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JSME SCATTEROMETER DATA PROCESSING

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1.0 INTRODUCTION

In early 1976 the NASA Johnson Space Center (JSC) Earth
Observation Division contracted with the Remote Sensing Center
to develop and implement the hardware and software required to
process raw radar measurements acquired using the 0.4 GHz,
1.6 GHz, and 13.3 GHz scatterometers to normalized radar cross
section. These scatterometers had been taken out of retirement
during 1976 and mounted on the NASA C-130 aircraft to be flown
in support of the NASA funded Agriculture Soil Moisture Experi-
ment (previously termed the Joint Soil Moisture Experiment).

A data processing system was developed and implemented by
Texas A&M University in 1976. The processing system was
structured to consist of two phases. First, digital magnetic
tapes of raw scatterometer measurements and ADAS/NERDAS data
were generated using the Remote Sensing Center (RSC) TI-980
mini-computer, a four channel analog-to-digital converter con-
structed by the RSC, an ADAS/NERDAS discriminator constructed
by the RSC, and a fourteen track analog recorder supplied by
NASA Johnson Space Center as government furnished equipment.
These tapes were then processed to normalized radar cross
section using a software package implemented on the TAMU
Amdahl 470. This processing system was documented in the
initial "final report" on the contract [1]. The program was

unique in that it utilized Hilbert transforms to sign sense the scatterometer data and discrete digital Butterworth filters to select the component of the return correspondence to specific incident angles. Detailed flow charts for this system are included in Appendix A.

Radar scatterometer data acquired during the 1976 Joint Soil Moisture Experiment at the LACIE supersite in Finney County, Kansas and a test site at Lawrence, Kansas was processed using this processing system in 1977. In evaluating these data several questions were raised concerning its validity. As a result, considerable effort was devoted to the evaluation of data acquisition, data pre-processing and final data processing. During this evaluation it was discovered that the analog tape recorder that had been provided as government furnished equipment by NASA Johnson Space Center (JSC) could provide only marginal performance and was inadequate for processing scatterometer data. These problems were summarized in the quarterly progress review presented at NASA/JSC on September 22 and 23, 1977. The pertinent portions of this presentation are contained in Appendix B. As a result, another more suitable analog tape recorder was provided to TAMU by NASA/JSC for processing scatterometer data.

Also during this evaluation, several other sources of error were discovered. The most significant of these were: 1) poor performance of the Hilbert transform at low incident

angles, 2) use of average flight parameters for each flight line to compute cell geometry and area, 3) poor and/or inadequate flight log documentation leading to misinterpretation of sensor parameters, 4) poor communication between sensor system engineers at NASA and TAMU leading to the use of incorrect and/or outdated sensor calibration constants, and 5) inconsistent identification of the sign and cosine channels of each scatterometer, and misleading identification of channel assignments of these signals to tape recorder tracks on the analog magnetic tape labels.

After the above mentioned problem areas were discovered and many of them resolved, NASA/JSC began to implement a software processing system in hopes of being able to process future radar data in-house at less cost. TAMU was given additional funding by the NASA/JSC Earth Observation Division to support the establishment of this software system by the Engineering and Development Division and evaluate its performance in conjunction with the continuing evaluation of the TAMU software system. TAMU was also given permission to expand its processing capability to include the newly acquired 4.75 GHz scatterometer. Within this same time frame TAMU was contracted by NASA/JSC Engineering and Development Division to develop and design a real time hardware on-board processor for the 1.6 GHz and 4.75 GHz scatterometer systems. Therefore, the hardware processor design and software processor evaluation proceeded simultaneously.

The simultaneous activities on the hardware and software processing systems proved to be extremely beneficial. Primarily as a result of the new techniques that were being developed for the hardware processor [2], two new software systems were developed for processing scatterometer data. The Hilbert transform and discrete digital filter approach was abandoned in favor of approaches that relied on discrete Fourier transforms for sign sensing and filtering. The major advantage of this approach is that the filters can be modified during data processing as a function of aircraft parameters in order to maintain constant resolution and incident angle.

One system developed by TAMU relies on real valued discrete Fourier transforms of each scatterometer quadrature channel. Sign sensing is accomplished by algebraic manipulations of each of these transforms. This system is identical in processing procedure to the system developed by NASA/JSC. The other processing system developed by TAMU has the identical processing procedure that will be used in the on-board scatterometer hardware processors. This system relies on a single complex valued discrete Fourier transform to sign sense and filter the quadrature signals [2]. This system is the best in terms of speed of operation since 1.6 GHz, 4.75 GHz, and 13.3 GHz data only half of the number of Fourier transforms must be computed. And it provides identical results.

The evaluation phase of the effort involved much personal communication between TAMU and NASA/JSC employees. The many performance tests and equation derivation verifications that were painstakingly executed will not be included in this report. Suffice it to say that agreement was finally achieved between the software processing system at NASA/JSC and the two processing systems developed at TAMU utilizing Fourier transform techniques. However, the programs developed at TAMU and NASA/JSC are not identical in their manner of construction or execution. Parameters such as resolution, integration time, percent of data utilization, etc. are different for the two processing systems. Users of scatterometer data should be aware of these differences since they could have important implications in the analysis of certain data sets.

In the following text the software processing systems developed by TAMU as a final product will be described. Differences in these programs and the NASA/JSC program will be pointed out where appropriate. It should be noted that the TAMU software system utilizing the single complex discrete Fourier transform for sign sensing and filtering operates in exactly the same manner as the TAMU design for the real time hardware processor [2].

2.0 GENERAL SYSTEM DESCRIPTION

The software system described in this document is the final product of the project and is currently being used exclusively for all radar scatterometer data processed at TAMU. The general processing procedures are described in Figures 1-4. The first step in processing scatterometer data is to digitize the raw radar measurements as well as the ADAS or NERDAS data stream, Figure 1. Both quadrature channels of radar measurements are digitized simultaneously for one radar frequency at a time. ADAS or NERDAS data are discriminated and digitized at the same time and a computer compatible digital magnetic tape is generated that contains the radar measurements and time correlated ADAS/NERDAS data. The digitization rate of the A/D converter is software controlled and depends on the radar frequency being digitized.

The percentage data utilization is a function of the A/D process and varies for each radar frequency. One hundred per cent utilization would mean that all of the raw radar measurements are digitized. This does not occur for either the TAMU processor or the NASA/JSC processor. However, this does not mean that the final output product does not provide continous ground coverage.

The minimum integration time of the processor is set by the record lengths and A/D rate used during the A/D conversion process. Both the TAMU and NASA/JSC processor use the

STEP 1: Data Digitization

Raw Radar Data

Raw Radar Data
Digital

1 Record/Cell

4112 Bytes/Record (includes
aircraft parameters and
radar data)

Radar data - 1024 words/record
for each channel (sine and
cosine)
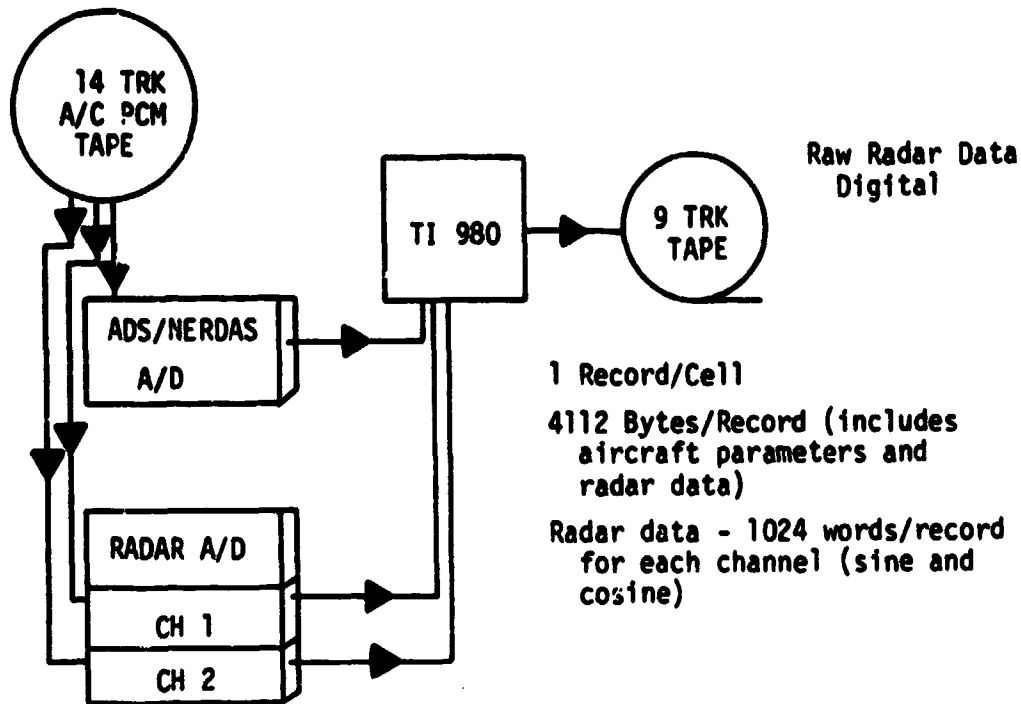
ADAS/NERDAS: Time, altitude, velocity, pitch, roll, drift

RADAR	Frequency	A/D Rate	Percentage Data Utilization
	13.3 GHz	25 KHz	16.4
	4.75 GHz	10 KHz	37.2
	1.6 GHz	5 KHz	51.2
	0.4 GHz	2.5 KHz	68.2

Figure 1. Simplified flow diagram of the first step of
the radar data processing procedure-Data
Digitization.

same record lengths and A/D rates. The minimum integration time determines the smear distance of a resolution cell. Although the basic integration times are the same between NASA/JSC and TAMU, NASA/JSC defines resolution differently than TAMU thereby causing the actual ground coverage obtained from the two processing systems generally to be different. This is discussed later.

Each radar frequency and polarization combination must be digitized individually. When this is complete, the 9 track computer compatible tape is used to input the digital data to the TAMU Amdahl 470 computer where the main processing software resides. The Amdahl 470 processes the measurements to normalized radar cross section using the program SCATTER.CZTA78 and produces both punched card and line printer output (Figure 2). The processed data are then put into report format for distribution using the TI-980 minicomputer, plotted for analysis purposes, or averaged as desired (Figure 3).

The principal component of the processing system is the program SCATTER.CZTA78. This program sign senses, filters, and computes the normalized radar cross section. A general flow chart of this program is shown in Figure 4.

In evaluating the processing system, each step of the process was investigated individually. The accuracy of the digitization process was tested and the ADAS and NERDAS

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STEP 2: Sigma Zero Computation
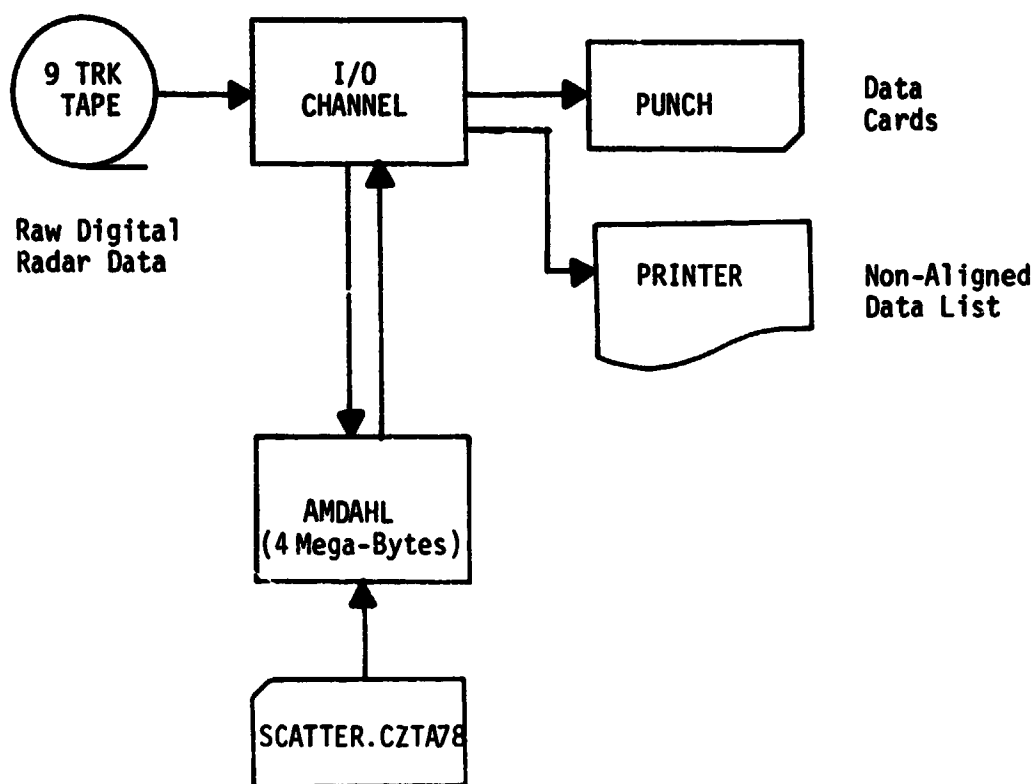
Figure 2. Simplified flow diagram of the second step
of the processing procedure - Sigma Zero
Computation.

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STEP 3: Output Product Production
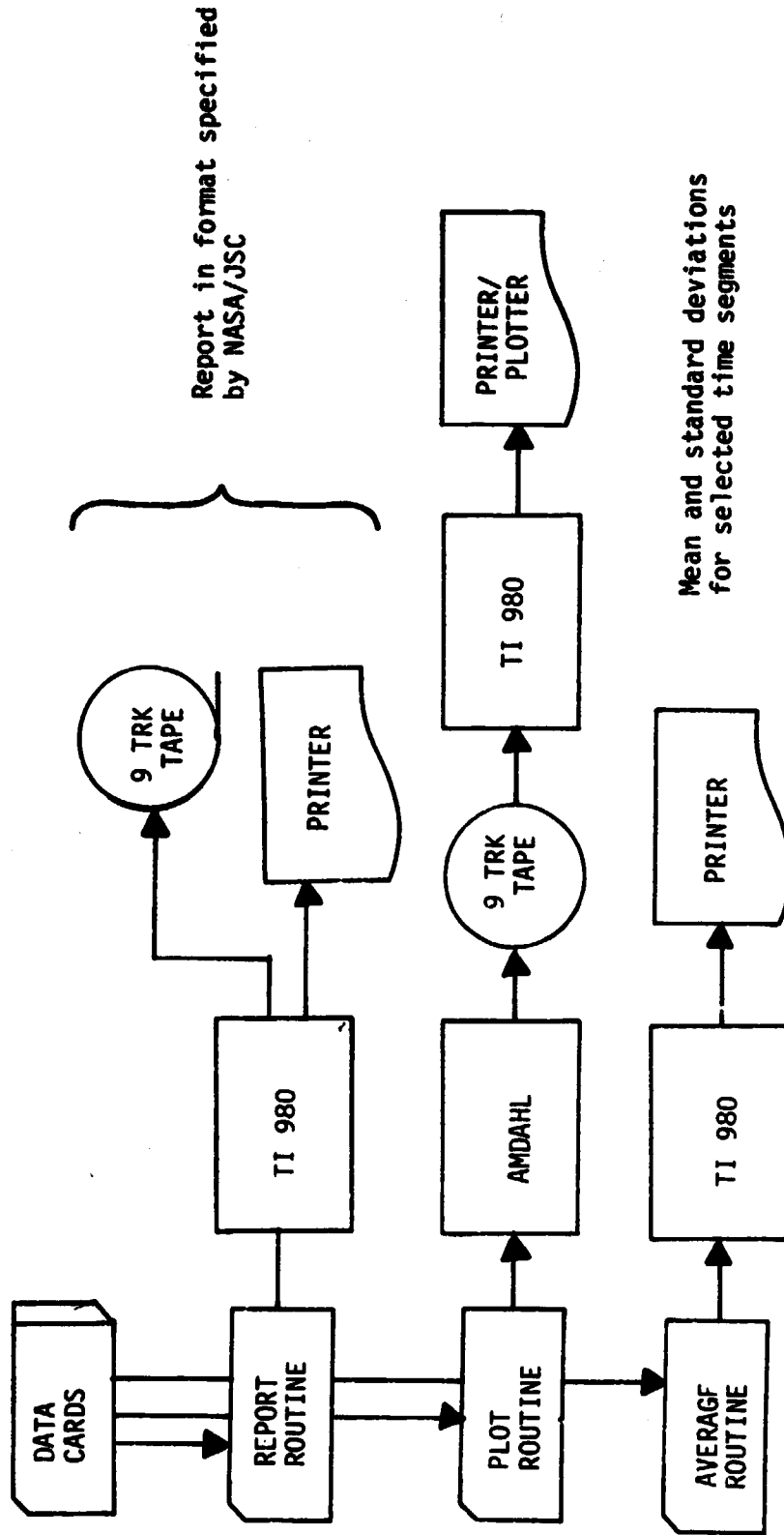
Figure 3. Simplified flow diagram of the third step of the data processing procedure with indications of the type of output product available.

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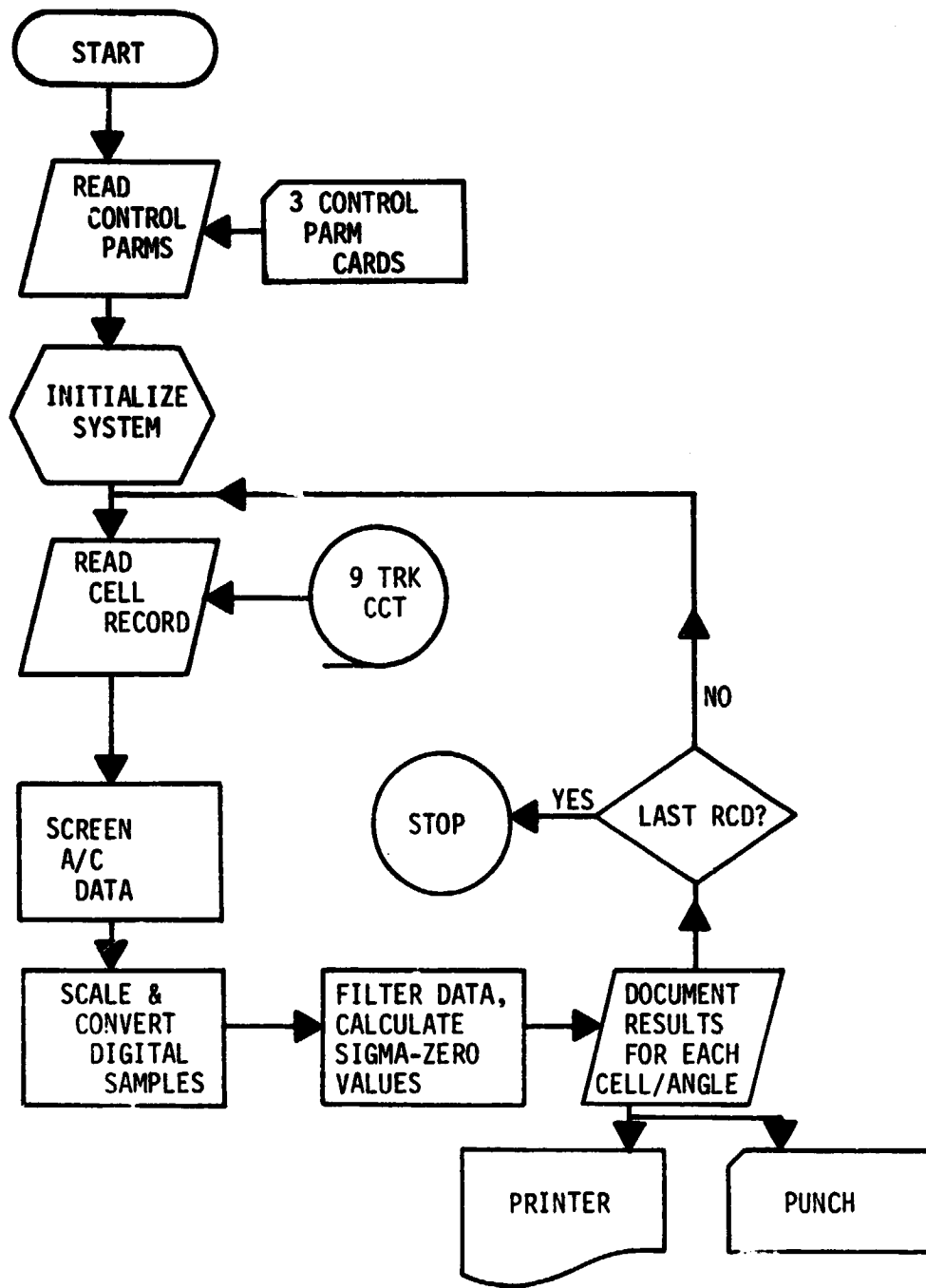
Figure 4a). Simplified Flow Diagram of Program SCATTER.CZTA78

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Main Program Module:

SCATTER.CZTA78

Gain, Beamwidth, Gamma Modules

1.6 HH	1.6 HV
1.6 VV	1.6 VH
400 HH	400 HV
400 VV	400 VH
13.3 VV	
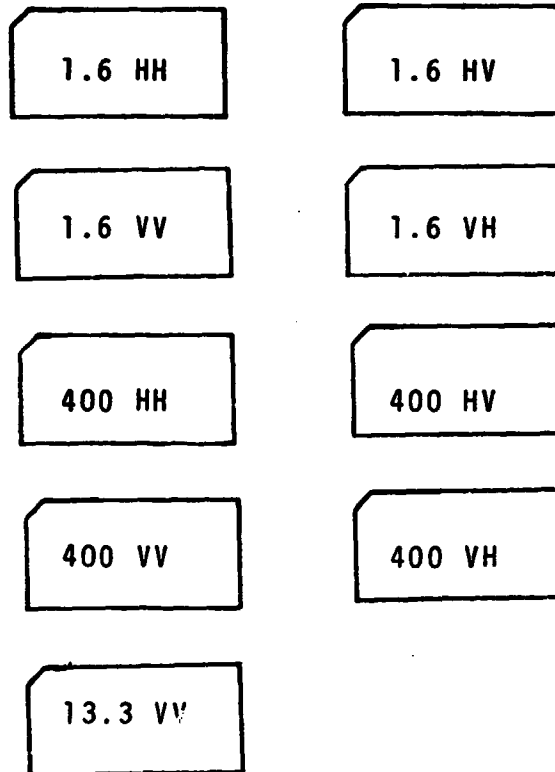
Figure 4.b) Antenna gain, beamwidth and roll-off function modules are loaded into main program Scatter at time of program execution for the frequency and polarization combination being processed.

discrimination tested. These were found to work satisfactorily and compare to NASA/JSC results for the same input data. The quality of the 9 track digital tape is tested each time a set of radar data are processed by executing a fast Fourier transform of the first few records and comparing the spectrum to that observed (and photographed) on the analog spectrum analyzer when the analog tapes are digitized. All of these functions proved to be satisfactory after the original analog tape recorder problems were rectified.

The major effort in the evaluation process proved to be the validation of the main program component, SCATTER.CZTA78. This program basically evaluates the radar equation as given by equation (1) for the normalized radar cross section. The assumptions upon which equation (1) is based were evaluated, and the techniques and accuracy of computing each of the terms in equation (1) were evaluated. The details of each of these evaluations will not be given, only a summary of several major points.

3.0   GENERAL RADAR EQUATION SOLUTION

At the outset of this report period two forms of the general radar equation were used to estimate the radar cross sections, $\hat{\sigma}^o$, from the scatterometer measurements. At TAMU the form used is

$$\hat{\sigma}^o = \frac{(4\pi)^3}{\lambda^2} \frac{C_L}{K_s} \frac{Z(f)}{G_r G_t} \frac{P_r}{P_t} \frac{R^4}{A} \tag{1}$$

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where λ = wavelength

C_L = cable loss

K_s = system constant, calibration

$Z(f)$ = roll-off function

$G_r G_t$ = antenna two-way gain

P_r = receiver power

P_t = transmitter power

R = range to ground cell in view

A = area of ground cell in view

At NASA/JSC the form used was

$$\hat{\sigma}^{\circ} = \left(\frac{4\pi}{\lambda}\right)^3 \left(\frac{C_L}{K_s}\right)\left(\frac{H^2 V}{G_r G_t \ Z(f)}\right)\left(\frac{E_r}{E_t}\right)^2\left(\frac{A_c}{\tan \beta/2}\right)\left(\frac{BW_c}{BW_i}\right) \qquad (2)$$

where E_r = rms volts corresponding to the received band-
width

E_t = rms volts corresponding to the calibration
bandwidth

H = aircraft altitude

V = aircraft velocity

A_c = $\cos\left(\frac{\Delta\theta}{2}\right) \cos\psi\cos\phi$

β = antenna beamwidth

BW_c = bandwidth of the calibration signal

BW_i = instantaneous bandwidth corresponding to the
i^{th} incident angle

ψ = roll angle

ϕ = drift angle

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The two expressions are related and equivalent if it is
assumed that the ground cell area, A, in equation (1) is
given by

$$A_i = \frac{BW_i \tan \frac{\theta_i}{2} H^2}{V \cos^4 \theta_i \cos(\frac{\Delta\theta}{2})} \qquad (3)$$

where

θ_i = instantaneous viewing angle to the ith ground
cell

$\Delta\theta$ = the angular width corresponding to the BW_i

The above assumption which connects equation (2) to equation
(1) is, unfortunately, valid only if the value of roll and
drift remain equal to zero. This is almost never true, there-
fore, the authors of the orginal NASA/JSC system were forced
to make another assumption to cover this situation; i.e., in
the presence of aircraft roll and drift the area becomes

$$A_i' = A_i / \cos\psi \cos\phi \qquad (4)$$

The validity of the above assumptions was extensively analyzed
at TAMU [3]-[4]. It was found that equation (3) (first
assumption) was accurate to within ±1% for the case where
$\phi=\psi=0$; however, for $\psi\neq0$, $\phi\neq0$, equation (4) (second assumption)
yielded erroneous values of ground cell area which were off by
as much as 7% for nominal aircraft perturbations. On the basis
of these analyses it was concluded that the more general form

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of the radar equation, expression (1) above, would be the best
form to use for data processing.

The results of this analysis also showed that the area
calculation should be done using the expressions and techniques
that have always been used at TAMU; i.e.,

$$A = \frac{W'(Y_2 - Y_1)}{\cos \phi}$$ (5)

as defined in reference [4]. The NASA/JSC program was modified
to compute area in the same manner for purposes of consistency
between the two software processors and the hardware processors
which are being implemented.

4.0 DOPPLER FREQUENCY SHIFT CORRECTIONS

4.1 Effect on Range and Area Computation

The value of R^4/A (equation (1) above) obviously makes a
substantial contribution to the value of $\hat{\sigma}^0$; therefore, a
careful evaluation of the technique for computing these values
was done. It was found that adjustments had to be made to
account for doppler filter center frequency and doppler filter
band-edge shifts associated with the discrete nature of the
Power Spectral Density (PSD) lines. For example, the center
frequency of the filter corresponding to a particular viewing
angle is given by

$$f_d = \frac{2V}{\lambda} \sin \theta_L$$ (6)

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where θ_L is the viewing angle with respect to the aircraft gravity vector. Now, as illustrated in Figure 5, this value may or may not fall as the center of one of the PSD lines. Similarly, the bandwidth, BW_i, is actually some integer set of PSD lines, and thus the filter band-edges do not actually fall at $fd \pm \frac{BW_i}{2}$, but in fact fall at the edge of one of the PSD lines. The true bandwidth may be calculated as

$$BW_t = [BW_i / \Delta f + 0.5]_I \Delta f \qquad (7)$$

where the notation $[\;]_I$ means taking the integer value, and Δf is the spectral line width given by $\Delta f = f_s/N$ where N is the number of lines in the PSD and f_s is the sample frequency used by the A/D converter. The true center frequency is then given by

$$fd_c = \Delta f [fd / \Delta f + 0.5]_I \qquad (8)$$

whenever the expression

$$NF_i = [BW_i / \Delta f + 0.5]_I \qquad (9)$$

is odd, and by

$$fd_c = \Delta f \left[[fd / \Delta f + 0.5]_I + 0.5 \right] \qquad (10)$$

whenever NF_i is even.

Center Frequency Offset Due to Digital
Representation of the Spectrum

Power Spectral Density

0

↑ ↑ Desired Center Frequency
Center Frequency Used
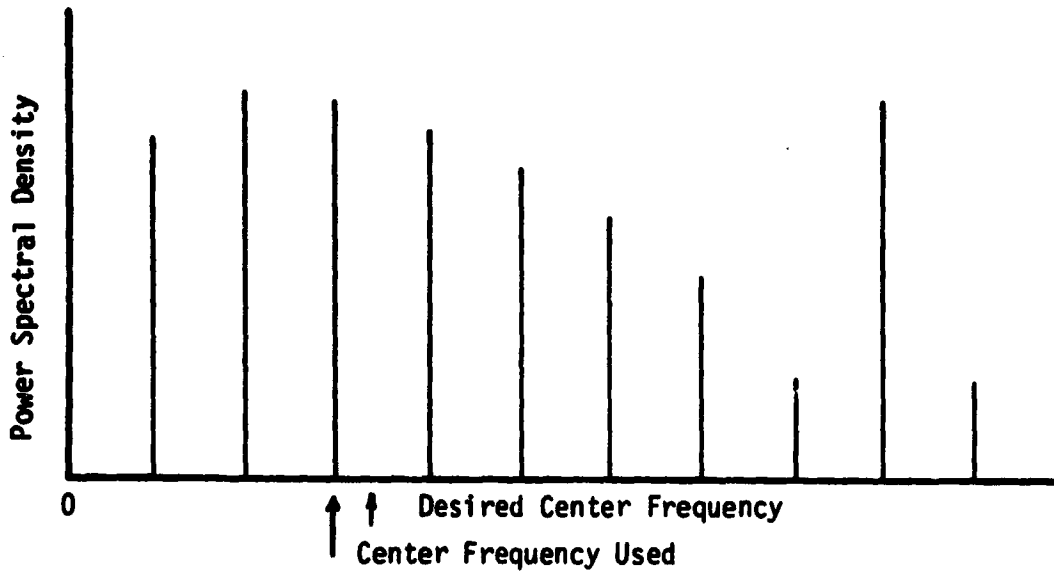
Bandwidth Difference Due to Digital
Representation of the Spectrum

Power Spectral Density

0

Desired BW

Actual BW_A
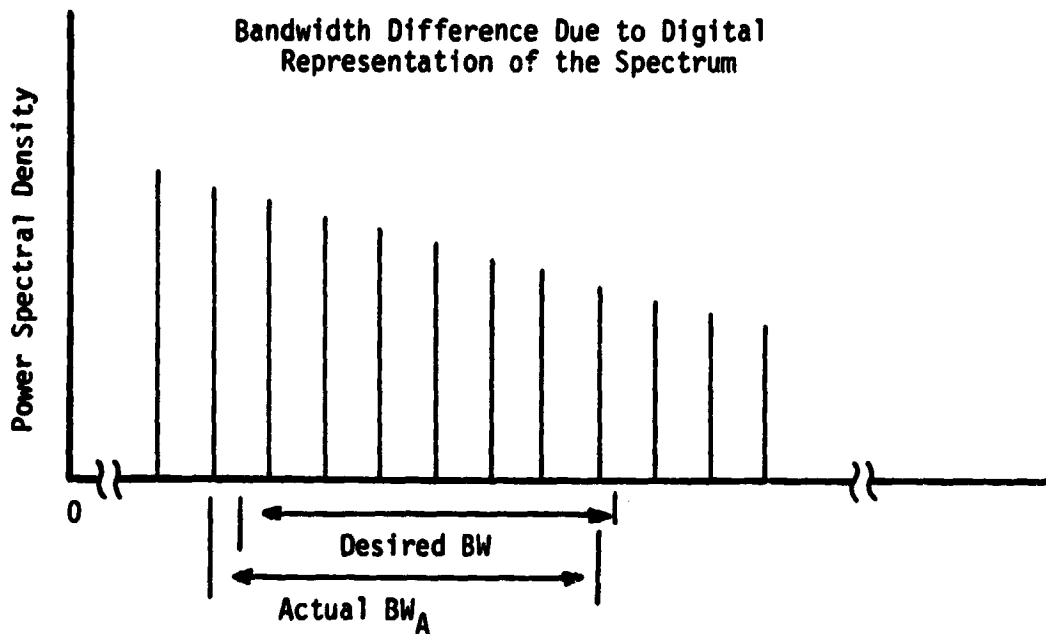
Figure 5. Effect of discrete nature of the DFT on filter
center frequency and bandwidth.

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Note that at most, the center frequency or the band-edge will be off by $\Delta f/2$. The influence of this perturbation on the value of range, R, can be evaluated. Range is given by

$$R_i = H \tan \theta_{Li} \qquad (11)$$

Since ∂_{Li} and f_d are related to equation (6), we can write

$$\frac{R_i'}{R_i} = \frac{\tan \theta_L'}{\tan \theta_L} \qquad (12)$$

where R_i' is the range to the repositioned ground cell with the center frequency off by $\Delta f/2$. It can be shown that this function is maximum when the value of λf_s is maximum. This maximum occurs at the lowest frequency, 0.4 GHz. Also, the largest percentage difference between R_i and R_i' occurs at the smallest θ_L; i.e., normally 5 degrees. Thus, the ratio in equation (6) can have values as large as 1.07. This implies that if the center frequency shifts are not accounted for in the calculation of R^4 the error can be as much as 33% when processing 0.4 GHz data. When this is applied to equation (1) to compute $\hat{\sigma}^o$, the result could be off by as much as 1.23db.

Similarly, the bandwidth shifts can produce effective cell length changes that result in actual cell area changes, consequently these shifts must also be accounted for in the evaluation of the cell area, A. This is automatically accounted for in the TAMU data reduction system because of the

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way the area is calculated [2]. This is discussed further in Section 5.0.

4.2 Effects on Usage of Antenna Gain and Roll-Off Filter Functions

The shift in filter center frequency must be accounted for in the system antenna gain, $G_r G_t$, and in the evaluation of the roll-off filter function, $Z(f)$. The effect on roll-off was found to be of less consequence than in the antenna gain. Because of the reportedly irregular shape of the antenna gain pattern, small frequency shifts tend to produce substantual changes in the resulting calculated value of $\hat{\sigma}^0$. The most dramatic effects were noted in the 13.3 GHz and 4.75 GHz antenna patterns. This effect is also explained in the last few viewgraphs in Appendix B. This effect has been subsequently diminished to some extent by using smoothed antenna gain tables [4].

4.3 Low Viewing Angle Effects

The analysis of geometry effects on the solution of equation (1) reveal that there are limits on the doppler bandwidth at low viewing angles. As illustrated in Figure 6, whenever half of the actual bandwidth, $BW_A/2$, is greater than the doppler center frequency, f_{dc}, for a specified filter; e.g., -5 degrees viewing angle, the lower bound of the bandwidth will extend off the end of the positive spectral filter

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look angle, θ_L

roll angle, ψ

Isodopplers Corresponding
to the Desired Bandwidth
(BWD). If $\psi \neq 0$ then $f_{dc} < BWA/2$
can occur.

f_{dc}
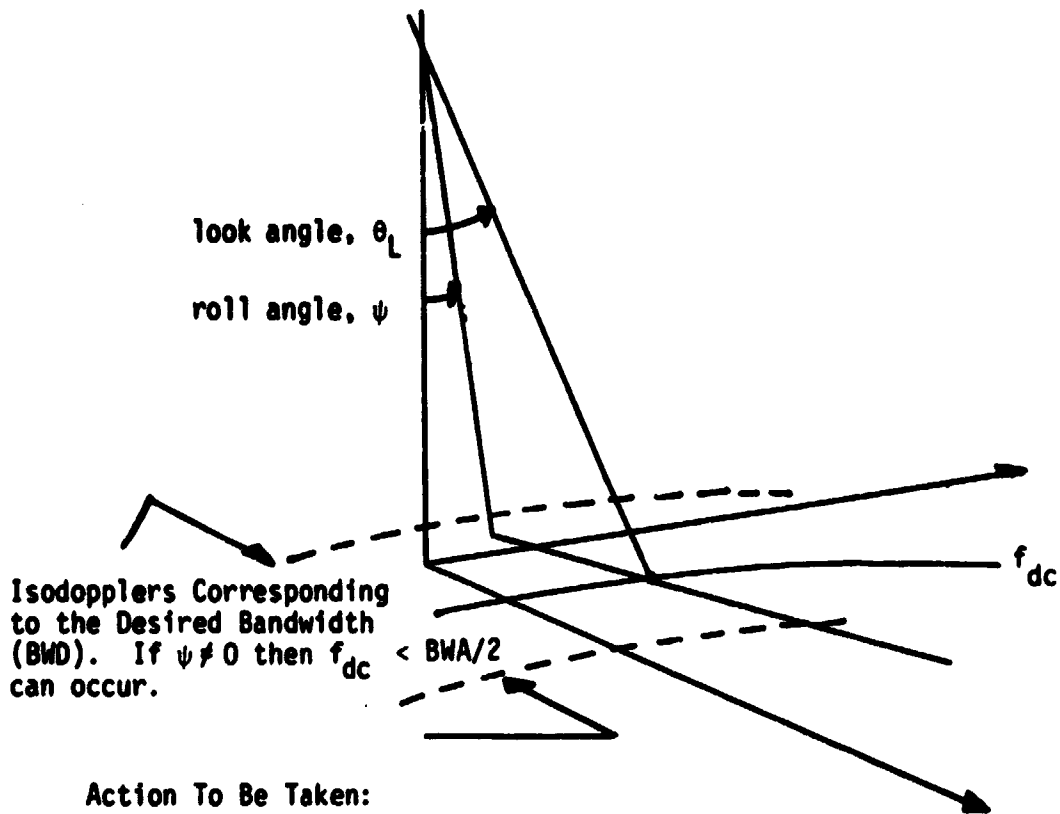
Action To Be Taken:

- If $f_{dc} < BW/2$, set $f_{dc} = BW/2$

  or

- If $f_{dc} < BW/2$, set a flag

Figure 6. Bandwidth and frequency limits at low
viewing angles.

region. This has the effect of limiting the actual viewing angle to certain minimum values. It can be shown that these minimum viewing angle values are given by [2]

$$\theta_{\ell\,min} = TAN^{-1}\left[k^2 + tan^2\psi\right]^{1/2}$$ (13)

where $\qquad k = \dfrac{L}{2Hcos\phi} - tan\psi\,tan\phi$

and

$\qquad$ L = ground cell length

$\qquad$ H = altitude of aircraft

$\qquad$ ϕ = drift angle of aircraft

$\qquad$ ψ = roll angle of aircraft

Some values of the above expression are illustrated in Figure 7. Note that for increasing cell sizes the limit rapidly approaches -5° when only a small amount of aircraft roll is applied.

Two approaches are used to handle the above limiting cases. At TAMU the value of the true viewing angle is limited so that the effective bandwidth never extends off the end of the PSD. At NASA/JSC the output data set is flagged with a caution note. Either technique is considered acceptable.

5.0 GROUND RESOLUTION CELL SIZE

Two different definitions of ground cell size or ground cell length were found to be in use by TAMU and NASA/JSC. First, TAMU software maintains a constant cell length, Figure 8,

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$$\theta_L \geq \tan^{-1}\{K+\tan^2\psi\}^{1/2}$$

where $K = \{L/2H\cos\phi\} - \tan\psi\tan\phi$

	Cell length	drift angle
– – – – –	40	10°
–·–·–·–.	40	0°
–·–··–·..	60	10°
– – – – – – –	60	0°

Roll Angle (degrees)

θ_{L_1} Minimum Viewing Angle (degrees)
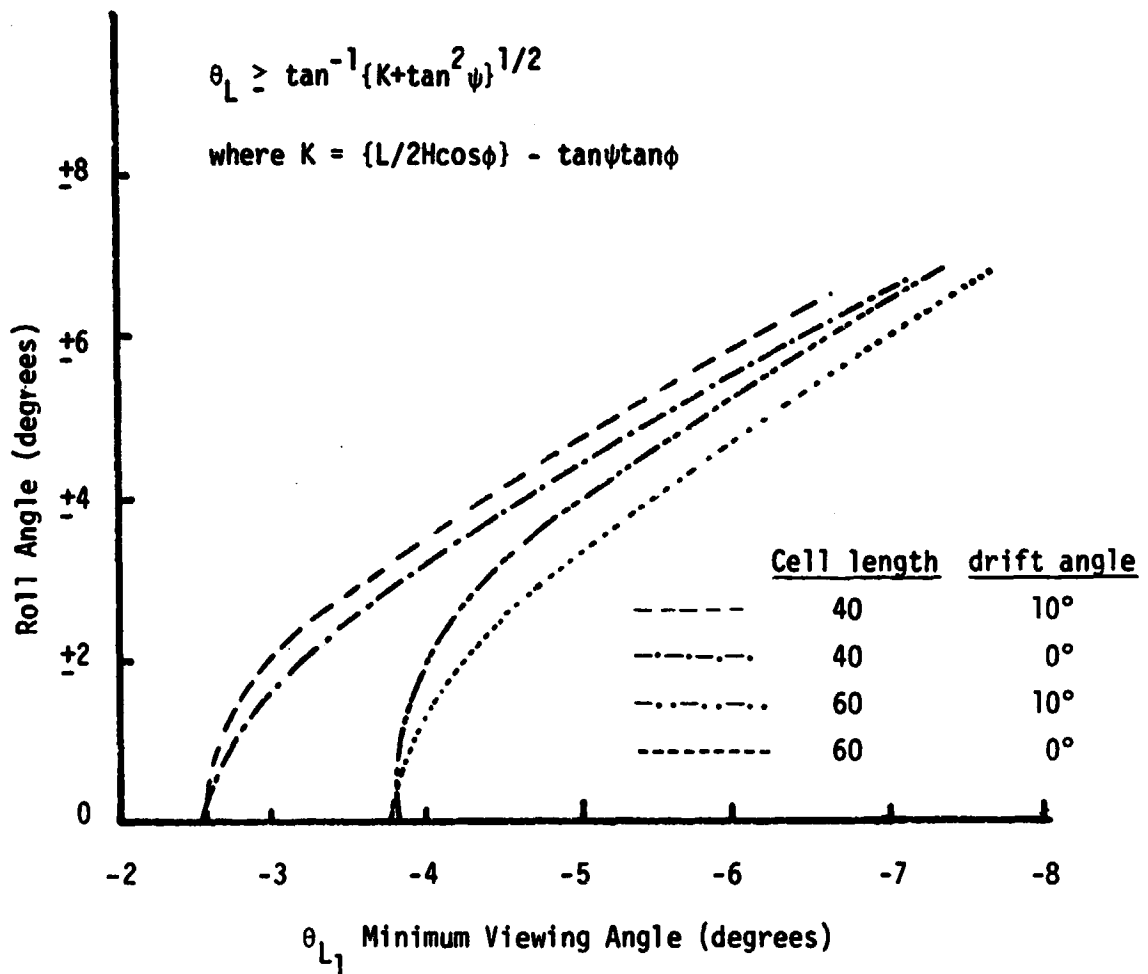
Figure 7. Viewing angle limits as a function of
roll angle and drift angle.

Typical Cell Lengths - TAMU Processor*

	T_1-T_0(sec)	L(meters)	L(feet)	L'(meters)	L'(feet)
13.3 GHz	0.08	25	82.02	18.68	61.3
1.6 GHz	0.41	50	164.04	18.42	60.4
0.4 GHz	0.82	75	246.06	11.84	38.84

*Computed for 2048 samples/record and 150 Kts ground speed
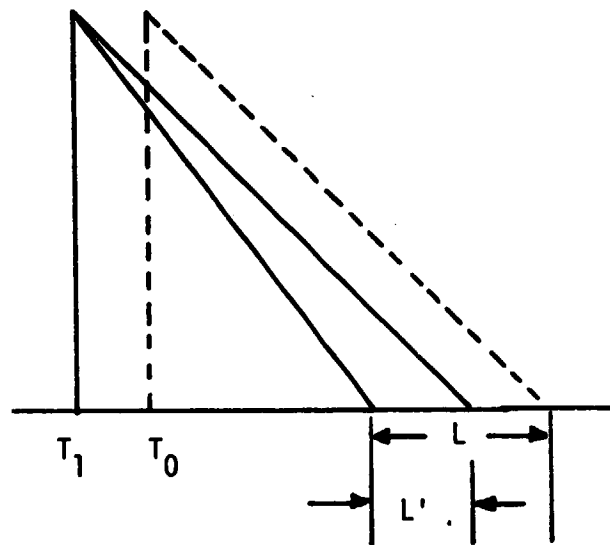
Bandwidth is adjusted to keep L constant for all θ_L and velocities.

Figure 8. Illustration of the ground cell length as defined by TAMU.

as aircraft parameters vary. <u>This cell length includes both</u> <u>the instantaneous viewing length and the "smear" distance</u> <u>moved by the aircraft during the integration time</u>, t_o to t_1. On the other hand, NASA/JSC defines the cell length as the instantaneous viewing length, Figure 9. In the NASA/JSC program the cell length, L', is a program input, and bandwidth, BW_i, is adjusted to keep the input value of L' constant for all viewing angles. However, as the aircraft flight parameters change the total ground coverage per cell, L, computed using the NASA/JSC processor will change slightly. This difference in the TAMU and NASA/JSC processors is not significant. <u>But</u>, <u>the fact that NASA/JSC defines the cell resolution length as</u> <u>the instantaneous resolution can be significant if the user</u> <u>does not understand what it means</u>. It is important since the actual ground coverage is greater than the instantaneous resolution by the "smear" distance that results from the time integration process involved in filtering.

6.0 COMPARISON OF GENERAL PROGRAM STRUCTURES

The over all systems used to compute $\hat{\sigma}^o$ at NASA/JSC and at TAMU are similar in the sense that both use the discrete Fourier transform to calculate the estimated PSD; however, they differ quite significantly in the way the data are handled before and after the PSD estimate is made. Also, there is a basic difference in the way the sign-sensing is accomplished.

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Typical Cell Lengths - NASA/ESD Processor*

	T_1-T_0(sec)	L(meters)	L(feet)	L'(meters)	L'(feet)
13.3 GHz	0.08	42.7	140.2	36.58	120
1.6 GHz	0.41	68.2	223.7	36.58	120
0.4 GHz	0.82	99.8	327.4	36.58	120

*Computed for 2048 samples/record and 150 Kts ground speed
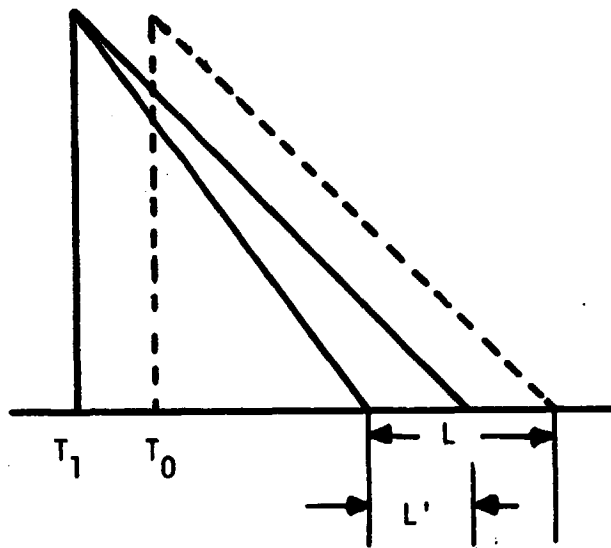
Bandwidth is adjusted to keep L' constant
for θ_L

Ground speed variations cause variations in L

Figure 9. Illustration of the ground cell length as
defined by NASA/ESD.

The general approach used by both TAMU and NASA/JSC is illustrated in Figure 10. Phase I consists of digitizing selected segments of analog data from the 14-track tapes made on board the aircraft. Phase II uses the 9-track CCT containing the digitized data to calculate and record $\hat{\sigma}^o$ along with appropriate aircraft parameters and time.

6.1 NASA/ESD General Program Structure

The NASA/ESD general program structure is illustrated in Figure 11. Note that the system builds two complete and separate files, one containing ADAS/NERDAS data and one containing filtered data for each record from the CCT digital data tape. After the last record is processed the two files are merged into an output data set by averaging both aircraft and filter data over approximately 0.5 second intervals for 13.3 GHz data and longer intervals for the lower frequencies. Next, these data are correlated to aircraft nadir time. The only time limitation noted in examination of this approach was that the two files built prior to merging dictate a limit on the length of the time segment that can be processed during any one execution phase. This limit is most severe for 13.3 GHz data where only lines of 250 seconds or less can be processed.

The sign sensing and PSD estimates are done by first calculating two discrete Fourier transforms, one for the sine

PHASE I

Analog Radar
Data

14 TRK
PCM TAPE → A/D → FORMAT AND
OUTPUT → LISTING

9 TRK
CCT   Digital
Radar
Data

PHASE II

9 TRK
CCT → PROGRAM
SCATTER → LISTING

CARD

9 TRK
CCT
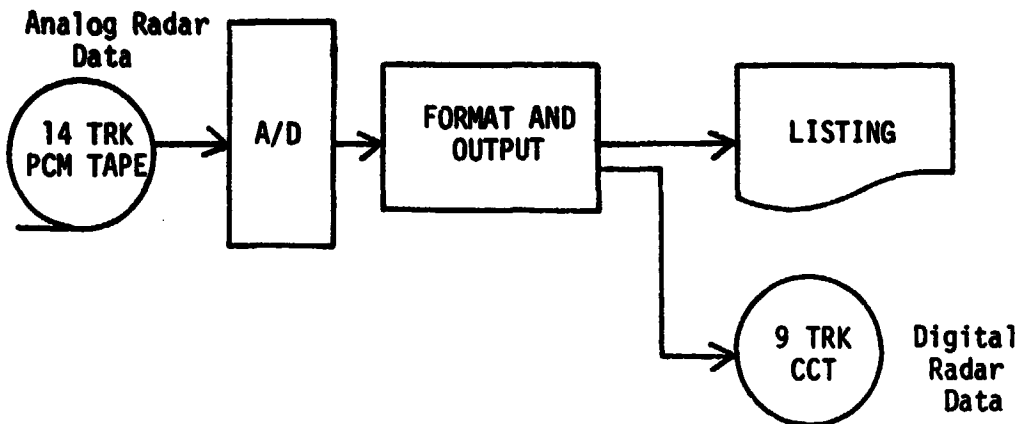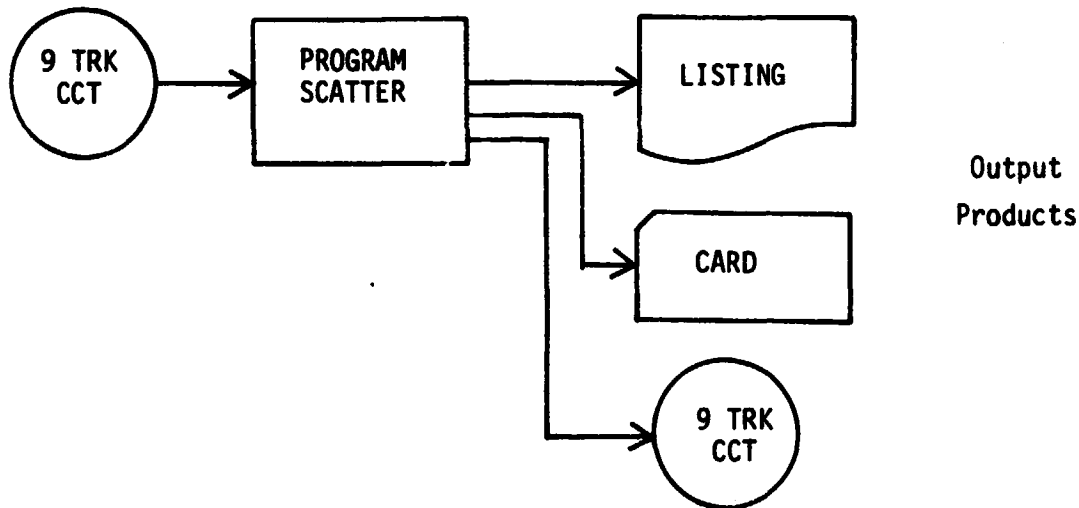
Output
Products

Figure 10. Scatterometer data processing procedure.

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START

B

CCT DIGITAL DATA → BUILD A/C DATA FILE → ADAS/NERDAS FILE → C

INITIALIZE SCAT CONSTANTS

A

READ DIGITAL RECORD

AVERAGE FILTERS(.5 SEC) EVALUATE CALIB. TONES

C → COMPUTE fd, BW, θ_L PERFORM 2-FFT'S

COMPUTE $\hat{\sigma}^0$, GAIN, Z_W, etc.

SIGN-SENSE, FILTER & BUFFER DATA FOR EACH RECORD

CORRELATE TO NADIR & INTERPOLATE TO .5 SEC INTERVAL ← C

LAST RECORD — NO

LAST FILE — NO → B

A

STOP
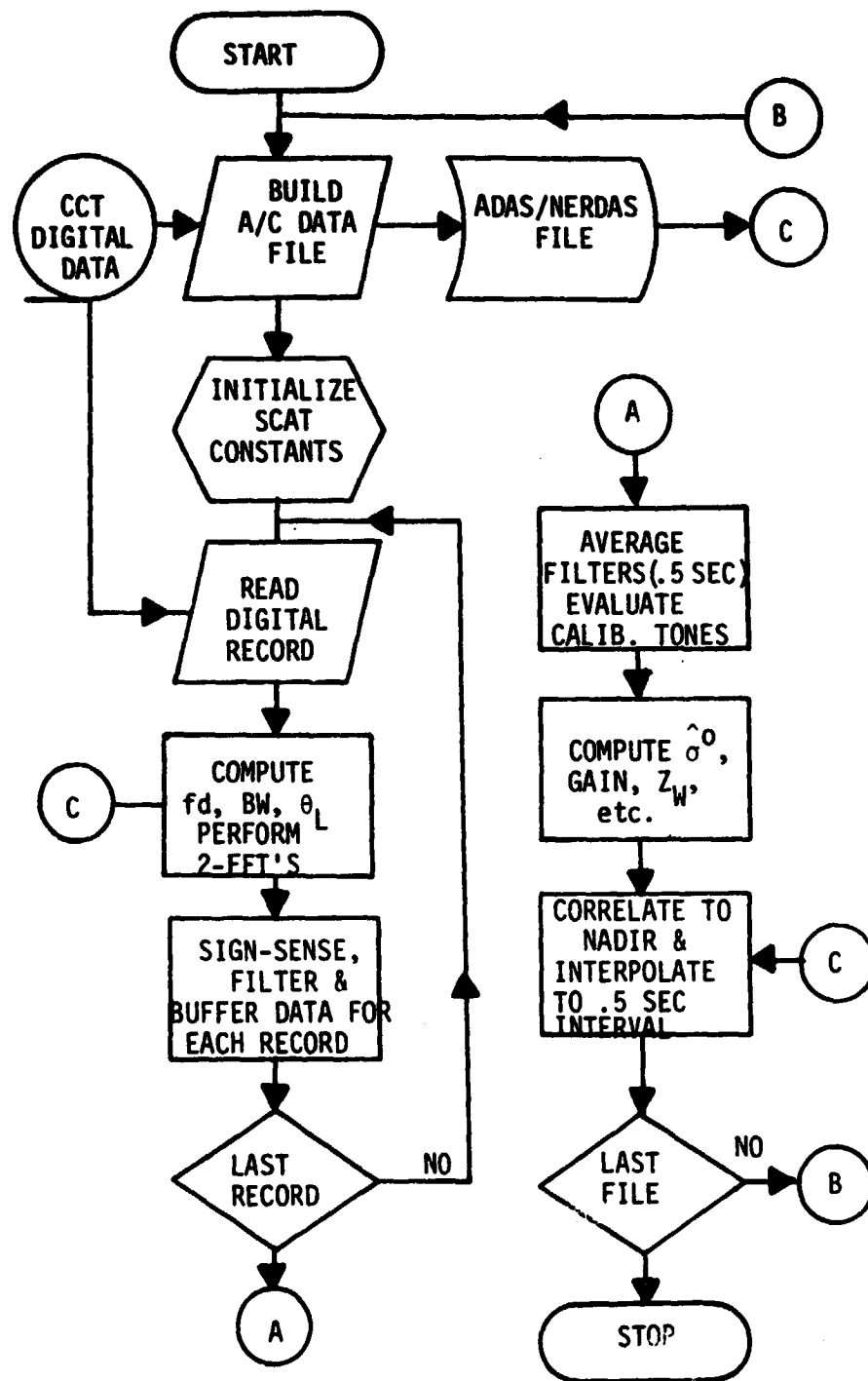
Figure 11. General program structure of the
NASA/JSC processing system.

channel and one for the cosine channel of the input data set.
The output of these two data sets are then used to get the PSD
coefficients for either the fore or aft data using the
expressions

$$A_+^2 = \left[(RS - IC)^2 + (RC + IS)^2 \right] k^2 \tag{14}$$

$$A_-^2 = \left[(RS + IC)^2 + (RC - IS)^2 \right] k^2 \tag{15}$$

where

A+ = fore PSD coefficient of ith frequency component

A- = aft coefficient of ith frequency component

RS = real Fourier coefficient of ith frequency component, sine channel

IS = imaginary Fourier coefficient of ith frequency component, sine channel

IC = imaginary Fourier coefficient of ith frequency component, cosine channel

RC = real Fourier coefficient of ith frequency component, cosine channel

k = scaling constant

6.2 TAMU General Program Structure

In contrast to the above, the TAMU system illustrated in
Figure 12 processes each digital record completely, from 9-
track input CCT to the output data set, in one pass. Using
this technique there is no specific limits on how long each
input data set must be. The processing begins with the first

START

RUN PARAMETERS → READ SET-UP DATA

START/STOP TIMES
TAPE FILE #
CONSTANTS, DUMP FLAGS

CCT DIGITAL DATA

INITIALIZE SYSTEM CONSTANTS BUFFERS

READ DIGITAL TAPE RECORD

COMPUTE f_A, BW_A, θ_{AL}, For each cell

PERFORM CX -DFT, EVALUATE FILTER PWR & CALIB. PWR

CALCULATE & BUFFER A/C DATA CORRELATED TO NADIR

A

PRINT BUFFER LINE

PUNCH BUFFER LINE

LAST RECORD?

NO

YES

STOP
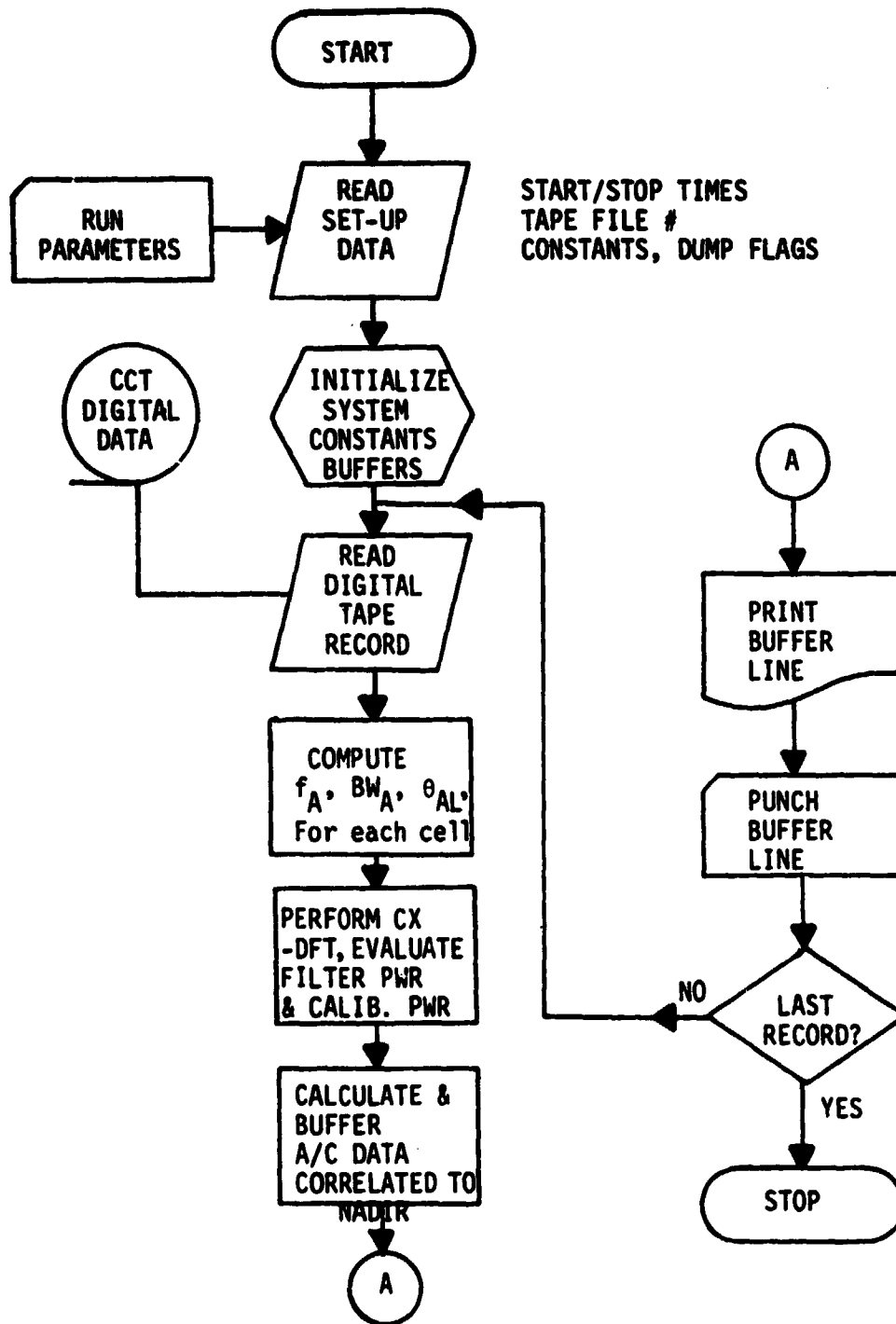
Figure 12. General program structure of the TAMU Processing System.

record and continues serially until the last record is done. The other important difference is in the way the discrete Fourier transform is used to do both PSD estimating and sign sensing in one pass. As illustrated in Figure 13, the NASA/ESD system requires two fast Fourier transforms to produce the aft data PSD, while with one complex fast Fourier transform the TAMU system produces both the fore and aft PSD.

Actual data runs of the TAMU system have established that the average machine computation time per record is 0.102 seconds. The average I/O time is 0.016 seconds per record for a total processing time of 0.118 seconds per record using the TAMU AMDAHL 470. Using the latest pricing equation at the TAMU Data Processing Center the cost per record comes to $0.01334.

Note that it matters some if the data is 0.4 GHz. In this scatterometer system the sign sensing is not done, and thus the TAMU system, as with NASA/ESD, performs two fast Fourier transforms to get the PSD estimate. Run records for 0.4 GHz data through the TAMU system indicate an average of 0.1763 seconds per record with the I/O time the same; i. e., 0.016 seconds per record, giving a total of 0.1923 seconds per record for 0.4 GHz processing.

6.3 Comparison of Processing Results

Comparisons were made of the output of the two scatterometer systems. The sample data set chosen to use for the test

NASA/JSC Double FFT
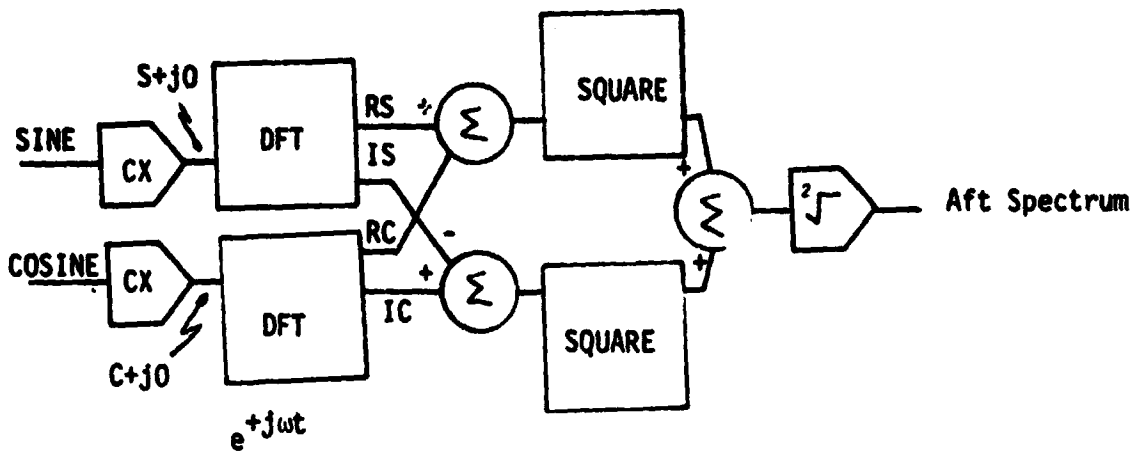
TAMU Single Complex FFT
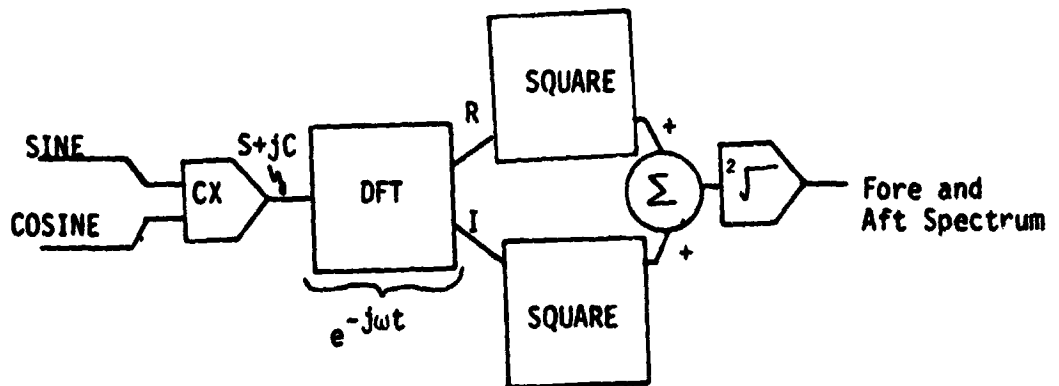
Figure 13   Sign sensing techniques used by TAMU and
NASA/ESD.

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was Line 5, Run 2, from Mission 347 made on 23 September 1976.
Data acquired over Fields 17 and 18 were used as test data.
In one test both TAMU and NASA/ESD processed the data using the
same digital input data (Figure 14a) and b)). The digital data
tape used for this test was produced by NASA/ESD. Some
reformatting was done by both NASA/ESD and TAMU to make the
input compatible with TAMU software. The results shown in
Figure 14 indicates that both systems gave the same estimated
$\hat{\sigma}^o$ within ± 1.5 db. This test demonstrated that Phase II of
the processing systems were comparable.

A second test was run at TAMU using the same data time
segment, but processing was done using as input a digital tape
made at TAMU. The results of this test, shown in Figure 15 a)
and b), indicate that both systems produce the same result from
end-to-end. This test demonstrates that Phase I, the digitaza-
tion process, is also comparable.

Some problems in getting equivalent results were encoun-
tered early in testing, but subsequently were resolved as
differences in the system constants, antenna patterns and
roll-off tables between the two systems.

7.0 TAMU COMPLEX DIGITAL FOURIER TRANSFORM SYSTEM

7.1 Advantages of New System Over the Hilbert Transform System

The Complex Discrete Fourier Transform (CDFT) software
system is designed to interface with the same digital computer

Mission 347 Line 5 Run 2 (Lawrence, Kansas)

September 23, 1976   16:57:58.0 to 16:58:01.5
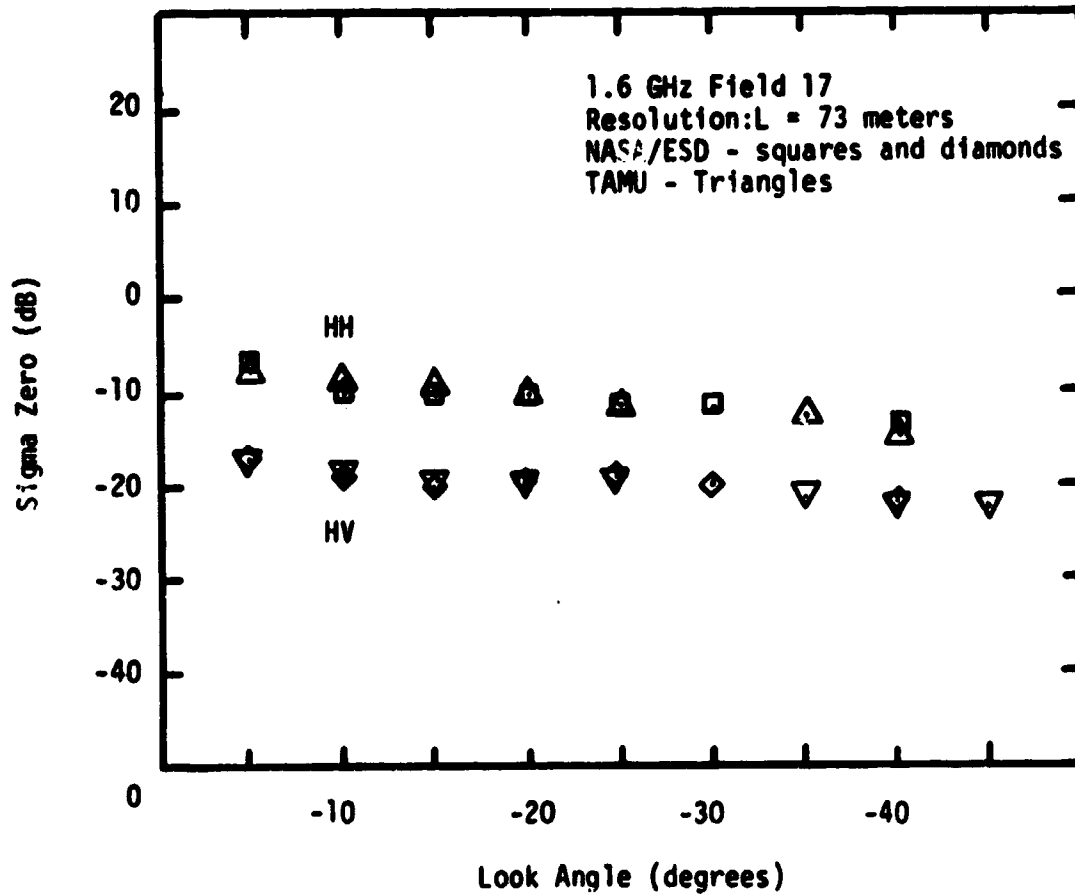
Figure 14.a) Comparison of TAMU and NASA/ESD processing
software using as input a common digital
tape generated by NASA/ESD.

Mission 347 Line 5 Run 2 (Lawrence, Kansas)

September 23, 1976   16:58:04.5 to 16:58:07.1
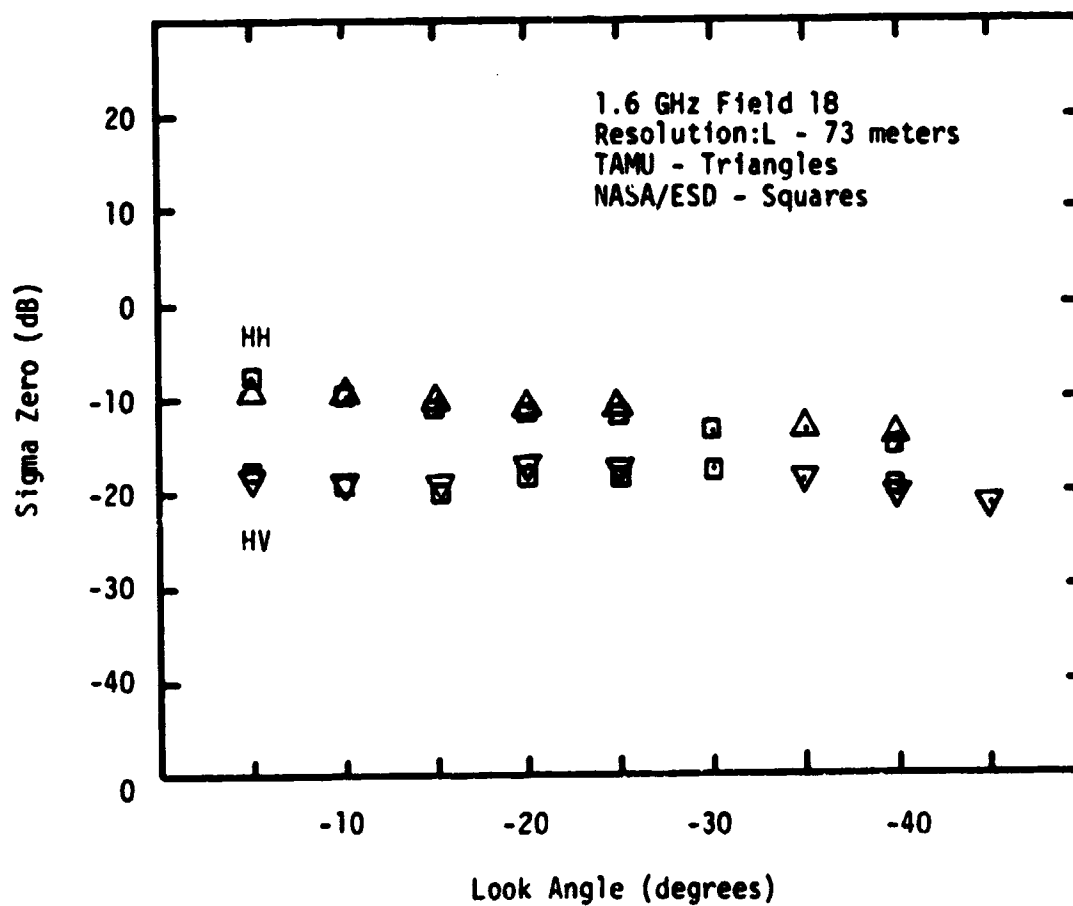
Figure 14.b) Comparison of TAMU and NASA/ESD
          processing software using as input a common
          digital tape generated by NASA/ESD.

Mission 347 Line 5 Run 2 (Lawrence, Kansas)
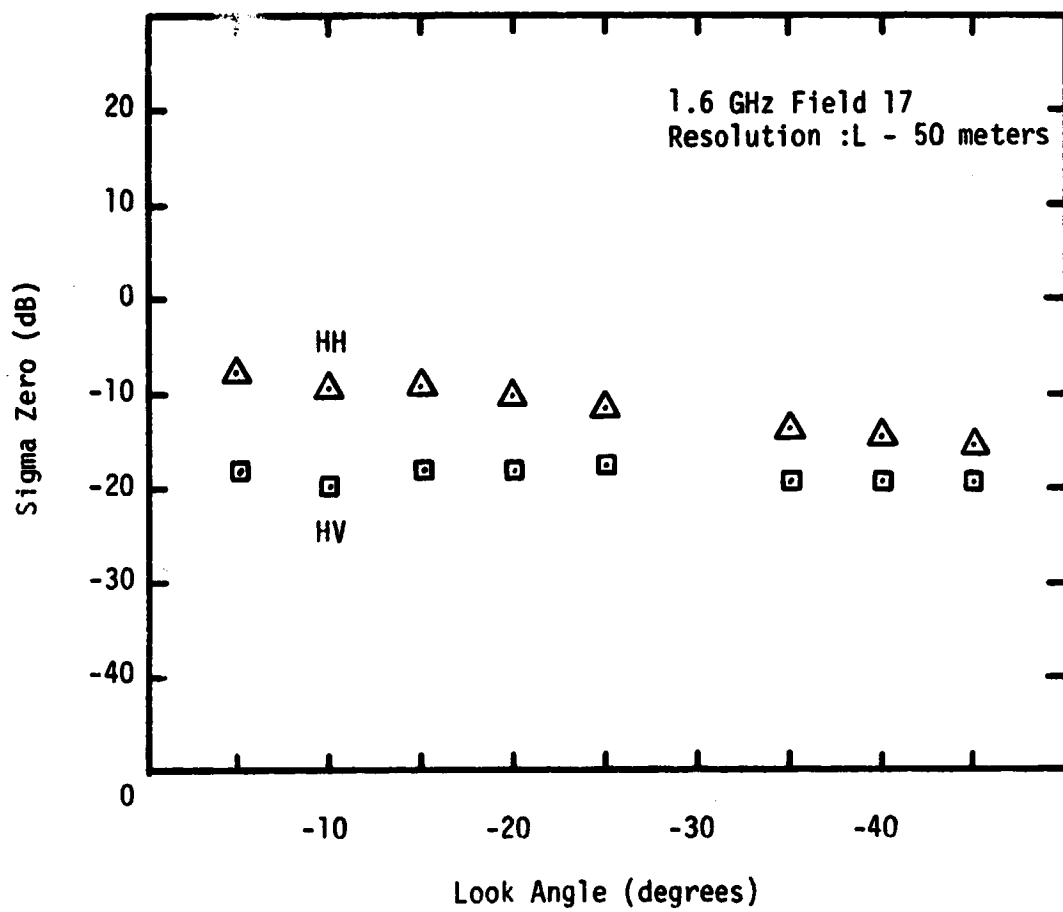
September 23, 1976

Figure 15.a) Mission 347 Field 17 processed by TAMU
using as input a digital tape generated
by TAMU.

Mission 347 Line 5 Run 2 (Lawrence, Kansas)

September 23, 1976
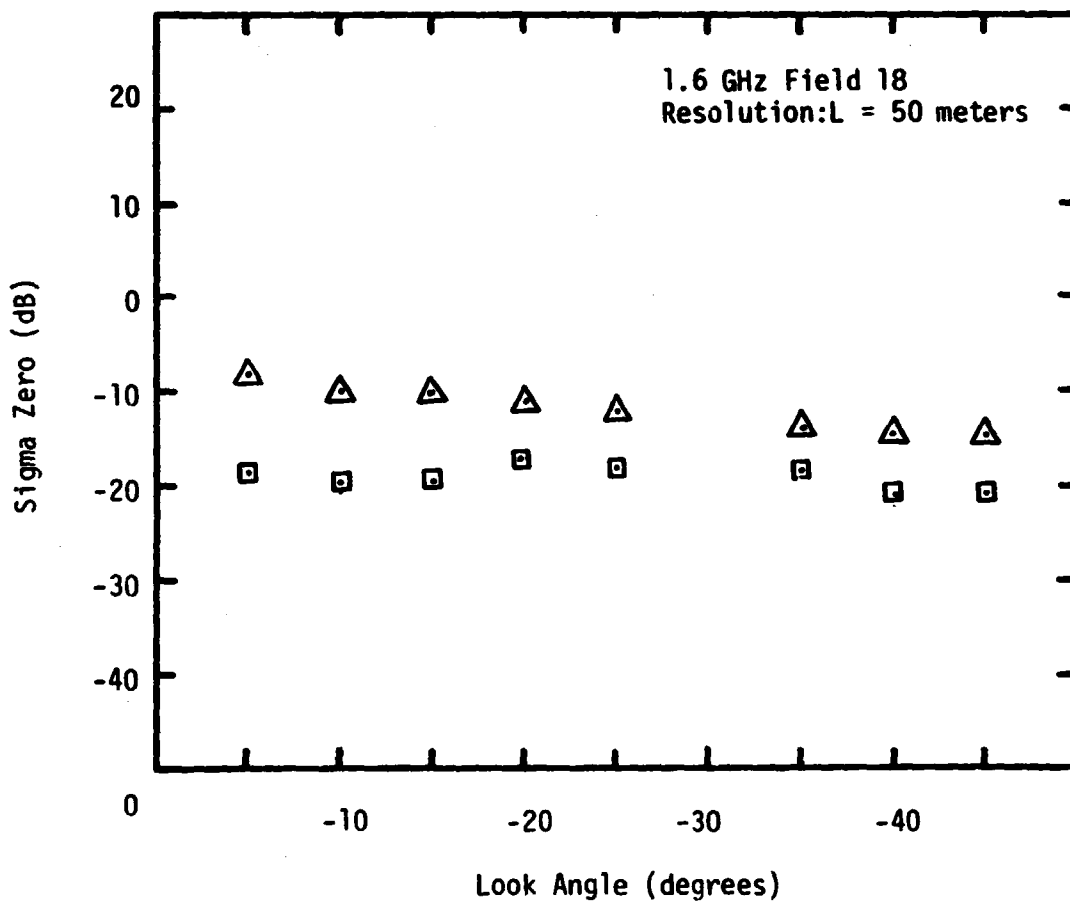
Figure 15.b) Mission 347 Field 18 processed by TAMU
using as input a digital tape generated
by TAMU.

respective filter, as opposed to an average center frequency used by the earlier HT system. Similarly, the value of the ground cell area, A, is calculated using the actual upper and lower doppler contours that bound the respective cell being viewed at that instant in time, rather than average frequencies for each cell over the flight line.

The ratio of the power received to the power transmitted is taken from the sum of the power spectral density (PSD) lines of the CDFT within the doppler frequency band defining the ground cell can be continuously updated as a function of aircraft parameters, the DFT filtering approach provides a technique to adaptively filter the radar output to maintain cell size and incident angle.

In the HT system the digital filter is used to acquire power within each band, including the calibration power, P_t. Each of the digital filters is pre-designed for an average center frequency over the entire flight line. This does not provide constant resolution or incident angle as aircraft flight parameters vary since aircraft dynamics cause the center frequency corresponding to each viewing angle to vary over the length of the flight line. To calculate a new center frequency and re-design each filter for each ground cell would be absolutely prohibitive in machine costs. However, the nature of the CDFT makes it quite easy to optimize band

compatible tape (CCT) format used by the Hilbert transform (HT) sysyem [1] previously developed at TAMU to process scattero- meter data. The system performs repeated scattering coeffi- cient estimates for eight aft viewing angles. The output data set has the scattering coefficients, $\hat{\sigma}^o$, aligned with respect to the aircraft nadir times. As before, the scattering coef- ficient is calculated using the expression

$$\hat{\sigma}^o = \frac{(4\pi)^3}{\lambda^2} \frac{R^4}{A} \frac{C_L}{K_s} \frac{Z(f_d)}{G_r G_t} \frac{P_r}{P_t} \tag{16}$$

where
λ = wavelength

R = range

A = area

C_L = cable loss

K_s = system constant

$Z(f_d)$ = roll-off

$G_r G_t$ = antenna gain

P_r = power received

P_t = power transmitted

The important difference in the solution techniques used by the CDFT is in the evaluation of the four variables R, A, P_r, and P_t.

First, the range, R, is calculated to the center of the actual ground cell based upon actual center frequency of the

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and center frequency for each cell evaluated by the stem.

7.2 CDFT Algorithm Summary

For each set of digital data taken from the CCT, the CDFT system must evaluate eight sets of range, area, roll-off, gain, and power-ratios. This is accomplished in the order illustrated in Figure 16. The symbols used are defined in Table 1. To evaluate θ_d, the doppler angles, the viewing point coordinates of each viewing angle are first calculated using the geometric relations in Figure 17.

$$y' = H \tan \psi \tag{17}$$

$$x' = \left[(H \tan \theta)^2 - (y')^2\right]^{1/2} \tag{18}$$

$$x = x' \cos \phi + y' \sin \phi \tag{19}$$

$$y = x' \sin \phi - y' \cos \phi \tag{20}$$

The doppler angle, θ_d, is then given by

$$\theta_d = TAN^{-1}\left[\frac{x^2}{H^2 + y^2}\right]^{1/2} \tag{21}$$

The doppler center frequency is then given by

$$f_d = \left(\frac{2V}{\lambda}\right) \sin \theta_d \tag{22}$$

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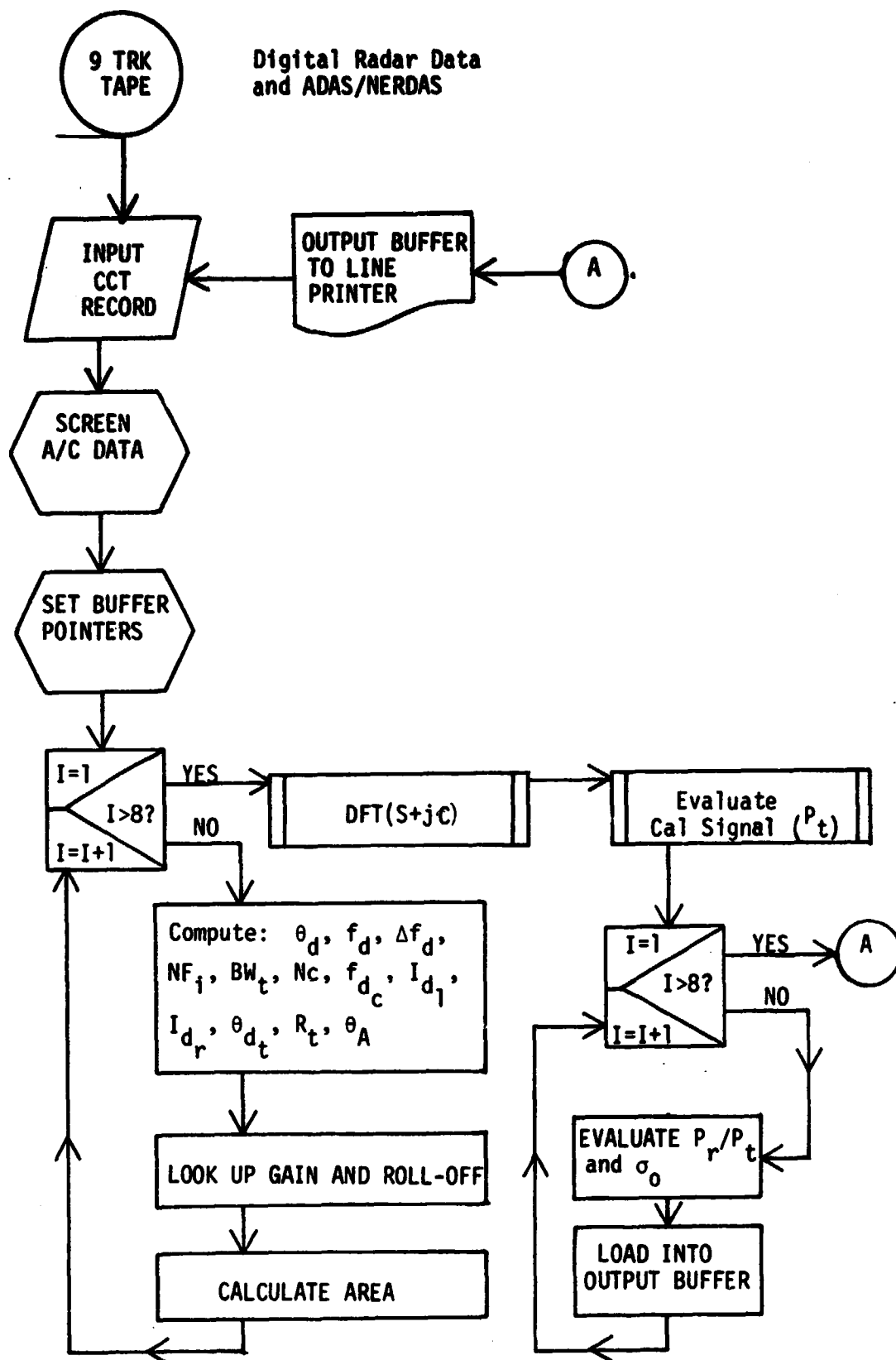
Figure 16. Computational algorithm for computing sigma zero.

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TABLE 1

Symbol Cross Reference/Definition

θ_d	Doppler Angle - Viewing angle referenced to the plane of the ground track and aircraft gravity vector.
f_d	Doppler frequency associated with a particular viewing angle.
Δf_d	Bandwidth desired or calculated.
NF_i	Number of filter elements (or discrete spectral lines) needed to make Δf_d.
BW_t	True bandwidth - NF_i times the spectral line width.
N_c	Center frequency index value.
f_{dc}	True doppler (center) frequency associated with the true bandwidth, BW_t.
I_{fdl}	Left-most doppler filter index pointer
I_{fdr}	Right-most doppler filter index pointer
θ_{dt}	True doppler angle associated with true doppler center frequency, f_{dc}.
R_t	True Range - range from antenna to the true center of the ground cell defined by f_{dc} and θ_{dt}.
θ_A	Viewing angle referenced to the aircraft coordinate system, but without pitch correction, used for gain look-up.
θ_{Lt}	True viewing angle, corrected for shift in doppler center frequency due to discrete PSD lines.

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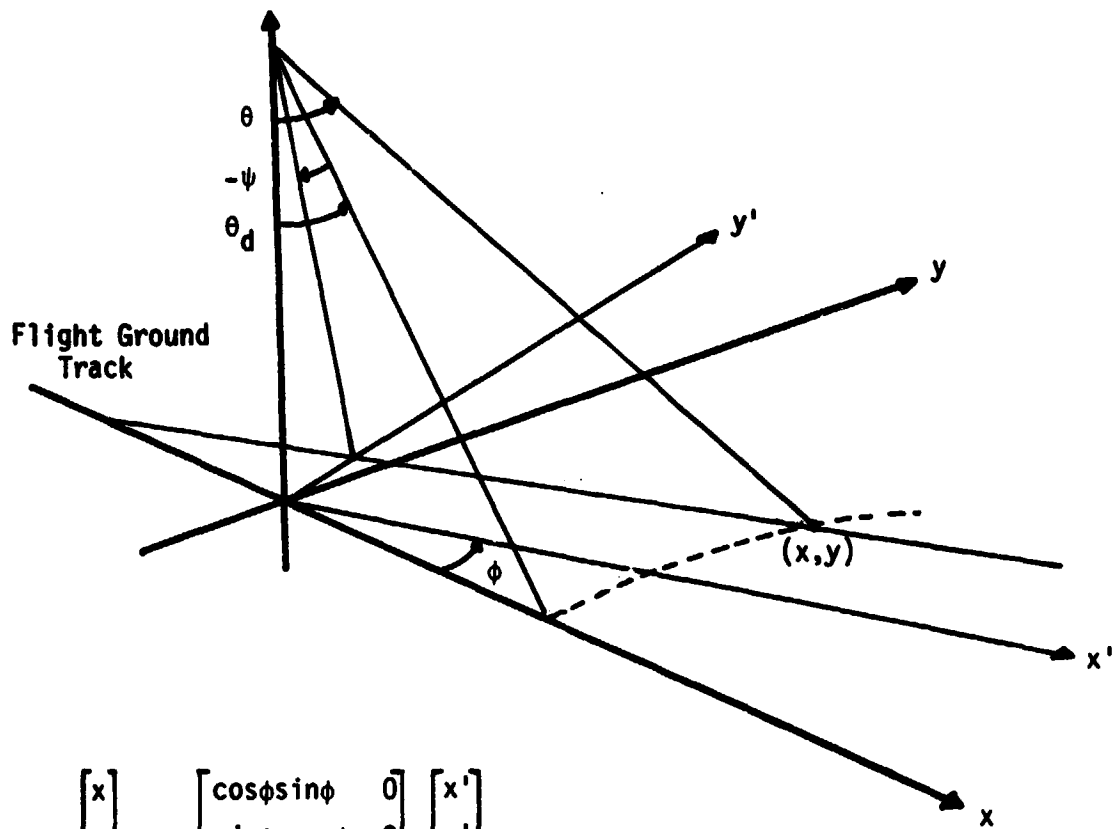
$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\phi\sin\phi & 0 \\ \sin\phi-\cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$

ψ - roll angle

ϕ - drift angle

Figure 17. Definition of processing coordinate system.

where v = aircraft ground speed

           λ = scatterometer wavelength

Next, the desired bandwidth, Δf_d, is calculated using

$$\Delta f_d = X_k \cos^3 \theta_d \tag{23}$$

where

$$X_k = \left(\frac{2V}{\lambda}\right)\frac{L}{H} \tag{24}$$

and L = instantaneous ground cell length

           H = aircraft altitude

The number of filter elements required in the PSD set to repre-
sent the desired bandwidth is calculated by

$$NF_i = \left[\Delta f_d \left(\frac{N}{f_s}\right) + 0.5\right]_I \tag{25}$$

where N = number of lines in the PSD.

           f_s = sample frequency of digitizer when making
                the CCT.

The notation $[\ ]_I$ means integer value of the floating point
expression enclosed.

Note that the true bandwidth is the sum of the filter
elements needed, NF_i, thus

$$BW_t = NF_i \left(f_s/N\right) \tag{26}$$

gives the actual bandwidth over which the power will be sumed.

The center frequency index for the PSD buffer is given by

$$N_c = \left[f_d \left(N / f_s \right) + 0.5 \right]_I \tag{27}$$

and the true center frequency is then

$$f_{d_c} = N_c \left(f_s / N \right) \tag{28}$$

whenever the value of NF_i is odd. When the value of NF_i is even, N_c is given by

$$N_c = \left[f_d \left(N / f_s \right) \right]_I \tag{29}$$

and the true center frequency is

$$f_{d_c} = \left(N_c + 0.5 \right) \left(f_s / N \right) \tag{30}$$

Similarly, the value of the PSD left and right power summation pointers depend on whether NF_i is odd or even. For the case where NF_i is odd the left pointer is given by

$$IPd_L = N_c - (NF_i - 1)/2 \tag{31}$$

when NF_i is even, the left pointer is given by

$$IPd_L = N_c + 1 - NF_i / 2 \tag{32}$$

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In either case the right pointer is given by

$$I\mathcal{R}_r = I\mathcal{P}_{d_L} + N\!F_i - 1 \tag{33}$$

Next, since the actual doppler center may have been shifted by as much as one-half a spectral line in the PSD, the true doppler angle, and thus the true viewing angle, may be shifted accordingly. The true doppler angle is given by

$$\theta_{d_t} = \sin^{-1}\left(\frac{f_{d_t}\,\lambda}{2V}\right) \tag{34}$$

The true (or corrected) viewing angle is now evaluated by

$$\theta_{L_t} = \tan^{-1}\left[\frac{\left((H^2+Y^2)\tan^2\theta_{d_t} + Y^2\right)^{1/2}}{H}\right] \tag{35}$$

The true range, R_t, to the cell may be evaluated by

$$R_t = H/\cos\theta_{L_t} \tag{36}$$

and the antenna angle, θ_A, is given by

$$\theta_A = \tan^{-1}\left[-\cos\psi\left(\tan^2\theta_{L_t} - \tan^2\psi\right)^{1/2}\right] \tag{37}$$

The value of antenna gain is evaluated using the actual viewing angle, θ_A. The value of system roll-off is evaluated using the true doppler center frequency, f_{dc}.

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The value of cell area, A, is calculated using the doppler contour technique described in [4], [5]; i.e.,

$$A = \frac{w'(y_2 - y_1)}{\cos \phi} \qquad (38)$$

where

$$w' = \frac{2H \cdot \tan \beta/2}{\cos \theta_{L_c} \cos \psi} \qquad (39)$$

and β = antenna beamwidth

The value of y_1 and y_2 are given by

$$y_i = \frac{-H}{1 - k_i \cos^2\phi}\left\{\tan\phi\tan\psi + \left(\tan^2\psi(k_i - 1) + k_i \cos^2\phi - 1\right)^{\frac{1}{2}}\right\} \qquad (40)$$

where k_i = $\left(\frac{2v}{\lambda f_i}\right)^2$

The value of f_i is interpreted to be f_1 = lower doppler frequency limit of the actual bandwidth and f_2 = upper doppler limit of the bandwidth.

After completing the above calculations for each of eight viewing angles, the PSD buffer is calculated using the CDFT. The input to the transform is programmed so that the real part is always the true sine signal and the imaginary part is always the true cosine signal from the radar analog data set. The output of the CDFT, which convolves on the basis of $e^{-j\omega t}$, is the set of Fourier coefficients arranged such that the aft data is associated with positive frequencies and the fore data

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is associated with the negative frequencies, Figure 18. The PSD buffer is then filled with the square of complex absolute values of the aft data coefficients.

Using the index pointers already computed, the P_r and P_t values are found by summing over the appropriate sets of PSD lines. Now one only needs to evaluate equation (1), above, for each of the eight viewing angles. This will complete the calculation cycle for one instant in time, and one CCT record.

The TAMU CDFT system is designed to process data from any one of four scatterometer frequencies; i. e., 0.4, 1.6, 4.75, or 13.3 GHz. The system has been tested extensively using 1.6 and 13.3 GHz data inputs. It has had some testing with both 0.4 and 4.75 GHz data, however, measurements at these frequencies were limited during the course of this evaluation.

Appendix C is a FORTRAN listing of the processing system and is complete with the exception of the antenna gain tables.

Appendix D contains references [3] and [4] which might otherwise be difficult to obtain.

FFT Coefficients for
AFT Spectrum

FFT Coefficients for
Fore Spectrum

$0 \ f_1 \ f_2 \ f_3 \qquad \ldots f_i \ldots \qquad \ldots -f_i \ldots \qquad -f_3 \ -f_2 \ -f_1$

$f_{N/2}$
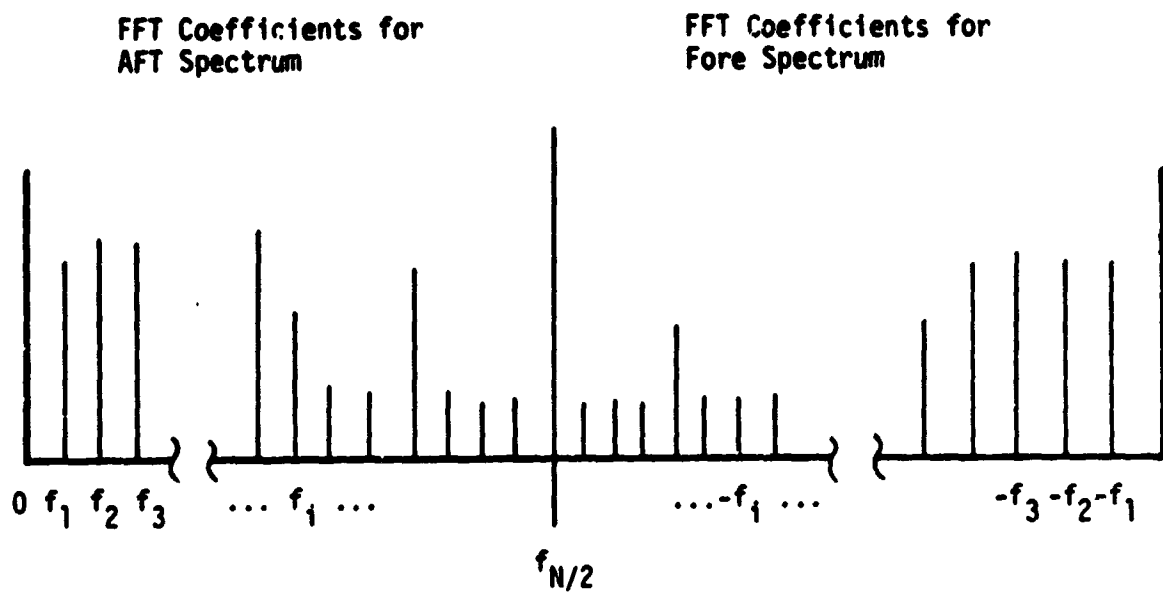
Figure 18. Spectral arrangement of the complex
digital Fourier transform.

8.0 REFERENCES

[1] "JSME Scatterometer Data Processing", Final Report RSC-3337, Texas A&M University, Remote Sensing Center, August 1977.

[2] "The System Hardware and Design of a Real-Time Fan Beam Scatterometer Data Processing", Final Report RSC-3556, Remote Sensing Center, Texas A&M University, March 1979.

[3] Clark, B.V. and R. W. Newton, "Comparison of Scatterometer Resolution Cell Area Approximations", Technical Memorandum RSC-159, Remote Sensing Center, Texas A&M University, March 1979.

[4] Newton, R.W., and B.V. Clark, "Equations For Computing the Area Term In the Radar Scatterometer Processing Algorithm", Technical Memorandum RSC-160, Remote Sensing Center, Texas A&M University, April 1979.

[5] "An Airborne Radar Scatterometer Signal Processing System", Progress Report RSC-3182-1, Remote Sensing Center, Texas A&M University, Feb-Apr 1975.

[6] Memorandum; Steve Reid, Lockheed Electronics, to Dr. Richard Newton, Remote Sensing Center, TAMU; dated 19 Jan 1978.

APPENDIX   A

FLOW CHARTS FOR HILBERT

TRANSFORM PROCESSING SYSTEM

ENTRY

Read & Write
Card #1

MSN, SIT., DATE
TIME, RUN, COMMENTS

Read
Card #2

Nbr Pts. = POINTS
Fore or Aft = LOOK
Nbr ang's = NANGL
Ang-Values = THETA(I),I=1,NANGL

Read
Card #3

Start Time = TIME
Nbr Secs To Process = DELTAT
Velocity (K) = VELOC
Alt. (F) = HEIGT
Drift = DRIFT
Roll = ROLL
Pitch = PITCH

Read
Card #4

CONFIG = 1,2, or 3 = ICON
Cell Length = LENGTH
Digitize Rate = FS
Gain Ch. 1 = GCH90
Gain Ch. 2 = GCH00
Calibr. Cnst. = CALREF
Cable Loss (2 way) = CABLE
Avg. Time Internal/rcd = DELT
Calibr. Filter BW = BAND

NPOLE = 2
FORE = .T.
AFT = .T.

Calibr. Filter BW = BAND = 100 @ 13.3
Calibr. Filter BW = BAND = 50 @ 1.6
Calibr. Filter BW = BAND = 25 @ 0.4

LOOK : 0 → AFT = .F.

LOOK : 0 → FORF = .F.

CALREF =
-CALREF+CABLE
FACT00 = 2048
LFLT = 2*NPOLE+1
N = 2*NPOLE

add cable loss to Calib. Ref

52 ← 3 ICON: 1 → 50

λ = 0.0225
FCAL1 = 1200
MHZ400 = .F.

FCAL2 = 8000

2

51

'13.3 ....
.... SYSTEM'

60

FORE = .F.
λ = 0.1875
FCAL1 = 1900
MHZ400 = .F

λ = LAMDA

FCAL2 = 1200

'1.6 GHz ...
... SYSTEM'

60

Flowchart (Sheet 1.1):

```
        ( 52 )
          │
          ▼
    ┌──────────────┐
    │ FORE = F.    │
    │ A = 0.75     │
    │ FCAL1 = 1000 │
    │ FCAL2 = 500  │
    │ HI2400 = .1  │
    └──────────────┘
          │
          ▼
    ┌──────────────┐
    │ '0.400 GHz...│
    │ ... SYSTEM'  │
    └──────────────┘
          │
( 60 )────┤
          ▼
    ┌──────────────┐
    │ PRINTER:     │
    │   FCAL:      │
    │   CALREF     │
    │   LAMDA      │
    └──────────────┘
          │
          ▼
    ┌──────────────┐
    │ PRINTER:     │
    │   GCH00      │
    │   GCH90      │
    └──────────────┘
          │
          ▼
    ┌──────────────────────────┐
    │ TSTART = TIME in Secs.    │
    │ TSTOP = TSTART + DELTAT    │
    └──────────────────────────┘
          │
          ▼
    ┌──────────────────────────────────────┐
    │ PRINTER:    { TSTART, TSTOP, POINTS, NPOLE }│
    │             { NANGL, VELOC, HEIGT, DRIFT }  │
    │             { ROLL, PITCH }                 │
    └──────────────────────────────────────┘
          │
          ▼
    ┌──────────────────────────┐
    │ PRINTER:                  │
    │   LENGTH      (Cell Length)│
    └──────────────────────────┘
          │
          ▼
    ┌──────────────────────────────┐
    │ CONVERT to Metric/Radians     │
    │ DRIFT,ROLL,PITCH = RADIANS     │
    │ VELOC = Meters/sec             │
    │ HEIGT = Meters                 │
    └──────────────────────────────┘
          │
          ▼
    ┌──────────────┐
    │ HTSAVE =     │
    │   HEIGT      │
    │ VELSAV =     │
    │   VELOC      │
    └──────────────┘
          │
          ▼
    ┌──────────────────────────────────────────────┐
    │ XK= 2*(LENGTH-VELOC*POINTS/FS)*VELOC/LAMDA/HEIGT│
    │                                                 │
    │ XK = 2(L - vn/fs) · v/λn                        │
    └──────────────────────────────────────────────┘
          │
          ▼
    ┌──────────────────────┐
    │ FREQ(NANGL+1)=FCAL1   │      NANGL = 8
    │ M = 1                 │      (NANGL = 8)
    │ FSUB0 = FCAL1         │
    └──────────────────────┘              12000 @ 13.3 GHz
          │                       FCAL1:  1900  @ 1.6
          ▼                               1000  @ 0.4
      ⌂ 2.0  Sheet 2.0
```

Title block:

NEXT ASSY   USED ON
APPLICATION

TOLERANCES
DEC ± .005
FRACTIONS±1/64
ANGLES± 5°

CONTRACT NO

ENGR   DATE
CK.
APVD.

REMOTE SENSING CENTER
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS

HILBERT TRANSFORM
PROCESSING SYSTEM

SIZE   B

CODE IDENT. NO.   DRAWING NO.

SCALE   SHEET 1.1

REVISIONS

ZONE   LTR   DESCRIPTION   DATE   APPROVED

Sheet 1.0

2.0

101

PRINTER:
FSUBO
BAND
FS

Subroutine
DESIGN   (See Sheet 5.0)

FSUBO
BAND
NPOLE
FILT
FS
AMPL

Subroutine
BFLY   (See Sheet 6.0)

LFLT
FILT
KM(M)
CM(M)   M=1, 2*NPOLE+1
VM(M)
FACTOR

MHZ400?   A

$M = M+LFLT$
$FREQ(NANGL=2) = FCAL2$
$FSUBO = FCAL2$

LFLT = 2*NPOLE+1 =5
(NANGL usually 8)
FCAL2 = 500

101

PRINTER:
FSUBO
BAND
FS

FSUBO = 500
FS = 2500
BAND = 25

Subroutine
DESIGN   (See Sheet 6.0)

FILT
AMPL

Subroutine
BFLY   (See Sheet 5.0)

KM(M)
CM(M)   M = 1,5
VM("")

9:   A

9:

(A) I=1 -NANGL yes → (3.0)   Sheet 3.0

I=I+1   no   (for each angle)

10:

M=M+LFLT
ANGLE = THETA(I)/57.3
FSUBO=2.*VELOC*SIN(ANGLE)*COS(DRIFT)/LAMDA   doppler f
BAND=XK*COS(ANGLE)**3,BWT=3.*FS/FLOAT(POINTS)

Subroutine
BFLY

BAND:BWT → BAND=BWT

FILT(1) =
FILT(1)/AMPL

SN=SQRT(BAND*POINTS/FS)   SN = BW*n / fs
CONF=5.*(ALOG10(1- 1/SN)+ALOG10(1+ 1/SN))
AK1(I)=4./(LAMDA*(FSUBO-BAND/2))**2   AK1 = 4. / ((f_0 - BW/2))^2
AK2(I)=4./(LAMDA*(FSUBO+BAND/2))**2   AK2 = 4. / ((f_0 + BW/2))^2
FREQ(I)=FSUBO   (fd)
ANGLO=ANGLE
ALPHA=GAMMA(FSUBO)   { FUNCTION Subroutine FOR {WATER}{LAND} Filter }

MH2400

(C)

f-doppler

RANGE = HEIGT/COS(ANGLO)/COS(ROLL)
KTWO = AK2(I)
KONE = AK1(I)

BEAM=BWIDTH(ANGLO,PITCH)/57.3   { FUNCTION Subroutine }
GAINSQ=GAIN(ANGLO,PITCH)

Subroutine
CAREA   (Sheet 6.0)

ANGLO=Look angle, radians
BEAM=Beam Width, radians
HEIGT=Radar Alt
LAMDA=Wave length
ROLL=Altitude, radians   Return
DRIFT=Altitude   AREA
PITCH=Altitude
VELOC=Speed, Knots
FSUBO=Radar Return Freq.

MH7400:

FSUBO =
500.-FSUBO   (500 - fd)

FSAMP = FS

103
PRINTER:
I,THETA(I),
FSUB,BAND,
CONF

(B)

106:
FORE: → .T. → PRINTER:
BEAM
GAINSQ

.F.

ANGLO = -ANGLO
BEAM=BWIDTH(ANGLO,PITCH)/57.3
GAINSQ=GAIN(ANGLO,PITCH)

AFT: → .T. → PRINTER:
BEAM,
GAINSQ
106:

Subroutine
DESIGN

(C)

105
PRINTER:
RANGE, AREA,
ALPHA

(B)

56

Sheet 2.

3.0

8

(Sheet 6.0)

Subroutine INDEX

ANGLPT(I),I=1,NANGL
MATRIX(I,J),I=1,25,J=1,200 = 0
PTRINP = 101
PTROUT = 100-ANGLPT(NANGL)

104: PRINTER:
THETA(I),
ANGLPT(I),   I=1,NANGL

FORE.OR.AFT → STOP
F.

LAST=DELTAT/DELT   NbrSecs to Process   Nbr Cells
                    Avg. time/Cell

M÷2400: .T. → CALREF = CALREF+3.0
.F.

20:
NDEX=1   yes → STOP
NDEX=LAST   (all cells done)
NDEX=NDEX+1   no   (For each Cell)

40
3.2
Sheet 5.0

Subroutine INPUT
(Read Tape Rcd)

POINTS
T = TIME = (Secs)
CH90 = SINE = radar
CH00 = COSINE = radar
HEIGT
VELOC
DRIFT
ROLL
PITCH

T:START

HEIGT=HTSAVE
54.25 → HEIGT = HTSAVE

VELOC=VELSAV
7.71 → VELOC = VELSAV

ROLL 10.17 → ROLL = 0.17

PITCH :005 → PITCH = 0.05

DRIFT :0.17 → DRIFT = 0.17

A

NEXT ASSY | USED ON
APPLICATION

TOLERANCES:
DEC.± .005
FRACTIONS±1/64
ANGLES± 5°

CONTRACT NO.
DATE
ENGR
CK
APVD

REMOTE SENSING CENTER
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS

SIZE CODE IDENT NO. DRAWING NO.
B

SCALE   SHEET

ZONE | LTR | DESCRIPTION | DATE | APPROVED
REVISIONS

57

58

Sheet 3.0

4.0

J = 1, NANGL
J = NANGL → yes → 3.1   Sheet 3.0

J = J + 1   no

31

M = M + LFLT

FORE: .T.

.F.

XPRIME = YFORE

Subroutine
FNORM   (Sheet 7.0)

XPRIME = YPRIME
M3 = 128 + M

Subroutine
FNORM   (Sheet 7.0)

XI = YPRIME
SIGMA(J) = MEANSQ(SIGMA(J), I, XI)

36
.T.   AFT:

.F.

XPRIME = YAFT

M2 = 64 + M

Subroutine
FNORM   (Sheet 7.0)

XPRIME = YPRIME
M4 = 192 + M

Subroutine
FNORM   (Sheet 7.0)

XI = YPRIME
SIGMA(J+NANGL) = MEANSQ(SIGMA(J+NANGL), I, XI)   FUNCTION

59

Sheet 3.0

30: ⬡ 4.1

(All points for cell done)

◇ M=7400: ——.T.—→ PT = PT*PT2/PT1

.F.

◁ I=1 / I = NANGL ▷ yes ——→ ⬡ 5.0   Sheet 5.0
  I=I+1   no

```
ANGLO = THETA(I)/57.29
BEAM = BWIDTH(ANGLO,PITCH)/57.3
FSUB0 = FREQ(I)         fd
KONE = AK1(I)
KTWO = AK2(I)
RANGE = HEIGT/COS(ANGLO)/COS(ROLL)
```

.T.
◇ FORE: ◇
.F.

Subroutine CAREA   (Sheet 6.0)

```
RATIO = SIGMA(I)/PT
GAINSQ = GAIN(ANGLO,PITCH)  } GAIN
ALPHA = GAMMA(FSUB0)        } FUNCTION(roll-off)
```

Subroutine CSIGMA   { $S_1 = (Ratio*RANGE**4)/AREA*1984.4/1/MHA**$ }
{ $SIGMA0 = 10.*ALOG10(S_1)-GAINSQ-ALPHA+CALRE1$ }
$\sigma = 10Log_{10}S_1 - G \cdots + CAL$

SIGMA(I) = SIGMA0

37
.T.
◇ AFT: ◇
.F.

ANGLO = -ANGLO

BEAM = BWIDTH(ANGLO,PITCH)57.3

Subroutine CAREA   (Sheet 6.0)

```
RATIO = SIGMA(I+NANGL)/PT
ALPHA = GAMMA(FSUB0)        } roll-off
GAINSQ = GAIN(ANGLO,PITCH)  } gain
```

Subroutine CSIGMA   (See note above)

SIGMA(I+NANGL) = SIGMA0

Sheet 4.0

5.0   (All 8 angle's done)

PT PT*PT1/PT2
PT1 10Log₁₀PT1
PT2 10Log₁₀PT2

PT-10.*ALOG10(PT)   PT 10Log₁₀PT

FORE: T. → PRINTER:
              A/C DATA
              CALIB.PWR
              SIGMA   UNIT 6
.F.

AFT: T. → PRINTER:
             A/C DATA
             CALIB.PWR
             SIGMA
.F.

FORE: T. → PUNCH:
              A/C DATA
              CALIB.PWR
              SIGMA   UNIT 4
.F.

AFT: T. → PUNCH:
             A/C DATA
             CALIB.PWR
             SIGMA
.F.

Subroutine
PUTIT   (See Sheet 8.0)
             (build aligned data matrix)

Unit 3

Subroutine
OUTPUT   (See Sheet 8.0)
             ("Aligned" data
              punched out)
40

3.2   Sheet 3.0

NEXT ASSY

APPLICATION

USED ON

TOLERANCES
DEC ± 005
FRACTIONS± 1/64
ANGLES± 5°

TOLERANCES
DEC ± 005
FRACTIONS± 1/64
ANGLES± 5°

CONTRACT NO

DATE

ENGR
CK
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REMOTE SENSING CENTER
TEXAS A&M UNIVERSITY
COLLEGE STATION, TEXAS

HILBERT TRANSFORM
PROCESSING SYSTEM

SIZE CODE IDENT NO   DRAWING NO
B

SCALE   SHEET 5.0

ZONE LTR   DESCRIPTION   DATE   APPROVED
REVISIONS

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Subroutine
BFLY

J = 1
J-1 LFLT → yes → KM(LFLT) = FACTOR*FILT(1) → RETURN
J = J+1 ↓ no

KM(J) = FACTOR*FILT(J+1)
CM(J) = FACTOR*SQRT(1.-FILT(J+1)**2)
VM(2) = FILT(LFLT+1)

Subroutine
CAREA

TERM1 = 2*(TAN(BEAM/2.)*HEIGT**2/(COS(ANGLO)*COS(ROLL))
TEMP1 = KTWO*VELOC**2
TEMP1 = (-TAN(DRIFT)*TAN(ROLL)-SQRT(TAN(ROLL)**2*(TEMP1-1.0)+
        TEMP1*COS(DRIFT)**2-1.0))/(1.0-TEMP1*COS(DRIFT)**2)
TERM2 = TEMP1
TEMP1 = KONE*VELOC**2
TEMP1 = (-TAN(DRIFT)*TAN(ROLL)-SQRT(TAN(ROLL)**2*(TEMP1-1.0)+
        TEMP1*COS(DRIFT)**2-1.0))/(1.0-TEMP1*COS(DRIFT)**2)
AREA = TERM1*(TERM2-TEMP1)

RETURN

Subroutine
INDEX

I = 1
I = NANGL → yes → A
I = I+1 ↓ no

ANGLPT(I) = IFIX(0.5*HEIGT*TAN(THETA(I)/57.3)/VELOC/DELT)

A

I = 1
I = 24 → yes → PTRINP = MATLEN/2+1
I = I+1 ↓ no   PTROU = PTRINP-ANGLPT(NANGL)-1

MATLEN = 200   RETURN

J = 1
J = MATLEN
J = J+1

MATRIX(I,J) = 0

Subroutine
FNORM

XPL[N+1]=XPRIME
YPRIME = 0

I = 1
TO N
I = I+1

XMI(1) = XPL(1)
YPRIME = YPRIME + VM(1)*XMI(1)
YPRIME = YPRIME*KM(N+1)

RETURN

M = N-I+1
XPL(M) = CM(M)*XPL(M+1)-KM(M)*XMI(M)
XMI(M+1) = KM(M)*XPL(M+1)+CM(M)*XMI(M)
YPRIME = YPRIME + VM(M+1)*XMI(M+1)

Subroutine
SIGNS

SIGNS(XSIN,XCOS,YFORE,YAFT,Z,DELAY)
Z(38),DELAY(?N)
DELAY & Z are initialized to 0 for
each new input record

ND = 19
ND1 = ND+1
XN = 0.00128*XCOS
Z(5) = Z(8)-1.684*(Z(6)+Z(2))+6.363*Z(4)+XN
Z(16)
Z(24)   See Program Listing
Z(32)
Z(38)
YN = Z(38)+Z(38)
YFORE = YN+DELAY(ND)
YAFT = YN+DELAY

I = 1
TO ND1
I = I+1

DELAY(1) = XSIN

M = ND-I+1
DELAY(M) = DELAY(M-1)

I = 1
TO 17
I = I+1

Z(1) = YN

RETURN

M = 18-I+1
Z(M) = Z(M-1)

DEN = 1./SQRT(EMAX)
EQRT = EMAX/4

VMAX = 0

(A)

(310)

J=1
J=MP
J=J+1   330   yes

no

PM = ABS(P(J))

(VMAX-VM):   VMAX = PM

|E(L)-EQRT|:   0

P(L) = P(L)/2.
IS(L) = 2*IS(L)
E(L) = 4*E(L)

(310)

W = VMAX
Q = SQRT(SUM/EMAX)

(W-Q):

510
W = Q
SO = SQRT(SUM)

515
W = VMAX/.999999

520

SO = W*SQRT(EA/AX)

J=1
J=MP
J=J+1   530   yes   SI = SQRT(1./EMAX)

no

P(J) = P(J)/W

RETURN

Subroutine
FIP

ITY = 6
MP = M+1

Subroutine   } Convert direct form
B2L   to lattice

SUM = A(1)

J=1
J=MP
J=J+1   yes

no

IE(J) = 0
IS(J) = 1
D(J) = 0
E(J) = 1

J=1
J=M
J=J+1   210   yes   EMAX = 0   (B)

JJ = M+1-J
P1(JJ) = 1./SQRT(AL(JJ))
P(JJ) = P(JJ)/P1(JJ)

(B)   J=1
J=M
J=J+1   250   yes   (A)

D(J):EMAX   EMAX = D(J)

E(J):EMAX   EMAX = E(J)

NEXT ASSY
USED ON
APPLICATION

TOLERANCES:
DEC.± .005
FRACTIONS:±1/64
ANGLES:±.5°

CONTRACT NO.

DATE

ENGR
CK
APVD

REMOTE SENSING CENTER
TEXAS A&M UNIVERSITY
COLLEGE STATION,TEXAS

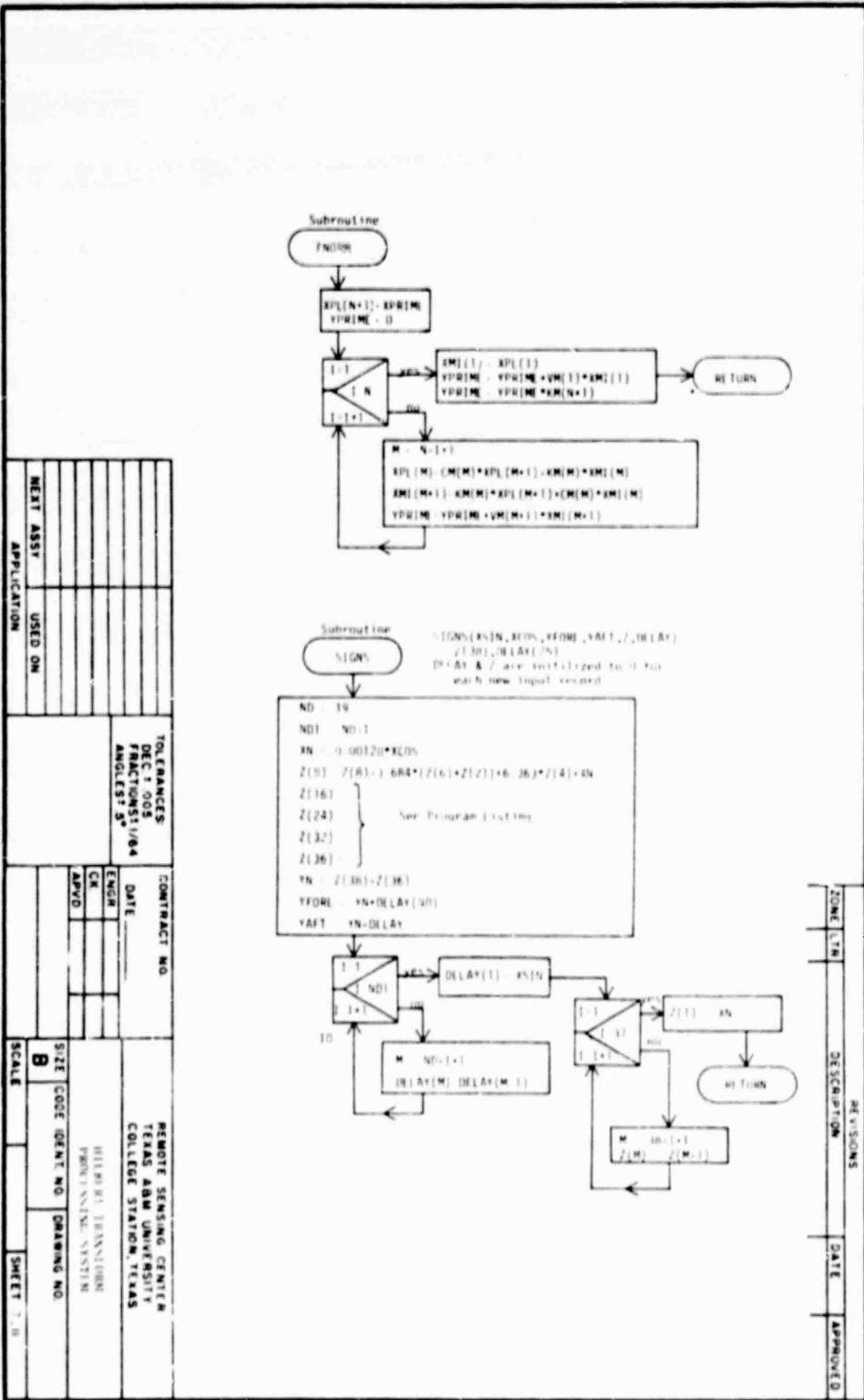HILBERT TRANSFORM
PROCESSING SYSTEM

SIZE   CODE IDENT. NO.   DRAWING NO.
B

SCALE   SHEET 9.0

ZONE LTR   DESCRIPTION   DATE   APPROVED

REVISIONS

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Subroutine **DIRECT** — cal. coefficients for filter

```
I=2, NPT, I=I+1   ──yes──►  A(I)=-Z(I)  ──►  I=2, N, I=I+1  ──yes──►  BSAV = REAL(A(I))  ──►  I=1, NP1, I=I+1  ──►  RETURN
        │no                                        │no                                              │
        ▼                                          ▼ 20                                            ▼
   A(I) = CMPLX(1.0,0.)                        N = I-1                                     B(I) = REAL(A(I))/BSAV
                                                   │
                                                   ▼
                                          J=1, J N, J=J+1  ──yes──►
                                                   │no  30
                                                   ▼
                                          K = I-J+1
                                          A(CK) = A(K-1)-A(K-1)*Z(I)
```

Subroutine **PUTIT**

```
MATLEN=200
   │
   ▼
I=1, NANGL  ──yes──►  Store Time,  ──►  Up-Date  ──►  RETURN
   │no                HEIGT,            Pointers
   ▼                  VELOC,
Compute indexes       PITCH,
into   matrix         ROLL,
   │                  DRIFT, PT
   ▼
Store  's into
matrix
```

Subroutine **OUTPUT**

```
I=1, 8, I=I+1  ──yes──►  Scale  ──►  PUNCH  ──►  RETURN
   │no                   PITCH, ROLL,  "ALIGNED"
   ▼                     DRIFT, & CAL   data
Scale radar              by 10
data by 10
```

APPENDIX   B

VIEWGRAPHS OF SEPTEMBER 1977

SCATTEROMETER DATA PROCESSING

SUMMARY

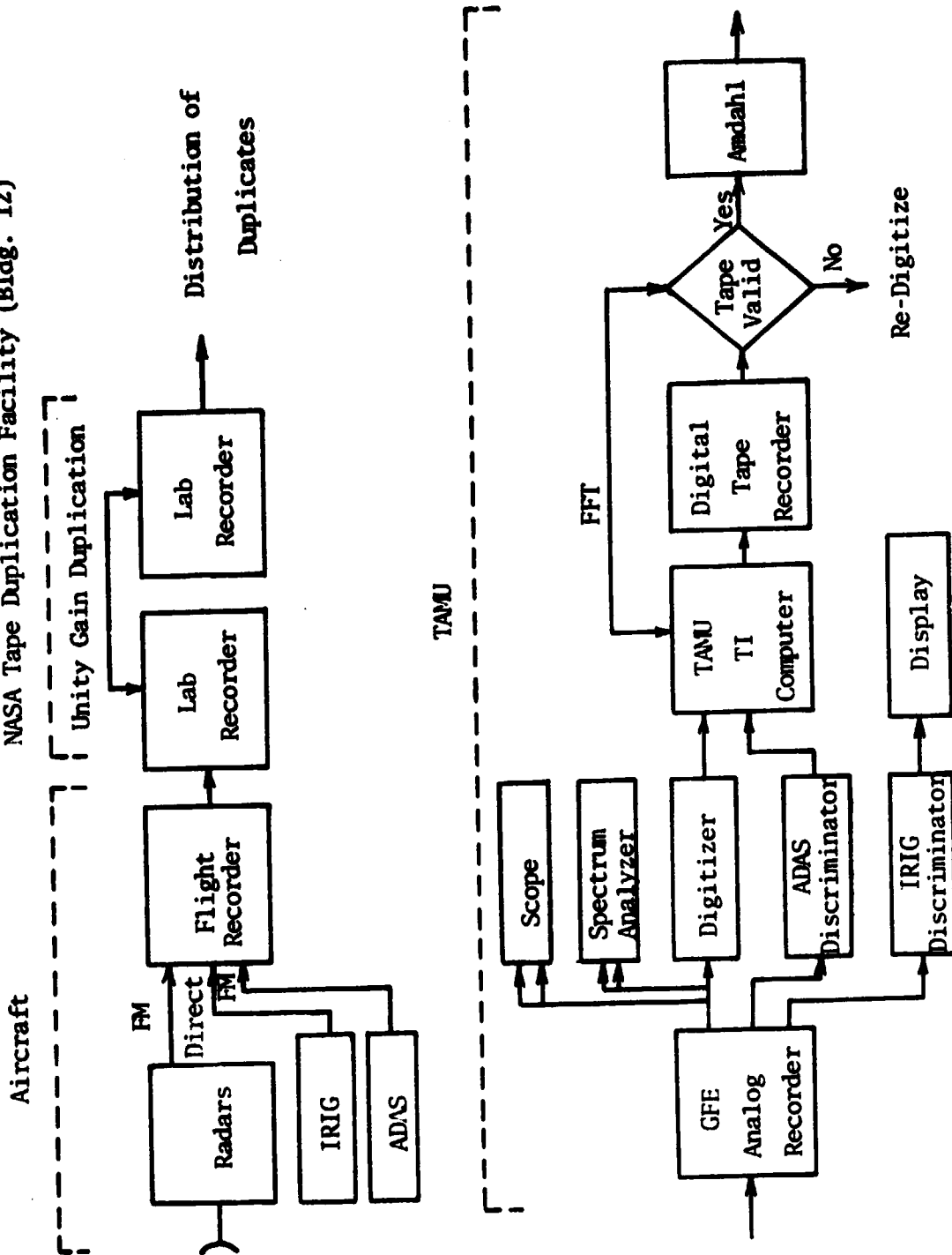DISCREPANCY: MISINTERPRETATION OF AIRCRAFT FLIGHT LOGS/TAPE I.D.

    1. 15 dB GAIN ASSUMED IN ONE CHANNEL OF THE 1.6 GHz SYSTEM.

    2. MISINTERPRETATION AS TO WHAT ROLL-OFF FILTER WAS USED ON SOME DATA RUNS.

    3. TERMINOLOGY DENOTING IN-PHASE AND QUADRATURE CHANNELS OF 1.6 GHz AND 13.3 GHz SYSTEM CONFUSING AND MISUNDERTSTOOD.

ACTION: 1. VERBAL CLARIFICATION OF MEANING OF FLIGHT LOG INFORMATION (CORRECTED 1. AND 2.)

    2. SPECTRUM ANALYSIS TO DETERMINE CHANNEL CONTAINING CALIBRATION SIGNAL AND TIME HISTORY PLOTS OF SEVERAL ANGLES OF NON-SHIFTED PROCESSED DATA TO DETERMINE WHICH OF THE QUADRATURE CHANNELS LEAD AND WHICH LAGS IN-PHASE.

RESULT: THE CALIBRATION SIGNAL WAS FOUND TO BE ON OPPOSITE QUADRATURE CHANNELS FOR THE 1.6 GHz AND 13.3 GHz RADARS.

NASA Tape Duplication Facility (Bldg. 12)

Distribution of Duplicates

Unity Gain Duplication

Lab Recorder

Lab Recorder

Flight Recorder

Aircraft

FM

Direct

FM

Radars

IRIG

ADAS

TAMU

FFT

Tape Valid

Yes

Amdahl

No

Re-Digitize

Digital Tape Recorder

TAMU TI Computer

Scope

Spectrum Analyzer

Digitizer

ADAS Discriminator

IRIG Discriminator

Display

GFE Analog Recorder

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SCATTEROMETER DATA PROCESSING (CONTINUED)

SUMMARY (CONTINUED)

DISCREPANCY: INCONSISTANCY OF TIME REFERENCE

1. ADAS INFORMATION COULD NOT BE DISCRIMINATED
   - POOR TAPE REPRODUCE CAPABILITY (GFE RECORDER)
   - ADAS DISCRIMATOR ADJUSTMENT

2. IRIG TIME USED TO PROCESS DATA
   - DID NOT PROVIDE ONE TO ONE TIME CORRELATION BETWEEN RADAR DATA AND PHOTOGRAPH
   - DID NOT PROVIDE TIME CONSISTANCE BETWEEN RADARS EVEN WITHIN SAME RUN

ACTION: 1. ADJUSTMENTS MADE TO ADAS DISCRIMATOR
         2. BETTER QUALITY TAPE RECORDER OBTAINED
         3. ADAS TIME REFERENCE USED FOR ALL PROCESSING
            - THIS PROVIDES TIME CONSISTENCY BETWEEN ALL RADARS, DATA RUNS, AND PHOTOGRAPHY

SCATTEROMETER DATA PROCESSING (CINTINUED)

SUMMARY (CONTINUED)

DISCREPANCY: MISALIGNMENT OF SIGMA FOR EACH GROUND CELL.

1. AVERAGE FLIGHT PARAMETERS USED TO COMPUTE AN AVERAGE TIME SHIFT FOR EACH ANGLE DURING EACH RUN

2. THE AVERAGE VELOCITIES THAT WERE USED TO COMPUTE SHIFTS INCORRECT.

- AVERAGES WERE COMPUTED FOR TIMES ON FLIGHT LOGS

- TIMES ON FLIGHT LOG INCLUDED SET-UP FOR DATA RUN AND USUALLY CONTAINED LARGE VELOCITY VARIATIONS

- VELOCITY ON FLIGHT LOG NOT ALWAYS REPRESENTATIVE OF VELOCITY DURING DATA RUN

ACTION: PROGRAM MODIFIED SO THAT FLIGHT PARAMETERS ARE UPDATED CONTINUOUSLY FROM ADAS DURING SIGMA COMPUTATIONS. TIME SHIFTS, AREA CALCULATIONS, ETC. ARE NOW AS ACCURATE AS POSSIBLE.

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Scatterometer Data Processing (continued)

Summary (continued)

Discrepancy: Calibration Constant Used In Processing Data

1. Compensation of calibration constant for the measurement technique improper

2. Compensation of the calibration signal for sign sensing improper (in analog processing)

Action: Program corrected after agreement was reached on proper compensation

(Note that this discrepancy only introduced a constant offset in the processed data.)

SCATTEROMETER DATA PROCESSING (CONTINUED)

SUMMARY (CONTINUED)

DISCREPANCY: SCATTEROMETER HARDWARE INCONSISTANCIES

1. 1.6 VV AND 1.6 VH DATA NO GOOD BEFORE
    MISSION 362

    • SWITCH IMPEDANCE MISMATCH

2. 400 MHz HORIZONTALLY POLARIZED ANTENNA HAD
    A LOOSE CONNECTOR DURING JSME FLIGHTS

ACTION: CORRECTED BY E&D PERSONNEL

SCATTEROMETER DATA PROCESSING (CONTINUED)

SUMMARY (CONTINUED)

DISCREPANCY: INABILITY TO REPRODUCE RAW DATA FROM ANALOG

TAPES WITHOUT DROPOUTS, CLIPPING, OR ADDITIVE NOISE

1. ANALOG GFE TAPE RECORDER AVAILABLE TO TAMU
    WAS AN <u>OLD</u> FLIGHT RECORDER THAT HAD VERY POOR
    REPRODUCE CAPABILITY

2. ANALOG DATA TAPES ARE DUPLICATES OF POOR
    QUALITY WITH CARRIER LEVELS EXTREMELY LOW

3. DUPLICATE FLIGHT TAPES GIVEN TO TAMU FOR PRO-
    CESSING ARE OF POOR MECHANICAL QUALITY (REUSED
    TAPES)

    NOTE: LITTLE QUALITY CONTROL IS APPARENT IN
           DUPLICATION PROCESS

4. FM MODULATION IN RECORDING RADAR DATA ON
    AIRCRAFT EXCEEDS THE 40% DEVIATION LIMIT
    OF THE RECORDERS MUCH OF THE TIME

5. CONSISTANCY OF AIRCRAFT RECORDER SET-UP IS
    POOR, ADDING TO DIFFICULTIES IN 3.

SCATTEROMETER DATA PROCESSING (CONTINUED)

SUMMARY (CONTINUED)

6. RECORDER CALIBRATION LEVELS PUT ON DATA TAPE
   ARE OF VERY POOR QUALITY

ACTION: 1. A BETTER QUALITY GFE LABORATORY TAPE RECORDER HAS
           BEEN PROVIDED TO TAMU AND INTEGRATED INTO THE
           DATA PROCESSING SYSTEM.

        2. TAMU DIGITIZER MODIFIED TO BE COMPATIBLE WITH
           INPUTS OF $\pm$ 5 VOLTS IN ORDER TO HANDLE THE OVER-
           MODULATED RADAR DATA

           • TESTS WERE PERFORMED TO INSURE THAT THE
             REDUCTION IN DIGITIZATION RESOLUTION DID
             NOT AFFECT THE FINAL SIGMA

        3. QUALITY CONTROL OF DATA RECORDING, TAPE REPRODUCE
           AND TAPES MUST BE DONE BY NASA.

SCATTEROMETER DATA PROCESSING (CONTINUED)

SUMMARY (CONTINUED)

DISCREPANCY: UNCERTAINTY IN ANTENNA PATTERNS

     1. 13.3 GHz DATA HAVE CONSISTENT "HUMPS"
        AT 30° AND 50°

     2. 13.3 GHz PATTERN (MEASURED IN 1976 BY NASA)
        HAS STEEP GRADIENTS AT 30° AND 45° - 50°

     3. 1.6 GHz DATA HAVE CONSISTENT "HUMP" AT
        20°

ACTION: 1. ATTEMPT TO APPROXIMATE MORE REALISTIC PATTERN

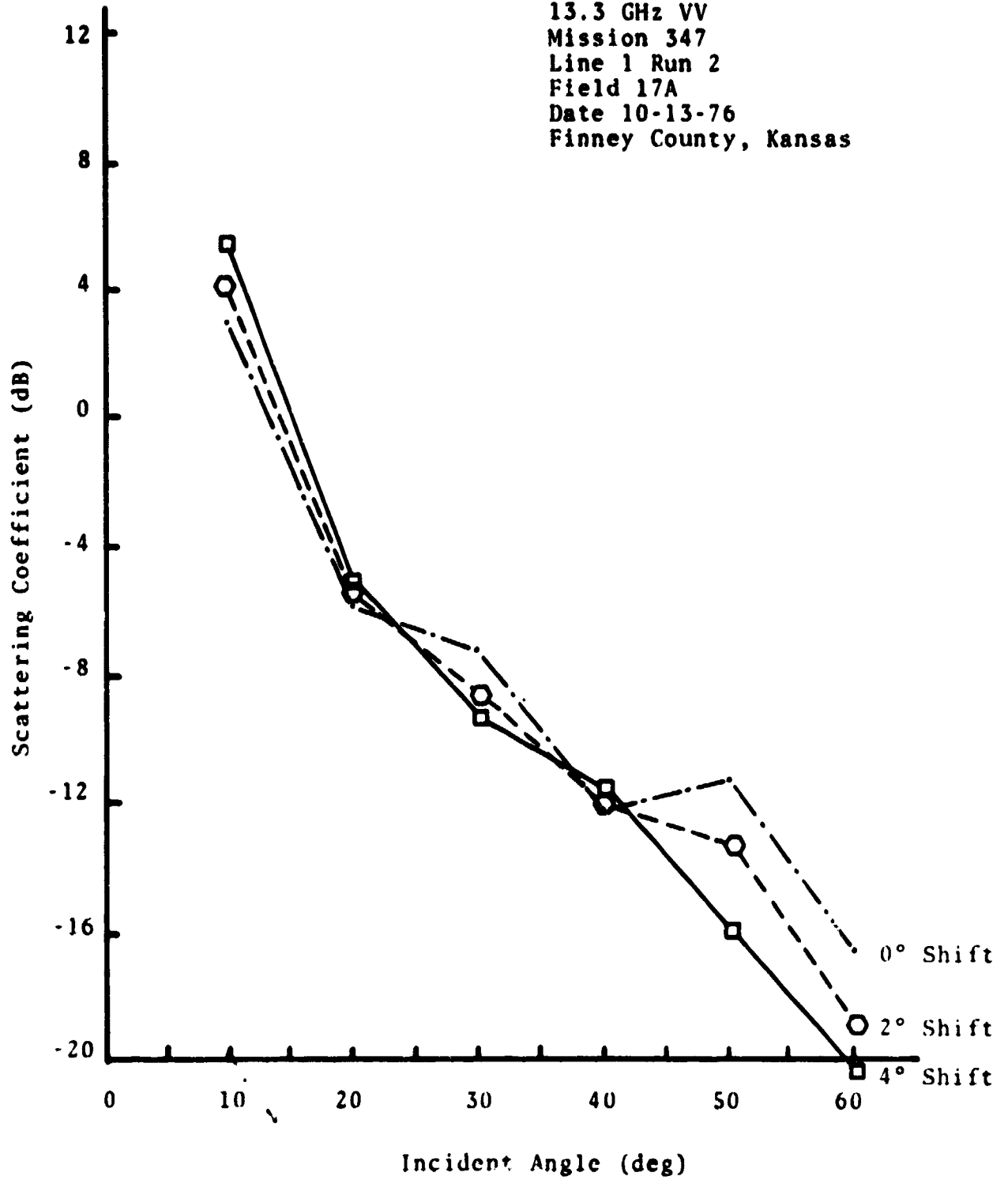   2. PROCESS DATA AT 5°, 10°, 15°, 20°, 25°, 35°,
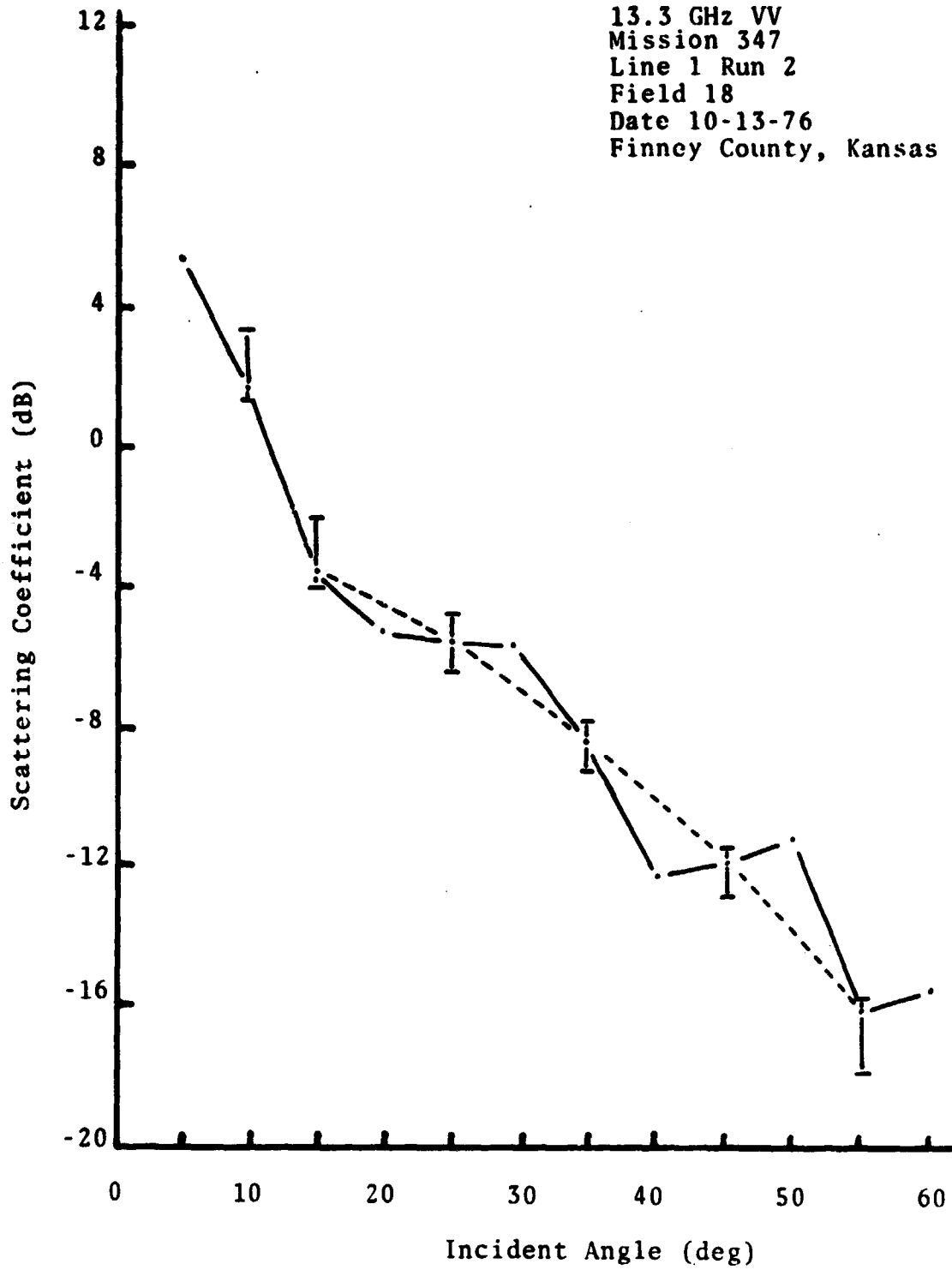   45°, AND 55°.

13.3 GHz

AFT ANTENNA PATTERN

η

13.3 GHz VV
Mission 347
Line 1 Run 2
Field 17A
Date 10-13-76
Finney County, Kansas

13.3 GHz VV
Mission 347
Line 1 Run 2
Field 18
Date 10-13-76
Finney County, Kansas

Scatterometer Data Processing (continued)

Status

1. Currently processing portions of FCF over Death Valley to further investigate antenna pattern discrepancies and as final check on software system

2. A list of specific ADAS times are being provided to TAMU by NASA for processing

3. Processing will commence after resolution of antenna pattern uncertainties

4. Character of 400 MHz data unexplained and must be taken at face value until more data are processed

APPENDIX   C

LISTING FOR PROGRAM SCATTER.CZTA78

```
C
C
C          >==   TEST PROGRAM FOR SIMULATING CHIRP=Z ALGORITHM   ==<
C
C
C          DEVELOPED AT TEXAS A&M UNIVERSITY
C                      REMOTE SENSING CENTER
C
C                      SEPT78 = MAY79
C
C          ALGORITHM PERFORMS COMPLEX DFT (X+JY) ON TWO INPUT CHANNELS
C
C
C     SYSTEM PROCESSES SCATTEROMETER DATA FOR 13.3, 1.6, 4.75, OR .4GHZ
C
C              >>>>>   VERSION DATED MAY 1979   <<<<<<
C
C     *****   INPUT PARAMETERS:
C
C        CARD #1 POINTS= COL 1=4, I4 (1024 OR 2048)
C                SYSK= COL 6=10, F5.0
C                CABL= COL 11=15, F5.0
C                DELT= COL 16=20, F5.0(NBR SECS TO PROCESS)
C                TS(1)= COL 21=22, F2.0(START OF
C                TS(2)= COL 23=24, F2.0(TIME SEGMENT .
C                TS(3)= COL 25=27,F3.1 HHMMSSS)
C
C
C        CARD#2  80 CHARACTERS OF COMMENTS
C
C        CARD#3  INCR= COL 1=5,I5(FFT LENGTH)
C                ITYPE= COL 6=10,I5 (1=13.3, 2=1.6, 3=4.75, 4=0.4 GHZ)
C                DT  = COL 11=15, F5.3,(AVG RCD TIME INTERVAL)
C                IBUG = COL 16=20  ,I5, (DATA DUMP SWITCH)
C                KPOLZ= COL 21=25,  I5, (SET IF V=POLARIZED C=BAND DATA)
C                IPLOT= COL 26=30,  I5,(SET IF SPECTRUM PLOT OF 1ST RCD)
C                CELL= COL 31=35,  F5.0(RESOLUTION,INSTANTANEOUS)
C
C
C
      DIMENSION ZW(8),A(8),BDW(9),IFDL(8),IFDR(8),GAINSQ(8),BEAM(8)
      DIMENSION MATRIX(19,100),R(8),TS(3),FDOP(8),THETA(9),DFDOP(8)
      DIMENSION SIGMA(8),IBPTR(8),FREQP(1024),AFT(1024),AFTC(1024)
      DIMENSION TRIX(16),PSPFC(8),ANGT(8),PROPT(8),ITHETA(8)
      INTEGER*2 TIME(3),ADAS(5),SINE(2048),COSINE(2048),ICOM(40)
      INTEGER POINTS
      REAL NTS
      REAL LAMDA,KONE,KTWO
      COMPLEX FRS(2048),CMPLX,FRC(2048)
      COMMON/FILT/ITYPE,KPOLZ
      COMMON/ITAPE/TIME,ADAS,SINE,COSINE
```

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```
      COMMON/KAREA/KONE,KTWO
      COMMON/RAT/FINCR,FCAL,FSAMP,INCR
      DATA FORPI/12.56637/
      DATA MATRIX/1800*=999/
C AFT ANGLE SET IN DEGREES, UP TO EIGHT VALUES
      DATA THETA/5.,10.,15.,20.,25.,35.,40.,45./
      DATA ITHETA/5,10,15,20,25,35,40,45/
C
C GET SYSTEM RUN PARAMTERS AND COMMENTS
      READ(5,10) POINTS,SYSK,CABL,DELT,TS
 10 FORMAT(I4,1X,3F5.0,2F2.0,F3.1)
C
C COMMENTS INCLUDE MSN,LINE,RUN,DATE,BAND IDENT,ETC.
      READ(5,11)ICOM
 11 FORMAT(40A2)
C
C READ DFT LENGTH, TYPE SCAT, AND AVG RECORD TIME DEL.A
C
C   SET IBUG SWITCH IF DATA DUMP DESIRED ON UNIT 9
      READ(5,12) INCR,ITYPE,DT,IBUG,KPOLZ,IPLOT,CELL
 12 FORMAT(2I5,F5.3,3I5,F5.0)
      GO TO (1,2,3,4), ITYPE
C
C 13.3GHZ SCATTEROMETER
  1 LAMDA=0.02254
      FSAMP=25000.
      FCAL=12000.
      FNOIZ=8000.
      BWID=6.3
      GO TO 13
C 1.6GHZ SCATTEROMETER
  2 LAMDA=0.18737
      FSAMP=5000.
      FCAL=1900.
      FNOIZ=1500.
      BWID=7.94296
      GO TO 13
C 4.75GHZ SCATTEROMETER
  3 LAMDA=0.06311
      FSAMP=10000.
      FCAL=2930.
      FCALV=3380.
      IF(KPOLZ.NE.0) FCAL=FCALV
      FNOIZ=3100.
      BWID=2.5
      GO TO 13
C 0.4GHZ SCATTEROMETER
  4 LAMDA=0.74948
      FSAMP=2500.
      FCAL=1000.
```

```
      FCPT=500.
      FNOIZ= 200.
      BWID=14.0
C
   13 FPNTS=FLOAT(POINTS)
      THET8=TAN(THETA(8)/57.3)
      ML=100
      ICLR=0
      PT4=1.
      PC4=1.
C  SET UP DEFAULT VALUES FOR CELL LENGTH
      IF(CELL.GT.0.) GO TO 15
      GO TO (101,102,103,104), ITYPE
  101 CELL=25.
      GO TO 15
  102 CELL=50.
      GO TO 15
  103 CELL=40.
      GO TO 15
  104 CELL=75.
   15 CONTINUE
C  TO CORRECT FOR MEASUREMENT OF CALREF
      IF(ITYPE.EQ.2) SYSK=SYSK+3.0103*2.
      VKDB=30.*ALOG10(FORPI)-20.*ALOG10(LAMDA)-SYSK+CABL
C POWER SPECTRUM LENGTH = (LENGTH OF FFT)/2.
      FINCR=FLOAT(INCR)
      INCR2=INCR/2
      DELFRQ=FSAMP/(FINCR)
C
C  INITIALIZE OUTPUT LOAD POINTER & LINE COUNTER
      MXRCTR=ML-10
      NOUT=0
C NTS IS THE INVERSE OF SPECTRAL LINE WIDTH(LINES/HZ)
      NTS=FINCR/FSAMP
C CALCULATE POINTERS TO CALIBRATION VALUES IN AFT DATA BUFFER
      MC=IFIX(FCAL*NTS+0.5)+1
      MC4=IFIX(FCPT*NTS+0.5)+1
C   CALCULATE POINTERS FOR NOISE BAND MEASUREMENTS
      IFNOIZ=IFIX(FNOIZ*NTS+0.5)
      NOIZL=IFNOIZ-2
      NOIZR=IFNOIZ+2
      TSTART=3600.*TS(1)+60.*TS(2)+TS(3)
C CALCULATE NBR OF RCDS TO PROCESS = (TIME INCREMENT)/(RCD LENGTH)
      TSTOP=DELT/DT
      IEND=IFIX(TSTOP+0.5)
      WRITE(6,60) ICOM,POINTS,LAMDA,FSAMP,FCAL,SYSK,CABL,DELT,TS,IEND
   60 FORMAT(1H1,5X,40A2,//,15X,'POINTS/RCD=',I5,5X,'WAVE LENGTH=',F7.4,
     $5X,'SAMPLE FREQ.=',F7.0,5X,'CALIB SIGNAL FREQ=',F6.0,/,
     $15X,'REFER CALIB:',F6.1,' DB',5X,'CABLE LOSS=',F6.1,5X,/,
     $15X,'NBR SEC PROCESSED=',F5.1,5X,'START TIME: ',2F3.0,F4.1,
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      $5X,'NBR RCDS:',I6,/)
        WRITE(6,16)NTS,MC,IFNOIZ
   16 FORMAT(1H ,14X,'SAMPLE INTERVAL:',F9.5,5X,'CALIB PWR PTR:',I6,
      $5X,'NOISE PWR PTR:',I6,///)
   20 CALL INPUT(POINTS,T)
C  *** DIGITIZER CHANNEL 1= SIN. CHANNEL 2= COSINE. IN CORE
C     IF 13.3GHZ TAPE CH11 => SINE. TAPE CH13 => COSINE. (CH11=TSINE,CH13=
C     IF  1.6GHZ TAPE CH 3 => SINE. TAPE CH 1 => COSINE. (CH3=TCOS,CH1=TSI
C     IF  1.6GHZ TAPE CH 7 => SINE. TAPE CH 5 => COSINE(CROSS POLZ)
C     IF 4.75GHZ(LIKE) TAPE CH1=TSINE, CH3=TCOSINE
C     IF 4.75GHZ(CROSS)TAPE CH5=TSINE, CH9=TCOSINE
C
        IF(TSTART.GT.T) GO TO 20
        IF(NOUT.EQ.0) WRITE(6,21) TIME,T,ADAS
   21 FORMAT(1H0,5X,'FIRST RECORD TIME ',2(I2,':'),I3,
      $10X,'TIME IN SECS:',F7.1,/,10X,'ALT:',I4,
      $5X,'VELOCITY:',I4,5X,'PITCH:',I4,5X,'ROLL:',I4,
      $5X,'DRIFT:',I4,/)
        H=ADAS(1)
        H=H*0.3048
        IF(H.LT.350.) H=450.
        VEL=ADAS(2)
        VEL=VEL*0.514
        IF(VEL.LT.60.) VEL=77.1
C  ADAS/NERDAS FORMAT ON TAMU DIGITAL TAPES HAS PITCH FIRST
        PITCH=ADAS(3)
        PITCH=PITCH/573.
        ROLL=ADAS(4)
        ROLL=ROLL/573
        DRIFT=ADAS(5)
        DRIFT=DRIFT/573.
C
C  FILTER THE AIRCRAFT DATA FOR OLD DIGITAL TAPES
C  LIMIT = 5 DEG FOR PITCH. 10 DEG FOR ROLL.AND 15 DEG FOR DRIFT
C
        APITCH=ABS(PITCH)
        AROLL=ABS(ROLL)
        ADRIFT=ABS(DRIFT)
        IF(APITCH.GT.0.08726)  PITCH=0.08726*(PITCH/APITCH)
        IF(AROLL.GT.0.17452)   ROLL=0.17452*(ROLL/AROLL)
        IF(ADRIFT.GT.0.26178)  DRIFT=0.26178 *(DRIFT/ADRIFT)
C
C  CALCULATE NBR OF CELLS IN VIEW
        XCELLS=H*THETB/(VEL*DT)
C
C  INITIALIZE PRINTER POINTER BIAS
        IF(NOUT.EQ.0) LPRNT=IFIX(XCELLS*1.3)
C
C  COMPUTE SIZE OF INSTANTANEOUS RESOLUTION CELL
        SLIP=VEL*FPNTS/FSAMP
```

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      SCELL=CELL-SLIP
C
C  COMPUTE BUFFER LENGTH NEEDED
      MLN=IFIX(XCELLS+0.5)
      IF(MLN.GT.ML) GO TO 900
C
C  CALCULATE THETA FUNCTION DATA VALUES
      VEL2OL=2.*VEL/LAMDA
      XK=SCELL*VEL2OL/H
      IF(NOUT.EQ.0) WRITE(6,22) H,VEL,PITCH,ROLL,DRIFT,SLIP,XCELLS,
     $SCELL,BWID ,CELL,INCR,ITYPE,VEL2OL
   22 FORMAT(1H ,5X,'RUN PARAMETERS',/,6X,'H: ',F6.1,
     $5X,'VEL:',F6.1,6X,'PITCH:',F6.1,5X,'ROLL:',F6.1,
     $5X,'DRIFT:',F6.1,/,6X,'SLIP:',F6.1,3X,'XCELLS:',F6.1,
     $3X,'SCELL:',F6.1,5X,'BEAMW:',F6.1,2X,'CELL:',F6.1,5X,
     $'INCR:',I5,/,6X,'ITYPE:',I4,5X,'2V/LAMDA:',F9.2,/)
C
      DO 30 I=1,8
C  FOR EACH AFT ANGLE IN THE SET
      ANGL=-THETA(I)/57.3
C
C  GUARD AGAINST DOPPLERS OF NEGATIVE FREQUENCIES OFF FILTER BAND
      AANGL=ABS(ANGL)
      IF(AROLL.GE.AANGL) ANGL=-AROLL
C
C  COMPUTE VIEWING POINT COORDINATES ON THE GROUND
      YPI=-H*TAN(ROLL)
      XPI=SQRT((H*TAN(ANGL))**2-YPI**2)
      TTP=-XPI*COS(ROLL)/H
      XT=-H/COS(ROLL)*TTP
      YT=H*TAN(ROLL)
      XI=XT*COS(DRIFT)+YT*SIN(DRIFT)
      YI=XT*SIN(DRIFT)-YT*COS(DRIFT)
C  FORCE THE DOPPLER BAND TO BE ON FILTER BANK
      IF(XI.LT.SCELL/2.) XI=SCELL/2.
C
C  COMPUTE CORRECTED DOPPLER ANGLES
      XN=XI**2
      XD=H**2+YI**2
      ANGLD=ATAN(SQRT(XN/XD))
C
C  COMPUTE DOPPLER CENTER FREQUENCY ==============
      FDOP(I)=VEL2OL*SIN(ANGLD)
      IF(ITYPE.EQ.4) FDOP(I)=500.-FDOP(I)
C
C   COMPUTE DOPPLER BANDWIDTH == == == ==
      DFDOP(I)=XK*COS(ANGLD)**3
C
C
C  COMPUTE NBR OF FILTER ELEMENTS NEEDED
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         NFI=IFIX(DFDOP(I)*NTS+0.5)
         IF(NFI.LT.1) NFI=1
C
C     CALCULATE TRUE BANDWIDTH
         DFDOP(I)=FLOAT(NFI)*DELFRQ
         IF(MOD(NFI,2).EQ.0) GO TO 25
C     ODD NBR OF FILTERS REQUIRED
C
C     CENTER FREQ INDEX IS:
         NC=IFIX(FDOP(I)*NTS+0.5)
C
C     TRUE DOPPLER CENTER FREQ
         FDOP(I)=NC*DELFRQ
C
C     LEFT INDEX POINTER
         IFDL(I)=NC-(NFI-1)/2
C
C     RIGHT INDEX POINTER
         GO TO 27
C
      25 CONTINUE
C     EVEN NBR OF FILTERS REQUIRED
C
C     CENTER FREQ INDEX
         NC=IFIX(FDOP(I)*NTS)
C
C     TRUE DOPPLER CENTER FREQ
         FDOP(I)=(FLOAT(NC)+0.5)*DELFRQ
C
C     LEFT INDEX POINTER
         IFDL(I)=NC+1-NFI/2
      27 CONTINUE
         IF(IFDL(I).LE.0) IFDL(I)=1
C     RIGHT INDEX POINTER
         IFDR(I)=IFDL(I)+NFI-1
         IF(ITYPE.EQ.4) FDOP(I)=500.-FDOP(I)
C
C     COMPUTE TRUE DOPPLER ANGLE AND VIEWING ANGLE
         ANGTD=ARSIN(FDOP(I)/VEL2CL)
         XTSQ=XD*TAN(ANGTD)**2
         YTSQ=YI**2
         ANGTL=ATAN(SQRT(XTSQ+YTSQ)/H)
C     CHECK FOR NEGATIVE DOPPLERS
         AROLL=ABS(ROLL)
         IF(ANGTL.LT.AROLL) ANGTL=AROLL
C      SET UP FOR AFT VIEWING ANGLES ONLY
         ANGT(I)=ANGTL*57.3
C     COMPUTE TRUE RANGE
         R(I)=H/COS(ANGTL)
C
```

```
C   CALCULATF AREA VARIABLES KONE & KTWO
      ICON=1
      KONE=4./(LAMDA*(FDOP(I)-DFDOP(I)/2.))**2
C   CHECK FOR  ZERO & NEGATIVE DOPPLERS
      IF((DFDOP(I)/2.).GE.FDOP(I)) ICON=-1
      KTWO=4./(LAMDA*(FDOP(I)+DFDOP(I)/2.))**2
C
C   **>   THIS SYSTEM FOR AFT ANGLES ONLY  <<<<<*******
C
C   COMPUTE CORRECTED VIEWING ANGLE THRU ANTENNA PATTERN COORD SYSTEM
      ANGLPI=ATAN(-COS( ROLL)*SQRT(TAN(ANGTL)**2-TAN(ROLL)**2))
C
C** FIND VALUE IN TABLES OF GAINSQ
      GAINSQ(I)=GAIN(ANGLPI,PITCH)
C
C   FIND VALUE OF WATER FILTER ROLL-OFF
      ZW(I)=GAMMA(FDOP(I))
C
C   CALCULATE CELL AREA BETWEEN ISODOP LINES USING TRUE LOOK ANGLE
      BEAM(I)=BWID/57.3
      CALL CAREA(A(I),BEAM(I),H,ANGTL,VEL,ROLL,DRIFT,ICON )
   30 CONTINUE
C
C   SET UP TO DO THE FFT WITH 'INCR' POINTS
      NU=IFIX(ALOG(FINCR    )/ALOG(2.)+0.5)
C
C   CONVERT DATA TO FLOATING POINT & PLACE IN FFT BUFFER
      GO TO (31,32,31,32), ITYPE
   32 CALL SCALX(POINTS,SINE,COSINE,FRS)
      IF(ITYPE.EQ.4) CALL SCALX(POINTS,COSINE,SINE,FRC)
      GO TO 331
C
C   IF 13.3GHZ OR 4.75 DATA (TAMU INPUT TAPES) PUT CHAN2 DIG DATA FIRST
   31 CALL SCALX(POINTS,COSINE,SINE,FRS)
  331 CONTINUE
      IL=POINTS/INCR
      DO 35 I=1,IL
      IS=(I-1)*INCR+1
C
C   BUILD SPECTRUM FOR (CH1)+J(CH2)
      CALL DFT(FRS(IS),NU,INCR)
C   BUILD CALIB CHANNEL SPEC FOR 0.4GHZ DATA
      IF(ITYPE.EQ.4) CALL DFT(FRC(IS),NU,INCR)
   35 CONTINUE
C
C   SUM THE IL SETS FOR AFT DATA
      DO 36 I=1,INCR2
      FREQP(I)=FLOAT(I-1)*DELFRQ
      AFT(I)=0.0
      AFTC(I)=0.0
```

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C
C   BUILD AFT DATA POWER BUFFER OF 'INCR/2' SPECTRAL LINES
      DO 37 K=1,IL
      IS=(K-1)*INCR+I
      AFT(I)=AFT(I)+CABS(FRS(IS))
      IF(ITYPE.NE.4) GO TO 37
      AFTC(I)=AFTC(I)+CABS(FRC(IS))
   37 CONTINUE
   36 CONTINUE
      IF(NOUT.GT.0) GO TO 34
C
C   CHECK PLOT FLAG, BYPASS IF ZERO
      IF(IPLOT.EQ.0) GO TO 34
      WRITE(6,33)ICOM
   33 FORMAT(1H1,//,5X,'AFT DATA SPECTRUM FOR RECORD NBR 1',5X,40A2,/)
      CALL PLOT(FREQP,AFT,INCR2)
      IF(ITYPE.NE.4) GO TO 34
      WRITE(6,133) ICOM
  133 FORMAT(1H1,//,5X,'AFT DATA SPECTRUM FOR 0.4GHZ CH2, RCD 1',
     $5X,40A2,/)
      CALL PLOT(FREQP,AFTC,INCR2)
   34 CONTINUE
C
C   GET VALUES OF NOISE POWER & CALIBRATION POWER LEVELS
      CALL PWR(NOIZL,NOIZR,AFT,FNOIZ)
      FNOIZ=FNOIZ/5
C   SUM CALIBRATION POWER
      LPP=MC-6
      LRP=MC+6
      CALL PWR(LPP,LRP,AFT,PSUBT)
      IF(ITYPE.NE.4) GO TO 39
C   SUM CALIB CHANNEL POWER FOR 0.4GHZ CH2(AT 1 KHZ)
      CALL PWR(LPP,LRP,AFTC,PC4)
      LPP4=MC4-6
      LRP4=MC4+6
C   SUM TRANSMIT POWER FOR 0.4GHZ CH2(AT 0.5 KHZ)
      CALL PWR(LPP4,LRP4,AFTC,PT4)
C
   39 CONTINUE
C
      IF(NOUT.GT.0) GO TO 38
      WRITE(6,138)FNOIZ,PSUBT,PC4,PT4
  138 FORMAT(1H ,'FNOIZ:',F9.5,5X,'PSUBT:',F9.5,
     $5X,'PCAL-4:',F9.5,5X,'PT-4:',F9.5)
   38 CONTINUE
C
C   BUILD SIGMA-ZERO SET
      DO 40 I=1,9
C
C   FIND VALUE OF RECEIVED POWER
```

```
      CALL PWR(IFDL(I),IFDR(I),AFT,PSUBR)
C
C  SAVE DEBUG DUMP VALUES
      PSPEC(I)=PSUBR
      PROPT(I)=10.*ALOG10((PSUBR/PSUBT)*(PC4/PT4))
C
C  COMPUTE FINAL SIGMA-ZERO ESTIMATES
      SIGMA(I)=VKDB-GAINSQ(I)+40.*ALOG10(R(I))-10.*ALOG10(A(I))+
     $PROPT(I)-ZW(I)
   40 CONTINUE
      IF(IBUG.EQ.0) GO TO 42
C
C  DUMP DEBUG VALUES TO PRINT SET NBR 2
      WRITE(9,41)TIME,PSUBT,PC4,PT4,PSPEC,R,A,BEAM,ANGT,PROPT,
     $FDOP,DFDOP
   41 FORMAT(1H ,2(I2,':'),I3,4X,'CAL PWR=',F8.2,
     $9X,'PCAL-4=',F8.2,11X,'PT-4=',F8.2,/,
     $5X,'FILT PWR:',8(F8.2),/,
     $5X,'R(I):',4X,8(F8.2),/,
     $5X,'A(I):',4X,8(F8.2),/,
     $5X,'BEAM(I):',1X,8(F8.2),/,
     $5X,'ANGTL(I):',8(F8.2),/,
     $5X,'PR/PT(I):',8(F8.2),/,
     $5X,'FD(I):',3X,8(F8.2),/,
     $5X,'BND(I):',2X,8(F8.2))
      WRITE(9,141) GAINSQ,ZW,SIGMA
  141 FORMAT(1H ,4X,'GRGT(I):',1X,8(F8.2),/,
     $5X,'ROFF(I):',1X,8(F8.2),/,
     $5X,'SIGMA(I):',8(F8.2))
   42 CONTINUE
C
C  BUILD POINTER SET FOR FILLING OUTPUT BUFFER
      K=MOD(MXRCTR,ML)+1
      DO 45 J=1,3
      MATRIX(J,K)=TIME(J)
   45 CONTINUE
C
C  PUT A/C DATA VALUES INTO OUTPUT BUFFER
      MATRIX(4,K)=IFIX(H*10.)
      MATRIX(5,K)=IFIX(VEL*10.)
      MATRIX(6,K)=ADAS(3)
      MATRIX(7,K)=ADAS(4)
      MATRIX(8,K)=ADAS(5)
      MATRIX(9,K)=IFIX(100.*ALOG10(PSUBT))
      MATRIX(10,K)=IFIX(100.*ALOG10(FNOIZ))
C  POSITION THE 8 SIGMA VALUES IN THE OUTPUT BUFFER
      DO 50 I=1,8
      IBPTR(I)=IFIX(TAN( ANGT(I)/57.3)/THETB*XCELLS+0.5)
      IBK=MXRCTR-IBPTR(I)
      IF(IBK.LT.0) IBK=0
```

90 90

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      IBK=MOD(IBK,ML)+1
      MATRIX(10+I,IBK)=IFIX(SIGMA(I)*10.)
   50 CONTINUE
      NOUT=NOUT+1
   52 MOUT=MXRCTR-LPRNT
C  TAKE CARE OF MXRCTR COUNTER OVER-FLOW
      IF(MOUT.LT.0) MOUT=MOUT+ML
      MOUT=MOD(MOUT,ML)+1
      IF(NOUT.GT.1 ) GO TO 70
C
C  DISPLAY FIRST RECORD INFORMATION
      WRITE(6,61)THETA,FDOP,DFDOP,R,A,ISPTR
   61 FORMAT(1H0,'RCD #1 PARAMETERS',/,10X,'ANGLES(DEG):   ',8(5X,F6.1),
     $/,10X,'DOPPLER FREQS:',8(5X,F6.1),
     $/,10X, 'BANDWIDTHS:    ',8(5X,F6.1),/
     $10X,'RANGES:     ',4X,8(5X,F6.1),/,
     $10X,'AREAS :     ',4X,8(5X,F6.1),/,
     $10X,'POINTER VALS:',8(5X,I6)/)
      WRITE(6,62) ITHETA
   62 FORMAT(3X,'TIME ',6X,'ALT  ',1X,'VEL  ',2X,'PITCH',3X,'ROLL ',3X,
     $'DRIFT',3X,'PT'    ,3X,'PNOIZ',3X,'SIGMA(I),I=1,8',/,
     $62X,8(I2,'DEG',2X),//)
C
C  FORMAT THE OUTPUT FOR PRINTER SET NBR 1
   70 DO 65 I=3,18
      TRIX(I-2)=FLOAT(MATRIX(I,MOUT))/10.
   65 CONTINUE
C
C  OUTPUT THE PRINTED DATA SET NBR 1
      WRITE(6,80)(MATRIX(K,MOUT),K=1,2),(TRIX(I),I=1,16)
   80 FORMAT(1X,2(I2,':'),F4.1,1X,15(F6.1,1X))
C
C  OUTPUT THE PUNCHED DATA SET NBR 1
      WRITE(7,81)(MATRIX(K,MOUT),K=1,18)
   81 FORMAT(2I2,I3,2I5,3I4,10I5)
C
C  BACK-FILL THE BUFFER LINES THAT HAVE BEEN OUTPUT
      DO 90 J=1,18
      MATRIX(J,MOUT)=-999
   90 CONTINUE
      MXRCTR=MXRCTR+1
C  TAKE CARE OF REGISTER OVER-FLOW
      IF(MXRCTR.EQ.0) MXRCTR=K+1
      IF(NOUT.GE.IEND) GO TO 777
      GO TO 20
  777 CONTINUE
C  PURGE THE BUFFER BEFORE STOPPING
      ICLR=ICLR+1
      IF(ICLR.GT.LPRNT) GO TO 778
      K=MOD(MXRCTR,ML)+1
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      GO TO 52
  778 WRITE(6,700) NOUT,TIME
  700 FORMAT(1H0,5X,'NMR OF RECORDS PROCESSED = ',I5,5X,
     $'LAST RECORD TIME = ',2(I2,':'),I3)
      STOP
  800 WRITE(6,801) MLN,ML
  801 FORMAT(1H ,'***> MATRIX BUFFER OVERFLOW <***',I6,
     $' LINES NEEDED,',I6,' LINES AVAILABLE',/)
      GO TO 777
      END
      SUBROUTINE PWR(IL,IR,AFT,PSD)
C   THIS ROUTINE USES LEFT & RIGHT POINTERS TO CALCULATE
C   THE MEAN VALUE OF POWER IN THE FREQ CELL SPECIFIED
C
      DIMENSION AFT(1024)
      TEMP=0.
      DO 10 I=IL,IR
      TEMP=TEMP+AFT(I)**2
   10 CONTINUE
      PSD=TEMP
      RETURN
      END
      SUBROUTINE INPUT(POINTS,T)
      INTEGER POINTS
      INTEGER*2 TIME(3),ADAS(5),SINE(  2048),COSINE(  2048)
      COMMON/ITAPE/TIME,ADAS,SINE,COSINE
      IPTS=POINTS/1024
      GO TO (10,20),IPTS
   10 READ(8,15,END=70) TIME,ADAS,(SINE(J),J=1,POINTS),
     $(COSINE(K),K=1,POINTS)
   15 FORMAT(8A2,16(64A2),16(64A2))
      GO TO 30
   20 READ(8,25,END=70) TIME,ADAS,(SINE(J),J=1,POINTS),
     $(COSINE(K),K=1,POINTS)
   25 FORMAT(8A2,32(64A2),32(64A2))
   30 HT=TIME(1)
      MT=TIME(2)
      ST=TIME(3)
      T=3600.*HT+60.*MT+ST/10.
      RETURN
   70 WRITE(6,75)
   75 FORMAT(1H ,10X,'END OF FILE ON TAPE UNIT ****',/)
      STOP
      END
      SUBROUTINE SCALX(POINTS,SINE,COSINE,FRS)
      INTEGER POINTS
      INTEGER*2 SINE(POINTS),COSINE(POINTS)
      COMPLEX FRS(POINTS),CMPLX
      COMMON/RAT/FINCR,FCAL,FSAMP,INCR
      COMMON/FILT/ITYPE,KPOLZ
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C    BYPASS AVERAGING WHEN 0.4GHZ DATA
     GO TO (4,4,4,6), ITYPE
   4 CONTINUE
C    AVERAGE OUT THE DC COMPONENT
     SUMC=0.
     SUMS=0.
     DO 5 M=1,POINTS
     ISIN=SINE(M)
     ICOS=COSINE(M)
     SUMS=SUMS+FLOAT(ISIN)
     SUMC=SUMC+FLOAT(ICOS)
   5 CONTINUE
     ISAVG=IFIX(SUMS/FLOAT(POINTS))
     ICAVG=IFIX(SUMC/FLOAT(POINTS))
   6 CONTINUE
C    BUILD (X+JY) BUFFER FOR DFT
     DO 10 K=1,POINTS
     ISIN=SINE(K)
     ICOS=COSINE(K)
C    ZERO CH2 WHEN 0.4GHZ DATA
     GO TO (8,8,8,7), ITYPE
   7 ICOS=0
     ISAVG=0
     ICAVG=0
   8 CONTINUE
     ISIN=ISIN-ISAVG
     ICOS=ICOS-ICAVG
     FRS(K)=CMPLX(FLOAT(ISIN/16)/2048.,FLOAT(ICOS/16)/2048.)
  10 CONTINUE
     RETURN
     END
     FUNCTION GAMMA(FREQ)
C    WATER ROLLOFF FILTER FOR CALCULATING ZW(I)
C    FREQ EXPECTED IN HZ
     COMMON/FILT/ITYPE,KPOLZ
     F=FREQ/1000.
     GO TO (10,20,30,40), ITYPE
C    THIS FUNCTION IS FOR 13.3GHZ
C    >> DATA TAKEN AFTER 1JAN78 <<<
  10 GAMMA=15.8532-F*(7.76831-F*(1.5464-F*(.109227-.000945247*F)))+
    $(4.62135-.172139/F)/F
  15 GAMMA = -GAMMA
  16 RETURN
C
C    THIS FUNCTION IS FOR 1.6 GHZ
  20 GAMMA=7.710938-F*(21.69141-14.94141*F)+(1.111816-0.0186787/F)/F
     GO TO 15
C
C    THIS FUNCTION IS FOR 4.75GHZ
  30 GAMMA=18.5575-F*(16.5981-F*(8.64097-F*(3.44443-0.653213*F)))-
```

```
      $(0.25549/F)
       GO TO 15
C
C   THIS FUNCTION IS FOR 0.4GHZ
    40 GAMMA=0.0
       GO TO 16
       END
       SUBROUTINE PLOT(X,Y,N)
       INTEGER Q
       INTEGER QA,QB,QC
C      INTEGER X,Y
C 30   FORMAT(' ',I9,5X,I9,5X,1X,103A1)
    30 FORMAT(' ',2E13.5,1X,103A1)
       DIMENSION Q(100),X(N),Y(N)
       DATA QA,QB,QC/2HII,2H++,2H==/
       DO 1 I=1,100
       Q(I)=QC
     1 CONTINUE
       YMAX=Y(1)
       YMIN=Y(1)
       DO 3 I=2,N
       IF(YMAX.LT.Y(I)) YMAX=Y(I)
       IF(YMIN.GT.Y(I)) YMIN=Y(I)
     3 CONTINUE
       SCALE=YMAX-YMIN
       IF(SCALE.EQ.0) GO TO 16
       DO 2 I=1,N
       NUM=((Y(I)-YMIN)*99.0)/SCALE+1
     2 WRITE (6,30) X(I),Y(I),QA,(Q(II),II=1,NUM),QB
       RETURN
    16 WRITE (6,33) YMAX
    33 FORMAT (' DEPENDENT VARIABLE IS CONSTANT ',D13.5 )
       RETURN
       END
       SUBROUTINE DFT(X,M,INCR)
C      A FAST FOURIER TRANSFORM THAT IMPLEMENTS THE
C              "DECIMATION-IN-FREQUENCY" ALGORITHM
C
C          CALLING PARAMTERS:
C          X = COMPLEX ARRAY OF DIMENSION N THAT CONTAINS INITIALLY
C              THE INPUT SEQUENCE X(N) AND FINALLY CONTAINS THE
C              TRANSFORM X(K).  THE QUANTITY M IS AN INTEGER, M=LOG2(N),
C              WHERE N IS THE NUMBER OF TIME VARYING DATA POINTS
C              INCR = SIZE OF THE ARRAY HOLDING THE TIME FUNCTION
C
       COMPLEX X(INCR),U,W,T,CMPLX
       N=2**M
       NV2=N/2
       NM1=N-1
       J=1
```

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```
      DO 7 I=1,NM1
      IF(I.GE.J) GO TO 5
      T=X(J)
      X(J)=X(I)
      X(I)=T
    5 K=NV2
    6 IF(K.GE.J) GO TO 7
      J=J-K
      K=K/2
      GO TO 6
    7 J=J+K
   15 PI=3.1459265
      DO 20 L=1,M
      LE=2**L
      LE1=LE/2
      U=CMPLX(1.0,0.0)
      W=CMPLX(COS(PI/FLOAT(LE1)),-SIN(PI/FLOAT(LE1)))
      DO 20 J=1,LE1
      DO 10 I=J,N,LE
      IP=I+LE1
      T=X(IP)*U
      X(IP)=X(I)-T
   10 X(I)=X(I)+T
   20 U=U*W
      RETURN
      END
      SUBROUTINE CAREA(AREA,BEAM,HEIGT,ANGLD,VELOC,ROLL,DRIFT,ICON)
      REAL KONE,KTWO
      COMMON/KAREA/KONE,KTWO
      TERM1=2.*TAN(BEAM/2.)*HEIGT**2/COS(ROLL)/COS(ANGLD)
      TEMP1=KTWO*VELOC**2
      ATD=TAN(DRIFT)
      TNR=TAN(ROLL)
      CDR=COS(DRIFT)
      TEMP1=(-ATD*TNR+SQRT(TNR**2*(TEMP1-1.0)+
     $TEMP1*CDR**2-1.0))/(1.0-TEMP1*CDR**2)
      TERM2=TEMP1
      TEMP1=KONE*VELOC**2
      TEMP1=(-ATD*TNR+SQRT(TNR**2*(TEMP1-1.0)+
     $TEMP1*CDR**2-1.0))/(1.0-TEMP1*CDR**2)
      IF(ICON.LT.0) TEMP1=0.
      AREA=TERM1*(TERM2-TEMP1)
      AREA=ABS(AREA)
      RETURN
      END
```

```
C   GAIN SUB-PROGRAM FOR 13.3GHZ VV DATA
      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE
      REAL ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C     GAIN VALUES FOR 13.3 KMC ANTENNA, VERTICAL POLARIZATION
C         >>>>  TABLE UP-DATED 16JAN1979  ...<<<
C
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *     ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)
     */17.00,17.00,18.30,19.50,21.00,
     * 22.50,23.80,24.70,26.00,27.50/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *     ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)
     */28.80,30.00,30.50,30.70,31.00,
     * 31.00,31.50,32.00,33.00,34.00/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *     ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)
     */34.40,34.80,35.30,35.50,35.50,
     * 35.50,35.30,35.00,34.00,33.20/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
     *     ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)
     */33.00,33.50,34.00,34.50,35.00,
     * 35.50,35.00,34.50,34.00,33.50/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *     ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)
     */33.00,33.20,34.00,35.00,35.30,
     * 35.50,35.50,35.50,35.30,34.80/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *     ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)
     */34.40,34.00,33.00,32.00,31.50,
     * 31.00,31.00,30.70,30.50,30.00/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *     ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)
     */28.80,27.50,26.00,24.70,23.80,
     * 22.50,21.00,19.50,18.30,17.00/
      DATA ANTNNA(071)/17.00/
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES OF ANGLE IS:   -70.9 TO 70.9 DEGREES.
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST ANGLE
C     VALUE WILL BE RETURNED
C
      ANGLE=ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
```

```
      IF(INDEX.GE.71) GO TO 10
      ANGLZ=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*
     $((ANGLE*57.3-ANGLZ)/2.0)
      RETURN
10    GAIN=ANTNNA(71)
      RETURN
30    GAIN=ANTNNA(1)
      RETURN
      END




      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE,ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C     GAIN VALUES FOR 1.6 KMC ANTENNA,VERTICAL POLARIZATION
C
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *     ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
     *   14.70,      15.40,      15.70,      16.40,      17.40,
     *   17.90,      18.70,      19.40,      19.90,      20.60/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *     ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
     *   21.60,      21.90,      21.90,      22.40,      22.70,
     *   22.90,      22.60,      22.90,      22.40,      22.20/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *     ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
     *   21.90,      21.40,      21.40,      21.10,      20.90,
     *   20.70,      20.40,      20.40,      20.10,      20.70/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
     *     ANTENA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
     *   20.70,      21.40,      21.40,      21.70,      22.10,
     *   22.20,      22.20,      22.10,      21.90,      21.40/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *     ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *   21.20,      20.90,      20.70,      20.10,      19.70,
     *   19.20,      18.70,      18.10,      17.60,      17.60/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *     ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *   17.40,      17.10,      17.20,      17.10,      16.90,
     *   16.90,      16.90,      16.70,      16.40,      15.90/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *     ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
     *   15.40,      14.90,      14.70,      14.20,      13.90,
     *   13.20,      12.70,      11.40,      10.40,       9.40/
      DATA ANTNNA(71)/8.90/
```

OF POOR QUALITY

```
C
C       THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C       ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C       ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C       PITCH IS THE AIRCRAFT PITCH ANGLE
C       ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C       THE RANGE OF VALUES FOR ANGLE IS:  -70.9 TO 70.9 DEGREES
C       IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
C       VALUE WILL BE RETURNED
C
        ANGLE = ANTANG-PITCH
        INDEX=IFIX((ANGLF*57.3+70.)/2.)+1
        IF(INDEX.LE.0) GO TO 30
        IF(INDEX.GE.71) GO TO 10
        ANGLZ=FLOAT(INDEX-1)*2.-70.
        GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
       $((ANGLE*57.3-ANGLZ)/2.0)
        RETURN
   10   GAIN=ANTNNA(71)
        RETURN
   30   GAIN=ANTNNA(1)
        RETURN
        END


        REAL FUNCTION GAIN(ANTANG,PITCH)
        REAL ANTNNA,ANGLE,ANTANG,PITCH
        DIMENSION ANTNNA(71)
C
C
        GAIN VALUES FOR 1.60 KMC ANTENNA, CROSS POLARIZATION (V-H)
C
        DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
       *     ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
       *   21.40,     22.20,     22.70,     23.20,     23.90,
       *   24.10,     24.60,     24.90,     25.10,     25.90/
        DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
       *     ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
       *   26.10,     26.20,     26.20,     26.40,     26.20,
       *   26.20,     25.60,     25.60,     24.60,     24.20/
        DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
       *     ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
       *   23.60,     22.90,     22.20,     21.60,     20.90,
       *   20.10,     20.10,     19.70,     19.40,     19.70/
        DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
       *     ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
       *   19.90,     20.10,     20.90,     20.90,     21.40,
       *   21.70,     22.20,     22.20,     22.20,     21.90/
        DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
```

```fortran
     *        ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *    21.40,      20.90,      20.70,      20.10,      19.70,
     *    19.70,      20.20,      20.40,      20.70,      20.90/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *        ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *    21.20,      21.40,      21.40,      21.40,      21.20,
     *    2?.60,      20.90,      20.40,      19.90,      19.10/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *        ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
     *    18.40,      18.10,      17.70,      17.40,      17.90,
     *    17.60,      17.90,      17.40,      16.60,      16.10/
      DATA ANTNNA(71)/15.60/
C
C
C     THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES FOR ANGLE IS:  -70.9 TO 70.9 DEGREES
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
C     VALUE WILL BE RETURNED
C
      ANGLE = ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
      IF(INDEX.GE.71) GO TO 10
      ANGLZ=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
     $((ANGLE*57.3-ANGLZ)/2.0)
      RETURN
   10 GAIN=ANTNNA(71)
      RETURN
   30 GAIN=ANTNNA(1)
      RETURN
      END



C **   ANTENNA GAIN FUNCTION FOR 1.6GHZ HH DATA
      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE,ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C     GAIN VALUES FOR 1.6 KMC ANTENNA,HORIZONTAL POLARIZATION
C
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *        ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
     *    23.10,      23.70,      24.20,      24.40,      24.40,
```

```fortran
     *    24.40,      24.60,      24.60,      24.60,      24.90/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *      ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
     *    24.60,      24.40,      24.40,      24.40,      23.90,
     *    23.70,      23.10,      22.90,      22.40,      21.90/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *      ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
     *    21.40,      20.90,      20.40,      19.90,      19.10,
     *    18.90,      18.60,      18.40,      18.40,      18.40/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
     *      ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
     *    18.90,      18.90,      19.70,      19.70,      19.70,
     *    19.70,      19.70,      18.90,      18.70,      18.10/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *      ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *    17.60,      17.70,      17.90,      18.40,      18.20,
     *    17.90,      17.90,      18.10,      19.40,      19.90/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *      ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *    20.70,      21.20,      20.90,      21.20,      21.90,
     *    23.10,      23.40,      23.40,      22.90,      22.20/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *      ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
     *    21.90,      22.10,      22.20,      22.20,      22.40,
     *    22.10,      21.90,      21.60,      21.90,      22.10/
      DATA ANTNNA(71)/22.10/
C
C     THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES FOR ANGLE IS:  -70.9 TO 70.9 DEGREES
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
C     VALUE WILL BE RETURNED
C
      ANGLE = ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
      IF(INDEX.GE.71) GO TO 10
      ANGLZ=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
     $((ANGLE*57.3-ANGLZ)/2.0)
      RETURN
   10 GAIN=ANTNNA(71)
      RETURN
   30 GAIN=ANTNNA(1)
      RETURN
```

```fortran
      END


C  **   ANTENNA GAIN FUNCTION FOR 1.6GHZ HV DATA
      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE,ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C     GAIN VALUES FOR 1.60 KMC ANTENNA, CROSS PLOARIZATION (H-V)
C
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *     ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
     *    16.40,      17.20,      17.40,      17.70,      18.20,
     *    18.40,      18.70,      19.40,      19.60,      19.90/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *     ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
     *    20.10,      20.20,      20.40,      20.40,      20.40,
     *    20.40,      20.60,      20.40,      20.20,      20.10/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *     ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
     *    20.20,      19.90,      19.90,      19.90,      19.40,
     *    19.40,      19.20,      19.40,      19.40,      19.90/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
     *     ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
     *    20.20,      20.40,      20.70,      20.70,      20.40,
     *    20.20,      19.70,      18.90,      18.40,      17.60/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *     ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *    17.40,      17.90,      17.90,      18.40,      18.20,
     *    17.40,      16.40,      16.40,      16.90,      16.90/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *     ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *    16.90,      16.90,      16.70,      17.20,      18.20,
     *    19.40,      19.40,      19.70,      19.40,      18.90/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *     ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
     *    18.90,      19.10,      19.20,      18.90,      18.40,
     *    17.40,      16.70,      16.10,      15.90,      15.60/
      DATA ANTNNA(71)/15.40/
C
C     THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES FOR ANGLE IS:  -70.9 TO 70.9 DEGREES
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
```

```
C     VALUE WILL BE RETURNED
C
      ANGLE = ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
      IF(INDEX.GE.71)GO TO 10
      ANGLZ=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
     $((ANGLE*57.3-ANGLZ)/2.0)
      RETURN
   10 GAIN=ANTNNA(71)
      RETURN
   30 GAIN=ANTNNA(1)
      RETURN
      END



C     GAIN VALUES FOR .400 KMC ANTENNA, VERTICAL POLARIZATION
      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE,ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *     ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
     *   10.40,      12.40,      14.80,      16.40,      18.40,
     *   19.40,      20.80,      21.80,      22.80,      23.40/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *     ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
     *   23.80,      24.40,      24.80,      24.80,      24.80,
     *   24.40,      23.80,      22.80,      22.40,      21.40/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *     ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
     *   19.40,      18.40,      16.80,      15.40,      13.40,
     *   11.40,       9.80,       7.80,       6.80,       5.80/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
     *     ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
     *    4.80,       4.40,       3.80,       3.40,       2.80,
     *    2.80,       1.80,       1.40,       0.40,      -0.60/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *     ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *   -1.60,      -2.20,      -3.20,      -4.20,      -4.60,
     *   -4.60,      -4.60,      -4.20,      -3.20,      -2.60/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *     ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *   -1.60,      -1.20,      -0.60,      -0.60,      -0.60,
     *   -0.20,      -0.60,      -0.60,      -1.20,      -1.20/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *     ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
```

```
*      -2.20,      -2.60,      -3.60,      -4.60,      -5.60,
*      -6.60,      -8.20,      -9.60,     -11.20,     -13.60/
      DATA ANTNNA(71)/-15.60/
C
C     THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES FOR ANGLE IS:  -70.9 TO 70.9 DEGREES
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
C     VALUE WILL BE RETURNED
C
      ANGLE = ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
      IF(INDEX.GE.71) GO TO 10
      ANGLZ=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
     $((ANGLE*57.3-ANGLZ)/2.0)
      RETURN
   10 GAIN=ANTNNA(71)
      RETURN
   30 GAIN=ANTNNA(1)
      RETURN
      END



C     GAIN VALUES FOR .400 KHC ANTENNA, HORIZONTAL POLARIZATION
      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE,ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *     ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
     *    29.40,      29.40,      29.40,      29.40,      29.40,
     *    28.80,      28.80,      27.80,      27.40,      26.80/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *     ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
     *    26.40,      25.40,      24.40,      23.40,      21.80,
     *    20.80,      19.40,      17.80,      15.80,      13.80/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *     ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
     *    11.80,       9.80,       7.80,       5.80,       3.80,
     *     2.40,       0.40,      -0.60,      -1.60,      -2.20/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
```

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```fortran
     *     ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
     *     -2.60,      -2.60,      -2.60,      -3.20,      -3.20,
     *     -3.60,      -4.20,      -4.20,      -4.60,      -5.60/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *     ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *     -6.20,      -7.20,      -8.20,      -8.60,      -9.20,
     *     -9.60,      -9.60,      -9.60,      -9.20,      -8.60/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *     ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *     -8.20,      -7.60,      -6.60,      -6.20,      -5.60,
     *     -5.20,      -4.60,      -4.60,      -4.20,      -3.60/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *     ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
     *     -3.60,      -3.60,      -3.60,      -3.60,      -4.20,
     *     -4.20,      -4.60,      -5.20,      -5.20,      -6.20/
      DATA ANTNNA(71)/-6.60/
C
C     THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES FOR ANGLE IS:   -70.9 TO 70.9 DEGREES
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
C     VALUE WILL BE RETURNED
C
      ANGLE = ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
      IF(INDEX.GE.71) GO TO 10
      ANGLE=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
     $((ANGLE*57.3-ANGLE)/2.0)
      RETURN
   10 GAIN=ANTNNA(71)
      RETURN
   30 GAIN=ANTNNA(1)
      RETURN
      END



C     GAIN VALUES FOR .400 KMC ANTENNA,   CROSS POLARIZATION
      REAL FUNCTION GAIN(ANTANG,PITCH)
      REAL ANTNNA,ANGLE,ANTANG,PITCH
      DIMENSION ANTNNA(71)
C
C
```

```fortran
      DATA ANTNNA(001),ANTNNA(002),ANTNNA(003),ANTNNA(004),ANTNNA(005),
     *    ANTNNA(006),ANTNNA(007),ANTNNA(008),ANTNNA(009),ANTNNA(010)/
     *    19.90,      20.90,      22.10,      22.90,      23.90,
     *    24.10,      24.80,      24.80,      25.10,      25.10/
      DATA ANTNNA(011),ANTNNA(012),ANTNNA(013),ANTNNA(014),ANTNNA(015),
     *    ANTNNA(016),ANTNNA(017),ANTNNA(018),ANTNNA(019),ANTNNA(020)/
     *    25.10,      24.90,      24.60,      24.10,      23.30,
     *    22.60,      21.40,      20.30,      18.90,      17.60/
      DATA ANTNNA(021),ANTNNA(022),ANTNNA(023),ANTNNA(024),ANTNNA(025),
     *    ANTNNA(026),ANTNNA(027),ANTNNA(028),ANTNNA(029),ANTNNA(030)/
     *    15.60,      14.10,      12.30,      10.60,      8.60,
     *    6.90,       5.10,       3.60,       2.60,       1.80/
      DATA ANTNNA(031),ANTNNA(032),ANTNNA(033),ANTNNA(034),ANTNNA(035),
     *    ANTNNA(036),ANTNNA(037),ANTNNA(038),ANTNNA(039),ANTNNA(040)/
     *    1.10,       0.90,       0.60,       0.10,       -0.20,
     *    -0.40,      -1.20,      -1.80,      -2.10,      -3.10/
      DATA ANTNNA(041),ANTNNA(042),ANTNNA(043),ANTNNA(044),ANTNNA(045),
     *    ANTNNA(046),ANTNNA(047),ANTNNA(048),ANTNNA(049),ANTNNA(050)/
     *    -4.10,      -5.10,      -5.90,      -6.60,      -7.10,
     *    -7.40,      -7.40,      -6.90,      -6.20,      -5.60/
      DATA ANTNNA(051),ANTNNA(052),ANTNNA(053),ANTNNA(054),ANTNNA(055),
     *    ANTNNA(056),ANTNNA(057),ANTNNA(058),ANTNNA(059),ANTNNA(060)/
     *    -5.10,      -4.40,      -3.90,      -3.40,      -3.10,
     *    -2.70,      -2.60,      -2.60,      -2.70,      -2.40/
      DATA ANTNNA(061),ANTNNA(062),ANTNNA(063),ANTNNA(064),ANTNNA(065),
     *    ANTNNA(066),ANTNNA(067),ANTNNA(068),ANTNNA(069),ANTNNA(070)/
     *    -2.90,      -3.10,      -3.60,      -4.10,      -4.90,
     *    -5.40,      -6.40,      -7.40,      -8.20,      -9.90/
      DATA ANTNNA(71)/-11.10/
C
C
C     THIS SUBROUTINE RETURNS A GAIN VALUE FOR AN ANGLE
C
C     ANGLE IS THE DIFFERENCE OF THE ANTENNA ANGLE AND THE PITCH
C     ANTANG IS THE ANTENNA ANGLE WITH RESPECT TO THE AIRCRAFT
C     PITCH IS THE AIRCRAFT PITCH ANGLE
C     ALL ANGLES ARE EXPECTED TO BE EXPRESSED IN RADIANS
C
C     THE RANGE OF VALUES FOR ANGLE IS:  -70.9 TO 70.9 DEGREES
C     IF AN ANGLE FALLS OUT OF THIS RANGE, THE CLOSEST GAIN
C     VALUE WILL BE RETURNED
C
      ANGLE = ANTANG-PITCH
      INDEX=IFIX((ANGLE*57.3+70.)/2.)+1
      IF(INDEX.LE.0) GO TO 30
      IF(INDEX.GE.71) GO TO 10
      ANGLZ=FLOAT(INDEX-1)*2.-70.
      GAIN=ANTNNA(INDEX)+(ANTNNA(INDEX+1)-ANTNNA(INDEX))*ABS
     $((ANGLE*57.3-ANGLZ)/2.0)
      RETURN
   10 GAIN=ANTNNA(71)
```

```
      RETURN
30 GAIN=ANTNNA(1)
      RETURN
      END
```

APPENDIX   D

MEMORANDUMS

RSC-159 AND 160

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TECHNICAL MEMORANDUM RSC-159

COMPARISON OF SCATTEROMETER RESOLUTION

CELL AREA APPROXIMATIONS

by

Billy V. Clark

and

Richard W. Newton

March 1979

/08

COMPARISON OF SCATTEROMETER RESOLUTION

CELL AREA APPROXIMATIONS

by

Billy V. Clark and Richard W. Newton

1.0 GENERAL

For some time there have been two approaches to evaluating area, A, used in the scattering coefficient equation

$$\hat{\sigma}_0 = \frac{(4\pi)^3}{\lambda^2}\frac{R^4}{A}\frac{P_r}{P_t}\frac{C_c}{K_s}\frac{z(f)}{G_r G_t}\qquad(1)$$

The approach used by NASA/ESD was to simply calculate the rectangular area along the ground track line, Figure 1. To account for roll and drift angles this area was divided by cosine roll times cosine drift.

The approach used at TAMU is to compute the actual cell length between doppler contours, BB' in Figure 2, accounting for actual roll and drift values. The width of the cell is approximated very closely by the expression for W' in Figure 2. The product, BB'xW', is the approximation to the area that is used by TAMU in scatterometer data reduction.

Since there have been some questions about the relative accuracy of the two area calculations, more detailed analysis of the area boundaries and more refined calculations of the area have been performed at TAMU Several types of calculations were made:
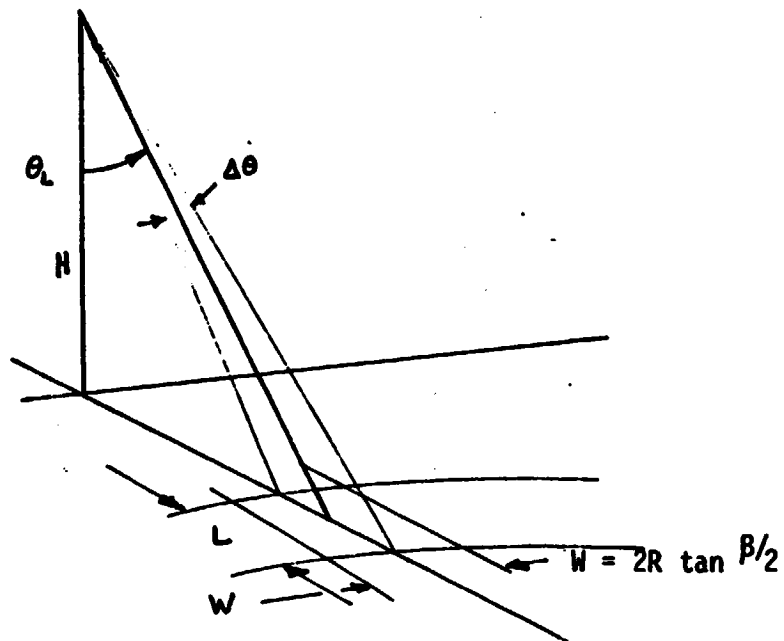
a)

$$L = \frac{(BWA)\lambda H \cos\frac{\Delta\theta}{2}}{2V \cos^3 \theta_L} \quad, \quad BWA = ACTUAL \ BANDWIDTH$$
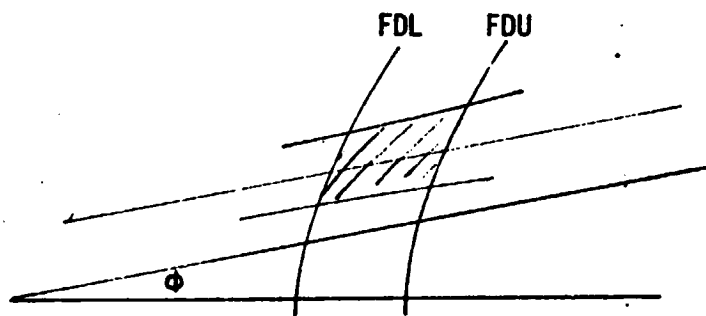
b)

$$W' = \frac{2H \tan \frac{\beta}{2}}{\cos\theta\cos\phi\cos\psi}$$

c)

$$Area \cong LW'$$

Figure 2. Equations used by NASA/ESD to compute area.

$$f_{d} = \left(\tfrac{2V}{\lambda}\right)\Big/ (X^{2}+Y^{2}+H^{2})^{\frac{1}{2}}$$

$$X = (Y+Y_{0})\tan\phi$$
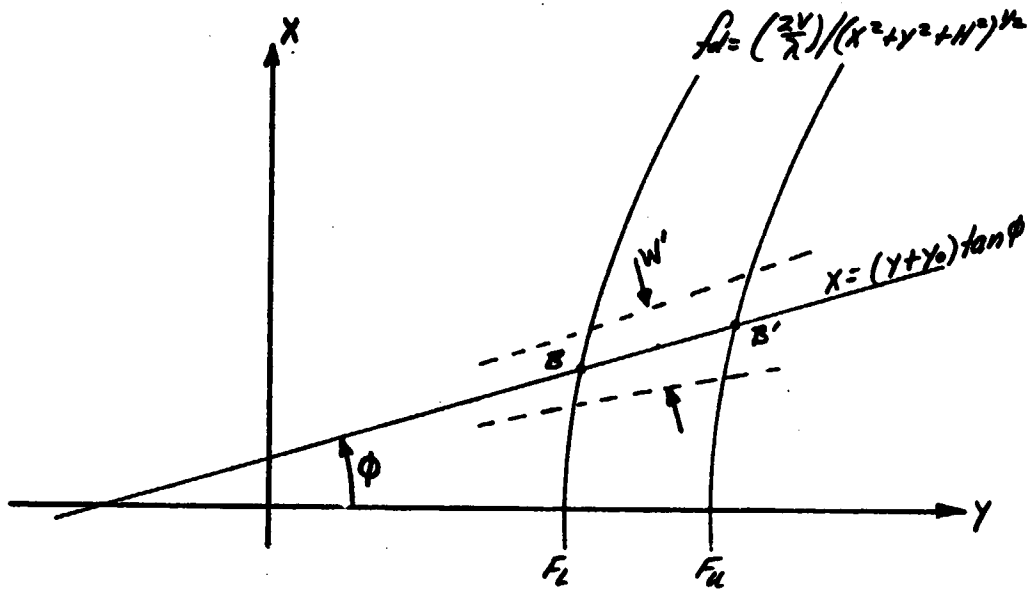
$$Y_{i} = \frac{-h}{1-k_{i}\cos^{2}\phi}\left\{\tan\phi\tan\psi \pm \sqrt{\tan^{2}\psi(k_{i}-1)+k_{i}\cos^{2}\phi -1}\right\}, \quad k_{i}=\left(\frac{2V}{\lambda f_{i}}\right)^{2}$$

$$BB' = (Y_{2}-Y_{1})/\cos\phi = L', \text{ actual cell length}$$

$$\beta = \text{beamwidth}$$

$$W' = \frac{2h\tan{}^{\beta\!/2}}{\cos\theta\cos\psi}$$
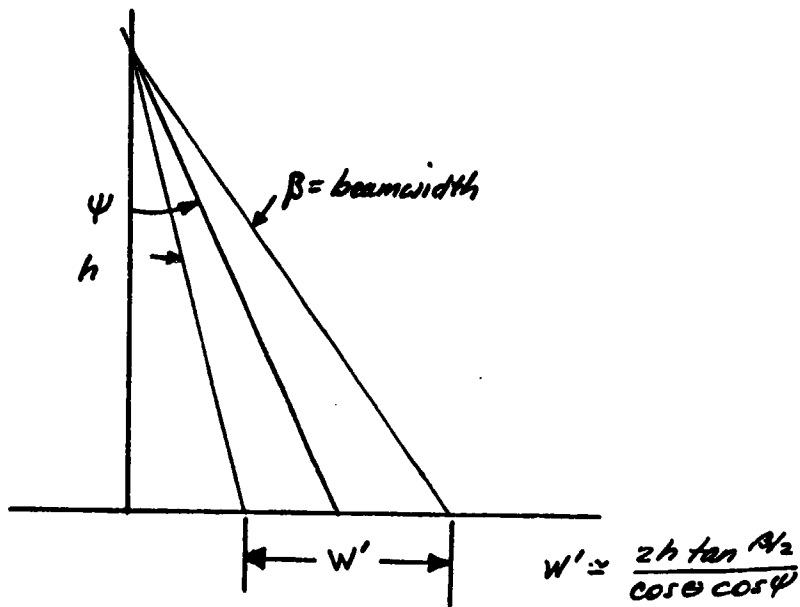
$$Area \simeq L'W' = \frac{W'(Y_{2}-Y_{1})}{\cos\phi}$$

Figure 2. Equations used by TAMU to compute area.

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a. Area of trapezium (no parallel sides)

b. Area of N parallelograms

c. Integration by Simpson's Rule

d. Quadratic Formula to calculate BB'.

The results of these different approaches to calculating the ground cell area indicate in all cases that the technique currently used at TAMU is a better over-all area estimator than the rectangular approximation. In the course of this analysis the mathmatical development of the expression for y, page 9 of Reference [1], was reviewed. It was found that if the sign used before the square-root symbol is positive, better agreement was achieved with the more accurate area values found by numerically integrating over the cell. The form of the equation that should be used follows:

$$Y = - \frac{h}{1 - k\cos^2\phi} \left\{ \tan\phi \tan\psi + \sqrt{\tan^2\psi(k-1) + k\cos^2\phi - 1} \right\} \qquad (1.a)$$

2.0 AREA ESTIMATE BY TRAPEZIUM

This approach makes only one assumption in computing the area; i.e., the lines connecting the four corner coordinates are straight, see Figure 3. Examination of the actual coordinate values at A, B, C, and D for viewing angles between -4° and -52° confirm that this is a reasonable assumption.

The calculation technique is to use the equations for the four lines labelled XU, XL, FL and FU, Figure 2, to derive the actual coordinates at A, B, C, and D. The value for X at any point along XU can be shown to be given by:

$$XU = \frac{Y(P2 + M\cos\phi) - H\sin\psi}{(P1 - M\sin\phi)} \qquad (2)$$

where

$$P1 = \cos\phi\cos\psi$$

$$P2 = \sin\phi\cos\psi$$

$$M = (\tan \beta/2)/\sin\theta'_L$$

β = antenna bemwidth referenced to the aircraft

θ'_L = viewing angle through the antenna coordinate system

H = aircraft altitude

ϕ = drift angle

ψ = roll angle

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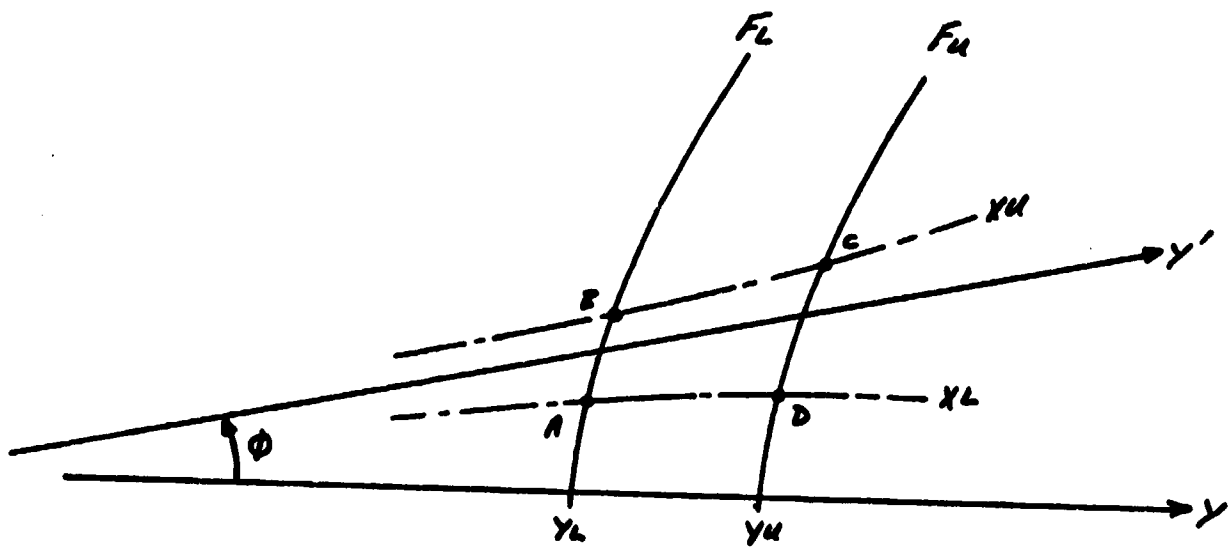
Figure 3.   Trapezium Area.

Similarly, along the curve XL, the value of X is given by

$$XL = \frac{Y(P2 - M\cos\phi) - H\sin\psi}{(P1 + M\sin\phi)} \tag{3}$$

And, of course, along the doppler contours the value of X is given by

$$XD = \left[\frac{Y^2 - H^2\tan^2\theta_d}{\tan^2\theta_d} \right]^{1/2} \tag{3.a}$$

where θ_d = viewing angle referenced to the ground track, Y-axis. By iterating the value of Y, beginning at YL, the corner coordinates are found.

Next, with the assumption that the connecting lines are straight, the area is found by

$$A = (A1 + A2) - (A3 + A4 + A5) \tag{4}$$

where

$$A1 = (X_B - X_A)(Y_B - Y_A)/2 \tag{5}$$

$$A2 = (Y_C - Y_B)(X_C + X_B)/2 \tag{6}$$

$$A3 = (Y_C - Y_D)(X_C - X_C - X_D)/2 \tag{7}$$

$$A4 = (Y_D - Y_A)(X_D - X_A)/2 \tag{8}$$

$$A5 = (Y_C - Y_D)(X_D - X_A) \tag{9}$$

3.0 AREA ESTIMATION BY STRIP INTEGRATION

This technique uses the sum of the area in N strips, each consisting of a selectively small parallelogram, to estimate the area. As illustrated in Figure 4, the length of mini-rectangle is the distance between the upper and lower frequency doppler lines. The length, DL, is calculated at each step using the expressions

$$Y_{L_i} = \frac{\left(-\tan\phi\tan\psi_i + \left[\tan^2\psi_i(K_L-1) + K_L\cos^2\phi - 1\right]^{\frac{1}{2}}\right)}{(1 - K_L\cos^2\phi)} \tag{10}$$

$$Y_{u_i} = \frac{\left(-\tan\phi\tan\psi_i + \left[\tan^2\psi_i(K_u-1) + K_u\cos^2\phi - 1\right]^{\frac{1}{2}}\right)}{(1 - K_u\cos^2\phi)} \tag{11}$$

where $\quad K_L = \left(\frac{2V}{\lambda F_L}\right)^2 \tag{12}$

$$K_u = \left(\frac{2V}{\lambda F_u}\right)^2 \tag{13}$$

and $\quad DL = (Y_u - Y_L)/\cos\phi \tag{14}$

The first step was performed with $\psi_i = \psi - \beta/2$, and at each successive step with $\psi_i + 1 = \psi_i + \Delta\psi$, using $\Delta\psi = \beta/500?$

●

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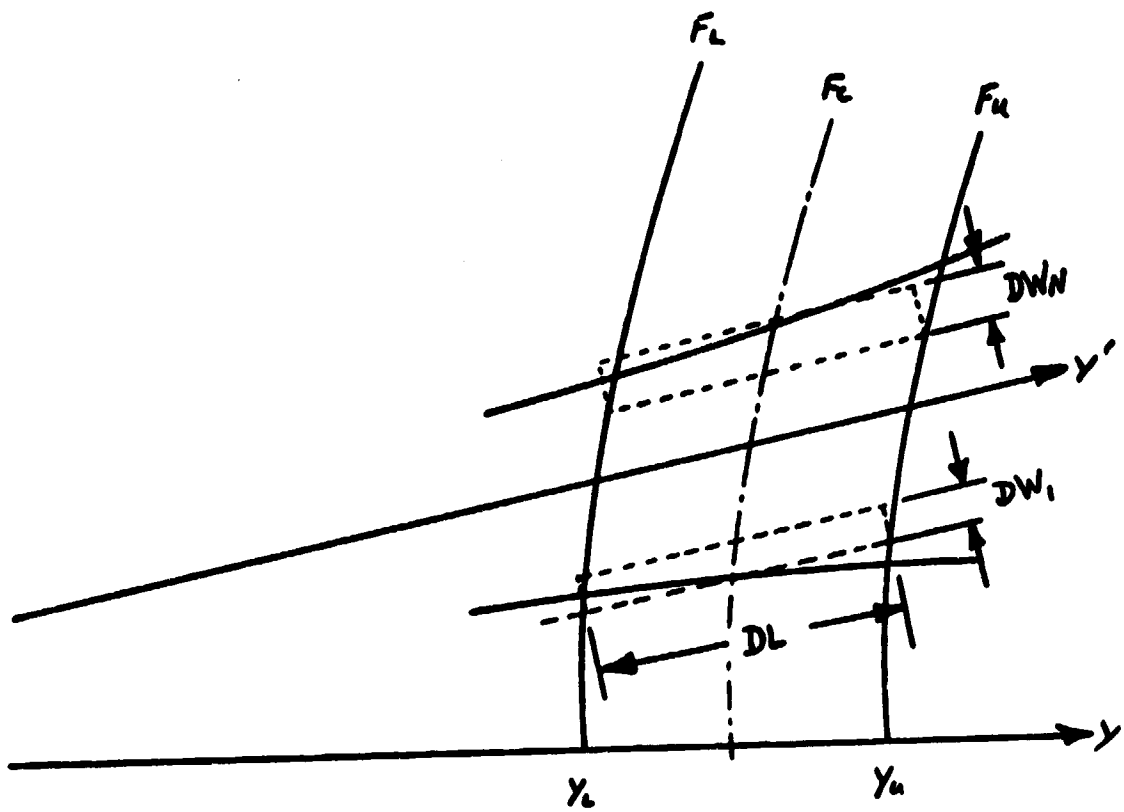
Figure 4. Area of N Parallelograms.

The value of DW_i was calculated by first evaluating range, R_i, to the center of the line DL and then using the expression

$$DW_i = R_i \tan \Delta \Psi \cos \Psi_i \left(1. + \tan \Psi_i \tan (\Psi_i + \Delta \Psi) \right) \qquad (15)$$

The basis for the above expression is shown in Figure 5.

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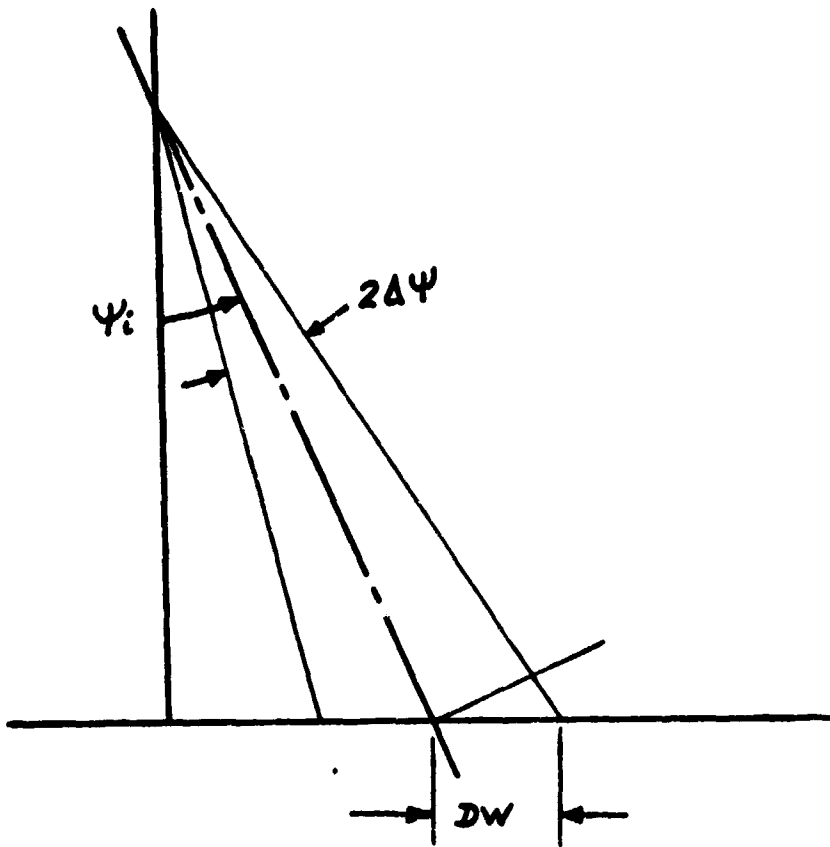
$$DW = R \tan \Delta\psi_i \cdot \cos\psi_i + R \tan \Delta\psi_i \cdot \sin\psi_i \cdot \tan(\psi_i + \Delta\psi)$$

$$DW = R \tan \Delta\psi_i \cos\psi_i \left(1 + \tan\psi_i \tan(\psi_i + \Delta\psi)\right)$$

Figure 5.   Evaluation of DW

The value of DW_i was calculated by first evaluating range, R_i, to the center of the line DL and then using the expression

$$DW_i = R_i \tan \Delta\Psi \cos\Psi_i \left(1. + \tan\Psi_i \tan(\Psi_i + \Delta\Psi)\right) \qquad (15)$$

The basis for the above expression is shown in Figure 5.
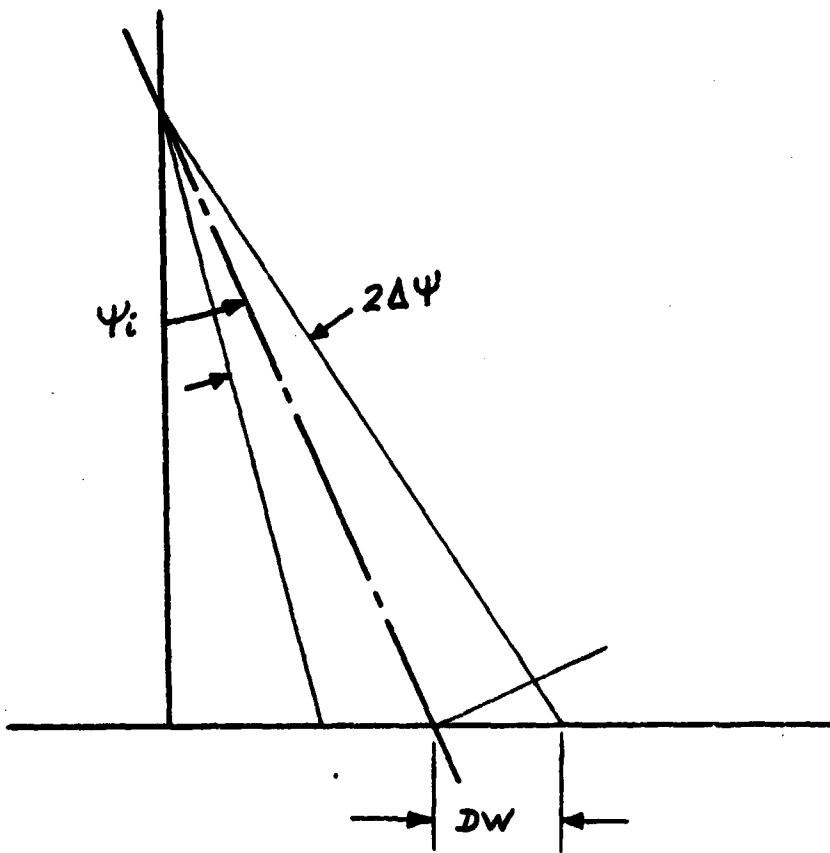
$$DW = R \tan \Delta \Psi_i \cos \Psi_i + R \tan \Delta \Psi_i \sin \Psi_i \tan (\Psi_i + \Delta \Psi)$$

$$DW = R \tan \Delta \Psi_i \cos \Psi_i (1. + \tan \Psi_i \tan (\Psi_i + \Delta \Psi))$$

Figure 5.   Evaluation of DW

4.0 AREA ESTIMATION FOR NUMERICAL INTEGRATION (SIMPSON'S RULE)

This approach is similar to the trapezium technique, but makes use of a more refined algebraic expression for areas beneath a curved line (2).

Using the equations (2), (3), and (3.a) above, and having already found the intersection YL, YU, A, B, C, and D in Figure 3, repeated applications of Simpson's rule for numerical integration are made to find the areas:

A1:   beneath line FL from Y = Y(A) to Y = Y(B),

A2:   beneath line XU from Y = Y(B) to Y = Y(C),

A3:   beneath line FL from Y = YL to Y = Y(A),

A4:   beneath line XL from Y = Y(A) to Y = Y(D),

A5:   beneath line FU from Y = YU to Y = Y(D),

A6:   beneath line FU from Y = YU to Y = Y(C).

For A1, A3, A5, and A6 a value of N = 8 was used. For A2 and A4 a value of N = 32 was used, where N specifies the number of times the interval is halved between the limits of integration. The total cell area is then calculated as:

A = A1 + A2 + A5 - (A3 + A4 + A6)

5.0 QUADRATIC FORMULA APPLICATION

Using the expression for Y in the quadratic form given at the top of
page 9, reference [1], the value of Y1 and Y2 were calculated. Next,
the final expression on the same page was implemented, using the value of
W' specified on the same page.

6.0 COMPARISON OF RESULTS

The results of area calculation using the above techniques were compared to the results of the Rectangular and Doppler techniques. These are summarized in Table 1. The results are graphically presented in Figures 6 and 7. The tables clearly show that the TAMU method has better general agreement with the integrated values for area.

Notice that in all cases where there is a drift value the Rectangular area approximation departs rapidly from the other estimation techniques. Although the so called Doppler Contour approximation is not considered perfect, it appears to be the best of the two "short cut" methods, Figures 1 and 2, for handling excursion in drift.

TABLE 1

Area Comparisons for Sever Calculation Tecniques

AT = Trapezium (4 - corners connected by straight lines)

AP = Parallelogram (integrating of stripes)

AQ = Quadratic Formula

AR = Rectangular (ESD algorithm)

AD = Doppler contour (Reference [1], page 9)

Roll, ψ, = 0.

Drift O, Deg	Viewing Angle θ_L, Deg	AT	AP	AQ	AR	AD	$\frac{AR-AD}{AD}$ *100
0	-5	2104.8	_____	2100.2	2100.2	2100.2	0.0
	-10	2207.4	2211.0	2202.4	2202.4	2202.4	0.0
	-20	2222.1	2211.35	2209.6	2209.6	2209.6	0.0
	-40	3053.4	3027.06	3024.7	3024.7	3024.7	0.0
-4	-5	1982.0	_____	2105.5	2105.3	2105.5	0.01
	-10	2161.4	2216.7	2208.5	2208.0	2208.5	-0.02
	-20	2209.9	2225.0	2217.9	2215.7	2217.9	-0.10
	-40	3001.7	2984.1	2974.6	2959.6	2974.6	-0.50
8	-5	1907.1	_____	2121.5	2121.0	2121.5	-0.02
	-10	2141.6	2251.7	2217.3	2215.4	2217.3	-0.09
	-20	2232.0	2267.0	2243.0	2234.2	2243.1	-0.40
	-40	3092.6	3091.7	3058.8	2996.5	3058.8	-2.04

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7.0 EVALUATION OF ROLL EXCURSION ON AREA VALUES

To illustrate the influence of roll on the ground cell area a typical viewing angle, -45°, and a typical drift angle, 5°, were selected. Successive ground cell areas were calculated for successively larger roll angles, beginning at 0.0°, and remaining on the same doppler center frequency. Table 2 summarizes the results. Again, as was the case in drift excursions, the rectangular area technique does not adequately approximate changes in area for the off-ground-track situation.

Finally, as can be seen from Table 2, the difference between the TAMU Doppler area and the integrated area, by Simpson's rule, is never greater than 0.5% for excursions in roll up to 6.7 degrees.

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H = 1500', VEL = 150 KTS, λ = 0.1875
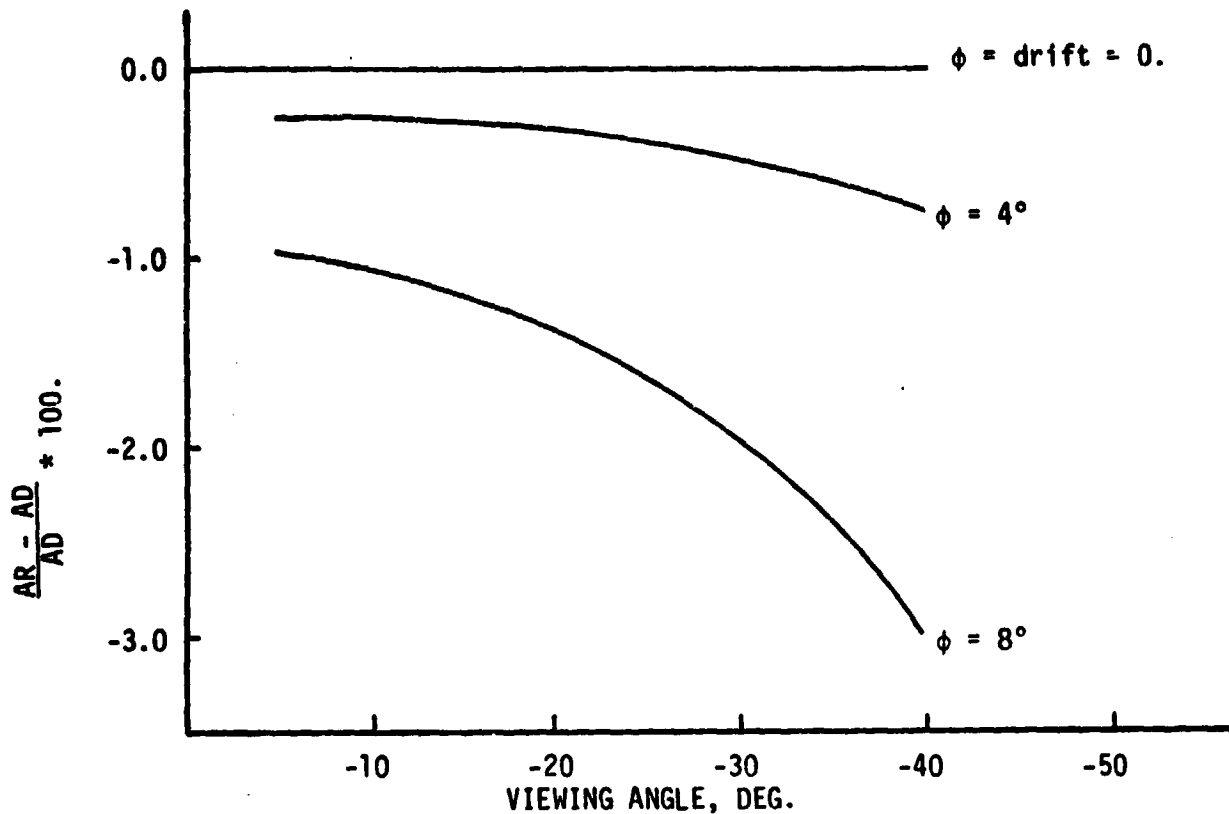
FIGURE 5.   AREA COMPARISONS, DRIFT EXCURSIONS
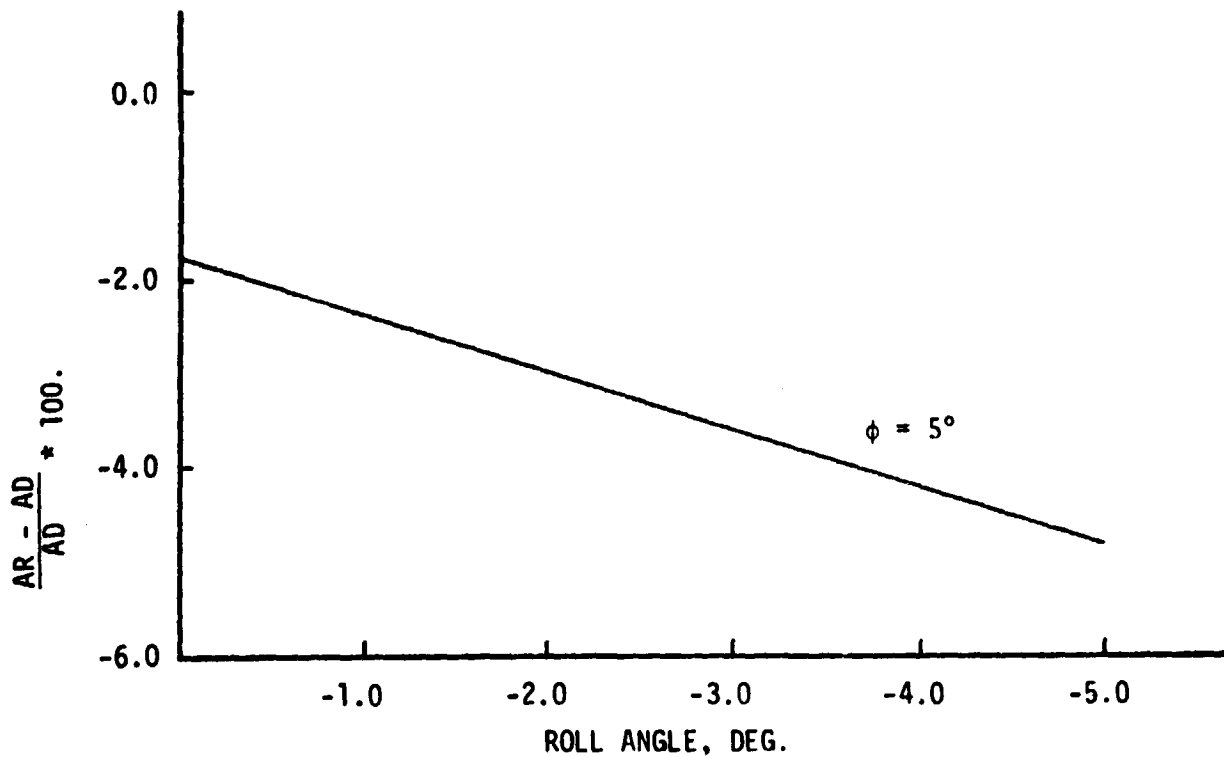
FIGURE 7.   AREA COMPARISONS, ROLL EXCURSIONS

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TABLE 2

Area Calculation Comparisons

AD = Doppler Area

AR = Rectangular

AQ = Quadratic Formula Application

AS = Simpson's Rules Integration

Roll, ψ Deg	DRIFT, ϕ Deg	AS	AQ	AD	AR	$\frac{AR-AD}{AD}$ *100
0.	5.	3132.9	3132.9	3133.9	3074.4	-1.9
-1.2	5.	3157.7	3141.9	3153.9	3075.1	-2.5
-2.5	5.	3184.1	3166.3	3178.4	3077.2	-3.2
-4.9	5.	3241.7	3228.8	3241.2	3085.8	-4.8
-6.7	5.	3289.1	3287.7	3300.4	3095.8	-6.2

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[1]. RSC 3182-1, "An Airborne Radar Scatterometer Signal Processing System", NASA Contract NAS 9-14493, Feb-Apr 1975.

[2]. Carnahan, Luther, Wilkes; "Applied Numerical Methods"; John Wiley & Sons, 1969, pp. 85-86.

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TECHNICAL MEMORANDUM RSC-160

EQUATIONS FOR COMPUTING THE AREA TERM

IN THE RADAR SCATTEROMETER PROCESSING ALGORITHM

BY

R. W. Newton

and

B. V. Clark

April 1979

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R. W. Newton and B. V. Clark

INTRODUCTION

The Remote Sensing Center has been funded by The Earth
Observations Division of NASA/JSC through Contract NAS9-14875
to evaluate the radar scatterometer processing techniques
developed by TAMU to the one recently implemented by the
NASA/JSC Engineering Systems Division. After several months
of effort and many personal and verbal communications, the
two processing techniques were demonstrated to be comparable.
The only subsystems that were not satisfactorily compared
were the area computational procedure. TAMU uses the algo-
rithm documented by Schell in Technical Memorandum RSC-119
[1], [2]. NASA/JSC used another algorithm. The largest
discrepancy between these algorithms occurred at large roll
and drift angles [3]. In order to insure that the output of
each processing system (TAMU, NASA/JSC, hardware processors)
were as consistant as possible, it was mutually agreed that
the same area algorithm should be used by both TAMU and
NASA/JSC. The algorithm that was agreed to by both TAMU and
NASA/JSC is the one utilized by Schell [1]. It is the purpose

of this memorandum to clarify the development and utilization
of these equations.

CELL LENGTH COMPUTATION

The area algorithm approximates the true cell area by
computing the length of the cell along the antenna center and
multiplying this length by the width of the cell at the cell
"center" defined by the filter center frequency. The cell
length at each incident angle is computed by determining the
points of intersection of the antenna center line with the
isodoppler hyperbolas defined by the center frequency and
bandwidth of the filter corresponding to each incident angle
(Figure 1). The equation of the line going through the center
of the antenna beam projected onto the surface can be deter-
mined by its slope and intercept (Figure 2). The equation
of this line is:

$$X = (slope)y + (x \text{ axis intercept})$$

From Figure 2 it can be seen that the slope is the tangent
of the drift angle. For the geometry in Figure 2

$$Slope = \tan \phi$$

Note that the drift, ϕ, is considered to be positive when
the nose of the aircraft is to the left of the aircraft
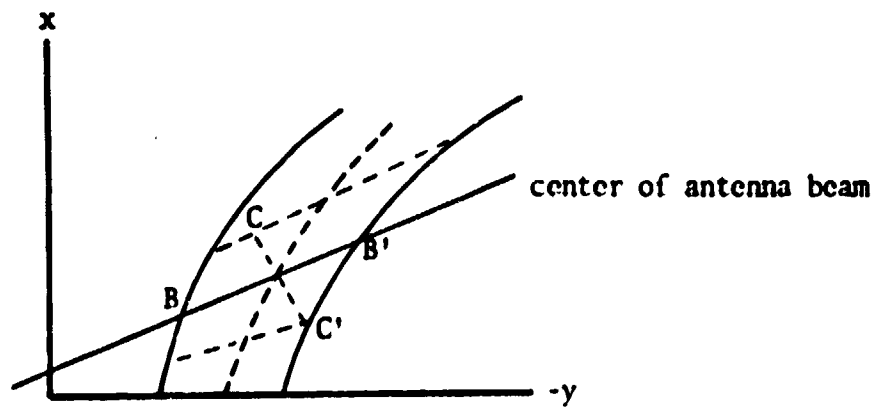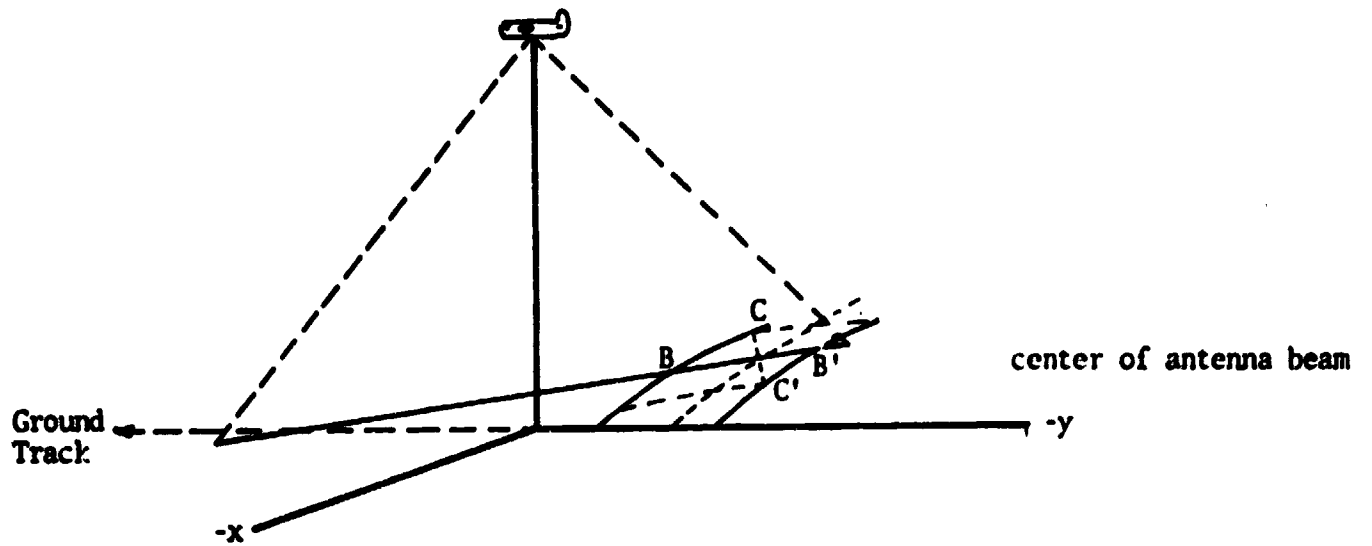
cell length: B to B'
cell width: C to C'

Approximate cell area: cell length x cell wid'

Figure 1. Definition of cell length and cell width.
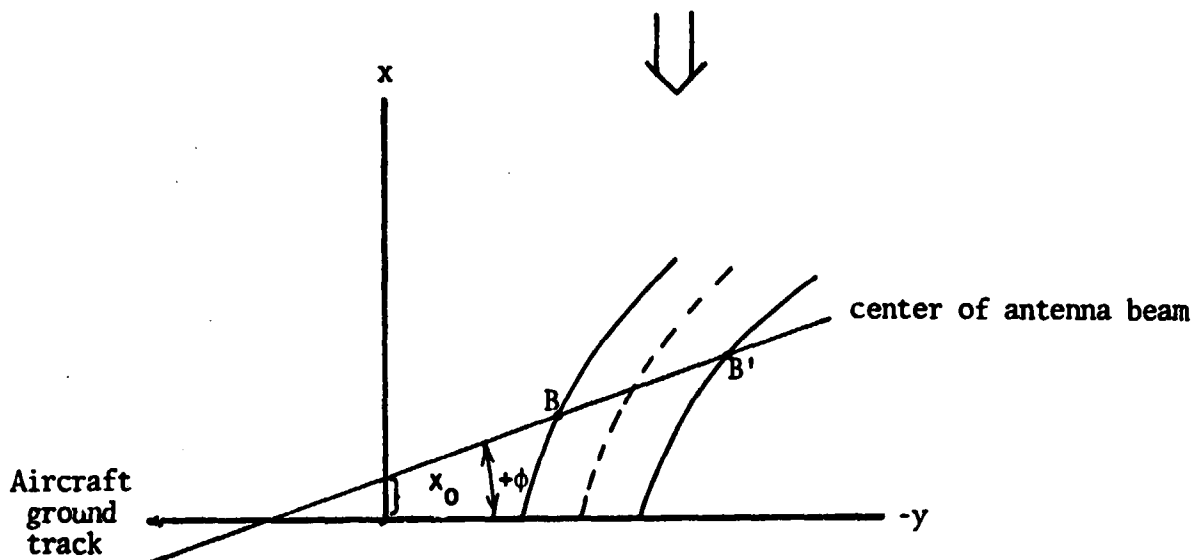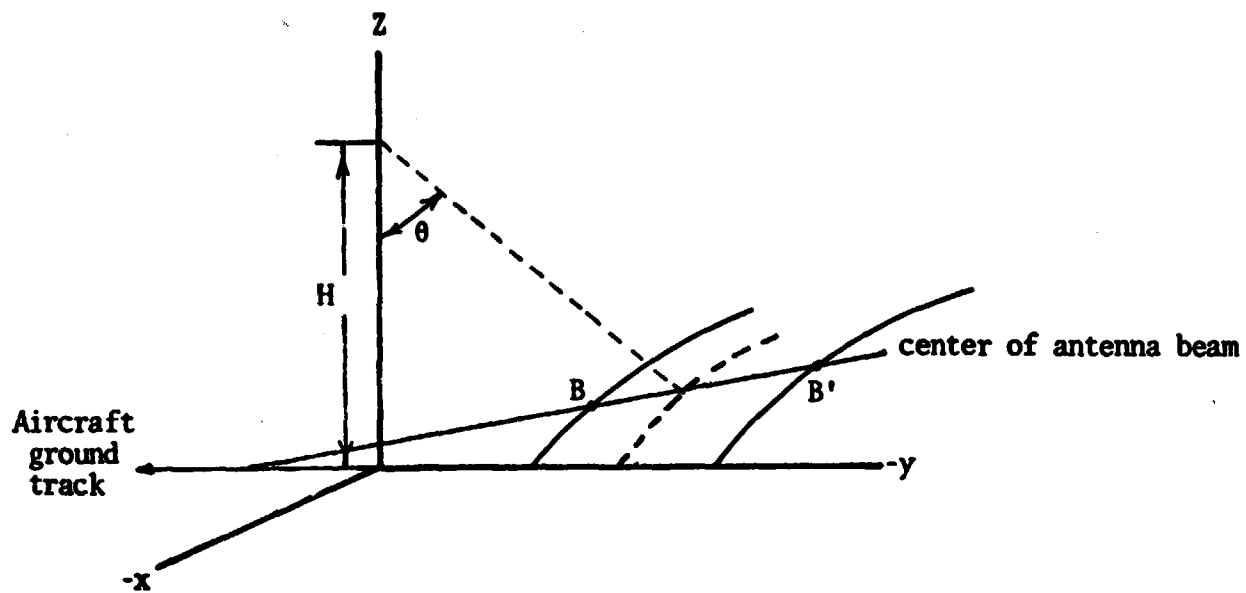
φ - drift angle (positive when aircraft nose is to left of
ground track)

x = (slope) y + x_0

Figure 2. Geometry describing projection of the center of the
antenna beam onto the surface.

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ground track. The x axis intercept, x_0, is given as

$$x_0 = \frac{H \tan(-\psi)}{\cos \phi} = \frac{-H \tan \psi}{\cos \phi}$$

where the angle, ψ, is measured off of the z axis and orthogonal to the center line of the antenna. It is considered to be negative when the left wing goes low. The equation of the line defining the center of the antenna beam is now

$$x = \tan \phi \, y - \frac{H \tan \psi}{\cos \phi} \qquad (1)$$

The cell length is determined by computing the intersection of this line with the isodoppler lines that define the cell end boundaries. The equation defining the isodopplers is determined from the doppler equation

$$f_d = \frac{2 \bar{v} \cdot \frac{\bar{r}}{|\bar{r}|}}{\lambda}$$

where $\bar{v}$ - the velocity vector (in the direction of the y axis

$\bar{r}$ - the range vector from the aircraft to the cell center (thus $\frac{\bar{r}}{|\bar{r}|}$ is a unit vector denoting the direction from the antenna to the cell center).

f_d - doppler frequency

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Now

$$f_d = \frac{2\,\bar{v}\cdot\bar{r}}{\lambda\,|\bar{r}|}$$

but from Figure 3

$$\bar{v}\cdot\bar{r} = |\bar{v}|\,|\bar{r}|\,\cos\theta_{rv}$$

$$= |\bar{v}|\,|\bar{r}|\,\cos(\theta' + \tfrac{\pi}{2})$$

$$\bar{v}\cdot\bar{r} = |\bar{v}|\,|\bar{r}|\,\sin\theta'$$

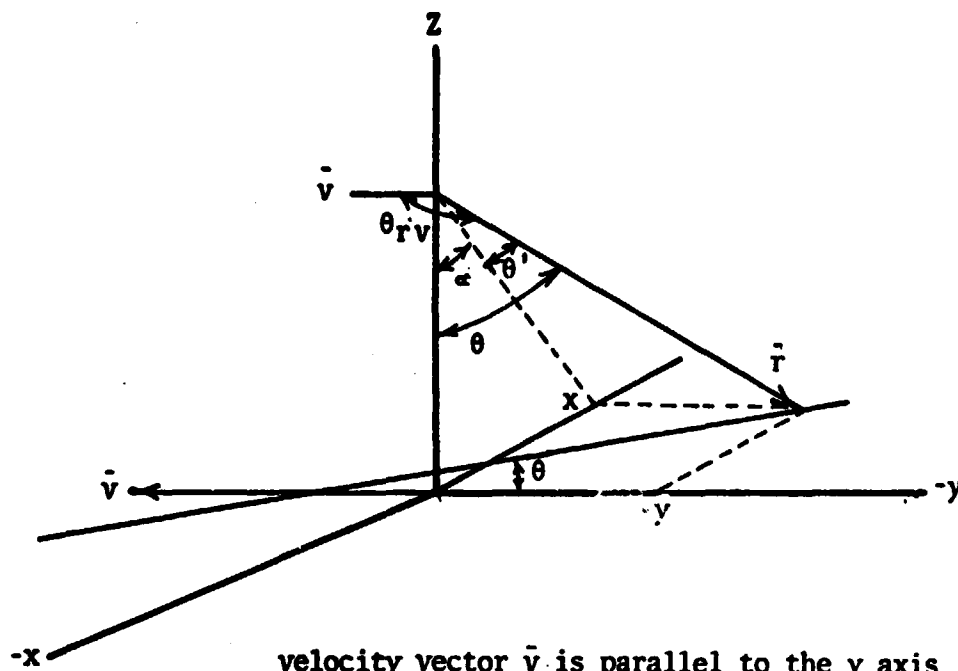where θ_{rv} is the angle between the velocity vector and the range vector. Now

$$f_d = \frac{2|\bar{v}|\,|\bar{r}|\,\sin\theta'}{\lambda\,|\bar{r}|}$$

Note that

$$|\bar{r}|\,\sin\theta' = -y$$

However, for small roll and drift angles

$$\sin\theta' \approx \sin\theta$$

velocity vector $\bar{v}$ is parallel to the y axis

$$\sin \theta' = \frac{y}{\sqrt{x^2 + y^2 + H^2}}$$

and

$$\sin \theta = \frac{\sqrt{x^2 + y^2}}{\sqrt{x^2 + y^2 + H^2}}$$

It is an approximation to assume $\sin \theta' = \sin \theta$ if ψ and ϕ are not zero.

Figure 3. Approximation involved in evaluations the doppler equation.

making this **assumption**, then

$$|\bar{r}| \sin \theta = -y$$

and

$$f_d = \frac{-2|\bar{v}| \, y}{\lambda |\bar{r}|}$$

Substituting for $|\bar{r}|$

$$f_d = \frac{-2|\bar{v}| \, y}{\lambda \sqrt{x^2 + y^2 + H^2}}$$

The factor k is constant for each incident angle.

$$\left(\frac{\sqrt{x^2 + y^2 + H^2}}{y} \right)^2 = \left(\frac{-2|\bar{v}|}{\lambda f_d} \right)^2 = k$$

$$\frac{y^2}{(k-1) H^2} - \frac{x^2}{H^2} = 1 \qquad (2)$$

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The cell length can now be computed from (Figure 4).

$$\text{cell length} = \frac{y_2 - y_1}{\cos\phi} \tag{3}$$

The y values are computed by solving for the intersection of the line defined by equation (1) and the hyperbolas defining the isodopplers, equation (2). Eliminating the variable x from these equations yields

$$\sqrt{y^2(k-1) - H^2} = \tan\phi\, y - \frac{H\tan\Psi}{\cos\phi}$$

$$(k-1)y^2 - H^2 = \tan^2\phi\, y^2 - 2H\tan\phi\tan\Psi\, y + \frac{H\tan\Psi}{\cos\phi}$$

$$y^2\left[\tan^2\phi - (k-1)\right] - \left[2H\tan\phi\,\tan\Psi\right]y + \left[\frac{H^2\tan^2\Psi}{\cos^2\phi} + H^2\right] = 0$$

$$a y^2 + b y + c = 0$$

$$y = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

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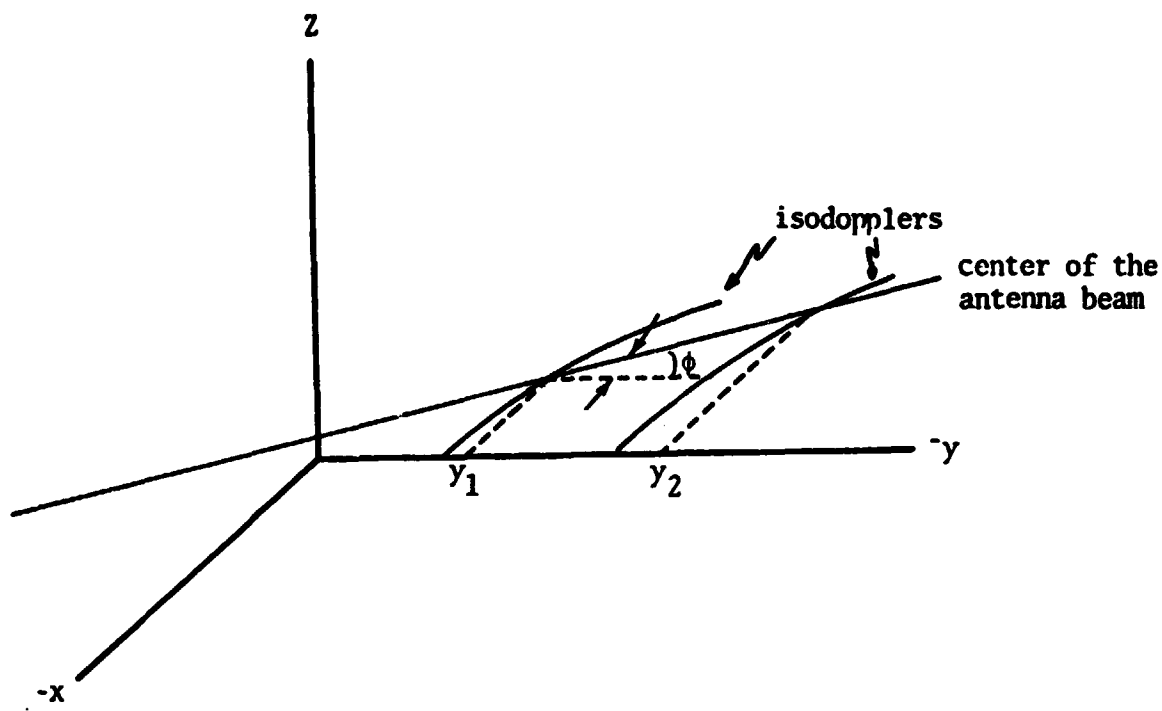
Figure 4. Cell length projection.

CELL WIDTH

The cell width can be computed with the aid of Figure 5.

$$r = \frac{H}{\cos\theta}$$

$$W = 2r \tan \beta/2$$

$$W = 2 \frac{H \tan \beta/2}{\cos\theta}$$
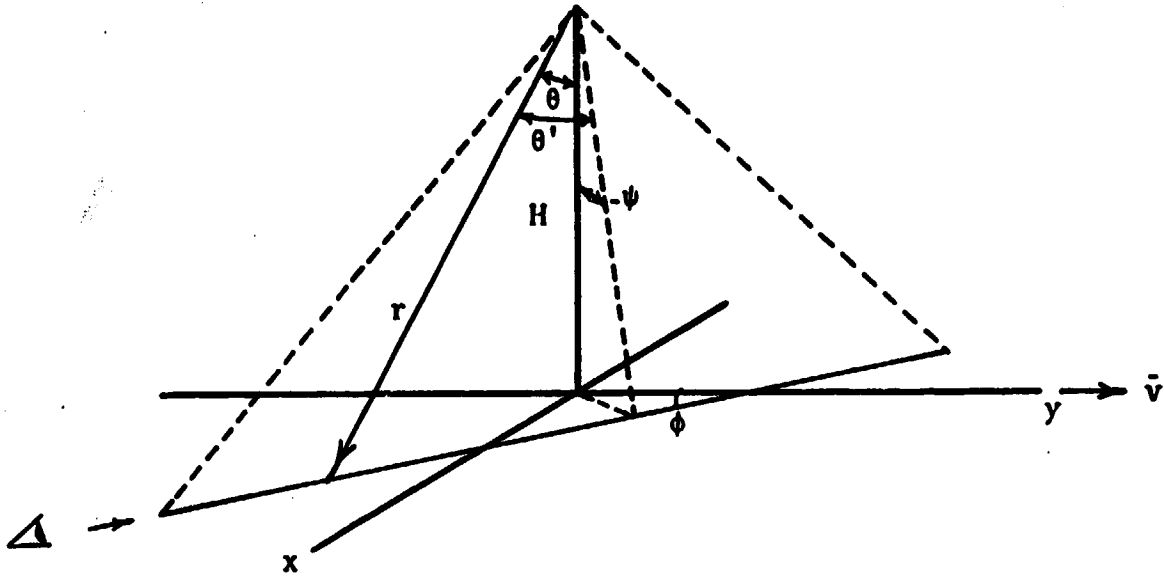
The cell width projected onto the surface is

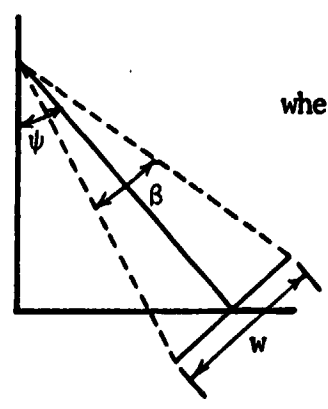$$W' = \frac{2H \tan \beta/2}{\cos\theta \cos\phi} \tag{4}$$

AREA COMPUTATION

The approximate cell area is computed by simply multiplying equation (3) by equation (4).

$$\text{Area} = W' \left(\frac{y_2 - y_1}{\cos\phi} \right)$$

$$\tag{5}$$

$$\text{Area} = \frac{2H \tan \beta/2}{\cos\theta \cos\phi} \left(\frac{y_2 - y_1}{\cos\phi} \right)$$

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Looking down the center line of the antenna.

where β is the beamwidth

Figure 5. Cell width geometry.

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REDEFINITION OF ROLL ANGLE

If it is determined that the roll angle is measured off the true nadir in the x z plane instead of orthogonal to the centerline of the antenna beam as assumed above, equation (5) can still be used to compute the area. However, the roll angle ψ used in the equations must be computed in the following manner:

$$\psi = \tan^{-1}(\tan\psi_{xz}\cos\phi)$$

where ψ is the angle in equations (1) through (5) above, and ψ' is the roll angle obtained from the NERDAS.

COMPARISON TO NASA EQUATION

The quadratic equation used to solve for y_2 and y_1 is

$$y^2[\tan^2\phi - (k-1)] - [2H\tan\phi\tan\psi]y + \left[\frac{H^2\tan^2\psi}{\cos^2\phi} + H^2\right] = 0$$

where   (6)

$$k = \left(\frac{2|\bar{v}|}{f_d\lambda}\right)^2$$

It can be shown that this equation is identical to the version that is contained in the NASA ESD program. The quadratic in the ESD equation is

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INH

$$y^2[\tan^2\theta \tan^2\phi -1] + [2H \tan\phi \tan\psi \tan^2\theta]y$$

$$+ H^2 \tan^2\theta \left[\frac{\tan^2\psi}{\cos^2\phi} +1\right] = 0$$

The constant k is obtained from

$$f_d = \frac{2|\bar{v}|\sin\theta}{\lambda}$$

$$\left(\frac{1}{\sin\theta}\right)^2 = \left(\frac{2|\bar{v}|}{f_d \lambda}\right)^2 = k$$

Substituting this into equation (6) gives

$$y^2\left[\tan^2\phi -\left(\frac{1}{\sin^2\theta}-1\right)\right] - [2H\tan\phi\tan\psi]y + \left[\frac{H^2\tan^2\psi}{\cos^2\phi} + H^2\right] = 0$$

$$y^2\left[\tan^2\phi -\left(\frac{1-\sin^2\theta}{\sin^2\theta}\right)\right] - [2H\tan\phi\tan\psi]y + H^2\left[\frac{\tan^2\psi}{\cos^2\phi} +1\right] = 0$$

$$y^2\left[\tan^2\phi - \frac{\cos^2\theta}{\sin^2\theta}\right] - [2H\tan\phi\tan\psi]y + H^2\left[\frac{\tan^2\psi}{\cos^2\phi} +1\right] = 0$$

$$y^2\left[\tan^2\phi - \frac{1}{\tan^2\theta}\right] - [2H\tan\phi\tan\psi]y + H^2\left[\frac{\tan^2\psi}{\cos^2\phi} +1\right] = 0$$

$$y^2\left[\tan^2\phi\tan^2\theta -1\right] - [2H\tan\phi\tan\psi\tan^2\theta]y + H^2\tan^2\theta\left[\frac{\tan^2\psi}{\cos^2\phi} +1\right] = 0$$

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This equation can be seen to be identical to the quadratic that ESD uses.

CONCLUSION

The equations developed in this document are identical to those developed by Schell in Technical Memorandum RSC-119 [1]. A question has recently been raised by NASA ESD concerning the reference for the roll angle that is measured by the NERDAS. It has been shown that the equations developed in this document can be used for either roll angle reference with a very simple roll angle adjustment.

The equations developed by Schell [1] are used in the real time 13.3 GHz radar processor and have always been used in the TAMU software processing programs. The only modification to the TAMU area computation that has ever been made is a change in the sign on the radical associated with the solution to the quadratic equation.

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[1]   Schell, J. A., "Ground Cell Area Calculation For a
      Radar Scatterometer Under Aircraft Pertubation,"
      Technical Memorandum RSC-119, Remote Sensing Center,
      Texas A&M University.

[2]   _____, "An Airborne Radar Scatterometer Signal
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[3]   Clark, B. V. and R. W. Newton, "Comparison of Scatter-
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