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Electronic Protection Measures In Modern Anti-Ship Missiles

William Vigder

Defence R&D Canada – Ottawa

Contract Report
DRDC Ottawa CR 2013-003
June 2013

Canada

Electronic Protection Measures In Modern Anti-Ship Missiles

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C. McMillan

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Abstract

Thirty radar-related electronic counter-countermeasure (ECCM) techniques have been identified and described. The identified techniques are those deemed appropriate to the current generation of operational anti-ship missiles (ASM). The techniques have been grouped according to ten defined ECCM categories. Each technique is described as to concept of operation, possible implementation and effectiveness. The specific naval electronic countermeasure (ECM) against which the ECCM technique has been devised is also briefly described (e.g. Barrage Noise, Range Gate Walk Off, Amplitude Modulation Jamming).

Résumé

Trente techniques de contre contre-mesure électroniques (CCME) radars ont été identifiées et décrites. Les techniques identifiées sont celles jugées appropriées pour la protection électronique contre la présente génération de missiles antinavires. Les techniques ont été regroupées en dix catégories de CCME. Chaque technique est décrite selon son concept d'opération, sa mise en œuvre probable et son efficacité. La contre-mesure électronique (CME) navale pour laquelle la technique CCME a été mise au point est aussi brièvement décrite (par exemple bruit de barrage, brouillage à vol de fenêtre et à modulation d'amplitude).

Executive summary

Electronic Protection Measures In Modern Anti-Ship Missiles

William Vigder; DRDC Ottawa CR 2013-003; Defence R&D Canada – Ottawa; June 2013.

DRDC Ottawa is currently undertaking a project entitled “Defence Against Future RF Threats”. An objective of the project is to target improvements to the defence of naval platforms against the terminal homing phase of anti-ship missiles (ASMs). To support this objective, DRDC Ottawa is studying advanced ECCM techniques in modern and future ASMs. This report, a compilation of known ECCM techniques taken from unclassified sources, has been produced as a part of this study.

Over 30 ECCM techniques, grouped into 10 categories, are discussed. The ECCMs are those deemed appropriate to the current generation of operational anti-ship missiles such as Harpoon (USA), Exocet (France), RBS 15M (Sweden), CSS-N-4 (China) and SS-N-22 (Russia). Each ECCM is described according to its concept of operation and possible implementation. As well, some preliminary assessment has been made of its effectiveness against the specific naval ECM for which it was designed (e.g. Barrage Noise, Range Gate Walk Off, AM Jamming). A brief description of each ECM is also included in the report.

Although the ECCM descriptions were extracted from what are considered reliable references, the source material is unclassified and there is very little information in the unclassified literature linking specific ECCMs to specific existing ASM systems. It was therefore not possible to verify that each listed ECCM is actually present in at least one modern operational ASM. The following ECCMs are considered to be the most important in terms of usefulness and effectiveness and are therefore deemed more likely to have been designed into existing missile systems:

- Frequency Agility
- Jittered PRF
- Linear FM Pulse Compression
- Leading Edge Track
- Home-On-Jam

Sommaire

Electronic Protection Measures In Modern Anti-Ship Missiles

William Vigder ; DRDC Ottawa CR 2013-003 ; R & D pour la défense Canada – Ottawa; juin 2013.

RDDC Ottawa mène actuellement un projet intitulé “La défense contre les menaces futures RF”. Un des objectifs du projet est de cibler les améliorations à la défense des plateformes navales contre la phase terminale de ralliement des missiles antinavires. Pour soutenir cet objectif, RDDC Ottawa, étudie les techniques de contre contre-mesure électroniques (CCME) de pointe modernes et futures. Ce rapport, une compilation des techniques CCME connues prises à partir de sources non classifiées, a été produit dans le cadre de cette étude.

Plus de trente techniques CCME regroupés en dix catégories sont discutées. Les techniques identifiées sont celles jugées appropriées pour la protection électronique contre la présente génération de missiles antinavires tels que Harpoon (USA), Exocet (France), RBS 15M (Suède), CSS-N-4 (Chine) et SS-N-22 (Russie). Chaque technique est décrite selon son concept d’opération, sa mise en œuvre probable. De plus, une évaluation préliminaire de leurs efficacité contre la contre-mesure électronique (CME) pour laquelle la technique fut mise au point est aussi incluse. Une brève description de chaque CME (par exemple bruit de barrage, brouillage à vol de fenêtre et à modulation d'amplitude) est également incluse dans le rapport.

Bien que la description des CCME ait été extraite de références fiables, le matériel provient de source non classifié. Très peu d'informations dans la littérature et les bases de données ouvertes au public confirment l’existence des CCME dans les missiles antinavires présentement en service. Il n'était donc pas possible de vérifier que chaque CCME décrit est effectivement présent dans au moins un système opérationnel. Les CCME suivants sont considérés les plus utiles et les plus efficaces, et sont les plus probable d’avoir été intégrés dans les systèmes de missiles existants:

- Agilité en fréquence
- Variation de la fréquence de répétition des impulsions (FRI)
- Compression d’impulsions par modulation de fréquence linéaire
- Poursuite de pointe
- Poursuite-brouilleur

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Introduction

Defence Research & Development Canada – Ottawa (DRDC Ottawa) is currently undertaking a project entitled “Defence Against Future RF Threats”. One of the objectives of the project is to target improvements to the defence of naval platforms against the terminal homing phase of anti-ship missiles (ASMs). To support this objective, DRDC Ottawa is studying advanced electronic counter-countermeasure (ECCM) techniques in modern and future ASMs. This report, a compilation of known ECCM techniques taken from unclassified sources, has been produced as a part of this study.

The ECCMs in this report are assessed to be those potentially applicable to existing modern ASMs. The reference material used to produce this report includes:

- Unclassified TTI reports
- Unclassified periodicals and publications
- Unclassified EW-related textbooks
- Unclassified web-site information

There are over 30 ECCMs, grouped into 10 categories, listed in this report. Each ECCM is described according to its concept of operation as well as its effectiveness against the specific naval electronic countermeasure (ECM) for which it was designed. The report includes a description of how the ECCM is implemented in as much detail as unclassified sources allow. There is also a 'Comments' section for each ECCM that assesses the strengths and weaknesses of the technique.

Although the ECCM descriptions were extracted from what are considered reliable references, the source material is unclassified so there is very little information linking specific ECCMs to specific existing ASM systems. It was therefore not possible to verify that each ECCM is actually present in at least one modern operational ASM. The ECCMs considered to be the most important are more likely to have been implemented in existing missile systems. These ASM-related ECCMs are [Ref 1 p142]:

- Frequency Agility
- Jittered PRF
- Linear FM Pulse Compression
- Leading Edge Track
- Home-On-Jam

In some cases an assessment of whether a particular ECCM might actually exist in an operational ASM was made based on fairly broad inferences. For example, for various chaff ECCMs, the following quotes were used to provide some guidance:

[Ref 9 p125]: "A possible ECCM is to distinguish chaff from a genuine target by its broader frequency spectrum..."

[Ref 10 p427]: "EP against chaff generally exploits the difference between the chaff return and that of an actual target. Some of the characteristics of chaff that are different than those of a target are:... different fluctuation characteristics... different polarization characteristics..."

[Ref 12 p47]: "With most modern radar seekers incorporating advanced logic to discriminate against chaff, there is some question whether chaff may have had its day."

For active jamming, the following quote was used (along with other references) to infer the existence of the Guard-Channel Detection technique:

[Ref 9 p124]: "An appropriate ECCM would be examination of the angle error signal in two adjacent narrow band filters after demodulation... in order to reject any signal which is off-axis."

Table 1 below lists some of the modern anti-ship missiles investigated for this report, their country of origin, and any identified ECCMs associated with their seekers. However, the seekers in these missiles are constantly being developed and it is difficult to determine with any certainty whether an identified ECCM is in production, in pre-production or perhaps just the result of some educated speculation.

Missile	Country of Origin	Seeker	Partial List of ECCMs (from unclassified sources)
Harpoon Block 1C	USA	?	Frequency Agility [25]
Harpoon Block 2	USA	?	Doppler Processing [25]
Exocet MM40 Block 2	France	Thales Aerospace Division ADAC Mk1	Frequency Agility [8] Leading Edge Track [8] Home-On-Jam [8]
Exocet MM40 Block 3	France	Thales Aerospace Division ADAC Mk2	Doppler Processing [25]
RBS 15M/F/K	Sweden	Saab 9GR-400	Frequency Agility [25] Jittered PRF [25] Home-On-Jam [25]
RBS 15 Mk3	Sweden	?	FM-CW [22 25]
SS-N-22	Russia	?	Supersonic [27] Passive ARM [27]
SS-N-25 'Switchblade'	Russia	Radar MMS ARGS-35E	Passive ARM [27] Coherent Processing [26 27]
BrahMos / SS-N-26 'Sapless'	India / Russia	?	Supersonic [27] Passive ARM [27] Frequency Agility [27] Pulse Compression (DSSS) [25 27]
SS-N-27 'Sizzler'	Russia	Radar MMS ARGS-54E	Zigzag Flight Path [27]
CSS-N-4 'Sardine'	China		?
CSS-N-8 'Saccade'	China		?
Hae Seong ASM/SSM-700K	South Korea		?
Marte Mk 2/S	Italy	Galileo Avionica SM-1S	?
Otomat Mk2 Mod 4	France / Italy	Galileo Avionica ST-2	Frequency Diversity [26]

Table 1. Some Modern Anti-Ship Missiles

In assessing whether or not to include an identified ECCM in this report, the following assumptions about the capabilities of modern ASMs have been made:

- The missile uses an active seeker with no Doppler processing. The references to Doppler processing found in the unclassified literature seem to indicate that this is a new technology for cruise missiles, more related to land attack and somewhat less certain for naval engagements.
- The antenna polarization is fixed.
- Pulse compression techniques using pulse coding are considered to be an emerging capability and were not included in this report.
- A seeker with a passive ARM mode is also capable of Home-On-Jam.

ECCM Categories

The ECCM techniques in this report are grouped according to categories, each of which is described in this section. The grouping by category is intended to provide organization to the techniques as well as insight into their purpose and operation [1]. The ECCM categories chosen for this report are taken from the classification system proposed by Li Neng-Jing and Zhang Yi-Ting [16], which is an enhancement of the classification system proposed by Brick and Galejs [21].

Spatial Filtering

This ECCM category associates techniques that distinguish the true signal (ship echo) from EA signals through spatial selectivity. Current ASMs have two available spatial filtering criteria:

1. Angle
The ASM seeker rejects EA signals based on their AOA (Angle-Of-Arrival). ECCM effectiveness depends on the precision with which the seeker can resolve angles with its antenna. A narrow beam and very low sidelobes mean good resolution in seeker angular measurement, enhancing the seeker's ability to reject EA signals based on AOA.

2. Range
The ASM seeker rejects EA signals based on their range position. With this category of technique, ECCM effectiveness depends on how well the seeker can resolve targets in range. Range resolution is dependent on transmitter pulse width: the narrower the pulse, the better the range resolution.

Frequency Filtering

This ECCM category associates techniques that are able to reject EA signals through frequency selectivity. Rejection by frequency may occur either at the RF front-end, in the seeker's IF channel, or during processing of the baseband video signal.

Waveform Filtering

This ECCM category associates techniques that are able to reject EA signals through waveform selectivity. With current ASMs, the discrimination criteria are most likely either the pulse width or the PRI.

Cancellation

This ECCM category associates techniques that are able to reject EA signals by first detecting and characterizing them in an auxiliary seeker channel and then using this information to eliminate them from the main receiver channel. Elimination is accomplished via a cancellation process, whereby the jamming signal (as detected in the auxiliary channel) is eliminated from the combined target + jamming signal (in the main channel).

Blanking

This ECCM category associates techniques that are able to reject EA signals by blanking them at critical times. This means the seeker briefly turns off during the time when the EA signal is likely to be most effective. Blanking techniques require that the seeker somehow be able to detect the presence of the EA signal. During seeker scan pattern or during a detected EA scan pattern, when the seeker assesses that there is about to be an overlap in angle, range and frequency between the EA signal and the seeker's search or track point, the seeker temporarily shuts off until the overlap condition has passed.

Dilution

This ECCM category associates techniques that are able to diminish the effects of jamming signals by forcing the jammer to spread its power across a wider frequency range or over a longer time duration than otherwise would be required in the absence of the ECCM technique. The current generation of ASMs typically use frequency agility and PRI agility for this category of ECCM.

Saturation Prevention

This ECCM category associates techniques that are able to mitigate the effects of very high powered jamming signals through saturation prevention. By preventing saturation, the seeker keeps its receiver channel within its normal operating region while being jammed. Once the jamming signal ceases, the seeker is fully operational without having to wait through a saturation recovery time period.

Jammer Direction Finding

This ECCM category associates techniques that are able to measure the angle-of-arrival of jamming signals. This information is then used by the seeker to home on the source of the jamming signal, under the assumption that the source is a self-protection ECM system on-board the ship. With respect to ASM, this would be the Home-On-Jam category of ECCM techniques.

Countermeasures to False Targets

This ECCM category associates techniques that are specifically designed to counter deceptive false targets generated by chaff clouds, decoys and active jamming systems. Techniques in this category reject false targets by making use of some differentiating characteristic of the true target (ship echo), such as scintillation or glint.

Low Probability of Intercept

This ECCM category associates techniques for designing ASM seekers that make the seeker’s transmit signal difficult to detect by electronic warfare support systems. This typically involves stretching the pulse out to keep the peak signal power low, spreading the power across a wide frequency spectrum, and using an intra-pulse wave form which is difficult to identify, such as spread spectrum or pseudo-noise [15].

The following table shows the 32 ECCM techniques discussed in the main body of this report, grouped according to the above categories. The table's first column lists the 10 categories. The second column identifies the ECCM technique associated with each category. The third column indicates if the technique is an effective countermeasure to decoys and, if so, for which type or types of decoys the ECCM is effective. The fourth column indicates if the technique is an effective countermeasure to active jamming and, if so, for which jamming techniques the ECCM is effective.

References

Reference 1:
Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), Collins, 1987

Reference 15:
Detection and Jamming of LPI radars, W. K. McRitchie and S. E. McDonald, MC Countermeasures Technical Report #99-03-01, 31 March 1999

Reference 16:
A Survey of Radar ECM and ECCM, Li Neng-Jing and Zhang Yi-Ting, IEEE Transactions on Aerospace and Electronic Systems, Vol. 31, No. 3, pp1110-1120, July 1995

Reference 21:
Radar Interference and its Reduction, D.B.Brick and J.Galejs, The Sylvania Technologist, Vol. 11, No. 3, pp96-108, July 1958

Category	ECCM Technique	Effective Against the Following Decoys Types	Effective Against the Following Jamming Techniques
Spatial Filtering	Stiff Neck	Chaff; Active Decoy; Passive Decoy	
	Height Discrimination	Chaff; Active Decoy; Passive Decoy	
Frequency Filtering	Notched AGC		Countdown
	Scintillation ECCM	Chaff	
	Glint ECCM	Chaff	
	RF Preselection		Barrage Noise; Image Jamming; Delta Jamming
Waveform Filtering	Fast Time Constant (FTC)	Chaff	Barrage Noise; Cover Pulse; Swept Spot Noise
	Instantaneous AGC	Chaff	Barrage Noise; Cover Pulse; Swept Spot Noise
	Feed Forward AGC	Chaff	Barrage Noise; Cover Pulse; Swept Spot Noise
	Multi-Gated AGC	Chaff	Barrage Noise; Cover Pulse
	AM ECCM: Clear Track with Automatic Video Limiting		AM Jamming
	Pulse-To-Pulse Coincident Video Correlator		False Targets
	Pulse-Width Discrimination	Chaff	False Targets
Cancellation	Feed Forward AGC	Chaff	False Targets; Cover Pulse; Swept Spot Noise
	Guard-Channel Detection		Barrage Noise; Cover Pulse; Swept Spot Noise
Blanking	AM ECCM: Clear Track with Jamming Blanked		AM Jamming
	Angle Gating	Chaff; Active Decoy; Passive Decoy	Blinking; SOJ
	Glint ECCM	Chaff	
	Guard-Channel Detection		Barrage Noise; Cover Pulse; Swept Spot Noise
Dilution	Frequency Agility		Barrage Noise; Cover Pulse; Swept Spot Noise; False Targets
	Jittered PRF		False Targets
	Frequency Diversity		Barrage Noise; Cover Pulse; Swept Spot Noise; False Targets
	Instantaneous AGC	Chaff	Barrage Noise; Cover Pulse; Swept Spot Noise
Saturation Prevention	Linear-Logarithmic Receiver		Countdown
Jammer Direction Finding (Home-On-Jam)	AM ECCM: Alternate Home-On-Jam and Clear Track		AM Jamming
	AM ECCM: Home-On-Jam		AM Jamming
	Passive Angle Track, End-of-PRI Range Bin		Barrage Noise
	Second-Harmonic Tracking		Barrage Noise → SPJ + SOJ
	Cover Pulse Channel		Cover Pulse
	Guard-Channel Detection		Barrage Noise; Cover Pulse; Swept Spot Noise
Countermeasures to False Targets	Guard Gates	Chaff; Active Decoy; Passive Decoy	Barrage Noise; False Targets
	Bulk Filtering	Chaff; Active Decoy; Passive Decoy	
	Scintillation ECCM	Chaff	
	Glint ECCM	Chaff	
	Auxiliary Tracking Gates	Chaff; Active Decoy; Passive Decoy	Barrage Noise; Cover Pulse; False Targets
	Maximum Acceleration		False Targets
	Leading-Edge Track		False Targets
	Trailing Edge Track		False Targets
	False Pulse Transmission		False Targets
	Previous Pulse AGC		False Targets
Low Probability of Intercept	Linear FM Pulse Compression (Chirp)		
	FM-CW		

Table 2. Summary of ECCM Techniques Applicable to ASM

ECCM Descriptions

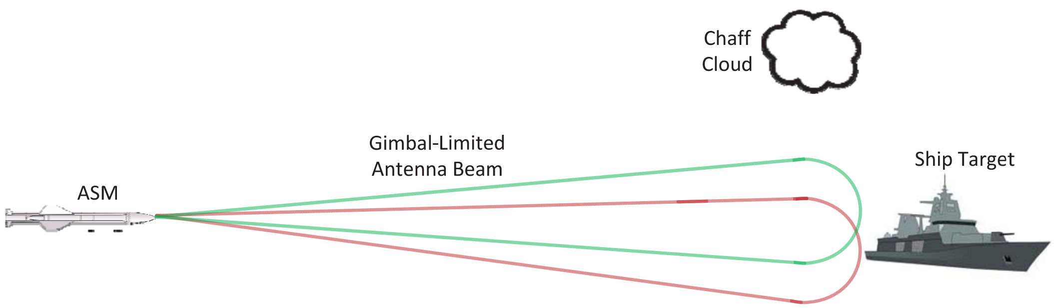
Stiff Neck

Concept
Stiff Neck is based on the premise that the ship is always situated at sea level whereas chaff clouds and other airborne decoys are almost always at some significant altitude above sea level. The technique operates by constraining the seeker through gimbal limiting to always 'look' at or below the horizon. This constraint causes the radar returns of targets at altitude to eventually pass out of the seeker antenna's main lobe as the missile approaches them.

ECCM Category
Spatial Filtering

ECM
This ECCM technique is useful against chaff clouds and other airborne decoys.

Implementation



When Stiff Neck ECCM is engaged, the elevation pointing direction of the seeker antenna is restricted to angles between zero (in-line with the missile body axis) and some negative angle (typically pointing slightly below the horizon while sea-skimming). If the missile is not sea-skimming and is capable of maneuvering in the vertical plane then when Stiff Neck ECCM is engaged there is the additional constraint that the missile may only maneuver downward and may not rise in altitude. If the missile is inadvertently tracking an airborne target, then as the missile approaches the target the Stiff Neck elevation gimbal-limiting will cause the target to eventually fall outside of the seeker antenna main lobe, resulting in a break-lock or lock-transfer to a lower altitude target.

Comment
This ECCM technique has been implemented and tested in TTI's ASM(AR) simulator. The effectiveness of the technique depends to a great extent on the altitude of the decoys and the elevation beamwidth of the seeker.

References

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

12. Naval EW: Making Soft-Kill Smarter, Richard Scott, JED, Vol. 34, No.11, pp 47, Nov 2011

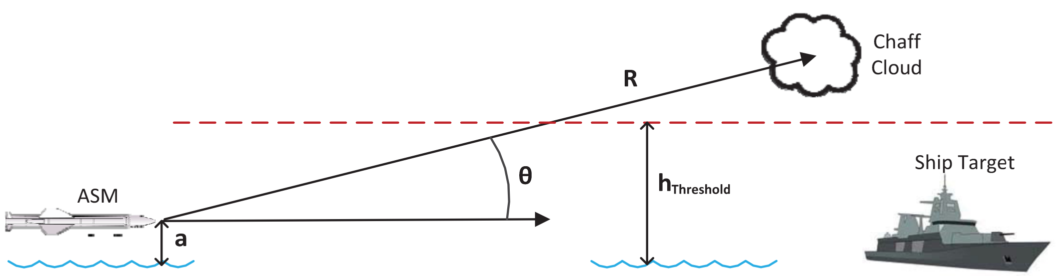
Height Discrimination

Concept
As with the Stiff Neck technique, this ECCM is based on the premise that the ship is always situated at sea level whereas chaff clouds and other airborne decoys are almost always at some significant altitude above sea level. Any target measured to be higher than a threshold altitude is assumed to be a chaff cloud or some other type of airborne decoy, not a ship floating on the sea surface. The seeker therefore forces a break-lock if it detects it is tracking such a target.

ECCM Category
Spatial Filtering

ECM
This ECCM technique is useful against chaff clouds and other airborne decoys.

Implementation



The seeker monitors the altitude above sea level of the target being tracked. Target altitude is computed based on the missile antenna pointing direction, the error signal induced in the discriminator of the seeker's elevation tracking loop, the seeker's range gate position while tracking the target, and the cruise height of the missile. If the target is measured as being above a threshold altitude, a break-lock is forced and the seeker transitions to a search mode. The search pattern is initiated in a direction other than that of the rejected target and detection may be temporarily blanked as the seeker scans over the former tracked location.

Let the missile cruise altitude be $\mathbf{a}$ and the height discrimination threshold altitude be $\mathbf{h_{Threshold}}$. If the missile starts tracking the chaff cloud at range $\mathbf{R}$ and elevation angle $\boldsymbol{\theta}$, and if $\mathbf{a} + \mathbf{R} \cdot \sin(\boldsymbol{\theta}) > \mathbf{h_{Threshold}}$, then the chaff cloud will be rejected as a legitimate target.

Comment
This ECCM technique has been implemented and tested in TTI's ASM(AR) simulator. Although similar in concept to Stiff Neck, this technique seems to be somewhat more effective than Stiff Neck. A calculated height measurement is more precise, allowing more control in its logic and implementation. Break-locks can occur sooner, giving the missile more time to acquire and lock-on to a new target and adjust course accordingly.

References

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

12. Naval EW: Making Soft-Kill Smarter, Richard Scott, JED, Vol. 34, No.11, pp 47, Nov 2011

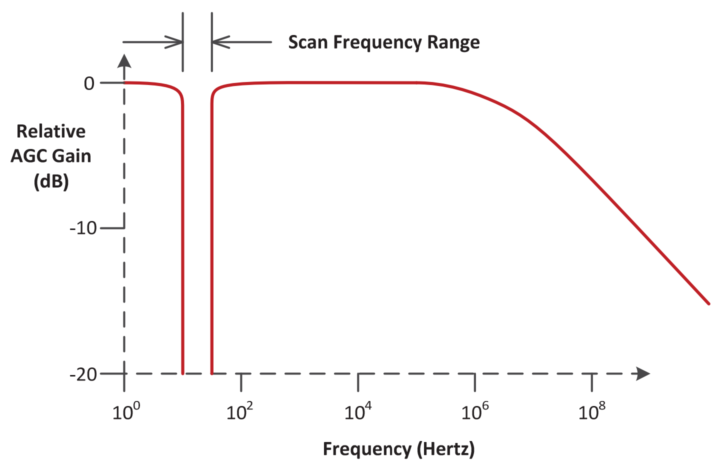
Notched AGC

Concept
For accurate target tracking in LORO, CONSCAN and COSRO seekers, a strong scan signal must be detected and extracted from the target echo. The AGC circuit in the receiver channel must therefore be non-responsive to the scan frequency to prevent its attenuation. Either a low-pass filter with a cut-off frequency below the scan frequency or a frequency notch at the scan frequency can be used in the AGC feedback loop for this purpose. However, the notch implementation has the advantage that it minimizes the bandwidth available to an ECM signal that is trying to 'capture' the AGC and deceptively manipulate it.

ECCM Category
Frequency Filtering

ECM
This ECCM technique is useful against countdown jamming, which uses high-power jamming signals outside of the seeker's AGC passband to capture the AGC and suppress the scan frequency signal, thus preventing the seeker from accurately angle tracking a target.

Implementation



In the seeker's baseband channel, the incoming signal is sampled and fed to a gain control amplifier that dynamically controls channel gain. A notch filter with the seeker's scan frequency notched out is placed at the input to the gain control amplifier. The notch blocks the scan modulation from entering the AGC loop, preventing the AGC from attenuating the scan signal.

Comment
This ECCM technique is only relevant for missile seekers that use a scanning technique for angle tracking (CONSCAN, LORO, COSRO) and that are therefore susceptible to countdown jamming. The notched AGC makes it more difficult, but not impossible, for countdown jamming to be effective.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p375, EW Engineering Inc., 1982

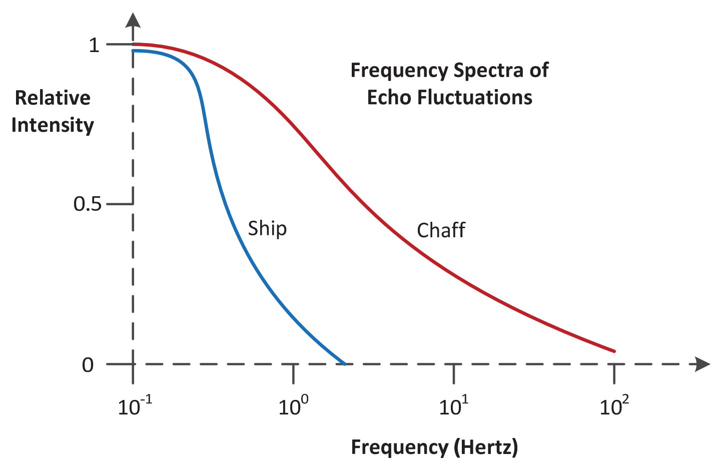
Scintillation ECCM

Concept
A ship's radar echo is typically composed of a relatively small number of scatterers in fixed positions with respect to one another. Usually one or two of the scatterers dominate the others in terms of RCS. A chaff cloud on the other hand consists of many small scatterers of roughly equal RCS constantly moving relative to one another. As a result, the correlation time for the scintillation associated with a chaff cloud echo will likely be much shorter than that of a ship echo. The fluctuations in the radar signature of the chaff cloud should therefore be much more rapid and contain higher frequency components than the fluctuations in a ship's signature. Chaff rejection may therefore be implemented by filtering and thresholding in the frequency domain. [Ref. 5: pg 18-11]

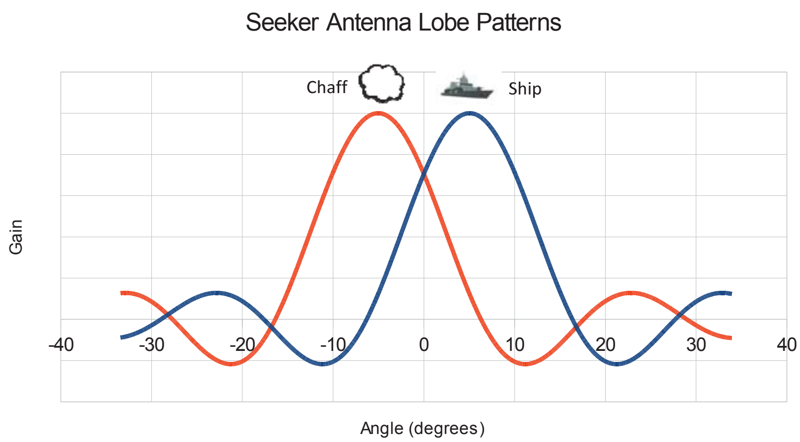
ECCM Category
Frequency Filtering
Countermeasures to False Targets

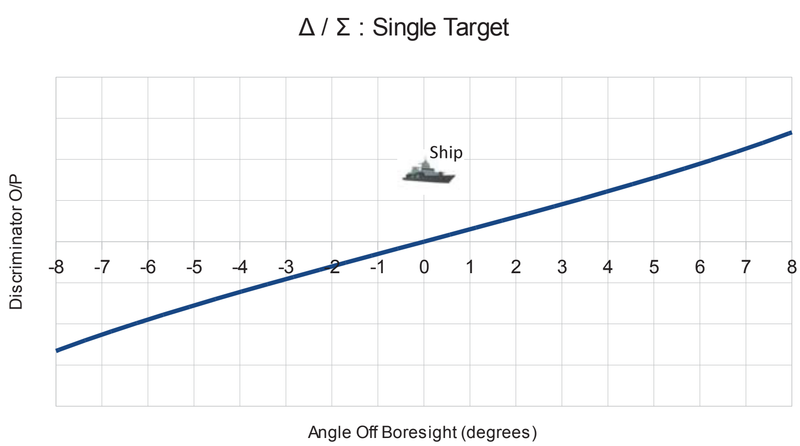
ECM
This ECCM technique is useful against chaff clouds.

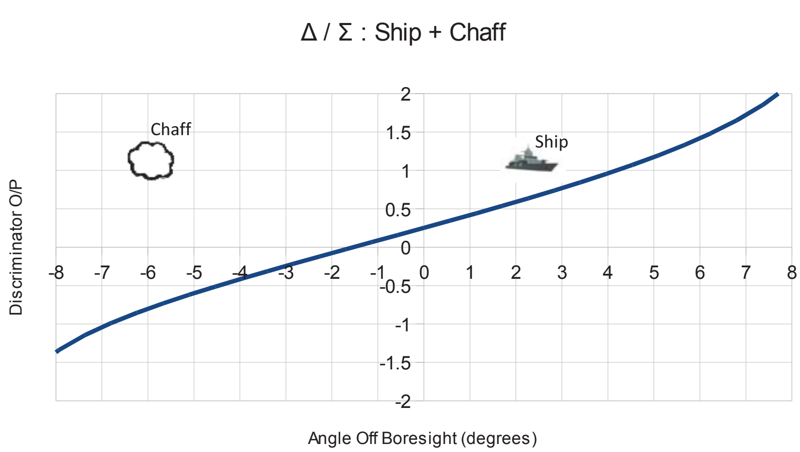
Implementation



A randomly scintillating target echo will have its power spread out across a finite frequency spectrum with a bandwidth from DC to approximately the inverse of the correlation time (Wiener–Khinchin theorem). Because the chaff cloud echo scintillates more rapidly than the ship echo, the chaff echo correlation time is shorter so it contains higher frequency components than the ship echo. A high-pass filter with a cut-off frequency below the inverse of the chaff echo correlation time but above that of the ship echo won't detect the ship signature but will detect the presence of the chaff signature.


Seeker Antenna Lobe Patterns
Chaff
Ship
Gain
-40
-30
-20
-10
0
10
20
30
40
Angle (degrees)


Δ / Σ : Single Target
Ship
Discriminator O/P
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
Angle Off Boresight (degrees)


Δ / Σ : Ship + Chaff
Chaff
Ship
Discriminator O/P
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
Angle Off Boresight (degrees)

In one possible ECCM implementation, high-pass filters are used to capture power above a reference cut-off frequency in each of the receive antenna's left and right lobe channels. The lobe powers are compared and their ratio used to increase the gain in whichever lobe channel recorded the higher measurement. The effect of this gain imbalance between lobes is to bias the seeker's angle discriminator curve and cause the tracking circuit to point the antenna boresight away from a rapidly fluctuating target and toward a slowly fluctuating target. This effect will only be observed if there are two targets within the beam with different scintillation characteristics and if they are spatially separated. A similar high-pass filtering approach may be applied within the range discriminator to bias the range track point toward a slowly fluctuating target.

Comment

The ECCM technique as described above has been implemented and tested in TTI's ASM(AR) simulator. The technique is designed to work against seduction chaff and causes the seeker to reject the chaff cloud in favour of the ship even when the chaff cloud has a significant advantage in echo strength.

References

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

5. Electronic Countermeasures, ed. J.A. Boyd et al, pp18-11, Peninsula Publishing, 1978

9. Radar Homing Guidance for Tactical Missiles, D.A. James, pp91+125, Macmillan Education Ltd, 1986

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p427, Artech House, 1999

12. Naval EW: Making Soft-Kill Smarter, Richard Scott, JED, Vol. 34, No.11, pp47-48, Nov 2011

24. Electronic Countermeasures, ed. J.A. Boyd et al, pp18.10-18.12, Peninsula Publishing, 1978

Glint ECCM

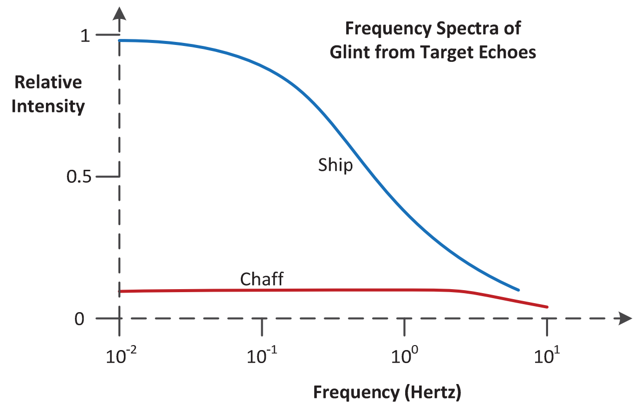
Concept
Complex targets consisting of a few widely-spaced scatterers tend to produce radar echoes with phase distortion at their wave fronts. When these distorted wave fronts impinge on the antenna of a missile seeker, they induce errors in the seeker's calculation of target angular position. If relative motion now exists between such a target and the missile, the magnitude of the phase distortion will be constantly changing, producing fluctuations in the seeker's estimate of the target angular position. This phenomenon of fluctuating target position due to constantly changing wave front distortion is called glint.

From the seeker's point of view, the glint signature generated by a chaff cloud will be noticeably different to that of a ship. There are many closely-spaced scatterers in a chaff cloud, all of which are constantly moving with respect to one another. The phase distortion produced by the chaff echo will likely be small due to averaging over all scatterers, the distortion pattern will be very indistinct and the pattern will be changing rapidly. On the other hand, the scatterers comprising the ship target are comparably few in number and remain in fixed relative positions. The interference pattern produced by the echoes from the ship's scatterers will likely be well-defined and will be changing more slowly. Because of these differences, glint for a chaff cloud is characterized with low-amplitude, high-frequency fluctuations and glint for a ship target is characterized with high-amplitude, low-frequency fluctuations. This basic difference in signature characteristics may be exploited by a glint ECCM technique in the seeker to reject chaff echoes.

ECCM Category
Frequency Filtering
Blanking
Countermeasures to False Targets

ECM
This ECCM technique is useful against chaff clouds.

Implementation
When Glint ECCM is engaged, the missile seeker only tracks targets whose glint characteristic correlates with that of a ship echo. Glint would typically be detected and characterized according to frequency and amplitude via the error signal in the discriminator circuit of the seeker's angle tracking servo. If glint is present then the error signal will fluctuate, causing the azimuth track point to wander. If the glint frequency falls within the seeker's servo bandwidth, a noticeable fluctuation in the seeker antenna's pointing direction will occur. The strength of this fluctuating signal is measured in a low frequency band above DC and compared to a reference level. If this power falls below the reference level (indicating extremely steady angular tracking) then the target echo is generating very little glint and is probably not coming from a ship target. This test for the presence of glint requires the seeker to be in track mode. If insufficient glint were detected, the seeker would transition to search mode and try to find and characterize a different target.



Comment

The ECCM technique as described above has been implemented and tested in TTI's ASM(AR) simulator. Because of the low frequencies associated with glint, the technique requires a relatively long time to make a determination about the target when compared to the duration of the engagement. The missile sometimes isn't able to react in time to find and home on to a new target if the seeker determines that the current target is a chaff cloud.

References

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

12. Naval EW: Making Soft-Kill Smarter, Richard Scott, JED, Vol. 34, No.11, pp47-48, Nov 2011

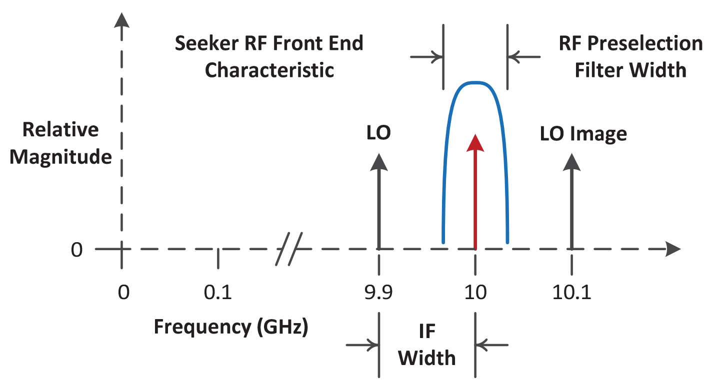
RF Preselection

Concept
This is an ECCM technique whereby narrowband filtering is applied at the seeker receiver front end, ahead of the first mixer. The purpose of RF preselection is to block image jamming and delta jamming, and to prevent wideband interference from entering the first mixer in the seeker where overloading effects might occur.

ECCM Category
Frequency Filtering

ECM
This ECCM technique is useful against image jamming, delta jamming, and high power barrage noise jamming.

Implementation



A narrow-band RF filter is placed at the front end of the seeker receiver. To prevent image jamming and delta jamming, the bandwidth of this filter needs to be smaller than the IF frequency in the seeker receiver. Ideally the filter should be as narrow as possible to minimize the amount of power received from wideband interference. If the seeker operates at a constant frequency, the center frequency of the filter is fixed at the transmitter RF. If the seeker operates in a frequency agile mode, then a tuning control device tunes the center frequency of the filter on a pulse-by-pulse basis so that it is always synchronized to the center frequency of the transmitter pulse.

Comment
RF preselection is probably quite effective against image jamming and delta jamming, ECM techniques intended to manipulate the seeker's phase detection circuits and disrupt angle tracking. However, image jamming and delta jamming are difficult to implement.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p164, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p425, EW Engineering Inc., 1982

Fast Time Constant (FTC)

Concept

The radar signature of a ship is typically composed of a number of discrete point scatterers with perhaps one of the scatterers being dominant. The ship echo in many engagement scenarios would therefore be similar to that of a point target with a resulting pulse width similar to the width of the seeker's transmitter pulse. Distributed targets on the other hand, as well as noise jammers or swept frequency jammers, would be expected to produce signals consisting of much wider pulses. An FTC circuit in the missile seeker processes radar returns in such a way as to reduce the power in long duration pulses. The FTC circuit passes only the leading portion of an incoming pulse and zeroes out the remainder of that pulse.

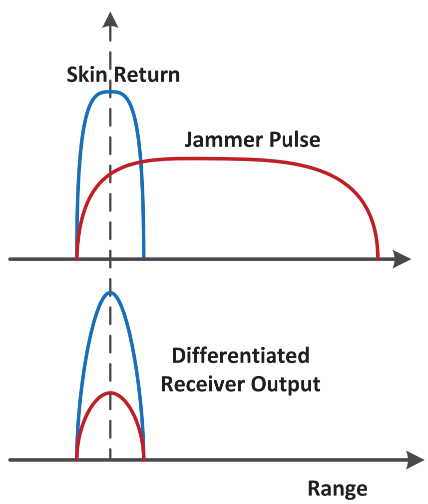
ECCM Category

Waveform Filtering

ECM

This ECCM technique is useful against distributed targets such as chaff clouds and clutter. It is also useful against jamming techniques that produce pulses in the seeker receiver that are much wider than the pulses being transmitted by the seeker. A CW noise signal will produce a wide pulse as it passes through the seeker's range gate. A slow CW frequency sweep will produce a wide pulse as it sweeps across the seeker's receive bandwidth.

Implementation



FTC is typically realized with a differentiator circuit or a wideband high-pass filter to extract and pass only the rising edge of pulses passing through the receiver.

Comment

FTC is similar in some ways to a matched filter. While a matched filter optimizes the signal-to-thermal noise ratio, the FTC filter attempts to optimize the signal-to-ECM ratio, assuming that the ECM signal has a long duration pulse width. FTC will only be effective if the peak power in the target signal is higher than the ECM peak power. FTC has the disadvantage that the receiver channel needs to be fairly wide band to pass the differentiated pulse edge, reducing S/N.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p165, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p234, EW Engineering Inc., 1982

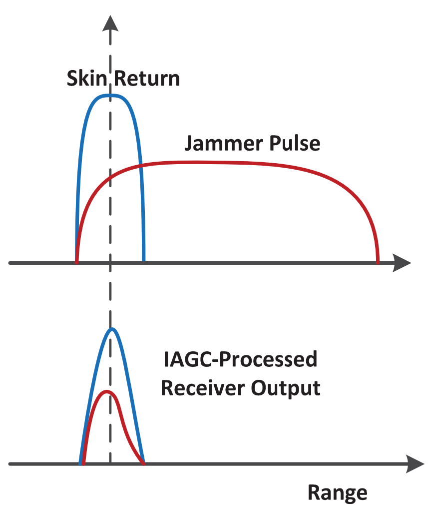
Instantaneous AGC

Concept
This is a method of obtaining a constant signal-voltage output in the seeker receiver over a range of incoming signal amplitudes, with a response time approximately equal to the seeker pulse width. The objective of this technique is similar to FTC, to discriminate against wide pulses.

ECCM Category
Waveform Filtering

ECM
This ECCM technique is useful against distributed targets such as chaff clouds and clutter. It is also useful against jamming techniques that produce pulses in the seeker receiver that are much wider than the pulses being transmitted by the seeker. A CW noise signal will produce a wide pulse as it passes through the seeker's range gate. A slow CW frequency sweep will produce a wide pulse as it sweeps across the seeker's receive bandwidth.

Implementation



Instantaneous AGC would be implemented in the IF and/or baseband channels of the seeker receiver. The time constant of the AGC is adjusted to match the expected pulse width of a point target echo. Incoming pulses wider than this will cause the AGC to reduce the gain in the receiver channel, suppressing the trailing portion of the pulse. In some implementations, IAGC will keep the IF amplifiers biased below their cut-off level, so that only the peak of the signal pulse is in the linear range of IF amplification.

Comment
Same comments as for FTC. For implementations where the IF amplifiers are biased below their cut-off level, there will be some pulse distortion and loss of S/N.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p164, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p309, EW Engineering Inc., 1982

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

18. Radar Anti-Jamming Techniques, M.V. Maksimov et al, pp105+168, Artech House, 1979

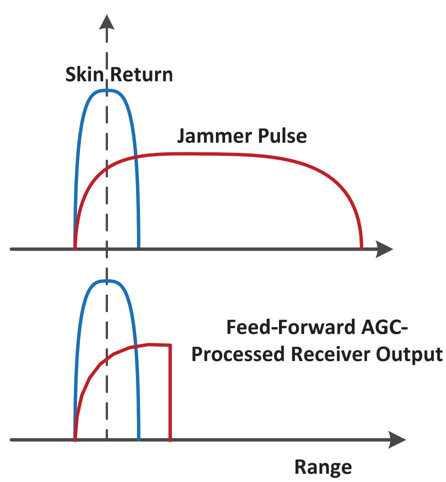
Feed-Forward AGC

Concept
The radar signature of a ship is typically composed of a number of discrete point scatterers with perhaps one of the scatterers being dominant. The ship echo in many engagement scenarios would therefore be similar to that of a point target with a resulting pulse width similar to the width of the seeker's transmitter pulse. Distributed targets on the other hand, as well as noise jammers or swept frequency jammers, would be expected to produce signals consisting of much wider pulses. A feed-forward AGC circuit in the missile seeker processes radar returns in such a way as to reduce the power in long duration pulses. The feed-forward AGC circuit passes only the leading portion of an incoming pulse and zeroes out the remainder of that pulse.

ECCM Category
Waveform Filtering
Cancellation

ECM
This ECCM technique is useful against distributed targets such as chaff clouds and clutter. It is also useful against jamming techniques that produce pulses in the seeker receiver that are much wider than the pulses being transmitted by the seeker. A CW or cover-pulse noise signal will produce a wide pulse as it passes through the seeker's range gate. A slow CW frequency sweep will produce a wide pulse as it sweeps across the seeker's receive bandwidth.

Implementation



In the seeker receiver, in a secondary ECCM video channel (separate from the main video channel), incoming pulses are processed to extract any portion of the pulse that exceeds the width of the transmitter pulse. The resulting signal, if it exists, is then applied to an AGC amplifier to attenuate the main video channel. This AGC has no effect on pulse widths that are less than or equal to the width of the transmitter pulse. However, on pulses wider than the transmitter pulse the feed-forward AGC suppresses that portion of the pulse width exceeding the transmitter pulse width.

Comment
Same comments as for FTC, except that this technique may not have the disadvantage of reduced S/N.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p65, EW Engineering Inc., 1982

18. Radar Anti-Jamming Techniques, M.V. Maksimov et al, pp168-171, Artech House, 1979

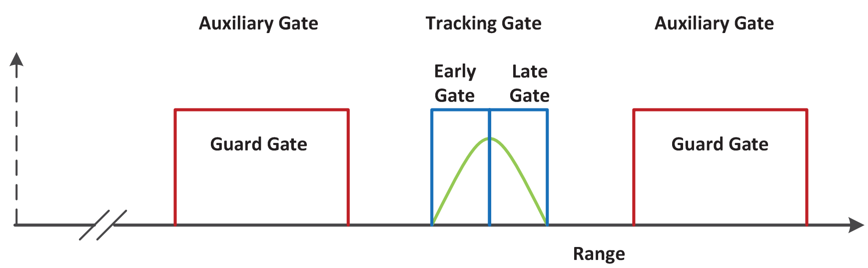
Multi-gated AGC

Concept
This is a guard gate technique for detecting and responding to the presence of signals from CW noise and distributed targets. The gain of the principal range gate is controlled by the signal levels detected in multiple auxiliary gates as well as the principal gate itself. The presence of CW noise jamming will cause signals to appear in the auxiliary gates. These signals are fed to the AGC logic to control the gain of the principal range gate and attenuate the signal in this gate. If sufficient attenuation occurs, the signal will fall below threshold and trigger a seeker mode change. Depending on the mode logic, the seeker may transition to a Home-On-Jam mode.

ECCM Category
Waveform Filtering

ECM
This ECCM technique is useful against CW noise jamming, cover pulse jamming, and multiple chaff clouds.

Implementation



Multiple auxiliary range gates, including perhaps an end-of-PRI gate, are placed at fixed positions on either side of the main tracking gate and monitored for signal activity. The signal strength in each gate is fed to an AGC logic circuit, which derives the gain control signal for the main receive channel. If high-amplitude signals are present in the auxiliary gates, the signal in the main channel is attenuated. If the signal in the main channel is sufficiently attenuated to drop below threshold, the seeker will undergo a mode transition, possibly to a Home-On-Jam mode.

Comment
This ECCM technique has been implemented in TTI's ASM(AR) and appears to be a very effective counter to CW noise jamming. The technique provides the seeker with a wide dynamic range in both the main receiver channel and also in the Home-On-Jam channel for detecting and responding to high-powered jamming signals.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p164, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p368, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

Amplitude Modulation ECCM

Concept
Amplitude modulation jamming is an ECM technique that tries to induce angle tracking errors into a CONSCAN, COSRO or LORO type seeker. Amplitude Modulation ECCM is a collection of possible responses to this jamming technique. The exact response is determined by evaluating the frequency and duty cycle of the incoming jamming signal. Possible responses are:

Clear Track with Jamming Blanked
The jamming is occurring at low duty cycle and at low blink frequencies. The seeker receiver can detect the jamming ON time and blank itself OFF in real time. Missile guidance should not be disrupted significantly when the target signal is lost for only a small amount of time.

Alternate Home-On-Jam and Clear Track
The jamming is occurring at medium to high duty cycle and at low blink frequencies. The seeker receiver switches from Home-On-Jam to clear track as the jammer goes from its ON condition to its OFF condition, and vice versa.

Home-On-Jam with Sample-and-Hold
The jamming is occurring at medium to high duty cycle and at medium blink frequencies. The seeker receiver uses Home-On-Jam as its primary homing mode. During the jammer ON time, the error signals generated in the angle and range tracking servos are sampled and held at those values during the jammer OFF time.

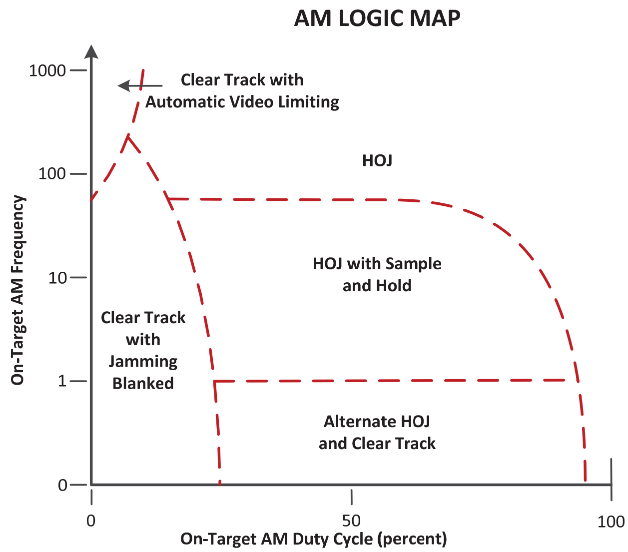
Home-On-Jam
The jamming is occurring at low to high duty cycle and at high blink frequencies. The seeker receiver stays in Home-On-Jam continuously.

Clear Track with Automatic Video Limiting
The jamming is occurring at very low duty cycle and at high blink frequencies. The very low duty cycle prevents effective use of Home-On-Jam. Instead, the seeker receiver incorporates automatic video limiting reduce the jammer power during its ON time such that average jammer power is too low to be effective. Clear track may then be employed.

ECCM Category
Waveform Filtering
Blanking
Jammer Direction Finding

ECM
This ECCM technique is useful against amplitude modulated noise jamming.

Implementation
The seeker requires circuitry such as guard gates to detect the presence of amplitude modulated noise jamming and measure its duty cycle and blink rate. Based on the duty cycle and blink rate measurements, response logic would then switch the seeker into the appropriate ECCM response mode.



Comment

According to Van Brunt (Ref.2), by using these or similar logic criteria and response modes, the scanning seeker can be made to accept all combinations of duty cycle and blink frequency and still perform well in the face of strong, on-target AM jamming. However, he also cautions that there will be bands of blink frequencies that may cause a break-lock in the seeker receiver.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p69, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

20. Electronic Countermeasure Effectiveness: Evaluation Methods and Tools, Lt(N) J.Johnson, Dr. T.W.Tucker, DREO/TTI Technical Report, February 2001

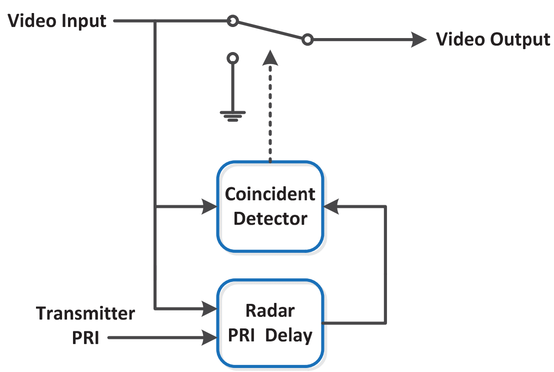
Pulse-To-Pulse Coincident Video Correlator

Concept
While in track mode, the seeker only accepts a received pulse for processing if the pulse is received on two consecutive PRI's. The rationale is this: If the PRI of the jamming signal is not synchronous with the PRI of the seeker, then the jamming signal will only randomly fall within the range gate at each PRI and will therefore only be detected when that occurrence happens twice. The use of a jittered PRI in the seeker will tend to make this ECCM technique more effective. This technique is also known as "PRF Correlator".

ECCM Category
Waveform Filtering

ECM
This ECCM technique is useful against non-synchronous PRF jamming and RGPI jamming.

Implementation



At the end of each PRI, an ECCM flag is set if a signal has been detected in the range gate AND the seeker is in track mode. If no signal is detected, the ECCM flag is reset. When a signal is detected in the range gate, the state of the ECCM flag is checked. If the flag is set, the signal is passed on for processing in the tracking circuits. If the flag is reset, the signal is discarded.

Comment
This might not be a good ECCM for sea-skimming missiles because of potential drop-outs due to multi-path effects and wind and swell waves.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p429 + p446, EW Engineering Inc., 1982

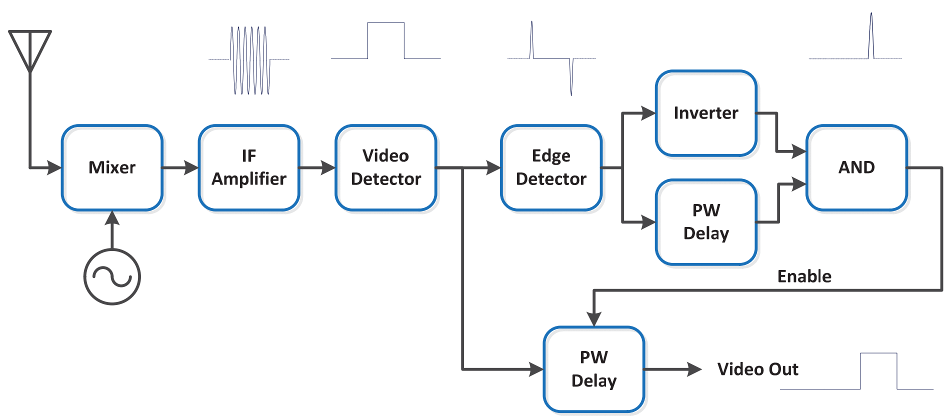
Pulse-Width Discrimination

Concept
The radar signature of a ship is typically composed of a number of discrete point scatterers with perhaps one of the scatterers being dominant. The ship echo in many engagement scenarios would therefore be similar to that of a point target with a resulting pulse width similar to the width of the seeker's transmitter pulse. Distributed targets on the other hand, as well as noise jammers or swept frequency jammers, would be expected to produce signals consisting of much wider pulses. With this technique, only return pulses whose widths correlate to that of the seeker transmit pulse are allowed to pass through the seeker receive channel. Other pulses are assumed to be countermeasure pulses.

ECCM Category
Waveform Filtering

ECM
This ECCM technique is useful against chaff and extended duration deceptive jamming pulses.

Implementation



A wideband receiver channel (to preserve the pulse edges) processes the incoming pulses to baseband. At baseband, the pulse is temporarily held and a differentiator circuit extracts the timing information for the rising and falling pulse edges. If the time separation between the two edges matches the required pulse width criterion, the baseband channel is 'enabled' and the pulse is allowed to pass on to the seeker tracking circuits. Otherwise the channel is disabled and the signal is discarded.

Comment
This technique adds a small constant time delay to the incoming pulse, approximately equal to the transmit pulse width. To preserve the relative timing of the pulse edges, the front-end filter is wideband and therefore unmatched, so the noise floor is substantially higher than it would otherwise be. This technique would probably work best with fairly narrow transmitter pulses, to maximize the relative difference in return echoes between point targets and extended targets like chaff and also to prevent multiple point targets on the ship from generating overlapping echoes and creating extended, but perfectly valid, target pulse widths.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p169, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p446, EW Engineering Inc., 1982

18. Radar Anti-Jamming Techniques, M.V. Maksimov et al, pp282-285, Artech House, 1979

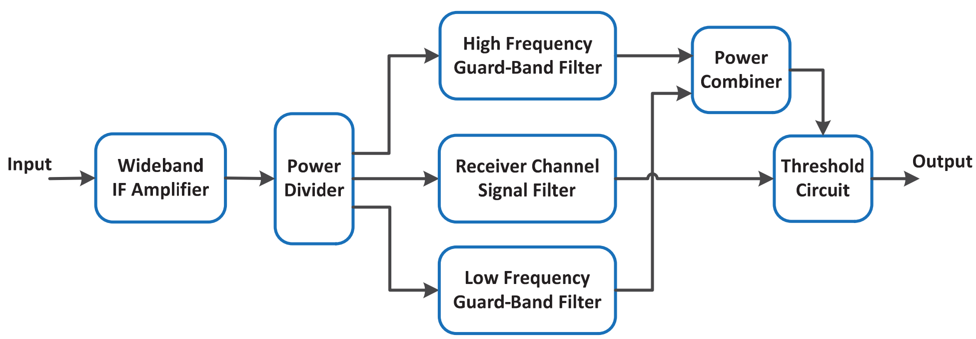
Guard-Channel Detection

Concept
This ECCM technique uses one or more auxiliary receiver channels (guard channels similar to guard gates only operating in frequency, not range) to detect out-of-band signals in the frequency band just above and/or below the radar carrier frequency. Signals detected in the guard channels may indicate CW or cover-pulse noise jamming or swept spot-noise jamming. Angle processing of the guard channel signal may indicate whether it originates from a stand-off jammer or from a self-protection jammer.

ECCM Category
Cancellation
Blanking
Jammer Direction Finding

ECM
This ECCM technique is useful against CW noise jamming, cover-pulse noise jamming, swept spot-noise jamming.

Implementation



Auxiliary receiver channels operating at frequencies above and below the carrier frequency are incorporated into the seeker receiver and monitored for signal activity. The type of signal detected in all channels and the ability to track the signal in the main channel will determine the seeker's ECCM response. For CW noise jamming or cover-pulse jamming, the seeker may transition to a Home-On-Jam mode if it appears to be originating from a self-protection jammer. If the jamming signal is assessed to be correlated between the main channel and the guard channels, then the guard channel signal may be used to cancel the jamming signal in the main channel, thereby reducing the J/S ratio. For swept spot-noise jamming, the seeker may use a blanking technique to ignore the jamming signal as it sweeps across the principal receiver channel.

Comment
As the name implies, this is primarily an ECM detection method with the guard channel providing a mechanism to support an ECCM response. Although it would probably be quite useful against the listed ECMs, this ECCM technique is probably relatively expensive to implement. Besides the added logic that would be needed to respond to any detected ECM, each additional frequency channel would

require its own set of LOs, down-converters, filters, amplifiers and detectors.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p166, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p237, EW Engineering Inc., 1982

9. Radar Homing Guidance for Tactical Missiles, D.A. James, p124, Macmillan Education Ltd, 1986

16. A Survey of Radar ECM and ECCM, Li Neng-Jing and Zhang Yi-Ting, IEEE Transactions on Aerospace and Electronic Systems, Vol. 31, No. 3, p1114, July 1995

18. Radar Anti-Jamming Techniques, M.V. Maksimov et al, p106, Artech House, 1979

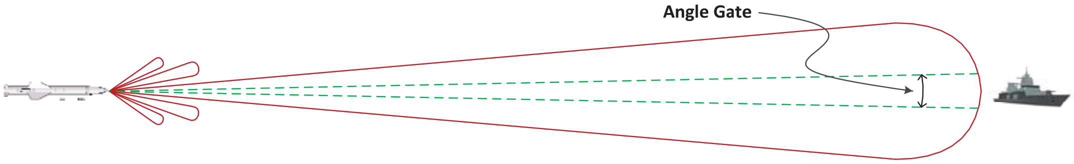
Angle Gating

Concept
The active portion of the missile antenna's beamwidth is synthetically decreased during target tracking in order to decrease the number of off-boresight signals that affect the angle servo.

ECCM Category
Blanking

ECM
This ECCM technique is useful against any off-boresight countermeasure signal such as chaff, decoys, blinking jamming, and stand-off jamming.

Implementation



While in track mode, the angle error signal generated in the seeker's angle tracking loop is constantly being monitored. If the error signal exceeds a threshold (an off-boresight angle threshold), it is zeroed before being passed to the angle servo input. While the error signal is zeroed, the missile flies unguided, either in a straight line or with the guidance command fixed to the value just prior to the threshold being exceeded. The threshold value represents a reference angle which defines the extent of the angle gate around the antenna boresight and will be some fraction of the seeker's beamwidth.

Comment
This ECCM would seem to be most effective against blinking jamming. The missile will only process the on-boresight blink and ignore the off-boresight blink as being outside the angle gate. If a constantly-on off-boresight stand-off jammer is present, then by zeroing out the angle error signal when ECM signals are present simultaneously with the target signal, the missile will be forced to fly unguided. Under this circumstance the assumption is made that as the missile continues to fly, the target signal remains inside the angle gate while the off-boresight ECM signal outside the angle gate will eventually also fall outside of the antenna main lobe. Once this happens, the angle error signal reduces to a value within the angle gate, the error signal is re-enabled and the missile once again homes on the target.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p73, EW Engineering Inc., 1982

18. Radar Anti-Jamming Techniques, M.V. Maksimov et al, pp111+292-304, Artech House, 1979

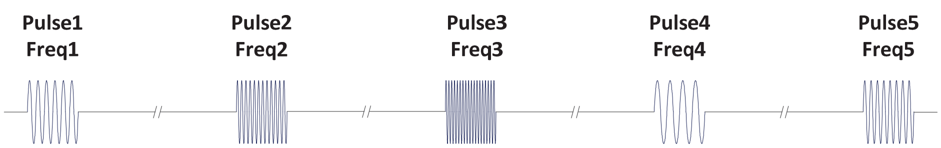
Frequency Agility

Concept
The seeker RF is constantly changing on a pulse-by-pulse basis. This reduces the effectiveness of noise jamming by forcing the jammer to spread its power over a wider spectrum. It also makes a Range-Gate-Pull-In technique very difficult to implement successfully if the jammer is unable to accurately anticipate the frequency of the upcoming transmit pulse.

ECCM Category
Dilution

ECM
This ECCM technique is useful against noise jamming and RGPI jamming.

Implementation



Just before each transmit pulse, the seeker RF is changed to a randomly selected new frequency and the bandwidth of the seeker's front-end filter is shifted so as to center on the new frequency. If the seeker is being jammed and the jamming signal bandwidth is not wide enough to cover the front-end filter's new frequency position, then the J/S ratio will be greatly reduced.

Comment
This ECCM technique is probably quite effective against any type of noise jamming. It would be especially effective against spot-noise jamming and RGPI jamming, which are techniques requiring the jammer to anticipate the seeker RF on a pulse-by-pulse basis.

This ECCM technique is purported to be used in the Exocet missile [8], the Harpoon missile [25] and the RBS 15 missile [25].

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p150, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p217, EW Engineering Inc., 1982

7. JED International Electronic Countermeasures Handbook, 2002 Edition, ed. Michael Puttré, p134, Horizon House Publications, 2002

8. Electronic Warfare, Mario de Arcangelis, p251, Bandford Press Ltd, 1985

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

11. Active Radar Electronic Countermeasures, E.J. Chrzanowski, p81, Artech House, 1990

25. The Naval Institute Guide to World Naval Weapon Systems (5th Edition), Norman Friedman, pp552-555+543, Naval Institute Press, 2006

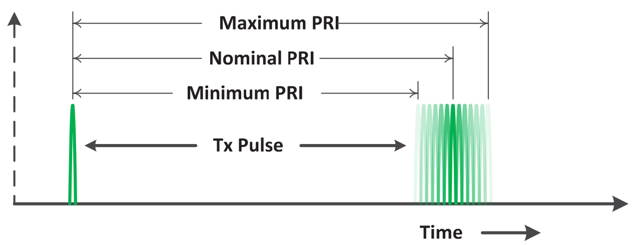
Jittered PRF

Concept
Range Gate Pull-In (RGPI) is a deceptive ECM technique used against missile seekers. To be effective, the jammer needs to anticipate the seeker Pulse Repetition Interval and transmit a false target pulse just before the next seeker pulse arrives. A jittered PRF makes it difficult for the jammer to do this reliably.

ECCM Category
Dilution

ECM
This ECCM technique is useful against Range Gate Pull-In jamming.

Implementation



Adding jitter to the PRF may be accomplished by automatically jittering between two or more frequencies, by randomly varying the PRF in both amplitude and frequency, or by changing from one frequency to other non-harmonic frequencies at a controlled rate.

Comment
This technique is probably very effective against RGPI. It also has advantages other than ECCM. It can potentially eliminate blind speeds in MTI systems and it increases seeker capability or compatibility in a dense electromagnetic environment.

This ECCM technique is purported to be used in the RBS 15 missile [25].

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p151, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p306, EW Engineering Inc., 1982

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

11. Active Radar Electronic Countermeasures, E.J. Chrzanowski, p82, Artech House, 1990

25. The Naval Institute Guide to World Naval Weapon Systems (5th Edition), Norman Friedman, pp543, Naval Institute Press, 2006

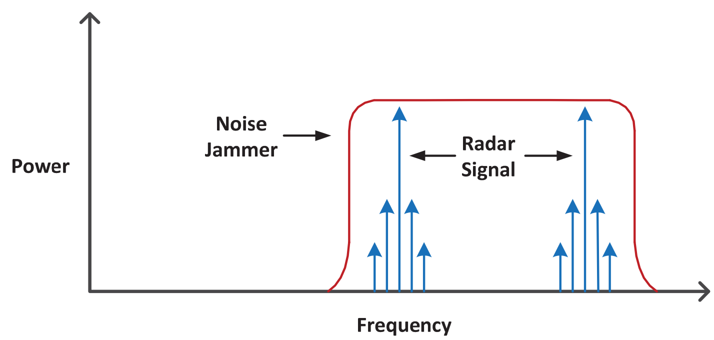
Frequency Diversity

Concept
Frequency diversity is the simultaneous operation of the seeker in widely separated frequency bands. The dual-band seeker transmits pulses at two separate frequencies, forcing the jammer to dilute its power by spreading it over both seeker bands. It also makes false target ECM techniques more difficult for the jammer to implement successfully, since the jammer must produce the same ECM effect in both frequency bands simultaneously.

ECCM Category
Dilution

ECM
This ECCM technique is useful against all types of noise jamming as well as false target jamming.

Implementation



This technique is implemented with a common antenna aperture and separate antenna feeds, one for each band. Two asynchronous RF pulses at different frequencies are transmitted through the single antenna. The two RF pulse widths are slightly different and are separated by a time equal to a few times the widest pulse width.

Comment
Van Brunt considers frequency diversity to represent a strong ECCM capability. However, its disadvantage is the cost involved in using more than one radar for similar purposes.

This ECCM technique is purported to be used in the OTOMAT missile [26].

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p150, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p226, EW Engineering Inc., 1982

7. JED International Electronic Countermeasures Handbook, 2002 Edition, ed. Michael Puttré, p134, Horizon House Publications, 2002

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

11. Active Radar Electronic Countermeasures, E.J. Chrzanowski, p81, Artech House, 1990

26. Jane's Radar and Electronic Warfare Systems 2007-2008, 19th Edition, ed. Martin Streetly, p163, Biddles Ltd, 2007

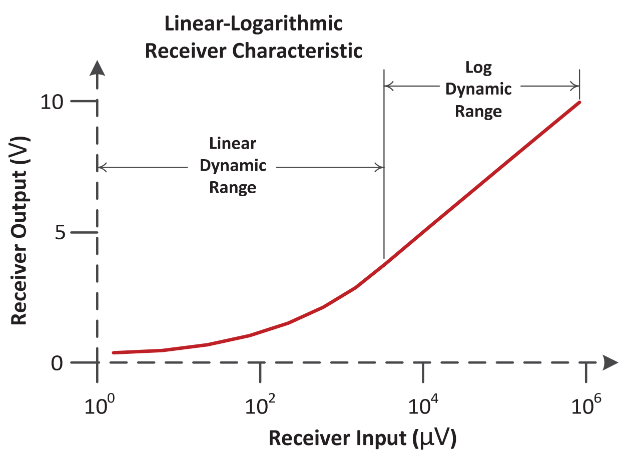
Linear-Logarithmic Receiver

Concept
To protect the seeker receiver from high-powered noise jammers that try to drive the receiver into saturation, the gain of the seeker receiver is designed to be logarithmic for large signal amplitudes. This should substantially increase the dynamic range of the receiver. For low-level signals, the receiver has a linear gain characteristic so as not to amplify the effect of low-level jamming signals.

ECCM Category
Saturation Prevention

ECM
This ECCM technique is useful against high-powered jamming signals.

Implementation



This technique may be implemented with a specially-designed IF amplifier which has a linear gain characteristic for low level signals and a logarithmic gain characteristic for higher level signals.

Comment
A receiver with a logarithmic response to high-powered signals makes it difficult for a jammer to drive the receiver into saturation. This type of receiver would be an alternative to a linear receiver that controls saturation through AGC and eliminates the ability of the jammer to capture the AGC through a countdown technique.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p320, EW Engineering Inc., 1982

18. Radar Anti-Jamming Techniques, M.V. Maksimov et al, pp146-156, Artech House, 1979

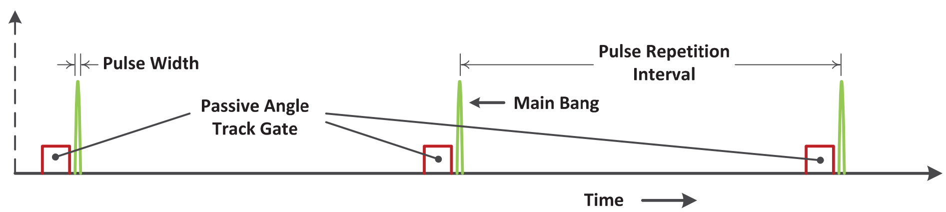
Passive Angle Track, End-of-PRI Range Bin

Concept
This is a Home-On-Jam technique applied against CW noise jamming. Using an end-of-PRI range bin to detect and measure CW noise, the seeker constantly monitors the incoming J/S ratio. If the ratio exceeds a threshold deemed to compromise target tracking, then the seeker switches from angle-tracking the target in the target gate to angle-tracking the CW noise signal in the end-of-PRI range bin.

ECCM Category
Jammer Direction Finding

ECM
This ECCM technique is useful against CW noise jamming.

Implementation



An ECCM range gate (end-of-PRI range bin) is designed into the seeker receiver and positioned at the end of the pulse repetition interval, just prior to the time of occurrence of the transmit pulse ('main bang'). When CW noise jamming appears, filling the entire extent of the PRI, the seeker uses this ECCM gate (end-of-PRI range bin) plus any additional guard gates to measure the power of the CW noise jamming signal and estimate a J/S ratio. If the J/S ratio exceeds a fixed threshold (e.g. -3 dB) and the power in the ECCM gate exceeds a S/N threshold that allows angle tracking, then the seeker transitions to a Home-On-Jam mode and angle-tracks the signal in the ECCM gate.

Comment
This is probably a very effective ECCM technique against an on-board CW noise jammer, since ships are relatively slow moving targets and range tracking in the seeker is therefore not critical for homing.

This Home-On-Jam ECCM technique may be used in the Exocet missile [8] and in the RBS 15 missile [25].

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p408, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

8. Electronic Warfare, Mario de Arcangelis, p251, Bandford Press Ltd, 1985

25. The Naval Institute Guide to World Naval Weapon Systems (5th Edition), Norman Friedman, pp543-544, Naval Institute Press, 2006

Second-Harmonic Tracking

Concept
This ECCM is applicable to the situation where a missile is in Home-On-Jam mode, homing on the jamming signals from two spatially separated targets. If the two jamming signals are of approximately equal intensity, the missile will often home on the centroid of the two targets. When the missile gets close enough to the targets so that one of them falls outside of the missile antenna's beamwidth, a late maneuver is made toward one of the targets. When the maneuver happens the missile may not have sufficient time or energy to intercept either target.

For scanning seekers (CONSCAN, COSRO), it is possible to force the missile to pick one of the targets much earlier. To do this, the missile guidance receiver is designed so that the second harmonic of the scan frequency is processed in addition to the fundamental for homing purposes. The second harmonic is present in the received signal when there are two targets in the scanning beam and scanning is occurring down on the skirts of the receiver antenna beam where nonlinearities exist. When the missile is aimed at a point exactly between the two targets, the fundamentals of the scan frequency from the two targets will tend to cancel each other, but their second harmonics will tend to reinforce each other, producing a detectable modulation that can be used to veer the missile towards one of the targets.

ECCM Category
Jammer Direction Finding

ECM
This ECCM technique is useful against CW noise jamming coming from two distinct sources, such as in a situation where a self-protection jammer and a stand-off jammer are operating at the same time.

Implementation
In the seeker's angle tracking servo, the incoming signal is down-converted with both the scanning reference frequency and the second harmonic of the scanning reference frequency. The two resulting signals are combined to produce a forcing function (error signal) that drives the servo output toward one of the two signal sources.

Comment
This ECCM would seem to have limited usefulness. It is only applicable to the situation where a missile is in Home-On-Jam mode and homing on the jamming signals from two spatially separated targets. Furthermore, the two jamming signals would have to be similar in magnitude as seen by the missile.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p534, EW Engineering Inc., 1982

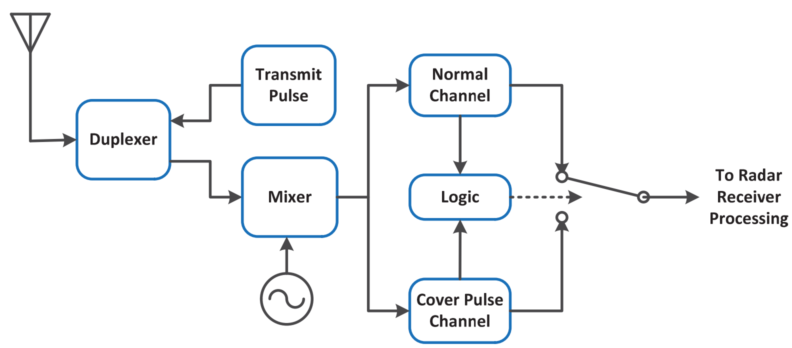
Cover Pulse Channel

Concept
This ECCM technique works in conjunction with pulse compression. The wide, complex pulse of a pulse compression signal is susceptible to cover pulse jamming. If the pulse-compression seeker detect it is being jammed by a cover pulse that has sufficient amplitude to compromise target tracking, it will switch its receiver channel from the normal pulse compression channel to a simpler, wide-pulse channel. The seeker uses this second channel to process the jamming pulse, tracking it in range and angle.

ECCM Category
Jammer Direction Finding

ECM
This ECCM technique is useful against cover pulse jamming

Implementation



Two receive channels are required, one for normal pulse-compression processing of the target echo and the second for processing a potentially large, noisy wide jamming pulse. If the seeker detects that the signal level in the normal channel is below threshold and that the signal level in the cover pulse channel is above threshold, it will switch to the cover pulse channel signal for range and angle tracking.

Comment
The existence of the cover pulse channel provides the ECM equipment designer with another component of the seeker to try and jam.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p155, EW Engineering Inc., 1982

Guard Gates

Concept
The receiver of an anti-ship missile seeker will typically include a range gate to isolate and track a single ship target. There are a variety of ECM techniques that attempt to disrupt seeker tracking by injecting signals in and around the range gate:

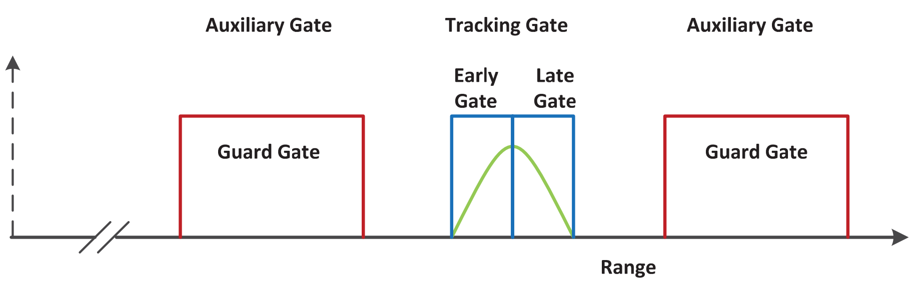
- Seduction chaff can be used to draw the seeker track point away from the ship.
- Deceptive jammers can apply a range gate steal technique to draw the seeker track point away from the ship.
- Strong CW jamming signals can cover the ship echo and deny accurate range information to the seeker.

Guard gates, which are auxiliary range gates placed around the tracking range gate and used for signal detection, can assist the seeker in identifying ECM signals and taking effective countering action.

ECCM Category
Countermeasures to False Targets

ECM
This a very versatile ECCM technique, useful against pulse repeater jamming, range gate steal, CW noise jamming, chaff clouds and other passive and active decoy techniques.

Implementation



One or more range gates are placed at fixed positions on either side of the main tracking gate and monitored for signal activity. These additional gates are used for ECM detection only. While the main tracking gate is locked onto a target, there are two possible detection results in the guard gates:

1. If a signal appears in one of these guard gates while the main tracking gate is locked onto a target, then this could indicate that either a chaff cloud or a deceptive jamming pulse has been deployed against the ASM. The ship target is presumed to be the signal in one gate and the ECM signal is now appearing in the other gate. Signal characteristics are measured (power level, scintillation characteristics, range rate) and ECCM logic is applied to determine which signal is likely to be coming from the ship. The tracking range gate is then re-positioned over this target.

2. If there are two or more guard gates and signals appear in all gates (including the tracking gate) simultaneously, then this could indicate CW noise jamming is occurring. If the ECCM logic concludes

that CW jamming is present and that the jamming signal is greater than the ship echo, then the seeker will normally transition to a Home-On-Jam mode.

Associated ECCM Techniques: AGC on Nearby Noise, Home-On-Jam

Comment
This would appear to be a very effective, versatile ECCM technique for ASMs.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p242, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

11. Active Radar Electronic Countermeasures, E.J. Chrzanowski, p129, Artech House, 1990

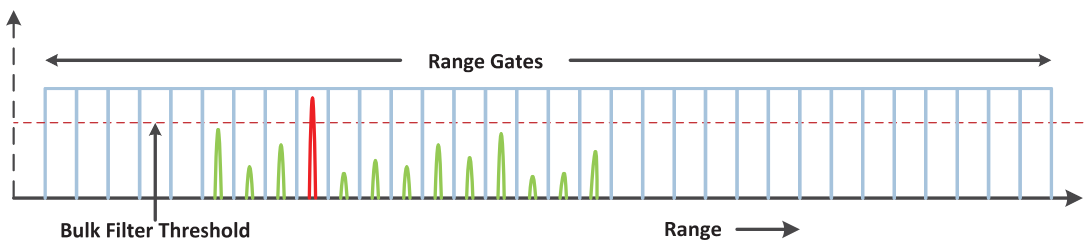
Bulk Filtering

Concept
Multiple objects are resolved into distinct targets using multiple range bins. Chaff clouds are then rejected by using simple measurement thresholds and by assuming that the ship has the largest RCS.

ECCM Category
Countermeasures to False Targets

ECM
This ECCM technique is useful against distraction chaff.

Implementation



During search mode, the seeker receiver uses a narrow-width transmitter pulse and monitors signal returns in multiple narrow-width range bins. Targets are detected and resolved in angle and range and thresholding is applied to reject those targets whose signal echo is below a threshold derived from the peak echo.

Comment
This ECCM technique probably works best against multiple distraction chaff clouds at seeker turn-on, during search and acquisition. The technique makes the rather critical assumption that the largest detected signal is always from the ship target, which may not necessarily be true.

References

3. Radar System Performance Modeling, G. Richard Curry, p242, Artech House, 2001

Auxiliary Tracking Gates

Concept
The receiver of an anti-ship missile seeker will typically include a range gate to isolate and track a single ship target. There are a variety of ECM techniques that attempt to disrupt this type of range tracking, by injecting signals in and around the range gate:

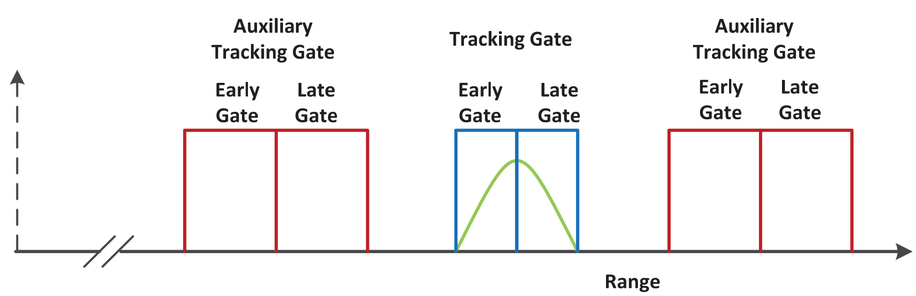
- Seduction chaff can be used to draw the seeker track point away from the ship.
- Deceptive jammers can apply a range gate steal technique to draw the seeker track point away from the ship.
- Strong CW jamming signals can cover the ship echo and deny accurate range information to the seeker.

ECCM Category
Countermeasures to False Targets

Auxiliary tracking range gates, initially placed close to the principal gate, are able to independently lock on to and track targets moving in either direction. These auxiliary tracking gates can provide additional information to the seeker about these targets beyond what may be available from the simpler guard gate technique, thus allowing the seeker to make a more precise assessment as to the presence of deceptive ECM.

ECM
This ECCM technique is useful against pulse repeater jamming, any type of deceptive jamming, CW noise jamming, chaff clouds and other passive and active decoy techniques.

Implementation



One or more tracking range gates are placed at positions around the principal gate. These auxiliary gates give the seeker the ability to conduct multi-target tracking and each tracked target can be monitored for multiple characteristics: magnitude, range position, range rate, scintillation and other forms of modulation. If more than one target is present, logic in the seeker can be used to evaluate the measured characteristics and assess which target is the ship and which targets are deceptive countermeasures. It is probably also feasible to use the auxiliary gates in a manner similar to guard gates to evaluate if CW noise jamming is present. As with guard gates, seeker logic can assess if the CW jamming signal is degrading the ability of the seeker to track the ship. If so, then the seeker will normally transition to a Home-On-Jam mode.

Comment

This would appear to be a very effective, versatile ECCM technique for ASMs. However, the auxiliary tracking loops required for this technique are considerably more expensive than the guard-gate technique and may not be worth the additional cost in a throw-away item such as a missile seeker.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p236, EW Engineering Inc., 1982

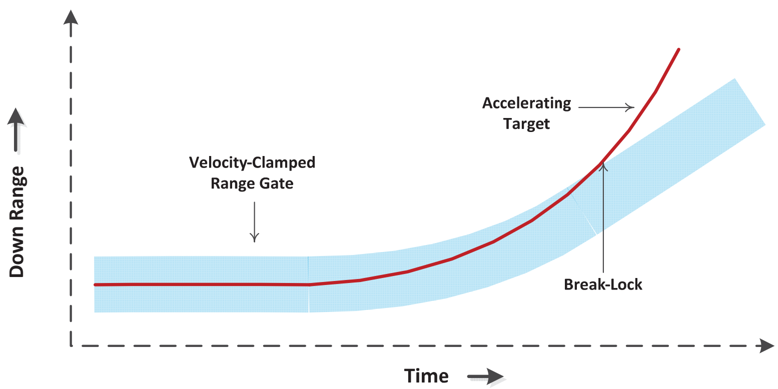
Maximum Velocity / Maximum Acceleration

Concept
If an upper limit on the velocity and acceleration of a ship is assumed, then the tracking servos within the missile seeker can be configured with equivalent limits to prevent the seeker from tracking excessively fast targets. These fast targets would probably be deceptive ECM signals.

ECCM Category
Countermeasures to False Targets

ECM
This ECCM technique is useful against deceptive jamming such as range gate steal.

Implementation



The velocity and acceleration at which the range and angle tracking servos are tracking a target can be measured by monitoring the servo output signal. These values can be used to derive an estimate of the target's velocity and acceleration. If the tracking rate exceeds a threshold, either a limiter on the range gate rate or the seeker mode logic can force a break-lock and have the seeker look for a new target.

Comment
This technique forces the deceptive jammer to simulate realistic ship speeds when generating walk-off pulses.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p55, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

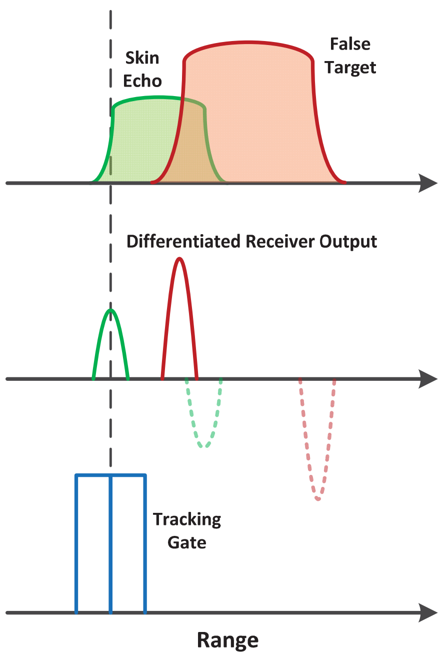
Leading-Edge Track

Concept
Range Gate Pull-Off (RGPO) is a common deceptive ECM technique used against missile seekers. To counter it, the Leading-Edge Track ECCM technique biases range tracking of the target toward the leading edge of the return signal. The intention is that the bias will obstruct deceptive jamming pulses from pulling the seeker range gate beyond the target position. As the jamming walk-off pulse pulls away from the target echo, it also pulls away from the leading edge of the combined target echo + jamming pulse signal. As it continues to pull away, the jamming pulse eventually falls outside the seeker's leading-edge tracking gate. At that point it no longer has any influence on the track position.

ECCM Category
Countermeasures to False Targets

ECM
This ECCM technique is useful against Range Gate Pull-Off jamming.

Implementation



There are a number of possible implementations of the Leading-Edge Track technique:

1) The incoming target echo is passed through a positive-going differentiator. The output of the differentiator, a very narrow pulse positioned at the leading edge of the incoming echo, is then tracked using a conventional, narrow split-gate discriminator circuit.

2) A fixed error is added to the output of the range discriminator to bias the track point toward the leading edge of the return pulse.

3) The gain in the range discriminator's early gate channel is reduced relative to that of the late gate, biasing the track point toward the early gate and the leading edge of the pulse.

4) The range discriminator uses a very narrow late gate, much narrower than the transmitted pulse width. The narrow late gate will bias the track point towards the leading edge of the incoming pulse.

Comment

The leading edge tracker exploits an inherent vulnerability in ECM systems – i.e. the delay incurred in detecting the incoming pulse and responding to it with a deceptive jamming pulse [Ref 11: pg 127]. The differentiator implementation probably has the best ECCM effect against RGPO jamming since it is tracking right at the leading edge of the incoming target echo. On the other hand it will have a reduced S/N ratio because: a) the receive channel must be fairly wide band to preserve the edges of the incoming pulse, and b) the differentiator captures only a portion of the pulse and will greatly reduce the energy in the received signal.

This ECCM technique is purported to be used in the Exocet missile [8].

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p142, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p309, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

6. Radar Vulnerability to Jamming, Robert N. Lothes et al, pp77-83, Artech House, 1990

8. Electronic Warfare, Mario de Arcangelis, p251, Bandford Press Ltd, 1985

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

11. 11. Active Radar Electronic Countermeasures, E.J. Chrzanowski, pp127-128, Artech House, 1990

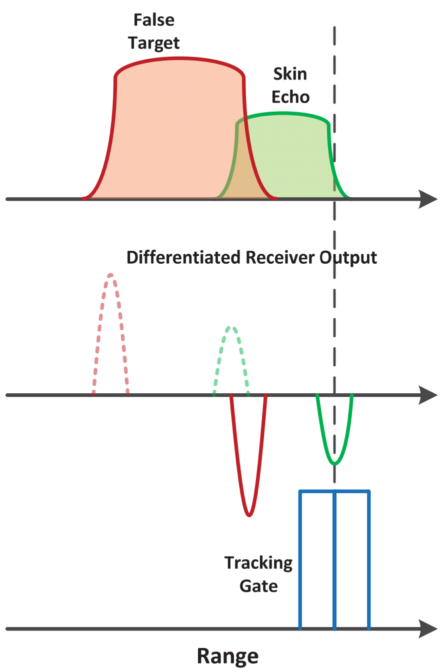
Trailing-Edge Track

Concept
Range Gate Pull-In (RGPI) is a deceptive ECM technique used against missile seekers. To counter it, the Trailing-Edge Track ECCM technique biases range tracking of the target toward the trailing edge of the return signal. The intention is that the bias will obstruct deceptive jamming pulses from pulling the seeker range gate beyond the target position. As the jamming RGPI pulse pulls away from the target echo, it also pulls away from the trailing edge of the combined target echo + jamming pulse signal. As it continues to pull away, the jamming pulse eventually falls outside the seeker's trailing-edge tracking gate. At that point it no longer has any influence on the track position.

ECCM Category
Countermeasures to False Targets

ECM
This ECCM technique is useful against Range Gate Pull-In jamming.

Implementation



There are a number of possible implementations of the Trailing-Edge Track technique:

1) The incoming target echo is passed through a negative-going differentiator. The output of the differentiator, a very narrow pulse positioned at the trailing edge of an incoming pulse, is then tracked using a conventional, narrow split-gate discriminator circuit.

2) A fixed error is added to the output of the range discriminator to bias the track point toward the trailing edge of the return pulse.

3) The gain in the range discriminator's late gate channel is reduced relative to that of the early gate, biasing the track point toward the late gate and the trailing edge of the pulse.

4) The range discriminator uses a very narrow early gate, much narrower than the transmitted pulse width. The narrow early gate will bias the track point towards the trailing edge of the incoming pulse.

Comment

As with the leading edge tracker, the differentiator implementation probably has the best ECCM effect against RGPI jamming since it is tracking right at the trailing edge of the incoming target echo. On the other hand it will have a reduced S/N ratio because: a) the receive channel must be fairly wide band to preserve the edges of the incoming pulse, and b) the differentiator captures only a portion of the pulse and will greatly reduce the energy in the received signal.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p580, EW Engineering Inc., 1982

4. Software Description Document for the ASM(AR) Simulator, Tactical Technologies Inc., 2012

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

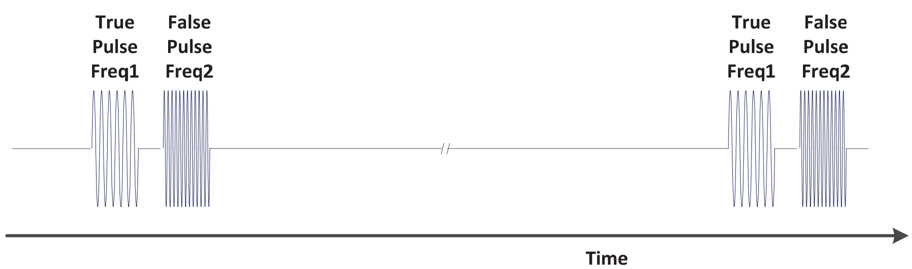
False Pulse Transmission

Concept
One or more pulse signals at different carrier frequencies are transmitted by the seeker slightly ahead of the pulse that is to be used for target detection and tracking. The 'false' seeker pulses are intended to interfere with jammers using older-generation microwave storage systems. These systems operate only on the leading portion of an intercepted signal and are usually blind to other signals until as much as 4 us after detection of the initial signal.

ECCM Category
Countermeasures to False Targets

ECM
This ECCM technique is useful against RGPO jamming.

Implementation



The seeker transmitter is able to generate two carrier frequencies for pulse transmission. The seeker then transmits two pulses in a row, one at each of these carrier frequencies. However, a narrowband front-end filter at the seeker receiver allows only the second carrier frequency to pass.

Comment
This ECCM technique would only be effective against older generation jammers.

References

11. Active Radar Electronic Countermeasures, E.J. Chrzanowski, p128, Artech House, 1990

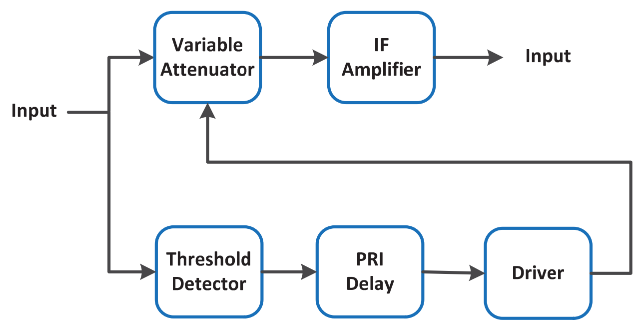
Previous Pulse AGC

Concept
This ECCM technique is used against a noisy, non-coherent deceptive jammer attempting a range gate steal technique. AGC is applied to the signal in the range gate. The control signal for the AGC is derived from the signal that was in the range gate one PRI ago. The detection threshold is set fairly high so that only a signal of comparable amplitude to that of the previous PRI will be detected. The rationale for this technique is this:
Because it is noisy and non-coherent, the amplitude of the jamming signal will vary widely from pulse to pulse, whereas the echo from a target is assumed to be somewhat correlated pulse-to-pulse. There should therefore be a high percentage of missed detections for a deceptive jamming signal.

ECCM Category
Countermeasures to False Targets

ECM
This ECCM technique is useful against range gate steal jamming.

Implementation



At least two range gates (a tracking gate and a guard gate) would probably be needed for this technique. The incoming pulse train is split into two channels. One channel is fed through a one-PRI time delay and demodulated to baseband. This signal is then used to dynamically control the gain in the range gates (tracking gate and guard gate) of the other, main channel. If a target echo is detected in one range gate and a deceptive jamming pulse is detected in the other range gate, the seeker can determine which target is valid by assessing which gate has the most hits per unit time and then adjust the position of the tracking gate accordingly.

Comment
This might not be an effective ECCM for sea-skimming missiles because of potential drop-outs due to multi-path effects and wind and swell waves.

References

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p427, EW Engineering Inc., 1982

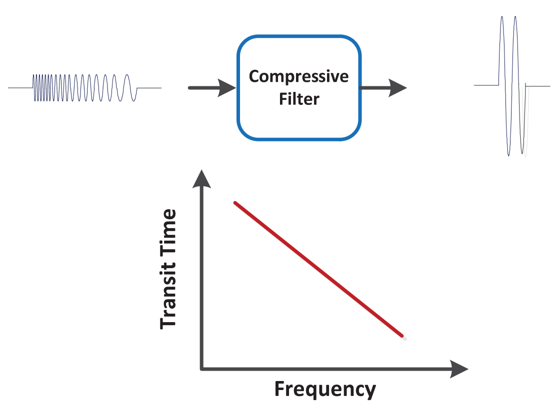
Linear FM Pulse Compression (Chirp)

Concept
Linear FM pulse compression is method by which the missile seeker transmits each of the frequency components of a very narrow width, high-powered pulse at slightly different moments in time so as to reduce the instantaneous peak power being transmitted at any one time. This process transforms the signal into a very wide, low-power pulse, modulated with a linear frequency sweep across the length of the pulse. The low peak power makes the pulse more difficult to detect by ES. To maximize signal-to-noise, a matched filter compresses the echo signals in the seeker receiver by correlating the echoes with the frequency modulation pattern of the transmitted pulse. The compressed pulse with enhanced S/N ratio has a narrow width which helps to resolve closely-spaced targets and to obtain good range-to-target information. Pulse compression is typically characterized by its compression ratio, which is the ratio of the width of the dispersed pulse to the width of the compressed pulse.

ECCM Category
Low Probability of Intercept

ECM
This ECCM technique is primarily useful as an LPI technique. It is also effective against non-coherent microwave signal storage devices that sample the leading edge of an intercepted signal, on the assumption that this sample is representative of the remainder of the signal.

Implementation



In a typical chirp implementation, the seeker transmitter creates a narrow RF pulse that is passed through a dispersive filter such as a surface acoustic wave device. The output of the filter is a wide pulse with an FM sweep occurring over the duration of the pulse. The wide, swept-frequency pulse is transmitted through the antenna and returning target echoes are passed through a matched filter, also typically a SAW device, which collapses the echoes via correlation with the frequency modulation pattern of the transmitted pulse.

Comment
Linear FM pulse compression is susceptible to cover pulse jamming. As the compression ratio

increases, there is a trade-off between decreasing probability of intercept by ESM and increasing noise jamming susceptibility. The long pulse width (which gives the ECM set more time to react) and complexity (which gives the ECM set more possible effective ECM techniques) makes it comparatively easy for the ECM set designer to degrade the effectiveness of pulse-compression systems through repeater techniques. On the other hand, a benefit of using this technique in an ASM is that wide bandwidth signals are more resistant to multi-path drop-outs.

References

1. Modern Radar Techniques, ed. M.J.B. Scanlan, (Chapter 4: Radar ECM and ECCM, Stephen L. Johnston), p142, Collins, 1987

2. Applied ECM Vol.2, LeRoy B. Van Brunt, p436, EW Engineering Inc., 1982

10. Electronic Warfare in the Information Age, D. Curtis Schleher, p124, Artech House, 1999

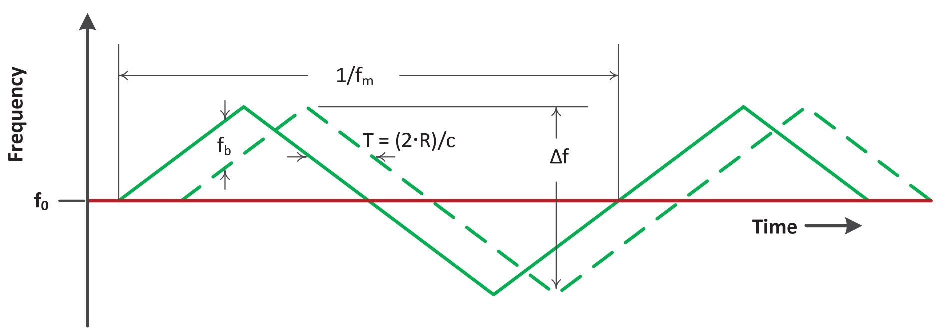
FM-CW

Concept
FM-CW is a method by which the missile seeker transmits a frequency modulated continuous wave signal. The range to the ship target is proportional to the difference between the frequency of the ship echo signal and that of the transmitted signal. Because the signal is CW, a good S/N can be attained with a very low peak transmit power compared to a pulsed system.

ECCM Category
Low Probability of Intercept

ECM
This ECCM technique is primarily useful as an LPI technique. It is also effective against non-coherent microwave signal storage devices that sample the leading edge of an intercepted signal, on the assumption that this sample is representative of the remainder of the signal.

Implementation



Frequency modulation of a CW signal can be realized with a voltage-controlled microwave oscillator. Typically a saw-toothed or triangular waveform is used for modulation.

In the above diagram, if there is a target at a distance **R**, an echo signal will return after a time:
$\mathbf{T = 2 \cdot R/c}$
If the frequency of the modulating signal is $\mathbf{f_m}$ and $\mathbf{f_b}$ is the beat frequency between the transmit and receive frequencies, then the range to the target may be calculated as:
$\mathbf{R = f_b \cdot c / (4 \cdot f_m \cdot \Delta f)}$

Comment
This technique is purported to be used in SAAB's RBS-15 MK3 ASM [22, 25]. The seeker uses FM-CW technology with an output power in the milliwatt range that is progressively reduced as the missile approaches the target. In addition the seeker infrequently illuminates its target to help decrease its probability of detection [15].

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ECM Descriptions

Barrage Noise

Barrage Noise is a self-screening and stand-off ECM technique that radiates high-power noise-like energy over a wide frequency band for the purpose of masking target echoes in an ASM seeker. Barrage noise may be generated in many ways and may take different forms but the purpose is always to spread jamming energy over a wide frequency band. The following are some of the possible barrage noise generating techniques:

- The output from a noise source (resistor, diode, vacuum tube) can be amplified directly up to a level where it can be radiated from an antenna. This is called DINA (Direct Noise Amplification).
- A voltage-controlled oscillator can be frequency modulated by a fast saw-tooth waveform producing closely-spaced lines in the power spectrum. This is also called comb jamming.
- A pseudo-random sequence can be generated digitally and used to control the frequency of a wide-band voltage-controlled oscillator.
- A very narrow, high-power impulse can be transmitted.

A disadvantage of barrage noise is that the jamming power is diluted by being spread over a frequency band that is much wider than the bandwidth of the seeker's receiver channel. Jamming effectiveness is dependent on the jammer power density in watts per MHz. When the available jammer power is fixed, widening the jammer bandwidth lowers the jammer power density. This has the effect of reducing the potential J/S ratio since much of the jamming power is outside the bandwidth of the victim seeker and is wasted.

Barrage noise is probably the oldest type of jamming and as a result any related ECCM techniques are more likely to be found in current and older generation ASMs.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp464-473, EW Engineering Inc., 1978

Cover Pulse

Cover-Pulse Jamming is a generic term that encompasses many forms of jamming. It is also known as Range Select Jamming, Range Blanking, or Wide-Pulse. With this technique, the ECM cover pulse is transmitted toward the ASM with a high J/S ratio (10 - 40 dB), such that the cover pulse arrives at the same time as the target ship echo. The width of the ECM pulse is normally wider than the ship echo. The leading edge of the cover pulse may lag that of the ship echo if the seeker's PRF is jittered and the ECM set logic can not anticipate the next pulse. However, it is generally intended that the cover pulse leading edge arrive back at the ASM ahead of that of the ship echo and that the cover pulse is wide enough to completely hide the ship echo from the ASM seeker.

The ECM cover pulse may consist of a gated CW signal (set-on oscillator) or gated noise. The width of the cover pulse is usually made as small as possible (just wide enough to be sure of covering the ship echo) to conserve the jammer's duty cycle. Note that the ASM may use the cover pulse itself for both range and angle tracking in a Home-On-Jam mode. Thus careful consideration must be given to this beacon effect in any ECM design.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp552-555, EW Engineering Inc., 1978

Blinking

Blinking jamming is a self-screening and stand-off ECM technique that alternately turns ON and OFF, at about a 50% duty cycle, one or more noise jammers whose spectrum covers the pass-band of the victim seeker. If more than one noise jammer is involved, they are normally synchronized and spatially separated from one another. The blink rate is relatively slow, from 0.1 to 10 Hz, and is intended to confuse the automatic Home-On-Jam mode of the victim ASM. Higher rates and other than 50% duty cycles are generally considered Countdown Jamming. For optimal effectiveness, the ON time is adjusted to a value that just exceeds the time it takes the seeker to transition to Home-On-Jam mode. The OFF time is just less than the time that it takes the seeker to reacquire the ship target. These two times may be different, but usually blink rates at 50% duty cycle are a satisfactory compromise.

Good blinking jamming always keeps the seeker either searching for the target or in the process of going into Home-On-Jam. A good blink jammer should have a 60 dB ON to OFF ratio to keep a very sensitive missile receiver from tracking on self-generated ECM system noise output power during the jammer OFF time. The term 'Blinking Jamming' is also used to refer to blinking a repeated CW signal or a repeated seeker pulse train.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp481-490, EW Engineering Inc., 1978

Countdown

Countdown is a self-screening ECM technique that is able to generate angle errors in an ASM seeker that uses AGC. In the countdown technique, the jammer gates a repeater or noise source ON and OFF with a waveform whose period is short compared to the victim AGC closed-loop time-constant. The duty-cycle is small so that on-time is very short relative to off-time. Only seekers containing an AGC circuit are affected by this technique.

The rapid, low duty cycle on-off jamming effectively 'captures' the seeker's AGC loop. The fast on-off rate is outside the AGC loop bandwidth, resulting in an averaging of the power by the AGC and an overall reduction in gain, even during the OFF portion of the cycle. During the ON portion of the cycle, the receiver channel is driven into saturation. Typical values for the on-off rate are in the range of 20-500 Hz.

For all AGC-based seekers, a well-executed countdown technique will attenuate the target echo, resulting in tracking degradation. For lobing seekers such as COSRO that angle track using the AM lobing signal, the technique also tends to suppress the modulation signal, resulting in very poor angle tracking.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp426-436, EW Engineering Inc., 1978

Swept Spot Noise

Spot Noise is a self-screening or stand-off ECM technique that radiates high-power noise-like energy over a relatively narrow frequency band for the purpose of masking target echoes in an ASM seeker. Spot noise differs from barrage noise in that the jamming energy is confined to a narrow frequency band so that jammer power is utilized more efficiently and a higher jamming density (in W/MHz) can be generated in the bandwidth of the victim seeker. The spot noise bandwidth is usually not much wider than the seeker bandwidth, taking the jammer stability into account. Spot noise can be generated by applying various forms of modulation (AM, PM, and FM) to a power source such as an RF oscillator.

It may be that the ECM system is unable to evaluate the seeker RF precisely, but instead make an assessment that the seeker RF falls within a certain RF band.. In this circumstance the jammer can sweep the centre frequency of the noise bandwidth through this assessed RF band in a repetitive pattern. For a portion of the sweep time, the jamming signal will fall within the seeker bandwidth.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp855-856, EW Engineering Inc., 1978

AM Jamming

AM Jamming is a self-screening ECM technique for use against seekers that track targets via an amplitude modulating antenna scan (CONSCAN, COSRO, LORO). The technique typically consists of jamming pulses synchronized to the received seeker pulses. The jamming pulses are amplitude modulated at a frequency intended to interfere with the scan demodulation process in the seeker angle tracker.

There are many variations to AM jamming. One of the more common ones is known as Swept Audio, which tries to create angle deception by offering the seeker an amplitude-modulated signal (normally with an on-off square wave) stronger than the target echo signal, with a phase different from that of the target echo. Since the scanning seeker uses the phase of the received signal to steer its antenna, the intent of the Swept Audio ECM signal is to introduce a composite echo and ECM signal possessing a phase that drives the seeker antenna away from the ship.

For a seeker that scans on receive only, the transmit signal is not amplitude modulated. The jamming platform may therefore not be able to directly measure the frequency and phase of the radar's reference scan signal and then use measured data to set an effective modulation pattern for the jamming signal. The jammer, in using Swept Audio ECM, endeavours to overcome this difficulty by sweeping the frequency of the amplitude modulation envelope of the jamming signal, usually using a triangular or saw-tooth frequency sweep, around the expected frequency of the radar's reference scan signal.

The success of Swept Audio jamming in inducing a significant angle tracking error strongly depends on the rate at which the AM of the jamming waveform is swept and on the upper and lower frequencies of the sweep relative to the seeker antenna scanning frequency.

Reference

20. Electronic Countermeasure Effectiveness: Evaluation Methods and Tools, Lt(N) J.Johnson, Dr. T.W.Tucker, DREO/TTI Technical Report, February 2001

Image Jamming

Image Jamming is a self-screening ECM technique for use against seekers that depend on phase-sensing for angle tracking. The technique jams by radiating a signal on the image frequency of the victim seeker. This technique depends on the fact that the phase angle at the seeker IF between two signals at the image frequency is the reverse of that which would appear at the IF if the two signals were at the normal frequency. A phase comparison seeker determines the direction of the angle tracking error from the direction of the phase error between two horn signals. By injecting a signal with a tracking error of the wrong sign, image jamming causes the antenna to be driven away from the target if the jamming power exceeds the signal power.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp702-705, EW Engineering Inc., 1978

Delta Jamming

Delta Jamming is a self-screening ECM technique that causes angle errors in monopulse seekers. The jammer transmits two RF signals whose frequency separation is controlled such that false IF signals are formed in the victim seeker's IF amplifier during down-conversion. The effect is to put a false bias or cause instability in the phase-correcting system used in the seeker IF circuits. These effects are achieved by mixing of the dual input frequencies and other frequency components in the first mixer of monopulse seekers. The technique is hard to implement in that the IF signal amplitude is proportional to the product of the strengths of the inter-modulation signals. The jamming signal strength must therefore be comparable to the geometric mean of the echo signal strength and the local oscillator signal strength. A priori knowledge of the victim seeker's IF, bandwidth, and IF range are required.

Delta Jamming is also possible when a single signal is transmitted by the jammer at one-half the IF away from the local oscillator frequency. The seeker’s mixer causes the second harmonic of the jammer-LO difference frequency to appear at the IF yielding a component equal to the IF. It should be noted that where the IF of the seeker is not known, the Delta jamming technique can employ sweeping frequencies so that the jamming would be effective only part of the time. Alternately, the frequency sweep could be combined with jog-detection to try and narrow in on the IF band.

Reference

19. Applied ECM Vol.1, LeRoy B. Van Brunt, pp602-606, EW Engineering Inc., 1978

False Targets

False targets are jamming signals that appear to the missile seeker as valid target echoes. They can be received and processed by the seeker either completely or in part in range and angle and they are intended to confuse or capture the seeker's track point. There are several different categories of false targets. Two of the most important that are relevant to ASMs are Range Gate Walk-Off and Range Gate Pull-In.

Range Gate Walk-Off

Range Gate Walk-Off (RGWO), also known as Range Gate Pull-Off (RGPO) and Range Gate Steal (RGS), is a false target ECM technique intended to deceive the range tracking loop of a missile seeker. The false target tries to capture the victim seeker's range gate, walk it off in range, then turn OFF, leaving the range-gate with no signal for the seeker to track. It is usually repetitive. The following jamming procedure is the conventional RGWO technique used against an ASM seeker:

(a) The seeker signal is received and amplified with a minimum delay, usually on the order of 150ns, and is retransmitted to provide the seeker with a strong beacon signal.

(b) The beacon signal causes the seeker receiver gain to decrease because of AGC action, thereby suppressing the ship echo and capturing the seeker range-gate.

(c) The time delay of the repeated signal is successively increased on a pulse-to-pulse basis from the minimum delay time out to a time equivalent to many seeker range-gate widths. During the walk-off, other false targets may be established. The walk-off function can take many shapes, but the maximum acceleration rate must not exceed the seeker's range-tracking limits.

(d) Upon reaching the outer walk-off limit, the false target signal is turned OFF, or a burst of on-frequency noise is transmitted, to make the seeker break its range track.

(e) The seeker goes into its reacquisition mode and starts a range search. If possible, the ship is reacquired by the seeker.

(f) The process is repeated.

Range Gate Pull-In

Range Gate Pull-In (RGPI) is a false target technique very similar in form and function to Range Gate Walk-Off. It differs from RGWO in the direction that the false target moves. The RGPI false target first captures the seeker's range gate and then pulls the range gate toward the missile rather (than away from the missile as in RGWO). The following jamming procedure is the conventional RGPI technique used against an ASM seeker:

(a) The ECM system receives the seeker's signal and then detects and measures the RF, pulse width and PRI of the incoming seeker pulses.

(b) The ECM system sets up a track on the seeker pulse train (pulse width and PRI) in order to be able to anticipate the arrival of each successive pulse from the seeker.

(c) Using the tracking information, the ECM system transmits a false target pulse coincident with the ship echo, which provides a strong beacon signal to the seeker.

(d) The beacon signal causes the seeker receiver gain to decrease because of AGC action, thereby suppressing the ship echo and capturing the range-gate.

(e) The timing of the false target pulse is gradually advanced on a pulse-to-pulse basis from the anticipated arrival time of the seeker pulse, so that the false target pulse arrives at the seeker ahead of the ship echo. The gradual advancement in time of the false target pulse causes the false target to appear to gradually move from the ship position toward the missile. As with RGWO, during this process other false targets may be established. Also similar to RGWO, the RGPI function can take many shapes, but the maximum acceleration rate of the pull-in must not exceed the seeker's range-tracking limits.

(f) Upon reaching the pull-in limit, the false target signal is turned OFF, or a burst of on-frequency noise is transmitted, to make the seeker break its range track.

(g) The seeker goes into its reacquisition mode and starts a range search. If possible, the ship is reacquired by the seeker.

(h) The process is repeated.

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The Defence of Small Ships against Missile Attacks, P. Yansouni, Proceedings from the 30th DRG Seminar, AC/243-TP/2 Vol. 1, Presented 12-14 September 1990, Ottawa

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List of symbols/abbreviations/acronyms/initialisms

AGC	automatic gain control
AM	amplitude modulation
ARM	anti-radiation missile
ASM	anti-ship missile
CONSCAN	conical scan
COSRO	conical scan on receive only
CW	continuous wave
DC	direct current
DINA	direct noise amplification
DRDC	Defence Research & Development Canada
DSSS	direct sequence spread spectrum
EA	electronic attack
ECCM	electronic counter-countermeasure
ECM	electronic countermeasure
EP	electronic protection
ES	electronic warfare support
EW	electronic warfare
FM	frequency modulation
FM-CW	frequency modulation – continuous wave
FTC	fast time constant
IF	intermediate frequency
J/S	jamming-to-signal ratio
LO	local oscillator
LORO	lobe on receive only
LOS	line of sight
LPI	low probability of intercept
MTI	moving target indicator
PM	phase modulation
PRI	pulse repetition interval
PRF	pulse repetition frequency
RCS	radar cross-section
RF	radio-frequency
RGPI	range gate pull-in
RGPO	range gate pull-off
RGS	range gate steal
RGWO	range gate walk off
SAW	surface acoustic wave
S/N	signal-to-noise ratio
SOJ	stand-off jammer
SPJ	self-protection jammer
SSM	surface-to-surface missile

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Thirty radar-related electronic counter-countermeasure (ECCM) techniques have been identified and described. The identified techniques are those deemed appropriate to the current generation of operational anti-ship missiles (ASM). The techniques have been grouped according to ten defined ECCM categories. Each technique is described as to concept of operation, possible implementation and effectiveness. The specific naval electronic countermeasure (ECM) against which the ECCM technique has been devised is also briefly described (e.g. Barrage Noise, Range Gate Walk Off, Amplitude Modulation Jamming).

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Electronic Protection Measures; Anti-Ship Missile

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