Temperature Effects on Transmission Line Phase and Group Delay

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An investigation of the phase and group delay stability of various coaxial and waveguide transmission lines has been initiated. The purpose of the test is to determine the feasibility of separating the receiver-exciter equipment from the tricone area of the 64-meter antenna.

Initial test results are reported from both controlled environment and field operating environment experiments.

I. Introduction

The increase in volume of electronic equipment mounted in the tricone area of the 64-meter antennas has led to a congested situation which calls for remedial action. Moving the Block IV Receiver-Exciter to a location remote from the tricone would be beneficial to this problem if the phase and group delay in the receiving system were not degraded. This current investigation relates to the phase and group delay thermal stability of various transmission lines that could be used for such a move.

II. Test Plan

The investigation was planned in two phases: (a) a controlled temperature investigation of relatively short lengths of commonly used transmission lines, and (b) field measurements on relatively long lengths of semi-rigid coaxial cable exposed to the external environment.

The controlled temperature tests are being conducted by Western Automatic Test Services (WATS) of Sunnyvale, California, on approximately 30-meter lengths of the following transmission lines:

1/2-inch Spir-O-Line semi-rigid coax

SF 214 coax

F545-AA Flexco coax

41656 Heliax semi-rigid coax

EW71 elliptical semi-flexible waveguide

In this series of tests, the sample is placed in an environmental chamber whose temperature is raised in 5.5°C steps from −18°C to 66°C. At each temperature, the sample is left for one hour to stabilize and then phase, attenuation and voltage standing wave ratio (VSWR) are measured over a programmed frequency range using the network analyzer technique. Group delay is calculated. All data are recorded.

In addition, an improvised thermal chamber has been set up at JPL to test a series of seven-meter lengths of rigid transmission lines. The following lines will be tested:

WR112 waveguide

WR430 waveguide

7/8 EIA rigid coax

The test arrangement is shown in Figure 1, with WR112 waveguide as the test sample. As shown in Figure 1, the length (approximately 13 meters) of the reference path is equivalent to the test sample path so that differential phase measurements have a good resolution. Again, in this test, phase vs. frequency measurements are plotted on an X-Y recorder after the sample temperature has stabilized at each new temperature setting.

The field tests were conducted at DSS 13, the Venus Station, at Goldstone, California. A bundle of four 305-meter lengths of 1/2-inch Spir-O-Line, which has been in use for approximately six years, was selected for S-band testing. This bundle of four cables, fastened together with cable ties, was removed from the cable tray and placed atop the tray where solar heating could give a wider temperature variation. The far ends of two of the cables were connected together with a short length of RG-214, a solid dielectric, flexible coaxial cable, with double braid shields.

The looped back cables, a stable-frequency S-band source, temperature monitoring, and a Hewlett Packard Network Analyzer were interconnected as shown in Figure 2. This 610-meter length of Spir-O-Line, with a propagation constant of 0.83, contains approximately 5846 wavelengths at 2388 MHz, the test frequency. This corresponds to 2.1×10^6 electrical degrees. To reduce apparent phase changes due to frequency changes in the test source, the frequency stability should be high. (A stability of 2×10^{-6} would limit errors from this source to approximately 1 degree.) The frequency source used was an exciter multiplier chain whose input frequency was derived from a rubidium frequency standard. Since all elements of the multiplier chain are mounted on a stabilized temperature cold plate, it is estimated the frequency stability of the source is better than 1×10^{-6}.

The temperature measurement was performed by a thermistor inserted into the cable bundle approximately 12 meters from the test position. This ensures that the thermistor records temperature rise due to solar heating.

III. Test Results

The controlled temperature tests at WATS are being conducted. Some of the test results received thus far are shown in Figures 3, 4, 5 and 6 for 1/2-inch Spir-O-Line and SF 214 coax. The phase and group delay characteristics of 1/2-inch Spir-O-Line vs temperature are shown for S and X-band in Figures 3 and 4 respectively. In both cases, the group delay variation is less than 0.5 nanosecond over the −18° to 66°C temperature range. The average phase shift variation with temperature is −2.7 and −8.3 electrical degrees per degree Centigrade at 2.3 and 7.2 GHz respectively. This represents a temperature coefficient of 23.6 parts per million (ppm)/°C.

Of particular interest however is an anomaly which is evident in Figures 3 and 4 in the 27° to 32°C range. This appears to be related to a transient phase characteristic also noted in the field tests. The preliminary conclusion is that some type of significant physical change occurs in the Spir-O-Line cross-section over certain transient temperature conditions.

Test results for SF 214 coax at S-band are given in Figure 5. The average group delay over the −18° to 66°C temperature range is 153.5 nanoseconds with a maximum variation of two nanoseconds. The phase shift variation with temperature is −47.3 degrees electrical per °C at 2.3 GHz. This represents a temperature coefficient of 326 ppm/°C.

The variation of attenuation with temperature of the Spir-O-Line and SF 214 cables is given in Figure 6.

The field tests were conducted at DSS 13. After several day–night cycles of continuous recording, observation of the data points to several conclusions: (1) Over a very limited temperature range (2.5 – 7.5°C), the phase stability of the cable appears to be approximately 8 parts per million per degree Celsius; (2) At temperatures near 0°C, the rate of differential phase change increases dramatically with changes as great as 255 degrees of phase for a decrease in temperature from 7.5 to 0°C. This "transition" temperature was approximately repeatable with some hysteresis being observed; (3) As the cable is cooled from approximately 25°C, a reversal in the direction of changes in the electrical length occurs at approximately 9°C, with reversal recurring at approximately 9°C as the cable is warmed from near 0°C. Figures 7, 8 and 9 illustrate the data from which these three conclusions were drawn.

The two principal components of the differential phase changes in this coaxial cable appear to be the physical differential length changes caused by the different thermal coefficients of expansion of the copper inner and aluminum outer conductor and the changes in the dielectric constant of the high density polyethylene inner conductor support. It is theorized that the reversals are caused by one of the principal contributors, probably the physical changes, overpowering the other and reversing the slope. The "transition" phenomena could well be caused by changes in characteristic impedance as the stress is relieved either by transverse or longitudinal movement of the center conductor.

Spir-O-Line semi-rigid coaxial cable is constructed with a copper inner conductor supported by a bundle of six semi-ellipsoidal hollow high density polyethylene tubes. Around the tube bundle is an outer conductor of aluminum with a black polyethylene jacket over all. The recommended connectors for this cable grip the outer conductor firmly while allowing the inner conductor to slip in a basket arrangement. Calculations indicated that, if the differential expansion stress were all relieved by longitudinal movement, the differential physical length of the cable would change approximately 0.5 cm/°C for the 610-meter length. The connector was removed from one end of the cable and a dial indicator was affixed in such a manner as to grip the outer conductor firmly while bearing on the inner conductor. After several day–night cycles, the total differential movement observed was 0.01 cm. Apparently stress is relieved by transverse as well as longitudinal movement, with transverse movement representing almost all the movement.

Another pair of cables, with similar lengths, were tested in an identical test set-up to check for uniqueness in the first pair. This second test disclosed that the "transition" phenomena noted with the first pair did not occur with the second pair. However, the phase reversal noted at approximately 9°C on the first pair was observed on the second pair although not at the same temperature. The average phase stability of the second pair of cables was also superior to the first pair.

The different test results indicate that the manner in which connectors are installed, and the past operational history of the cable, are also factors in differential phase stability.

IV. Future Plans

Further testing of other cable and waveguide types is in process and will be reported on at a later date. Additional tests at DSS 13 are planned to ascertain what performance can be expected from typical cables assembled in the field in accordance with the manufacturer's instructions.

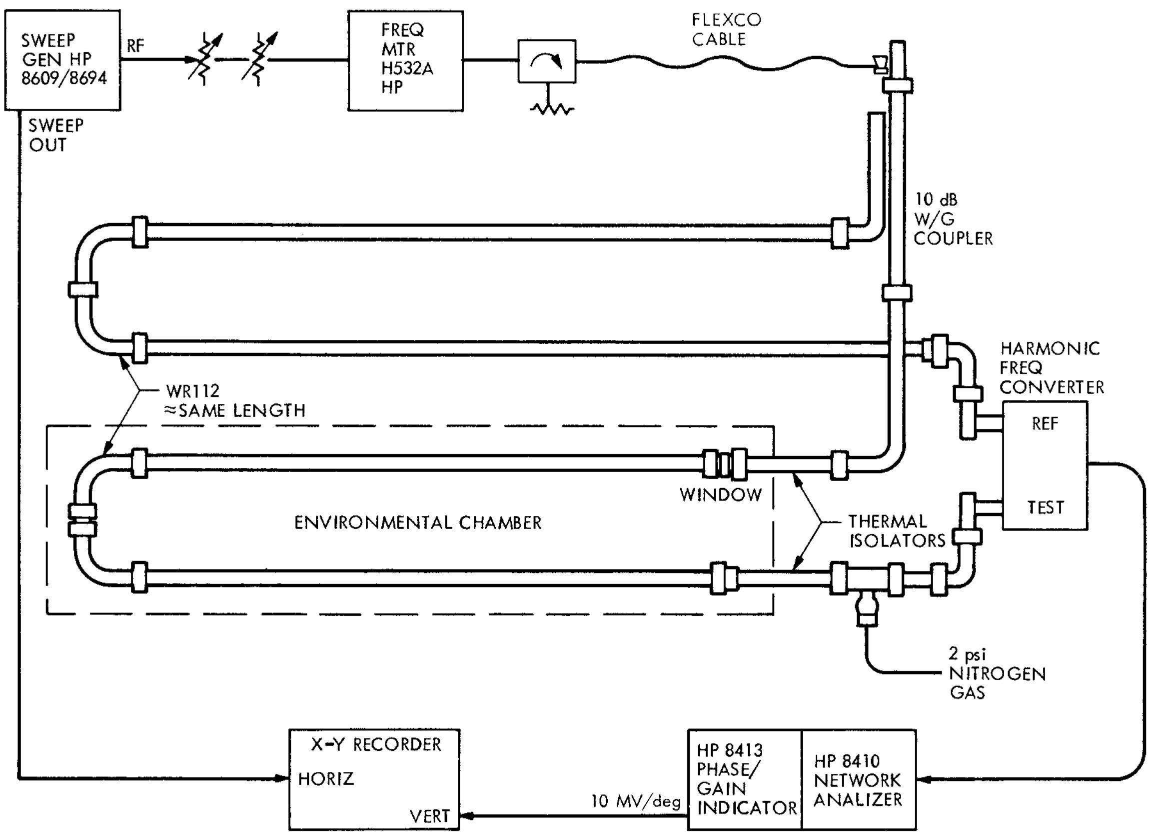

Fig. 1. Test configuration phase stability vs. frequency/temperature

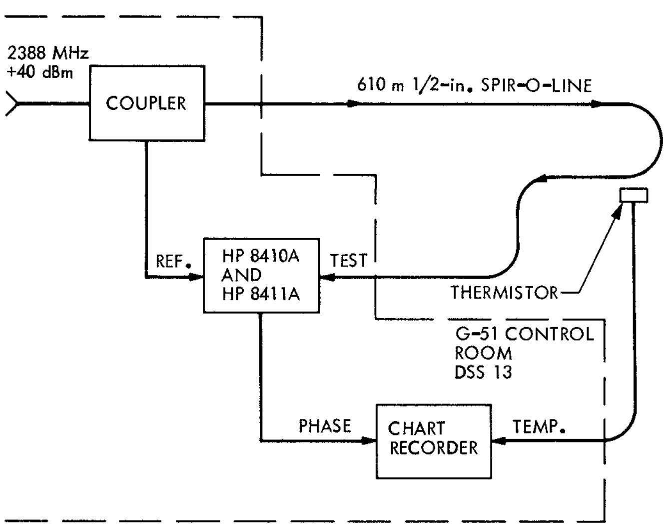

Fig. 2. Field test set-up, differential phase vs. temperature

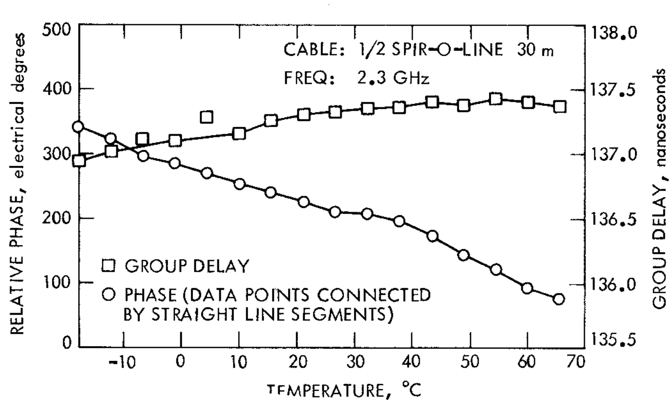

Fig. 3. Phase and group delay vs. temperature (cable: ½ Spir-O-Line; frequency: 2.3 GHz)

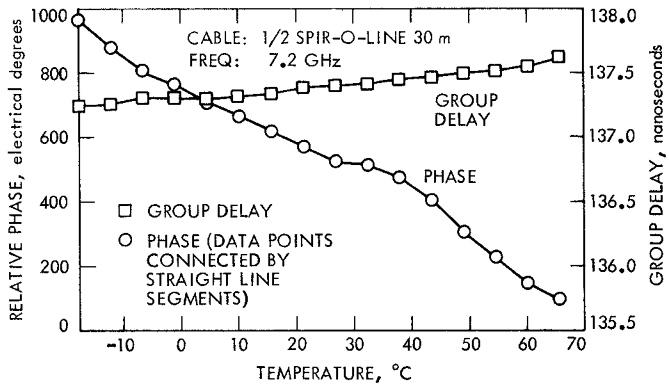

Fig. 4. Phase and group delay vs. temperature (cable: ½ Spir-O-Line; frequency: 7.2 GHz)

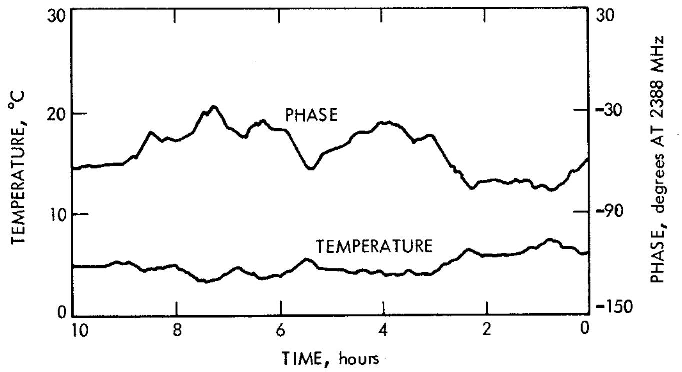

Fig. 7. Differential phase, illustrating anticipated phase vs. temperature

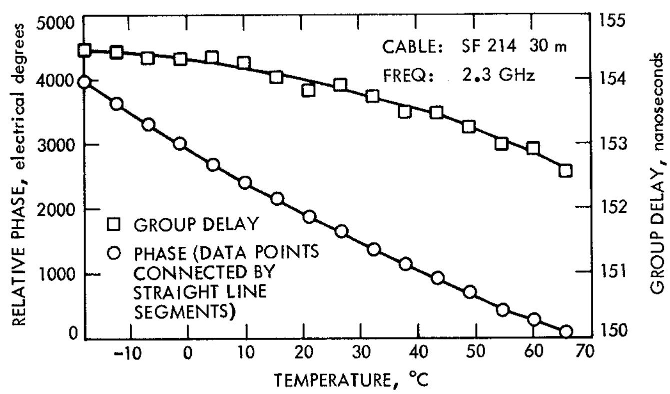

Fig. 5. Phase and group delay vs. temperature (cable: SF 214; frequency: 2.3 GHz)

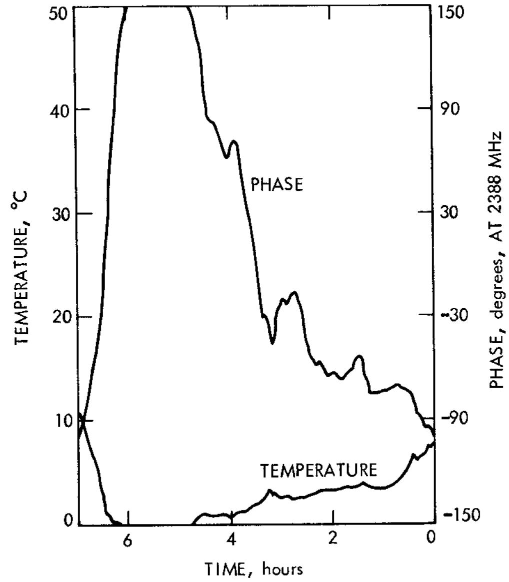

Fig. 8. Differential phase, illustrating "Transition" phenomena at temperatures near 0°C

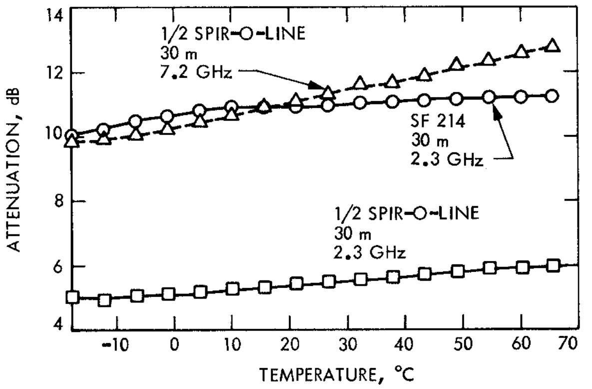

Fig. 6. Attenuation vs. temperature

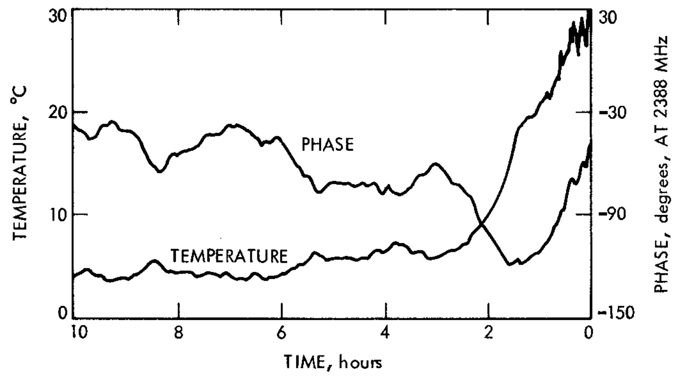

Fig. 9. Differential phase, illustrating phase reversals with temperature changes