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EFFECTS OF RANGE BIN SHAPE AND DOPPLER FILTER RESPONSE IN A DIGITAL SAR DATA PROCESSOR

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SUMMARY

In calibrating the backscatter coefficient obtained with an imaging synthetic aperture radar (SAR) system to determine absolute values of radar cross-section and reflectivity it is common practice to use a target of known radar cross-section placed within the scene. A corner reflector acts as a point target, but the return from it may not be centered in the resolution cell. It is important, for accurate calibration, to perform straddling corrections based on the range bin and doppler filter response curves.

1.0 THE CALIBRATION PROBLEM

A method commonly used to calibrate the backscatter coefficient in an imaging SAR system is to place a point target of known radar cross-section (RCS), such as a corner reflector, within the imaged area. Without the calibration target, the absolute RCS or σ° value can only be inferred. Figure 1 is a SAR map made by the FLAMR (Forward Looking Advanced Multimode Radar) System, a digital processor system using binary phase coded pulse compression and a doppler signal processor with 16 pre-summed doppler filters (sixteen point Complex Fourier Transform). This is a map of a vehicle array at the Marine base near Barstow, California. With a suitable calibration target available in the array, cross-section data on these vehicles may be extracted provided certain corrections are made.

1.1 RESOLUTION CELL STRADDLING

The calibration target, a trihedral corner reflector, may be located within the imaged area, and if its nominal RCS is known as a function of aspect angle, it may be used as a reference, provided it is in the peak response of the range and azimuth filter response, and is not saturating the radar receiver. The corner reflector should also be an isolated point target well above the surrounding clutter level. Figure 2 is of an array of three corner reflectors positioned in an agricultural scene mapped by the FLAMR SAR. The reference corner reflector for σ^o and RCS data is the one in the center of the array 45.72 cm (18 in.) on the inside dimension. Figure 3 is the measured response of this target, so that its value may be known, provided its aspect to the radar is known. Frequently, however, the sampling grid of the radar system straddles the point target and it then becomes necessary to correct the observed response in both range and cross-range for such effects. In order to make such a correction, the shape of the range bin and of the doppler filter response must be known. These points may be summarized as followsfor the special case of impulse response symmetry, and invariance of the impulse response in azimuth:

Let f = amplitude response of a resolution cell = $f(r, a)$ with r the range dimension, a the azimuth dimension, then

$$|f^2| = \text{power response} = f(a, r_o)\ f(r, a_o) \qquad (1)$$

and r_o, a_o is the point of maximum response. For a point target, power received P_R is

$$P_R = K\,\sigma\, f^2\,(r_t, a_t), \text{ in which} \qquad (2)$$

all the constant radar parameters (including the range, although it may cause a usually negligible error) are lumped into a constant K, and r_t, a_t define the actual position of the scatterer of cross-section σ in the resolution cell. The value of $f^2\,(r_o, a_o) = 1$. The straddling corrections in azimuth and range are made to effectively convert the value of $f^2\,(r_t, a_t)$ to unity, so that the result is:

$$\frac{P_R}{f^2\,(r_t, a_t)} = K\,\sigma\, f^2\,(r_o, a_o) = K\sigma \qquad (3)$$

from which K may be known

$$K = \frac{P_R}{f^2\,(r_t, a_t)} \qquad (4)$$

assuming σ is known for the reference calibration target (corner reflector).

1.2 STRADDLING CORRECTIONS

The process of modifying P_R by the factor f^2 (r_t, a_t) is a two-step one using the range and azimuth straddling correction curves. These are derived from the response curves of a range bin and doppler filter, which are presented in Figure 4. This particular SAR system had 3 nominal resolutions of 6 meters, 12 and 24 meters (20, 40 and 80 feet). The doppler filter shape was constant for the 3 resolutions but the range bin shape was not, as may be observed. Figure 5 indicates how two adjacent range bins overlap and the correction curve which may be derived for straddling corrections.

1.3 THE CORRECTION CURVE

The straddling correction curve is obtained by plotting the difference between the maximum of the response curve and the value at every other point as a function of the difference between one curve and its adjacent neighbor, up to the point of zero difference, both toward, and away from, the radar. From this, it is evident that the maximum correction will be required when the target exhibits equal returns in adjacent range bins. This procedure for obtaining the correction curves may be understood by referring to Figure 5. When the filter response is symmetrical, as it is in azimuth, the correction curve is the same either in the mapping direction or away from it.

2.0 CORRECTION OF OBSERVED DATA

A print-out of the pixel data is useful in making the straddling correction, on a point target. The entire map, which in the FLAMR case consists of 356 azimuth lines and 384 range bins, need not be printed. The corner reflector can usually be roughly located using a measurement of a map photograph. Figure 6 illustrates the procedure. The filter magnitude value next largest to the maximum is used in azimuth, and in range, to obtain the difference. The larger range difference is away from the radar, 15 filter magnitude values. Entering the range straddling correction curve "away from the radar" the upper curve of Figure 5, gives a correction in filter magnitude values to be added to the maximum. The filter magnitude values can be converted to dB by multiplying by the factor .376 or approximately 3/8.

This is because the recorded filter magnitude logarithmic data is

$$M_R = 16 \text{ Log}_2 \sqrt{f_I^{\ 2} + f_Q^{\ 2}} = 16 \text{ Log}_2 f \tag{5}$$

ignoring computer function algorithm error. The digital filter magnitude data are recorded in an 8-bit format with a maximum possible recorded value of 199. In decibels the filter magnitude is given by

$$M_{dB} = 20 \text{ Log}_{10} \sqrt{f_I^{\ 2} + f_Q^{\ 2}} = \left(\frac{20}{16}\right) \left(\text{Log}_{10} 2\right) M_R \tag{6}$$

$$= .376 \ M_R$$

2.1 OBTAINING THE CALIBRATION FACTOR

The straddling correction curve may be either in dB or in filter magnitudes. Figure 6 illustrates how the value of K is reached with straddling corrections and corrections for off-bore site aspect of the radar to the corner reflector.

2.2 DETERMINING AN AREA FACTOR FOR σ^o.

The effective area for the resolution cell is required in calculations of reflectivity for different types of terrain. The usual procedure is to average the values for a representative sample of pixels, apply the calibration factor and then divide by the effective area of a pixel.

$$\sigma^o \text{ (dB)} = \sigma \text{ (dBm}^2\text{)} - 10 \text{ Log Area (m}^2\text{)} \tag{7}$$

The effective area is the effective range dimension times the effective azimuth dimension, found by integrating the areas under the impulse response curves and dividing by the peak response. Table 1 provides these values as obtained for the FLAMR System.

TABLE 1

EFFECTIVE RESOLUTION CELL AREA

RESOLUTION	NOMINAL DIMENSIONS				BALDWIN HILLS TEST RESULTS			
	AZ (m)	RNG (m)	Area (m^2)	Area (dBm^2)	AZ (m)	RNG (m)	Area (m^2)	Area (dBm^2)
LOW	24	24	576	27.6	28.6	18.3	523.4	27.1
MEDIUM	12	12	144	21.6	14.3	9.1	130.1	21.1
HIGH	6	6	36	15.6	7.2	4.6	-3.1	15.2

3.0 OBTAINING THE RANGE AND AZIMUTH FILTER RESPONSE

The system was measured using a large (30,000 m^2) corner reflector situated on a hill (Baldwin Hills) about 10 kilometers from the Los Angeles International Airport with a clear radar line-of-sight. Figure 7 is a view of the test bed aircraft on the ramp at its operating base. The system is put under manual control and with the corner reflector return positioned in the zero doppler (d.c.) filter, the range is incremented by .75 meters by changing the start range window. The start range is moved through at least three range bins, and the data recorded from d.c. filter. Of course, system power is monitored and various system parameters are recorded for any configuration variables, such as number of pulses per array, pulse compression length, code and sequence. The data obtained may then be plotted as a function of range and several of the curves averaged to obtain the average response of the system in range for the different bandwidths (resolutions) available. The doppler filter shape may be measured in much the same way, by adjusting the frequency synthesizer in approximately 1/10 filter width increments over a range of from at least the center of filter fc-4 to the center of fc + 4. The digital doppler filter is well behaved, and for FLAMR is characterized by the expression

$$f(x) = \frac{\sin\left(\frac{\pi x}{12}\right)}{\left(\frac{\pi x}{12}\right)} \left[\frac{1 + .06 \left(\frac{x}{12}\right)^2}{1 - \left(\frac{x}{12}\right)^2} \right] \qquad (8)$$

which may be squared and the area obtained in watt-seconds by integrating under the curve using the method of residues. The curves for range response may be integrated using Simpson's Rule or some other procedure.

4.0 TYPICAL RESULTS

Without going into detail, some typical results are provided in Figure 8, for the reflectivity of various types of scene content from Figure 1. These values were obtained by use of the calibration factor obtained using the corner reflector data of Figure 3. Aspect angle data were obtained from the aircraft data tapes (altitude), from the radar map (azimuth lines vs. road directions), and ground truth information regarding the orientation of the reflector.

5.0 REFERENCES

1. Griffin, C. R., Amendment to ARL:UT Technical Report TR-76-8 "Radar Reflectivity Study", ARL-ITM-77-1, 6 January 1976
2. Rasco, W. A., and Griffin, C. R., Radar Reflectivity Study, ARL-TR-76-8, Air Force Avionics Laboratory, March 1976

Figure 1. FLAMR Map of Barstow Vehicle Array

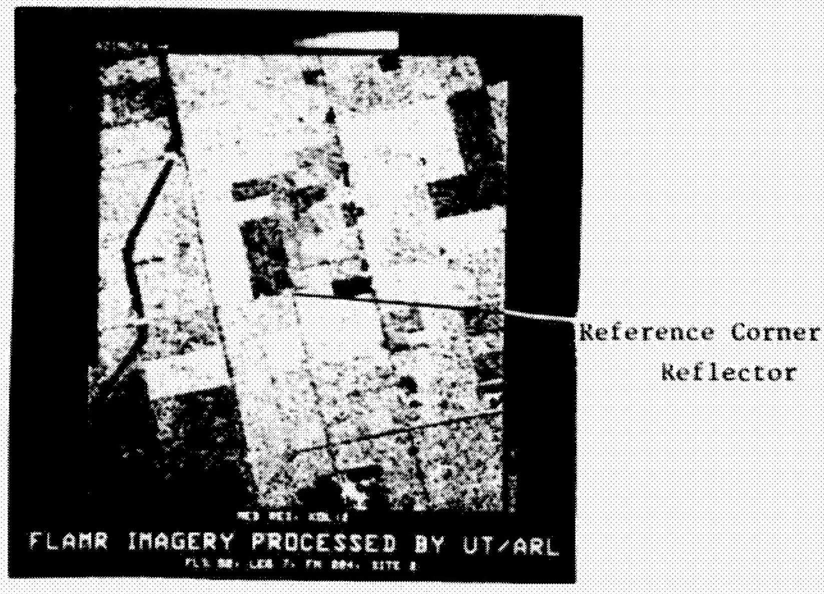

Figure 2. FLAMR Doppler Beam Sharpened Map, San Joaquin Valley Rural Scene

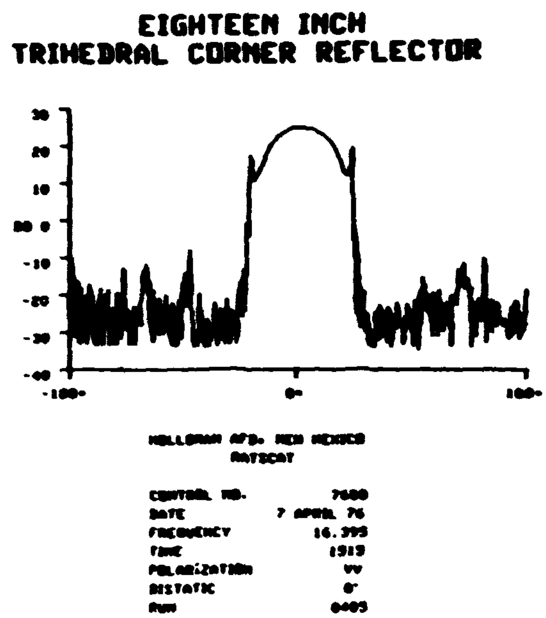

Figure 3. Measured RCS of a 45.72 cm Trihedral Corner Reflector

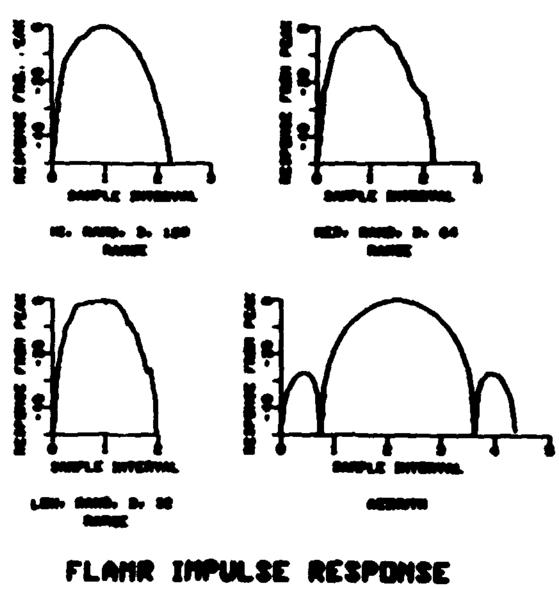

Figure 4. Range Bin and Doppler Filter Response Curves for FLAMR

STRADDLING CORRECTIONS FOR
RANGE AND AZIMUTH FILTER SHAPES

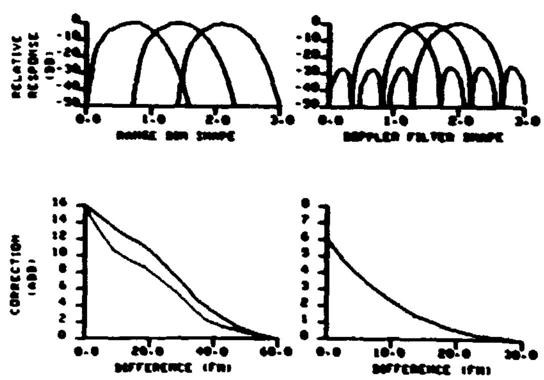

Figure 5. Adjacent filter overlap and Derived Straddling Correction Curves

Filter Magnitude	Original Value 163
Data in Region of	Azimuth Straddling Correction 001
Corner Reflector	Range Straddling Correction 012
	176

Range ↑

	148	
128	163	149
	105	

← Azimuth

σ CR = 27.4 dB

Az/El correction = -2.1 dB

σ CR = 25.3 dB

$K = (.376)(176) - 25.3 = 40.7$ dB

Figure 6. Establishing the value of K using straddling and Aspect Angle Corrections.

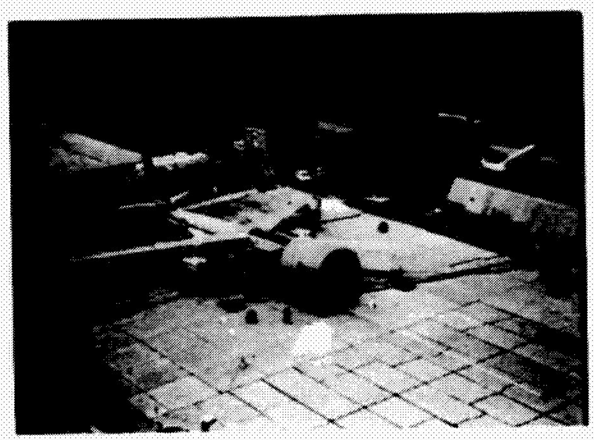

Figure 7. FLAMR System Test Bed, Ramp Ground Testing, Los Angeles International Airport

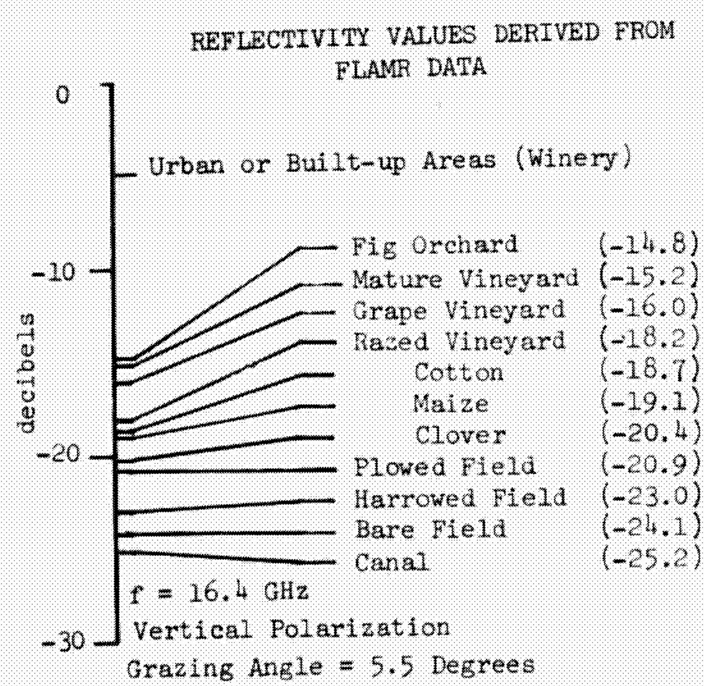

Figure 8. Typical Reflectivity Values