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Analyzing Noise Interference Effects within Unbalanced Monopulse Receiver Channels

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Abstract

Mono pulse receivers have become integral components in angle tracking systems employed in ground-based, airborne radars, and communication setups. Existing literature has extensively discussed the deviations in open-loop angular measurements relative to the antenna's bore sight axis. However, this paper delves into a comprehensive exploration of deliberate noise interference originating from the target platform, which leads to angular errors. The primary focus is on understanding the intricate interplay between the sum and difference channel noise, in conjunction with interfering noise from the target platform, while placing special emphasis on Mono pulse receiver channel imbalances. In scenarios where there exists an imbalance in Mono pulse receiver channels, both the sum and difference channel noise, along with interfering noise from the target platform, can collectively contribute to angular errors. Conversely, in the absence of channel imbalance (as found in ideal conditions), noise interference does not possess the capability to induce angular errors, regardless of the interfering noise power. This investigation is contextualized within a two-horn Mono pulse system, which is a representative and commonly encountered scenario. Through our analysis, we uncover that channel imbalances within the Mono pulse receiver system can exacerbate open-loop angular errors when exposed to noise interference.

Introduction

In the realm of modern radars, MONOPULSE transmit-receive systems play a crucial role in accurate angle tracking [1]. These systems leverage the normalized difference channel voltage to determine angular errors, which subsequently contribute to closed-loop servo tracking of targets. This angular error showcases a linear variation concerning the angle off the bore sight axis of the dual-element antenna system, portraying an ideal scenario. Such ideal conditions entail perfect matching of the sum and difference channels [2]. However, practical applications often involve imbalances between these channels due to disparities in antenna gains, low noise amplifiers, mixers, IF amplifiers, and detector video amplifiers. These imbalances, in turn, lead to angular errors. This paper centers its focus on investigating these angular errors arising from channel imbalances [3]. Furthermore, the practical scenario also encompasses the addition of channel noise to the signal, along with transmitter noise, target fluctuations, and clutter. In addition to these factors, potential interference from deliberate jamming needs consideration. The paper acknowledges previous analyses of interference effects on MONOPULSE radars, both from external sources and noise jamming originating from the target platform [4]. The central objective of this paper revolves around the computation and simulation of angular errors. The study aims to quantify these errors in the presence of channel noise, channel imbalance, and intentional noise jamming stemming from the target platform. In essence, this study delves into the intricate interplay of various factors contributing to angular errors within MONOPULSE transmit-receive systems. By comprehensively evaluating the impact of channel imbalances, channel noise, and deliberate noise jamming, the paper adds to the understanding of real-world challenges faced by these systems.

THE MONOPULSE RECEIVER AND INTERFERING SOURCE

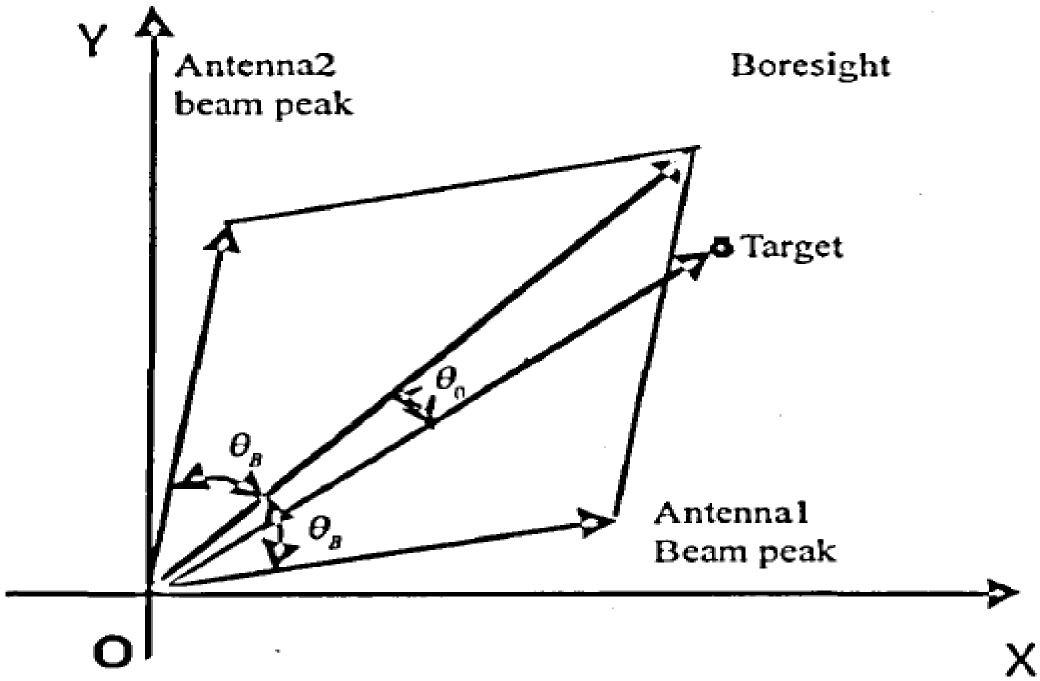

Fig 1 Geometry of monopulse receiver

MATHEMATICAL FORMULATION

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The voltage input to the two antennas is assumed to be,

$$V_1 = A\sin(\omega\tau + \phi_1) + A_N \quad (1)$$

where

A = Amplitude of the echo signal at the input of monopulse antennas

A_N= Noise amplitude of the echo signal seen at the input to antennas

ω = Radian frequency

ϕ_1 = Phase w.r.t transmitter reference signal

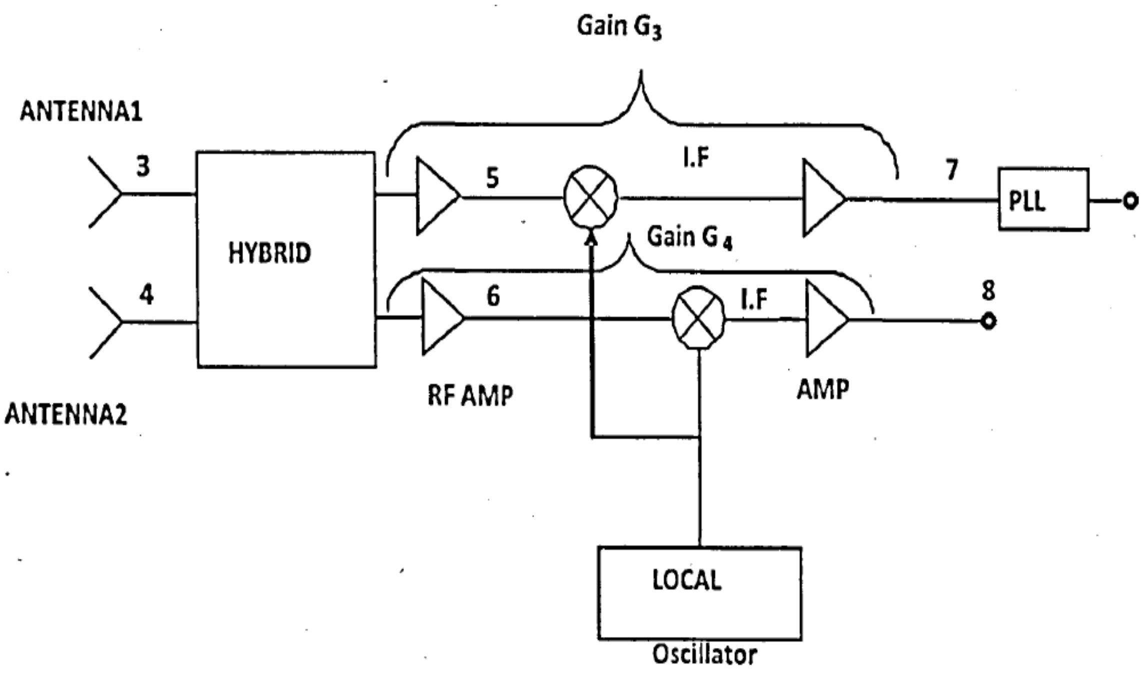

Fig 2 Block diagram of monopulse system

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This signal impinges on both the squinted antennas. The two antennas are squinted away from boresight at an angle of θ_0. The gain patterns of both the antennas are assumed to follow a Gaussian curve, which is a close approximation to pyramidal horn patterns upto a signal level 10 dB down the peak of the beam. The power gain patterns are given by,

$$G_1 = G_{01} \exp\{-2.776[\theta - \theta_0)/\theta_B]^2\} \quad (2)$$

$$G_2 = G_{02} \exp\{-2.776[\theta - \theta_0)/\theta_B]^2\} \quad (3)$$

where

G_1, G_2 = Power gains of antenna 1 and 2 respectively

G_{01}, G_{02} = Maximum power gain of antennas 1 and 2 including plumbing losses

θ_0 = Squint angle of antennas

θ_B = Half power beamwidths of antennas1 and 2

The voltage outputs and are given by,

$$V_3 = G_1^{0.5} V_1 \quad (4)$$

$$V_4 = G_2^{0.5} V_1 \quad (5)$$

The subscripts refer to voltage points in Fig 1.

These echo signals pass through a 180° hybrid and sum and difference outputs are generated.

$$V_5 = V_3 + V_4 \text{ (Sum voltage)} \quad (6)$$

$$V_6 = V_3 + V_4 \text{ (Difference)} \quad (7)$$

The sum and difference voltages are amplified in an r.f amplifier, down converted and channel noise gets added. The I.F. output voltages are given by,

$$V_7 = V_5 + G_3^{0.5} + CHN_1 \text{(Sum voltage)} \quad (8)$$

$$V_8 = V_6 + G_4^{0.5} + CHN_2 \text{(Difference voltage)} \quad (9)$$

where, G_3 and G_4 are power gains of both the receiver channels measured from the output of the hybrid. CHN_1 and CHN_2 are sum and difference noise output voltages generated independently using different seeds.

The final expression of voltages are given by,

$$V_7 = [(G_1G_3)^{0.5} + (G_2G_3)^{0.5}]\, V_1 + CHN_1 \quad (10)$$

$$V_8 = [(G_1G_4)^{0.5} + (G_2G_4)^{0.5}]\, V_1 + CHN_2 \quad (11)$$

The above expressions may be simplified as

$$V_7 = K_1 V_1 + CHN_1$$

$$V_8 = K_2 V_1 + CHN_2$$

where, the gain terms have been replaced by K_1 and K_2.

The voltage error V_e at the I.F. output is given by,

$$V_e = V_{diff}/V_{sum} \quad (12)$$

when an interfering source such as a jammer noise source is located on the target platform itself, whatever may be the jammer to signal power, the angular error remains zero and the angle tracker tracks the target accurately in the ideal case of matched channels [7]. When imbalance is introduced in the two channels, angular errors are generated and the angle tracker does not point to the target. This is further aggravated by additive channel noise.

When interfering noise source is added, the above equations (4) and (5) get modified as

$$V_3 = G_1^{0.5}(V_1 + V_j) \quad (13)$$

$$V_4 = G_2^{0.5}(V_2 + V_j) \quad (14)$$

Where V_j is the noise jammer voltage at the input to the antennas and the analysis is exactly the same as without the jammer. The expression of voltage error is given by,

$$V_e = \frac{[G_4^{0.5}(V_1 + V_j)(G_1^{0.5} - G_2^{0.5}) + CHN_1]}{[G_3^{0.5}(V_1 + V_j)(G_1^{0.5} - G_2^{0.5}) + CHN_2]} \quad (15)$$

$$V_e = \frac{[k_1 - k_2)(V_1 + V_j) + CHN_1]}{[k_3 + k_4)(V_1 + V_j) + + CHN_2]} \quad (16)$$

where,

$$k_1 = (G_1 + G_4)^{0.5} \quad ; \quad k_2 = (G_2 + G_4)^{0.5}$$

$$k_3 = (G_1 + G_3)^{0.5} \quad ; \quad k_4 = (G_2 + G_3)^{0.5}$$

From this equation the following inferences can be made.

(*a*) If channel imbalance is zero ($k_1 = k_2$), and since k_3 and k_4 are large being products of gain terms, the voltage error is quite low and insignificant, depending only on channel noise.

(*b*) If there is some channel imbalance, ($k_1 \neq k_2$), the voltage terms in the numerator get multiplied

Results

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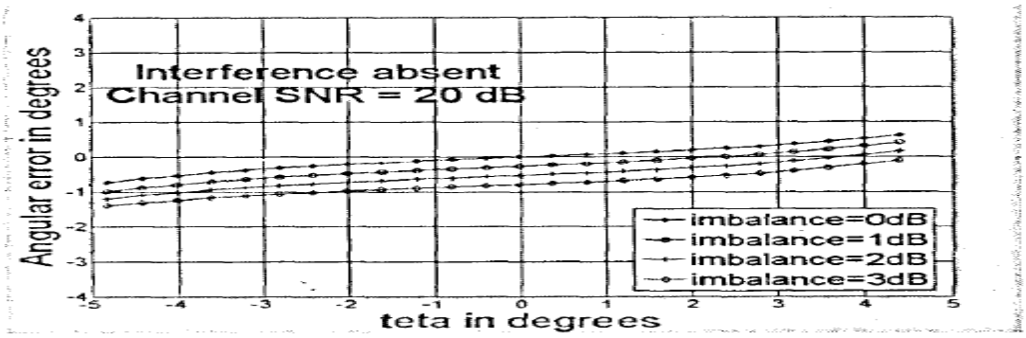

Fig 3 Angular error vs angle off boresight when the imbalance is varied in the absence of jammer noise and high channel signal to ratio

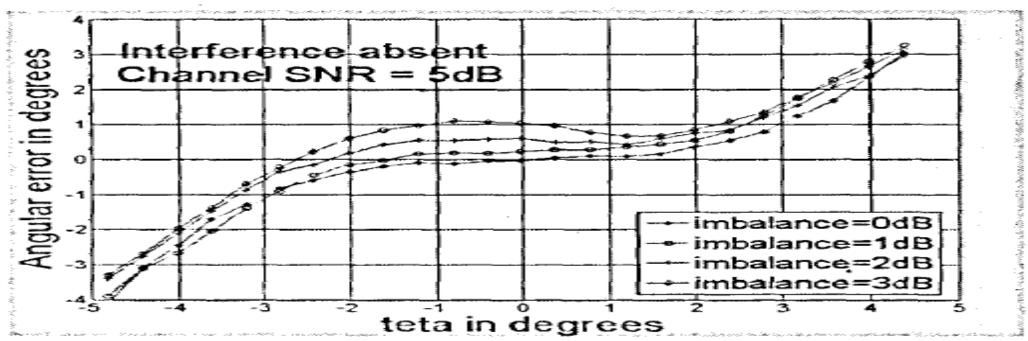

Fig 4 Angular error when the imbalance is varied in the absence of jammer noise and low channel signal to ratio

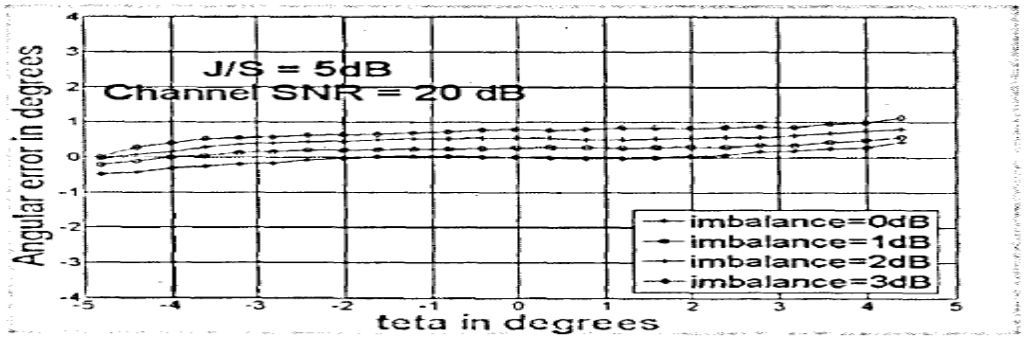

Fig 5 Angular error when the imbalance is varied for high J/S and high channel SNR.

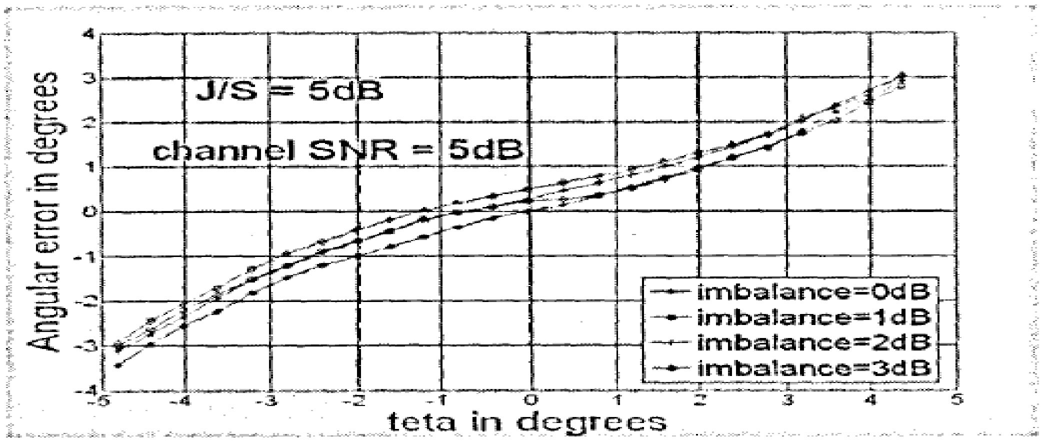

Fig 6 Angular error when the imbalance is varied for high J/S and low channel SNR.

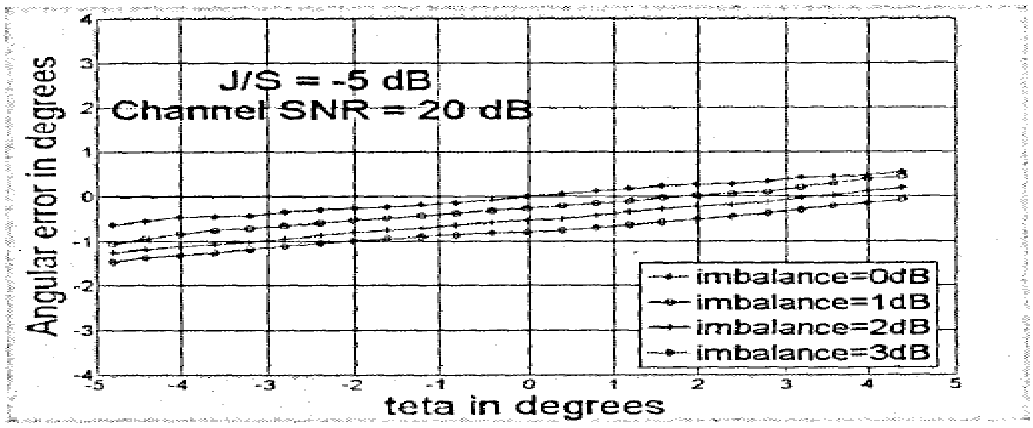

Fig 7 Angular error when the imbalance is varied for low J/S and high channel SNR.

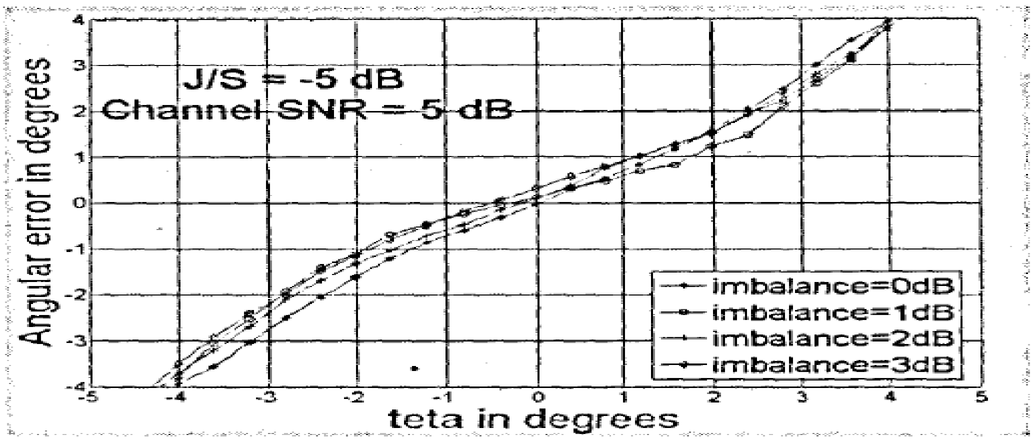

Fig 8 Angular error when the imbalance is varied for low J/S and low channel SNR.

Conclusions

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Additionally, it's crucial to highlight that channel noise plays a pivotal role in introducing angular errors. The presence of channel noise significantly impacts the precision of angular measurements, underscoring the multifaceted challenges faced by these systems. To effectively counteract the detrimental effects of jamming originating from the target platform, it becomes imperative to implement online calibration for both sum and difference channels. This calibration procedure is indispensable for ensuring the alignment of channels, thereby reducing susceptibility to errors caused by noise jamming. Without this essential calibration step, Mono pulse receivers remain vulnerable to errors due to the gradual and differential degradation of channels over time, resulting in imbalanced sum and difference channels.

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