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An Analysis of Digital Signal Processing in Monopulse Radars

Mathew Oommen[1], Sahaya Lenin[2], Md. Sohrab Ansari[3], Shobhit Mishra[4]

Student, M.Tech. , Hindustan University, Chennai, India[1,3,4]

Assistant Professor, Hindustan University, Chennai, India [2]

Abstract: The most effective method for deriving information about spatial angles of a target is using Monopulse Radars. The name derives from the fact that the method is theoretically capable of obtaining a target`s angles using only one (mono) pulse. The Monopulse Radar System is mainly used for target detection and tracking. The information on the target angular position is determined by comparison of signals received in two or more simultaneous beams. A target will be seen by radar from the moment it enters the main antenna beam or from the moment it is illuminated by the transmitted radar antenna beam. The signal processor is that part of the system that separates the target from clutter on the basis of Doppler content and amplitude characteristics.

Keywords: Spatial Angles, Bore sight Axis, Clutter and Doppler content.

I. INTRODUCTION

RADAR stands for Radio Detection and Ranging. It is an object-detection system that 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 that bounce off any object in their path. The object returns a tiny part of the wave's energy to a dish or antenna that is usually located at the same site as the transmitter.

The modern uses of radar are highly diverse, including air traffic control, radar astronomy, air-defence systems, antimissile systems; marine radars to locate landmarks and other ships; aircraft anti-collision systems; ocean surveillance systems, outer space surveillance and rendezvous systems; meteorological precipitation monitoring; altimetry and flight control systems; guided missile target locating systems; and ground-penetrating radar for geological observations. High tech radar systems are associated with digital signal processing and are capable of extracting useful information from very high noise-levels.

A. Types of Radars:

Monopulse Radar System is a Tracking Radar system used for target`s angle measurement and tracking.
The 3 main angle-sensing techniques for monopulse radars are:

1. Amplitude Comparison.
2. Phase Comparison.
3. Combination of the above 2.

B. Amplitude Comparison Monopulse Tracking:

Requires 4 sequential beams to measure the Target`s angular position. These 4 beams are generated simultaneously rather than sequentially. For this purpose a special feed antenna is used to provide the 4 beams with a single pulse, hence the term monopulse.

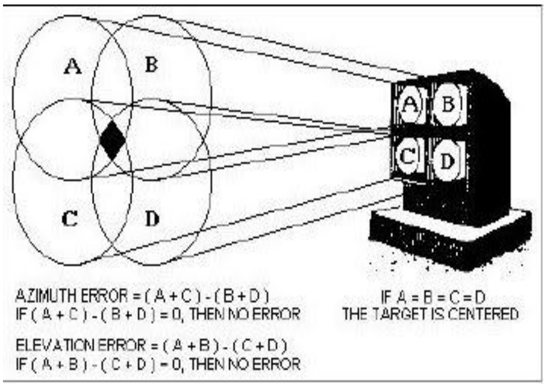

Figure 1.1 Azimuth and Elevation Error

The 4 feeds (mainly horns), are used to produce the antennae pattern. Amplitude Modulation requires that the 4 signals have the same phase but different amplitudes.

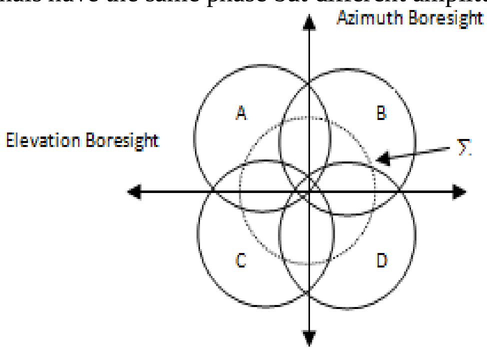

Figure 1.2 Bore-sight of Azimuth and Elevation

The 2 overlapping beams for each of the 2 orthogonal axes are generated from a single reflector illuminated by 4 adjacent feed horns. Σ = *Sum pattern* of the 4 horns. This used for Range measurement in transmit and receive antenna.

If the 4 horns receive equal amount of energy, it indicates that the target is located on the antenna`s tracking axis. But when the target is off the tracking axis, an imbalance

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of energy occurs in different beams. This imbalance is used to generate an error signal that drives servo-central system. Mono-pulse Processing consists of computing a sum Σ and 2 differences Δ (i.e. Elevation and Azimuth Angle) Antenna patterns. Then by dividing a Δ channel voltage by the Σ channel voltage, the angle of the signal can be determined.

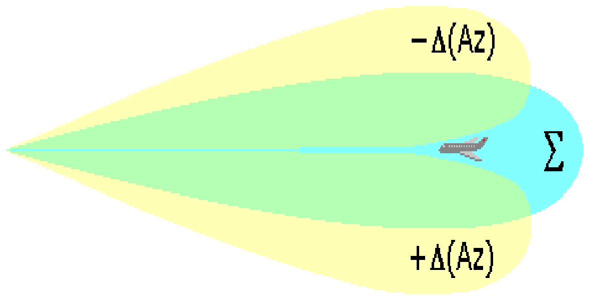

Figure 1.3 Sum and Difference Angles

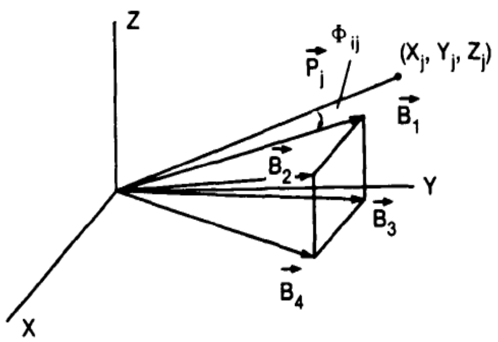

Figure 1.4 Radar Beams in Cartesian Co-ordinate System

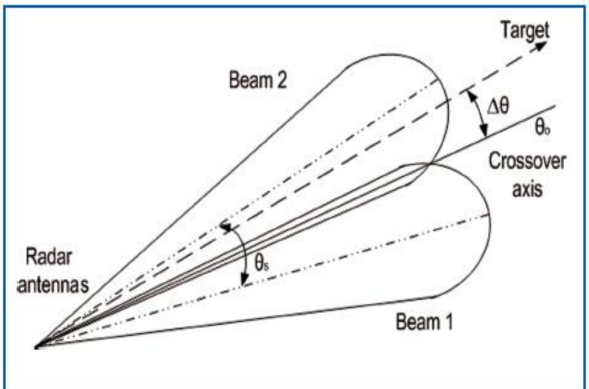

Figure 1: Antenna patterns for amplitude-comparison (Σ-Δ) monopulse system

Figure 1.5 Antenna Patterns for Σ-Δ

Sum channel is used for both Receiver and Transmitter. In Receive mode, Sum channel provides phase reference for the other 2 differences channels. Range measurement can also be obtained from Sum channel.

- $\Sigma(\Phi) = [\ \mathrm{Sin}(\Phi-\Phi_0)/\ (\Phi-\Phi_0)\ +\ \mathrm{Sin}(\Phi+\Phi_0)/\ (\Phi+\Phi_0)\ ]$
  i.e. Sum channel in one co-ordinates.
- $\Delta(\Phi) = [\ \mathrm{Sin}(\Phi-\Phi_0)/\ (\Phi-\Phi_0)\ -\ \mathrm{Sin}(\Phi+\Phi_0)/\ (\Phi+\Phi_0)\ ]$
  i.e. Difference channel in same co-ordinates.

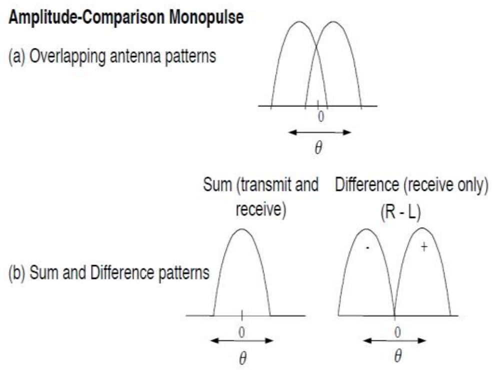

Figure 1.6 Sum and Difference Patterns

II. MONOPULSE SIGNAL PROCESSING

The ideal monopulse radar calculates the target off-axis angle error by a comparison between the difference channel signal and the sum channel amplitude at each range gate. When a complex target with range extent less than the range cell determined by the transmitted pulse-width is illuminated with a frequency-agile monopulse radar, the target can be resolved in range with higher resolution by using the DFT algorithm. The absolute range is then determined by the time delay to the sampling window, and the relative range within that window is further resolved using the DFT. In addition, the difference-channel data can be processed using the DFT to provide a downrange profile of both azimuth and elevation error signals. By applying a cross-range calibration to these error signals, we can determine the cross-range position of the scattering centre.

III. DEFINITION AN OPTIMUM MONOPULSE SYSTEM AS ONE THAT SATISFIES 3 CONDITIONS

1. The error channel`s real output voltage due to the target, at the time of the target, must be zero if the target`s direction is that of the reference axis.
2. The error channel`s real output voltage due to the target, at the time of the target, must be proportional to the target`s error angle θ_x from the reference axis, with the proportionality constant being known.
3. For additive input noise the system must provide the smallest possible variance of error in the measurement of θ_x of all linear systems.

IV. BLOCK DIAGRAM

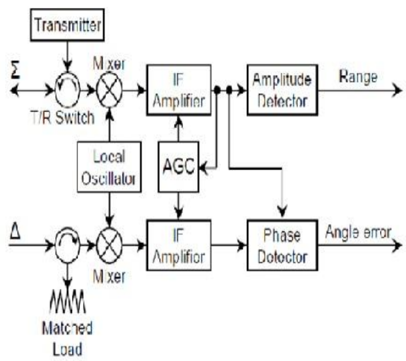

Fig 4.1 Block Diagram of Monopulse radar

A. Module Design & Purpose of each module:

All Monopulse systems breakdown into 2 basic parts. One is the antennae and its associated microwave elements (together called the comparator), and the second is a signal processor appropriate for the type of antenna patterns used. The 3 stages are used to change the frequency to required range. While the first 2 stages uses analog signals, the 3rd stage uses DDS i.e., Direct Digital Synthesizer to convert into Digital signals. The IF (intermediate frequency) range signals are introduced into the Digital Signal Processing unit. It consists of an ADC (Analog to Digital Convertor) combined to another frequency generator through a Mixer.

To reduce the frequency range we use a BPF (Band Pass Filter), we use the down-sampler or up-sampler to reduce/increase the number of samples for signal processing. The signal processor is that part of the system that separates the target from clutter on the basis of Doppler content and amplitude characteristics. In modern Radar systems, the signal processor sets the conversion of Radar signals to digital form after IF amplification and phase sensitive detection. While overlaying 2 different signals, there are two possibilities for the result-

- In case of a component with a linear characteristic curve (resistor), then a beat arises. Beat - amplitudes of the two signals add up dependent on its algebraic sign.
- If component has a non-linear characteristic curve (diode), a mixture of the frequencies of the input signals arises with the result in addition to the initial frequencies

$$f=|f_1+f_2| \ \&$$
$$f = |f_1-f_2|$$

The simplest type of radar mixer is the Unbalanced Crystal Mixer. It has one major disadvantage- its inability to cancel local oscillator noise. Advantage is its simplicity. The Balanced or Hybrid mixer eliminates the noise of the local oscillator effectively.

Single antenna for both transmitting-receiving (radars), an electronic switch is used. These switching systems are Duplexers. Switching the antenna between the transmit and receive modes presents one problem; ensuring that maximum use is made of the available energy is another. The simplest solution- Use a switch to transfer the antenna connection from the receiver to the transmitter during the transmitted pulse and back to the receiver during the echo pulse. Practical mechanical switches unavailable that can open-close in a few microseconds. Therefore, electronic switches used.

RF-carrier enters from the antenna and applied to a filter. Filter Output are frequencies of the desired frequency-band only, which are applied to the mixer stage. The mixer also receives an input from the local oscillator. These two signals are beat together to obtain the IF through the process of *Heterodyning.*

Difference in frequency between Local Oscillator and RF signal is the Intermediate Frequency (IF). This fixed difference tuning ensures a constant IF over the frequency range of the receiver. IF-carrier is applied to IF-amplifier. The amplified IF is then sent to the detector. Output of the detector is video component of the input signal.

Most radar receivers use some means to control the overall gain. This usually involves the gain of one or more IF amplifier stages. Manual gain control by the operator is the simplest method. Gain control is necessary to adjust the receiver sensitivity for the best reception of signals of widely varying amplitudes. A complex form of automatic gain control (AGC) or instantaneous automatic gain control (IAGC) is used during normal operation. The simplest type of AGC adjusts the IF amplifier bias (and gain) according to the average level of the received signal. With AGC, gain is controlled by the largest received signals.

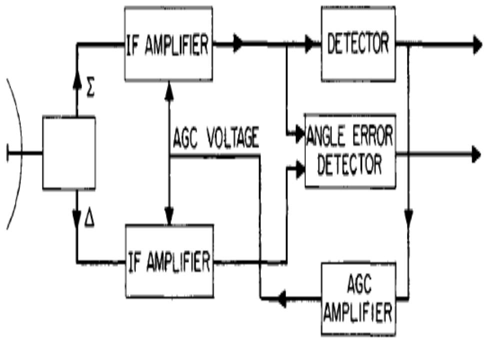

Figure 4.2 AGC in Monopulse Tracking

The classic Radar Range equation:

$$Range \cong \left(\frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 S_{min}} \right)^{1/4}$$

P_T = transmitted power

G_T = transmit antena gain

P_R = receive antenna gain

λ = radar signal wavelength

σ = radar cross - section

S_{min} = minimum detectable signal

V. EXISTING SYSTEMS

1. *Angle Estimation for Two Unresolved Targets with Monopulse Radar*

Most present-day radar systems use monopulse techniques to extract angular measurements of sub-beam accuracy. The familiar "monopulse ratio" is a very effective means to derive the angle of a single target within a radar beam. For the simultaneous estimation of the angles of two closely-spaced targets, a modification on the monopulse ratio was derived in, while presented a maximum likelihood (M-L) technique via numerical search.
Monopulse is a simultaneous lobing technique for determining the angle of arrival of a source of radiation or of a target: two squinted beams (actually four, if resolution in both azimuth and elevation is desired) are used to receive the target echo, and sub-beam accuracy is achievable through comparison of the difference to the total return amplitude.

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When only a single target is assumed present in a given range cell, estimation of the DOA (direction of arrival) of the target is well understood, and carries a considerable literature. It is possible to obtain the maximum likelihood (ML) solution for the DOA of a target, but traditionally the DOA is estimated via the monopulse ratio: it is very quick, and for signal-to-noise ratios (SNRs) that are moderate or high its accuracy is close to the Cramer-Rao Lower Bound (CRLB). However, when two or more targets are closely spaced in the range and angle with respect to the resolution of the radar (i.e., the detections from two targets become merged into a single detection due to both being within the radar beam), then the traditional DOA estimator based on the monopulse ratio is incapable of resolving them, with its "merged" angular estimate often far from either true target.

This issue of finite radar resolution is obviously of great concern for multi-target detection and tracking applications, and certainly techniques more sophisticated than the standard monopulse (i.e., two beams per angular coordinate) have been explored to estimate DOAs of unresolved targets. These naturally include array signal processing (beam-forming, interference nulling or high-resolution direction finding) and multiple-beam monopulse.

2. Monopulse MIMO Radar for Target Tracking

We propose a multiple input multiple output (MIMO) radar system with widely separated antennas that employs monopulse processing at each of the receivers. Use of Capon beam-forming to generate the two beams required for the monopulse processing. Also propose an algorithm for tracking a moving target using this system. This algorithm is simple and practical to implement. It efficiently combines the information present in the local estimates of the receivers.

Since most modern tracking radars already use monopulse processing at the receiver, the proposed system does not need much additional hardware to be put to use. We simulated a realistic radar-target scenario to demonstrate that the spatial diversity offered by the use of multiple widely separated antennas gives significant improvement in performance when compared with conventional Single Input Single Output. (SISO) monopulse radar systems. We also show that the proposed algorithm keeps track of rapidly manoeuvring airborne and ground targets under hostile conditions like jamming.

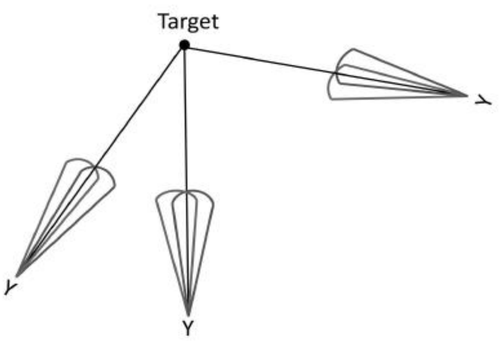

Figure 5.1 MIMO Target Tracking

VI. OUTPUT

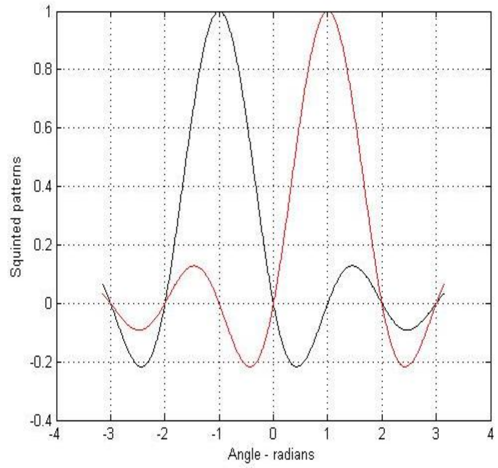

Fig 6.1: Comparison of 2 Signals (Y_1 & Y_2)

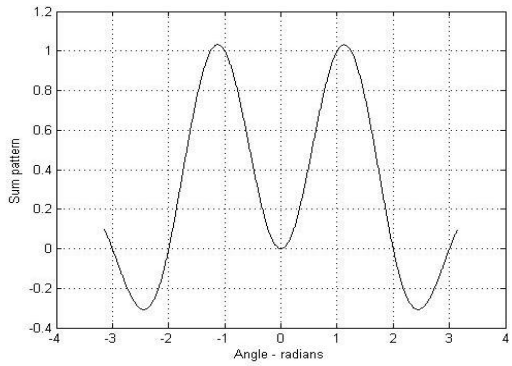

Fig 6.2: Sum of the 2 signals Y_1 & Y_2 (Y_{sum})

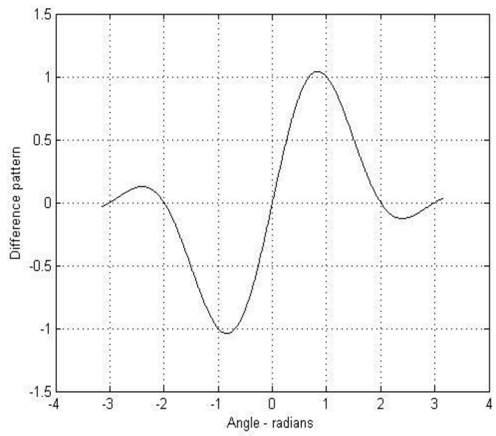

Fig 6.3: Difference of the 2 signals Y_1 & Y_2($Y_{difference}$)

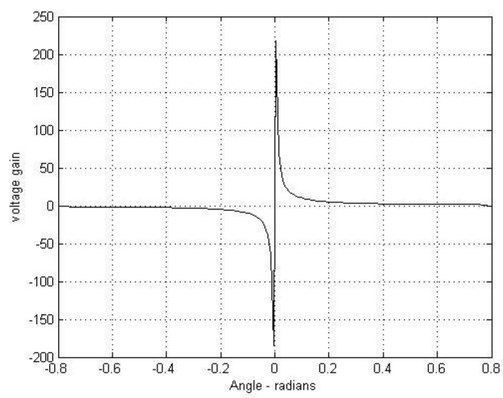

Fig 6.4: $Y_{Difference}/Y_{Sum}$

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A. SIMULATION OUTPUT

The figure 6.1 shows the 2 signals Y_1 & Y_2 being generated. The 2 signals are colour-marked to show their difference. In the figure 6.2, the 2 signals Y_1 & Y_2 are added to generate the sum channel. Similarly in figure 6.3, the 2 signals are subtracted from one another to generate the difference channel. The ratio of the difference channel to the sum channel is dented as ratio Δ / Σ (delta over sum). It can be used to accurately estimate the error angle that only depends on the target`s angular position. This is shown in figure 6.4.

$$\Sigma(\varphi) = \frac{\sin(\varphi - \varphi_0)}{(\varphi - \varphi_0)} + \frac{\sin(\varphi + \varphi_0)}{(\varphi + \varphi_0)}$$

$$\Delta(\varphi) = \frac{\sin(\varphi - \varphi_0)}{(\varphi - \varphi_0)} - \frac{\sin(\varphi + \varphi_0)}{(\varphi + \varphi_0)}$$

VII. CONCLUSION

The simulation of the Monopulse radar was carried out in MATLAB as function program. The Outputs are shown above. The theoretical analysis was studied in depth from various journals and books. Its advantages, applications, working and operational criteria were analysed. Improved angle sensing, resolution and angular accuracy offered by monopulse radars are their main advantage over classic radar systems. The main advantage of a monopulse system in comparison to standard angle measurement methods is that it is not affected by amplitude fluctuations of the target echo because the angle information is acquired by comparing signals received by several simultaneous beams and produced by a single echo pulse. If the echo amplitude changes, it changes in the same way in all receiver channels.

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