}^{\infty} S(\tau) S^*(\tau - t) d\tau \text{ ------- } (34)$$

Equ (34) represents auto correction function (ACF) of the input signal S(t)

Thus, it is obvious that the auto-correlation operation is mathematically equivalent to the matched filter with a time reversed complex conjugate of the signal. In the frequency domain, the product of the fourier transform of the signal S(t) and its time-reversed complex conjugate can represent the matched filter.

$S_o(t) = F^{-1}\{F[S(\tau)]\ FS^*(\tau)\}$ ----------- (35)

1.5.1 IMPLEMENTATION OF DIGITAL MATCHED FILTER CORRELATION PROCESSOR

For the purpose of simulation and digital representation using a discrete time representation, suppose S(t) is sampled using a sampling duration T_s and has a finite number of samples $N = T/T_s$, the auto-correction sequence can be obtained as :

$$S_{o(m)} = \sum_{n=-\infty}^{\infty} S(n) \otimes S^*(n-m) \quad m = 0,1, \ldots\ldots\ldots N-1 \text{ ------- } (36)$$

Since the auto-correction sequence is symmetric, it is sufficient to consider only the positive lags.

The above operation can be implemented using matched filter operation.

By defining; h(n) = S*(-n), we have

$$S_{o(m)} = \sum_{n=-\infty}^{\infty} S(n)\, h(m-n) \text{ ------------}(37)$$
$$S_{o(m)} = S(n) \otimes S^*(-n) \text{ --------------}(38)$$
$$S_o(m) = IFFT\,[FFT\{S(n)\} \times FFT\{S^*(-n)\}] \text{ ------------- } (39)$$

Where the FFT and IFFT operations were used to simplify the correlation operation

The digital correlation processor operates on the principle that the spectrum of the time convolution of two waveforms is equal to the product of the spectrum of these two signals as shown in figure 1.7

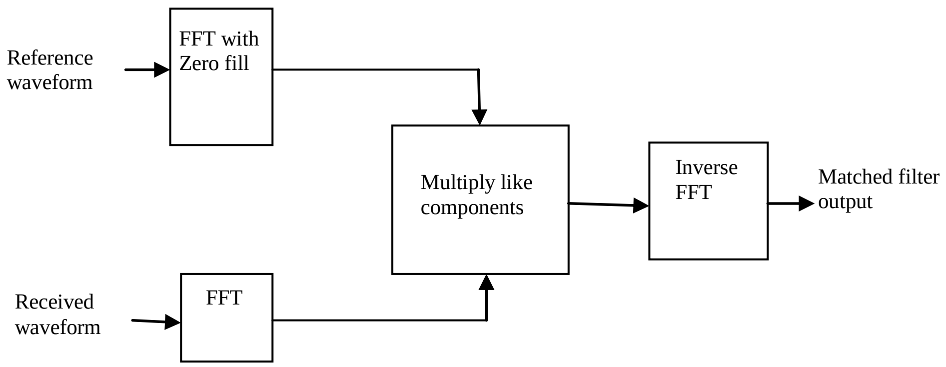


Figure 1.7: Digital matched filter correction processor

If M range samples are to be provided by one correlation processor, the number of samples in the Fast Fourier Transform (FFT) must equal M plus the number of samples in the reference waveform. These added M samples are filled with zeros in the reference waveform FFT. For extended range coverage, repeated correlation processor operations are required with range delays of M samples between adjacent operations. A Fast Fourier Transform in the pulse-compressor function correlates the received signal return spectrum with the known spectrum of the transmitted signal. The FFT is analogous to a spectrum analyzer. Thus, the inverse FFT is the auto-correlation function of the input signal which represents the output of the matched filter (FanWarg, Huotao Gao, 2011).

1.6 MATCHED FILTER SIMULATION RESULT AND ANALYSIS

The MATLAB simulation result for the output of the matched filter shows that the autocorrelation function of the modulated input signal is used to maximize the signal-to-noise ratio.

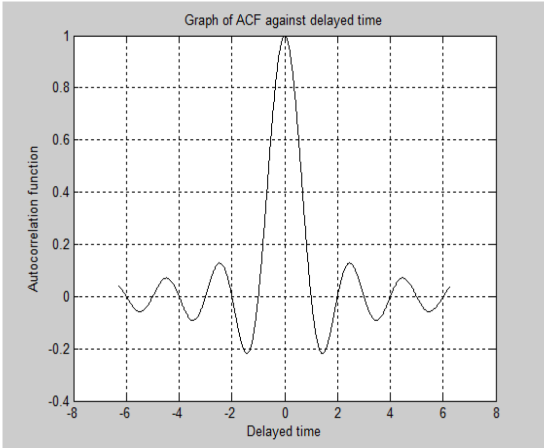
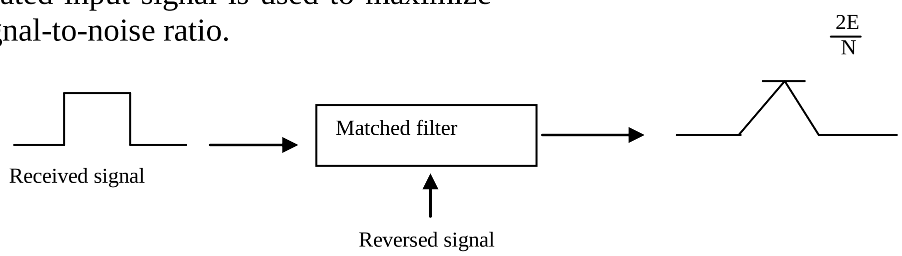


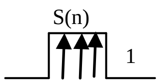
Figure 1.8: Graph of autocorrection function vs delayed time

A pulse compression matched filter is applied when one wants to pass the received radar echo through a filter whose output will optimize the signal-to-noise ratio (SNR). For a rectangular pulse, matched filter is a simple pass band filter.

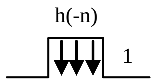


In digital system, matched filter is implemented by ‘’convolving’’ the reflected echo with the ‘’time reversed’’ transmit pulse as illustrated using three bits.

Received echo pulse



Time reversed pulse



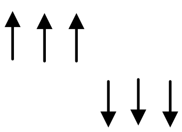
Note: Each arrow represents 1 bit.

The processes involve in the convolution are:

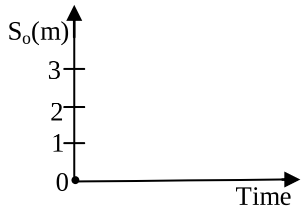
- Move digitized pulses by each other in steps
- When data overlaps, multiply samples and sum them up to obtain the output signal.

$S_O(m) = \sum_{n=-\infty}^{\infty} h(n)\, S(m-n)$

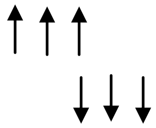
1) When there is no overlap in the filter, the output of the matched filter is zero

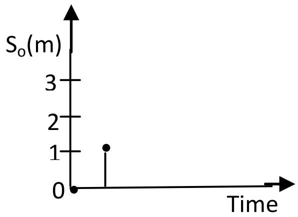


N.B: No overlap output = 0



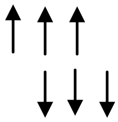
2) When one sample overlaps in the filter, the output of the matched filter is 1

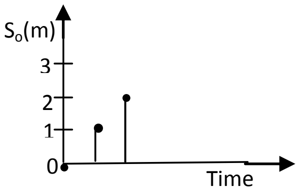




N.B: One sample overlaps 1x1 = 1

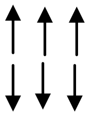
3) When two samples overlap, the output of the matched filter is 2

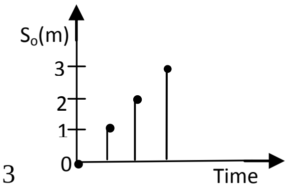




N.B: Two samples overlap (1x1) + (1x1) = 2

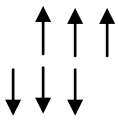
4) When three samples overlap, the output of the matched filter is 3

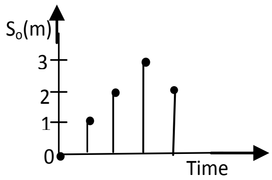




N.B: Three samples overlap (1x1) + (1x1) + (1x1) = 3

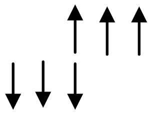
5) When two samples overlap, the output of the matched filter is 2

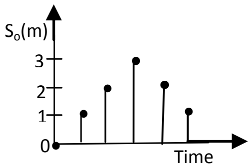




N.B: Two samples overlap (1x1) + (1x1) = 2

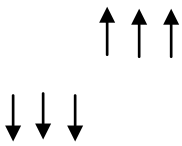
6) When one sample overlaps, the output of the matched filter is 1

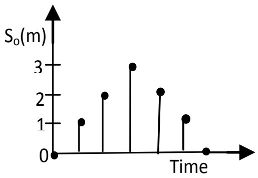




N.B: One sample overlaps 1x1 =1

7) When no sample overlaps, the output of the matched filter is zero (0)





N.B: No sample – output 0

Matched filter is used to maximize the signal-to-noise ratio (SNR) so that targets can be detected even at high precipitation when there is an increase in sensitivity.

1.7 CONCLUSION

A successful modification of the monostatic radar system was presented. It produces an increase in maximum detection range as well as range resolution through pulse compression when long transmitted pulse width is applied. It is an air-search system that provides automatic detection and reporting of targets within its surveillance volume. When the air traffic controllers on the ground station generate RF pulse modulated messages to aircraft known as INTERROGATION MODES, the transponders carried on these aircraft detect the messages and answer by sending back RF pulse modulated messages known as REPLIES. These RF signals are then processed for analysis by external equipment (extractors, processors and display console) which contain information about the frame pulse detection, range measurement, azimuth measurement, altitude report decoding, identification decoding etc. With the implementation of long pulse width and pulse compression matched filter, a solid state radar transmitter can be used to detect objects beyond 256nm and provide greater capability at heavy precipitations due to higher sensitivity.

With an improved radar performance, pilots and air traffic controllers can observe immediately and precisely where surrounding air traffic is at a given time within their surveillance volume. Future research work can be carried out in developing a model for suppressing autocorrelation side lobes of matched filter to enhance its performance.

1.8 RECOMMENDATION

There is need to keep airplanes spaced at least five nautical miles horizontally apart when flying across a country and no closer than three nautical miles when preparing to land. Therefore, safety rules must be followed without compromise to avoid much traffic in the air which might lead to plane crash. A well-designed radar system, with all other factors at maximum efficiency, should be able to distinguish targets separated by one-half the pulse width time. The degree of range resolution depends on the width of the transmitted pulse, the types and sizes of targets, and the efficiency of the receiver and indicator. Pulse width is the primary factor in range resolution and detection. Its increase will enhance the performance of the Nigeria radar system by improving its effectiveness in detecting targets even at heavy precipitation.

However, the state of Port-Harcourt airport and navigational aids calls for urgent attention especially in the areas of:

- Infrastructural development such as rehabilitation of the runway.
- Upgrade of VHF/UHF radio communication gadgets of the air traffic controllers.
- Uninterrupted electric power supply both in the radar system and the entire airport.
- Upgrade of Eurocat C ATM System for APP positions used by air traffic controllers
- Upgrade of RSM 970 MSSR to the one with higher pulse width.
- Training and retraining of members of the air traffic controllers for optimum performance.

I vehemently believe that with a careful implementation of these observations and more, our airspace will be very safe to fly.

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APPENDIX A: MATLAB PROGRAM LISTINGS

No. 1

```
% Sensitivity versus range curve as it varies with pulse width
R = [1 50 200 1000]; % values of range
S1 = [-27.47 -95.43 -119.51 -147.47]; % values of sensitivity at 0.8pulse width
S2 = [-23.49 -91.45 -115.53 -143.49]; % values of sensitivity at 2.0pulse width
S3 = [-19.51 -87.47 -111.55 -139.51]; % values of sensitivity at 5.0pulse width
S4 = [-16.50 -84.46 -108.54 -136.50]; % values of sensitivity at 10.0pulse width
plot(R,S1,'k') % to be plotted with black colour
hold on
grid off
xlabel('Range[km]'); % x-axis label
ylabel('Sensitivity[dBm]'); % y-axis label
plot(R,S2,'r') % to be plotted with red colour
plot(R,S3,'b') % to be plotted with blue colour
plot(R,S4,'g') % to be plotted with magenta colour
legend('0.8us','2.0us','5.0us','10.0us')
title('Graph of Sensitivity versus Range')
```

No. 2

```
% Graphical illustration of how pulse width varies with range and snr
Pt = 2570; % value of peak power
G = 4381; % value of gain(36.4dB)
L = 0.3; % value of wavelength
Rcs = 1.0; % value of radar cross section
w1 = 2.0; % 2.0us pulse width
w2 = 5.0; % 5.0us pulse width
w3 = 10.0; % 10.0us pulse width
K = 1.38*10^(-23); % Boltzman constant
Te = 290; % effective temperature
F = 2.0; % value of noise figure(3dB)
lo = 128.8; % value of radar system loss(21.1dB)
snr = 1:1:18; % range of values of snr
R1 = ((Pt*G^2*L^2*Rcs*w1)./((4*pi)^3*K*Te*F*lo*snr)).^(1/4); % function of R1
R2 = ((Pt*G^2*L^2*Rcs*w2)./((4*pi)^3*K*Te*F*lo*snr)).^(1/4); % function of R2
R3 = ((Pt*G^2*L^2*Rcs*w3)./((4*pi)^3*K*Te*F*lo*snr)).^(1/4); % function of R3
pSlot (snr,R1,'k',snr,R2,'r',snr,R3,'b'); % for graph plotting
hold on
grid off
xlabel('Signal-to-Noise Ratio[dB]')% x-axis label
ylabel('Range[M]') % y-axis label
legend('2.0us','5.0us','10.0us')
title('Graph of Range vs SNR for three different Pulse Width')
```

No. 3

```
% Graph of the matched filter output simulation
wt = -2*pi:0.01:2*pi;
So = sinc(wt); % So is the output of the signal
plot (wt,so,'k'); % Output signal vs the phase angle of function
hold on
grid on
xlabel('Delayed time') % x-axis label
ylabel('Autocorrelation function') % y-axis label
title('Graph of ACF against delayed time')
```

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