Electrical Length Stability of Coaxial Cable in a Field Environment

P. A. Clements
Communications Systems Research Section

Various environmental conditions will cause a coaxial cable to change electrical length. In the past, the effects of these changes were not important; however, recent requirements for future DSS accuracies have forced their consideration. Preliminary studies on the effects due to temperature changes and mechanical stress have been made. Results to date indicate some problem areas.

I. Introduction

The most critical cables in the DSIF receiver exciter assembly are the long cables connecting the control room to the antenna. The changes in electrical length of certain cables directly affect the accuracy of the range and/or differenced range versus integrated doppler (DRVID) measurements. Typical critical cables are the exciter-transmitter cable, and the local oscillator cable. These cables are being studied at DSS 14 to determine the existence of and the nature of any problems in their stability and to find possible solutions to such problems.

II. Stability Required of Cables

The hydrogen maser frequency standard has made frequency stabilities of better than 10^{-13} for averaging times of more than 1 second available to the DSN. The station cables should not degrade hydrogen maser performance, if maximum use is to be made of the obtainable stability.

Future requirements for the delay error for the DSN have established $\leq$0.10-meter stability for the system over 12 hours, of which 0.01-meter stability is allocated to system cables.

III. Conditions Affecting the Electrical Length of Cable

Several things affect the electrical length of cable. They are: mechanical changes (vibration, bending, stretching, etc.), humidity, and temperature variations. Mechanical changes affect the length and orientation of the conductors. Humidity changes the value of the dielectric constant. Temperature variation changes the physical length of the conductors, and the value of the dielectric constant.

IV. Effects of Changes in Electrical Length of Coaxial Cables

A. Group Delay

If a cable changes its electrical length by some Δl, then the time required for a signal to travel through the cable is changed by an amount Δt:

$$\Delta t \text{ seconds} = \frac{\Delta l \quad \text{meters}}{cK \ \dfrac{\text{meters}}{\text{seconds}}} \tag{1}$$

where c is the velocity of light and K is a constant associated with a particular type of cable (usually around 0.80).

B. Frequency Offset

If a cable is changing electrical length at some rate dl/dt, then the frequency offset f_0 is

$$f_0\,\mathrm{Hz} = \frac{dl}{dt}\frac{\text{meters}}{\text{second}} \times \frac{f\,\dfrac{\text{cycles}}{\text{second}}}{cK\,\dfrac{\text{meters}}{\text{second}}} \qquad (2)$$

where f is the input frequency, K and c are as in Eq. (1).

Example. In the cable at DSS 14 from the hydrogen maser facility to the control rooms (Ref. 1), the maximum temperature variation on the cable is approximately 0.116×10^{-4} °C/second. The specification on the cable for electrical length stability with temperature is 20 ppm/°C. The length of the cable is approximately 136 meters. Hence, the rate of change of the electrical length of the cable is

$$\frac{\Delta l}{\Delta t}\frac{\text{meters}}{\text{second}} = 0.116 \times 10^{-4}\frac{^\circ\mathrm{C}}{\text{second}} \times 20 \times 10^{-5}\frac{1}{^\circ\mathrm{C}} \times 136\,\text{meters}$$

$$= 3.15 \times 10^{-7}\,\text{meters/second}$$

At a frequency of 100 MHz, the resulting frequency offset is

$$\frac{3.15 \times 10^{-7}\dfrac{\text{meters}}{\text{second}}}{\dfrac{2.4 \times 10^{8}\dfrac{\text{meters}}{\text{second}}}{10^{8}\dfrac{\text{cycles}}{\text{second}}}} = 1.3 \times 10^{-7}\,\mathrm{Hz}$$

with a resultant stability of

$$\frac{f_0}{f} = \frac{1.3 \times 10^{-7}}{10^{8}} = 1.3 \times 10^{-15}$$

Measurements of this cable have shown it to have a stability of better than 10^{-14} over several hours, the limit of sensitivity of measuring equipment.

V. Measurements of Hardline Cable at DSS 14

During the week December 8-15, 1971, a set of measurements was made on some of the hardline cables (RG 253/U) at DSS 14. A block diagram of the test setup is shown in Fig. 1.

Most of the phase angle plots (Fig. 2) were smooth with two exceptions:

(1) There were three jumps of approximately 17 degrees of phase. These jumps occurred only when the antenna was being moved from zenith to the horizon or back. It seems probable that these jumps were caused by a poor contact in a connector at the elevation bend point.

(2) There were rapid phase changes of approximately 0.003 to 0.004 degrees/second, which corresponded to frequency stabilities of 10^{-13}. This noise may be caused by bending the cables.

During the smooth portion of the curve the maximum phase slope was approximately 4.8×10^{-4} degrees/second. This corresponds to a frequency stability of

$$\frac{f_0}{f} = 6.6 \times 10^{-15}$$

Except for the large phase jumps of 17 degrees, the phase angle stayed within 6 degrees for any 12-hour period, corresponding to a 0.035-meter change in the two-way path.

It appears, except for the jumps, that the stability of the cable electrical length is within the requirements for total system change, but above the amount allocated for cables. However, the temperature of exposed objects is presently (in winter) dominated by the cold air blowing with a velocity of seldom less than 8 km/h (5 mph).

Let us assume that the temperature of the exposed part of the cable is always the same as the outside air. During the first week of December 1971, the air temperature in the vicinity of the antenna at DSS 14 varied approximately 12°C per day. About 30 meters of the cable is exposed. The temperature phase coefficient of RG 253/U is 10^{-5} per °C. We would expect a change of the electrical length of this 30 meters of cable of

$$\Delta l = 12^\circ\mathrm{C} \times 10^{-4}\frac{1}{^\circ\mathrm{C}} \times 30\,\text{meters} = 0.04\,\text{meters}$$

However, the temperature of the part of the cable inside (approximately 130 meters) is changing approximately 2.5°C with a 12-hour lag with the outside temperature. Thus, the expected change of electrical length is

$$\Delta l = 2.5^\circ\mathrm{C} \times 10^{-4}\frac{1}{^\circ\mathrm{C}} \times 130\,\text{meters} = 0.03\,\text{meters}$$

This gives a resultant change for the entire cable of ≈ 0.01 meters.

In the summer the cable temperature is not always the same as the air. The radiant heating can produce daytime cable temperatures of $> 60°C$. At night, cable temperature becomes the same as air temperature, approximately 15°C. This is a total change of 45°C. Hence, the change of electrical length of the exposed part of the cable would be

$$\Delta l = 45°C \times 10^{-4} \frac{1}{°C} \times 30 \text{ meters} = 0.135 \text{ meter}$$

VI. Conclusions

Tests are planned to isolate all the problem areas in the cables. These tests will last long enough to examine the expected degradation of stability during the summer. Measurements will include:

(1) A more detailed long-term look at temperatures along and in the cables.

(2) As continuous as possible monitoring of cable length changes.

(3) A record of relative humidity and temperature in the vicinity of the connectors.

With these and other tests and observations, changes in physical layout and hardware can be suggested, which will improve stability and reliability. Any necessary electronic equipment to control the electrical length of the cable can then be designed to achieve the required stability.

Reference

1. Clements, P., "Frequency Generation and Control: A Method for Temperature Stabilization of Cables Transmitting Standard Frequencies," in *The Deep Space Network*, Space Programs Summary 37-62, Vol. II, pp. 70–71. Jet Propulsion Laboratory, Pasadena, Calif., Mar. 31, 1970.

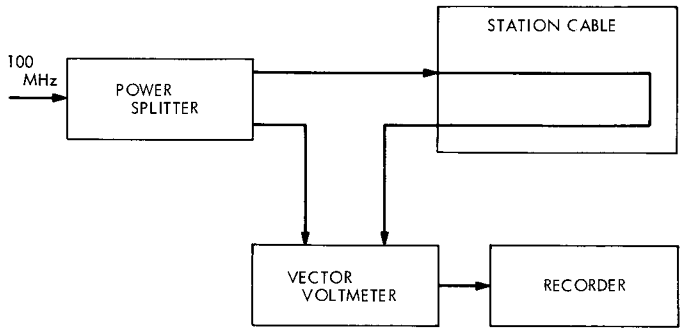

Fig. 1. Block diagram of test setup at DSS 14

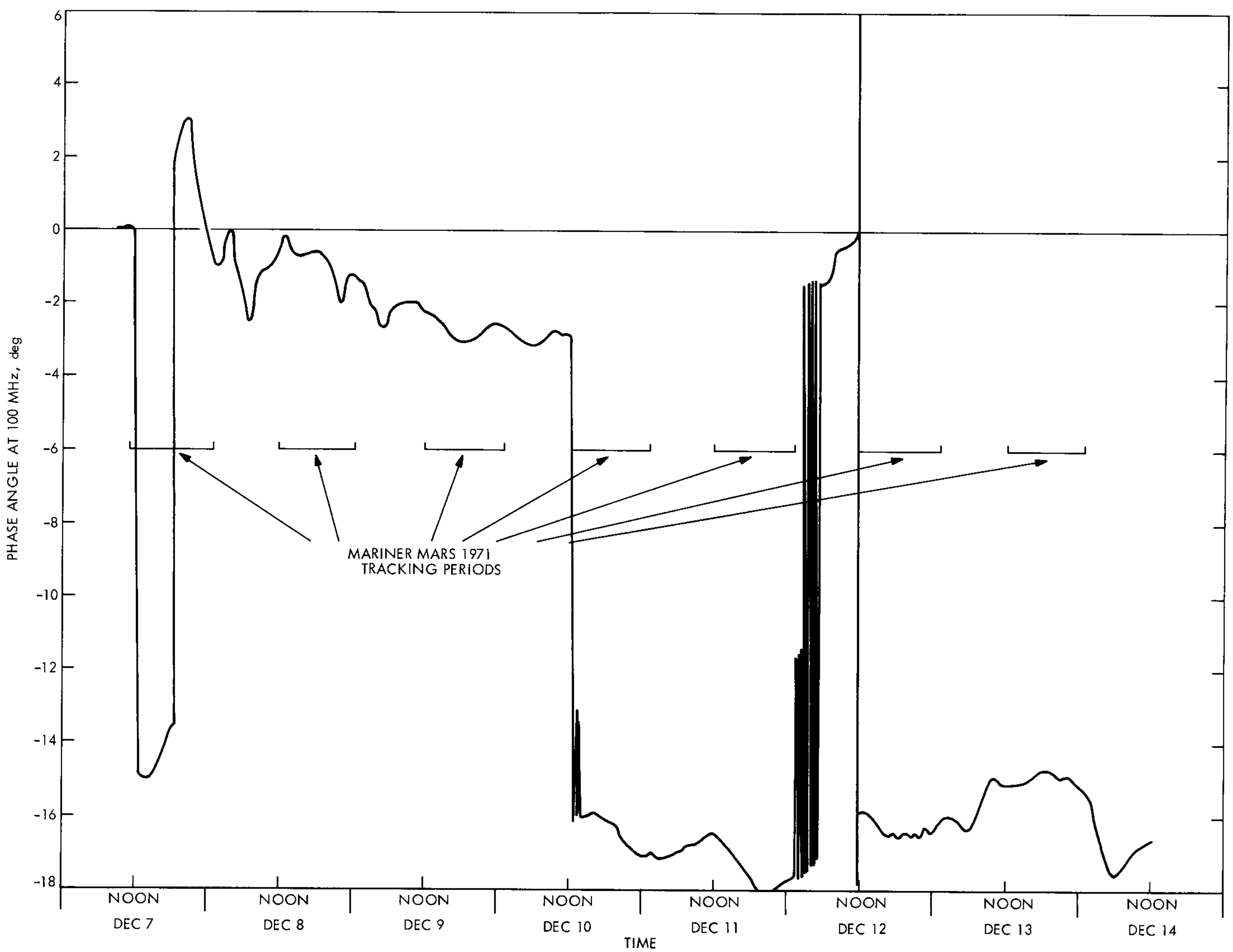

Fig. 2. Phase angle plot of cable at DDS 14