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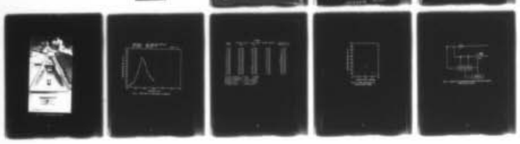

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High Sensitivity Chaff Measurement System

ARMONDO D. ELIA

Advanced Techniques Branch
Tactical Electronic Warfare Division

October 1977

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A system is described which measured the Radar Cross Section of very small chaff elements. The system consists of an anechoic chamber, transmit and receive circuitry with associated antennas, and a special circuit used to reduce system "noise." The system and measurement procedure is described and some typical measurements are shown. Alternate uses for the system are also described.

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CONTENTS

HIGH SENSITIVITY CHAFF MEASUREMENT SYSTEM

INTRODUCTION

Chaff is an indispensible electronic countermeasures technique employed for the protection of Navy aircraft and ships from the attack of enemy weapons. The chaff elements, usually foil or metal-coated fiber dipoles cut for specific frequencies, are packaged in containers that are deployed from a ship or aircraft under attack. The canister dispenses the chaff elements in such a way as to form a reflective cloud of sufficient radar cross-section to deceive the enemy weapon system into tracking the chaff cloud or to produce enough error in the guidance system so that the weapon misses the target.

The ever increasing number of enemy weapon systems at different frequencies within the RF spectrum as well as the large RF cross-sections that have to be protected dictate that a large number of chaff elements for many frequencies have to be packaged into each chaff canister. This requirement for a large number of elements means that the chaff has to be very thin and lightweight. The primary technology used in U.S. systems is chaff formed by placing a very thin layer of aluminum on a fiberglass substrate drawn to roughly .001 inch (.025mm). It has been observed that the quality of the coating and hence the performance of the chaff varies considerably from manufacturer to manufacturer. In addition research is continuing in the chaff industry to develop even finer glass fibers and to apply coatings other than aluminum. To evaluate these new glass elements as well as others of more unconventional shape NRL required a measurement facility which could quickly and inexpensively determine the properties of individual chaff elements. The development and use of such a system capable of direct measurement of the backscattering from extremely small RF reflectors is the subject of this report.

CHAFF MEASUREMENTS

A chaff measurement system was designed and built for the purpose of measuring the radar cross-section (RCS) of very small RF reflectors across I and J band. The system consists of an anechoic chamber, transmit and receive circuitry with associated antennas, and a special circuit which is used to reduce the effect of mutual coupling between transmit and receive antennas as well as signals that reflect into the receive antenna from within the test chamber. The design of the system is such that with simple modifications the measurement system can be extended in frequency.

Note: Manuscript submitted October 17, 1977.

ELECTRICAL SYSTEM

Figure 1 shows the circuit diagram of the chaff measurement system while Table 1 lists the equipment used. A CW signal is amplified by a 1 watt TWT and transmitted towards the target by the first antenna. After the other antenna receives the reflected signal it is transferred by a transmission line to the 3 dB hybrid. From the hybrid, the signal goes to the receiver for detection and processing. Before a chaff element is placed into the test chamber for measurement, the mutual coupling between antennas as well as the reflections into the receive antenna from within the test chamber are nulled at the hybrid for each frequency. Balancing the system is crucial in maintaining the high sensitivity of the measurement system as the mutual coupling and chamber backscatter may be as much as 40 dB greater than the target signal.

Nulling is accomplished simply and directly by amplitude and phase adjustment of a coupled portion of the transmitted signal to exactly cancel the unwanted power present in the signal line. The cancellation power and the unwanted signal are summed in a hybrid just before the RF receiver terminals. At each measurement frequency this procedure is repeated before the desired samples are run through the chamber.

The minimum RCS measurable with this system is determined by the effective radiated power (ERP), free space transmission loss, phase and amplitude stability of the balancing network, and the minimum detectable received signal. The ERP is a function of the transmitter power, antenna gain and transmission line loss. Typical parameters are 1 watt of transmitter power, 15 dB antenna gain, and 4 dB transmission line loss. The free space transmission loss is around 45 dB. The phase and amplitude stability of the balancing network depends upon how well this network phase and amplitude tracks in frequency with the main network after they are once matched with the variable phase shifter and attenuator. Their ability to track is affected by differential line lengths, dissimilar components, mutual coupling between antennas, and the distribution of surfaces within the chamber that reflect energy back into the receive antenna. Therefore, even though the transmission line lengths can be balanced between the two networks, the existence of the latter three frequency-dependent disturbances in our system requires a signal generator frequency stability of $\pm$ 10 kHz to maintain a background "noise" level of -70 dBm. A frequency change of $\pm$ 100 kHz increases the noise level to around -50 dBm. These frequency dependent parameters were empirically determined. The following calculation will give some indication as to what these values mean in terms of measurable cross-section. The power reflected and received from an arbitrary cross-section surface is given by

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

where for our case

P_r = received power, mw

P_t = transmitted power = 1 w (30 dBm)

G = antenna gain = 31.6 (15 dB)

λ = wavelength = 3.5 cm (i.e., frequency = 8.6 GHz)

σ = radar cross-section = 10.6 cm^2 ($0.87\lambda^2$ for a $\lambda/2$ dipole)

R = range to target = 91.5 cm

L = transmission line loss = 2.51 (4 dB)

Therefore,

$$P_r \text{ (dB)} = 30 + 30 + 20 \text{ Log } \lambda + 10 \text{ Log } \sigma - 30 \text{ Log } 4\pi - 40 \text{ Log } R - 4 \text{ dBm}$$

$$= -33.8 \text{ dBm}$$

Using a signal to noise ratio of 10 dB, this calculation implies that with a generator frequency stability of 10 KHz signals that are about 25 dB below the theoretical peak response of a chaff dipole cut to resonate at 8.6 GHz are measurable. A similar calculation can be made for reflectors of different RCS.

MECHANICAL SYSTEM

The anechoic chamber, shown in Figures 2 and 3, consists of a tapered metal enclosure lined with RF absorption material and housing two waveguide transmission lines with their associated antennas. A mechanical means for rotating the antenna polarization is provided. Because of the high angles of incidence that exist within the small chamber between the transmitted energy and the absorption material, absorption fences were judiciously placed within the chamber to minimize the amount of energy reflected back into the receive antenna. A mechanism for quickly placing the chaff elements into and removing them from the anechoic chamber was also designed and fabricated. Two narrow slots were cut in the chamber walls and the upper half of a continuous fiberglass belt passed through them. Two external pulleys, one with a handle, drive the belt, and an idler arm is used for adjusting the tension of the belt. The elements to be tested are mounted on small foam blocks, one end of which is secured in a plastic clip that is glued to the fiberglass belt. The chamber was deliberately tapered to allow more chaff elements to be placed on a given size belt. This type of construction permits the use of a modest length belt for processing 15-20 chaff elements. A normal run covering 7-10 GHz takes about two hours. If a large number of elements need not be tested at a given time, then a rectangular chamber would be more desirable since it would decrease the angle of incidence between the transmitted signal and the absorption material.

The construction of the supports for the chaff elements is a very critical part of the test set up. The supports are made from a low density foam, cut about 0.6 cm (0.25") thick so that they are not detectable by the measurement system even after the "noise" cancelling process. This permits a less critical alignment of the supports. Care must also be taken in mounting the chaff elements onto the foam supports. A variety of substances such as clear adhesive tape, thin coatings of wax, and the like were tried to fasten the chaff element to the foam; all seemed to affect the RCS vs frequency curves of the various chaff elements. The approach which finally proved to be satisfactory was to cut a thin pocket into the foam supports to hold the chaff element with no additional adhesives required.

MEASUREMENT PROCEDURE

The measurement procedure consists of first running a blank foam block into the test chamber and using the variable phase shifter and attenuator to minimize the interference caused by mutual coupling and reflections. Next, the items to be tested and a metal calibration sphere are manually moved, one at a time, into the measurement zone of the test chamber and the amplitude level of each of the reflections recorded. This procedure is repeated for each frequency. The true RCS of the calibration sphere can be readily computed[1]. Thus, with the calculated RCS of the calibration sphere and the measured difference in reflected energy between the sphere and test chaff element the RCS of that element can be accurately determined.

Figure 4 and Table II depict the measured RCS of a typical chaff dipole, 1.68 cm (0.66 in.) in length and 0.025mm (0.001 in.) in diameter, measured from 7.2 to 10.0 GHz. The curve, plotted with the aid of an Hewlett-Packard model 9830A desk calculator and a 9862A plotter, shows that the frequency at which the maximum return occurs for this piece of chaff is 8.6 GHz, and the 3 dB bandwidth is approximately 1 GHz. This particular RCS profile was measured with the antennas horizontally polarized and the chaff elements aligned at a zero degree rotation angle, but testing is not constrained to these conditions since polarization or rotation angle can be set up with this system. Figure 5 shows the response of a chaff element as a function of rotation angle at 8.6 GHz. With these techniques a reflecting object can be fully described as to polarization or rotation angle.

CONCLUSIONS

In conclusion, a very sensitive system has been designed and constructed for the purpose of measuring the RCS of very small chaff elements. This system has aided in the quantitative analysis of various chaff element designs. Even though the measurements are made on a single frequency basis, many chaff elements can be evaluated quickly using the pulley mechanism designed into the system. Although such an arrangement was sufficient for this effort, other configurations of this system can be envisioned.

The chaff measurement system could be used as an aid in statistically determining the effective RCS of a chaff cloud. Since the element can be set to any desired angular orientation with respect to the transmitter, measurements can be made at a number of orientations, and this information could be used in a statistical model for a free falling chaff cloud.

The system can also be used, with slight modifications, to measure the absorptive characteristics of a material. One of the antennas would have to be moved to the other end of the chamber so that the two antennas are in line, with the sample to be measured in between.

Finally, for large volume testing, automatic frequency stepping and data collection could be designed into this system. One method for implementing this is shown in Figure 6. The microprocessor is used to set the frequency of the signal generator, control the digital phase shifter and attenuator for setting the calibration null, and for instructing the receiver when to take a measurement. The microprocessor senses the coupled voltage from the hybrid and systematically changes the phase shifter and attenuator to reduce the voltage to a predetermined threshold during the initial calibration at a given frequency. After the measurement is taken, the frequency is changed and the measurement process is repeated.

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The author is grateful to Dr. Gerald Friedman and Mr. Richard Gurney for a thorough technical review of the report and to Mr. Hollis Vaughan of Locus, Inc. who, under NRL contract N00173-77-D-0004 has made numerous measurements with the system, including those published here.

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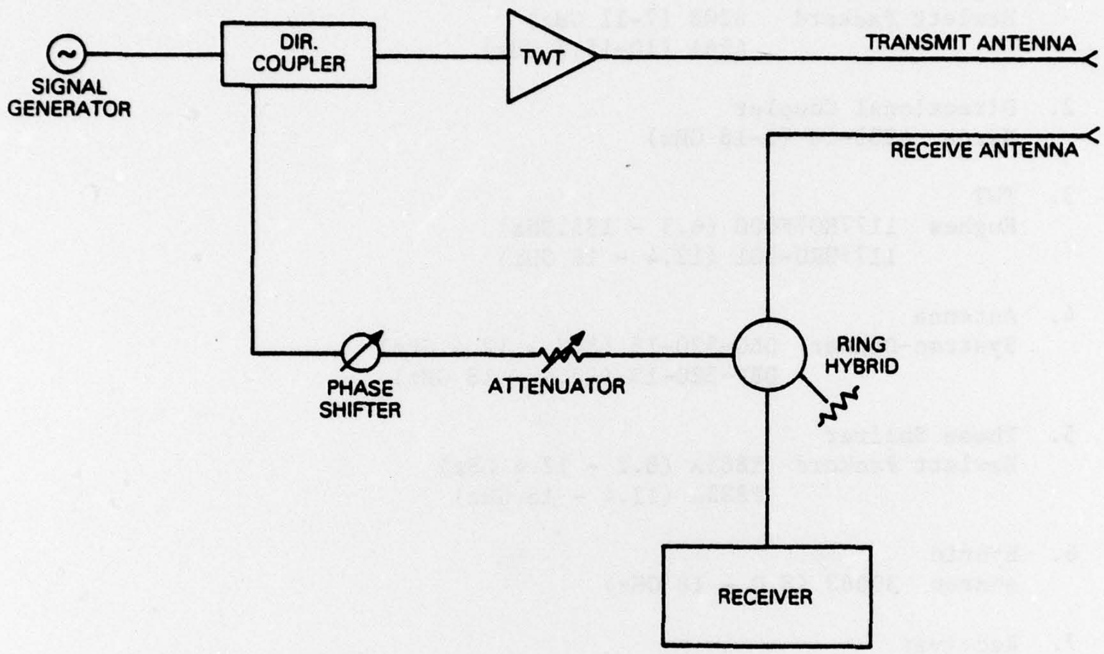

Fig. 1 — Schematic diagram cw chaff measurement system

TABLE 1

1. Signal Generator
   Hewlett Packard 620B (7-11 GHz)
   626A (10-15.5 GHz)

2. Directional Coupler
   Narda 4203-10 (2-18 GHz)

3. TWT
   Hughes 1177H07F000 (6.5 - 135.GHz)
   1177HKU-001 (12.4 - 18 GHz)

4. Antenna
   Systron-Donner DBG-520-15 (8.2 - 12.4 GHz)
   DBF-520-15 (12.4 - 18 GHz)

5. Phase Shifter
   Hewlett Packard X885A (8.2 - 12.4 GHz)
   P885A (12.4 - 18 GHz)

6. Hybrid
   Anaren 30060 (8.0 - 18 GHz)

7. Receiver
   Scientific-Atlanta 1741 w/ 1830 Log/Lin Display

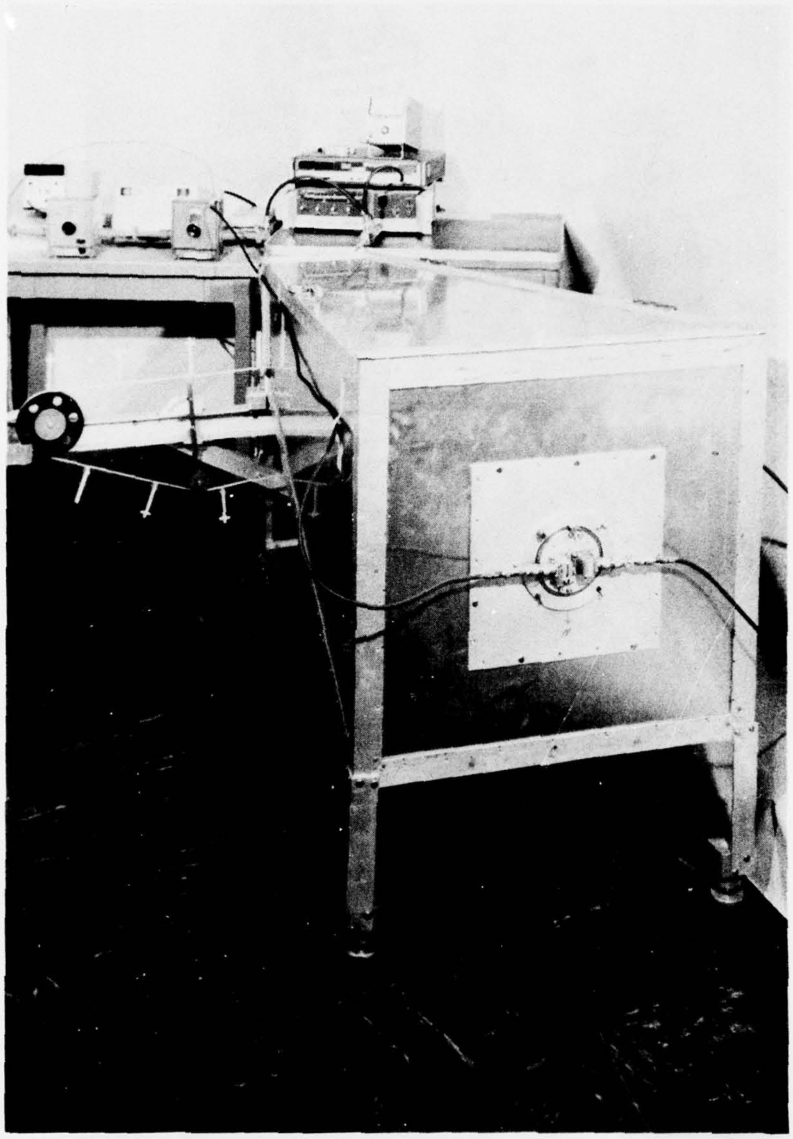

Fig. 2 — Chaff measurement system

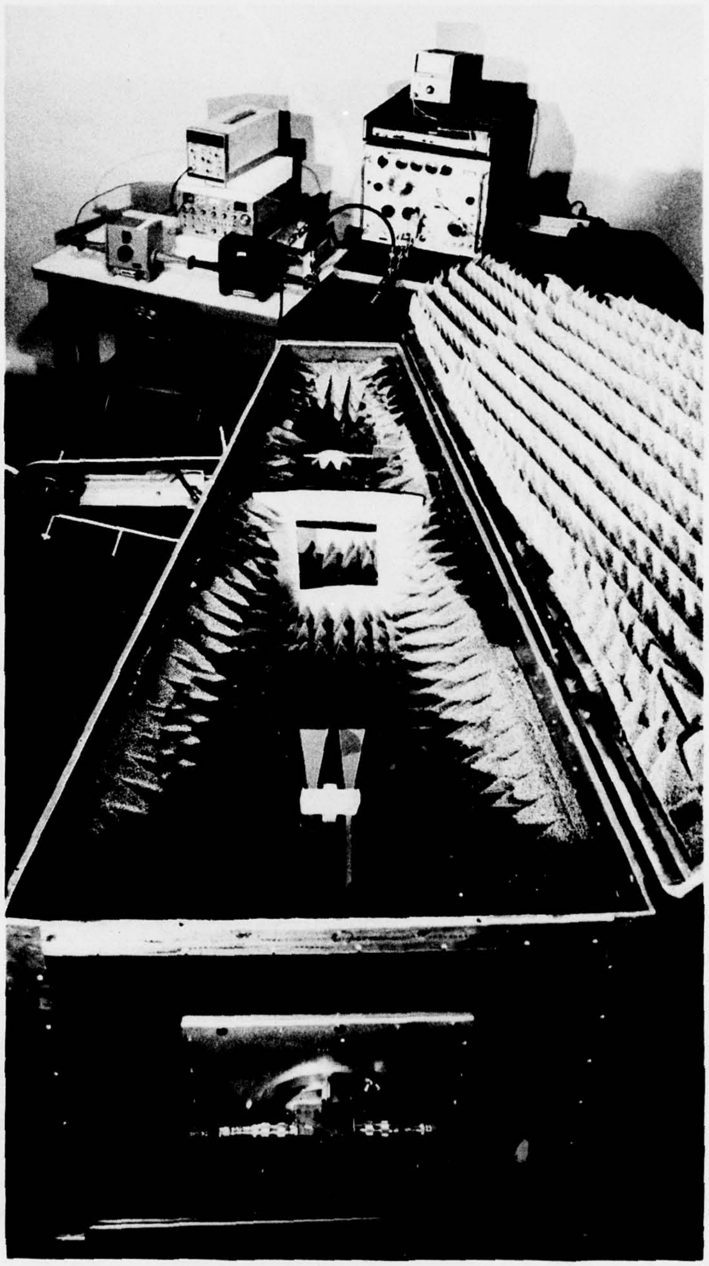

Fig. 3 — Chaff measurement system

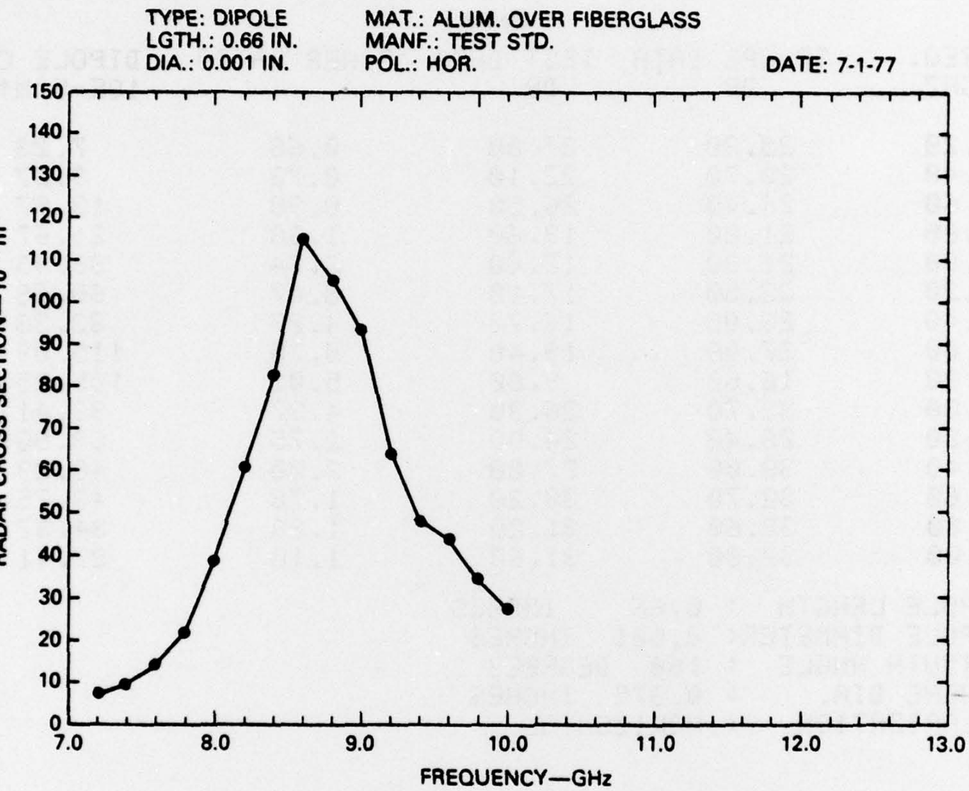

Fig. 4 — RCS (0.66 in. chaff dipole) vs frequency

Table 2

FREQ. GHZ	SPHERE DATA DB	TEST DATA DB	POWER RATIO	DIPOLE C.S. 10E-5(M↑2)
7.20	25.30	27.00	0.68	7.23
7.40	20.70	22.10	0.72	9.27
7.60	26.40	26.50	0.98	13.97
7.80	21.00	19.60	1.38	21.67
8.00	21.30	17.60	2.34	38.45
8.20	22.50	17.10	3.47	60.68
8.40	23.00	16.70	4.27	82.33
8.60	27.00	19.40	5.75	115.09
8.80	16.60	9.60	5.01	105.25
9.00	32.70	26.30	4.37	93.41
9.20	28.40	24.00	2.75	63.90
9.40	30.00	27.00	2.00	48.29
9.60	32.70	30.20	1.78	43.75
9.80	32.60	31.20	1.38	34.37
10.00	32.00	31.60	1.10	27.41

DIPOLE LENGTH : 0.66 INCHES
DIPOLE DIAMETER: 0.001 INCHES
AZIMUTH ANGLE : 160 DEGREES
SPHERE DIA. : 0.375 INCHES
POLARIZATION : HORIZONTAL

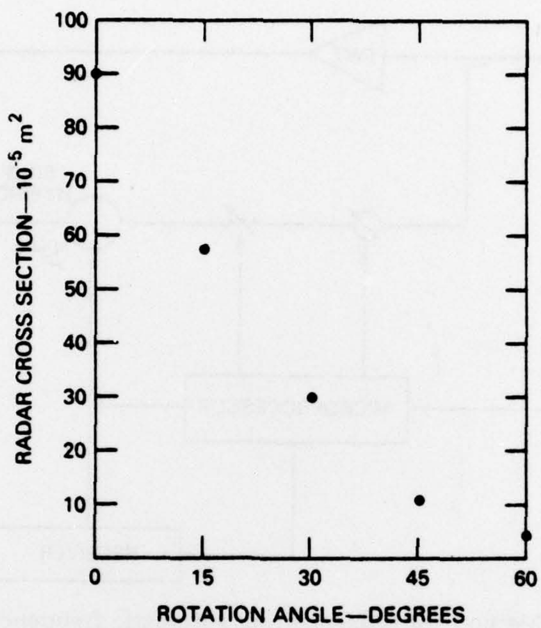

Fig. 5 — RCS vs frequency for various rotation angles

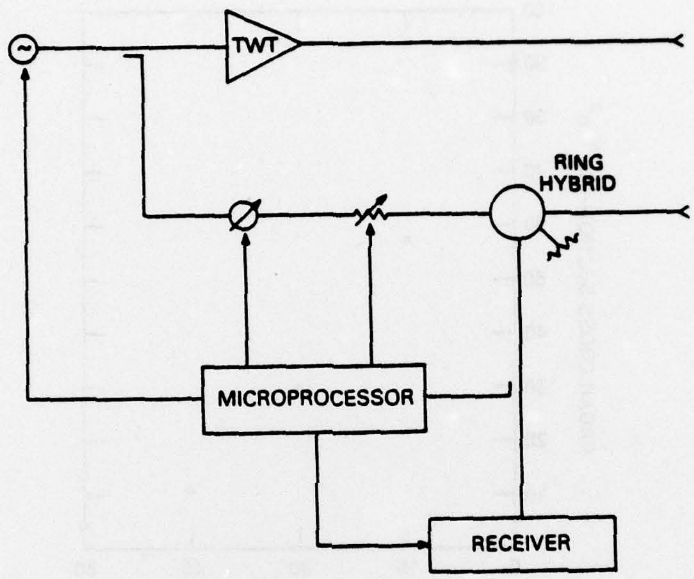

Fig. 6 — Method for implementing automatic frequency stepping data collection system