PRINCIPLE OF THE THREE-CABLE METHOD FOR COMPENSATION OF CABLE VARIATIONS

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ABSTRACT

A novel technique has been devised that permits a length of cable to be measured in place and its transfer characteristic monitored as motion occurs. The scheme is to measure the cable in transmission as a member of a pair and to infer the characteristic of the cable from a set of three pair-wise measurements, in analogy to the well-known three-antenna technique. From the resulting knowledge of the signal cable's characteristic one can correct the measured data to account for the changes in the cable through which the signal of interest was passed.

Key Words: Microwave Network Measurements, Antenna Phase Measurements

1. INTRODUCTION

In making measurements of a microwave signal there often arises a need to pass that signal through a moving RF path. A very simple case occurs in millimeter-wave component measurements with a network analyzer where the steps of calibration and connection of the device under test cause unwanted cable motion. A more challenging case occurs in the example of planar near-field scanning measurements where a moving probe antenna's received signal must be passed down a flexing coaxial cable path to a stationary measurement receiver where the phase and amplitude of the signal are digitized and displayed. See Figure 1. The moving cable might be of modest length–a few feet–or in more difficult cases, many tens of feet. As the length of the cable path becomes greater, the difficulty of maintaining sufficient phase-stability in the path to achieve measurement accuracies on the order of one degree of phase, becomes insurmountable. This can be a serious limitation in constructing low sidelobe phased array antennas. A similar situation appears in spherical near-field measurements, where the received signal cable must pass through several moving rotation axes to reach the stationary receiver. See Figure 2.

In antenna pattern measurements, the quantity of interest in the measurement is always the change in the received complex phasor voltage as a function of coordinate axis position–either x&y as in planar near-field measurements or θ&ϕ as in spherical near-field measurements. A very undesirable effect occurs if the signal at the receiver also depends on the state of motion of the connecting path.

2. CONVENTIONAL SOLUTIONS

Conventional solutions to the problem of how to pass a signal satisfactorily through an RF path whose characteristic is varying take two forms. One either designs the RF path to be stable under flexing or he designs the RF path with appropriate monitors to accumulate auxiliary data with which to correct the data quantity of interest–the amplitude and phase of the transferred signal.

Design of the RF path to be inherently stable versus flexure can often achieve surprisingly good results given the difficulty of the problem–the sensitivity of the transferred signal even to small dimensional changes in cable. Phase-stable cable and rotary joints both offer methods of design that yield phase stability versus flexure in an RF path. Rotary joints work well with rotary axis positioners and are also employed in articulated arm systems, used in planar near-field scanning. In the case of rotary positioners these have the advantage of providing continuous motion where cables would require that limits be used. Rotary joints can be very good in providing phase stability–perhaps less than one degree per rotary joint. Modem phase-stable cable is often an excellent choice for planar near-field scanners where linear motion is employed. Sometimes as a simple cable droop, sometimes confined in a segmented-track cable carrier or sometimes in conjunction with articulated arms, phase stable cable permits one to realize a phase stability of a few degrees at X-band, for example.

In general, however, it is very difficult to achieve an overall phase stability versus motion in an RF path system that is consistent with the accuracy of the modem antenna receivers or network analyzers, whether with rotary joints or phase-stable cable. One can envision a correction scheme where a cable monitoring receiver is employed to record the changes in transfer characteristic of the moving cable. The data for the signal of interest could be adjusted to correct for the changes seen to have occurred in the moving RF path cable. See Figure 5. In principle one could take advantage of the inherent accuracy of the monitoring receiver–perhaps 0.1 degree of phase or better to improve upon the phase data obtained with even the best available RF path stability. The schematic of Figure 5 shows a generic network analyzer set-up monitoring the primary signal path through dual directional couplers and secondary signal paths. This approach is obviously fundamentally flawed because the secondary signal paths also undergo motion and therefore change in their characteristic. A solution to this feature has been devised: It is the idea of the switched reflectometer. The use of six-port methodology to avoid the phase instability of the monitoring cables, might also be employed.

A version of the switched reflectometer scheme, which is shown in Figure 4, has been employed by Tuovinen et.al. (Ref. 1) to obtain monitoring data with which to correct the signal data. This has the advantage that only one moving cable needs to be used. However experience has shown that it has certain limitations when the cable lengths exceed several tens of feet and great accuracy is needed. The basic problem is that the returning reflected signal can become comparable to or even smaller than the unwanted leakage signal in an imperfect directional coupler. Correction techniques help this but cannot overcome the weakness of the returning signal which is due to cable attenuation. The method requires twice the resolution and dynamic range to get the same sensitivity to cable changes as a transmission measurement would yield. Another drawback here is that there are secondary reflections arising from connectors and other discontinuities with the result that the returning signal is not purely composed of only one complete round trip signal reflected from the short. Time domain methods are not helpful when fast data rates are needed.

3. THE THREE-CABLE METHOD

Consider Figure 5 where the general cable-monitoring scheme based on a conventional network analyzer is shown. Notice that multiple cables connect the fixed and moving ends of the primary signal path. The idea of the three-cable method is to employ such multiple cables but to overcome the assumption of a network analyzer approach that presumes, falsely in this case, a stable secondary signal path.

The schematic of the three-cable method is shown in Figure 6. To understand the principle of how the three-cable scheme operates it is useful to recall first the three-antenna method known to antenna engineers for many years. In Figure 7 the schematic of the three-antenna method is shown, whereby the characteristics of three unknown antennas are determined by a set of three pair-wise measurements made on the antennas taken two at a time. From three successive measurements on the three pairs the gains of each of the three antennas is determined although none was known to begin with. A similar approach can be taken to obtain the transfer characteristic of each of three cables. By measuring each of three combinations of cables taken pair-wise from among a set of three cables, one can determine the transfer characteristic of each cable.

The relationship of the three pairs of cables to the multiple cable path of Figure 6 is understood by considering Figures 8 and 9. Figure 8 shows the three cables laid out in a fashion identical to the three antenna layout. Simply by altering the layout but not the method one arrives at the schematic of Figure 9 which is an alternative schematic of a three-cable measurement process. The schematics of Figures 8 and 9 call for manually swapping the pairs of cables–connecting and disconnecting them, just as one would for antennas.

The scheme assumes that the cables do not change characteristic during the process of swapping the pairs. However if they change slowly–for example by aging–then the manual process can monitor the changes, even though no cable remains constant and all have become different from the cables that are measured at the beginning. A similar approach is used to monitor changes in cables undergoing flexure. The measurements are made by electronically switching among the pairs rapidly in comparison to the speed with which change occurs due to cable flexure. The schematic of Figure 6 shows the switches that enable the rapid swapping among the pairs.

4. THEORY OF THE THREE-CABLE METHOD

The theory of the three-cable measurement scheme begins by writing the transfer equation for the first cable combination of Figure 8 as follows:

$$b^A = F_1 F_0 a$$

where

a = complex input voltage, from source.
F_0 = insertion factor of primary cable,
F_1 = insertion factor of 1st secondary cable,
b^A = complex output voltage, for 1st combination, labelled combination A.

Similarly for the other combinations labelled B and C.

$$b^B = F_2 F_0 a,$$

and

$$b^C = F_1 F_2 a.$$

It is useful to define the relative phasor quantities

$$\overline{b}^A \equiv b^A/a,$$

and similarly for $\overline{b}^B$ and $\overline{b}^C$.

For each combination the input voltage is assumed to be the same complex quantity given by a; the measured output voltage in ratio to a is different and is given by $\overline{b}^A$, $\overline{b}^B$ and $\overline{b}^C$, for the three cases. The system of equations is then

$$\overline{b}^A = F_1 F_0,$$
$$\overline{b}^B = F_2 F_0,$$
$$\overline{b}^C = F_1 F_2.$$

The unknown cable characteristics are given from the measured voltage quantities by

$$F_0 = \pm \frac{\sqrt{\bar{b}^A \bar{b}^B}}{\bar{b}^C}$$

and similarly by cyclic permutation for F_1 and F_2.

To see how to use this result to correct for changes in cable characteristic, suppose that the primary cable is used to pass a signal at two different times t_0 and t_1 between which the cable characteristic has changed from $F_0(t_0)$ to $F_0(t_1)$. The relationship between the received voltages at t_0 and t_1 is

$$\frac{b(t_1)}{b(t_0)} = \frac{F_0(t_1) \cdot a}{F_0(t_0) \cdot a} = \frac{F_0(t_1)}{F_0(t_0)}$$

If one measures the output of the cable at time t_1, but wishes to know what it would have been at time t_0–i.e. at time t_1, in the absence of change, he can correct by use of

$$b(t_0) = \frac{F_0(t_0)}{F_0(t_1)} b(t_1)$$

The correction factor is given by

$$F_C = \frac{F_0(t_0)}{F_0(t_1)} = \sqrt{\frac{\bar{b}^A(t_0)}{\bar{b}^A(t_1)} \, \frac{\bar{b}^B(t_0)}{\bar{b}^B(t_1)} \, \frac{\bar{b}^C(t_1)}{\bar{b}^C(t_0)}}$$

This expression calls for an initial measurement at t_0 of the three monitoring voltages $\bar{b}^A$, $\bar{b}^B$, $\bar{b}^C$ to calibrate the system. Then the measured data at $t_1, b(t_1)$ together with the three monitoring voltages at t_1 yield the corrected value.

It is important to note that the theory permits any changes to be accounted for–both those due to cable motion as well as to temperature or aging or other effects. Both the amplitude and phase are corrected.

SUMMARY

A novel method of cable correction has been devised which can be applied to correcting for variations in cable characteristic due to motion, flexure, temperature change or other environmental conditions. It employs three cables measured pair-wise, two at a time, with the combinations rapidly switched. By measuring in transmission, rather than in reflection it overcomes the limitation imposed by cable loss on the use of the switched reflectometer. It yields a method of correction that is limited only by the stability and accuracy of the monitoring receiver.

NOTE

A patent has been applied for based on the method of three-cables for compensation of cable variation described in this paper.

REFERENCES

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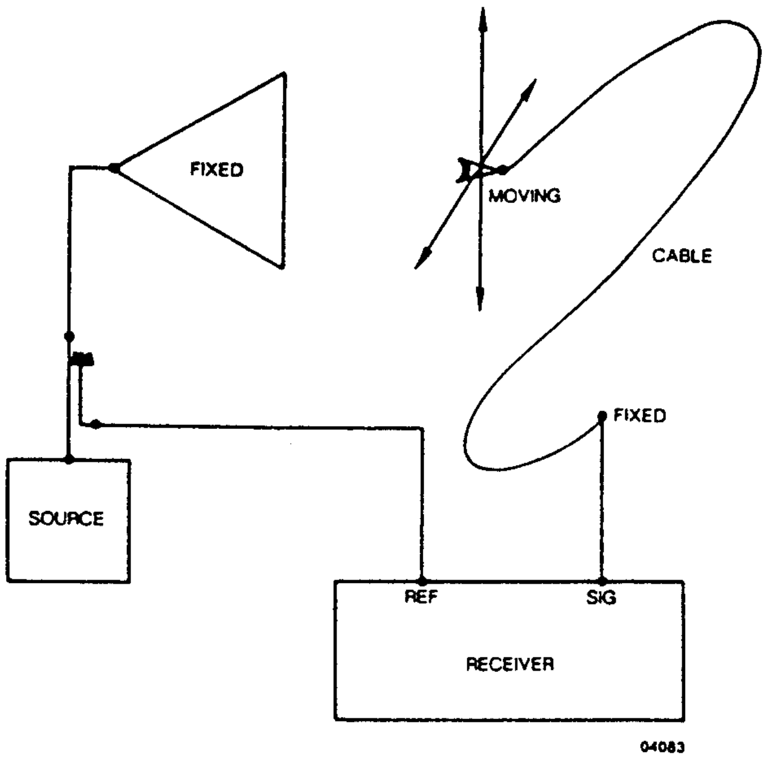

Figure 1. Schematic - Cable Motion with Planar X-Y Positioner

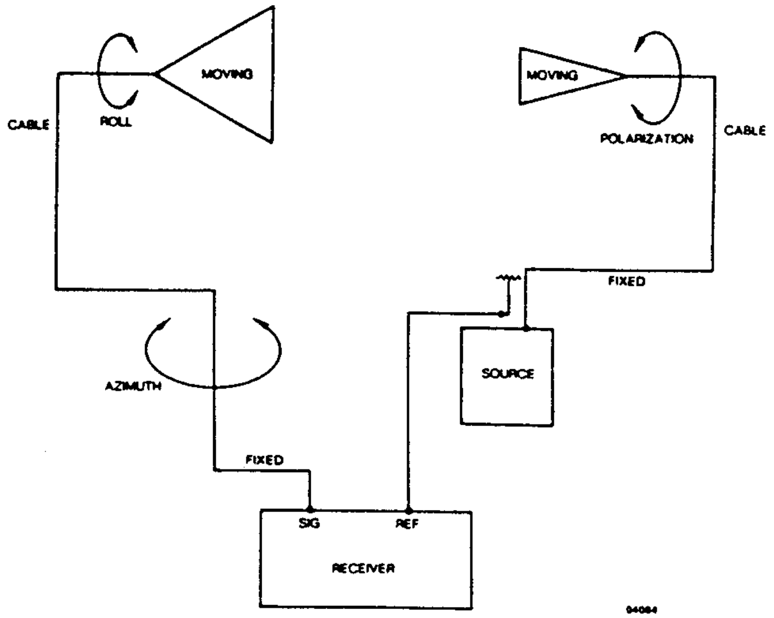

Figure 2. Schematic - Cable Motion with Rotating-Axis Positioners

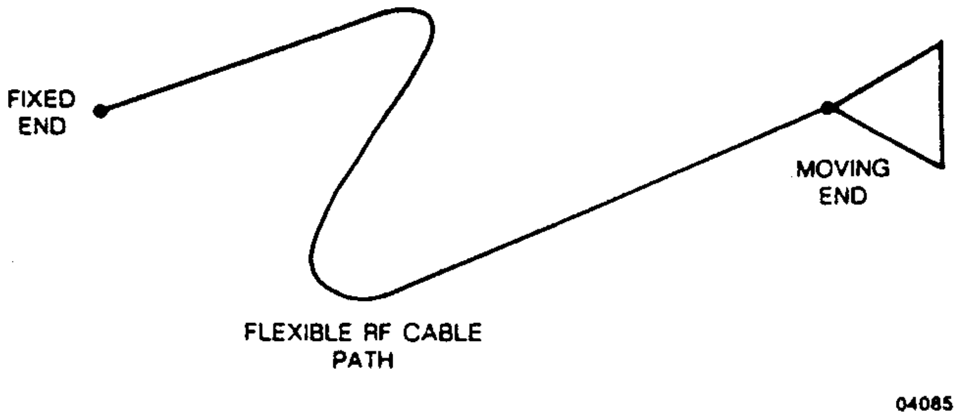

Figure 3. Schematic -
Moving Signal Cable

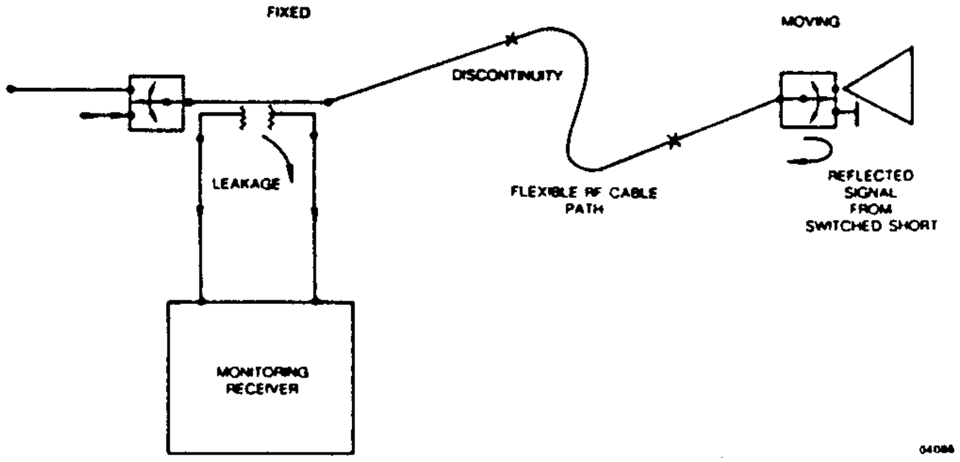

Figure 4. Schematic -
Switched Reflectometer

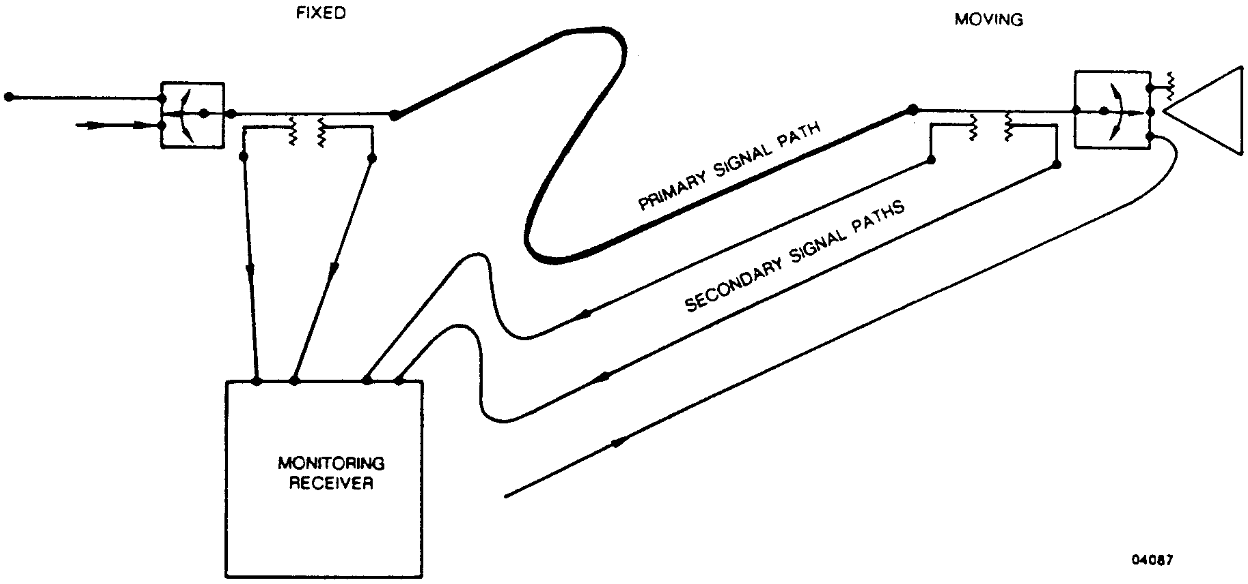

Figure 5. Schematic -
Moving Signal Cable with Monitoring

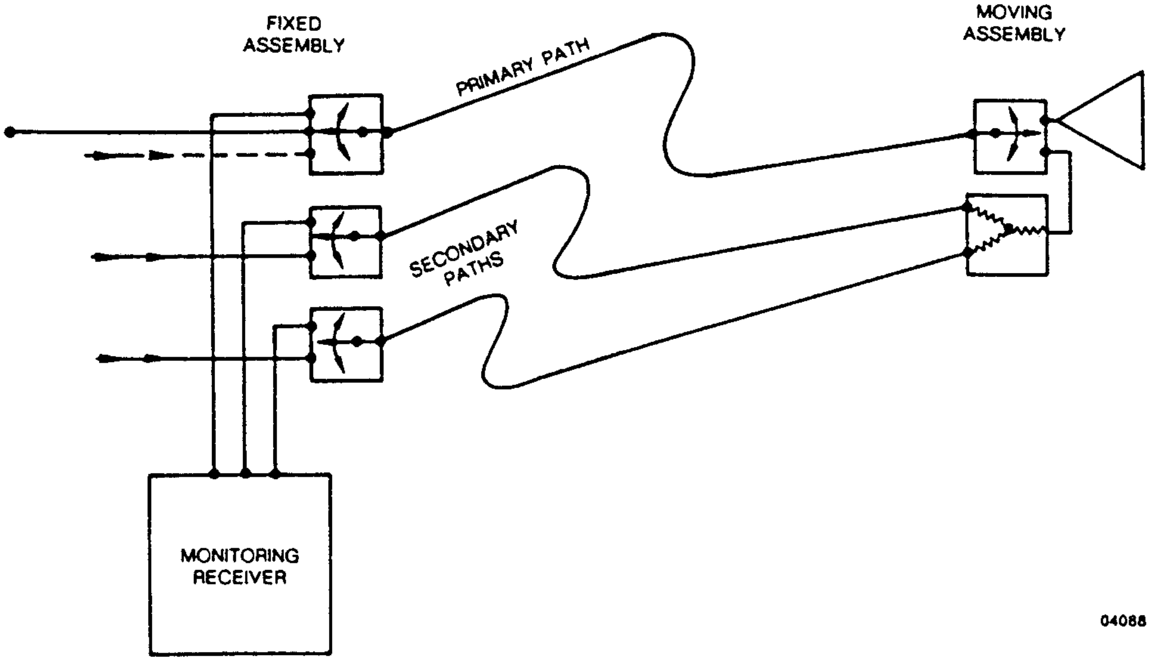

Figure 6. Schematic -
Three-Cable Method with Automatic Switching

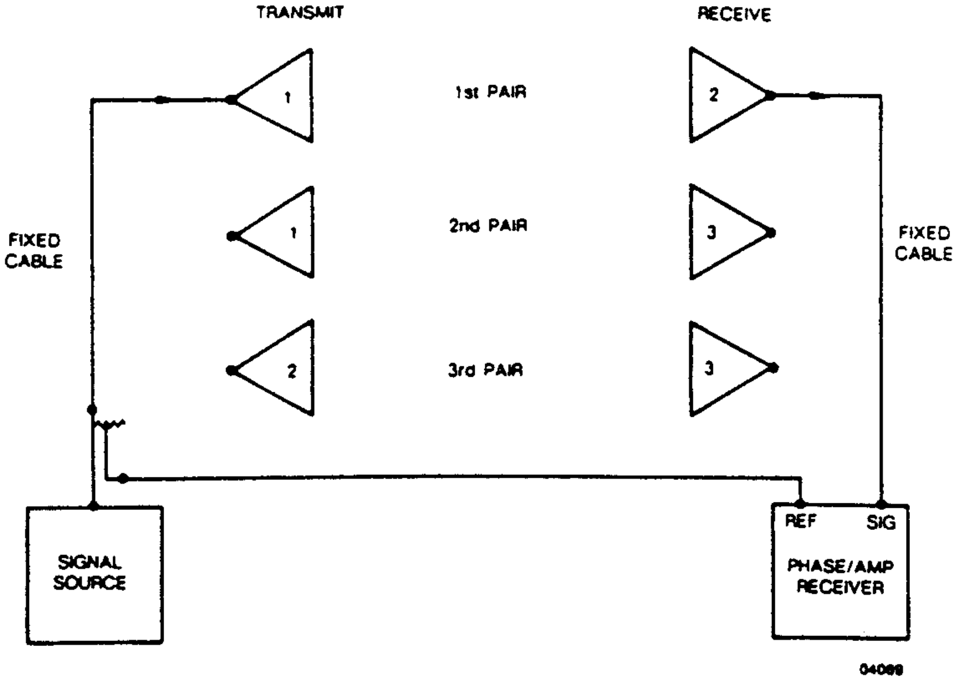

Figure 7. Schematic - Three-Antenna Method

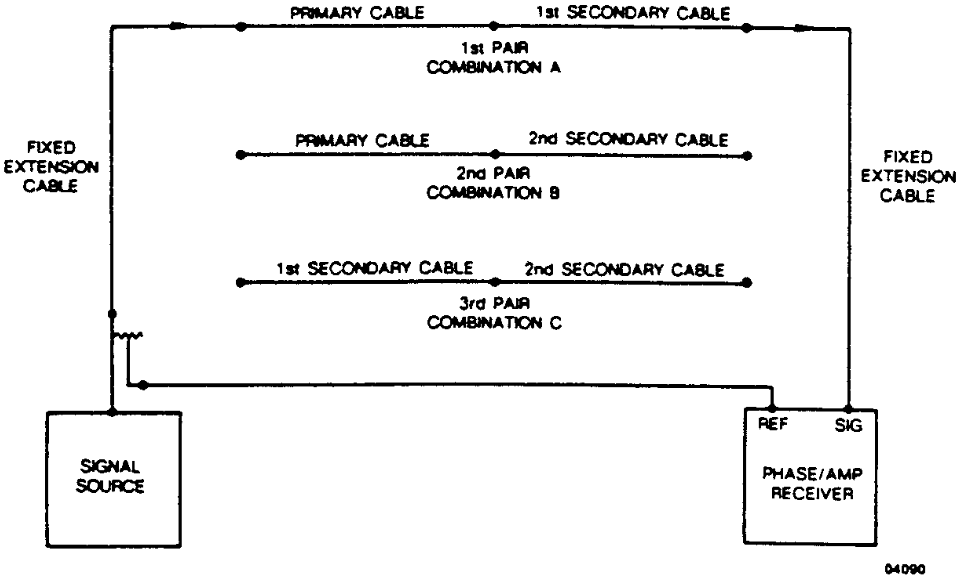

Figure 8. Schematic - Three-Cable Method

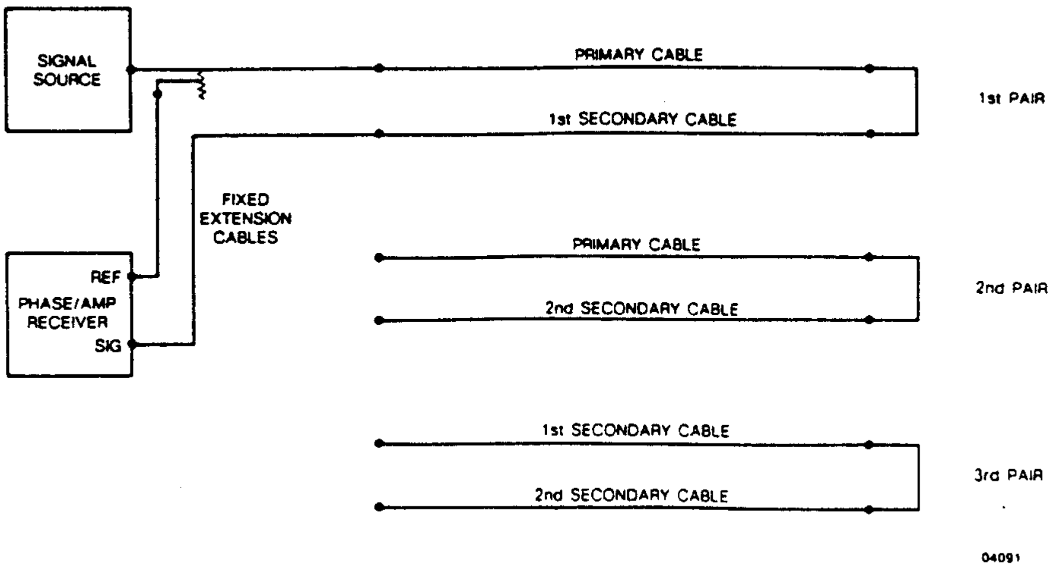

Figure 9. **Schematic -**
Three-Cable Method with Manual Switching