RADSCAN
A NOVEL CONICALLY SCANNING TRACKING FEED

Arthur Sullivan
Electro Magnetic Processes, Inc.
9616 Owensmouth Ave.
Chatsworth, CA 91311

ABSTRACT

This paper presents a description of RADSCAN, a novel conically scanning tracking feed which has only one moving part and utilizes a solid state optical commutator for reference. The feed operates continuously from 1435 to 2400 MHz thereby covering all the existing telemetry bonds in addition to the proposed new bond from 2300 to 2400 MHz. The performance of RADSCAN is compared to that obtainable with the single-channel monopulse technique.

INTRODUCTION

One of the first tracking systems developed was the SCR-584 Radar. This system was developed during the beginning of 1942 and used a conically scanning technique. Polarization was rotated with scan frequency causing an undesirable modulation at the second harmonic of the scan frequency.

By 1943 nutating Systems were developed to eliminate the second harmonic modulation problem. These nutating systems were mechanical monsters and reliability was very poor.

By 1955 conical scanners were developed using circular waveguide to maintain polarization while scanning and used hollow shaft motors to increase reliability. Reliability problems were still encountered with the rotary joint.

Because of reliability three (3) channel monopulse systems were developed in the early 1950’s. While these systems were highly reliable they were very expensive since three (3) receivers were required. In the early 1960’s techniques were developed to time share the difference channels and two (2) channel monopulse systems were produced. While reliability was high, cost was considerably higher than for a conscan system.

In 1968 single-channel monopulse systems were developed which sequentially sampled the difference channels and added the difference channel information to the sum channel. While reliability was considerably higher with single-channel monopulse than with conventional conscan, system performance was degraded.

RADSCAN

EMP has developed a unique conically scanned feed called RADSCAN which has but one moving part and no rotary joint. A drawing of the RADSCAN feed is shown in Figure 1. A pair of stationary orthogonal printed circuit dipoles are used to excite the TE_{11} mode in the rotating circular waveguide, which has its axis displaced from the boresight axis. The displacement of the phase center of the circular waveguide from the boresight axis causes the conical scanning. The one moving part is driven by a hollow shaft brushless two phase motor thereby eliminating power transmission devices such as gears or drive belts. The conventional heavy reference generator required for position reference is replaced by an all solid state optical commutator consisting of a pair of LEDs and photo transistors. The LEDs illuminate a rotating disc, half of which is chrome plated and highly reflective, and the other half black anodized and highly absorbent. The output of the photo transistors is a square wave. The dual chips are in space quadrature so the two square waves are in phase quadrature.

Because of the optimum illumination toper and minimum aperture blocking of RADSCAN, secondary patterns with side lobes of 25 dB nominal are obtained over L and S bands for reflectors with diameters of 8 feet or greater. Figure 2 is a typical pattern of RADSCAN in a 12 foot diameter reflector.

SING LE-CHANNEL MONOPULSE

Single-channel monopulse is a technique for deriving a modulated output similar to that obtained from a conically scanning antenna. The single-channel monopulse technique utilizes a three-channel monopulse antenna feed and a device called a scan converter. A simplified diagram of a scan converter is shown in Figure 3. The azimuth and elevation error channels are sampled sequentially. Each one is phase shifted between 0 and 180° in accordance with the timing diagram shown and added to the sum channel through a coupler. The result is a sum channel carrier modulated with the error information.

Single-channel monopulse has become very popular in the last few years. Most of the arguments for its use are based on reliability since there are no moving parts. The major drawbacks of single-channel monopulse are: degraded low angle tracking caused by high <u>effective</u> sidelobes and an inherently high level of crosstalk. A three-channel monopulse feed can be designed with low sidelobes in both the sum and difference channels.

However, in a single-channel monopulse system these sidelobes are not the controlling factor in low angle multipath problems. The tracking receiver is looking at the output of the scan converter and it sees the effective sidelobes of the vectorially combined sum and difference patterns. It is these effective sidelobes that degrade the low angle tracking performance.

Most single-channel monopulse systems use a 12 dB coupler in the scan converter. Less coupling would decrease the on-axis gain reduction; however it would also decrease the sum channel modulation and therefore degrade tracking performance similar to the effect of using a lower crossover level on a conically scanning antenna. A detailed analysis indicates that the loss of on-axis gain and tracking sensitivity are approximately equivalent for single-channel monopulse and con-scanned antennas.

Based on the use of a 12 dB coupler, Figure 4 and 5 show the sum and difference patterns of a monopulse antenna and the pattern resulting from their vector addition. The lowest effective sidelobe level obtainable is on the order of 15 dB. 15 dB sidelobe levels cause severe low angle multipath problems.

It is not possible to achieve low levels of crosstalk in the single-channel monopulse system because of mutual coupling and parasitic effects between the elements. Crosstalk is usually limited to about 15 dB at best compared to crosstalk levels of 30 - 35 dB in con-scan systems.

COMPARISON OF RADSCAN AND SING LE-CHANNEL MONOPULSE

Reliability

Figure 6 and 7 are reliability models of the RADSCAN feed and a printed circuit single-channel monopulse feed for a polarization diversity configuration. Table 1 is a reliability comparison of the RADSCAN feed versus single-channel monopulse. The results indicate that the RADSCAN feed increases reliability by a factor of 4.5 over single-channel monopulse. While it hardly seems possible that a device containing all reliable elements and no moving parts would be much less reliable than a device with a rotating mechanism the results are achieved by the simplicity of the rotating device. Although all components of the single-channel monopulse feed are reliable by themselves the number of components required exceeds the number of components of the RADSCAN system by Greater Than An Order Of Magnitude. Antenna elements alone are increased by a factor of five. Diodes are reliable devices; however, a minimum of twelve are required for single-channel monopulse and none is required for RADSCAN. Solder connections which are indeed a source of failure are an important factor in reliability. Single-channel monopulse in its reliable form, i.e. all stripline construction, consists of 86 soldered connections.

RADSCAN uses six (6) soldered connections. RF connectors which are another source of operational failure are also considerably reduced by the RADSCAN system, in fact by a factor of six (6).

Low Angle Tracking

Low angle tracking is considerably enhanced because of the low sidelobes of the RADSCAN system compared to a single-channel monopulse system. The sidelobe levels in a RADSCAN system are nominally 25 dB as compared to 15 dB in a single-channel monopulse system. Because of the severe multipath problem with single-channel monopulse, loss of track can occur since the apparent phase center of the target moves above and below the target, and in certain dynamic conditions, the phase center movement is faster than the acceleration capability of the tracking pedestal. Loss of track because of multipath has never been experienced on a RADSCAN system.

Beam Crossover Variation with Frequency

The variation in crossover with frequency of RADSCAN is comparable with the variation of crossover level of single-channel monopulse -- except that an inverse relationship exists between the two systems: the crossover level of RADSCAN varies in direct proportion to frequency (deepens), whereas the crossover level of single-channel monopulse varies inversely with frequency (crossover depth becomes shallower with increasing frequency). The effect of increasing crossover depth with increasing frequency, when the antenna beam narrows, is to provide a constant acquisition angle over the frequency band. Single-channel monopulse, because of its inverse relationship, does exactly the opposite -- resulting in the highly undesirable characteristic of a decreasing acquisition angle with increasing frequency.

Crosstalk

The crosstalk of a RADSCAN system is improved from that of single-channel monopulse by approximately 20 dB.

Error Modulation

If a perfect phase relationship were maintained throughout the single-channel monopulse antenna and scan converter between the sum and difference channels, the error modulation of single-channel monopulse would be almost identical to that of a RADSCAN system for identical crossover levels. It is not possible to maintain a perfect phase relationship in single-channel monopulse since non-linear phase changes occur in the hybrids, diode switches and the coupler. The phase error is usually in the order of 25° for telemetry band applications. This phase error induces phase quadrature effects which reduce the error modulation.

Boresight Shift with Frequency

Boresight shift with frequency in the RADSCAN system is minimal. The only cause of boresight shift in a conically scanning system is a change in gain of the beam with position of the beam which can be caused by surface tolerance errors of the reflector. It is easy to maintain adequate surface tolerances so this effect is negligible. Improper surface tolerance of the reflector will cause the same boresight shift with a single-channel monopulse system. However, other factors such as phase errors and amplitude errors in the comparator network also induce boresight shift in single-channel monopulse systems.

Axial Ratio

The axial ratio of single-channel monopulse would be comparable to that of RADSCAN except for the mutual coupling and parasitic effects of the multiple elements. These effects cause a degradation in achievable axial ratio.

Cost

The cost of a RADSCAN feed is about one-half the cost of a single-channel monopulse feed because of simplicity of design.

CONCLUSION

RADSCAN, because of its simplicity, is a low cost and highly reliable telemetry tracking feed that outperforms single-channel monopulse in all respects. Although single-channel monopulse feeds provide semi-acceptable performance over a narrow band of frequencies, performance is definitely compromised when this type of feed is broad-banded to attempt to cover (say) 1435 to 2400 MHz, because of mutual coupling and parasitic effects. Covering this bandwidth with RADSCAN presents no such problem.

Because of increased performance, lower cost and higher reliability, RADSCAN feeds are being purchased to replace single-channel monopulse on many telemetry ranges. One of the first RADSCAN feeds was delivered to Naval Air Station at Patuxent River, Maryland approximately ten (10) years ago. This tracking system is used for approximately 100 flights per month with the scanner being turned on for at least 100 hours per month. This RADSCAN feed has therefore logged over 12,000 hours in a ten (10) year period without a failure. Because of the success of this feed four (4) single-channel monopulse feeds were replaced by RADSCAN at Patuxent River. The most reliable tracking systems on the Navy

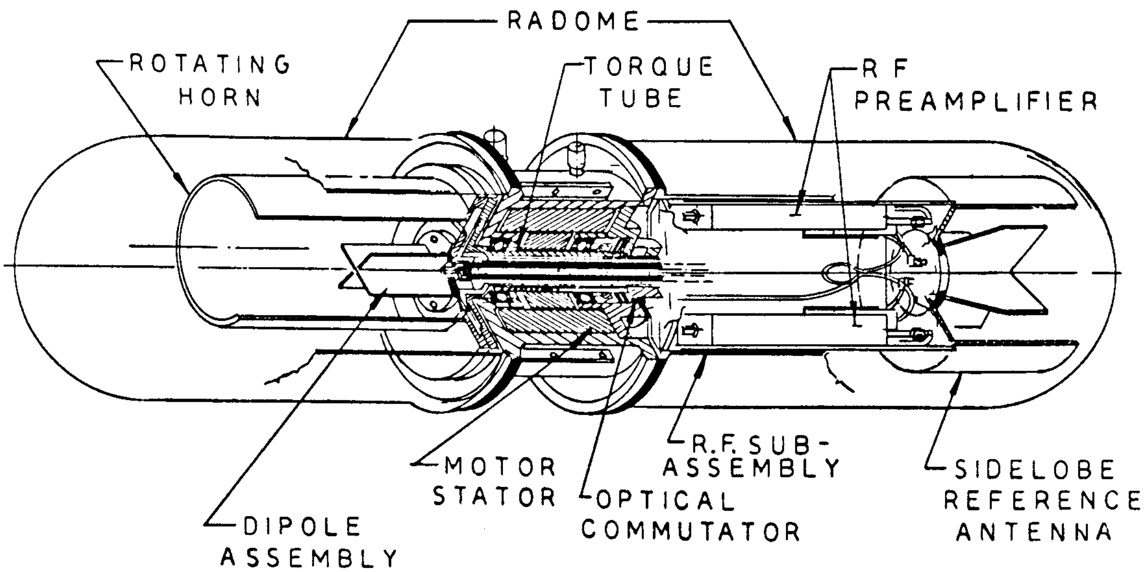
Telemetry Range at Roosevelt Road, Puerto Rico, use the RADSCAN feed. Currently under procurement is a RADSCAN feed that will be used to replace existing feeds on the Navy Telemetry Range on the Island of Crete. The Naval Weapons Center at China Lake, California has recently purchased a RADSCAN feed for evaluation to replace their single-channel monopulse feeds.

	Dual Axis Single Channel Monopulse			RADSCAN			
Component	n	λ	n λ	n	λ	n λ	Reference
RF Pin Diode	12	0.70	8.400	-	-	-	Hewlett Packard
RF Choke	8	0.210	1.680	-	-	-	MIL-HDBK-217A
Bypass Cap	4	0.005	0.020	-	-	-	MIL-HDBK-217A
RF Load	10	0.0035	0.035	-	-	-	MIL-HDBK-217A
Dipole Element PC Boards	10	0.0001	0.001	2	0.0001	0.0002	Estimate
Hybrid PC Board	2	0.0001	0.0002	1	0.0001	0.0001	Estimate
Coupler & Converter PCB	2	0.005	0.010	-	-	-	MIL-HDBK-217B
Solder Connection	86	0.0057	0.490	6	0.0057	0.034	MIL-HDBK-217A
RF Connector Pairs	24	0.648	15.555	4	0.648	2.592	MIL-HDBK-217B
Drive Motor Winding	-	-	-	1	0.092	0.092	MIL-HDBK-217B
Drive Motor Mechanical	-	-	-	1	0.45	0.45	MIL-HDBK-217B
Capacitor (Start/Run)	-	-	-	1	0.016	0.016	MIL-HDBK-217B
Optical Comm PC Board	-	-	-	1	0.005	4.514	MIL-HDBK-217B
SUB TOTAL			26.191			7.698	
Scan Gen & Driver PC Board	1	8.50	8.50	-	-	-	MIL-HDBK-217B
			34.691			7.698	

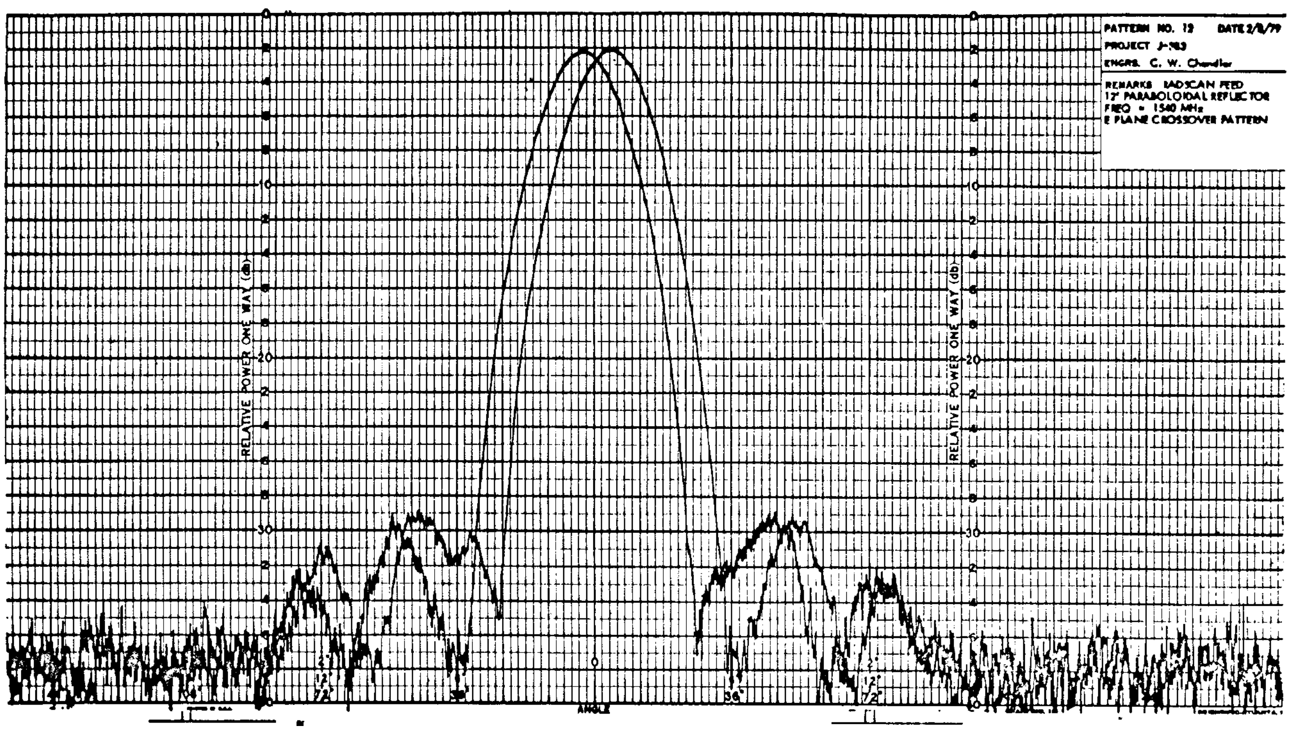
n = Number of Elements/Assembly

λ = Failures/10^6 Hours

TABLE 1



RADSCAN FEED
FIGURE 1



TYPICAL RADSCAN ANTENNA PATTERNS
FIGURE 2

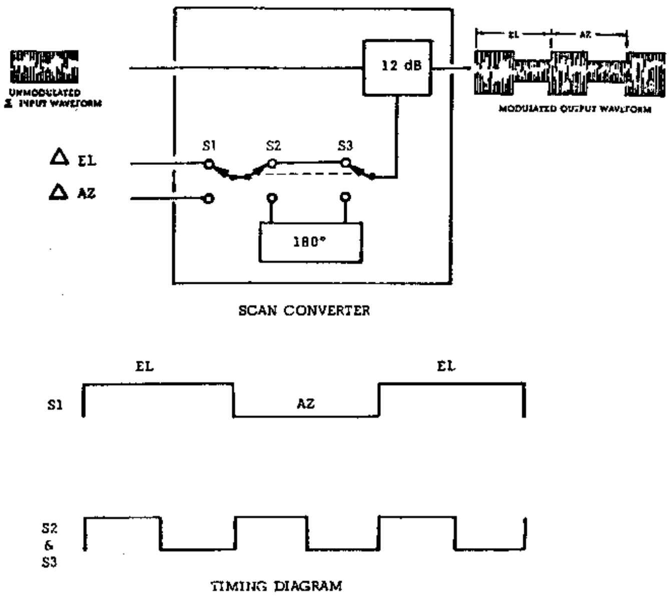
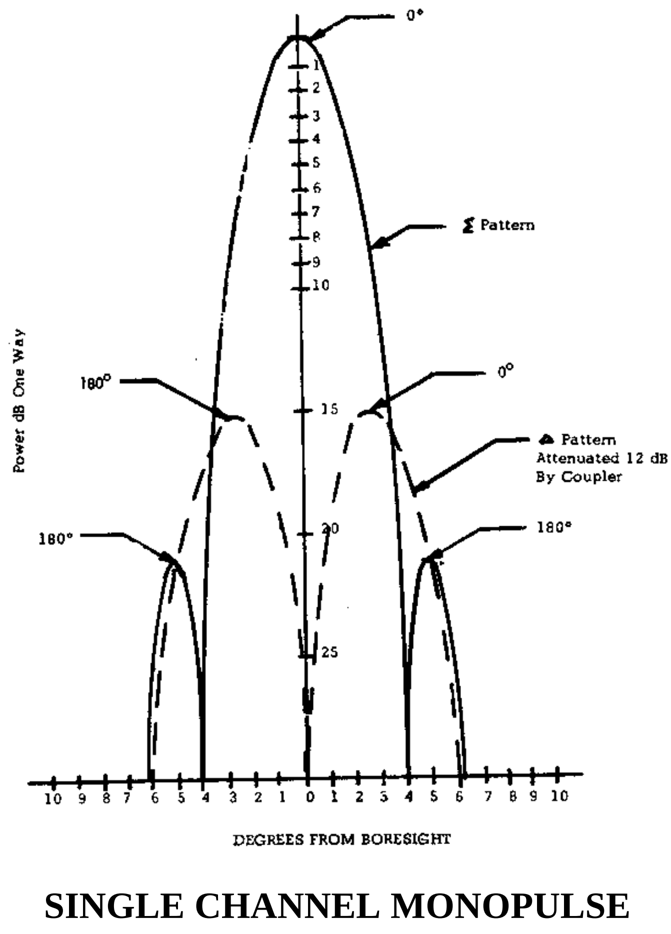
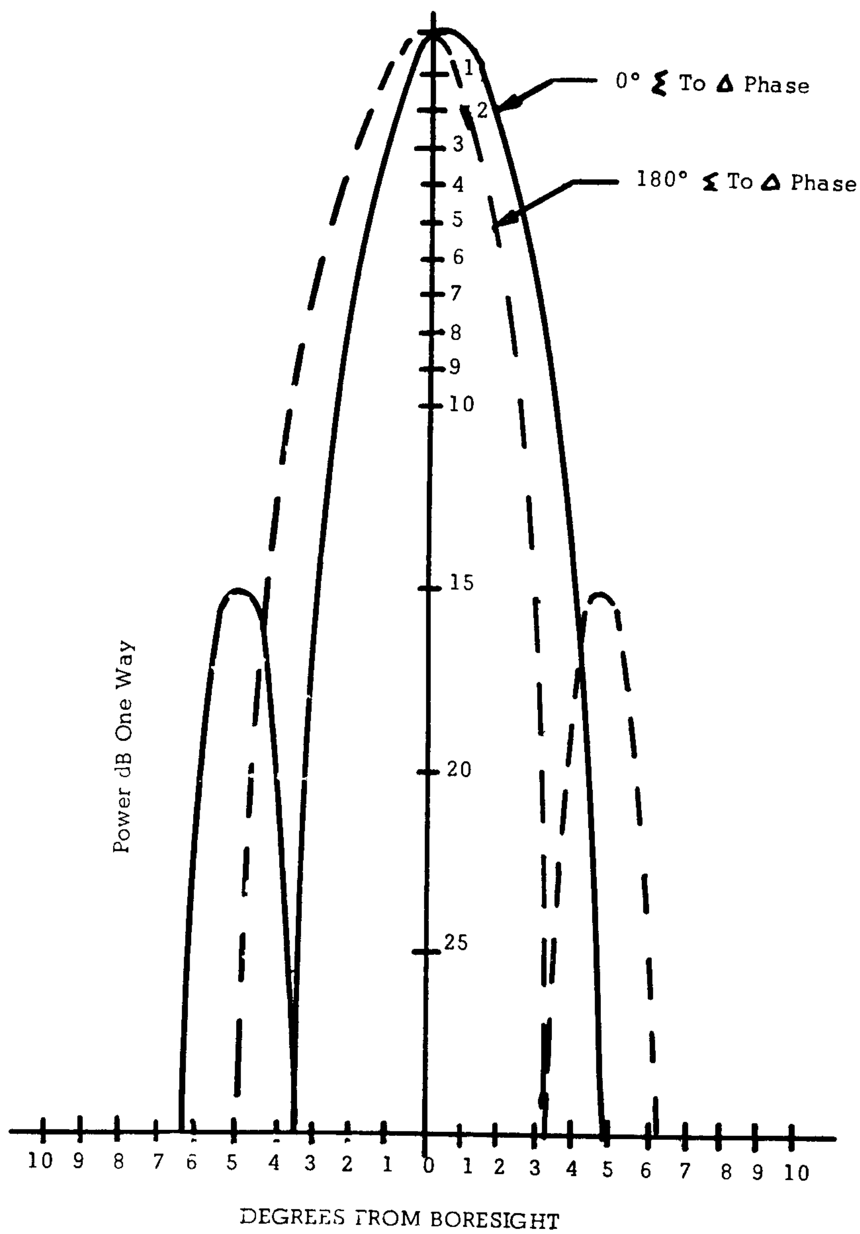


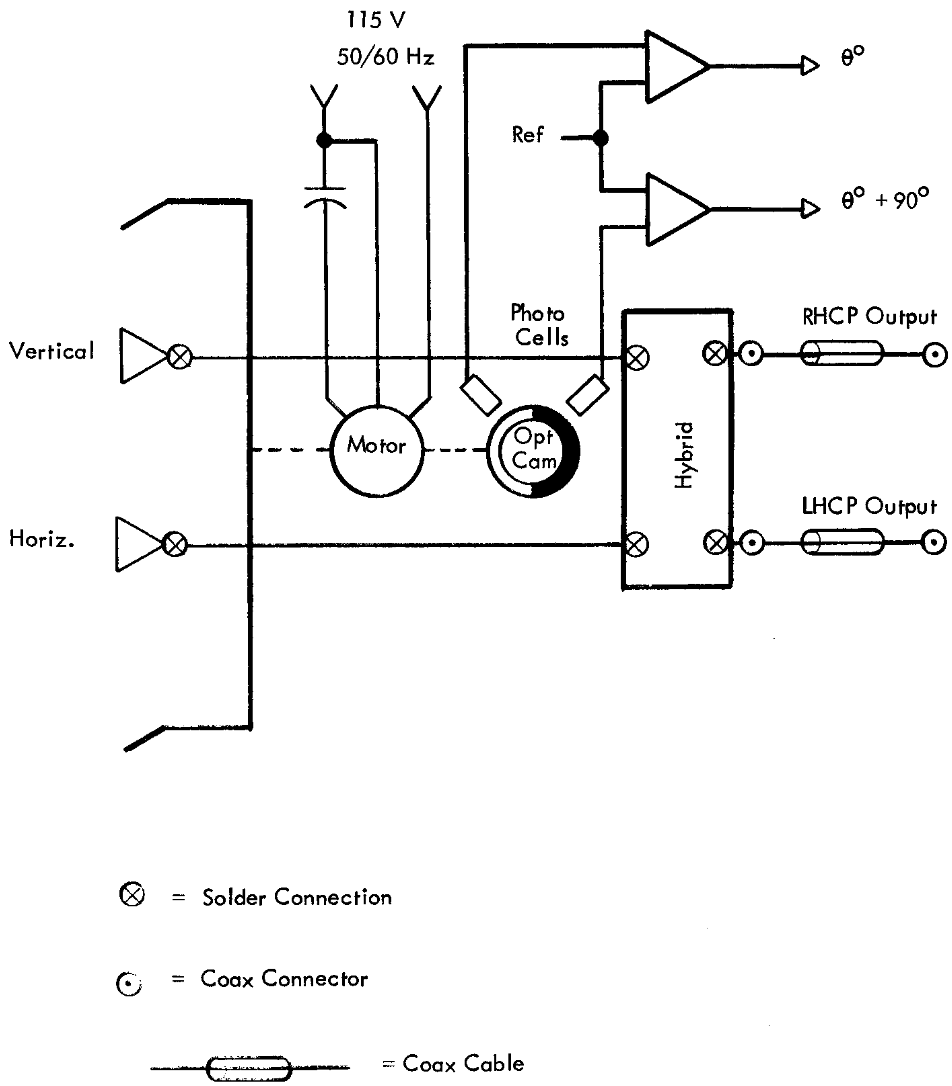
FIG. 3
SCAN CONVERTER



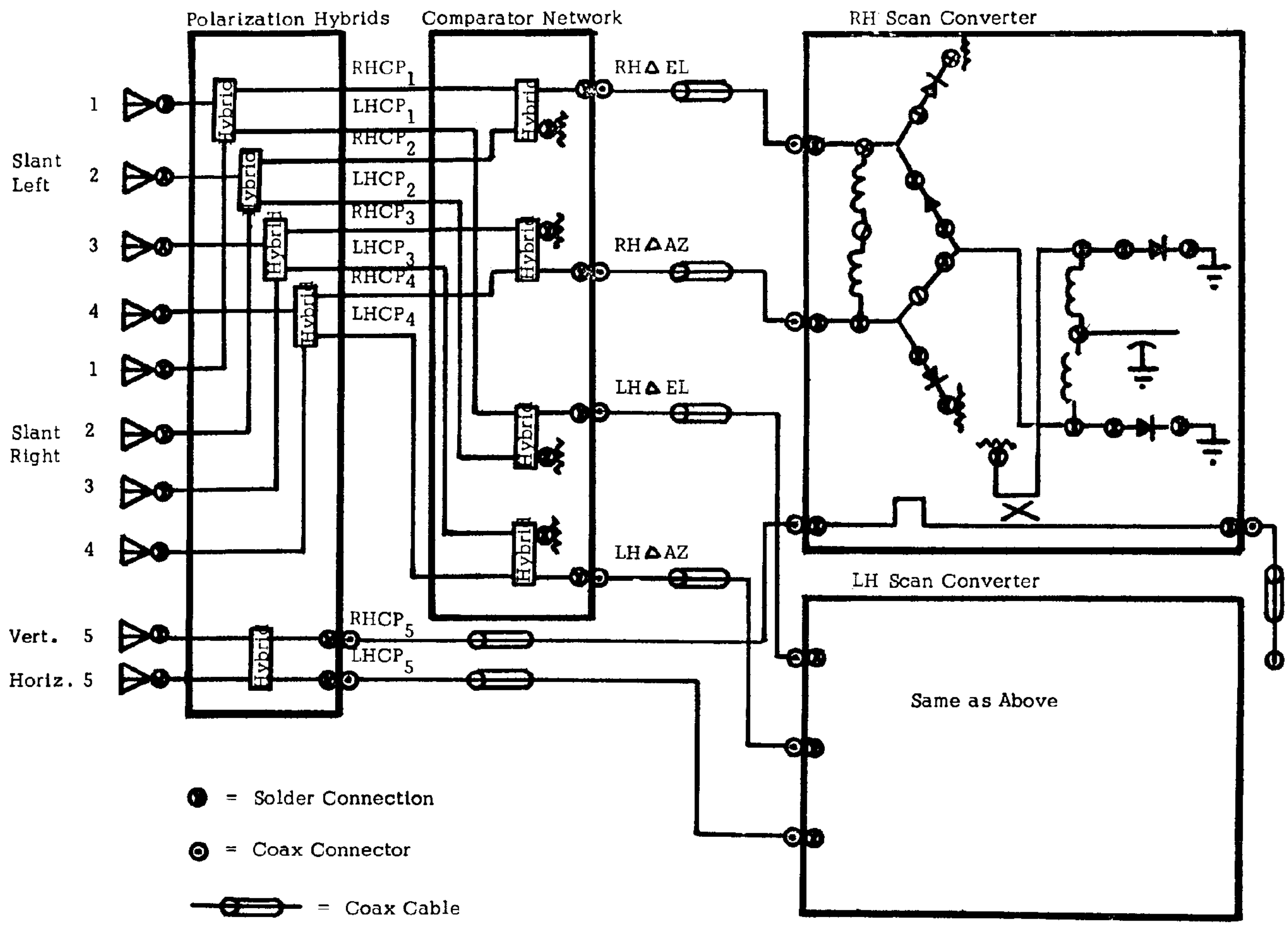
SINGLE CHANNEL MONOPULSE
SUM AND DIFFERENCE PATTERNS
FIGURE 4



SINGLE CHANNEL MONOPULSE CROSSOVER PATTERNS
FIGURE 5



RADSCAN ANTENNA MODEL
FIGURE 6



SINGLE CHANNEL ANTENNA MODEL
FIGURE 7