Phase-Stable Receiver Development

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Physical changes in coaxial cable parameters cause corresponding phase variations to RF signals being transmitted through them. In some types of receivers these variations directly affect the information signal. A phase-correcting circuit has been developed which greatly reduces the cable effects upon an RF signal. This article describes two types of correcting loops and test results from breadboard units.

I. Introduction

Stable reference frequencies, such as those generated by atomic standards, are being incorporated as local oscillators within newer receiver subsystems where the phase stability of the detected signal is directly affected by the phase stability of the reference signals. One example of a system in this category is a very-long baseline interferometry (VLBI) type receiver.

Maintaining a constant reference phase becomes difficult to achieve where long coaxial cables are used between the reference source and other remote locations, such as between the control room and the antenna at a DSS. Temperature, humidity, cable flexure and other effects cause cable properties to change, creating a corresponding variation in its electrical length. Methods have been devised (Refs. 1 and 2) to compensate for phase delay variations over very long distances, such as between two tracking stations, where transmission losses are large. Because of the transmission loss, these have been sophisticated systems and very costly.

To reduce the cost for a single cable phase control circuit, the use of a simple phase-correcting loop, rather than a phase-locked loop, was investigated. The phase-correcting loop utilizes a simple voltage-variable phase shifter instead of a crystal voltage-controlled oscillator. Two such types of control loops were investigated.

II. Type 1 Loop

The block diagram of the first type of loop constructed is shown in Fig. 1. It closely resembles one of the block diagrams suggested by J. W. MacConnell and R. L. Sydnor

(Ref. 1) in that it utilizes two phase detectors whose dc outputs are summed, filtered and then applied to the phase-variable element within the loop.

Figure 2 shows a mathematical model of the Type 1 loop using Laplace notation. When the loop is in operation, the phase-correcting signal at point A of Fig. 2 is

$$\text{Phase correction} = \frac{-2K\theta_E(S)}{2K+1} \tag{1}$$

where K is the total loop gain and $\theta_E(S)$ is the cable phase variation. The signal output phase, at point B, is the summation of the signal phase variation, due to cable perturbations, and the phase correcting signal at point A:

$$\text{Output phase} = \theta_E(S) - \frac{2K\theta_E(S)}{2K+1} = \frac{\theta_E(S)}{2K+1} \tag{2}$$

Therefore, phase variations for this type of loop can be greatly reduced by using a high loop gain.

The loop gain K is the product of the phase detector constant K_D in volts/degree, the dc amplifier gain G_A in volts/volt and the voltage variable phase shifter gain K_ϕ in degrees/volts; i.e.:

$$K = K_D \cdot G_A \cdot K_\phi \tag{3}$$

The breadboard unit was designed for a loop gain of 20. To assure correct phase compensation, the phasing of the 100-MHz reference signals into the phase detectors (D1 and D2) and the detector gains must be carefully adjusted. Gain and phasing adjustments on the breadboard unit proved to be difficult, but once achieved, the unit performed nearly as predicted.

To test the circuit, a line stretcher was inserted into the line at point X in Fig. 2. The unit was aligned by phasing the 100-MHz reference signals into the phase detectors, and the detector gains were equalized by varying the line stretcher while adjusting the detector gains until the phase variation between the input to the control room unit and the output of the antenna unit was minimized. With the loop inoperative (open-loop) the total phase deviation supplied by the line stretcher was approximately 14 deg. With the loop operating (closed-loop), the total phase deviation was reduced to about 0.4 deg, which is a correction factor (CF) of 35; i.e.,

$$\text{CF} = \frac{\Delta\phi \text{ open-loop}}{\Delta\phi \text{ closed-loop}} \tag{4}$$

Using the design value of $K = 20$, the calculated value of the output phase, for a 14-degree cable variation, is

$$\text{Output phase} = \frac{14}{2 \times 20 + 1} = \frac{14}{41} = 0.34 \text{ deg} \tag{5}$$

and the calculated correction factor is

$$\text{CF} = \frac{\Delta\phi \text{ open-loop}}{\Delta\phi \text{ closed-loop}} = \frac{14}{0.34} = 41.2 \tag{6}$$

The difference between the calculated and measured correction factors is due to alignment tolerances and mismatches at the cable ends. Signal reflections, due to these mismatches, add to the desired signals, thus altering the original phase variation caused by cable.

III. Type 2 Loop

Because of the difficulty in aligning the Type 1 loop design, the possibility of using a single phase detector circuit was investigated. Several block diagrams of this type are shown in Fig. 3. A breadboard of the type shown in Fig. 3a has been constructed. Figure 4 shows the signal phases within the loop.

Ideally, the Type 2 correction loop can be adjusted to completely compensate a coaxial cable. To explain the loop action, refer to Fig. 4. Point A will be designated the correcting phase $\theta_C(S)$. The total phase at point E is the sum of this correcting phase and twice the cable error:

$$Phase_E = \theta_C(S) + 2\theta(S) \tag{7}$$

The point A and E phases are differenced in the phase detector, yielding a dc error voltage of

$$Error_{dc} = \theta_C(S) - [\theta_C(S) + 2\theta(S)] = -2\theta(S) \tag{8}$$

This dc error is multiplied by the loop gain K, as previously defined, causing a phase change at the phase shifter output:

$$\theta_C(S) = -2K\theta(S) \tag{9}$$

In order to obtain an output phase equal to the input phase,

$$\theta_C(S) = -\theta(S) \tag{10}$$

Therefore,

$$K = \frac{1}{2} \tag{11}$$

Thus when the total loop gain is exactly 1/2, complete cable compensation is attained, but due to alignment tolerances and impedance mismatches at the cable ends, it is not possible to achieve 100% compensation. The measured correction factor (CF) of the loop evaluated in the lab was 70.

To assure that the compensating loop does not contribute to the phase error, the hardware must be packaged in temperature-stable enclosures both in the antenna and control room.

IV. Conclusion

The feasibility of using simple phase-correcting loops for compensation of cable drifts has been successfully demonstrated. It is planned to use this type of loop for stabilizing the local oscillator frequencies within the Pioneer Venus differential long baseline interferometry (DLBI) receiver to permit accurate system calibrations. Also, a loop will be used at the Goldstone Mars Station (DSS 14) for generating a stable X-band reference signal to allow making phase stability measurements on the Block IV X-band local oscillator, to determine if the Block IV meets the Viking VLBI requirements.

References

1. MacConnell, J. W., and Sydnor, R. L., "A Microwave Frequency Distribution Technique for Ultra Stable Standard Frequencies," in *The Deep Space Network Progress Report* 32-28, pp. 34–41, Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1975.
2. Chernoff, R. C., "Large Active Retrodirective Arrays for Space Applications," to be published.

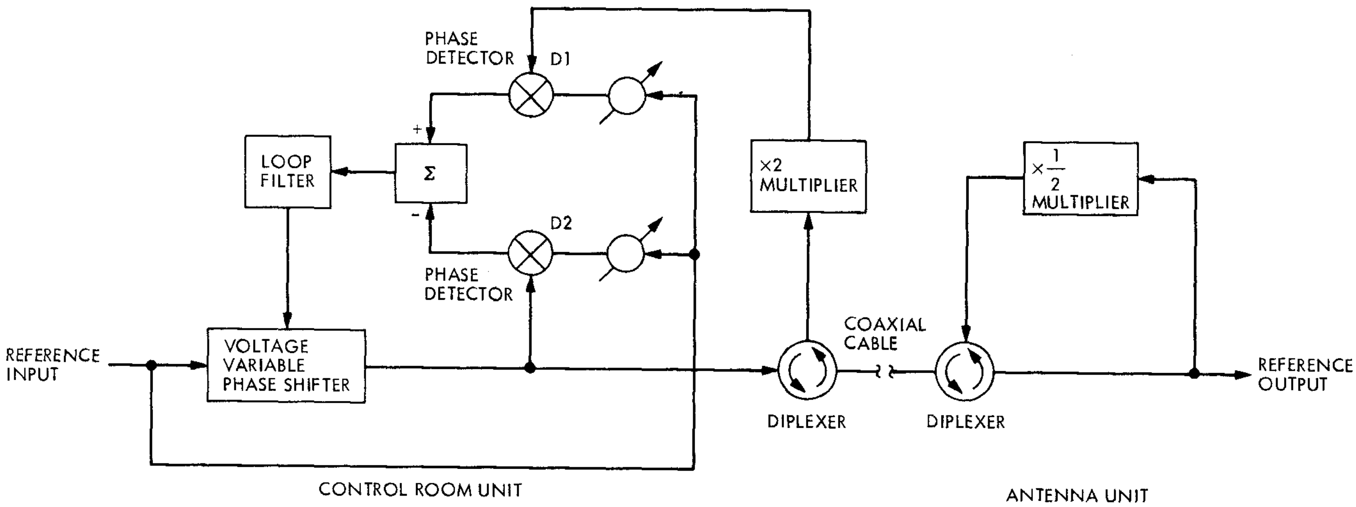
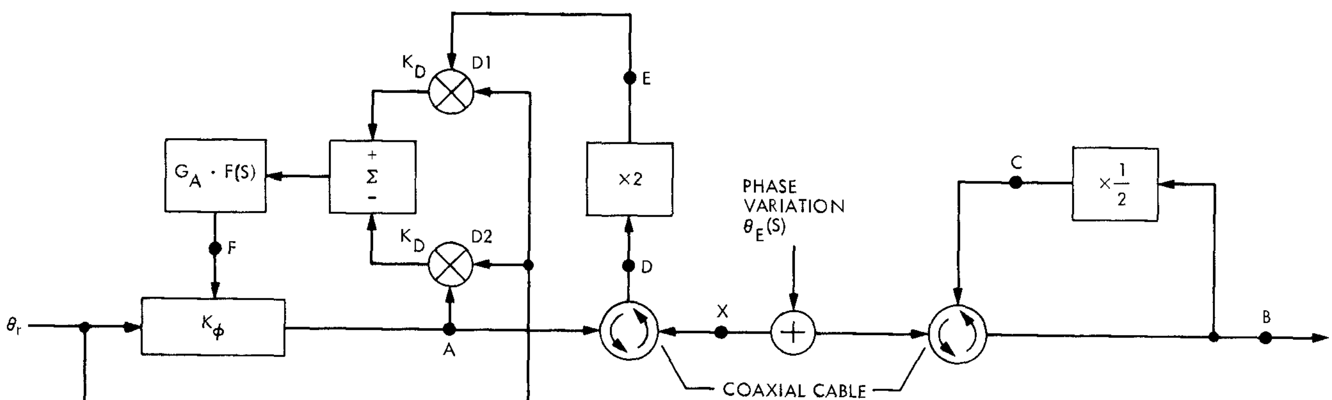


Fig. 1. Type 1 phase-correcting loop



NOMENCLATURE

K_ϕ, VOLTAGE VARIABLE PHASE SHIFTER GAIN, deg/V

$G \cdot F(S)$, ACTIVE LOW-PASS FILTER WITH DC GAIN, V/V

K_D, PHASE DETECTOR GAIN, V/deg

$\theta_r(S)$, INPUT REFERENCE PHASE

$\theta_E(S)$, SIGNAL PHASE VARIATION DUE TO CABLE

K, TOTAL LOOP GAIN = $K_D \cdot G \cdot K_\phi$

LOOP SIGNAL PHASES

A. $\dfrac{-2K\theta_E(S)}{2K+1}$, PHASE CORRECTING SIGNAL

B. $\dfrac{\theta_E(S)}{2K+1}$, SIGNAL OUTPUT PHASE

C. $\dfrac{\theta_E(S)}{2(2K+1)}$, $\dfrac{1}{2}$ SIGNAL OUTPUT PHASE

D. $\theta_E(S)$, RETURNED SIGNAL PHASE

E. $2\theta_E(S)$, $2 \times$ RETURNED SIGNAL PHASE

F. $\dfrac{2\theta_E(S)}{K_\phi(2K+1)}$, DC PHASE ERROR/$K_\phi$

Fig. 2. Type 1 phase-correcting loop, signal phases

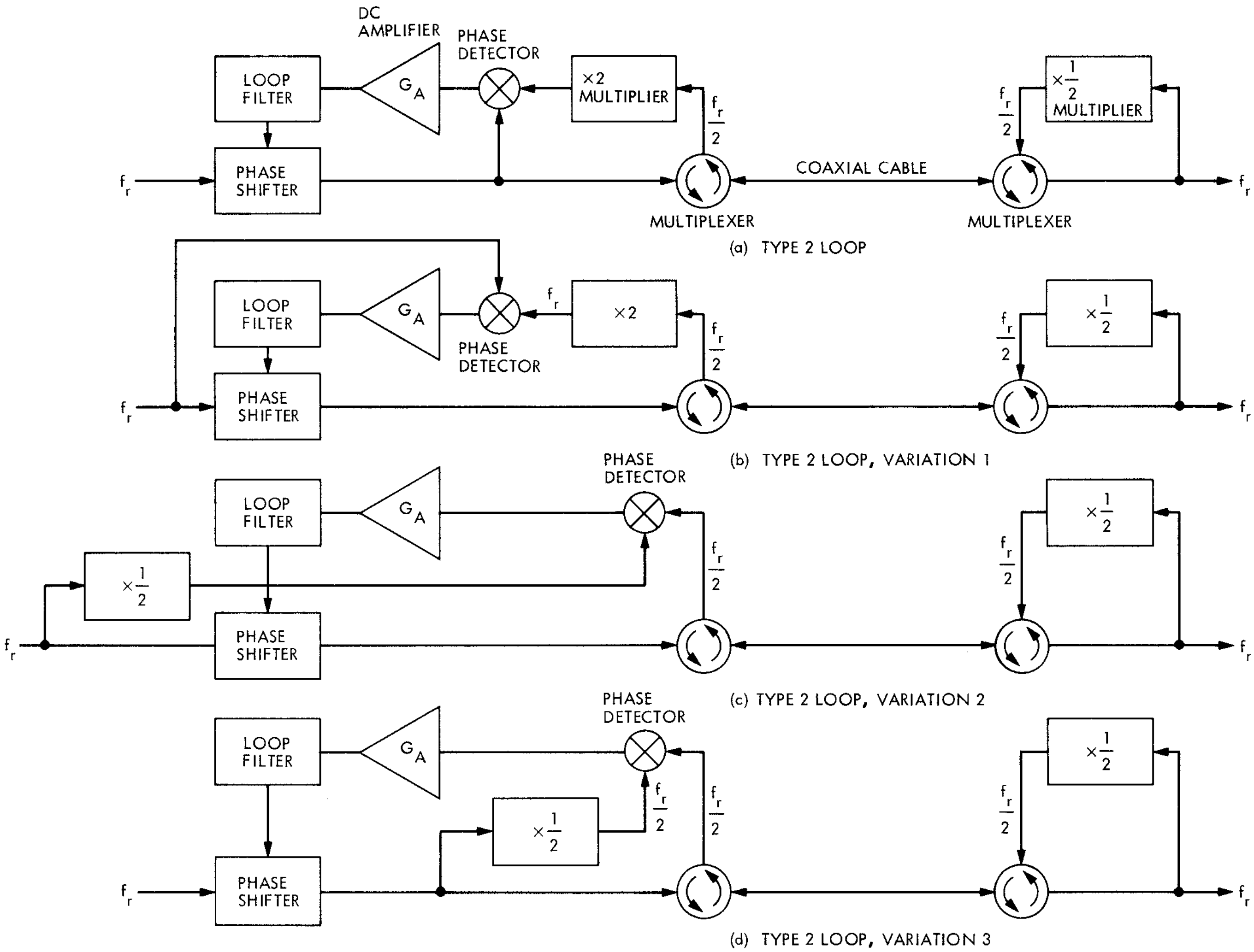
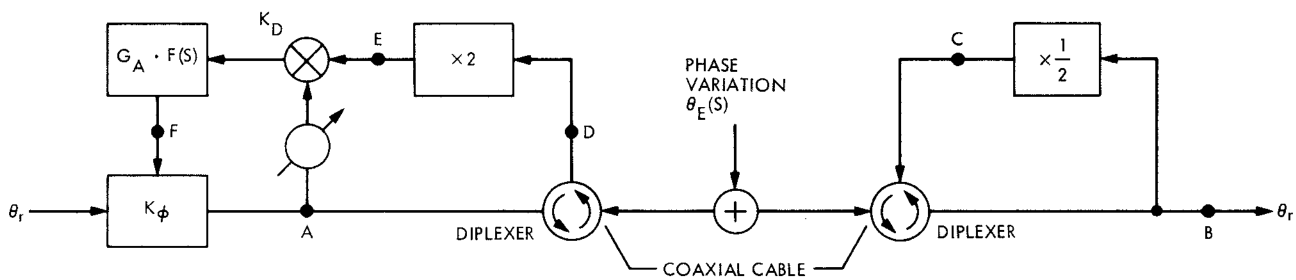


Fig. 3. Type 2 phase-correcting loops



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LOOP SIGNAL PHASES

A. $-\theta_E(S)$, PHASE CORRECTING SIGNAL

B. $\theta_r(S)$, SIGNAL INPUT/OUTPUT PHASE

C. $\frac{\theta_E(S)}{2}$, $\frac{1}{2}$ SIGNAL PHASE VARIATION

D. $\theta_E(S)$, RETURNED SIGNAL PHASE

E. $2\theta_E(S)$, $2 \times$ RETURNED SIGNAL PHASE

F. $\theta_E(S)$, DC CORRECTING ERROR/K_ϕ

Fig. 4. Type 2 phase-correcting loop, signal phases