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Effectiveness of Noise jamming with White Gaussian Noise and Phase Noise in Amplitude Comparison Monopulse Radar Receivers

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***Abstract*— In the missile borne monopulse radar system, effectiveness of jamming the receiver in presence of internal and external noise is much significant. In this paper, jamming of such radar receiver in frequency domain is studied when White Gaussian Noise (WGN) and Phase Noise (PN) signals are injected into the receiver in two separate cases. The missile radar receiver operates on unmodulated continuous wave sinusoidal echo signal and the jammer is assumed to be a WGN source which generates Gaussian noise samples with zero mean. The Gaussian noise signal is injected into the receiver along with the radar echo signal and the noise power required for breaking the frequency lock in the receiver is reported. Initially, it is assumed that receiver is locked onto the desired radar echo signal frequency as the noise power is too less to break the frequency lock of the receiver. It is verified that Gaussian noise power required for jamming the receiver depends upon how the power is interpreted. For our simulation, the noise power is interpreted in symbol rate bandwidth, sampling frequency bandwidth, and in single-sided and double-sided power spectral density. The break-lock in the radar receiver is presented. In the case of phase noise, the noise is added to phase of the radar echo signal and the phase noise mask required for break-lock in the receiver is studied. The phase noise is specified through a phase noise mask consisting of frequency and dBc/Hz values. It is verified that phase noise mask required for jamming the receiver is less when frequency offset from echo signal is large. The effects of windowing techniques when implemented in the phase noise measurement are presented. It is shown that the windowing technique reduces the phase noise required for breaking the frequency lock in the receiver. The effectiveness of noise jamming is carried out through computer simulation using AWR (Visual System Simulator) software. The receiver response is observed online in the frequency spectrum of the signal.**

Keywords- Gaussian noise, monopulse receiver, noise jamming, phase noise, power spectral density.

I. INTRODUCTION

The monopulse method of target angle measurement has been widely used in the modern missile trackers. In this method, the complete information about target angle is obtained through processing of a single echo pulse. In the monopulse system employing amplitude comparison angle sensing, two identical overlapping antenna patterns are formed. These two patterns are offset by some angle from the equi-signal axis. When the target is offset by certain angle from this axis, the amplitude of the two patterns becomes unequal. The amplitude of the difference signal determines the angular offset of the target from the equi-signal axis and the sign of the difference signal indicates the direction of the target.

Jamming of monopulse radar receivers with noise sources and repeat jammers has been successful to some extent. On-board noise jamming is possible in the specific case of mismatched monopulse sum and difference channels [1]. The receiver is said to be tracking a target perfectly if it tracks in all the three domains namely, frequency, angle and range [2]. A receiver is said to be jammed completely if and only if all the three tracking loops cited above are broken leading to the receiver tracking away from the target, so that acquisition and tracking the set points in these domains is impossible during the mission time and the target is missed out. If jamming is effective in one domain only, there is a possibility of recovery and jamming may not be successful [3].

In this paper, noise jamming of missile borne monopulse radar receiver with external White Gaussian Noise (WGN) and Phase Noise (PN) signal is analyzed. In earlier study, it is seen that noise jamming aims at injecting interference signal into the receiver such that the desired radar signal is completely submerged by the interference as in case of denial jamming. In principle, the optimal jamming signal has the characteristics of receiver noise; in practice this may be difficult to achieve [4]. For significant effectiveness of the noise jamming, WGN is chosen ideally because of maximum entropy, or uncertainty of any random waveform for a specific average power. For our simulation, a monopulse radar receiver with third order loop is designed with a typical loop bandwidth of 1 MHz. The receiver operates on unmodulated sinusoidal radar echo signal of 10 dbm power. The radar echo after down converted to an intermediate frequency of 30 MHz is injected into the receiver along with the WGN signal and the noise power required for break-lock in the receiver is reported. It is seen that the noise power required for break-lock in the receiver depends upon how the power is interpreted. In this context, the noise power is interpreted in symbol rate bandwidth, sampling frequency bandwidth, and in single-sided and double-sided power spectral density which are discussed in detail in the subsequent section.

In another case, phase noise is generated by passing WGN through a FIR filter and added to the phase of the radar echo to simulate the phase noise which is specified through phase noise mask consisting of frequency and dBc/Hz values. The phase noise mask required for break-lock in the receiver is presented. It is seen that phase noise power required for break-lock depends upon how the phase noise is simulated and the frequency offset from the radar echo signal.

II. AMPLITUDE COMPARISION MONOPULSE RADAR

There are several methods have been used in monopulse radar to measure target angle. Mainly in amplitude comparison monopulse radar, the target angle is measured by comparing the amplitude of the received echo signal patterns [5]. The block diagram of amplitude comparison monopulse radar for a single angular coordinate is shown in fig.1.

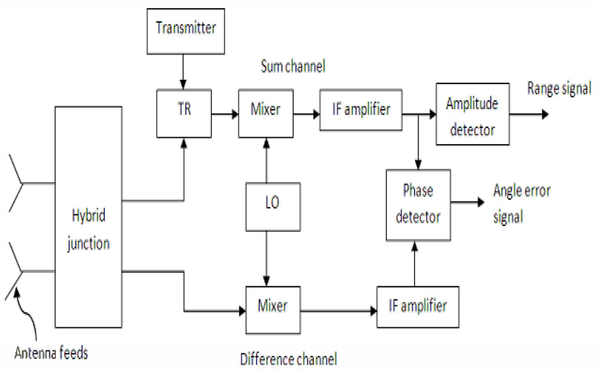

Fig.1. Block diagram of Amplitude comparison Monopulse radar

It is seen from fig.1 that the monopulse radar consists of two antenna feed horns which receives the target echo signals simultaneously. These two horns are separated symmetrically offset from the antenna main axis. The outputs of these horns are given to the input ports of a hybrid junction. The hybrid junction produces sum and difference signal. The outputs of the sum and difference arms are each heterodyned to an intermediate frequency using a local oscillator and then amplified. The sum channel signal is used as a reference to find the sign of the error signal. Since the sum channel signal is in phase with the transmitted signal, hence this channel is connected to the transmitter for retransmission of the radar signal. The output of this channel is given to automatic range tracking system from which range information of the target is extracted. The outputs of sum and difference channels are the inputs to a phase sensitive comparator. The output of the phase detector is an error signal whose amplitude is proportional to the angular error [6]. The sign of the output of the phase detector indicates the direction of angular error relative to the equi-signal axis of the antenna patterns. The difference signal is directly used by the antenna control system for finding the target direction or automatic tracking.

III. WHITE GAUSSIAN NOISE JAMMING

In this section, the jamming of monopulse radar receiver with WGN is presented. The additive WGN noise has Gaussian probability density function. The power spectral density of noise is given by

$$\phi_{NN}(f) = N_0/2 \qquad (1)$$

where, N_0 is average output noise power.

The monopulse radar receiver with additive WGN noise source is shown in fig.2.

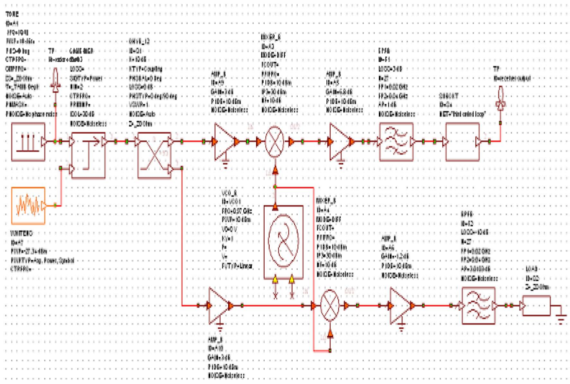

Fig.2. Monopulse radar receiver with WGN noise

As shown in fig.2, the additive WGN along with radar echo signal is injected into the radar receiver. The WGN noise source generates independent Gaussian noise samples with zero mean. The radar echo is typically operating at 30 MHz and at 10 dbm power. The receiver is designed with a third order loop with a typical bandwidth of 1 MHz using the standard method [7]. Initially, it is assumed that the receiver is locked onto the desired radar echo frequency as the Gaussian noise power is less compared to radar echo power. The Gaussian noise power is then increased without causing the loop to lose the frequency lock from the echo signal. Further, when the noise power is increased, it is seen that the loop loses the frequency lock from the radar echo signal and locks onto certain other frequency. The simulations are carried out with the Gaussian noise power estimated in symbol rate bandwidth, sampling frequency bandwidth, in single-sided and double-sided power spectral density and are discussed below.

Case-I: In the symbol rate bandwidth, the noise power is the average power in the symbol rate bandwidth. The output noise power (N_0) is specified as:

$$PWR = N_0/2.\ (f_s/SMPSYM) \qquad (2)$$

where, f_s is the sampling frequency and SMPSYM is samples per symbol.

Case-II: In the sampling frequency bandwidth, the noise power is the average power in the sampling frequency bandwidth. The output noise power is specified as:

$$PWR = N_0/2 \cdot f_s \qquad (3)$$

Case-III: In the single and double-sided power spectral density (PSD), the noise power is equal to the power spectral density of N_0. The output noise powers for single and double sided power spectral density are specified as:

$$PWR = N_0, \text{ for single sided PSD} \qquad (4)$$

$$PWR = N_0/2, \text{ for doubled sided PSD} \qquad (5)$$

The entire simulation is carried out with a sampling frequency of 640 MHz and SMPSYM of 320 with Data_ rate of 2 MHz. The sampling frequency is determined as

$$f_s = \text{Data\_rate} * \text{SMPSYM} \tag{6}$$

A. Implementation Details

The model generates a pseudo-random sequence of values with a Gaussian distribution using a modified version of the Box-Muller method [8]. A pair of values is generated at a time using the following:

$$y_1 = \sqrt{-2\ln(1-x_1)}.\sin(2\pi x_2).\sigma \tag{7}$$

$$y_2 = \sqrt{-2\ln(1-x_1)}.\cos(2\pi x_2).\sigma \tag{8}$$

where x_1, x_2 are the first and second uniform deviates from the random number generator and y_1, y_2 are the two independent normal deviates with a standard deviation of σ.

The noise generated by the model has a probability density function of:

$$p(\eta) = \frac{1}{\sqrt{\pi N_0}} \exp\left(\frac{-\eta^2}{N_0}\right) \tag{9}$$

The response of the radar receiver to different Gaussian noise power is observed online in the frequency spectrum of visual system simulator. The receiver responses to different WGN power computed in symbol rate bandwidth, in sampling frequency bandwidth, in single and double sided PSD are shown in fig.3 (a), (b), (c) and (d) respectively.

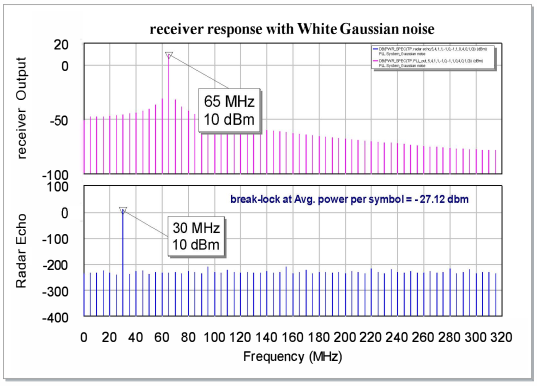

Fig.3. (a) Receiver response to noise in symbol rate bandwidth

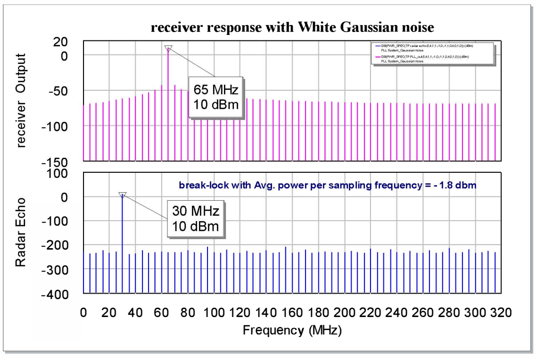

Fig.3. (b) Receiver response to noise in f_s bandwidth

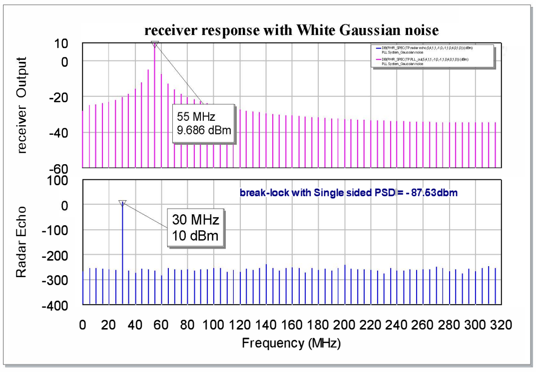

Fig.3. (c) Receiver response to noise in single sided PSD

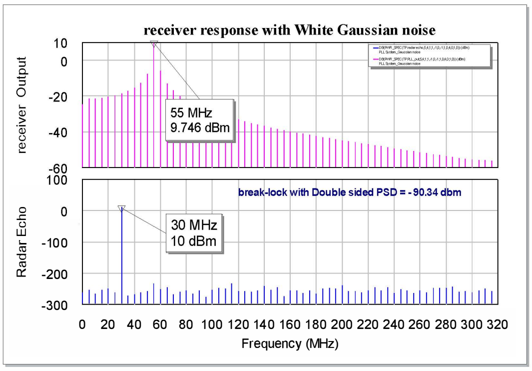

Fig.3. (d) Receiver response to noise in double sided PSD

The receiver response to Gaussian noise interpreted in the symbol rate bandwidth is shown in fig.3. (a). It is seen that radar echo frequency is 30 MHz and receiver output frequency is 65 MHz which is different from radar echo frequency at Gaussian noise power of -27.12 dbm. This shows that -27.12 dbm or more noise power is required to break the frequency lock of the receiver in the symbol rate bandwidth. Similarly, it is clear from fig.3. (b) that Gaussian noise power of -1.8 dbm is required to break the frequency lock of the receiver when the noise power is computed in sampling frequency bandwidth. Similar results are shown in fig.3. (c) and (d) for the noise power in single-sided and double-sided PSD. It is seen that when noise power is computed in double-sided PSD, the Gaussian power required for break-lock is -90.34 dbm and it is -87.53 dbm when computed in single-sided PSD. From these results it can be suggested that Gaussian power estimated in double-sided PSD should be used for effective jamming of the receiver as it is less compared to other noise power.

The Gaussian noise signal voltage required for break-lock in the receiver is shown in fig.4.

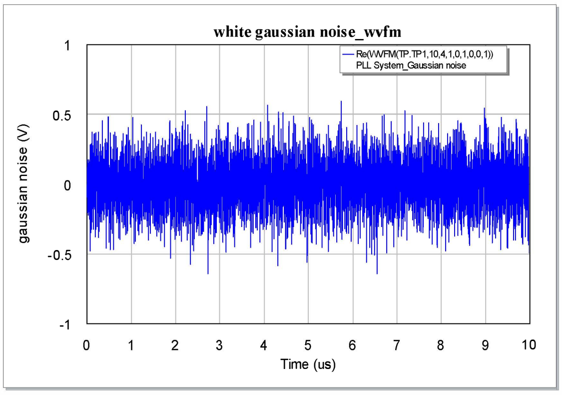

Fig.4. Gaussian noise voltage

It is seen from fig.4 that the Gaussian noise voltage of about 0.35 volt is required for breaking the frequency lock in the receiver.

The spectrum of the Gaussian noise signal in the sampling frequency bandwidth is shown in fig.5.

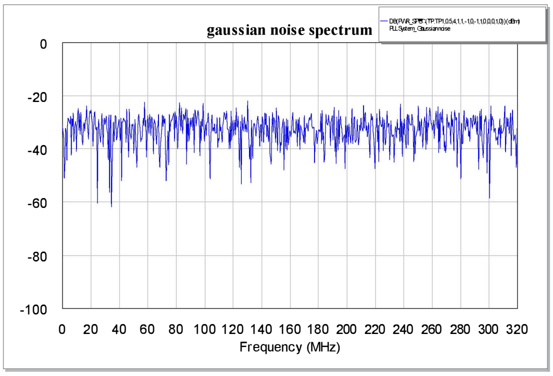

Fig.5. Gaussian noise spectrum

IV. PHASE NOISE JAMMING

In noise jamming scenario, the phase noise significantly degrades the tracking behavior of monopulse radar. The phase noise is generated by passing a white Gaussian noise signal through an FIR filter. With reference to fig.2, the phase noise along with radar echo signal after down converted to an intermediate frequency is applied into the receiver. The phase noise source generates colored noise that is added to the phase of a signal to simulate phase noise. The colored noise has non-constant amplitude spectrum. The shape of the amplitude spectrum may be specified. The phase noise is specified through a phase noise mask consisting of frequency and dBc/Hz values. The phase noise is then added to the phase of the radar echo signal and the phase noise mask required for break-lock in the receiver is observed online in the frequency spectrum of the signal.

A. Implementation details

Phase noise is synthesized by passing White Gaussian noise through an FIR filter that mimics the shape of the phase noise mask. The coefficients of FIR filter are obtained from phase noise mask. The frequency specification for the filter is converted to time domain, and then a Blackmann-Harris window is applied to obtain the FIR filter coefficients. The windowing improves the general shape of the phase noise at the expense of reducing the frequency resolution. The amount of phase noise that can be successfully modeled is inversely proportional to the sampling frequency. This is due to the random phase samples wrapping around $\pm\pi$. As the amount of phase noise to be generated increases, more of the noise wraps around $\pm\pi$, effectively aliasing the noise. In general, as the average phase noise of the FIR filter bins approaches the inverse of the sampling frequency, the ability to generate phase noise near the desired dBc/Hz level diminishes.

The phase noise mask required for complete break-lock in the receiver for different frequency offset from the echo signal frequency is shown in Table1.

TABLE I. PHASE NOISE MASK REQUIRED FOR BREAK-LOCK

Phase noise mask(dBc/Hz)	
Frequency offset from echo (MHz)	Phase noise power(dBc/Hz)
10	-72
12	-75
14	-78
16	-79
18	-80
20	-81

From the Table1, it is clear that the phase noise power required for breaking the frequency lock in the receiver is less when the frequency offset from the radar echo signal is large. The receiver response to phase noise with a frequency offset of 10 MHz is shown in fig.6.

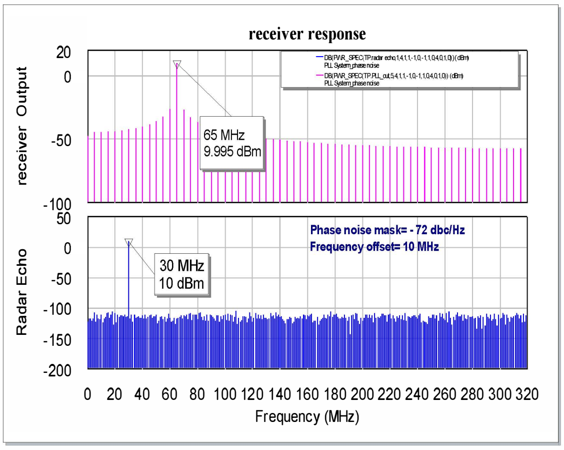

Fig.6. Receiver response to phase noise at -72 dBc/Hz

As shown in fig.6, the radar echo signal frequency is 30 MHz and the receiver output frequency is 65 MHz at phase noise power -72 dBc/Hz. So, it is clear that phase noise power of -72 dBc/Hz is required for break-lock in the receiver with a frequency offset of 10 MHz from the radar echo signal.

V. PHASE NOISE JAMMING USING WINDOWING TECHNIQUES

In this section, the noise jamming of the radar receiver is presented when phase noise is computed using different window techniques. The phase noise is computed using Kaiser-Bessel window and Hamming window techniques. The phase noise mask required for jamming the receiver when computed using window techniques are compared with the reference phase noise. The result obtained is shown in fig.8.

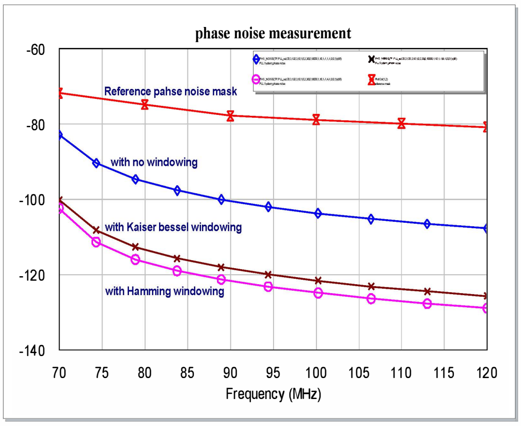

Fig.8. Phase noise mask comparison

The phase noise mask required for break-lock in the receiver with and without window techniques is shown in fig.8. It is seen from fig.8 that the phase noise mask varies between -81 and -108 dBc/Hz with offset frequency from the echo signal when no window technique is used where as it varies between -100 and -130 dBc/Hz when window techniques are used. From the above results, it is clear that there is a large deviation in phase noise required for jamming the receiver with and without windowing techniques as compared to reference phase noise. The phase noise required for jamming the receiver is significantly less with hamming window.

VI. CONCLUSION

In this paper, the effectiveness of noise jamming with white Gaussian noise and phase noise signal has been estimated through extensive simulations. Results are presented for various values of Gaussian noise and phase noise power at which break-lock in the receiver occurs. It is verified that the Gaussian noise characteristics determines the noise power required for jamming the receiver. It is shown that effectiveness of jamming the receiver is significant when Gaussian noise power is computed in double-sided PSD which is found to be -90.34 dbm. It is also shown that the Gaussian noise signal voltage of about 0.3 volt is sufficient enough for breaking the frequency lock in the receiver. In the case of phase noise jamming, it is shown that the phase noise mask required for break-lock in the receiver is less when the frequency offset from the radar echo signal is more. So, it can be recommended that phase noise with larger frequency offset is desired for effective jamming of the receiver. The reference phase noise required for jamming is compared with the phase noise when computed using window techniques. It is verified that the phase noise required for effective jamming of the receiver is significantly less when computed using window technique as compared to the reference phase noise.

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