RELIABILITY EVALUATION OF THE RARF FERRITE PHASE SHIFTER*

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ABSTRACT

Reliability evaluation is made on the more than 3600 phase shifters of the RARF Array. Types of failures, and numbers of each type, and analysis of their cause are given where known.

Introduction

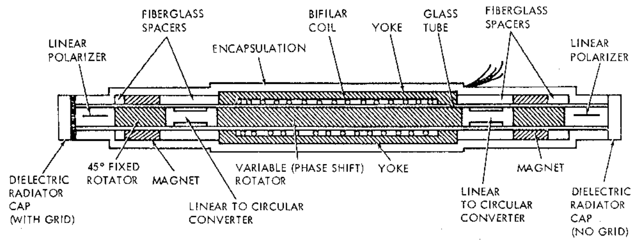
This paper reports the results of tests conducted on the ferrite phase shifter used in the RARF (Radome, Antenna and RF Circuitry) Phased Array. These phase shifters were manufactured over the period of 1967 to 1970 after which they were integrated into the RARF array. Following ground testing the array was installed into a B-47 and underwent flight test for the next 5 years accumulating more than 4500 operational hours.

Phase Shifter Physical Description

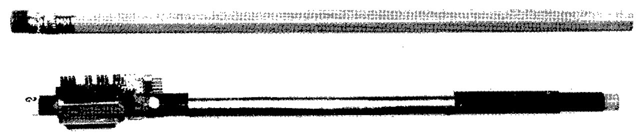
The RARF phase shifter has a structure consisting of a circular waveguide loaded with ferrite and ceramic dielectric of similar dielectric constant. The arrangement of ferrite and dielectric elements is shown in Figure 1(a). In the center portion of the assembly is the switched ferrite, which is axially magnetized to the desired level for a given amount of phase shift. On either side of this central section are dielectric elements whose circular symmetry has been perturbed such that they act as quarterwave plates to convert between circular and linear polarizations. Beyond the quarterwave plates are short ferrite sections which are also axially magnetized, but to a permanent value providing 45° of Faraday rotation to linearly polarized waves. At the extreme ends of the structure are dielectric members containing thin resistivefilm elements whose function is to absorb one sense of linearly polarized r-f energy while allowing the orthogonal sense to pass with minimal insertion loss. This whole assembly is carefully fitted within a glass envelope whose outer surface is metallized to form the waveguide. Finally, a ferrite yoke is fitted over the metallized surface in register with the switching ferrite section to enhance the remanent field of that section and thus permit latching operation of the phase shifter. The phase shifter driver, shown mounted on the phase shifter in Figure 1(b), is tailored for and integrated with the unit described above to make up the complete phase shifter.

Test Method

The tests consisted of antenna pattern measurements, on array phase shifter measurements, and disassembling the array and measuring phase shifter data in a microwave bridge. The same antenna range and essentially the same equipment was used as in the original evaluation of the array.



(a) CROSSECTIONAL VIEW



(b) COMPLETE PHASE SHIFTER

FIGURE 1 RARF PHASE SHIFTER ASSEMBLY

On array phase shifter measurements were made using a microwave phase/amplitude receiver and a specially designed probe which couples directly to the radiator cap of phase shifter. An RF signal was coupled to the sum feed of the array with a sample to the receiver. The phase shifter was then switched to several phases. By observing the receiver it could be determined if the phase shifter was changing phase. This test was used to identify failed phase shifters.

Individual phase shifters were measured using a microwave waveguide bridge. The phase shifters were stepped through the desired phase states with the test set used in taking the original data. It was found during these tests that the build in power supplies in the test set were not sufficiently stable to obtain repeatable results. Replacing these supplies with standard Lab power supplies considerably improved the stability and repeatability of the data.

While the array was installed on the antenna range for pattern test, lightning struck power lines in the vicinity knocking out the transformer supplying power to the antenna range. This surge was apparently coupled to the control lines running between the Beam Steering Computer Control Unit located in the control room of the antenna range and Beam Steering Computer located on the array. This resulted in the loss of 274 IC and transistors and a three month delay in testing. It is also considered very likely that some of the phase shifter driver circuits were burned out or degraded as a result of this damage.

*This work sponsored by USAF, Contract No. F33615-77-C-1102.

Test Results

Of the over 3600 phase shifters in the array, original data taken prior to assembly into the array was available on only 1850 units. When disassembling the array the phase shifters were separated into two groups, those for which data was available and the no data group. The group on which no data was available were only tested to determine if the drivers had failed. The data group were all tested on the manually operated microwave bridge (as the data was originally measured) measuring phase and insertion loss for three phase setting at center frequency. As a result of these tests it was determined that 97 phase shifters were bad. Of these, 5 were physically broken - 2 had high insertion loss and 90 had failed drivers.

The on array test indicated that 155 phase shifters were not changing phase. This is a rather large discrepancy from the 90 units with failed drivers identified on the microwave bridge. Part of these can be accounted for by assuming that only one phase shifter failed so that it loaded down the line driver knocking out an entire row or column. The remainder must be attributed to the technique used in the on array test and to failed phase shifter array connectors.

After completion of the data gathering the old (original) data and the new data were placed in the computer. These data files were then sorted by serial number, and checked for duplicate serial numbers. They were then compared to each other eliminating all serial numbers not found in both sets. Histograms were then plotted for the three phase states and insertion loss (at 0°) for both the old and new data. These histograms of the 0° and 180° phase state are given in Figures 2 through 5. The numbers immediately below the column is the actual number of phase shifters falling into that category. The general observation that can be made from this data is the new data generally has a greater dispersion than the old. This can be attributed to aging of the driver components and differences in measurement techniques.

Since it had been observed earlier that there was a phase difference between the front and rear entry phase shifters the new data was identified with an F or R for front or rear entry. The new data was then separated into these two categories and plotted as before. Average values for each set of the just described data are given in Table 1.

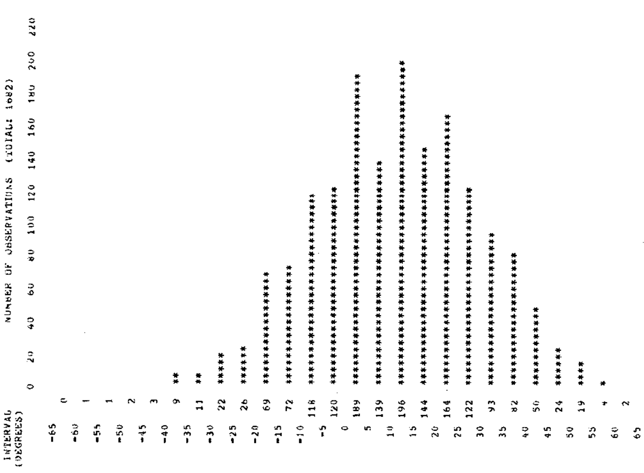


FIGURE 2 PHASE SHIFTER FOR 0° SETTING - OLD

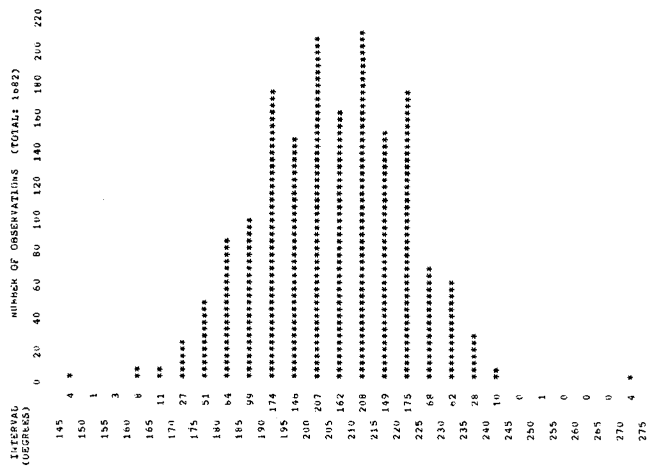


FIGURE 3 PHASE SHIFTER FOR 180° SETTING - OLD

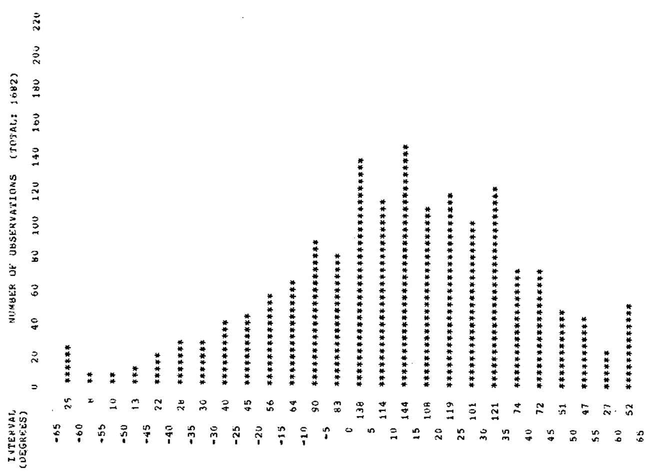


FIGURE 4 PHASE SHIFTER FOR 0° SETTING - NEW

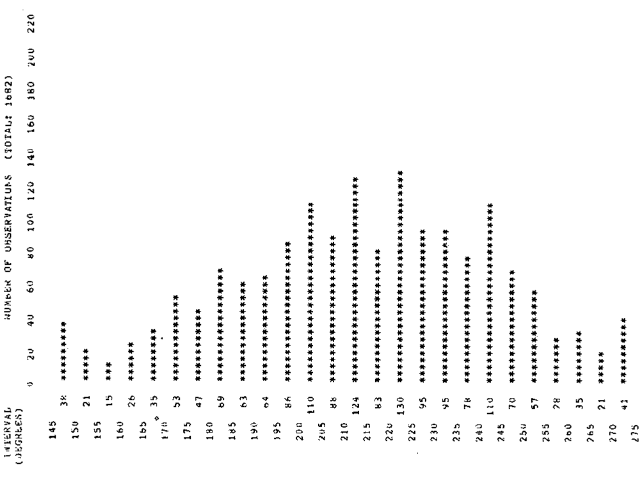


FIGURE 5 PHASE SHIFTER FOR 180° SETTING - NEW

TABLE 1
AVERAGE VALUE OF PHASE SHIFTER DATA

PHASE SETTING	TYPE OF DATA OLD	NEW	NEW F	NEW R
0	11.3	11.2	5.5	16.8
180	205.5	214.1	206.1	221.9
315	328.0	334.3	328.1	340.3

All values are in degrees.

During the testing of the phase shifters it was observed that the increments between phase settings seemed much closer to being correct than the spread on the histographs would indicate. To verify this, for each phase shifter, the zero phase state value was subtracted from the other two values for both old and new data. This normalized data was plotted as above. These results are very interesting and show that the phase shifters could be much better if the zero state were set more accurately. The phase spread about the average value required to include 68% of the phase shifters (or one sigma spread) is given in Table 2.

TABLE 2
ONE SIGMA DATA SPREAD

PHASE SETTING	TYPE OF DATA OLD	NEW	NEW F	NEW R
0	35	50	45	50
180	32.5	55	55	50
315	35	50	50	50
After Data was Normalized to 0^{o} Phase State				
180	12.5	15	15	15
315	35	7.5	7.5	7.5

All values are in degrees

Failure Analysis

A failure analysis was done on a portion of the 97 failed phase shifters to determine the failure mechanisms involved. The five broken units are fairly easily explained as fatalities due to disassembling the unit, however it is possible that some may have been cracked due to misalignment during assembly. This number is insignificant compared to the total. The two units with high insertion loss (10 db and 6 db) were placed in a vacuum chamber for one hour in an effort to remove any trapped moisture, this had no effect on the loss. Next the phase shifters were baked at $71^{o}C$ for 75 minutes this also had no effect on the loss. An effort was made to examine the plating on the glass tube. By the time the conformal coating was removed it was impossible to tell if the plating had been bad or was damaged by removal of the conformal coating. Next the ferrite rod was removed from its glass rod and installed in the glass rod of one of the broken units which had a low insertion loss. The loss decreased from 6 db down to 2.5 db. Bad plating on the glass rod is considered to be the most likely cause of the high insertion loss. Again this is an insignificant number.

Ten of the ninety bad drivers were examined by measurements made between the connector pins and the pins on the IC's. The results of these tests are:

3 open lines on the substrate
2 open base-emitter of the set output transistor
1 bad solder connection on IC at output of set transistor
1 open base-emitter of set input transistor
1 open set coil
2 indeterminant (internal to the IC)

As might be expected a large number of failure types were observed and if the remaining 80 were examined other failure mechanisms would likely be found.

Conclusion

This total number of failures (97) is only about 2.7% which falls into the category of graceful degradation. This number is very small when one takes into account all that the array has been through including being shipped to the West Coast and back by truck, 4 years of flight test and the lightning induced damage.