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ELECTRONIC WARFARE IN RADAR SYSTEMS: A COMPARATIVE ANALYSIS OF ECM AND ECCM

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Abstract: **In electronic warfare, electronic counter measures (ECM) and electronic counter-counter measures (ECCM) are always in competition with each other. These are used for aircrafts under high risk against the enemy's air defense radars are incapable of attacking and detecting in the sensitive areas. In this paper, ECM are explained with the noise jamming and deception jamming and ECCM are explained with Pulse compression, Frequency hopping, Side lobe blanking and Polarization. Jammer peak power and radar peak power versus burn through range are simulated, Finally, the paper reports on the use of ECCM techniques to retain use of the spectrum when jammers are present in radar and communications systems.**

Keywords - Electronic warfare, ECM, ECCM, Noise jammers, Deception jamming, pulse compression.

I. INTRODUCTION

Electronic warfare is an any action involving in the use of electronic magnetic spectrum to electronically attack or detect the enemy's electronic system. Since, World War II there is an sophistication in radar thus, electronic warfare has grown with rapid peace militaries around the world has serious attenuation in sophistication of their weaponry and their control. Thus, electronic warfare and radar performance has a rapid increase since World War II [12].

Electronic warfare is divided into three types, namely: electronic support measures (ESM), electronic counter measures (ECM), and electronic counter-counter measures (ECCM). Electronic support measures is an actions takes under direct control of operator commander to detect, identify, locate, record analyze sources of radiated electromagnetic energy for the purpose of threat recongization and gather the intelligence through passive listening to electromagnetic radiation of military applications in electronic support measures are mainly used for electronic protection(EP) and electronic attack(EA). EA is used in electronic counter measures; EP is used in electronic counter-counter measures.

Electronic warfare is mainly divided into two parts. ECM and ECCM. ECM are use to detect the target threats of radar within lessen abilities and to ensure proper operations radars are equipped with ECCM. ECCM is also a part of electronic warfare which is used to nullify the effects of ECM. In development of technology across the world the electronics played a vital role. Any threat that comes in electronic may rescues against electronics.

During worldwar II radar jamming was started by the royal air force with the name 'window'. Now-a-days it is known as "chaff". In this German's radio communication started jamming.

Detectability of target is dependent on characteristic of target .RCS is the parameter of the target describes the strength of electronic magnetic wave reflected from the target [9].

$$\sigma = \lim_{r \to \infty} 4\pi r^2 \frac{|E_s|^2}{|E_i|^2} \qquad (1)$$

Es is the magnitude of scattered electric field; Ei is the magnitude of incident electric field. Designers designed the equipments in such a way that ECM has less RCS and ECCM has greater value of RCS.

II. ELECTRONIC COUNTER MEASURES

Electronic counter measures are the actions taken to prevent or reduce the enemy's effective use of electromagnetic spectrum. ECM is used for detection attacking and monitoring, jamming purpose. Thus, we can say that it is used to disturb the normal operation done in the magnetic spectrum [1].

Digital radio frequency (DRF) technique is used, to store the incoming signal high speed sampling and digital memory is used. The signal which is mixed and corrupted are reconstructed coherently and sent to the target threat. Digital radio frequency modulation (DRFM) systems are equipped in jamming in ECM systems are implemented by the principal of DRFM [4][5].

ECM is used by off sense to accomplish one, several, or possibly all of the following objectives. 1) Deny proper target detection. 2) Generate operator confusion and/or deception. 3) Initiation of force delays in detection and tracking. 4) Generate false tracks of non-real targets. 5) Measurements of target range and radar range. 6) Introduce errors in target position and range rate. ECM is categorized in to two types they are: Denial ECM and Deception ECM.

1)Denial ECM: It includes active and passive where active denial ECM includes CW, short pulse, spot noise, barrage noise, side lobe repeaters. Whereas, passive ECM includes chaffs and radar absorbing material (RAM) techniques.

2)Deception ECM: It is also classified into active and passive techniques whereas, active deception ECM includes repeaters jammers and false target generators and passive deception ECM includes chaff and RAM techniques.

Major actions in ECM are noise jamming and deception jamming.

A: Noise Jamming

Disturb normal operation the radar by re-radiation, radiation or reflection of electromagnetic energy is known as noise jamming.

Noise jamming is again classified into two types they are: active jamming and passive jamming. In active jamming, spot, sweep, barrage jamming is done and again in passive jamming chaff and RAM technology is used.

i. *Spot jamming:* In spot jamming the jammer power concentrated on specific frequency range of the radar it must be ideal.
ii. *Sweep jamming:* Here, the jammer power is shared, because the jammer sweeps its frequency one to another over multiple frequencies it covers wide range frequencies.
iii. *Barrage jamming:* In barrage jamming, the jamming disturbs its power to multiple frequencies at same time. Thus, draw backs of other jammers are avoided.

It is used to increase the noise level across the entire radar operating bandwidth. It is difficult to detect the targets. Since, it has lower SNR at the receiver. Thus, barrage jammers are known as “maskers”.

Barrage jammers are deployed in main beam or in side lobes of radars. If jammer is located in mean beam radar it is has an advantage to amplify the noise signal with maximum gain of the antenna and main beam barrage jammer can be deployed in either on-board attacking vehicle or act as an escort of the target. Whereas, side lobe jammers are used for operating in shorter range and consumes more power compared to main beam jammers. These, jammers are deployed to interfere with specific radar and they do not stay close to the target, thus have variety of stand-off development options.

- ***Self-screening jammers (SSJ):*** These jammers are used in operating at main beam radar location. It is known as self-protecting jammers (or) escort jammers (or) main beam jammers. It is carried on the vehicles for attacking the other vehicles.

$$S = \frac{P_t G^2 \lambda^2 \sigma \tau}{(4\pi)^3 R^4 L} \tag{2}$$

This is the single pulse power received by radar from the target of RCS at range R. Radar power received by SSJ jammer at same range is:

$$J = \frac{P_J G_J}{4\pi R^2} \cdot \frac{A_r}{B_J L_J} \tag{3}$$

Band width of jammer is greater than the bandwidth of the radar. Thus, we can say that the jammers are designed to operate over the wide variety of radar systems with different bandwidth. Thus, S/J ratio in case of SSJ is given by:

$$\frac{S}{J} = \frac{P_t \tau G \sigma B_J}{(ERP) 4\pi R^2 L} \tag{4}$$

- ***Stand-off jammers (SOJ):*** These jammers do not stay close to the target. These SOJ emit ECM signals from long ranges which are beyond its capability.

Power received by the radar from SOJ at range RJ is:

$$J = \frac{P_J G_J}{4\pi {R_J}^2} \cdot \frac{\lambda^2 G'}{4\pi} \cdot \frac{1}{B_J L_J} \tag{5}$$

$$J = \frac{ERP}{4\pi {R_J}^2} \cdot \frac{\lambda^2 G'}{4\pi} \cdot \frac{1}{B_J} \tag{6}$$

The SOJ terms are same SSJ jammers expect the ‘G’ that is radar antenna gain, which represents the direction of jammer and to be the side lobe gain .SOJ radar equation is given as:

$$\frac{S}{J} = \frac{P_t \tau G^2 R_J^2 \sigma B_J}{4\pi (ERP) G' R^4 L} \tag{7}$$

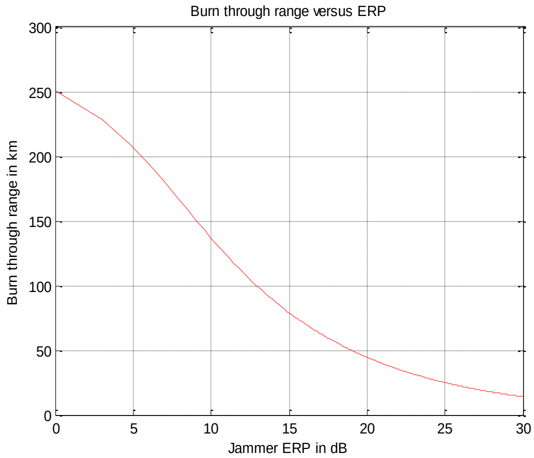

Figure 1. Burn-through range versus the jammer ERP.

B: Deception jamming

In radar transmission it carryout the incoming signals and analyze with radar receiving signals, and it sends out the false target information. In order to interrupt (or) mislead (or) confuse the radar by false target information. Deceptive jammers are also known as repeaters jammers. They are two similar types of repeaters jammers they are (i) spot noise repeaters and (ii) deceptive repeaters.

i. *Spot noise repeaters*: It measures the transmitted bandwidth and jams the particular range of frequency.

ii. *Deceptive repeaters:* It sends out false targets information these are also known as ghosts. These ghosts are created by a single jammer. These jammers make an efficient use of their jamming power. Radar frequency ability is the only way possible to detect the spot noise repeaters.

Deception jamming is divided into two types they are range deception and velocity deception.

- ***Range deception***: In order to confuse the radar about the original radar the jammers first locks the targets, and then it generates the pulse signals in the jammer and use time delays. Deception jamming where multiple false targets are appearing at the plan position indicator of the radar at different ranges and velocity.
- ***Velocity deception:*** In order to make the difficulty for the radar in identifying the correct location of target. The velocity deception, jamming alters frequency and phase of the signal and that it sends back [3].

Jamming of the radar affects the signal to noise ratio in the receiver. If jamming is employed in the form of Gaussian noise, radar receiver has to deal with noise power in radar. Detection, tracking of the radar signal is no longer dependent on the SNR.

$$\frac{S}{J+N}=\frac{\left(\dfrac{P_t G\sigma A_r\tau}{(4\pi)^2 R^4 L}\right)}{\left(\dfrac{(ERP)A_r}{4\pi R^2 B_J}+KT_0\right)} \tag{8}$$

symbol	Description	units	status
pt	Radar peak power	W	input
g	Radar antenna gain	dB	input
sigma	Target cross section	m	input
freq	Radar operating frequency	Hz	input
tau	Radar pulse width	seconds	input
T0	Effective noise temperature	Kelvin	input
loss	Radar losses	dB	input
R	Range can be single value or a vector	Km	input
pj	Jammer peak power	W	input
bj	Jammer band width	Hz	input
gj	Jammer antenna gain	dB	input
lossj	Jammer losses	dB	input
SIR	S/(J+N)	dB	output

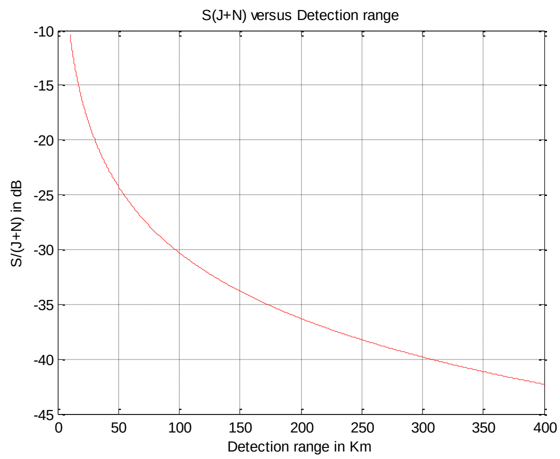

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Figure 2: S/(J+N) versus detection range.

Where, K is Boltzmann's constant and T0 is the effective noise temperature. S/(J+N) is used in place of SNR for the radar equation and probability of detection using coherent or non-coherent pulse integration.

$$\text{ERP=Effective radiated power} = \frac{P_J G_J}{L_J} \quad (9)$$

This shows simulation of SNR jamming ratio of 5-6GHZ of radar operating frequency. In the radar jamming power involve one-way transmission where as two-way transmissions involve target echoes. Thus, target signal power is always less than jamming power. S/J is less than unity, as jammer becomes closer to radar the SNR becomes closer to radar S/J is equal to unity. This is known as cross-over range. The range where SNR (OR) S/J is greater than unity it is known as detection range.

Cross-over range is SSJ is given by:

$$(RCO)_{SSJ} = \left(\frac{P_t G \sigma B_J}{4\pi B_r L(ERP)} \right)^{\frac{1}{2}} \quad (10)$$

$$(RCO)_{SOJ} = \left(\frac{P_t G^2 R_J^2 \sigma B_J P_{PC}}{4\pi B_r G' L(ERP)} \right)^{\frac{1}{4}} \quad (11)$$

Burn- through range versus jammer and radar peak powers.

symbol	Description	Units	status
br	Radar operating bandwidth	Hz	input
loss	Radar losses	dB	input
BR_range	Crosss-over range	Km	output

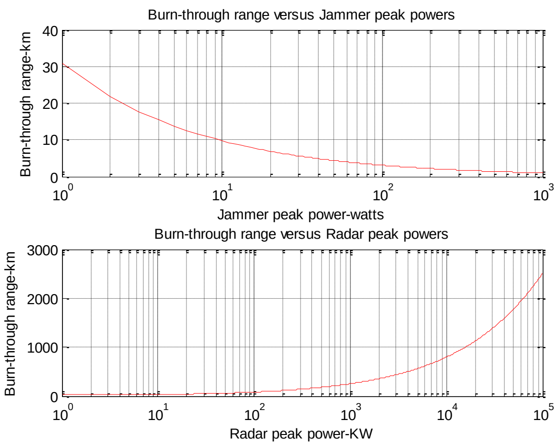

Figure 3: Jammer peak power and Radar peak power

III. ELECTRONICCOUNTER-COUNTER MEASURES

It is used to nullify the effects of ECM and make radar capable of detect the target which is implying the ECM.

An action taken to ensure friendly and effective use of electronic magnetic spectrum despite the enemy's use of EW is known ECCM. The radars without ECCM cannot be used in modern wars (or) battles. To counter the advancements in ECM and nullify its effects and make radar capable in identifying the target and detection [6].

IV. CURRENT DEVELOPMENTS OF RADAR ECCM TECHNOLOGIES

Mainly focused on time domain, frequency domain, and polarization etc., new technologies are used by emerging on the time and space domain [13]. Self adopting signal and multi carrier encoded signal [14]. Where as AN/APY-2 radar equipped in E-3C early warning aircrafts is an example.

It uses Omni directional coverage and S-band pulse-pulse Doppler five working patterns, low side lobe high pulse frequency digital processing techniques are used radar with good capacity of ECCM and high reliability the main advantages of new technologies is self adapting to different battle conditions.

The radar ECCM technologies in research mainly include the following [15] [16].

- Design of radar such as frequency modulation, poly phase code, multi modulation.
- With ultra low side lobe and side lobe cancellation design of antenna.
- Frequency diversity, frequency ability are to be adopted.
- Increasing peak power, pulse compression, beam composing and pulse repetition frequency increase.
- Adopting technologies in polarizing diversity and self-adapting. Polarizing ability in polarization field.
- Design of ECCM circuit with CFR, band limit narrow circuit automatic gain control.

V. CHALLENGES IN ECCM TECHNOLOGIES

- Presently existing radar aim is blanking noise interference and deceptive interference is severe threat for the radar than blanking interference, so, anti-deceptive interference methods need to be proposed soon.
- Present radars can't recognize pattern interference, used only for single interference. Can't be used in multiple interference methods. Now, radar ECCM methods are not effective for interference methods combining blanking and deceptive interference. So, radar anti-combination interference is required.
- Now a survey on anti-active interference technologies, major aim is to prevent the interference entering from radar receiving system. Impossible to achieve the aim totally so, development of interference and counter-interference pair the contradictions. The side lobe

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cancellation technology is also limited. There is a threshold in side lobe canceller (SLC). Side lobe bandwidth (SLB) while improving ECCM performance in radar losses much information.

Some techniques can be used in ECCM are:

i. *Pulse compression:*

The radar return from the receiver add a delay as a function of frequency, and it appears stronger this signal strength is stronger over the noise jamming.(or) in other words, boosting the signal strength by the radar receiver. Frequency is carried out with respect to the pulse.

By pulse compression high resolution is maintained by average transmitted power can be achieved [10].

$$\Delta R = \frac{C\tau}{2} = \frac{C}{2B} \tag{12}$$

Where, ΔR = range resolution

B = band width

τ = pulse width

ii. *Frequency hopping:*

In certain time interval it makes difficult for the jammer to jam a particular frequency, whereas, the frequency transmitted signal is switched rapidly and hence, receiving the same frequency within the time. And also, by the jammer next frequency cannot be predicted. In barrage jamming, frequency hopping is more useful. Since, the jammer spreads power among different frequencies.

Frequency change greatly varies for the RCS of larger objects like aircrafts at some frequencies the RCS may be small and other is high.

Radar operating at single frequency might result in lost detection for a result of smaller target echo for multiple frequencies RCS can vary but detection probability would increase.

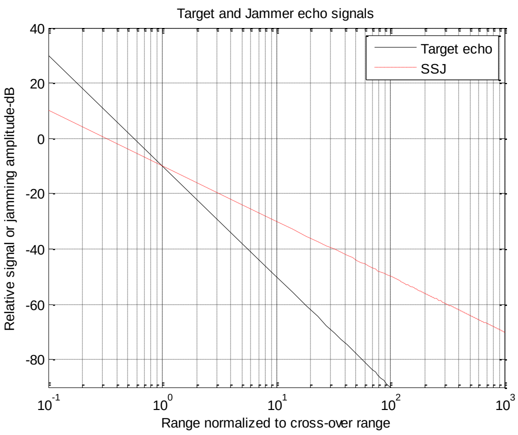

Figure 4. Target and jammer echo signals.

iii. *Side lobe blanking:*

Through side lobes of antenna the jamming entering thus, because of it detection range is decreased. The radar receiver can detect the energy present at outside of the main beam. Thus, multi static radars with multiple receivers are gaining more popularity. Thus, problem is eliminated i.e., when jammer tries to jam the main beam of the radar at a time lowering the side lobes is important.

In radars directional antenna is present it aims certain elevation and azimuth angle. The target is aimed by jammer signal. Other direction it is strong that radar receiver can detect it from a low gain side lobe. If they are coming from main lobe the radar processes it. To overcome this Omni-directional antenna signal strength is compared for side lobe and main lobe. Thus, unwanted signals are removed at the receiver. In many countries to counter the ECM effects on modern phase array antenna technologies they are working on radar technologies [9].

False alarms due to interference coming through side lobes can be reduced by side lobe blanking devices [2]. ECCM systems designers want the side lobe levels to be as small as possible. The advantage of ECCM designers is side lobe blanking devices.

iv. *Polarization:*

Jamming signals can be filter out. At receiver if it does not have same polarization, jamming, Signal losses it effectiveness. So there, antenna diversity can be used by radar receiver. It can use multiple antennas for different polarization and correlate signals in the receiver.

For further improvement, study of all these methods and technologies for radar ECCM is done in recent years [7]. In ECCM of radar systems many researchers believe signal processing has maximum potential [8].

Pulse compression in jamming:

In coherent jamming and incoherent jamming, the main advantage is it requires less transmitter power. Pulse compression gain is for target information processing DRFM technology is used.

Pulse compression increases the jamming. This technique is used in modern radar systems as a solution for radar resolution and detection distance. In pulse compression, a matched linear invariant time filter is used to maximizes the output of SNR, when noise is white.

Maximum SNR of matched filter at t=t0

$$SNR_{max} = \frac{E_S}{\sigma^2} \tag{12}$$

Where, E_S = Energy

σ^2 = Variance of noise.

Assume, radar signal is LFM signal with time width T before pulse compression. The power of signal is backscatter from point scatter t0 and distributed uniformly over time interval (t0,t0=T). Power of signal is S (t-t0) and time instant (t0, t0+T). so, power of noise is n(t). After pulse compression signal power is reallocated and signal becomes a sync. Pattern function majority signal is at main lobe whereas; minority signal is at side lobes.

Jamming against target: transmitter power require coherent deceptive jamming against target. DRFM based repeaters, modulation, and retransmission of radar signal. Jammers works in noise jamming under Gaussian noise with equal bandwidth.

VI. CONCLUSION

This paper gives over view of electronic counter counter measures (ECCM). ECCM is a ground based radar systems used for jet aircrafts. ECCM nullifies the effect of costly ECM system. ECM and ECCM has more competition and these two make use in reliable air defense system and study of jamming technology is also done.

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