Accuracy Study For A Moderate Production Quantity Of Reciprocal Ferrite Phase Shifters

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Abstract

A moderate quantity of X-band dual-mode reciprocal, latching ferrite phase shifters has been built and tested in a computer-controlled station. Ensemble phase shift distributions and statistics have been investigated using stored test data. Variation with frequency is small over the design band, and the phase-state dependent data show the effects of curve-fitting computed during testing.

I. Introduction

Latching reciprocal ferrite phase shifters of the "dual-mode" type were first employed in the RARF two-axis scanning phased array antenna more than ten years ago. The unit produced for this initial application was described in the literature in 1968 [1], and subsequently stimulated further development and application of the technique. Although workers in the U.S. and elsewhere have since incorporated dual-mode ferrite phase shifters into a number of other antenna systems, virtually no statistics have been published concerning performance of a quantity of units. A noteworthy exception is the paper presented to this symposium by Lindauer [2] in 1978, reviewing reliability evaluation of units used in the original RARF antenna. The material presented here is intended to provide limited additional statistics on phase accuracy for a moderate quantity of dual-mode units of more recent design than the RARF type. These phase shifters were designed and built for the USAF/Westinghouse Electronically Agile Radar (EAR) airborne phased array antenna.

II. Phase Shifter Configuration

The phase shifter configuration, shown in Figure 1, differs from the usual dual-mode arrangement in several important aspects. Impedance matching at the feed end of the unit is via a ceramic plug that projects into the driving waveguide, but at the antenna end a transformer couples directly to a radiating surface. That is, the phase shifter units provide the radiating elements of the antenna aperture.

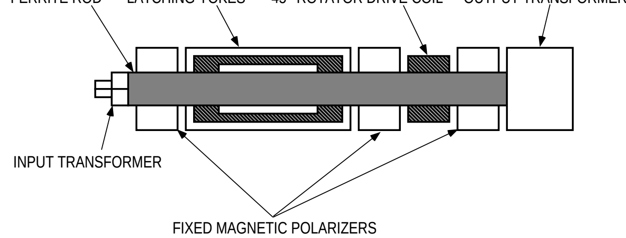

Fig. 1: Phase shifter configuration

Another feature is the addition of a means for changing polarization of transmitted and received energy from linear to circular. This is accomplished by cascading a short Faraday rotation section and a third magnetic quarter-wave plate between the dual-mode phase shifter section and the antenna radiating element. The principal axes of this third quarter-wave plate are aligned at 45 degrees mechanically relative to those of the dual-mode phase shifter. When the Faraday rotator is set for zero rotation, energy passes between the phase shifter and the radiator in alignment with one of the principal axes of the magnetic quarter-wave plate. In this case the sense of polarization is not altered, but remains linear. With excitation of the Faraday rotator to 45 degrees rotation, the waves going from phase shifter to radiator experience conversion from linear to circular polarization in the third magnetic quarter-wave plate. Because the Faraday rotator and the magnetic quarter-wave plate both exhibit antireciprocal behavior, the combined effect permits the unit to receive the same sense of circular polarization as will be transmitted.

A photograph of an EAR phase shifter produced by Microwave Applications Group (MAG) is shown in Figure 2. The diameter of the unit is 0.520 inch (13.2 mm), and its overall length is approximately 3.580 inches (91 mm), including transformers. Weight was about 1.1 ounces (31 grams), consistent with the projected use in an airborne phased-array antenna application. A lithium-titanium ferrite was used, with the design balanced for a compromise between insertion loss and weight, using previously published information [3].

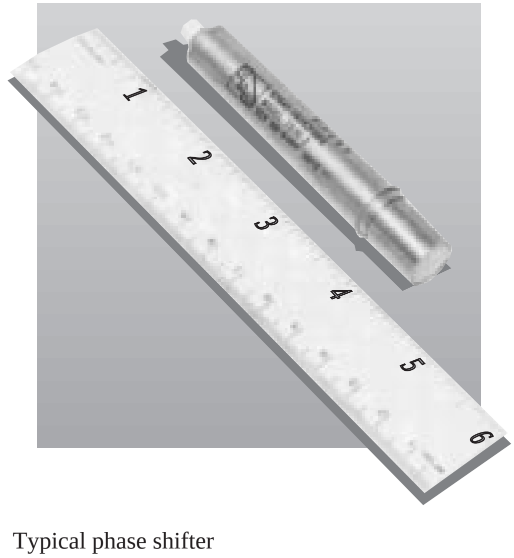

Fig. 2: Typical phase shifter

III. Production Test Approach

More than 6,000 units were built and tested to ensure delivery of the required quantity of 4,400 phase shifter assemblies. Special attention was given to the problem of testing in order to facilitate rapid performance of test routines plus long term storage and retrieval of test data for future analysis. These test arrangement evolved around a computer-controlled setup using a Hewlett-Packard 8410A Network Analyzer as the measurement device. A block diagram of the test system is shown in Fig. 3.

position with waveguide openings of the bridge by indexing the turret. Serial number and temperature readout, as well as driver commands, were coupled by means of spring-loaded contacts to the cartridge of the unit under test. After undergoing an initial linear regression routine to determine zero phase reference and optimum driver scale factor, each unit was tested at eight phase–locked frequencies for a total of 1152 data points in phase shift, insertion loss, return loss, and cross-polarization rejection, in a mixture of linear and circular polarization modes. Individual data points were stored in files coded by serial number on disk cartridges, and unit statistics were computed and printed on data sheets produced by a line printer. The test and print routines were stored as separate programs in different CPU memory partitions, with the print routine serviced on a lower priority basis during pauses programmed in the test routine to allow for equipment settling times. In practice, the two programs appeared to run simultaneously, with the data sheet for a unit being printed while the next unit was already being tested. Total test time per unit was less than 2-1/2 minutes. A sample data sheet is shown in Fig. 4.

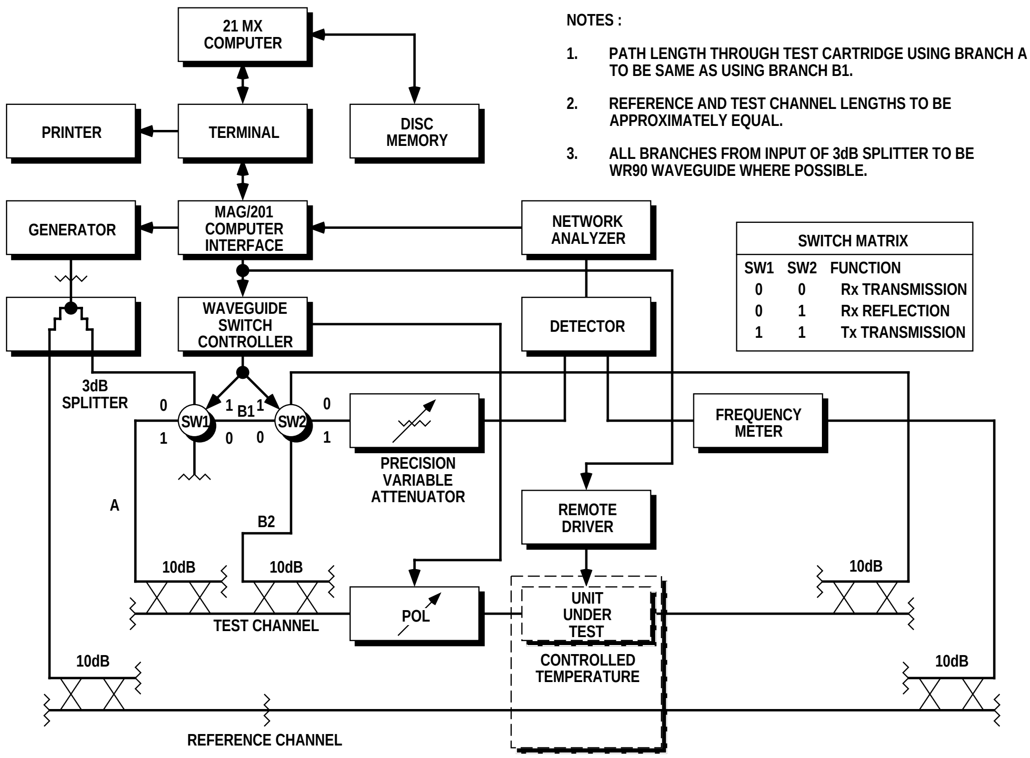

Fig. 2: EAR phaser test station

Program control was provided by Hewlett-Packard 21MX minicomputer equipped with 64K words of memory and operating under the manufacturer's RTE-III multitasking software. Communication with the test apparatus was by means of a multiplexing interface specially developed at MAG for use in the test setup. A temperature-controlled chamber was also built, with a motor-driven turret having removable cartridges into which units to be tested were inserted. The turret motor, waveguide switches, phase shifter driver and rf generator frequency were all under control of the computer test program. After initial calibration, the operator's function was only to monitor system behavior, load and unload units from the test chamber, and collate data sheets.

The computer program provided for initial calibration by means of reference amplitude, reflection and transmission phase cartridges that were recognizable by serial number (unit serial numbers were provided to the computer by setting thumbwheel switches on the test cartridges). Each cartridge was sequentially moved into

IV. Phase Accuracy Statistics

Data storage over the production run was accumulated on a series of 7 data disks, each disk accommodating a maximum of 960 units. A detailed study of phase shift accuracy was carried out for each of the data disks. First, a compilation of the deviation of the ensemble average phase shift from the nominal value was computed for each of sixteen phase states at eight test frequencies, in the receive direction. A tabulation of the rms variation of

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ACCEPTANCE TEST DATA

X-BAND PHASE SHIFTER

MAG MODEL NO. 75191-2

WESTINGHOUSE PART NO. 583R210

UNIT SERIAL NUMBER MA110

TEST DATE 8/18/77 START TIME 9: 1:21 OPERATOR K B ALM

TEST PARAMETER	DEMERIT PTS	PERFORMANCE AT INDICATED MEGAHERTZ ABOVE F1 37	112	187	262	337	412	487	562
RMS PHASE ERROR DEG. RECEIVE DIRECTION	0	2.84	4.08	1.96	1.83	2.10	2.16	2.36	4.63
RMS PHASE ERROR DEG. TRANS DIRECTION	0	2.93	3.11	3.23	2.77	2.17	3.36	2.13	2.51
MEAN TRANS COEFF DB. LINEAR MODE	0	.85	.76	.77	.86	.92	.95	1.16	1.08
RMS TRANS MOD PCT LINEAR MODE	0	.57	1.07	.83	.86	.74	1.23	1.22	1.10
MEAN TRANS COEFF DB. CIRCULAR MODE	0	.87	.72	.75	.96	.90	1.00	1.14	1.10
RMS TRANS MOD PCT CIRCULAR MODE	0	1.16	.98	1.02	1.59	.96	1.66	1.34	.82
MEAN REFLECT COEFF LINEAR MODE(DB)	0	24.75	19.09	22.21	18.03	22.90	24.01	13.48	12.31
RMS REFL MOD PERCENT LINEAR MODE	0	1.51	5.13	2.92	2.61	2.58	2.52	3.12	3.45
MEAN REFLECT COEFF CIRCULAR MODE(DB)	0	22.72	20.62	20.59	23.70	22.98	26.62	24.18	26.45
RMS REFL MOD PERCENT CIRCULAR MODE	0	3.00	5.47	3.30	2.27	2.67	2.24	2.79	1.46
MEAN OPP POL TRANS CIRCULAR MODE	0	23.59	22.97	20.77	19.38	19.12	17.34	16.88	15.20

TOTAL NBR DEMERITS 0

UNIT CLASSIFICATION A01

RX PHASE ZERO 18.1 DEG, TX-RX PHASE DIFF -92.5 DEG AT TEST FREQ 4

SET PULSE LENGTH SCALE FACTOR 1.060, MAXIMUM PULSE LENGTH 54.3

POLARIZATION SWITCH CURRENT 64.4 MA.

M.A.G. PROJECT 247, TEST CONFIGURATION REV E (7/21/77)

Fig. 4: Sample data sheet

individual phase shift values around the actual mean values for the same ensemble at the same phase states and frequencies was also made. Histograms were also computed for the marginal distributions over frequency and phase states in the receive direction. That is, the deviations from nominal values were averaged over all phase states at each frequency for each unit, and a tally of the number of units within two-degree error intervals was printed. The results give an indication of how well the units track each other over the frequency band. The frequency-averaged marginal distribution shows the extent of unit-to-unit tracking as a function of the commanded phase shift.

A set of plots was made for the histograms for data disk number 1. The phase-state averaged data is shown in Figure 5, and the frequency-averaged data in Figure 6. The significant indication in Figure 5 is that the units behave in a very similar manner over the design frequency band. The set of histograms in Figure 6 display a bunching of values around phase states 3 and 12. This phenomenon is believed to be the result of the curve-fitting process, which has the capability of two-point matching in a least-square-error sense for functions with low-order curvature. Of great interest also is the shape of the histograms away from the compensation points, for example, at state 6 or 15. At these states, the distribution looks very much like a randomizing parameter exists that cannot go beyond a limiting value. It is possible that this parameter is related to the squareness of the composite hysteresis loop of the dual-mode phase shifter.

V. References

1. W. E. Hord, C. R. Boyd, Jr., and F. J. Rosenbaum, "Application of Reciprocal Latching Ferrite Phase Shifters to Lightweight Electronic Scanned Phased Arrays", Proc. IEEE, Vol. 56, pp. 1931-1939, November, 1968.

2. G. A. Lindauer, "Reliability Evaluation of the RARF Ferrite Phase Shifter", 1978 IEEE MTT-S International Microwave Symposium Digest, pp. 100-102, June 1978.

3. C. R. Boyd, Jr., "Comments on the Design and Manufacture of Dual-Mode Reciprocal Latching Ferrite Phase Shifters", IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-22, pp. 593-601, June, 1974.

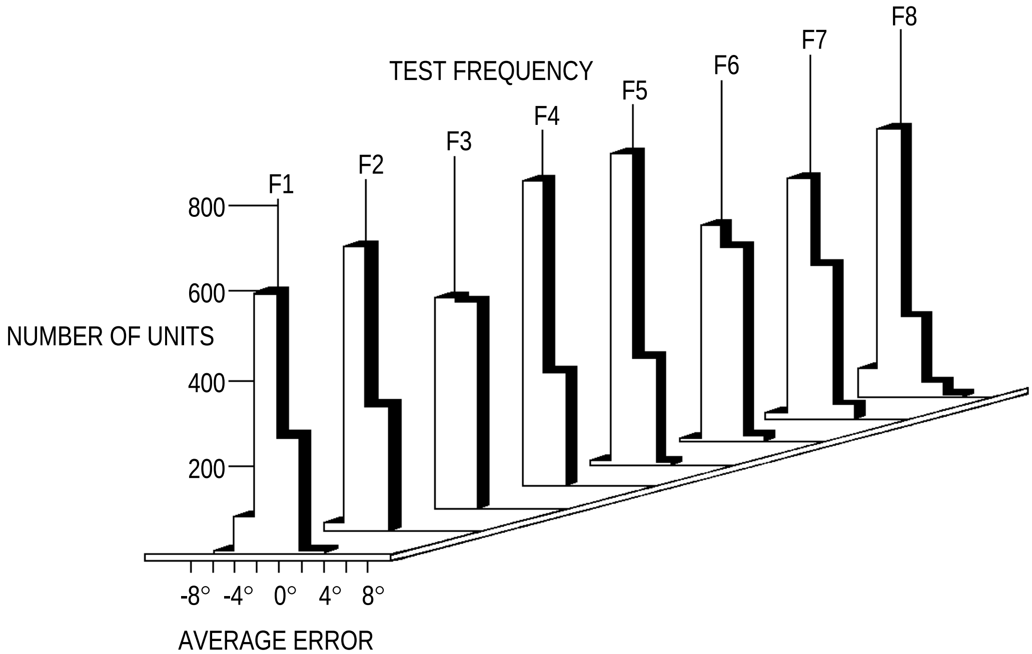

Fig. 5: Histograms of phase-state averaged error vs. test frequency

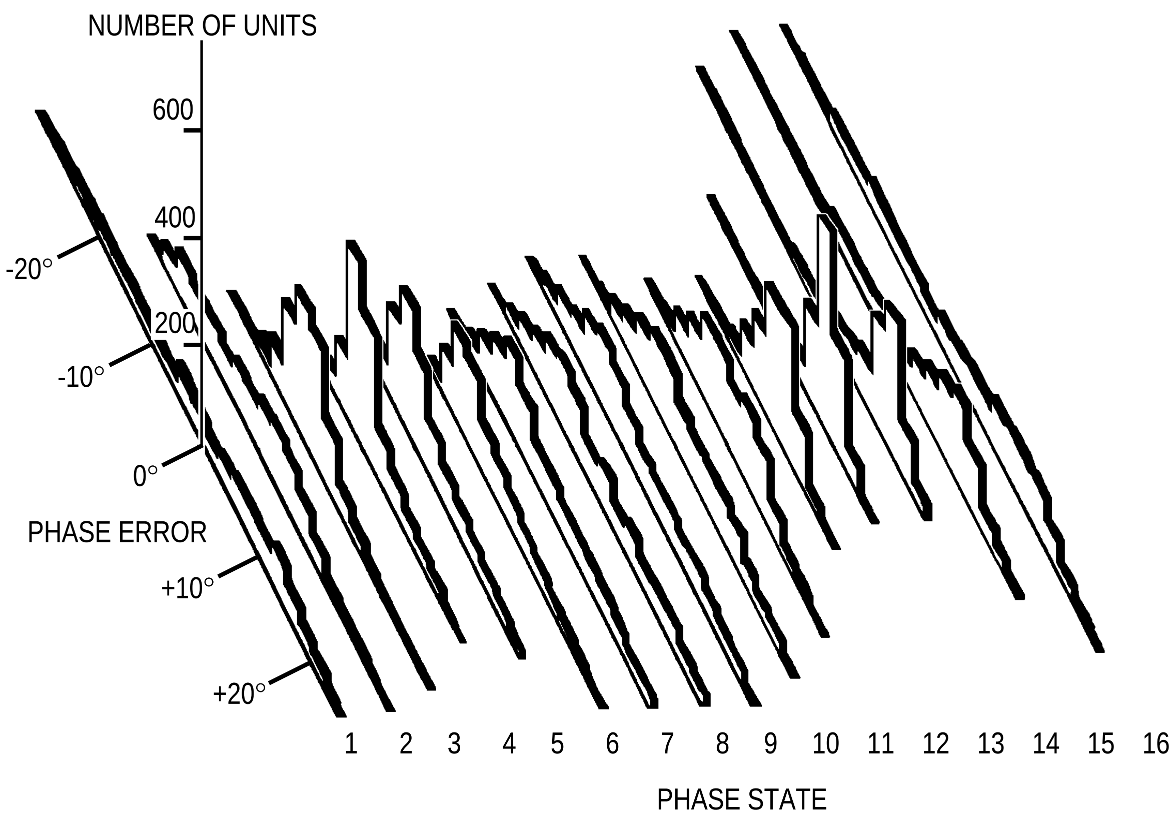

Fig. 6: Histograms of frequency-averaged error vs. phase state