Broadband Repeat Jamming of Monopulse Receivers in Missile Borne Tracking Radar

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Abstract

Jamming of radar guided missile receivers are extremely difficult as the frequency lock and the servo lock requires no deviations in the repeater waveform of the jammer and its frequency. Broadband repeat jamming of such missile radar receiver is illustrated in this paper for effective deception in the presence of FM CW (Continuous Wave) interference signal. The modulation index of the FM jammer required for breaking the frequency lock of the monopulse receiver is determined and its variation with radar echo signal amplitude is presented. It is shown that modulation index required for jamming the receiver increases with increase in amplitude of the received radar echo. It is also verified that for particular radar echo amplitude, less modulation index is required for jamming the receiver when the modulating voltage in the FM jammer is maintained at large value. It is seen that break-lock in the receiver occurs when the FM modulation index is $8.75x10^3$ or more for typical radar echo amplitude of 1 volt and FM modulating voltage of 5 mV and frequency of 0.2 MHz. The effectiveness of the jamming is estimated through computer simulation using Visual System Simulator.

Keywords: *Electronic warfare, monopulse, radar echo, repeat jamming, tracking radar.*

1. Introduction

Tracking radars have pencil beam pattern to receive echoes from the targets efficiently and these radars track the target in angle, range and it's velocity by Doppler Effect. A tracking radar system measures the coordinates of a target and provides data which may be used to determine the target path from which future position of the target can be determined. All or only a part of the available radar data may be used in predicting future position [1]. In general, on-board radar guided missile receivers track the target in three domains namely frequency, range and angle. In most of the missile seekers applications, monopulse radar receivers are widely used which employs Phase Locked Loop (PLL) for coherent detection of the echo signal and to become jam resistant [2-3]. So long as the loop is locked-on to the radar echo signal frequency, the missile maintains its course and tracks the target. Once there is a disturbance to the loop either in the form of noise or deliberate repeat jamming, the missile loses the frequency lock onto the desired radar echo signal and becomes ineffective [4]. Similarly, in the angular domain if the missile receiver can be deceived, the missile gets disturbed and goes away from its target and hence the target is saved [5]. Same can be said in the case of range tracking also. In this paper, broadband repeat jamming of monopulse receiver with third order loop is analyzed for effective deception of the receiver when FM (Frequency Modulation) CW (Continuous Wave) jammer signal is applied to the receiver. The bandwidth of the jammer signal is large enough compared to the receiver bandwidth which is typically designed at 1 MHz. The radar receiver receives the radar echo which is unmodulated sinusoidal CW signal along with FM CW interference signal. It is assumed that, initially the receiver locks onto the radar echo signal as the frequency deviation between the radar echo and jammer signal is less. The modulation index of the FM jammer signal is then increased.

This results in increase in frequency deviation between the two signals and hence the loop error. At a particular value of the modulation index, the receiver loses the frequency lock to the radar echo signal and locks onto certain other frequency. Thus, break-lock in the receiver is achieved. The modulation index required for breaking the frequency lock in the receiver is determined for different radar echo signal amplitude. The variation in the frequency sensitivity (K_f-Hz/V) and frequency deviation of the jammer with received radar echo signal amplitude is also examined for typical values of modulating signal amplitude such as 5 mV, 15 mV, 25 mV and so on. It is shown that modulation index required for jamming the receiver increases with increase in amplitude of the received radar echo amplitude. It is also shown that for given radar echo amplitude, less modulation index is required for break-lock when modulating signal voltage in the FM jammer is large. For our simulation, the mathematical model for CW radar receiver with third order loop is developed and is implemented using Visual System Simulator. The model includes the generation of sinusoidal radar echo signal and FM jammer signal at the receiver input to achieve effective jamming. The radar echo is operating at a typical intermediate frequency of 30MHz and receiver bandwidth is set to 1 MHz while the bandwidth of FM jammer is set to 10 MHz to achieve broadband jamming.

2. Radar Receiver with Third Order Loop

The schematic of monopulse receiver with third order loop is shown in fig.1.

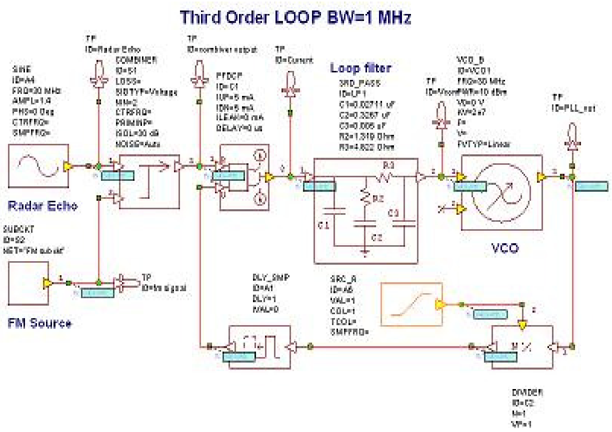

Fig.1. Radar receiver with third order loop

As shown in fig.1, the sinusoidal CW radar echo signal along with FM CW jammer signal after down conversion to IF (Intermediate Frequency) are applied to the loop. The key parameters in design of the loop are loop bandwidth (fc), phase detector gain (K_Φ) and VCO gain (K_{vco}) .The bandwidth of the loop depends upon loop filter components. Since the loop filter is crucial to robust against jamming, hence careful design has been carried out and inserted into the overall simulation of the receiver. The design of the loop filter involves choosing proper filter order, phase margin, loop bandwidth and pole ratio [8]. From these, the time constants of the filter are determined and then the loop filter component are calculated. For our simulations, the loop with a typical bandwidth of 1 MHz is designed using the standard method.

3. Broadband Jamming with FM CW Signal

With reference to the fig.1, the radar echo which is assumed to be CW sinusoidal signal after down conversion to IF frequency is applied at the input of the receiver operating at typical frequency of 30 MHz and amplitude of 1 volt. A sinusoidal modulated FM CW signal of modulating signal frequency (f_m) of 0.2 MHz, amplitude of 5 mV and carrier frequency of 30 MHz is applied as a typical case to the loop along with the echo signal. It is observed that initially, the loop locks onto the radar echo signal frequency as the FM modulation index is very less (of order of 10 or so). The FM modulation index is then increased until the loop loses the frequency lock from the echo signal. It is observed that when the FM modulation index attains the value of $88.75x10^3$, the loop loses the frequency lock to the radar echo and locks onto certain other frequency. Similar simulations are carried out by increasing the radar echo amplitude in steps of 0.2 volt and the modulation index required for break-lock is determined. The break-lock in the loop is also observed for other modulating voltage such as 15 mV and 25mV and so. The break-lock in the frequency spectrum of the radar receiver output is shown in fig.2 (a) & (b) and fig.3 (a) & (b).

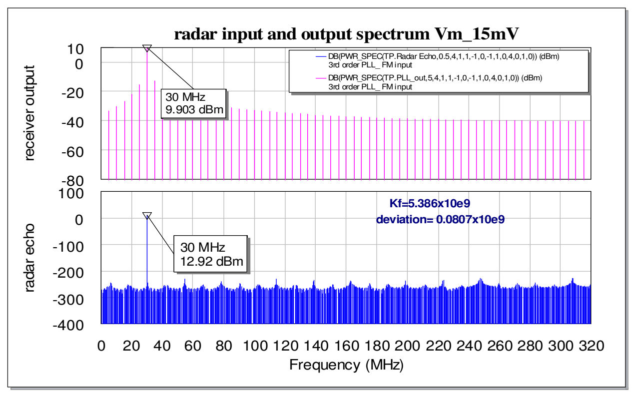

Fig.2. (a). Response at Vm=15 mV, Kf= 5.386x109 Hz/V

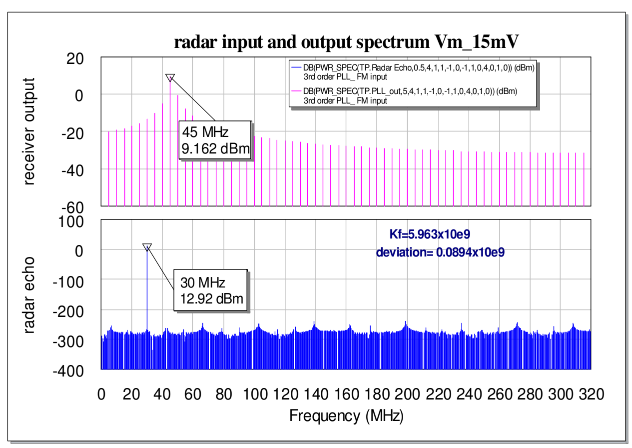

Fig.2. (b). Response at Vm=15 mV, Kf= 5.963x109 Hz/V

The receiver response for modulating signal voltage of 15 mV is shown in fig. 2(a). It is seen in Fig.2(a) that the radar echo frequency is 30 MHz and receiver output frequency is also 30 MHz when K_f=5.386x10^9 Hz/Volt and frequency deviation=0.0807x10^9 MHz. This shows that the radar tracks the echo signal frequency. As shown in Fig.2 (b), at K_f = 5.963x10^9 Hz/Volt and deviation = 0.0894x10^9 MHz, the receiver output frequency is 45 MHz which is different from radar echo frequency which indicates that the radar receiver lost the frequency lock to the echo frequency. The similar results for V_m= 25 mV are shown in fig. 3(a) and fig.3 (b).

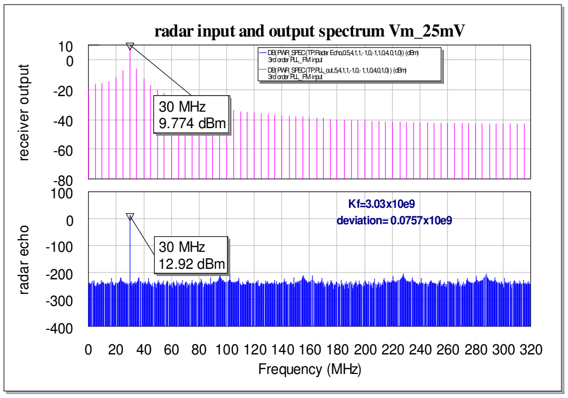

Fig.3 (a). Response at Vm=25 mV, Kf= 3.03x109 Hz

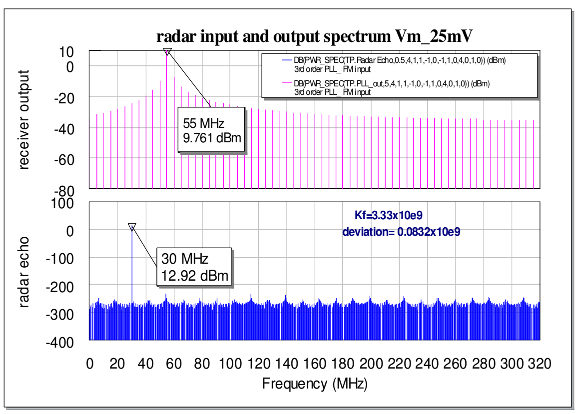

Fig.3. (b). Response at V_m=25 mV, K_f= 3.33x10^9 Hz/V

It is seen in Fig.3(a) that the radar echo frequency is 30 MHz and receiver output frequency is also 30 MHz when K_f = 3.03x10^9 Hz/Volt and frequency deviation = 0.0757x10^9 MHz. This shows that the radar tracks the echo signal frequency. As shown in Fig.3(b), at K_f = 3.33x10^9 Hz/Volt and deviation = 0.0832x10^9 MHz, the receiver output frequency is 55 MHz which is different from radar echo frequency which indicates that the radar receiver lost the frequency lock to the echo frequency. The variation in K_f and frequency deviation of the FM jammer with radar echo amplitude is determined and is shown in the fig.4 (a) and fig.4 (b).

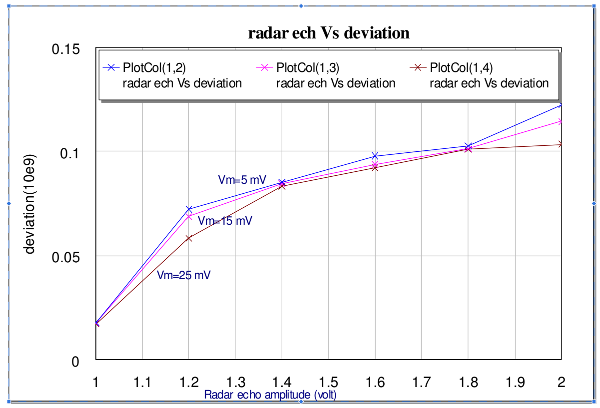

Fig.4 (a). Kf Vs Radar echo

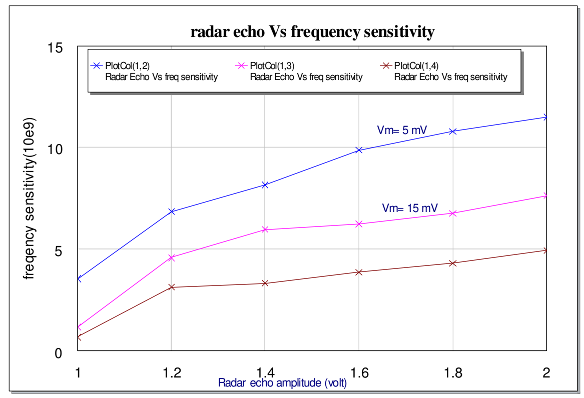

Fig.4 (b). Frequency deviation Vs Radar echo

It is clear from the fig.4 (a) and 4(b) that as the radar echo amplitude increases, the frequency sensitivity and the frequency deviation required for break-lock also increases and hence the modulation index. Thus, it can be concluded that larger modulation index is required for breaking the frequency lock in the receiver when radar echo amplitude is increased. However, it is seen that for a given radar echo amplitude; less modulation index is required for break-lock in the receiver when modulating signal voltage of the FM jammer is large.

4. Conclusion

In this paper, the repeat jamming of monopulse radar receiver in the presence of FM CW signal has been discussed. The simulation study shows that the modulation index required for break-lock is 88.75x10^3 or more for a typical modulating signal frequency of 0.2 MHz and amplitude of 5 mV. The method developed here permits the computation of modulation index for other values of modulating frequency and voltage. It is seen that lower values of modulation index are enough for break lock to occur at higher values of modulating signal voltage. The frequency sensitivity of the FM jammer has significant effect in jamming the receiver. Thus, it can be concluded that modulation index and frequency sensitivity are the two key parameters which are to be taken into account for effective jamming of the monopulse receiver in the case of FM broadband jamming.

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