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DISTRIBUTED CLUTTER MODEL: REAL-TIME FFT PROGRAM

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R. L. MITCHELL

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FOREWORD

The work performed under Contract DAAK40-78-C-0031 that resulted in specific deliverables (principally computer programs) is described in two volumes of a final report. This is Volume 1, which describes the work that led to the distributed clutter model. Volume 2, entitled "Extended Target Model: Real-Time Simulation Program," describes the work relevant to that subject.

The AP120B array processor programs described in this report (but documented elsewhere) were designed and developed by Dr. I. P. Bottlik, as well as the interfaces to the host computer and Digital Signal Generator. Dr. Bottlik was assisted by Mr. D. L. Brandon.

1. INTRODUCTION AND SUMMARY

This report describes a real-time simulation procedure for generating replicas of the gound clutter signal as received on the three monopulse channels of an airborne radar. The procedure is based on first computing the power spectra of the clutter (on the three monopulse channels) according to the engagement geometry, then randomizing these power spectra, and finally executing an FFT in real time to create the quadrature video components of the clutter sequences.

The procedure permits any spectral shape to be simulated, so that it is inherently very accurate. However, the computation is time-consuming so that its application in real time is limited. With one AP120B array processor interfaced to a Datacraft/6 computer, only a single range gate of clutter can be simulated in real time.

 \sim > Listings of a Fortran program are included. The program has been tailored to a specific missile system under test at the RFSS.

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2. GENERATING CLUTTER SEQUENCES IN REAL TIME

The use of an FFT to generate finite-length sequences of correlated random samples is described in Reference 1. First, a sequence of independent, complex random samples is generated throughout one frequency repetition interval. Next, given an amplitude spectrum of interest (the square-root of the ensemble-averaged power spectrum) we multiply the random samples by the corresponding samples of the amplitude spectrum. Finally, the complex spectral sequence is Fourier transformed (via an FFT) to obtain the quadrature components of the correlated time sequence.

The above time sequences have the property that they are circularly periodic; i.e., the sequence repeats with a period $1/\Delta f$ where Δf is the sample spacing in the frequency domain. If the random process is stationary we can make Δf small enough (at least in theory) so that the repetition period will be longer than the process time of interest. However, if the process is nonstationary, as with clutter received on a missile radar, the power or amplitude spectrum of the process will be continually changing and any procedure based on a single FFT will not lead to the proper time sequence.

One procedure that does work, however, is to take a sequence of FFT's where the spectrum for any one FFT will be relatively stationary. The procedure is discussed in Reference 2 (Section 6). In order to avoid the abrupt transition that would result if one resulting time sequence directly followed another, it is imperative that the sequences overlap as shown in Figure 1. Different weighting functions are discussed in Reference 2, and the conclusion is that linear weighting, as shown in Figure 1, is satisfactory with an overlap that is about 1/8 of the FFT length. More overlap would provide slightly lower residual sidelobes but at the expense of a more time-consuming computation.



Figure 1. Sequence of Weighting Functions

3. GROUND CLUTTER SPECTRA

The ground clutter spectra on the three monopulse channels are determined by the engagement geometry and the antenna pattern shapes. In this section we will derive the basic relationships for a pulse-Doppler radar with the antenna pointing within about 30° of the velocity vector.

3.1 Engagement Geometry

In Reference 2 (Section 4) it was shown that the clutter spectral shapes on the three monopulse channels are functions of only five angles, where the geometry is given in Figure 2:

1) azimuth angle of antenna boresight, α

2) depression angle of antenna boresight, β

3) depression angle of range ring of interest, γ

4) missile dive angle, δ

5) missile roll angle, ω

Two additional parameters are required to complete the specification of the clutter spectra:

- 6) missile altitude, h
- 7) missile velocity, V

The engagement geometry may not be expressed directly in terms of the five angles above. Instead of (α,β) it is most likely that the azimuth and elevation of the antenna boresight (θ_0, ϕ_0) relative to the missile velocity vector will be given. The transformation of (θ_0, ϕ_0) to (α,β) is derived in Appendix A.

The missile altitude and slant range are related by

$$r = h/\sin\beta \tag{1}$$

3.2 Assumed Antenna Patterns

In the analysis that follows we will assume the following set of receive voltage gain patterns:

sum channel:
$$g_{r}(\theta,\phi) = g_{r}(\theta) g_{r}(\phi)$$
 (2)

 $\Delta Az \text{ channel:} \quad g_{\Delta A}^{(\theta,\phi)} = g_{\Delta}^{(\theta)} g_{\Sigma}^{(\phi)}$ (3)



Figure 2. Engagement Geometry for Ground Clutter

$$\Delta \text{El channel:} \quad g_{\Delta E}^{(\theta)}(\theta, \phi) = g_{\Sigma}^{(\theta)}(\theta) \quad (4)$$

where θ and ϕ are the azimuth and elevation angles, respectively, and

$$g_{\Sigma}(\zeta) = \exp(-a|\zeta|^{D})$$
 (5)

$$g_{\Lambda}(\zeta) = k\zeta \exp(-c|\zeta|^d)$$
 (6)

where ζ designates either angle. We also assume the specific parameters

where ζ is in degrees in (5) and (6). The half-power width of the sum pattern is about 14°. It is assumed that the radar transmits on the sum channel. The patterns for the sum and one difference channel are plotted in Figure 3.

3.3 Spectral Shape

In Reference 2 (Section 4) it was shown that the spectral shapes of clutter are primarily a function of two parameters, α and ω . The remaining parameters in the list in Section 3.1 act as scaling parameters, either in frequency or power.

Note:

Throughout the remainder of this report clutter spectra will be shown for the three monopulse channels. Unless otherwise indicated, all plots will be in the format of Figure 4.







Figure 4. Format for Plots of Clutter Spectra

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Actual Doppler Frequency =

C

 $(2V/\lambda) \times Relative Doppler Frequency$

Σ = sum-channel spectrum

ΔA = del-az channel spectrum

ΔE = del-el channel spectrum

The azimuth angle, α , strongly affects the spectra on all three monopulse channels as is shown in Figure 5 through 8 for $\alpha = 0$, 10°, 20°, and 30°, respectively (in all cases $\beta = \delta = \omega = 0$ and $\gamma = 10°$, and frequency is relative to $2V/\lambda$). Note the different scales in frequency. When the azimuth angle is small (less than about 50% of the antenna half-power beamwidth), all spectra are truncated sharply at the relative Doppler frequency given by cos (δ - γ), which in the case of the figures is 0.985. It is this strong variation with respect to the azimuth angle that greatly limits the use of a single spectral shape to describe the clutter spectra.

The missile roll angle, ω , affects primarily the monopulse difference channels as is shown in Figures 9 through 17 for $-45^{\circ} \leq \omega \leq 45^{\circ}$ in steps of 11.25° (in all cases $\beta = \delta$ and $\alpha = \gamma = 10^{\circ}$). Due to the symmetry in the antenna patterns of Section 3.2, the spectra for ω and $\omega \pm 180^{\circ}$ are identical. The spectra for ω and $\omega \pm 90^{\circ}$ are also identical except the monopulse difference channels are interchanged (e.g., see Figures 9 and 17). Note that the sum channel spectrum is not a strong function of the missile roll angle.

3.4 Frequency Scaling

The maximum Doppler frequency within the range gate of interest is given by

$$f_{\text{max}} = \frac{2V}{\lambda} \cos (\delta - \gamma)$$
(7)

In Reference 2 (Section 4.6) it was suggested that (7) represents a valid frequency scaling of the spectra for most cases of interest. In other words, spectra computed at one combination of δ and γ could be simply scaled in frequency for other values by the use of (7). The approximation is good as long as δ and γ are not large.

In order to demonstrate how well the spectra can be scaled we show in Figures 18 through 23 cases for which $|\delta-\gamma| = 10^{\circ}$ ($\alpha = 10^{\circ}$, $\beta = \delta$, and $\omega = 0$). The first three cases where $\delta \leq 20^{\circ}$ and $\gamma \leq 30^{\circ}$ are practically identical. In Figure 21 there is some deviation in the tail of the ΔA spectrum, but otherwise the spectra are still within a few dB of the other cases. It is only when we go to the steeper geometries in Figures 22 and 23 that



Figure 8. Clutter Spectra for $\alpha = 30^{\circ}$

Figure 7. Clutter Spectra for $\alpha = 20^{\circ}$











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Figure 23. Clutter Spectra for $\beta = \delta = 50^{\circ}$, $\gamma = 60^{\circ}$

the differences become significant. These results indicate that the simple frequency scaling law of cos $(\delta - \gamma)$ applies with reasonable accuracy as long as δ and γ do not exceed about 35 or 40°.

3.5 Clutter Power for Sum Channel

With the use of Figure 24, the power received from the clutter cell of area r $_{\rm g}$ Δr $_{\rm g}$ $\Delta \alpha$ is given by

$$\Delta P_{R} = \frac{P_{T} G^{2} \lambda^{2} \sigma_{o} (r_{g} \Delta r_{g} \Delta \alpha)}{(4\pi)^{3} r^{4}}$$
(8)

where P_T is the peak transmit power, G is the one-way power gain in the direction of the clutter cell, λ is the wavelength, r is the range, and σ_0 is the clutter backscatter coefficient (radar cross section per unit area on the ground). The ground range, r_g , is related to the slant range, r, by

$$r_{g} = r \cos \gamma$$
 (9)

The intersection of the range resolution cell on the ground is Δr . It is straightforward to show that

$$\mathbf{r} \Delta \mathbf{r} = \mathbf{r} \Delta \mathbf{r} \tag{10}$$

where we define Δr to be the range resolution (range gate width). Thus (8) becomes

$$\Delta P_{R} = \frac{P_{T} G^{2} \lambda^{2} \sigma_{o} \Delta r \Delta \alpha}{(4\pi)^{3} r^{3}}$$
(11)

The total received power is obtained by integrating (11) over all azimuth angles within the range gate intersection on the ground. If σ_0 is constant (as it will be for homogeneous clutter), the total power is

$$P_{R} = \frac{P_{T} \lambda^{2} \sigma_{o} \Delta r}{(4\pi)^{3} r^{3}} \int G^{2}(\alpha) d\alpha \qquad (12)$$



Figure 24. Clutter Geometry

where $G(\alpha)$ is defined as the one-way power gain in the direction of a point at an azimuth α within the range gate intersection on the ground.

3.6 Effective Radiated Power

In the RFSS the clutter signal will be radiated from the RFSS array at a distance D from the radar receiver. Let us designate the effective radiated power as P_e . Thus the power density at the receive antenna will be

$$P_{d} = P_{e}/4\pi D^{2}$$
(13)

The received power will be

$$P_{R} = P_{d}A = P_{e}A/4\pi D^{2}$$
(14)

where A is the antenna aperture area. Since the peak gain is given by $G_0 = 4\pi A/\lambda^2$, we can write

$$P_{e} = P_{R} \frac{(4\pi)^{2} D^{2}}{G_{o} \lambda^{2}}$$
 (15)

so that with (12) we obtain

$$P_{e} = \frac{P_{T}\sigma_{o}\Delta rD^{2}}{4\pi G_{o}r^{3}} \int G^{2}(\alpha) d\alpha \qquad (16)$$

It is more convenient to work with normalized antenna patterns, so we define

$$G_{n}(\alpha) = G(\alpha)/G_{n}$$
(17)

where G_{α} is the peak gain on the sum channel. Thus (16) becomes

$$P_{e} = \frac{(P_{T}G_{o}D^{2})\sigma_{o}\Delta r}{4\pi r^{3}}\int G_{n}^{2}(\alpha) d\alpha \qquad (18)$$

which is our final result.^{*} In some cases σ_0 is defined as a function of the grazing angle, γ , such as a sin γ dependence.

For several types of antenna patterns, it has been empirically determined that for the sum channel

$$\int G_n^2(\alpha) \, d\alpha = \text{const} \times G_n^2(\gamma - \beta)$$
(19)

which is accurate to within about 0.2 dB for all engagement geometries. For the antenna pattern defined in Section 3.2 the constant has a value of .20 so that

$$\mathbf{P}_{e} = 0.16 \frac{(\mathbf{P}_{r} \mathbf{G}_{o} \mathbf{D}^{2}) \sigma_{o} \Delta \mathbf{r}}{r^{3}} G_{n}^{2} (\gamma - \beta)$$
(20)

"The integral in (18) is the quantity "POWER" computed by a subroutine /(SPCTRA) written by the author.

Note that the antenna patterns in (2) through (6) are defined in the normalized form.

3.7 Clutter Spectral Parameters

Let us refer to Figure 2. As viewed from the radar, the range ring intersection with the ground plane will be approximately a straight line, at least for γ not too large and for points on the range ring that are not too far away from the vertical plane ROA. Thus we have the approximate geometry given by Figure 25, where points A and G represent vectors \overline{RA} and \overline{RG} in Figure 2, respectively. The apparent angle between the two points is $\Delta = \gamma -\beta$. The skewed coordinates in Figure 25 represent the principal planes of the antenna, θ being the azimuth axis and ϕ the elevation axis. The angle ξ is the angle between the ϕ -axis and the vertical plane, which is derived in Appendix B as a function of the engagement geometry. Point Q is some arbitrary point along the ground "line" at an angular distance η from Point G. In the following discussion we will assume that Δ , the angular distance between Points A and G, is smaller than about 20° so that the actual spherical geometry reduces to the plane geometry in Figure 25.

The two-way antenna gain pattern for any of the three monopulse channels is assumed to be the product of two functions (see Section 3.2) as

$$G(\theta,\phi) = G_1(\theta) G_2(\phi)$$
(21)

where $G_1(\phi)$ and $G_2(\phi)$ are given in the following table:

Channel	<u>G₁(θ)</u>	G ₂ (φ)
sun	$g_{\Sigma}^{4}(\theta)$	$g_{\Sigma}^{4}(\phi)$
∆ -Az	$g_{\Delta}^{2}(\theta)g_{\Sigma}^{2}(\theta)$	g _Σ ⁴ (φ)
∆- E1	g _Σ ⁴ (θ)	$g_{\Delta}^{2}(\phi)g_{\Sigma}^{2}(\phi)$

with $g_{\Sigma}()$ and $g_{\Delta}()$ being defined in (5) and (6), respectively. From Figure 25 we can write for an arbitrary point Q on the ground within the 'range ring of interest



Figure 25. Engagement Geometry as Viewed from Radar

 $\theta = -\Delta \sin \xi + \eta \cos \xi \qquad (22)$

 $\phi = -\Delta \cos \xi - \eta \sin \xi \tag{23}$

where η is the angular distance of Point Q from Point G. Thus we can write the two-way antenna gain along the ground line as

$$G(\eta) = G_1(-\Delta \sin \xi + \eta \cos \xi) G_2(-\Delta \cos \xi - \eta \sin \xi)$$
$$= G_1(\Delta \sin \xi - \eta \cos \xi) G_2(\Delta \cos \xi + \eta \sin \xi) \quad (24)$$

where symmetry was assumed to obtain the second result in (24).

For the monopulse sum channel the two-way pattern will be nearly circularly symmetric about Point A in Figure 25, assuming the pattern in (2). Therefore, the peak gain along the ground line occurs at Point G, and the angle from the boresight axis is $\Delta = \gamma - \beta$. This is the reason why the effective radiated power for the sum channel scales as $G_n^2(\gamma - \beta)$ in (20).

For the monopulse difference channels the reasoning is similar, except that there is no longer any dominant circular symmetry about the boresight axis. Instead, the symmetry is about the principal antenna axes. For example, the azimuth difference pattern has a null along the ϕ -axis, so that Point N on the ground line corresponds to a null. The angular separation of the null from Point G is

$$n_{N} = \Delta \tan \xi$$
 (25)

By referring to Figure 2 we see that the azimuth angle of the null is $\alpha + \eta_N$. The normalized Doppler frequency of the null (ψ_N is the corresponding Doppler angle) is

$$\cos \psi_{N} = \cos \gamma \cos \delta \cos(\alpha + \eta_{N}) + \sin \gamma \sin \delta$$
 (26)

If we use the approximation derived in Reference 2 (Section 4.6), we can write for most cases of interest

$$\cos \psi_{y} = \cos(\delta - \gamma) \cos (\alpha + \eta_{y})$$
 (27)

With the use of (7) we can write the Doppler frequency of the null as

$$f_N = f_{max} \cos (\alpha + \eta_N)$$

For the azimuth difference channel there will be two points along the ground line in Figure 25 for which the two-way gain will be a local maximum. One of these points will lie to the left of Point N and one will lie to the right. (When $\xi \approx \pm 90^{\circ}$ there will be only one local maximum of significance which occurs near $\eta = 0$, and the null will occur so far away from Point G that the small-angle approximation will no longer be valid. In effect, the clutter spectrum will be unimodal for the azimuth difference channel when ξ is in the neighborhood of $\pm 90^{\circ}$, and for the elevation difference channel when $\xi \approx 0$ and 180° as can be seen in Figure 13.) There is no convenient way to find these peaks other than to perform a computer search for them. Since the geometry is specified by only two parameters, Δ and ξ , we have tabulated the peak gain of the azimuth difference channel that occurs to the left of Point N in Figure 25 as a function of these two angles. The peak gain is shown in Table 1 (referenced to the peak gain of the sum channel) and the location of the peak, η_L , is shown in Table 2. Because of the symmetry we

Table 1. Two-way Gain of Left-Side Peak (dB)

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7(DEC)	0	10	20	ANGLE I 30	BETWEEN 40	N PLANE 50	ES,ξ 60	(DEG) 70		
-18	-61.2									
-17	-54.8	-62.6								
-15	-48.9	-56.1	-65. Ó							
-15	-43. 4	-50.0	-58.7							
-14	-38.4	-44.4	-52. 3	-63.4						
-13	-33. 8	-37.3	-46.4	-56.4				•		
-12	-27.6	-34.6	-41.0	-49.9	-63. 3					
-11	-25. 9	-30.4	-36.1	-43. 9	-55.6					
-10	-22. 6	-25.5	-31.7	-38.5	-48.6	-65.6				
-9	-19.7	-23. 2	-27.7	-33. 7	-42.3	-56.6				
-8	-17.2	-20. 2	-24.1	-27.3	-36.7	-48.5				
-/	-15.1	-17.6	-21.0	-25.4	-31.8	-41.4	-59.8			
-0	-13.3		-18.2			-37.2	-47. 7			
-5		-13.0	-17 0	-17.0	-20.0	-75 1	-77 5	-67.2		
-3	-10.0	-12.1	-10.7	-10.0	-17 7	-71 7	-33.5	-32.1		
-3	-10.0	-10.7	-11 1		-14 9	-19 0	-77 4	-31 0	-57 5	
-1	-9.2	-40.1	-10.2	-11 3	-13.0	-15.0	-19 7	-24 2	-37 0	
ō	-91	-9.2	-9 6	-10.3	-11 5	-13.2	-15 7	-19 2	-25 2	
ĭ	-9.2	-91	-9.2	-9 6	-10 4	-11 6	-13.3	-15 6	-19 4	-21 6
2	-9.5	-9.2	-9.1	-9 3	-9.7	-10.4	-11.6	-13.0	-14 7	-15.8
3	-10.0	-9.4	-9.2	-9.1	-9.3	-9.7	-10.3	-11.2	-12.1	-12.7
4	-10.8	-9.9	-9.4	-9.2	-9.1	-9.2	-9.6	-10.0	-10.5	-10.8
5	-11. 9	-10.7	-9.9	-9.4	-9.2	-7.1	-9.2	-9.4	-9.6	-9.7
6	-13. 3	-11.7	-10.7	-9.9	-9.5	-9.2	-9.1	-9.1	-9.2	-9.2
7	-15. 1	-13. 1	-11.7	-10.8	-10.1	-7.6	-9.4	-9.3	-9.2	-9.2
8	-17. 2	-14. 9	-13. 2	-11.9	-11.0	-10.4	-10.0	-9.7	-9.6	-9.6
9	-19.7	-17.0	-14. 9	-13.4	-12, 2	-11.4	-10. 9	-10.6	-10.5	-10.4
10	-22. 6	-19.5	-17. 0	-15.2	-13. 8	-12.9	-12.2	-11.8	-11.7	-11.6
11	-25. 9	-22. 3	-17.5	-17.3	-15.7	-14.6	-13.8	-13.4	-13. 2	-13.2
12	-29.6	-25.6	-22.4	-19.9	-18.0	-16.7	-15.8	-15.3	-15.1	-15.1
13	-33.8	-29.3	-25.7	-22.8	-20.7	-17.2	-18.1	-17.6	-17.4	-17.4
14	-38.4	-33.4	-29.3	-26.1	-23.7	-22.0	-20.8	-20. 2	-20.0	-20.0
17	-43.4	-37.9	-33.4	-29.8	-27.1	-25.1	-23. 8	-23.1	-23.0	-23.0
10	-48.9	-42.9	-37.9	-33.9	-30.8	-28.6	-27.2	-26.4	-20.2	-26.4
17	-24.8	-48.3	-42.7	-38.4	-39.0	-32.7 -34.7	-25.0	-30.1	-27.7	-30.0
10	-01. «		-40.2	-43.3	-37.3	-33.7	-32.0	-29 4	-33.7	-38.1
20		-47 4			-44.4	-44 3	-37.4	-30.4	-JJ. 2	-33.4
.21		-07.4	~67.0	-40 5	-55 2	-40.3 -51 /	-49.1	-40.1 -ΔΩ 1	-46.7 -47 0	-4J. 2 -19 7
22			U/. V	-67 0	-61 A	-57 4	-54 9	-53 5	-57 7	-53 7
23				U7. V	-67 9	-63 4	-60 A	-59 2	-50 1	_50 K
24					ω/. /		UV. O	-45 3	-45 7	-45 7

21

- ---

Table 2. Location of Left-Side Peak, n_L (deg)

22

μ.,

can write the location of the peak on the right side of the ground line as

$$n_{R}(\Delta,\xi) = -n_{L}(-\Delta,\xi)$$
 (29)

For the peaks we also have the symmetry

$$n_{R}(\Delta,\xi) = -n_{L}(\Delta, -\xi)$$
 (30)

Note that nothing changes if $\xi \pm 180^{\circ}$ is substituted for ξ . For the elevation difference channel we can use the above results by substituting either $\xi + 90^{\circ}$ or $\xi - 90^{\circ}$ for ξ .

In converting the azimuth location of either peak to Doppler frequency we can write for any η

$$f = f_{max} \cos(\alpha + \eta)$$
 (31)

Note, however, that the left peak will generally be at a *higher* frequency than the right peak (as defined above) so that $f_R < f_L$ (at least for $\alpha > 0$). When $\alpha < \eta_L$ we get a foldover or wraparound effect that results in the spectrum being sharply truncated at f_{max} . In this case only the lower-frequency peak, namely the one at $f = f_{max} \cos(\alpha + \eta_R)$, will be relatively undistorted.

In the process of converting a power distribution in angle to a power distribution in frequency, we must also include the effect of the Jacobian. Thus the peak gains in Table 1 (in linear units) must be divided by $\sin(\alpha + \eta)$ where η is the corresponding entry in Table 2 (provided $\alpha + \xi > 0$.

3.8 Two Examples

Let us refer to the parameters of Figure 15, for which $\alpha = 10^{\circ}$, $\beta = 0$, $\gamma = 10^{\circ}$, $\delta = 0$, and $\omega = 22.5^{\circ}$. Immediately we note that $\Delta = 10^{\circ}$ and from (B-3) we have $\xi = 22.2^{\circ}$. The parameters that were discussed in Section 3.7 are summarized in Table 3. The peak gain for the sum channel is defined as $G_n^2(\gamma-\beta)$, where $G_n()$ is the one-way power of the antenna pattern, and the Jacobian is defined as $1/\sin(\alpha+\eta)$. The normalized Doppler is designated by f in Table 3. In the last column the "corrected gains" are referenced



Table 3. Summary of Example I

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α=10°, β=0, γ=10°, δ=0, ω=22.5°

ξ=22.2°, ξ-90°=-67.8°, Δ=10°

Refer to Figure 15 for spectral plots Gain Rel. to **D** -22.7 dB -0.4 +0.6 I Note that "R-peak" appears at a Corrected Gain -5.4 dB -28.1 -5.8 -4.8 Jacobian +7.6 dB +10.8 +5.1 +7.1 -13.0 dB -33.2 -16.6 -11.9 Gain ** .970 .936 .966 .955 .981 44 4.9 -14.5* 10.0° 휜 11.3 14.1 18.1 -24.5 1.3 8.1 -5.1 ° 4.1 디 R-peak L-peak R-peak Feature L-peak null null peak Channe1 Bum Az El

* spectrum folds over for $\alpha + \eta < 0$ ** peak is below -60 dB in Table 2

lower frequency than "L-peak"

to the corrected gain in the sum channel. If we compare the results of Table 3 with Figure 15 we note that the location of the peaks and nulls is in excellent agreement, and the peak values of the various lobes agrees to within 1 dB.

As a second example we have arbitrarily selected $\alpha = 30^{\circ}$, $\beta = 5^{\circ}$, $\gamma = 10^{\circ}$, $\delta = 15^{\circ}$, and $\omega = 20^{\circ}$. The results are summarized in Table 4 along with a plot of the "exact" sprectum. The agreement is again excellent as noted on the figure.



4. APPROXIMATING SPECTRA IN REAL TIME

As was concluded in Reference 2 (Section 4.6) one cannot implement the "exact" computation of the clutter spectra in real time, at least in a practical sense. One is forced to use some approximation technique. In this section we discuss one possibility that is based on describing the clutter spectra by a few parameters that are functions of the engagement geometry.

4.1 Description of Method

In the format of the plots in Figure 4 through 23, all spectra are composed of either a single lobe or two adjacent lobes where the lobes are either distorted parabolas or triangular-shaped functions. For any of the lobes we have decided to implement the parametric description that is diagramed in Figure 26. First of all, a reference level (base) is established that is, say, 40 dB below the sum channel peak. On the log-scale of the figure a second level is established that is midway between the lobe peak and the reference base. Five normalized frequencies can then be determined, f, through f₅ for Points 1 through 5, respectively, in Figure 26. The sixth parameter in Figure 26 is the peak height. A seventh parameter, as shown in Figure 27, describes the shape of the lobe. To reconstruct the spectral lobe in the format of Figure 26, a straight line is drawn between Points 1 and 2. Between Points 2 and 3 either a straight line (TYPE = 0) or a parabola with zero slope at Point 3 (TYPE > 0) is drawn. Between Points 3 and 4 either a straight line (TYPE \leq 1) or a parabola with zero slope at Point 3 (TYPE = 2) is drawn. A straight line is drawn between Points 4 and 5.

4.2 Application to Specific System

For the system based on the antenna patterns in Section 3.2 we have determined the spectral parameters for all combinations of $\alpha = 0$, 10°, 20°, 30° and $\omega = -45°$ to 45° in steps of 11.25° (in all cases $\beta = \delta = 0$ and $\gamma = 10°$). The results are shown in Figures 28 through 59, where the a. figure designates the "exact" case and the b. figure designates the approximate one. The agreement is generally within 1 dB throughout the 40 dB range for all cases. The parameters are summarized in Tables 5 through 8. All power values

(text continues on Page 49)


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Figure 33a. Clutter Spectra for $\alpha = 0$, $\omega = 11.25^{\circ}$





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Figure 47b. Approximation to Figure 47a

Figure 47a. Clutter Spectra for $\alpha = 20^{\circ}$, $\omega = -11.25^{\circ}$

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and a second second





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Figure 59b. Approximation to Figure 59a

Figure 59a. Clutter Spectra for $\alpha = 30^{\circ}$, $\omega = 33.75^{\circ}$

Table 5. Clutter Spectrum Parameters for Sum Channel (frequencies are normalized to $2V/\lambda_{\star}$ PEAK is in dB)

•	ALPHA	-45.00	-33. 75	-22, 50	-11.25	0750A 0.00	11.25	22. 50	39.75	45.00
F1	0	. 956	. 956	- 955	. 754	753	. 754	953	955	. 954
	10	. 896	. 897	394	. 372	.370	. 970	892	. 394	. 396
	20	. 810	. 310	- 308	. 303	.300	. 800	802	. 805	. 310
	30	. 697	. 698	- 697	. 470	.489	. 886	689	. 692	. 497
52	0 20 30	972 924 850 749	97 <u>0</u> 922 . 349 . 747	. 971 922 . 345 . 743	920 920 843 740	970 . 920 . 841 . 736	. 970 . 922 . 343 . 739	771 724 845 741	. 972 926 . 849 . 743	. 97 <u>2</u> . 926 . 930 . 749
F3	0	. 784	. 984	. 785	. 985	. 984	. 994	. 784	. 984	, 984
	10	. 7 80	. 980	. 780	. 980	. 7 60	. 990	. 780	. 780	, 980
	20	. 730	. 925	. 725	. 925	. 933	. 735	. 733	. 733	, 930
	30	. 856	. 852	. 348	. 852	. 860	. 964	. 964	. 840	, 854
F4	0	985	. 985	- 785	. 985	. 985	. 995	. 985	. 985	. 985
	10	985	. 985	- 785	. 985	. 985	. 785	. 985	. 985	. 985
	20	975	. 975	- 777	. 979	. 973	. 977	. 975	. 975	. 975
	30	933	. 935	- 738	. 939	. 940	. 939	. 935	. 934	. 933
F5	0 10 20 30	985 985 983 983 956	985 783 783 958	985 985 985 983 959	. 785 . 785 . 783 . 757	. 985 . 985 . 983 . 983 . 959	. 985 . 985 . 953 . 958	985 995 983 983	. 985 . 985 . 983 . 983	985 985 983 983
PEAK	0	40, 0	40, 0	40, 0	40. 0	40, 0	40. 0	40, 0	40, 0	40, 0
	10	40, 0	40, 0	40, 0	40. 0	40, 0	40. 0	40, 0	40, 0	40, 0
	20	40, 0	40, 0	40, 0	40. 0	40, 0	40. 0	40, 0	40, 0	40, 0
	30	40, 0	40, 0	40, 0	40. 0	40, 0	40. 0	40, 0	40, 0	40, 0
TYPE	0 10 20 30	0 6 14 64	0. U U U	0 11 11 11	0 CA CA CA	เมณฑ	כי נא נא נא	C (2 A A	0 0 0 0	0 (N (N (N

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Table 6. Clutter Spectrum Parameters for Left-lobe of $\triangle Az$ Channel

(frequencies are normalized to $2V/\lambda\,,$ PEAK is in dB)

						Oreser				
)	ALPHA	~43.00	-33.75	-22, 50	-11.23	ంేంం	11 25	22, 50	33, 75	45 00
Fl	0	94 <u>2</u>	917 913	-12	. 941 544	940	01 <u>1</u> 27-	. 942 555	. 942 966	54 <u>5</u>
	20	. 000	744	745	725	. 000	770	7000	510	370
	20	. / 30	. / 30		. 700 434	- 797		. <u></u> .	7070 .070	714
	20	. 345	. 340		. 044	. 640		هير برت	. 2 / 7	. / 10
52	9	955	. 963	9.51	95 9	957	753	. * = 1	540 5	265
	10	. 902	. 900	3-9	394	375	900		= 10	
	20	. 815	. 810	308 -	203	303	8.3	520 720	320	. 340
	30	. 704	. 578	. 575	595	. 473	. 709	- 798	. 7/20	730
F3	0	. 984	. 984	. 984	984	993	994	984	984	. 984
	10	. 952	. 953	. 954	. 950	947	742	. 3 58	. 728	. 915
	20	. 905	. 999	. 895	. 889	. 983	. 379	. 870	. 857	. 848
	30	. 522	. 812	. 808	. 800	. 794	. 786	. 780	. 764	. 750
F4	0	. 785	. 985	985	985	985	. 985	985	995	985
	10	. 784	. 982	. 978	. 976	. 968	961	952	938	. 920
	20	. 959	. 950	. 941	. 931	. 920	910	. 395	. 876	. 860
	30	900	. 897	. 874	. 850	. 847	. 832	. 814	. 789	. 765
FS	0	. 985	. 985	. 995	. 985	985	. 985	. 985	985	. 985
	10	. 985	. 985	. 980	975	. 970	- 2 64	953	944	. 932
	20	. 968	. 958	_ 948	. 935	. 925	. 912	, 2 00	- 883	. 858
	30	. 914	. 900	. 384	. 369	852	. 836	. 320	. 796	. 7 53
PEAK	0	37. 5	35, 3	32, 3	31.0	29.0	30. 0	32. 3	35, 3	37. 5
	10	37.5	36.1	34.4	32.1	28. 1	23.0	15.4	7.4	Ū į
	20	38.0	36.7	35, 1	32.9	29.5	24, 3	18.7	10.2	. 0
	30	38. 0	36.7	35 1	33. 0	30. 0	23.7	21. 1	12.5	. 0
TYPE	0	n	o	o	o	0	ñ	n	ŝ	o
7 ft han	. 10	Ĩ	2	2	. . .	ž	2	2	2	Ĩ
	20	114	2	2	- C.4	i i	1 T T		e	2
	30	2	ĩ	2	2	6.1	2	2	6	2

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Table 7. Clutter Spectrum Parameters for Right-lobe of ΔAz Channel

(frequencies are normalized to $2V/\lambda$, PEAK is in dB)

				· ·		UME SA.	• .		• • •	• • • •
•	ацрна	-45,00	-33, 75	-22, 50	-11.25	0,00	11.25	22, 50	23, 75	45.00
FL	0	. 000	. 000	. 000	. 000	000	. 909	. 000	. 000	. 200
	10	.000	. 000	. 980	975	. 970	. 754	P35	₹44	. 732
	20	968	. 955	. 948	935	- 725	. 912	, ≈00	883	. 358
•	30	. 914	. 900	. 884	. 869	. 852	836	. 820	. 796	. 753
F2	Q	. 000	. 000	. ೦೦೦	. 000	. 000	. 000	000	000	. 00 0
	10	. 000	. 060	. =80	977	972	. 968	782	73 3	948
	20	. 971	. 960	949	43 9	930	-20	210	393	883
	30	. 926	. 704	. 871	. 972	. 360	. 944	835	. 816	. 788
F3	o	. 000	. 000	. 000	000	000	. 000	. 000	. 000	. 000
	10	. 000	. 000	. 954	?34	634	<u>் 5</u> 27		. 984	. 784
	20	. 975	. 970	. 905	. 753	÷.⇒0	. 738	955	953	. 748
	30	. 932	. 720	. 914	. 908	. 905	. 902	. 900	872	. 580
F4	o	. 000	. 000	. 000	. 000	000	. 000	. 000	. 000	. 000
	10	. 000	. 000	. 785	. 983	. 795	. 985	. 985	. 985	. 985
	20	. 979	. 781	. 983	. 982	.984	. 985	985	. 953	. 984
	30	942	. 749	. 944	. 955	. 957	958	. 957	. 955	. 954
F5	0	. 000	. 000	. 000	. 000	. 000	. 000	. 000	. 000	. 000
	10	. 000	. 000	. 985	. 985	985	. 785	785	> 85	985
	20	984	984	. 985	. 985	. 985	. 9 <u>05</u>	985	985	785
•	30	. 948	. 958	. 964	. 968	. 971	. 971	. 971	. 971	. 971
PEAK	0	. 0	. 0	. 0	. 0	. 0	. 0	. 0	. 0	. 0
	10	. 0	. 0	27.0	33.1	37.0	39.4	41.9	41.7	42.0
	20	2.5	14.7	22. 5	28.3	32.5	35. 2	37.1	38.4	37.8
•	30	4, 0	15.2	22. 5	27 9	31.8	34. 4	36. 3	37. 3	39.7
TYPE	Ō	0	0	0	n	٥	o	a	0	n
_	, 10		J	ō	ō	ō	ō	, S	Ó	õ
	120	3	2	2	2	2	2	2	2	2
	30	Ĩ	2	2		â	2	2	2	2

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Table 8. Clutter Spectrum Parameters for Δ El Channel (frequencies are normalized to 2V/ λ , PEAK is in dB)

							. OMEGA.				45 00
		ALPHA	-45.00	-33. 75	-22, 50	~11,25	0,00	11.25	22.50	33.70	43.00
•	F1	0 10 20 30	. 942 . 932 . 859 . 753	. 944 . 915 . 838 . 729	. 946 . 906 . 322 . 711	. 950 . 395 . 303 . 375	. 952 . 888 . 799 . 684	. 9 50 . 876 . 788 . 672	. 946 . 874 . 778 . 861	. 944 . 370 . 772 . 352	. 9 42 . 345 . 763 . 645
٠	F2	0 10 20 30	, 746 , 748 , 883 , 788	. 966 . 940 . 870 . 772	. 966 . 934 . 858 . 758	. 767 . 926 . 848 . 744	969 916 338 732	967 . 7 12 . 830 . 724	. 966 . 908 . 824 . 715	. 755 . 904 . 318 . 70 7	. 965 . 902 . 315 . 704
٠	F3	0 10 20 30	. 984 . 934 . 948 . 880	, 984 , 984 , 943 , 874	. 984 . 984 . 938 . 938	. 995 . 993 . 935 . 862	. 985 . 980 933 . 860	, 985 , 977 , 929 , 854	. 995 . 974 . 923 . 848	. 785 . 972 . 715 . 835	. 985 . 970 . 906 . 822
•	F4	0 10 20 30	985 985 984 954	. 785 . 785 . 782 . 752	. 985 . 985 . 982 . 982 . 950	. 985 . 985 . 980 . 945	. 985 . 985 . 978 . 978 . 941	, 985 , 985 , 975 , 935	,995 ,995 ,971 ,929	. 985 . 985 . 967 . 919	. 985 . 964 . 959 . 900
٠	FS	0 10 20 30	. 985 . 985 . 985 . 971	. 785 . 785 . 785 . 785 . 769	. 985 . 983 . 983 . 983	, 995 , 995 , 995 , 985 , 964	985 985 985 985 960	, 785 , 785 , 785 , 755	. 985 . 985 . 985 . 985 . 949	- 985 - 785 - 785 - 742	. 985 . 985 . 985 . 935
٠	PEAK	0 10 20 30	37, 5 42, 0 39, 8 39, 7	39.3 42.4 40.5 40.5	40.6 42.5 41.3 41.2	41, 5 42, 5 41, 8 41, 7	40, 8 41, 9 41, 9 41, 9	40, 5 40, 9 41, 2 41, 4	40: 6 39: 3 40: 4 40: 7	39.3 19.7 39.4 39.3	37, 5 37, 5 38, 0 38, 0
٠	TYPE	10 10 20 30	0 1 2 2	012		0	0 - (1 N	0 M M W	କୁ ମ ମ ଲ	0 to 19	لې د. لې د دو د.

are referenced to the -40 dB level below the sum-channel peak (i.e., the sum channel peak has a value of 40 dB). The azimuth-difference channel is characterized by two lobes, designated by "right" and "left" in the tables, where the orientation is with respect to the spectrum. In some cases the right lobe is below the reference level; the parameters are set to zero to designate this situation.

In Tables 5 through 8 a constant value of $\Delta = \gamma - \beta = 10^{\circ}$ was assumed. In Section 3.7 it was shown that the spectral parameters are also a function of Δ . The dependence is slight for all parameters except the peak power values for the various azimuth-and elevation-difference channel lobes. Here the effect is strong as we see in Table 1. To include the dependence of Δ on the peak power values, the parameters in Tables 6 through 8 should be adjusted by the values in Table 1 in a procedure that is consistent with the examples in Section 3.8.

5. SIMULATION ARCHITECTURE

The computer resources that are available at the RFSS to generate clutter signals consist of a Datacraft/l minicomputer that acts as a host to the AP120B array processor built by Floating Point Systems. The input to the host computer consists of the state of the engagement geometry (θ_0 , ϕ_0 , r, δ , ω , h, V) and the output of the AP120B is the set of three clutter timesequences. In deciding which operations are to be assigned to the two processors, the following factors were applied:

- the array processor works best on arrays where the number of operations on each sample is few;
- the program construction is costly for the array processor so that program should be fairly stable;
- 3) modifications are best made in the host computer; and
- there should be relatively little traffic over the real-time interface between the host computer and the array processor.

With these factors in mind, the assignment of the various processing steps to generate clutter signals reduces naturally to:

The host computer

- 1. derive and/or transform engagement geometry
- 2. compute spectral parameters

The array processor

- 1. compute power spectral arrays
- 2. randomize spectra
- 3. take Fourier transform to time domain
- 4. weight, overlap, and sum time sequences
- 5. normalize time sequences to reference power

In order to minimize the computation load on the host computer, one should take advantage of table-lookup procedures to compute the spectral parameters. The real-time interface between the host computer and the array processor consists of, at most, 28 parameters if the format of Section 4 is used.

In Appendix C we describe and give listings for a clutter simulation program that conforms to the above architecture.

References

- 1. Mitchell, R. L., Radar Signal Simulation, Artech House, 1976, p. 113.
- Mitchell, R. L., and I. P. Bottlik, "Design Requirements for Simulating Realistic RF Environment Signals on the RFSS," MRI Report 132-44, 23 Sept. 1977.

APPENDIX A

COORDINATE TRANSFORMATIONS FOR GROUND CLUTTER

There are several coordinate systems involved for the ground clutter as observed by a missile-borne radar. The transformations from one system to another are derived here. We begin with a transformation derived in Reference 2 (Appendix A), where one typographical error is corrected. Arbitrary Point on Ground to Antenna Coordinates

Let us begin with the geometry of Figure 60 where R designates the location of the radar at the origin of a rectangular coordinate system referenced to the ground, $\overline{\text{RV}}$ designates the velocity vector which is contained in the y-z plane by definition, and P is the point of interest. We can define the dive angle of the missile as δ , the azimuth and depression angles of point P as ζ and γ , respectively, and ψ as the Dopple: angle. Designating the direction cosines a_x , a_y , a_z on the x, y, z axes, we can write

$$a_x = \cos\gamma \sin\zeta$$

 $a_y = \cos\gamma \cos\zeta$ (A-1)
 $a_z = -\sin\gamma$

To define missile coordinates we can rotate the x-axis clockwise (looking in) by δ so that the new y-axis corresponds to the velocity vector. Now the direction cosines in the new coordinate system are

$$b_{x} = a_{x}$$

$$b_{y} = a_{y} \cos \delta - a_{z} \sin \delta \qquad (A-2)$$

$$b_{z} = a_{y} \sin \delta + a_{z} \cos \delta$$

Note that $\cos \delta = b_{y}$ or

$$\cos \psi = \cos \gamma \cos \zeta \cos \delta + \sin \gamma \sin \delta$$
 (A-3)

If the missile rotates (rolls) by an amount ω counterclockwise looking out • the velocity vector, then we can rotate the previous y-axis by the corresponding angle. Defining the new z-axis to be the missile "vertical" axis, we obtain new direction cosines as



Figure 60. Geometry of Arbitrary Point on Ground

$$c_{x} = b_{x} \cos \omega + b_{z} \sin \omega$$

$$c_{y} = b_{y} \qquad (A-4)$$

$$c_{z} = -b_{x} \sin \omega + b_{z} \cos \omega$$

We have now arrived at the geometry of Figure 61 where θ_0 and ϕ_0 are the azimuth and elevation angles, respectively, for the antenna boresight (in this derivation we assume that the longitudinal axis of the missile is coincident with the velocity vector). To define a coordinate system referenced to the antenna, we will first rotate the x-axis in Figure 61 clockwise by θ_0 to obtain the new direction cosines as

$$d_{x} = c_{x} \cos\theta_{0} - c_{y} \sin\theta_{0}$$

$$d_{y} = c_{x} \sin\theta_{0} + c_{y} \cos\theta_{0}$$
 (A-5)

$$d_{z} = c_{z}$$

Now rotate the x-axis counterclockwise by $\boldsymbol{\varphi}_{0}$ to obtain the new direction cosines as



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Figure 61. Missile Geometry

$$e_{x} = d_{x}$$

$$e_{y} = d_{y}\cos\phi_{0} + d_{z}\sin\phi_{0}$$

$$e_{z} = -d_{y}\sin\phi_{0} + d_{z}\cos\phi_{0}$$
(A-6)

Finally, we can reference Point P to the antenna coordinates as in Figure 62 where the antenna azimuth (θ) and elevation (ϕ) angles are given by

$$\tan \theta = e_x/e_y$$
 (A-7)
 $\sin \phi = e_z$ (A-8)

Antenna Boresight $(\alpha,\beta) \neq (\theta_{0},\phi_{0})$

In Figure 60 we can define $\zeta = \alpha$ and $\gamma = \beta$ so that Point P is the intersection of the antenna boresight vector with the ground as shown in Figure 63. The transformation then follows (A-1) through (A-4) so that

$$a_{x} = \cos\beta \sin\alpha$$

$$a_{y} = \cos\beta \cos\alpha$$
(A-9)
$$a_{z} = -\sin\beta$$

/ and



Figure 63. Geometry for Antenna Boresight

$$b_x = a_x$$

$$b_y = a_y \cos \delta - a_z \sin \delta$$
 (A-10)

$$b_z = a_y \sin \delta + a_z \cos \delta$$

and

.

$$c_{x} = b_{x} \cos \omega + b_{z} \sin \omega$$

$$c_{y} = b_{y}$$

$$c_{z} = -b_{x} \sin \omega + b_{z} \cos \omega$$
(A-11)

These direction cosines define the A-vector in Figure 61, so that

$$\tan \theta_0 = c_x/c_y \qquad (A-12)$$

$$\sin \phi_0 = c_z \qquad (A-13)$$

Antenna Boresight $(\theta_{0}, \phi_{0}) \rightarrow (\alpha, \beta)$

This transformation is the inverse of the one just derived. We begin with the A-vector in Figure 61, which has direction cosines

$$c_{x} = \cos\phi_{0} \sin\theta_{0}$$

$$c_{y} = \cos\phi_{0} \cos\theta_{0}$$

$$c_{z} = \sin\phi_{0}$$
(A-14)

To obtain the direction cosines of the A-vector in a coordinate system that has the z-axis in a plane vertical to the ground we must rotate the old y-axis by ω in the counterclockwise direction (looking in) so that

$$b_{x} = c_{x} \cos \omega - c_{z} \sin \omega$$

$$b_{y} = c_{y}$$

$$b_{z} = c_{x} \sin \omega + c_{z} \cos \omega$$

(A-15)

The missile dive angle δ is referenced to the horizontal so we can define a new coordinate system referenced to the ground, that in Figure 63, by rotating the old x-axis by δ in the counterclockwise direction (looking in). The new direction cosines are

$$a_{x} = b_{x}$$

$$a_{y} = b_{y} \cos \delta + b_{z} \sin \delta$$

$$a_{z} = -b_{y} \sin \delta + b_{z} \cos \delta$$
(A-16)

The A-vector is now defined by

$$\tan \alpha = \frac{a_x}{a_y}$$
$$\sin \beta = -\frac{a_z}{z}$$

APPENDIX B

ANGLE BETWEEN TWO PLANES

Plane 1: Vertical plane containing antenna boresight axis Plane 2: Plane containing antenna boresight axis and antenna ϕ -axis

Assume that the missile dive angle is δ , the missile roll angle is ω , and the antenna boresight axis is at an angle (θ_0, ϕ_0) from the velocity vector. The direction cosines of the antenna boresight axis in the groundreferenced coordinate system (the A-vector in Figure 63) are given by the coordinate transformations in (A-14) through (A-16), which we denote as (a_x, a_y, a_z) . If we replace ϕ_0 by $\phi_0 + 90^\circ$ in these transformations, we define a vector that is coincident with the antenna ϕ -axis. Let us designate the direction cosines of this vector as (a'_x, a'_y, a'_z) . A vector that is perpendicular to the A-vector in the vertical plane has the direction cosines

$$a_{xN} = a_{x}a_{z}/a_{zN}$$

$$a_{yN} = a_{y}a_{z}/a_{zN}$$

$$a_{zN} = \sqrt{a_{x}^{2} + a_{y}^{2}}$$
(B-1)

The two vectors A' and A_N , defined by their direction cosines (a'_x, a'_y, a'_z) and (a_{xN}, a_{yN}, a_{zN}) , respectively, are both perpendicular to the A-vector, which is the intersection of the two planes of interest. The cosine of the angle between these two vectors is the dot product $\overline{A}' \cdot \overline{A}_N$. The sign of the angle is given by the sign of $(\overline{A}' \times \overline{A}_N) \cdot \overline{A}$, which can be rewritten as $(\overline{A}_N \times \overline{A}) \cdot \overline{A}'$. The direction cosines of $(\overline{A}_N \times \overline{A})$ are (-cosa, sina, o), so that

$$(\overline{A'} \times \overline{A_N}) \cdot \overline{A} = (\overline{A_N} \times \overline{A}) \cdot \overline{A'} = -a'_x \cos \alpha + a'_y \sin \alpha$$
 (B-2)

If (B-2) is positive the angle between the two planes is positive, and vice versa.

Instead of beginning with the coordinate (θ_0, ϕ_0) we could have begun with (α, β) as in Figure 63. The procedure then would be to obtain (θ_0, ϕ_0) by the use of (A-9) through (A-13), with the remaining calculation as outlined above.

The use of the above results is straightforward, but somewhat time consuming for real-time applications. We are thus motivated to find a faster method of computing the desired angle. Unfortunately, the direct analysis to find approximate solutions based on small angles is very cumbersome. But with a computer one can find through the process of trial and error the basic behavior of this function of four variables. After many iterations we have found

$$\xi = \omega + \alpha(\beta + (\delta - \beta)\cos\omega) + \frac{1}{4}((\delta - \beta)^2 - \alpha^2)\sin 2\omega - \frac{1}{3}\alpha(\delta - \beta)\omega^2\sin^22\omega$$
(B-3)

as the angle between the two planes of interest, where all angles are in radians. The solution has been evaluated for $0 \le \alpha \le 30^{\circ}$, $-20^{\circ} \le \beta \le 20^{\circ}$, $-20^{\circ} \le \delta \le 20^{\circ}$, and $-90^{\circ} \le \omega \le 90^{\circ}$. The error in the approximation is shown in Table 9. In general, the peak error is less than 1°, except when $|\delta-\beta|$ is large.

, ... -:

Table 9. Residual Errors in Approximation for Angle Between Two Planes (all angles in degrees)

APPENDIX C

FORTRAN PROGRAM FOR GENERATING REAL-TIME CLUTTER SEQUENCES

This Fortran program generates continuous time sequences of ground clutter that would be received on an airborne radar platform for a timevarying engagement geometry. Signals are generated for the three monopulse channels. It is assumed that these signals will be radiated into specific positions on the receive antenna pattern so that each signal will be received by the proper channel and rejected by the others.

This program was written for a single range gate of a pulse-Doppler radar, although it is easily extended to multiple range gates (but not in real time with a single AP120B). The organization of this program is sketched in Figure 64. At the RFSS it is assumed that the real-time state of the environment will be set up in COMMON/C1/ and periodic calls will be made to CLUTTR in the Datacraft/6. The subroutines that actually generate the clutter sequences (FILL, CURVE, PARAB, CONVRT, TIMESQ, GAUSS4, FOURT) will be implemented in the AP120B. Their Fortran equivalents are included in this package.

A test program (TEST) is also included to compare results on different computers. The output of this program is a power spectral estimate of the clutter sequences generated under stationary conditions.

Note: this program does not include an adjustment for Δ on the monopulse difference channel spectra as discussed in Sections 3.7 and 4.2. The modification is minor to include this adjustment, and only the portion of the program that resides in the host computer will be affected.



Figure 64. Block Diagram of Clutter Signal Program

STATISTICS.

PROGRAM SUMMARY

Main or Driver

TEST (for this example)

Initialization

RCDATA TIMSQI GAUSSI (GAUSS3,RAND)

Real-time Fortran

CLUTTR (GAIN) PARMS (AINT)

Utility

PR ACCUM POWSPT XMIT FOURT

Real-time AP120B

FILL
CURVE
PARAB
CONVRT
TIMESQ
GAUSS4
```
PROGRAM TEST(INPUT, OUTPUT, TAPE5=INPUT, TAPE6=OUTPUT)
C TEST OF SUBROUTINE CLUTTR
С
C THE TEST CASE CORRESPONDS TO ALPHA=20., BETA=0., GAMMA=10., DELTA=0., AND
C OMEGA=-22.5 (ALL DEGREES).
C
       DIMENSION SR(2240, 3), SI(2240, 3), S(200, 3), WORK(600)
      COMMON /C1/ WL, H, V, R, FR, DE, OM, THO, PHO
      COMMON /C2/ PTGDSQ, SIGO, DR
       COMMON /C3/ NFFT, NOVLP, NF, A(64)
       COMMON /C5/ PEFF,
     1
                    XR1(320), XI1(320), XR2(320), XI2(320), XR3(320), XI3(320)
С
C THE FOLLOWING PARAMETERS MUST BE SET....
C
      DATA WL, H, R, FR, V/. 02, 1736., 10000., 10000., 500. /
      DATA DE, DM, THO, PHO/O. , -. 3927, . 3244, . 1313/
      DATA PTGDSQ, DR, SIGO/1., 20., .01/
      DATA NFFT, NOVLP/256, 32/
 HERE WE INITIALIZE
С
С
      CALL RCDATA
      CALL TIMSQI
      CALL GAUSSI
С
 HERE WE GENERATE CONTIGUOUS TIME SEQUENCES IN THE SR AND SI ARRAYS
С
      L=1
      DO 20 I=1,10
      CALL CLUTTR
      CALL XMIT(NF, XR1, SR(L, 1))
      CALL XMIT(NF, XR2, SR(L, 2))
      CALL XMIT(NF, XR3, SR(L, 3))
      CALL XMIT(NF, XI1, SI(L, 1))
      CALL XMIT(NF, XI2, SI(L, 2))
      CALL XMIT(NF, XI3, SI(L, 3))
      L=L+NF
   20 CONTINUE
C HERE WE COMPUTE THE (AVERAGED) POWER SPECTRUM
C
      L=1
    / DO 30 I=1,11
      CALL POWSPT(SR(L, 1), SI(L, 1), 200, 200, 0., WORK)
      CALL POWSPT(SR(L, 2), SI(L, 2), 200, 200, 0., WORK)
      CALL POWSPT(SR(L, 3), SI(L, 3), 200, 200, 0., WORK)
      CALL ACCUM(SR(L, 1), S(1, 1), 200, I)
      CALL ACCUM(SR(L, 2), S(1, 2), 200, I)
```



SUBROUTINE RCDATA

C

C

C THIS SUBROUTINE READS THE CLUTTER DATA BASE INTO COMMON /C6/.

DIMENSION IW(4), W(22)

 COMMON /C6/ S(180), IS(4), A1(216), IA1(36), A2(180), IA2(36), E(216),

 1
 IE(36)

 DATA IW/10HIS.
 , 10HIA1.
 , 10HIA2.
 , 10HIE.

 DATA W/10HS1.
 , 10HS2.
 , 10HS3.
 , 10HS4.
 , 10HS4.

 1
 10HS5.
 , 10HA11.
 , 10HA12.
 , 10HA13.
 , 10HA12.

 2
 10HA14.
 , 10HA15.
 , 10HA1P.
 , 10HA22.
 , 10HA22.

3 10HA23....,10HA24....,10HA25....,10HA2P...., 4 10HE1....,10HE2....,10HE3....,10HE4...., 5 10HE5....,10HEP..../ READ 102, S

READ 101, IS READ 102, A1 READ 101, IA1 READ 102, A2 READ 101, IA2 READ 102, E READ 101, IE

PRINT 200

K1=1 K2=36 DO 10 L=1,5 PRINT 202,W(L),(S(K),K=K1,K2) K1=K1+36 K2=K2+36

10 CONTINUE

PRINT 201, IW(1), IS

```
K1=1

K2=36

DO 20 L=6,11

PRINT 202,W(L),(A1(K),K=K1,K2)

K1=K1+36

K2=K2+36
```

20 CONTINUE

, PRINT 201, IW(2), IA1

K1=1 K2=36 DO 30 L=12, 16

PRINT 202, W(L), (A2(K), K=K1, K2)

- 23684 -1.1 67 K1=K1+36 K2=K2+36 30 CONTINUE PRINT 201, IW(3), IA2 K1=1 K2=36 DQ 40 L=17,22 PRINT 202, W(L), (E(K), K=K1, K2) K1=K1+36 K2=K2+36 40 CONTINUE PRINT 201, IW(4), IE . RETURN 100 FORMAT(20F4. 0) 101 FORMAT(3612) 102 FORMAT(2(9F4.0,4X)) 200 FORMAT(1H1, 50HGROUND CLUTTER DATA BASE READ BY SUBROUTINE RCDATA/) 201 FORMAT(/1XA10, 3X3613) 202 FURMAT(/1XA10, 3X9F7. 3/(14X9F7. 3)) END

68 SUBROUTINE TIMSGI С THIS SUBROUTINE PERFORMS INITIALIZATION FOR SUBROUTINE TIMESO. С C THE INITIALIZATION PARAMETERS ARE..... С С NFFT = SIZE OF FFT (=2**INTEGER) C NOVLP = NUMBER OF SAMPLES THAT THE FFTS OVERLAP (NFFT/8 IS OK) C C THE ARRAYS MUST BE DIMENSIONED AS LARGE AS..... C C NFFT+NOVLP-1 XR1, XI1, ETC С NOVLP-1 A C COMMON /C3/ NFFT, NOVLP, NF, A(64) COMMON /C5/ PEFF, 1 XR1(320), XI1(320), XR2(320), XI2(320), XR3(320), XI3(320) NF=NFFT-NOVLP N1=NOVLP-1 N2=NFFT+N1 DO 10 K=1, N1 A(K)=K/FLOAT(NOVLP) **10 CONTINUE** CALL XMIT(-N2, 0., XR1) CALL XMIT(-N2, 0, , XR2) CALL XMIT(-N2, 0., XR3) CALL XMIT(-N2, 0., XI1) CALL XMIT(-N2, 0., XI2) CALL XMIT(-N2, 0., XI3) RETURN END

SUBROUTINE GAUSSI

C THIS SUBROUTINE FILLS ARRAYS TR AND TI WITH INDEPENDENT GAUSSIAN C RANDOM NUMBERS FOR USE WITH SUBROUTINE GAUSS4.

C ARRAYS TR AND TI MUST BE DIMENSIONED AS LARGE AS NTR+NMAX AND NTI+NMAX C RESPECTIVELY.

C IF N BELOW IS NOT EVEN, ADD 1 TO THE DIMENSION OF TI.

С

С

С

COMMON /GS/ IRSET, NTR, NTI, NMAX, KR, KI, TR(1253), TI(1353) DATA NTR, NTI/997, 1097/, NMAX/256/, KR, KI/1, 1/ N=NTR+NTI+2*NMAX DO 20 K=1, N, 2 CALL GAUSS3(TR(K), TR(K+1), 1.) 20 CONTINUE RETURN END

69

70 : SUBROUTINE GAUSS3(X, Y, P) C THIS SUBROUTINE GENERATES RANDOM PAIRS FOR THESE DISTRIBUTIONS..... С C CALL GAUSS3(X, Y, P).... GAUSSIAN COMPONENTS OF AVERAGE POWER P C CALL RANG3(X, Y, P).... RANDOM PHASOR COMPONENTS OF POWER P С DATA Z/0. / С)X(FNAR=)X(DNAR IF(P) 30, 20, 10 . 10 E=SQRT(-P*ALOG(RAND(Z))) GO TO 15 ENTRY RANG3 IF(P) 30, 20, 12 12 E=SQRT(P) 15 A=RAND(Z) A=A+A-1. B=RAND(Z) B=B+B-1. A2=A+A B2=B*B C=A2+B2 IF(C.GT. 1.) GO TO 15 X=E+(A2-B2)/C Y=E+2. +A+B/C RETURN 20 X=0. Y=0. RETURN 30 STOP 44 END

FUNCTION RAND(Z) C FOR TEST PURPOSES ONLY. DIMENSION A(8) DATA A/.1,.2,.3,.4,.5,.6,.7,.8/ DATA K/1/ RAND=A(K) K=K+1 IF(K.GT.8) K=1 RETURN END

-	·
	SUBROUTINE CLUTTR
	C
	C IN THIS SUBROUTINE WE GENERATE THE CLUTTER MODULATION SIGNALS FOR ONE C RANGE GATE ON EACH OF THREE MONOPULSE CHANNELS.
٠	C THE BACKSCATTER COEFFICIENT OF THE GROUND IS ASSUMED TO VARY AS THE C SINE OF THE GRAZING ANGLE.
	C THE REAL-TIME PARAMETERS ON INPUT ARE
٠	C WL = WAVELENGTH C H = PLATFORM ALTITUDE C V = PLATFORM VELOCITY C R = RANGE TO RANGE GATE OF INTEREST (UNAMBIGUOUS)
٠	C FR = EQUIVALENT SAMPLE RATE IN RECEIVER (PROCESSING BAND) C DE = DELTA, THE MISSILE DIVE ANGLE C OM = OMEGA, THE MISSILE ROLL ANGLE (CCW IS POSITIVE) C THO = THETA-ZERO, THE AZIMUTH ANGLE OF THE ANTENNA BORESIGHT C PHO = PHI-ZERO, THE ELEVATION ANGLE OF THE ANTENNA BORESIGHT
	C THE NONREAL-TIME PARAMETERS ON INPUT ARE C
۲	 C PTQDSQ = PRODUCT OF TRANSMIT POWER, GAIN, SQUARE OF CHAMBER LENGTH C DR = RANGE RESOLUTION C SIGO = GROUND BACKSCATTER COEFFICIENT AT 30-DEG GRAZING ANGLE
	C THE REAL-TIME OUTPUT FOR THAT PORTION COMPUTED IN THE DATACRAFT IS C THROUGH /C4/, AND IT IS COMPUTED IN SUBROUTINE PARMS.
•	C SOME OF THE OTHER QUANTITIES USED IN THIS SUBROUTINE ARE
	C AL = ALPHA, THE AZIMUTH ANGLE OF THE BEAM AXIS IN GROUND COORD. C BE = BETA, THE ELEVATION ANGLE OF THE BEAM AXIS IN GROUND COORD. C GA = GAMMA, THE GRAZING ANGLE AT THE RANGE RING ON THE GROUND
•	C ALL ANGLES ARE IN RADIANS AND ALL DISTANCES IN METERS.
_	COMMON /C1/ WL,H,V,R,FR,DE,OM,THO,PHO COMMON /C2/ PTGDSG,SIGO,DR COMMON /C3/ NFFT DATA FCTR/1 /
•	C C COMPUTE GEOMETRY AND DOPPLER PARAMETERS
	C / SGA=H/R
•	CQA=SQRT(1SGA++2) QA=ATAN(SGA/CGA) CPHO=COS(PHO) SPHO=SIN(PHO) CTHO=COS(THO)
•	

STHO=SIN(THO) COM=COS(OM) SOM=SIN(OM) CDE=COS(DE) SDE=SIN(DE) AX=CPHO*STHO AY=CPHO*CTHO AZ=SPHO BX=AX+COM-AZ+SOM BY=AY BZ=AX*SOM+AZ*COM CX = BXCY= BY*CDE+BZ*SDE CZ=-BY*SDE+BZ*CDE AL=ATAN(CX/CY) BE=ATAN(-CZ/SQRT(1.-CZ**2)) PEFF=. 013*PTGDSQ*(2. *SIGO*SGA)*DR*GAIN(GA-BE)/R**3 FMAX=2. +V/WL FMC =FMAX*(CGA*CDE+SGA*SDE) FSCL=. 9848*FMAX/FMC IAMB=FMC/FR FNP1=(IAMB-1)*FR*FSCL/FMAX DFNP=FNP1/FLOAT((IAMB-1)*NFFT) FNP1=, 9848-FCTR*(, 9848-FNP1) DFNP=FCTR+DFNP ALD=57. 3*AL OMD=57. 3*0M IF(ALD. GT. 0.) GD TD 10 OMD=360. -OMD ALD=-ALD 10 OMDP=OMD IF (OMD. GT. 315.) OMDP=OMDP-360. ICASE=(OMDP+45.)/90. CMDP=OMDP-ICASE*90. IROT=0 IF(ICASE. EQ. 1. OR. ICASE. EQ. 3) IROT=1 С)/4. 21E, 4. 9F3, 1. 9F2, 1. 8F3, 4. 8F3, 4I3/.... RTTULC H21/(TAMROF OD С FFEP, PNFD, 1PNF С , LCSF, CMF, XAMF, PDMO, DMO, DLA, EB, LA, AG, TORI, ESACI, BMAI, 001 TNIRP С C COMPUTE REAL-TIME PARAMETERS С CALL PARMS(ALD, OMDP, FNP1, DFNP) C GENERATE REAL-TIME SPECTRA Ĉ IROT=0 IF(ICASE. EQ. 1. OR. ICASE. EQ. 3) IROT=1 CALL FILL(IROT) RETURN END

FUNCTION GAIN(PHI) С C HERE WE COMPUTE THE 2-WAY POWER GAIN BY TABLE LOOKUP. PHI IS THE C ANGLE IN RADIANS. С С NB = NUMBER OF SAMPLES IN TABLE С DB = SAMPLE SPACING (DEG) C C THE FIRST SAMPLE IS AT PHI=O. С DIMENSION BEAM(101) DATA NB/101/, DB/. 5/ DATA A/. 00389/, 8/2. 30/ DATA NO/0/ IF (NO. GT. 0) GO TO 30 NO=1DO 20 K=1, NB BEAM(K)=EXP(-4, *A*((K-1)*DB)**B) 20 CONTINUE 30 E=57. 3*ABS(PHI) IE=E/DB+1.5 GAIN≈O. IF(IE. LE. NB) GAIN=BEAM(IE) RETURN END

```
SUBROUTINE PARMS(ALPHA, OMEGA, F1, DF)
C IN THIS SUBROUTINE WE COMPUTE THE REAL-TIME PARAMETERS THAT WILL BE
C SENT TO THE AP120B. THE PARAMETERS ARE DETERMINED BY INTERPOLATION
 WITHIN THE DATA BASE STORED IN COMMON /C6/.
С
C
C
  THE INPUT IS ....
С
C
       ALPHA = ABSOLUTE VALUE OF AZIMUTH ANGLE (DEG)
       OMEGA = MISSILE ROLL ANGLE (DEG, -45. LE. OMEGA. LE. 45. )
С
          F1 = NORMALIZED DOPPLER OF FIRST SAMPLE
C
C
          DF = SAMPLE SPACING IN DOPPLER
С
С
 THE OUTPUT IS THROUGH COMMON /C4/....
C
С
       IS, SPK. ..... SUM SPECTRUM PARAMETERS
       IA1, A1PK. ... DEL-AZ SPECTRUM PARAMETERS, LEFT HALF
С
С
       IA2, A2PK. ... DEL-AZ SPECTRUM PARAMETERS, RIGHT HALF
С
       IE, EPK. ..... DEL-EL SPECTRUM PARAMETERS
С
       PSL......SIDELOBE LEVEL (SEE SUBROUTINE FILL)
С
  SKP, A1PK, A2PK, EPK, AND PSL MUST BE IN THE SAME UNITS (NEPERS).
С
С
                                                                  TNIA LANRETXE
С
      COMMON /C4/ IS(6), IA1(6), IA2(6), IE(6), SPK, A1PK, A2PK, EPK, PSL
      COMMON /C6/ S1(36), S2(36), S3(36), S4(36), S5(36), IST(4),
              A11(36), A12(36), A13(36), A14(36), A15(36), A1P(36), IA1T(36),
     1
                       A22(36), A23(36), A24(36), A25(36), A2P(36), IA2T(36),
     2
                   E1(36), E2(36), E3(36), E4(36), E5(36), EP(36), IET(36)
     З
      COMMON /CINT/ K1, K2, K3, K4, HOM, HAL
      DATA NAL, NOM/4, 9/
      DATA DAL, DOM/10., 11.25/
      ISAMP(A) = (AINT(A) - F1)/DF+1.5
С
 HERE WE FIND THE PARAMETERS FOR INTERPOLATION
      AL=ALPHA/DAL
      IAL-AL
      HAL HAL - IAL
      IAL = IAL +1
         LAL GE NAL) HAL=1.
          AL JE NAL) IAL=NAL-1
                    . / DOM
           WEGA+45
```

76 K3=K1+NOM K4=K2+NOM KAL=ALPHA/DAL+1. 5 KAL=MINO(KAL, NAL) KOM=(OMEGA+45.)/DOM+1.5 K=(KAL-1)*NOM+KOM Ĉ C HERE WE COMPUTE THE REAL-TIME PARAMETERS C IS(1) = ISAMP(S1)IS(2) = ISAMP(S2)IS(3) = ISAMP(S3)IS(4) = ISAMP(S4)IS(5) = ISAMP(S5)IA1(1) = ISAMP(A11)IA1(2)=ISAMP(A12) IA1(3)=ISAMP(A13) IA1(4) = ISAMP(A14)IA1(5) = ISAMP(A15)IA2(1)=IA1(5) IA2(2)=ISAMP(A22) IA2(3)=ISAMP(A23) IA2(4) = ISAMP(A24)IA2(5) = ISAMP(A25)IE(1) =ISAMP(E1) IE(2) = ISAMP(E2)IE(3) = ISAMP(E3)IE(4) = ISAMP(E4)IE(5) =ISAMP(E5) SPK =40. PSL =0. A1PK=AINT(A1P) A2PK=AINT(A2P) EPK =AINT(EP) IS(6) = IST(KAL)IA1(6) = IA1T(K)IA2(6) = IA2T(K)IE(6) =IET(K) С C CONVERT DB TO NEPERS (AMPLITUDE) C SPK =. 11513*SPK A1PK=, 11513#A1PK A2PK=. 11513+A2PK EPK =. 11513*EPK PSL =. 11513*PSL RETURN END

FUNCTION AINT(A)

С

Ċ

C INTERPOLATION FOR SUBROUTINE PARMS

DIMENSION A(1) COMMON /CINT/ K1, K2, K3, K4, HOM, HAL A1=(1. -HOM)*A(K1)+HOM*A(K2) A2=(1. -HOM)*A(K3)+HOM*A(K4) AINT=(1. -HAL)*A1+HAL*A2 RETURN END

SUBROUTINE PR(A, NX, NY) С C IN THIS SUBROUTINE WE PRINT THE 2-DIMENSIONAL ARRAY A WITH THE FORMAT C EQUIVALENT TO THE DIMENSION A(NX, NY). С C THE PRINTING IS ON FILE LU, WHICH MUST BE EQUIPPED. С DIMENSION A(1) COMMON /MESGE/ MFLAG DATA LU/6/ IF(MFLAG. NE. 1) WRITE (LU, 100) MFLAG=0 DO 20 J=1, NY L1=(J-1)*NX+1L2=L1+9 L2MAX=J*NX L2=MINO(L2, L2MAX) DO 20 I=1, NX, 10 IF(I.LE.1) WRITE (LU, 101) J, (A(K), K=L1, L2) IF(1.GT. 1) WRITE (LU, 102) (A(K), K=L1, L2)L1=L1+10 L2=MINO(L2+10, L2MAX) 20 CONTINUE RETURN 100 FORMAT(1H1) 101 FORMAT(/14,2X10E12,4) 102 FORMAT(6X10E12.4) END

SUBROUTINE ACCUM(X,Y,N,IREP) C C IN THIS SUBROUTINE WE ACCUMULATE AN ARRAY. AT ALL TIMES ARRAY Y C REPRESENTS A RUNNING AVERAGE. C DIMENSION X(1),Y(1) IF(IREP.EQ.1) GO TO 30 REP=IREP DO 20 K=1,N Y(K)=((REP-1.)+Y(K)+X(K))/REP 20 CONTINUE RETURN 30 CALL XMIT(N,X,Y) RETURN END

SUBROUTINE POWSPT(XR, XI, NIN, NOUT, ALPHA, W) IN THIS SUBROUTINE WE COMPUTE THE POWER SPECTRUM OF THE COMPLEX TIME С С SEQUENCE IN THE ARRAY-PAIR (XR, XI) OF LENGTH NIN. THE POWER SPECTRUM C IS RETURNED IN ARRAY XR, AND IT IS NOW OF LENGTH NOUT. С C THE SAMPLE SPACING OF THE POWER SPECTRUM IS 1/NOUT OF THE REPETITION C FREQUENCY. С С A COSINE-ON-A-PEDESTAL WEIGHTING IS APPLIED TO THE INPUT SAMPLES. С ALPHA IS THE RATIO OF THE WEIGHTING FUNCTION AT THE EDGE TO THE С ALPHA=. 08 FOR HAMMING AND ALPHA=1. 0 FOR UNIFORM WEIGHTING. CENTER. C C ARRAY W IS A WORKING ARRAY AND IT MUST BE DIMENSIONED AS LARGE AS..... С C IF NOUT, EQ. 2**INTEGER NIN С NIN+2*NOUT IF NOUT. NE. 2**INTEGER С C THE WEIGHTS ARE NORMALIZED SO THAT THE SUM IS UNITY. DIMENSION XR(1), XI(1), W(1) DATA TWOP1/6. 2831853/ DATA NO/0/ IF (NO. GT. 0) GO TO 25 NO=1N=NOUT-NIN A=(1. +ALPHA)/2. B=(1. -ALPHA)/2. CN=(NIN+1)/2XN=NIN DO 10 K=1, NIN W(K) = A + B + COS(TWOPI + (K - CN)/XN)10 CONTINUE SUM=0. DO 15 K=1, NIN SUM=SUM+W(K) 15 CONTINUE WNORM=SUM DO 20 K=1, NIN W(K)=W(K)/WNORM 20 CONTINUE 25 IF(N) 60, 35, 30 30 CALL XMIT(-N, O., XR(NIN+1)) CALL XMIT(-N, O., XI(NIN+1)) 35 DO 40 K=1, NIN XR(K) = XR(K) + W(K)XI(K) = XI(K) + W(K)40 CONTINUE CALL FOURT(XR, XI, NOUT, 1, 1, 1, W(NIN+1), W(NIN+NOUT+1)) DO 50 K=1, NOUT

• • . . . • • . 81 XR(K)=XR(K)**2+XI(K)**2 50 CONTINUE RETURN 60 PRINT 100, NIN, NOUT STOP 100 FORMAT(/1X49H***ERROR IN POWSPT , NOUT IS SMALLER THAN NIN ***/ 1 /10X4HNIN=16, 10X5HN0UT=16) END ÷ 1

SUBROUTINE XMIT(N, A, B)

С

C IN THIS SUBROUTINE WE EITHER TRANSMIT ARRAY A TO ARRAY B (IF N. GT. O) C OR WE TRANSMIT THE CONSTANT A TO ARRAY B (IF N. LT. O). IN EITHER CASE C THE ARRAY LENGTH IS IABS(N). С C THIS SUBROUTINE SHOULD BE WRITTEN IN ASSEMBLY LANGUAGE C DIMENSION A(1), 3(1) IF(N) 10,20,25 10 NN=-N A=A(1)DO 15 K=1, NN B(K)=AA **15 CONTINUE** 20 RETURN 25 DO 30 K=1, N B(K)=A(K)30 CONTINUE RETURN END

SUBROUTINE FILL(IROT)

C IN THIS SUBROUTINE WE GENERATE THE REAL-TIME CLUTTER MODULATION C SIGNALS ON THE THREE MONOPULSE CHANNELS (FOR ONE RANGE GATE ONLY). C THIS SUBROUTINE, AS WELL AS SUBROUTINES CURVE, CONVRT, PARAB, TIMESG, C GAUSS4, AND FFT2, WILL BE IMPLEMENTED ON THE AP120B.

THE REAL-TIME INPUT IS THROUGH /C4/....

THE REAL-TIME OUTPUT IS THROUGH /C5/....

PEFF = EFFECTIVE POWER RADIATED FROM RFSS ARRAY (FROM SUB. CLUTTR) XR1 = REAL ARRAY CONTAINING SUM CHANNEL MODULATION SIGNAL XI1 = IMAG ARRAY CONTAINING SUM CHANNEL MODULATION SIGNAL XR2 = REAL ARRAY CONTAINING DAZ CHANNEL MODULATION SIGNAL XI2 = IMAG ARRAY CONTAINING DAZ CHANNEL MODULATION SIGNAL XR3 = REAL ARRAY CONTAINING DEL CHANNEL MODULATION SIGNAL XI3 = IMAG ARRAY CONTAINING DEL CHANNEL MODULATION SIGNAL

C IROT IS A ROTATION FLAG. IF IROT. GT. O THE AZ AND EL ARRAYS ARE C INTERCHANGED.

C THIS PROGRAM GENERATES A CONSTANT-LEVEL SIDELOBE SHOULDER OF (SPK-PSL) C DB BELOW THE SUM SPECTRUM PEAK. C

C ARRAYS S, A, AND E ARE FOR TEMPORARY STORAGE OF THE SUM, AZ- AND EL-C DIFFERENCE SPECTRA. THEY MUST BE DIMENSIONED AS LARGE AS 2*NFFT.

C THE DIMENSIONED ARRAYS IN COMMON /C5/ MUST ACCOMMODATE NFFT+NOVLP C WORDS (SEE TIMESQ).

 COMMON /C3/ NFFT

 COMMON /C4/ IS(6), IA1(6), IA2(6), IE(6), SPK, A1PK, A2PK, EPK, PSL

 COMMON /C5/ PEFF,

 1
 XR1(320), XI1(320), XR2(320), XI2(320), XR3(320), XI3(320)

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INITIALIZE ARRAYS TO SIDELOBE LEVEL

COMMON /C7/ S(512), A(512), E(512)

CALL XMIT(-NFFT2, PSL, S) CALL XMIT(-NFFT2, PSL, A) CALL XMIT(-NFFT2, PSL, E)

COMMON /LIM/ NFFT2

NFFT2=NFFT+2

С C GENERATE LOG-AMPLITUDE SPECTRA С CALL CURVE(S. IS, SPK) CALL CURVE(A, IA1, A1PK) CALL CURVE(A, IA2, A2PK) CALL CURVE(E, IE, EPK) С C CONVERT TO LINEAR AMPLITUDE AND FOLDOVER С SNORM=0. CALL CONVRT(S, SNORM) CALL CONVRT(A, SNORM) CALL CONVRT(E, SNORM) С C GENERATE TIME SEQUENCES С CALL TIMESQ(S, XR1, XI1) IF(IROT. GT. 0) GO TO 35 CALL TIMESQ(A, XR2, XI2) CALL TIMESQ(E, XR3, XI3) **GO TO 40** 35 CALL TIMESQ(A, XR3, XI3) CALL TIMESQ(E, XR2, XI2) 40 RETURN

END

SUBROUTINE CURVE(S, II, PK)

C

C THIS SUBROUTINE GENERATES A CURVE IN ARRAY S BETWEEN SAMPLES II(1) AND C II(5). THE CURVE IS DEFINED IN FOUR SEGMENTS BETWEEN FIVE POINTS C WHERE THE POINTS ARE GIVEN BY....

С С SAMPLE VALUE С C **II(1)** 0. С 11(2)PK/2. С II(3)PK С II(4)PK/2. С II(5)0. С II(6)=ITYP IS A PARAMETER THAT DEFINES THE TYPE OF SEGMENTS..... С С С ITYP SEGMENTS С С 0 LINE, LINE, LINE, LINE Ċ 1 LINE, PARAB, LINE, LINE C 2 LINE, PARAB, PARAB, LINE С С THE PARABOLA IS ALWAYS CONSTRAINED TO HAVE ZERO SLOPE AT THE CENTER C POINT. С DIMENSION S(1), II(6) COMMON /ABC/ A.B.C IF (PK. LE. O.) RETURN P2=. 5*PK ITYP=II(6) C C COMPUTE FIRST SEGMENT C=0. B=P2/AMAXO(II(2)-II(1), 1)A = -B + II(1)CALL PARAB(S, II(1), II(2)) COMPUTE SECOND SEGMENT С C IF(ITYP. GT. 0) GD TD 20 C=0. B=P2/AMAXO(II(3)-II(2),1)A=P2-B+II(2)**GO TO 25** 20 C=-P2/AMAXO(II(3)-II(2),1)**2 B = -2, +C + II(3)A=P2-B+II(2)-C+II(2)++2 25 CALL PARAB(S, II(2)+1, II(3))

C C COMPUTE THIRD SEGMENT C IF(ITYP.GT.1) GD TO 30 C=0. B=-P2/AMAXO(II(4)-II(3),1) A=PK-B*II(3) GD TO 35 30 C=-P2/AMAXO(II(4)-II(3),1)**2 B=-2.*C*II(3) A=PK-B*II(3)-C*II(3)**2 35 CALL PARAB(S,II(3)+1,II(4)) C C COMPUTE FOURTH SEGMENT C

C=O. B=-P2/AMAXO(II(5)-II(4),1) A=P2-B*II(4) CALL PARAB(S,II(4)+1,II(5))

RETURN



SUBROUTINE CONVRT(S, SNORM)

C IN THIS SUBROUTINE WE CONVERT THE SPECTRUM IN ARRAY S OF LOG-AMPLITUDE C UNITS TO LINEAR-AMPLITUDE UNITS. IN ADDITION, TWO PRF INTERVALS ARE C FOLDED (SUMMED). THE INPUT S-ARRAY IS OF LENGTH 2*NFFT AND THE OUTPUT C S-ARRAY IS OF LENGTH NFFT. AN APPROXIMATION IS USED IN THE DO-20 LOOP C FOR A FASTER COMPUTATION.

C FOR THE SUM SPECTRUM SET SNORM=ZERO ON INPUT (DO NOT USE THE CONSTANT C O., HOWEVER). THE NORMALIZATION FACTOR SNORM WILL BE RETUPNED. FOR C THE DIFFERENCE SPECTRA USE THIS SAME VALUE ON INPUT. C

DIMENSION S(1) COMMON /C3/ NFFT D0 20 K=1, NFFT S(K)=EXP(S(K)+S(K+NFFT)) 20 CONTINUE IF(SNORM.GT.O.) G0 TD 35 SUM=0. D0 30 K=1, NFFT SUM=SUM+S(K)**2

- 30 CONTINUE SNORM=1. /SQRT(SUM)
- 35 DO 40 K=1, NFFT S(K)=S(K)*SNORM
- 40 CONTINUE RETURN END

C



SUBROUTINE TIMESQ(SA, XR, XI) IN THIS SUBROUTINE WE GENERATE A CORRELATED TIME SEQUENCE THAT HAS AN C AMPLITUDE SPECTRAL FUNCTION DESCRIBED BY ARRAY SA OF LENGTH NFFT. THE C METHOD USED IS THE ON-LINE FFT APPROACH DESCRIBED IN SECTION 6 OF MRI C REPORT 132-44, WHERE SUCCESSIVE CALLS TO TIMESQ WILL CREATE CONTIGUOUS TIME SEQUENCES BASED ON OVERLAPPING FFTS IN THE FREQUENCY DOMAIN. C ON INPUT.... С С NFFT = SIZE OF FFT (=2**INTEGER) C NOVLP = NUMBER OF SAMPLES THAT THE FFTS OVERLAP (NFFT/B IS OK) С SA(K) = SPECTRAL AMPLITUDE OF KTH SAMPLE, K=1,...,NFFT С С С ON OUTPUT.... С С XR(K) = KTH SAMPLE OF IN-PHASE SIGNAL, K=1,..., NF XI(K) = KTH SAMPLE OF GUADRATURE SIGNAL, K=1, ..., NF С C С WHERE NF=NFFT-NOVLP. C C THE ARRAYS MUST BE DIMENSIONED AS LARGE AS..... С С SA NFFT С NFFT+NOVLP-1 XR C XI NFFT+NOVLP-1 C 8 NOVLP-1 С С NOTE THAT THE INFORMATION IS STORED IN THE XR AND XI ARRAYS FROM С NFFT+1 TO NFFT+NOVLP+1 THAT WILL BE USED ON THE NEXT CALL. PRIOR TO THE FIRST CALL TO TIMESQ THE INITIALIZATION SUBROUTINE (TIMSQI) MUST С С BE CALLED. C C THE WORK ARRAYS WRKR AND WRKI NEED BE DIMENSIONED ONLY IF NFFT, NE. C 244 INTEGER, IN WHICH CASE THE DIMENSION SIZE MUST BE NEFT. С DIMENSION WRKR(160), WRKI(160) DIMENSION SA(1), XR(1), XI(1) COMMON /C3/ NFFT, NOVLP, NF, A(1) CALL GAUSS4(SA, XR, XI, NFFT) CALL FOURT(XR, XI, NFFT, 1, 0, 1, WRKR, WRKI) N1=NOVLP-1 DO 20 K=1, N1 XR(K) = A(K) + (XR(K) - XR(K+NFFT)) + XR(K+NFFT)XI(K)=A(K)*(XI(K)-XI(K+NFFT))+XI(K+NFFT)XR(K+NFFT)=XR(K+NFFT-NOVLP) XI(K+NFFT)=XI(K+NFFT-NOVLP) 20 CONTINUE RETURN END

SUBROUTINE GAUSS4(A, XR, XI, N) C GENERATES RANDOM PHASOR COMPONENTS (XR(K), XI(K)) OF ZERO MEAN WITH THE C AVERAGE POWER OF XR(K) ** 2+XI(K) ** 2 GIVEN BY A(K) ** 2 FOR K=1, ..., N. C THE RANDOM NUMBERS ARE ACCESSED FROM RECIRCULATING TABLES. NTR AND NTI ARE THE CIRCULATION PARAMETERS AND NMAX=MAX(N). WE SHOULD CHOOSE С NTR AND NTI RELATIVELY PRIME. С С C ARRAYS TR AND TI MUST BE DIMENSIONED AS LARGE AS NTR+NMAX AND NTI+NMAX C RESPECTIVELY. С C IF IRSET=1 IN COMMON /GS/, THE POINTERS WILL BE RESTORED ON EXIT TO THEIR DRIGINAL VALUES WHEN GAUSS4 WAS ENTERED. THIS MEANS THAT THE C SAME GAUSSIAN SEQUENCE (EXCEPT FOR THE WEIGHTS A) WILL BE GENERATED ON С C THE NEXT CALL. С C PRIOR TO CALLING GAUSS4, THE RANDOM NUMBERS IN ARRAYS TR AND TI MUST C BE INITIALIZED WITH A CALL TO GAUSSI. DIMENSION A(1), XR(1), XI(1) COMMON /GS/ IRSET, NTR, NTI, NMAX, KR, KI, TR(1253), TI(1353) IF (N. GT. NMAX) STOP DO 35 I=1, N XR(I)=A(I)+TR(XR) XI(I) = A(I) + TI(KI)KR=KR+1 KI=KI+1 35 CONTINUE IF(IRSET. NE. 1) GO TO 40 KR=KR-N KI=KI-N 40 IF(KR. GT. NTR) KR=KR-NTR IF(KI.GT.NTI) KI=KI-NTI RETURN END

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