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JSME SCATTEROMETER DATA PROCESSING

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

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INTRODUCTION

The Remote Sensing Center at Texas A&M University has developed for the National Aeronautics and Space Administration/Johnson Space Center a software system which processes digitized scatterometer data from the 13.3 GHz, 1.6 GHz and 400 MHz scatterometer systems. In addition to this, the hardware capability has been developed to recover the raw analog radar signals and the aircraft parameters from an ADAS data stream in a digital format for processing by the software package.

Software for the preparation of data reports and chart presentation of scattering coefficients time histories has also been developed.

This report documents the development of the software, describes key components of the processing system and presents examples of the processed data and procedures for software operation.

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BACKGROUND

The developed software system processes raw data from the 13.3 GHz single polarized scatterometer, the dual polarized 1.6 GHz scatterometer and the 400 MHz dual polarized scatterometer systems. The 13.3 and the 1.6 GHz system processing requirements are similar since both are recorded by inphase and quadrature channels with zero baseband signals. Both data sets require sign-sensing to separate fore and aft Doppler signals before scattering coefficients are determined. Since the frequency spectrum of the 400 MHz system is centered at 500 MHz, the fore and aft Doppler are separated and sign-sense operations are not required. The software system is developed to process single sets of inphase and quadrature channels or the data and calibration channels for the 400 MHz system. Multiple polarization must be processed sequentially rather than simultaneously.

SYSTEM OPERATION

The software system is designed to interface with NASA scatterometer systems. An understanding of these instruments and their signal outputs is essential to the design of the processor system. The NASA scatterometers are active microwave sensors which illuminate a target area with microwave energy and receive the return which is scattered from the target. Subsequently, the return signals are modified and recorded for signal reduction and processing.

The Radar Equation

The radar equation is used to describe the viewing of a target by a radar system. The following development of the radar equation follows that of Moore in [1, equations 9-66 through 9-69, p. 419].

Consider the geometry of a radar remote sensor as illustrated in Figure 1. The power density at the target is that from an antenna of transmitter gain G_t radiating a power P_t upon a target at range R, thus,

$$\text{Power density at target} = \frac{P_t G_t}{4\pi R^2}$$

The power received at the receiving antenna is the power density of the target backscatter across the effective

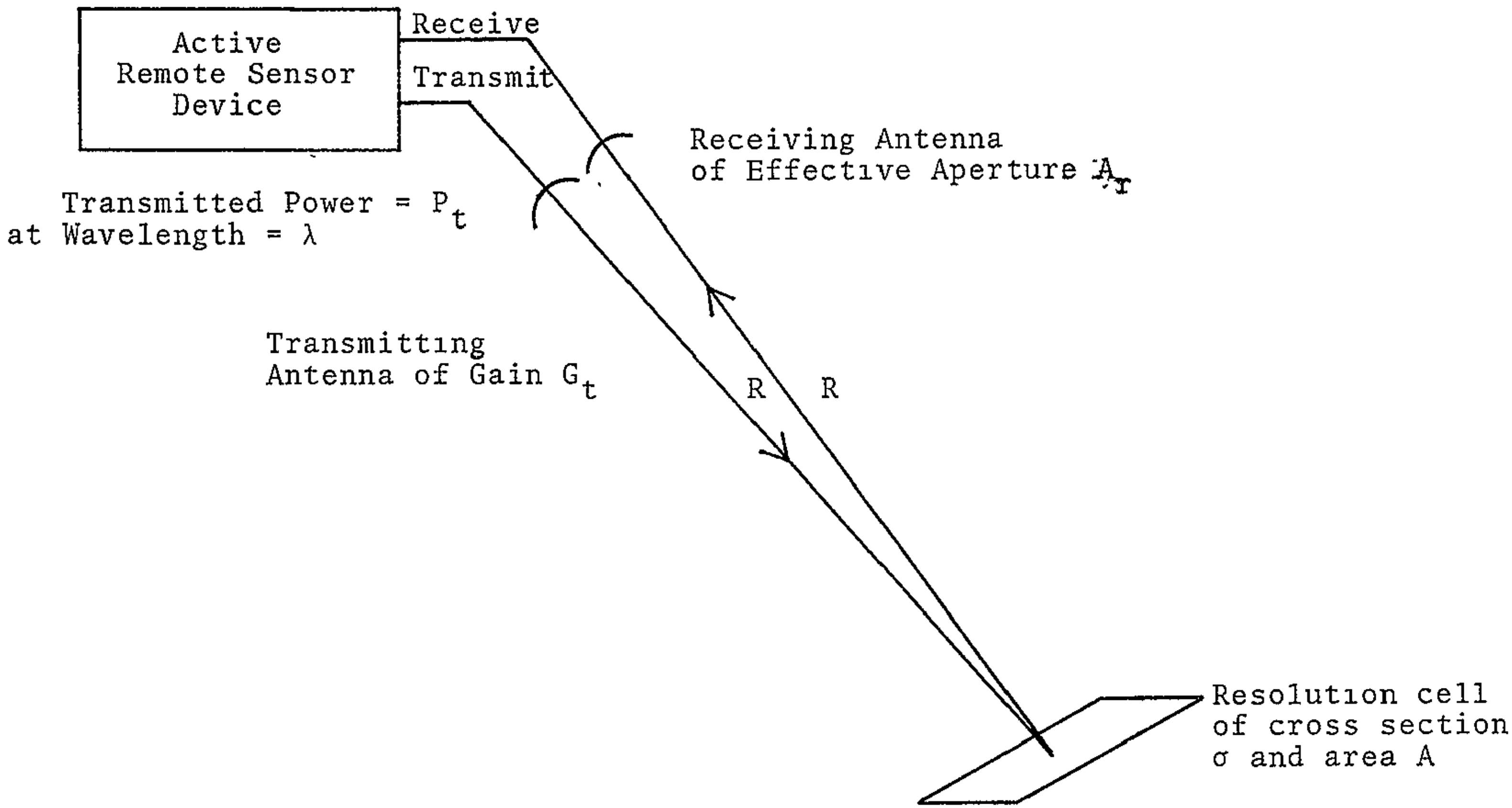

Figure 1. Active Remote Sensor Configuration.

aperture of the receiving antenna, that is,

$$\text{Power received} = P_r = \frac{P_t G_t}{4\pi R^2} \cdot \sigma \cdot \frac{1}{4\pi R^2} A_r$$

where σ is the effective backscatter area or cross section of the target and A_r is the effective receiver aperture.

If the radar system employs a duplexed antenna, i.e., if the receiver and transmitter utilize the same antenna, or if antennas of equal parameters are used for receiver and transmitter, then the relationship

$$G_t = G_r = G = \frac{4\pi A_r}{\lambda^2}$$

reduces the equation for received power to give one form of the radar equation:

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

The quantity in the radar equation of most interest to investigators is the radar cross section σ, since it is the only parameter relating information about the target. The cross section is generally expressed as an average over the cell area, A, and has been demonstrated [2, 3] to be a function of several parameters.

They are,

$$\sigma^\circ = \sigma/A = f(F, P, \theta, \phi, S, \varepsilon)$$

where

σ° = normalized target cross section

F = frequency of incident energy

P = polarization of incident energy

θ = angle of incidence

ϕ = target aspect angle

S = surface roughness factor, and

ε = target complex dielectric constant.

Remote sensing applications rely on the cross section's dependence on the latter two factors, the surface roughness and dielectric constant of the target cell. These two factors are indicative of important surface parameters. For example, soil moisture content affects the dielectric constant [4], and wind speed over large bodies of water has been related to the surface roughness [3, 5, 6].

Radar Scatterometers

An important class of radar systems is the scatterometer. A scatterometer irradiates the target with a beam of energy and receives the return energy at a separate antenna. This return power may be compared to the transmitted power to determine the scattering cross section.

The NASA/JSC scatterometer employ the Doppler effect; that is, the change in frequency of energy emitted from a source because of a velocity difference between the source and the receiver. For an airborne Doppler system moving horizontally over the earth, the Doppler effect causes a return spectrum of frequencies from the illuminated area, with positive Doppler shifts from the fore targets (approaching) and negative shifts from the aft targets (receding).

The amount of Doppler frequency shift, f_d, introduced into the radar return from a particular point on the ground is related to the incident energy frequency, f_i, by

$$f_d = \frac{2v_r f_i}{c}$$

where

v_r = relative velocity of target toward the receiver, and

c = propagation velocity, 3×10^8 m/sec.

Since the relative velocity can be positive or negative, the return power is usually distributed in an asymmetric spectrum centered around the transmitted frequency. Thus, with a Doppler system, the return from a particular angle of incidence has a unique corresponding frequency in the return spectrum.

Spectrum Folding and 'Sign-Sensing'

The processing of the data is difficult to achieve at the high transmitter frequency; therefore, for the 13.3 GHz and 1.6 GHz systems, the return signal is heterodyned at the radar receiver with a portion of the transmitter energy to produce a baseband signal. Unfortunately, this causes a "folding" of the fore and aft Doppler frequencies about zero Hertz in the frequency spectrum. In the NASA systems, two baseband signals, termed the inphase and quadrature channels, are provided by splitting the received signal into quadrature signals before mixing. Figure 2 illustrates the nature of these two signals. Additionally, a signal proportional to the transmitter power is inserted into the quadrature channel. Recovery of the fore and aft Doppler spectra (sign-sensing) and of the calibration signal is an essential step in the reduction of the 13.3 GHz and 1.6 GHz scatterometer signals.

Spectrum Sampling and Cell Definition

In the recovered spectrum for the 13.3 GHz and 1.6 GHz systems and the original spectrum for the 400 MHz

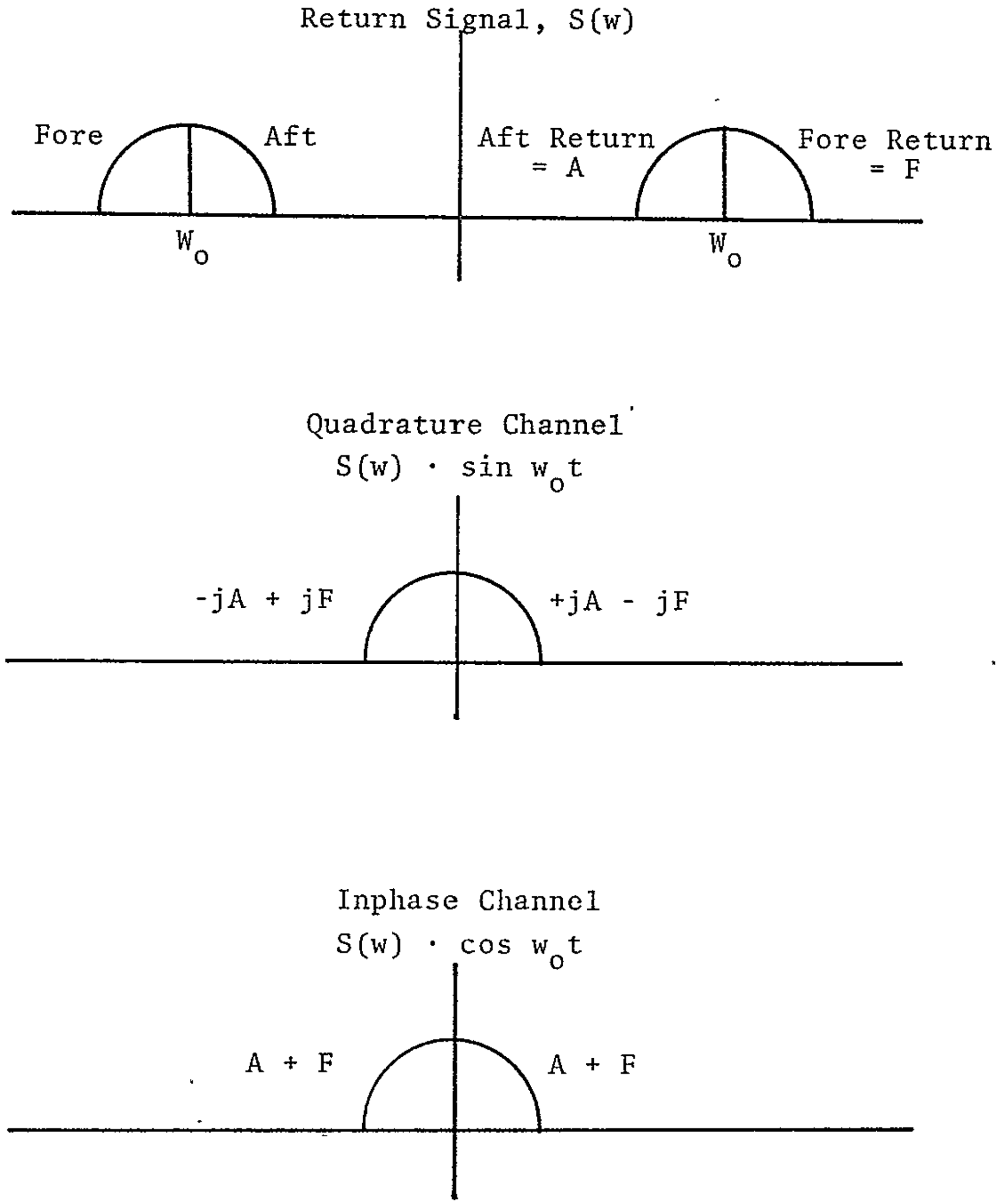

Figure 2. The NASA Scatterometer Output Signal.

system, each frequency corresponds to signal return from a unique angle of incidence. The return spectrum is sampled by a finite bandwidth filter which defines an area, or cell, on the ground. As shown by Jean [7], the sampled cell is outlined on the across track side by lines of constant Doppler shift having Doppler return frequencies equaling the upper and lower frequency limit of the band-pass sampled, while the along track sides are formed by the antenna beamwidth. The lines of constant frequency shift correspond to the intersection with the ground of cones of constant Doppler, concentric about the aircraft velocity vector.

In sampling the return spectrum, an estimate of the power return from a cell sampled is obtained. This estimate is then used in the determination of the scattering cross section. By plotting these lines of constant Doppler shift, called isodops, for a constant frequency difference, Δf, between each isodop, the cell definition and angular dependence can be demonstrated. Such a plot is given in Figure 3. The isodops are seen to form hyperbolas which, for a constant Δf, become more widely separated as the angle of incidence increases. Thus, the cell length defined by the bandpass of the spectral sampling filter increases as the incident angle

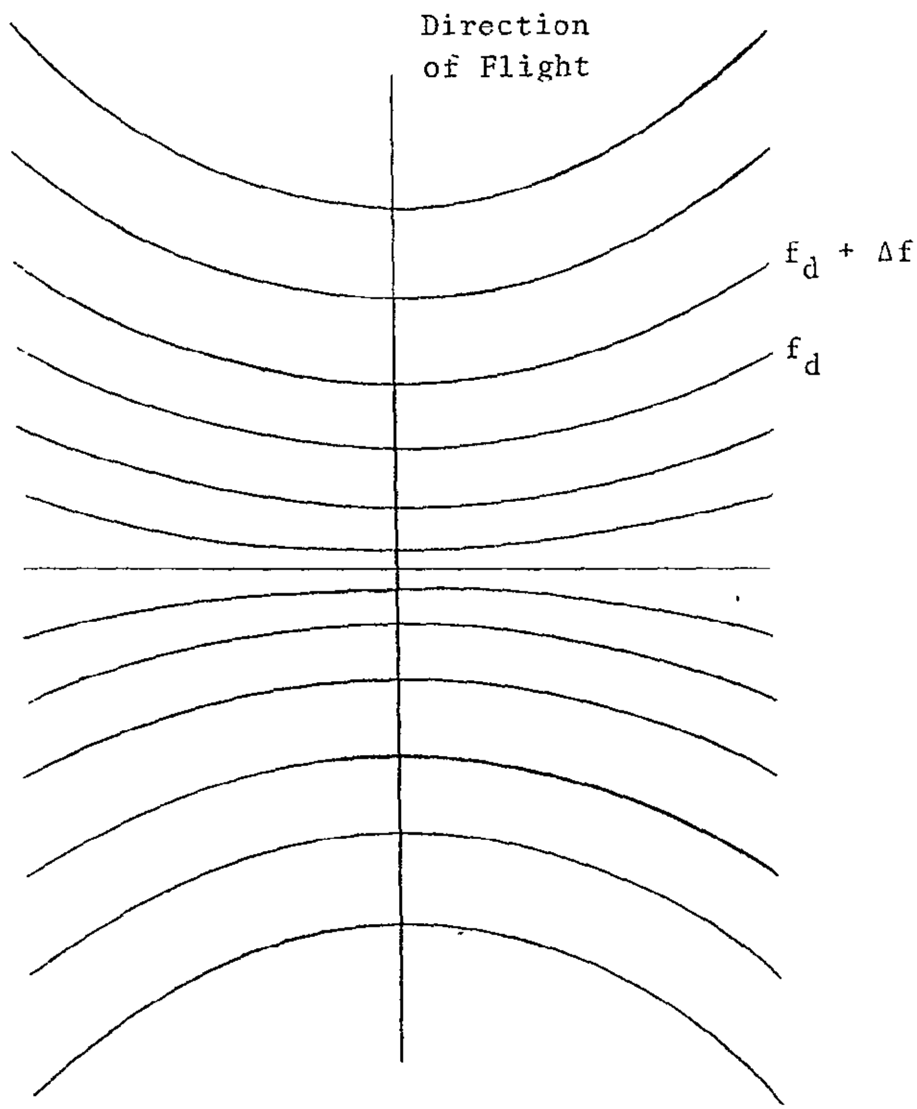

Figure 3. The Lines of Constant Doppler Frequency Shift, or Isodops.

is increased. The cell area is then delineated by the intersection of the bandpass of the spectral filter and the limits imposed by the fan beam pattern of the antenna. A typical target cell is outlined in Figure 4.

When the aircraft roll or drift is introduced, the area within the antenna pattern changes. In Figure 5 is shown a typical target cell under aircraft roll or drift perturbations. The scattering cross section is calculated from this target cell.

Coefficient Calculation

The objective of scatterometer data reduction is to obtain the normalized scattering cross section, for a target cell, and ultimately to obtain a cross section function of a particular cell as a function of incident angle. Solution of the radar equation for $\sigma°$ identifies the parameters which are needed for the calculation of cross section,

$$\sigma°(\theta) = \frac{(4\pi)^3}{\lambda^2} \cdot \frac{1}{G^2(\theta)} \cdot \frac{R^4(\theta)}{A(\theta)} \cdot \frac{P_r(\theta)}{P_t}$$

The calculation of $\sigma°(\theta)$ involves known constants, system parameters, calculated geometric parameters and dynamically measured signal values. The system antenna gain parameter $G_1G_2(\theta)$ is determined for the particular scatterometer

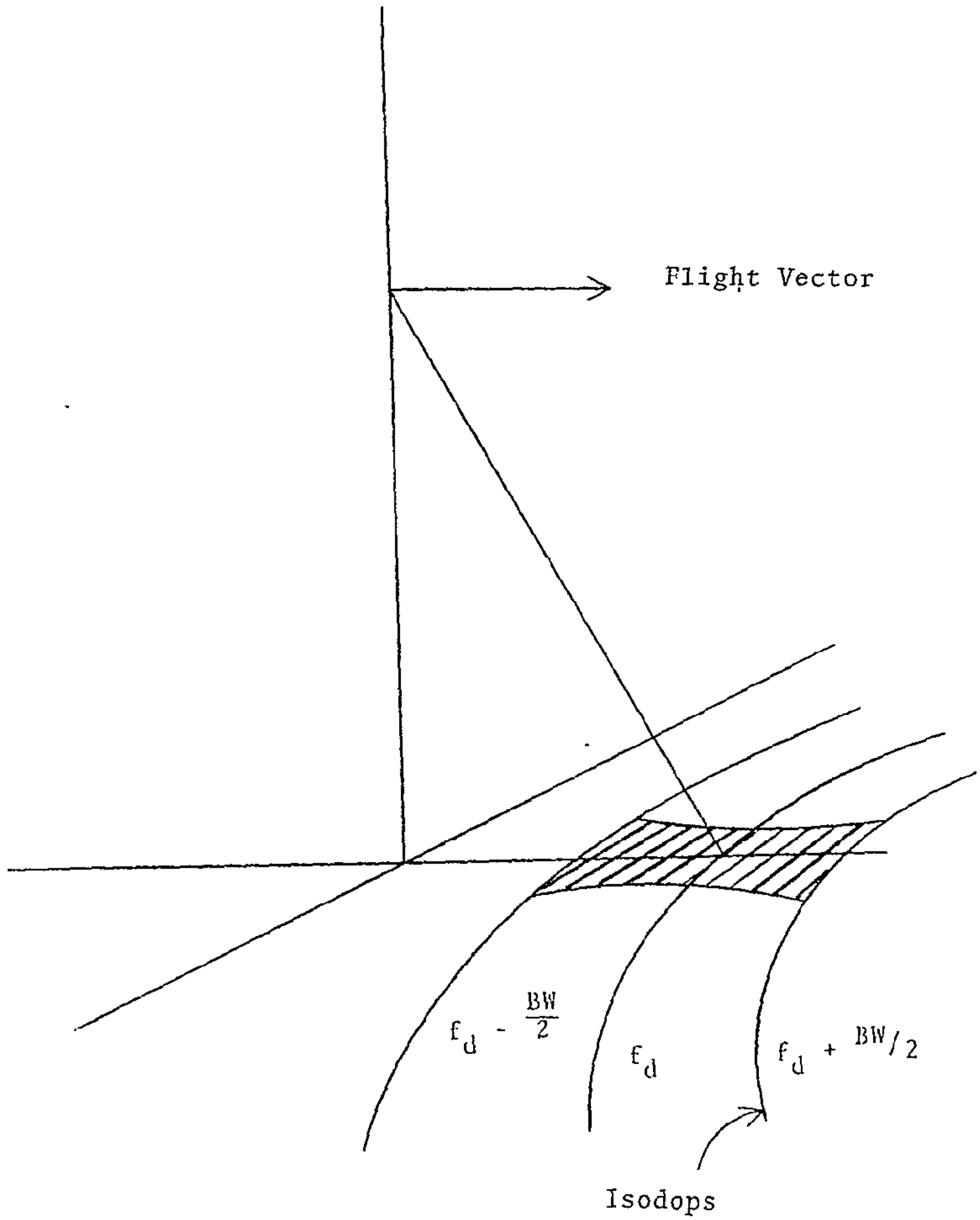

Figure 4. Instantaneous Ground Cell Area
with no Aircraft Perturbation

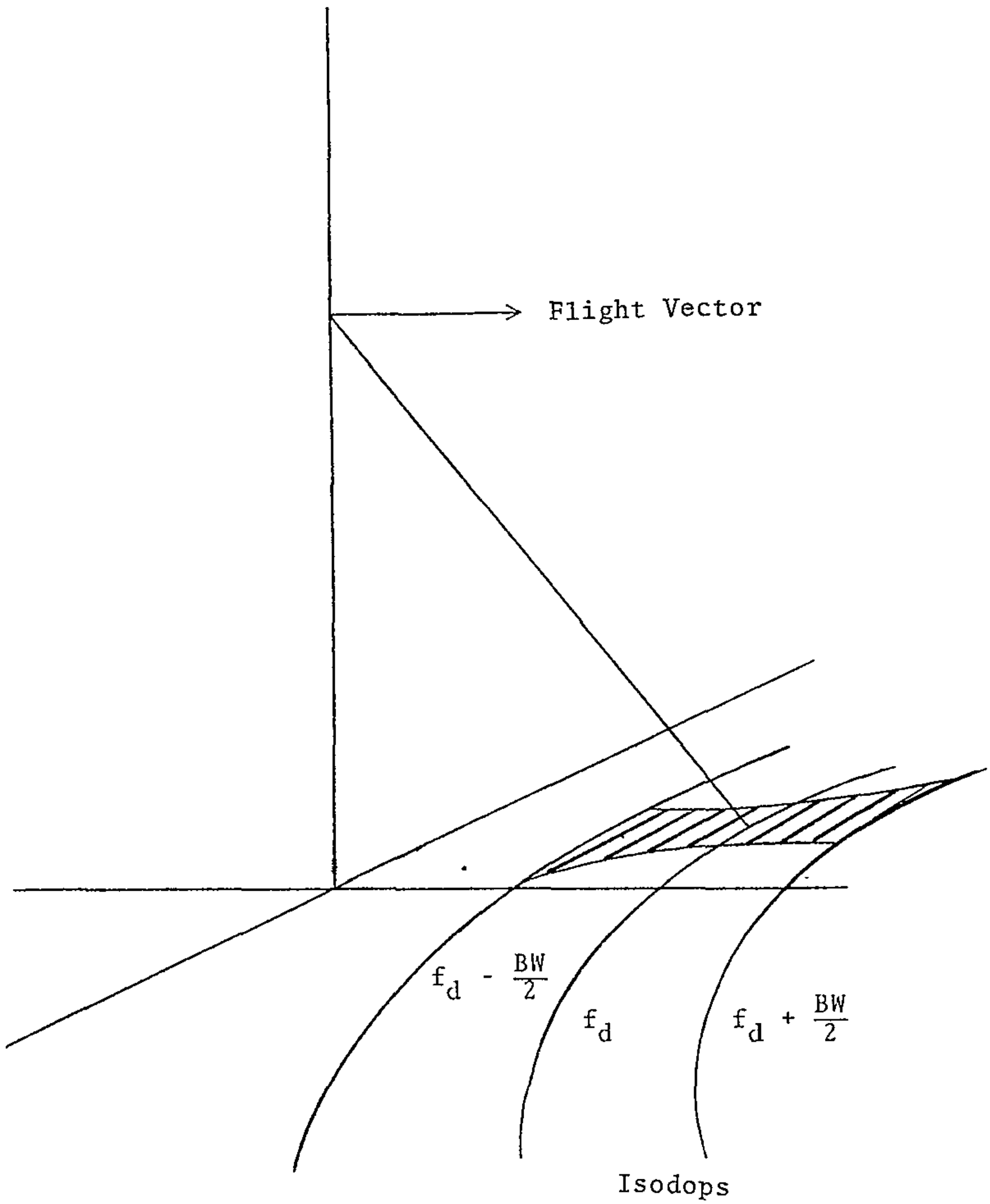

Figure 5. Instantaneous Ground Cell Area with Aircraft Drift and/or Roll.

system as a function of incident angle. The geometric parameters which appear in the solution of the radar equation are slant range to the target, R, and the illuminated cell area, A. These values are calculated using aircraft parameters.

The processing determines both the transmitted and received power by measuring the sign-sensed radar signals through bandpass filters. For a given angle, a Doppler frequency, based upon aircraft parameters, is calculated and the bandpass filter is set for that frequency. The output of the filter is related to the received power P_r. The filters are also set for the calibration voltage and its value is related to the transmitted power P_t. The ratio of powers required for the scattering coefficient calculation is obtained by

$$P_r(\theta)/P_t = \frac{H(f_\theta)E^2{}_\theta}{KE^2{}_{cal}}$$

where

E_{cal} = measured voltage for a filter frequency at the calibrator,

E_θ = measured output voltage,

$H(f_\theta)$ = the frequency response characteristic of the radar land/sea filter, and

K = calibration constant.

Alignment

The incident angle at which a target cell is viewed depends upon the relative position of the aircraft to that target. It is evident that the angle of incidence to a fixed target changes with the flight of the aircraft. Thus, radar return at different viewing angles from a single target cell must be measured at different times. Consequently, aligning the calculated scattering coefficients for a single target requires time shifting the calculated results. This time shift requirement is of major importance in providing a suitable data product from the scatterometer/processor system.

Processing Requirements

The processing requirements for the reduction of 13.3 GHz and 1.6 GHz radar scatterometer data are:

1) sign-sense the signals to unfold the data into fore and aft spectra;
2) sample the power spectra at the appropriate frequencies to recover the radar return measurement and to obtain the measurement of the calibration level;
3) obtain the aircraft flight parameters so

that geometric calculations of slant range and target area can be determined;

4) calculate the normalized radar cross section from the solution of the radar equation; and

5) time align the scattering coefficients from a single target so that the output from the processor gives aligned cross sections for each target area.

For the 400 MHz system, step number one is omitted since sign-sensing is not required. This set of requirements defines, in general, the functions which must be implemented by the processor to accomplish the required data reduction and presentation.

SOFTWARE SYSTEM

The developed software system is designed to accept and process data from three scatterometer systems. These systems include the 13.3 GHz single polarized, 1.6 GHz dual polarized and 400 MHz dual polarized systems operated by NASA. The software is written in FORTRAN and is normally executed on the TAMU Amdahl 460/VS computing system.

The input data requires two channels of digitized radar signals and the aircraft parameters of time, altitude, ground speed, roll, drift and pitch. These data are required to be in integer form with a two-byte (16-bit) length. Time is input in hours, minutes and tenths of seconds; altitude is in feet; ground speed is in knots; and pitch, roll and drift are in tenths of degrees. The radar data are expected to have 12-bit significance with two's complement representation of negative numbers. Each input record is digitized data acquired for the period of time for which the data are to be averaged.

In Figure 6 is shown a flowchart which describes the major functions of the software package and the processing procedure. The implementation of the Hilbert transform for sign-sensing, the calibration and Doppler filter algorithms, area calculation and angle alignment

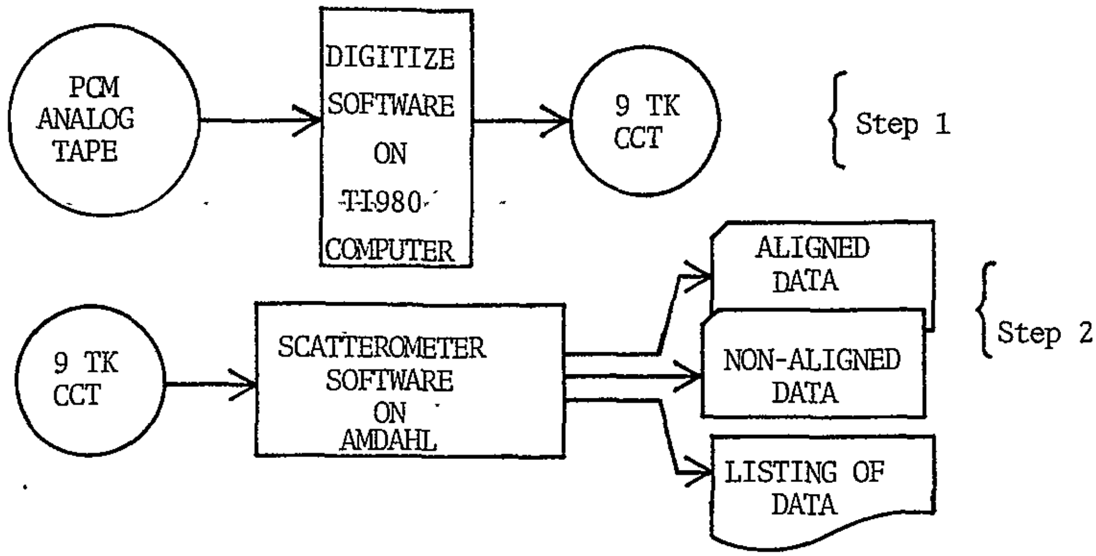

Figure 6a. Major steps in data processing.

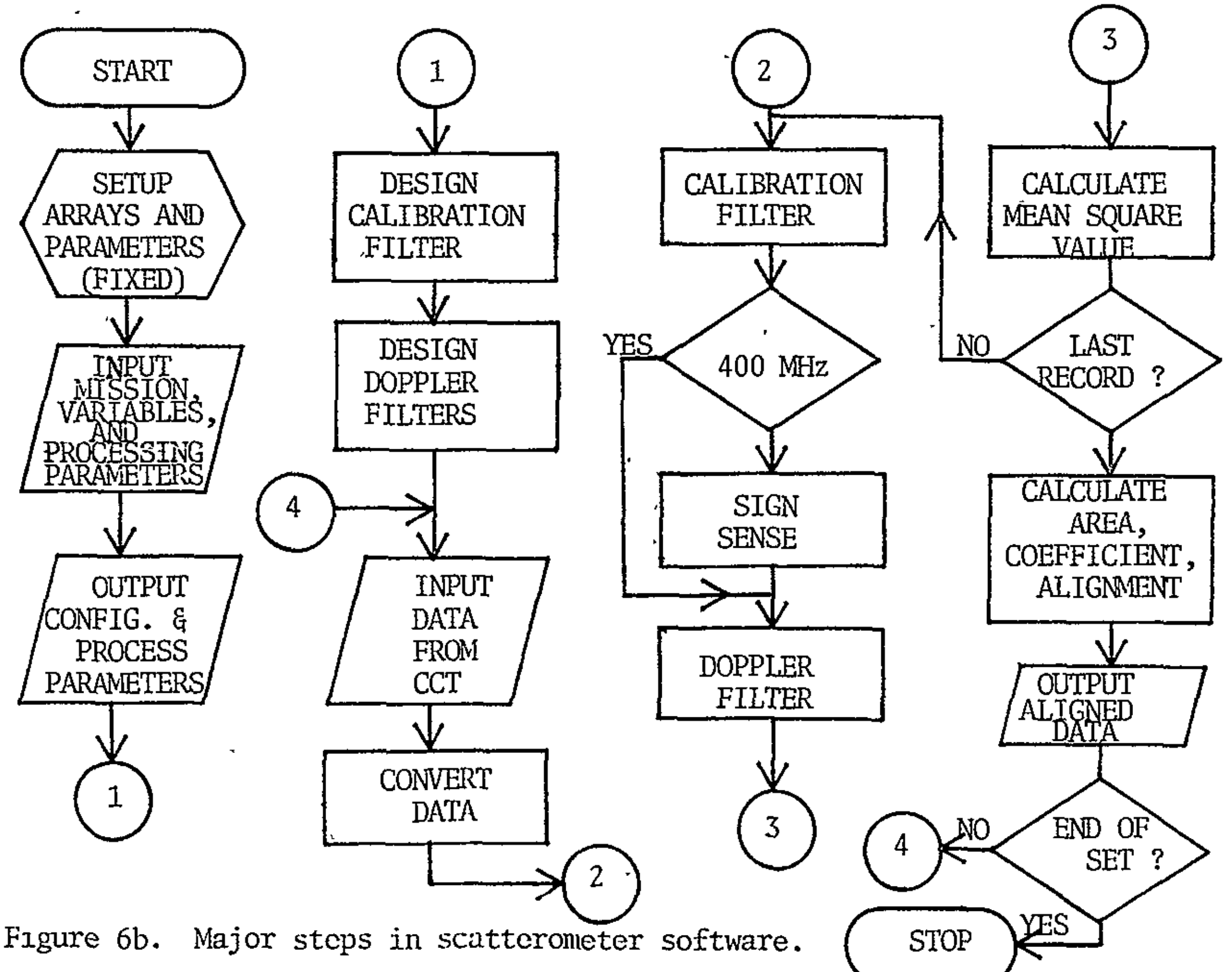

Figure 6b. Major steps in scatterometer software.

The REMOTE SENSING CENTER was established by authority of the Board of Directors of the Texas A&M University System on February 27, 1968 The CENTER is a consortium of four colleges of the University; Agriculture, Engineering, Geosciences, and Science. This unique organization concentrates on the development and utilization of remote sensing techniques and technology for a broad range of applications to the betterment of mankind.