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# Analysis of Mono-Static Radar Performance Under Active ECM

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**Abstract**

ECM plays a vital role in aerial combat which dictates the results of modern warfare. Without ECM, attacking aircrafts would never be able to mask their movements from the target/victim radar. The main goal of this paper is to analyse only the active ECM techniques and their effects on radar range. In this regard, self protection ECM and support ECM were considered and their effects on the cross-over range and the burn-through range were simulated using MATLAB. From the results their dependency on the jammer peak power is identified. Thereafter, the mathematical definition of the range reduction factor (RRF) is presented and the effects of ECM on RRF are thoroughly investigated. Generated results emphasize on the use of controlled active ECM for optimum effect on radar performance.

***Keywords***: Electronic Countermeasure (ECM), Self-screening Jammers (SSJ), Stand-off Jammers (SOJ), Effective Radiated Power (ERP), Chaff, Cross-over Range, Burn-through Range, Range Reduction Factor (RRF).

## 1. INTRODUCTION

Any deliberate electronic effort undertaken to degrade the radar performance is called an Electronic Countermeasure (ECM). ECM can be employed for either jamming or deception. Jamming uses ECM to flood the radar receiver and hide the targets using some form of noise as transmitted ECM signal. Deception uses ECM to create false target signals that is detected by radar receiver as real targets. Jamming and deception techniques can be either passive or active. Passive jamming and deception include chaff (composed of large number of small RF reflectors that have large RCS values) and Radar Absorbing Material (RAM). Active jamming techniques include CW, short pulse, long pulse, barrage noise and sidelobe repeaters. Active deception include repeater jammers and false target generators. In this paper we have focussed on the effects of active ECM on the radar range performance.

When factoring ECM into radar equation, the quantities of interest are Signal to jamming ratio (S/J), burn-through range and the cross over range. Burn-through range is the radar to target range where the target return signal can first be detected through the ECM and is usually slightly farther than crossover range where J = S. It is usually the range where the S/J just equals the minimum effective S/J. The cross over range could be the burn-through range, but it is not because normally S/J < 0 dB to be effective due to the task of differentiating the signal from the jamming noise floor.

There are two different methods of employing active ECM against radars: Self protecting ECM and support ECM. In practice, self protection ECM is usually deception and support ECM is usually noise jamming.

## 2. SELF PROTECTION ECM

In this section, the impacts of self protection ECM on the performance of mono-static radar system has been analysed. Self protection ECM is used to protect the platform that it is on. It is often called "self screening jamming" or SSJ, and also "DECM", which is an acronym for either "Defensive ECM" or "Deception ECM". The top half of Fig-1 shows self screening jamming

(DECM). The bottom half of Fig-1 illustrates escort jamming which is a special case of support jamming. If the escort platform is sufficiently close to the target, the S/J calculations are the same as for DECM.

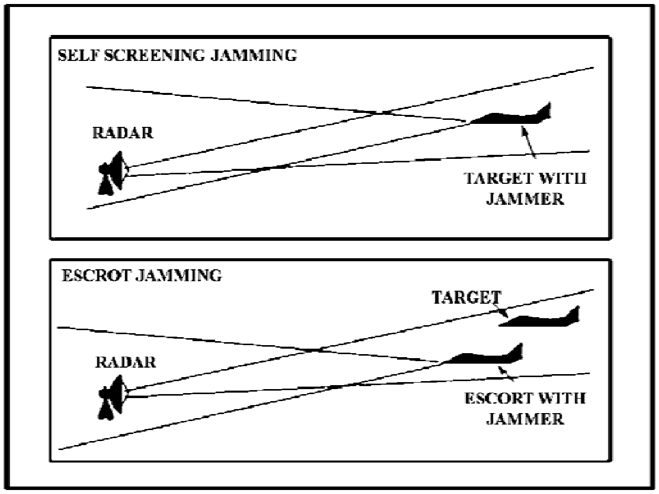



Fig-1 Self protection and escort jamming

The single pulse power received by the radar from target is given by [1]

$$P_S = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 L R^4} \tag{1}$$

Where, $P_t$ = radar transmitted power, G = gain of radar antenna, λ = wavelength being used, σ = target RCS, L = radar losses, R = range. Power received by radar from an SSJ jammer at the same range is

$$P_{SSJ} = \frac{P_J G_J}{4\pi R^2} \frac{\lambda^2 G}{4\pi} \frac{B}{B_J L_J} \tag{2}$$

Where, $P_J$, $G_J$, $B_J$, $L_J$ are jammer peak power, antenna gain, operating bandwidth and losses respectively. Radar equation for SSJ is thus obtained from Eq-1 and Eq-2 as

$$\frac{S}{S_{SSJ}} = \frac{P_t G_p \sigma B_J L_J}{4\pi P_J G_J R^2 B L} \tag{3}$$

Where, $G_P$ is the radar processing gain.

### *A. Cross-over Range*

The jamming power reaches the radar on a one-way transmission basis, whereas the target echoes involve two-way transmission. Thus, the jamming power is generally greater than the target signal power. In other words, the ratio $S/S_{ssj}$ is less than unity. However, as the target becomes closer to the radar, there will be a certain range such that the ratio is equal to unity. This range is known as the crossover range. The range window where the ratio is sufficiently larger than unity is denoted as the detection range. In order to compute the crossover range $R_{CO}$, we set $S/S_{SSj}$ to unity in Eq-3 and solve for range. It follows [4]

$$(R_{CO})_{SSJ} = \left( \frac{P_t G \sigma B_J L_J}{4\pi P_J G_J B L} \right)^{1/2} \tag{4}$$

If we implement Eq-4 using MATLAB it generates plots as in Fig-2a and Fig-2b.

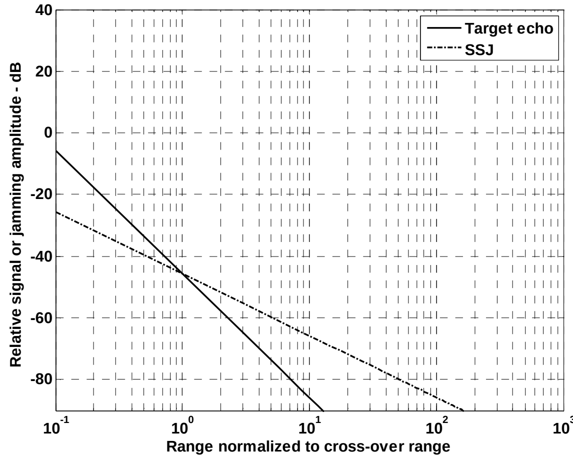



Fig-2a Cross-over range for SSJ

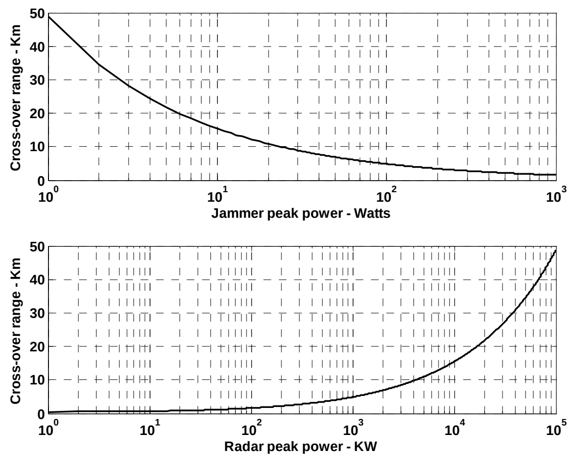



Fig-2b Cross-over range versus peak powers

Fig-2a depicts that SSJ jammer signal is not constant throughout the range as the jammer moves along with the target. Hence cross-over range depends on the ratio of both the jammer and radar signal power. Radars want the cross-over range to be as long as possible to be able to detect targets as early as possible. In Fig-2b it is observed that cross-over range decreases with the jammer peak power and it increases with the radar peak power.

### *B. Burn-through Range*

Fig-3 shows the distinction between the burn-through range and the cross-over range. Here, the jamming signal decays as 20 dB per decade (one-way loss) whereas the radar signal decays as 40 dB per decade (two-way loss). The point where the radar power overcomes the jamming signal is the burn-through range. At this range the radar can detect and perform proper measurements for the target because the radar signal overcomes the minimum ECM power required which in this case is 6 dB.

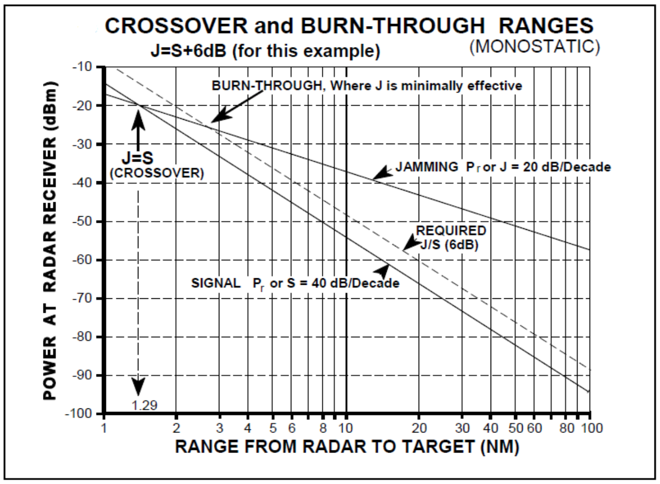



Fig-3 Cross-over and burn-through range

If jamming is employed in the form of Gaussian noise, radar receiver must calculate the S/(J+N) ratio rather than SNR. If we define jammer effective radiated power, ERP = $(P_j G_j)/L_j$ Then,

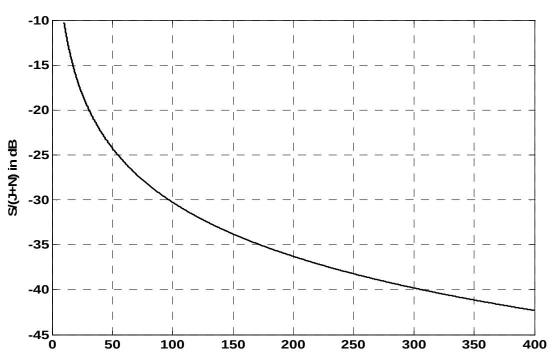
$$\frac{S}{J+N} = \frac{\left(\dfrac{P_t G \sigma A_r \tau}{(4\pi)^2 R^4 L}\right)}{\left(\dfrac{(ERP)A_r}{4\pi R^2 B_j} + kT_0\right)} \tag{5}$$

Where k is Boltzmann's constant and $T_0$ is the effective noise temperature. The range at which the radar can detect and perform proper measurements for a given S/(J+N) value is defined as the burn-through range and is given by [4]

$$R_{BT} = \left\{ \sqrt{\left(\frac{(ERP)A_r}{8\pi B_j k T_0}\right)^2 + \frac{P_t G \sigma A_r \tau}{(4\pi)^2 \dfrac{S}{(J+N)} kT_0}} - \frac{(ERP)A_r}{8\pi B_j k T_0} \right\}^{\frac{1}{2}} \tag{6}$$

Fig-4a implements Eq-5 and Fig-4b implements Eq-5 and Eq-6. Results of Fig-4a reveals that as S/(J + N) in dB becomes more negative, radar detection range is increased. J usually (but not always) must exceed S by some amount to be effective, therefore the desired result of S/(J + N) calculation in dB is a negative number.

Fig-4b reveals that as the jammer effective radiated power increases, the burn-through range from radar to target is decreased. In another way, target can reach radar much closer without being detected as the jammer ERP is increased.



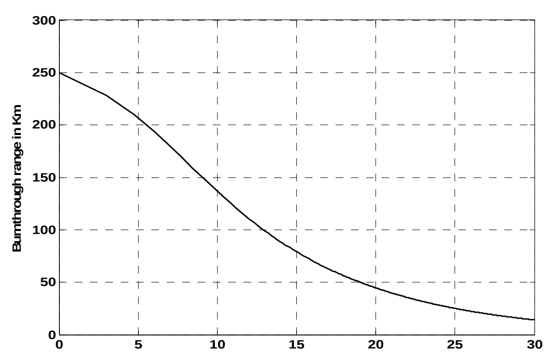




Fig-4a S/(J + N) versus detection range    Fig-4b Burn-through range versus jammer ERP

### 3. SUPPORT ECM

Support ECM is radiated from one platform and is used to protect other platforms. It can be either stand-off jamming (SOJ) or stand-in jamming (SIJ). For SOJ jamming platform maintains an orbit at a long range from radar – usually beyond weapons range. For SIJ, a remotely piloted vehicle (RPV) orbits close to the victim radar. Jamming power required for SOJ is much greater than the jamming power required for SIJ.

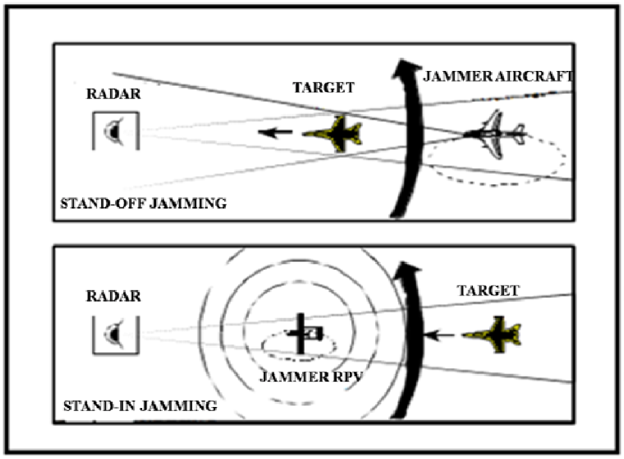



Fig-5 Support jamming

However, the equations used are same for both the cases. The power received by the radar from an SOJ jammer which is normally at range $R_J$ is

$$P_{SOJ} = \frac{P_j G_j}{4\pi R_j^2} \frac{\lambda^2 G}{4\pi} \frac{B}{B_j L_j} \qquad (7)$$

Where $G'$ represents radar antenna gain in the direction of the jammer and is considered to be the side lobe gain. The SOJ radar equation is then found from Eq-7 and Eq-1 as

$$\frac{S}{S_{SOJ}} = \frac{P_t G^2 R_j^2 \sigma B_j L_j}{4\pi P_j G_j G R^4 BL} \qquad (8)$$

Similarly the cross over range is

$$(R_{CO})_{SOJ} = \left( \frac{P_t G^2 R_j^2 \sigma B_j L_j}{4\pi P_j G_j GBL} \right)^{\frac{1}{4}} \qquad (9)$$

The MATLAB simulation result of Eq-9 is shown in Fig-6 which reveals that SOJ jammer signal is constant throughout the range as the jammer does not usually move with the target.

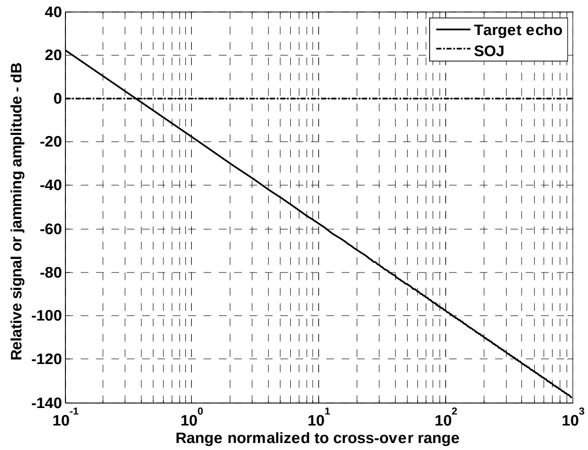



Fig-6 Target echo and SOJ jammer signal

## 4. RANGE REDUCTION FACTOR (RRF)

RRF denotes reduction in radar detection range due to jamming. If $R_{dj}$ and R are the radar detection range with and without jamming then

$$R_{dj} = R \times RRF \tag{10}$$

After a brief calculation it is possible to show that RRF can be expressed as

$$PRF = 10^{\frac{-\gamma}{40}} \tag{11}$$

Which is always less than unity since the value of γ is given by

$$\gamma = 10.0 \times \log\left(1 + \frac{T_J}{T_e}\right) \tag{12}$$

Where, $T_e$ is the effective noise temperature in degree Kelvin and $T_J$ is the jammer effective temperature.

The effect of jammers on the reduction of radar range will be clear from the following plots generated by MATLAB simulation. The simulation implements both Eq-11 and Eq-12.

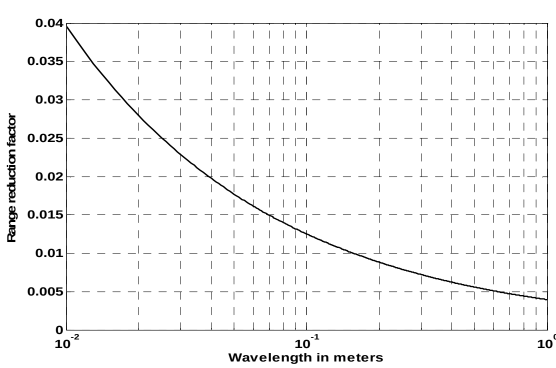



Fig-7a RRF versus radar operating wavelength

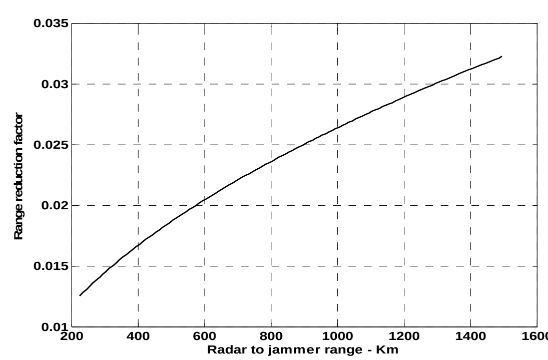



Fig-7b RRF versus radar to jammer range

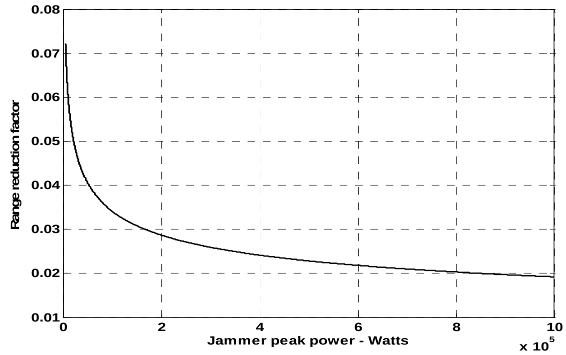



Fig-7c  RRF versus jammer peak power

The simulation generates three plots and the analysis of these plots are listed below :

- Fig-7a shows that the value of the RRF decreases with increasing wavelength (i.e. decreasing frequency). It means if the radar operates at higher frequencies value of RRF will be more. Hence, one way to improve radar performance once being jammed is to shift to a higher operating frequency.
- Fig-7b depicts that the value of RRF increases almost linearly as the distance between the radar and the jammer increases.
- Fig-7c reveals that the value of RRF decreases sharply for a small increase of jammer peak power, but after that the decrease of RRF is not much for any further increase of jammer peak power. This means that after an optimum value is reached, there is no use of increasing jammer peak power.

The significance of S/J is thereby sometimes misunderstood. The effectiveness of ECM is not a direct mathematical function of S/J. The magnitude of the S/J required for effectiveness is a function of the particular ECM technique and of the radar it is being used against. Different ECM techniques may very well require different S/J ratios against the same radar. When there is sufficient S/J for effectiveness, increasing it will rarely increase the effectiveness at a given range. Because modern radars can have sophisticated signal processing and/or ECCM capabilities, in certain radars too much S/J could cause the signal processor to ignore the jamming, or activate special anti-jamming modes. Increasing S/J (or the jammer power) does, however, allow the target aircraft to get much closer to the victim radar before burn-through occurs, which essentially means more power is better if it can be controlled when desired.

## 5. CONCLUSIONS

The main goal of this paper is to study the effects of active ECM on radar performance. In this regard, the different forms of mono-static radar equation under different active ECM techniques have been presented. With intent to investigate the effects of various active ECM, firstly we have analysed the self protection ECM. Simulation results depict that SSJ jammer signal is not constant throughout the range and the cross-over range decreases as the jammer peak power increase. It is also found that the burn-through range decrease as the jammer effective radiated power (ERP) increases. Thereafter, the effects of support ECM are studied and it is revealed that SOJ jammer signal is constant throughout the range. Finally, the effect of jammers on the range reduction factor (RRF) is clear from the simulation, where it is observed that if the radar operates at higher frequencies, the value of RRF will be more. Hence, one way to improve radar performance under jamming condition is to operate the radar at higher frequency. It is also revealed that the value of RRF depends on the distance between the radar and the jammer as well as on the jammer peak power. Furthermore, it is confirmed that increasing jammer peak power beyond an optimum value has no significant effect on radar performance.

Further study can be carried out about the passive ECM techniques. A study on the ECCM techniques for the radar systems can also be significant.

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