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Protection of Transmitting Systems using Ground Bounce Technique

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Abstract

Ground bounce technique is a self-screening or support Electronic Counter Measure (ECM) technique that consists of aiming the ECM antenna in a direction other than the tracking system's direction in order to deceive the tracking system.

Ground reflection property can be used to deceive angularly a tracking system, either airborne or ground based. To achieve a deception to the tracking system, it is necessary to present to it a greater level of signal coming from the ground (after reflection) than from the aircraft direction.

This paper introduces the analysis of ground reflection of EM waves, parameters optimization of ground bounce technique, and a proposed dual mode of operation for an airborne ECM system.

الخلاصـــــة

تعتبر تقنية البقعة المضيئة إحدى تقنيات الحماية الذاتية لمعدات الحرب الالكترونية نوع (ECM) حيث يتم توجيه هوائي هذه المعدات بأتجاه آخر غير أتجاه منظومة المتابعة للطرف الآخر لغرض مخادعة منظومة المتابعة.

يمكن استخدام الخاصية الانعكاسية لسطح الأرض للمخادعة الزاوية لمنظومة المتابعة المحمولة جوا وكذالك الموجودة في قاعدة أرضية. لغرض مخادعة منظومة المتابعة بهذه الطريقة يتطلب تامين مستوى أعلى للإشارة المستلمة بعد الانعكاس الأرضي من تلك التي تستلم بشكل مباشر من منظومة الإرسال.

يتناول هذا البحث تحليلا لانعكاس الموجات الكهرومغناطيسية على سطح الأرض وتحقيق الأمثلية للمعاملات الخاصة بتصميم وتنفيذ تقنية البقعة المضيئة، و مقترح لنظام عمل ثنائي لمنظومة (ECM) محمولة جوا.

1. Introduction

Ground bounce technique is a self-screening or support Electronic Counter Measure (ECM) technique that decreases the look-on probability of a tracking system.

ECM energy can be bounced from chaff clouds (called JAFF), from the surface of the ocean, from relatively smooth surfaces of the earth, or any large, flat, nearby object and be reradiated to the tracking system direction. This reflected signal can enter the radar antenna from any direction, depending on the geography and other parameters of the radar installation. As a transmission system (ECM system), using the bounce technique to produce false angle strobing, approaches a radar, peaks and nulls will be produced at the radar receiver due to interferometry between the bounce and direct signal paths, if the transmission side lobe signal of the ECM antenna in the direction of the tracking system is comparable to the reflected signal level. The sidelobes of the transmission antenna in the direction of the tracking system should, therefore, be low enough so that their effect on the tracking system is less than the effect due to the bounce path [1,2].

2. Passive Detection and Tracking

Passive detection and tracking is an Electronic-Counter-Counter-Measure (ECCM) technique for use in a tracking system where the transmitting signal emanating from a target is used to develop the information necessary for the tracking system. This is also known as Angle Track on Transmission. Angle-tracking information using either conical-scan or monopulse-tracking concepts is readily extracted from a signal received from a transmission signal source [1,2].

3. Ground Reflection of EM Waves

Reflection of EM waves from earth's surface can be classified as:

- Specular reflection (from smooth surface),
- Diffuse reflection (from rough surface), or
- Combined reflection.

The condition for smooth surface is given by [3]:

$$\bar{h} < \lambda / (8 \sin \alpha)$$

where:

$\bar{h}$ = *the surface mean height.*
α = *grazing angle.*
λ = *wavelength*

For specular reflection, the reflection coefficient for horizontally, and vertically polarized EM waves from smooth surface can be expressed as [4,5]:

$$R_h = [\sin \alpha - (\varepsilon^* - \cos^2 \alpha)^{1/2}] / [\sin \alpha + (\varepsilon^* - \cos^2 \alpha)^{1/2}] \quad \dots\dots (1)$$

$$R_v = [\,\varepsilon^* \sin\alpha - (\varepsilon^* - \cos^2\alpha)^{1/2}\,] \,/\, [\,\varepsilon^* \sin\alpha + (\varepsilon^* - \cos^2\alpha)^{1/2}\,] \quad \text{.......................} (2)$$

$\varepsilon^* = \varepsilon / \varepsilon_o = \varepsilon' - j\,\varepsilon''$

where:

ε^*: is the relative complex permittivity of the reflecting surface.

Brewster angle (angle at which the reflection has minimum value at vertical polarization) occurs when [5]:

$\varepsilon^* \sin\alpha = (\varepsilon^* - \cos^2\alpha)^{1/2}$, i.e. when $\tan\Phi = (\varepsilon^*)^{1/2}$, where $\Phi = 90 - \alpha$

where:

Φ: is the angle of incidence (between the incident ray and the normal to the reflecting surface).

Equations (1) and (2) show that the reflection coefficient very high at small grazing angle, so that for the purpose of ground bounce deception the angle must be less than 25º.

$\therefore \alpha < 25^o$

Large number of samples was selected from different Iraqi soils from an area extended from North of Baghdad to Basrah [6]. These samples were first classified geologically to the standard geological classes according to each sample contents, and then the complex permittivity was measured at 10GHz. The measurements of the relative complex permittivity ε^* show that the real part ε' varies from 2.142 to 2.62 and the imaginary part varies from 0.119 to 0.565 for the 28 measured samples. The reflection of EM wave has been investigated experimentally for this area at 10GHz frequency. The results of these experiments show that the reflection coefficient for horizontal polarization varies from 1 (at $\alpha = 0$) to 0.5 (at $\alpha = 25^o$), and for vertical polarization varies between 1 (at $\alpha = 0$) to 0.12 (at $\alpha = 25^o$).

4. Deception Coverage

The deception coverage area depends on the following parameters [1,2,7]:

- Transmitter height.
- Transmitter antenna beam width.
- Grazing angle.

From **Fig.(1)**, these Parameters are related by the following equations:

$AB = H_r / \tan(\alpha + \theta/2)$

$AC = H_r / \tan\alpha$

$AD = H_r / \tan(\alpha - \theta/2)$

where:

H_r = Transmitter height.

α = Grazing angle.

θ = Transmitter antenna beam-width.

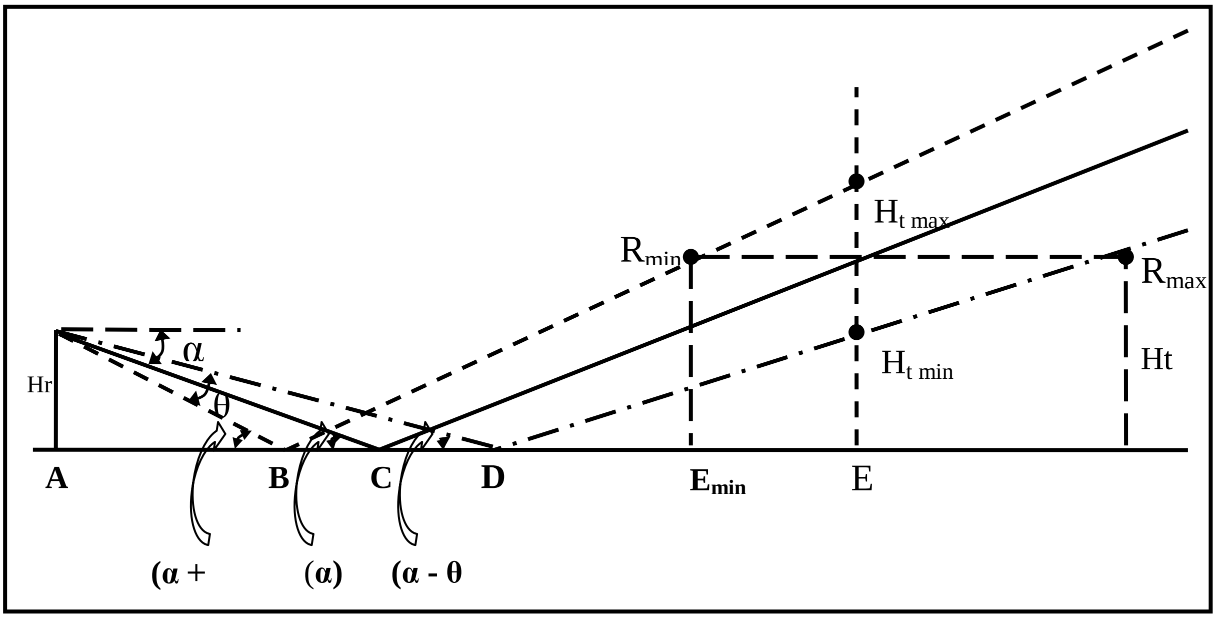

Figure (1) System geometry

4-1 Maximum and Minimum Height of the Deception Coverage

At certain distance AE, the maximum height, $H_{t\ max}$, of deception coverage can be calculated as follows:

$$H_{t\ max} = BE \tan(\alpha + \theta/2) = (AE - AB)\tan(\alpha + \theta/2)$$
$$= [AE - H_r / \tan(\alpha + \theta/2)] \tan(\alpha + \theta/2)$$

$$\therefore\ \mathbf{H_{t\ max} = AE \tan(\alpha + \theta/2) - H_r} \quad \text{.......... (3)}$$

and the minimum height, $H_{t\ min}$, is given by:

$$H_{t\ min} = DE \tan(\alpha - \theta/2) = (AE - AD)\tan(\alpha - \theta/2)$$
$$= [AE - H_r / \tan(\alpha - \theta/2)] \tan(\alpha - \theta/2)$$

$$\therefore\ \mathbf{H_{t\ min} = AE \tan(\alpha - \theta/2) - H_r} \quad \text{.......... (4)}$$

4-2 Maximum and Minimum range within the Deception Coverage

At certain height H_t, the maximum distance, R_{max}, of the deception coverage can be calculated as follows:

$$R_{max} = AD + DE_{max} = H_r / \tan(\alpha - \theta/2) + H_t / \tan(\alpha - \theta/2)$$

$$\therefore\ \mathbf{R_{max} = (H_r + H_t)/\tan(\alpha - \theta/2)} \quad \text{.......... (5)}$$

and the minimum distance, R_{min}, is given by:

$$R_{min} = AB + BE_{min} = Hr / \tan(\alpha + \theta/2) + Ht / \tan(\alpha + \theta/2)$$

$$\therefore\ \mathbf{R_{min} = (Hr + Ht) / \tan(\alpha + \theta/2)} \quad \text{.......... (6)}$$

4-3 Effective Flying Time within the Deception Coverage

The effective flying time of the tracking system within the deception coverage can be calculated as follows:

$T_e = (R_{max} - R_{min}) / V$

$= [(H_r + H_t)/\tan(\alpha - \theta/2) - (H_r + H_t)/\tan(\alpha + \theta/2)] / V$

$$\therefore \mathbf{Te = (H_r + H_t)\,[1/\tan(\alpha - \theta/2) - 1/\tan(\alpha + \theta/2)] / V} \quad \text{.............................. (7)}$$

where:

V: is the velocity of the tracking system, m/s

4-4 Effective Height

The height of the deception coverage is not constant and changes with the distance from the transmitter position, and the effective height, H_e, can be calculated as follows:

$H_e = H_{t\ max} - H_{t\ min}$

$$\therefore \mathbf{H_e = AE\,[\tan(\alpha + \theta/2) - \tan(\alpha - \theta/2)]} \quad \text{.. (8)}$$

4-5 Dead-Zone Height

At distances greater than AD, there is a dead zone whose height is changed with distance and can be calculated as follows:

$$\mathbf{H_d = H_{t\ min} = AE\,\tan(\alpha - \theta/2) - H_r} \quad \text{... (9)}$$

5. System Design and Simulation

The idea of ground bounce deception can be applied to any self-screening (protecting) ECM system. In this paper the design and simulation was done on certain ECM protection system, which has the following specifications:

- Frequency range = X- band.
- Transmitting power = 90 Watts.
- Azimuth beam width = $\beta = 120^o$.
- Elevation beam width = $\theta = 24^o$.

5-1 System Parameters Optimization

The determination of grazing angle (α) and transmitter height (H_r) depends on:

- Effective height, H_e, of deception coverage.
- Flying time, T_e, within the deception coverage.
- Dead-Zone height, H_d, and its effect on low flying targets.

These parameters can be optimized by using the above equations, for the proposed system ($\theta = 24^o$), as follows:

5-1-1 Grazing Angle Determination

Assuming that the transmitter flying at a height of 200 meter and the tracking system velocity 960 m/s, the parameters T_e , H_e and H_d can be calculated using equations (7), (8) and (9) for different values of α, (10º, 15º, 20º, 30º, 50º). The results of these calculations were illustrated in the **Table (1)**.

Table (1) T_e, H_e and H_d for different values of grazing angle

α	T_e (sec) (Ht = 3Km)	H_e (Km) (AE = 30Km)	H_d (Km) (AE = 30Km)
10º	87.2	11.073	0.848
15º	57.056	13.713	1.372
20º	18.38	14.529	4.016
30º	6.55	17.252	9.548
50º	2.49	32.982	23.238

Table (1) indicates that lower grazing angle gives good results for the flying time (T_e) and smaller dead-zone height (H_d), but at the same time gives lower effective height (H_e). This lead to the conclusion that a value of 15º can be considered as a compromising solution for the selection of grazing angle which is also agree with constrain that implies by minimum reflection that occurs at Brewster angle for vertical polarization which occurs at angles higher than this value.

5-1-2 Transmitter Height Determination

For grazing angle α = 15º and tracking system velocity 960 m/s, the parameters T_e, H_e, and H_d can be calculated by using equations (7), (8) and (9) for different transmitter height H_r, (50m, 100m, 200,300m, 500, and 1000m). The results of these calculations were illustrated in **Table (2)**.

Table (2) T_e, H_e and H_d for different values of transmitter height

H_r (m)	T_e (sec) (H_t = 3Km)	H_e (Km) (AE = 30Km)	H_d (Km) (AE = 30Km)
50	54.38	13.713	1.522
100	55.273	13.713	1.472
200	57.056	13.713	1.372
300	58.839	13.713	1.272
500	62.405	13.713	1.072
1000	71.32	13.713	0.572

Table (2) indicates that higher transmitter height gives good results for flying time, dead-zone height, and effective height of the deception coverage. But higher transmitter height increases the ground illuminating area (BD), and the tracking system flying over this area will receive a direct and ground reflected waves. The tracking system requires certain time to correct its direction toward the transmitter; this time can be achieved for large illuminating area only. So that a value of 200m for the transmitter height can be considered as a compromising solution for the selection of transmitter height.

5-2 Proposed System Layout

The proposed system can be arranged to perform two functions or modes; normal mode and ground bounce mode. The selection between these two modes of operation can be achieved through a waveguide switch which permits the propagation of the transmitting energy either in the main path (original antenna) or in the auxiliary path (additional antenna) which is inclined by 15º toward the ground. The waveguide switch has to be controlled by the pilot through a control panel.

Figure (2) illustrates the block diagram of the proposed system.

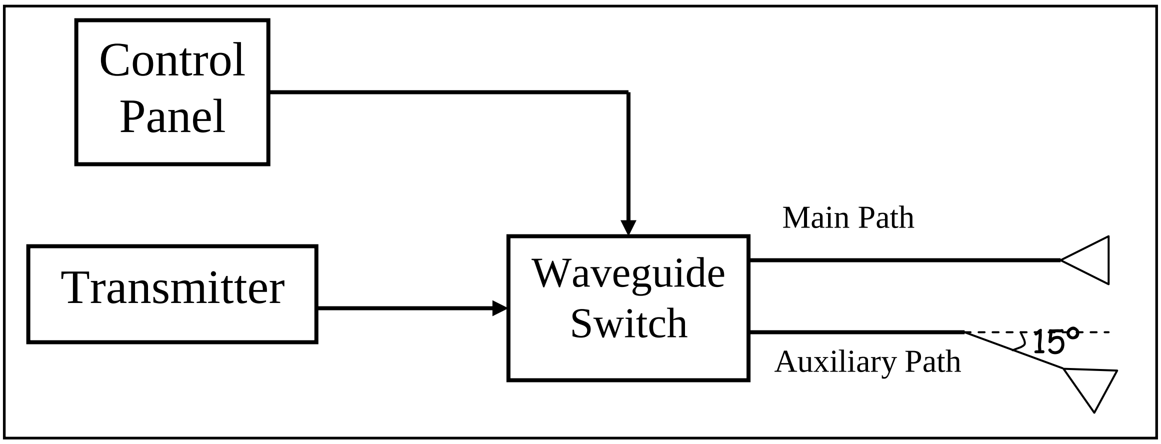

Figure (2) Proposed system layout

5-3 System Simulation and Discussion of Results

The proposed system can be simulated as three major segments, transmitter segment, ground segment, and tracking system segment. These segments can be analyzed as follows:

5-3-1 Transmitter Segment

According to the previous analysis the transmitter segment can be implemented as shown in **Fig.(2)**, where the auxiliary path inclined by 15^0 toward the ground. The transmitter should be flying at altitude of 200 meters to get the optimum performance of the deception process.

5-3-2 Ground Segment

The reflection coefficient is a function of the surface condition, frequency, polarization, and grazing angle.

Since the auxiliary path is inclined by an angle of 15^0, the ground reflection coefficient for this angle at X-band frequencies is approximately 0.65 for horizontal polarization and 0.32 for vertical polarization. This leads to additional losses of about 3.7dB for horizontal polarization and 9.8 dB for vertical polarization in comparison with the main path.

5-3-3 Tracking System Segment

Ground surface can be considered (after reflection) as a radiating source and becomes as a target for the tracking system instead of the protected transmission system.

6. Conclusion

This paper introduces a complete analysis for the ground bounce deception technique. This analysis shows that the quality of deception process was found to depend on many parameters. These parameters are the grazing angle, transmitter height, and ground reflection coefficient. The analysis and optimization of these parameters show that 15^0 grazing angle and 200 meters of transmitter height to get the optimum deception coverage. The reflection coefficient analysis shows that, for horizontal polarization, the ground reflection introduces losses of 3.7dB and these losses will be increased to 9.8 dB in the case of vertical polarization. These losses can be considered acceptable values for this mode of operation (auxiliary path) which represents a protected mode used in the urgent cases, while the main (original) path is used in the normal condition.

7. References

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