AN IMPLEMENTATION OF THE THREE CABLE METHOD

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ABSTRACT

The three cable method for removing the amplitude and phase variations of microwave cables due to temperature change and movement can offer a substantial improvement in antenna measurement accuracy. Implementation details of the method are provided for a planar near-field range. Items specifically addressed are range configuration, hardware requirements, data collection methodology, identification and assessment of error sources, and data reduction requirements.

Key Words: Antenna Measurements, Error Correction
Near-Field Measurements

1. INTRODUCTION

The three cable method as described by Hess (1) presents the required framework for correction of amplitude and phase measurement errors in an environment where the test apparatus has instabilities due to any combination of movement, time or temperature variations. It is a theoretically universal and robust technique applicable to near-field, far-field, and compact range configurations. Since the method requires no reflection parameter measurements, both amplitude and phase errors can be corrected to levels approaching the uncertainties of typical high level transmission measurements. The following sections will summarize the implementation details and present the validation results of removing a quantified induced error from actual measurements on a planar near-field antenna range.

2. RANGE CONFIGURATION

A three cable correction configuration for operation on a near-field range is shown in Figure 1. It consists of two RF switching networks, the cables themselves, a synthesized signal source and a phase/amplitude receiver. One RF switching network is mounted on the probe carriage close to the near-field probe. The other RF switching network is located at a fixed point at the middle of the scanner base.

The technique is inherently broadbanded although the actual implementation presented in this paper is bandlimited to operation below 12 GHz. The bandlimiting was a result of minimizing the cost of the cables and their losses due to the large size of the near-field scanner. An important benefit of the technique is that it is independent of whether the AUT is tested under transmit or receive conditions. The technique as implemented on this planar near-field range operated in both the AUT transmit and receive modes.

3. SYSTEM REQUIREMENTS

A few critical performance factors must be considered when implementing the correction method. First, the method requires automated measurements. The additional data collection and subsequent data reduction processes eliminate any possibility of a manual implementation. Second, high speed measurements at a continuous rate are needed. This is a requirement for two reasons. The first reason is that the number of measurements required increases by a factor of 2.5 when compared to collecting dual polarized AUT data only. Typical scan speeds and grid point spacings allow only 100 milliseconds per grid point for five measurements at each test frequency or antenna state. Continuous data collection rates exceeding 1000 measurements per second with burst capabilities to 5000 measurements per second are required to provide the throughput expected on modern ranges. The second reason mandating high speed operation lies in time correlation of the measurements. One of the underlying assumptions of the correction theory is that the cable characteristics are random variables which drift over time and are not necessarily repeatable. Although experiments on a particular system may prove that some cables offer repeatable characteristics over time versus movement, the method does not assume it to be true. If the measurements are separated in time from each other, the possibility exists for errors to propagate through the correction process. Therefore, simultaneous measurements of the AUT and cable responses is recommended. This need for minimal time separation between AUT and cable measurements leads to the third critical performance factor, high speed repeatable switching. The RF switching networks used to select the AUT signal or the loopback signals through the three cable pairs must have both a short switching time and a high stability over time and temperature variations.

Finally, one potential drawback of the correction method is that it does not support the use of remote mixers. This is due to the constraint that all the signals through all the cables must be at the actual AUT test frequency. Although cable loss increases in direct proportion to frequency for a given cable size, antenna and scanner sizes tend to decrease in direct proportion to their operating frequency. In general, cable lengths and loss budgets are manageable for the vast majority of near-field range configurations even without the customary advantages of remote mixing.

4. IMPLEMENTATION DETAILS

An implementation of the three cable correction system hardware is shown schematically in Figure 2. In theory the RF path characteristics need not be of the highest quality or identical either in design or construction. However, from a practical standpoint the best configuration utilizes a primary cable which is of the highest quality possible. Secondary cables #1 and #2 can be of a somewhat lesser quality for cost reduction purposes without seriously impacting the results of correction. The use of high quality components, especially phase stabilized low loss cable, reduces the initial amount of error to be corrected and produces the best possible final result. The one vital RF path characteristic is that it must have good "short term" stability. Short term stability is defined by how the test and correction data is collected. It may range from less than 1 millisecond to many hours, depending on how the data collection process is organized. The implementation presented in this paper collected both AUT and cable data at the same time for each grid point, thus requiring stabilities only on the order of 1 millisecond. Measurable cable variations have not been observed in this short time interval. For instance, at a typical 10 cm/sec scanning speed the probe moves less than 0.01 cm while the cable correction data is acquired.

The RF switching units operate cooperatively and perform similar tasks in switching between AUT data collection and cable data collection at the fixed ends and the probe ends of cables. The RF switches are all high speed PIN diode types under direct real time control of the Scientific-Atlanta 2095 Microwave Measurement System. A separate electro-mechanical switch is utilized to allow testing under AUT transmit or receive conditions. An additional RF switch is present in the Probe Switch Unit to allow dual polarized measurements from an orthomode transducer. A one watt power amplifier is used in a separate enclosure at the scanner base to compensate for cable loss. Correspondingly, an LNA is used in the receive path to preserve dynamic range that would be lost due to cable loss. Filters are used to bandlimit the signals to the frequencies of interest and reduce the noise figure compared to a wideband system. Control of reflected signals in the transmission path from multiple interfaces such as connectors and rotary joints is accomplished using isolators. Shielded enclosures are used for the RF switch units to maintain high isolation between paths. Leakage signals would corrupt the small error correction terms that are produced by the technique. Also temperature control of the RF switch enclosures is utilized to minimize thermal drift of amplifiers, couplers, isolators, pads, and mixers.

5. DATA COLLECTION METHODOLOGY

The data collection method used when acquiring both AUT and cable correction data is identical to the standard multi-channel technique used in the Model 2095. All measurement channels are time division multiplexed using a measurement aperture time of 200 microseconds per channel. A total of five channels are required for the planar near-field application. Two channels are used for the dual ported orthomode transducer and three channels are used for the three different cable combinations. All measurements are ratioed to a reference signal to remove any signal source power drift over time. The amplitude and phase fluctuations in the cable paths are collected along with the AUT response. Cable characteristics are only assumed to be stable at each grid point as previously discussed. Therefore only one set of cable measurements are required per frequency regardless of the number of antenna beam states that are tested.

Not only does the technique provide cable corrections to antenna test data, it also offers a method of recording a history of system stability for the entire duration of the data collection process. This data could be later correlated with temperature fluctuations in the range, source power variations, or other monitored parameters. Another important function that the historical data can provide is tracking degradation of moving components over time. Connectors, rotary joints, and cables are subject to wear in a moving system. Comparison of the transmission measurements used in the three cable method can show how the system has changed and aid in the isolation of the degraded components.

6. ERROR SOURCES

Due to the robust nature of the correction algorithm, there are only two general sources of error that the technique cannot eliminate. These are error terms that result from residual instabilities that lie beyond the signal path encompassed by the three cables and effects due to the multiple measurements required to collect the correction data itself. The error terms that are not encompassed by the three cable measurements include amplitude and phase variations that occur in the cabling from the probe to the Probe Switch Unit, the Probe Switch Unit and the RF Switch Unit themselves. Since three additional measurements are required to collect the correction data, the uncertainty associated with these measurements must be included as a potential source of error (2). A system design which maintains the error correction signals at levels close to the peak allowable signal at the receiver will result in the lowest error contributions due to the instrumentation's measurement uncertainty.

Virtually all of the residual system instabilities not eliminated by the three cable method are temperature related. An error budget for a temperature span of four degrees Celsius shows that amplitude errors are reduced from .13 dB to .09 dB compared to the traditional single cable range configuration. Phase errors are substantially reduced from 2.01° to 0.39°. The error components consist of both an ambient and gradient thermal drift. Since these error components are assumed to be uncorrelated, a root sum squared approach is used to arrive at a composite error bound at the peak pattern level. The significant improvement in phase accuracy facilitates accurate alignment of narrow beam phased array antennas on the range.

7. DATA REDUCTION

AUT test data correction utilizing the measurements made on the moving cable assembly is accomplished after a complete data collection process is completed. A post processing algorithm implements the equations developed by Hess (1) to correct both the co-polarized and cross-polarized components of the measured field in both amplitude and phase. This data is then available for further post processing operations such as near-field to far-field transformation or aperture field distribution analysis.

8. MEASUREMENT RESULTS

A verification procedure was designed which tested the ability of the complete hardware and software system to remove a stable and quantified error from a set of near field measurements. The procedure simply introduced a known amplitude and phase offset into one of the three cables in the three cable assembly. A step attenuator was inserted into one of the cable paths and introduced an additional 1 dB of loss and 20 degrees of phase shift during a small portion of one x axis scan. Figures 3 and 4 are data plots which show these offsets in the actual data. Figures 5 and 6 show the offsets in the isolated three cable data. After the error correction process was performed on the perturbed data, it was compared with unperturbed data for the same scan conditions. These results are shown in Figures 7 and 8 and are almost indistinguishable from the non perturbed data. Typical residual errors were 0.01 dB and 0.15 degrees in phase. This performance is greatly superior to that predicted by the error budget. The duration of this test was short compared to that required of a complete near field scan and any temperature variations were not a contributing factor. These residual errors are at a level low enough where the short term uncertainty and repeatability of the system components are the major contributors to error (2).

9. SUMMARY

A successful technique for the implementation of the three cable method for compensation of cable variations described by Hess (1) has been described. An automated system utilizing standard antenna range instrumentation and custom microwave switching networks was used to perform high precision measurements on a planar near- field range. Results analyzed from known introduced errors show that corrected measurements with amplitude deviations less than 0.02 dB and with phase deviations less than 0.25 degree from the ideal values can be produced at X band. The technique has been integrated into the Scientific-Atlanta Model 2095/PNF system for high precision planar near-field measurements.

10. ACKNOWLEDGEMENTS

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11. REFERENCES

1. Hess, Doren W., "Principle of the Three Cable Method for Compensation of Cable Variations", Presented at the 14th AMTA Symposium, Columbus, Ohio, October 1992

2. Caldwell, O. M., "The Effects of Non-Systematic Errors on Measurement Uncertainty", Presented at the 12th AMTA Symposium, Philadelphia, PA., September 1990

FIGURE 1 SYSTEM BLOCK DIAGRAM

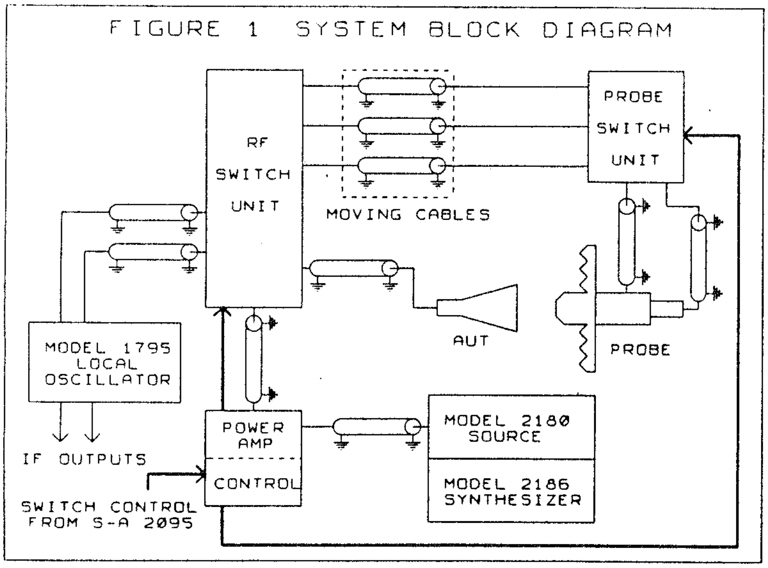
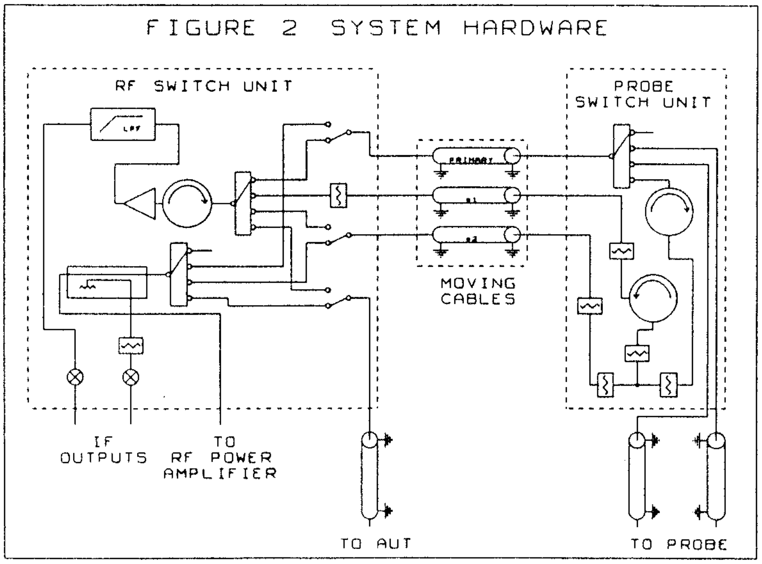


FIGURE 2 SYSTEM HARDWARE



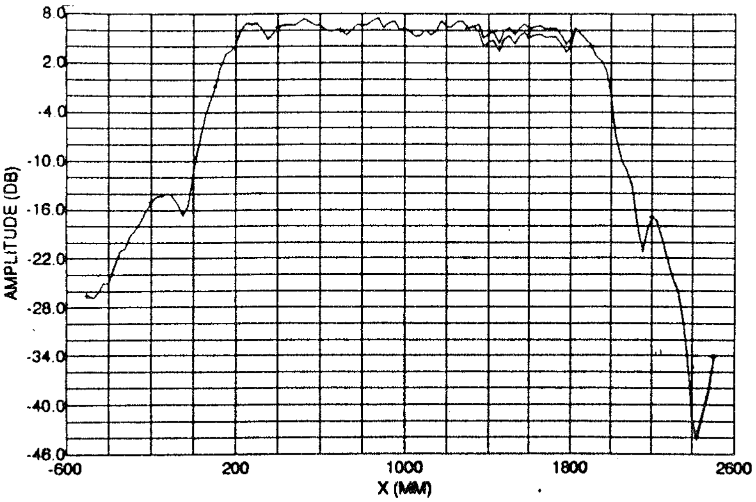


FIGURE 3 - ORIGINAL & PERTURBED NEAR-FIELD AMPLITUDE

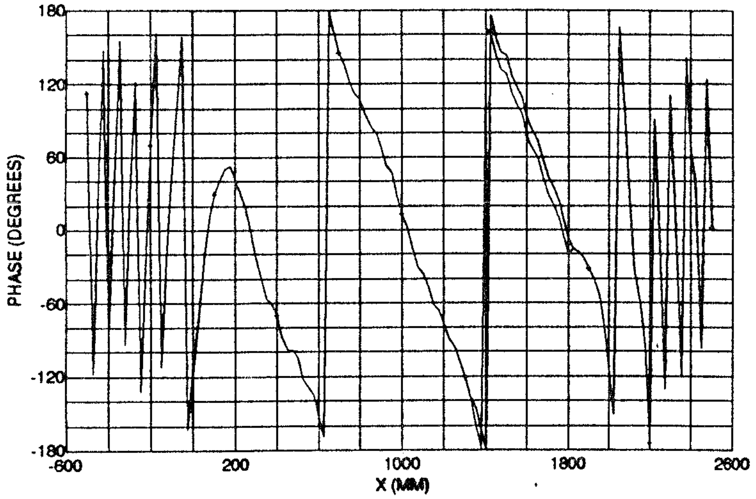


FIGURE 4 - ORIGINAL & PERTURBED NEAR-FIELD PHASE

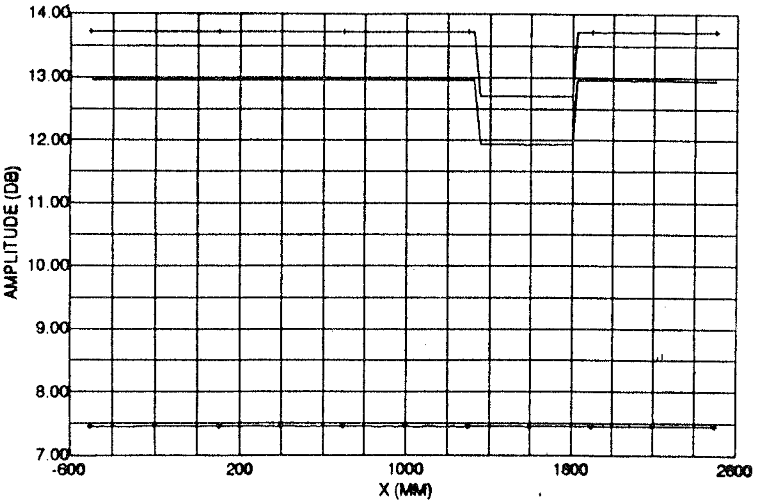


FIGURE 5 - THREE CABLE AMPLITUDE

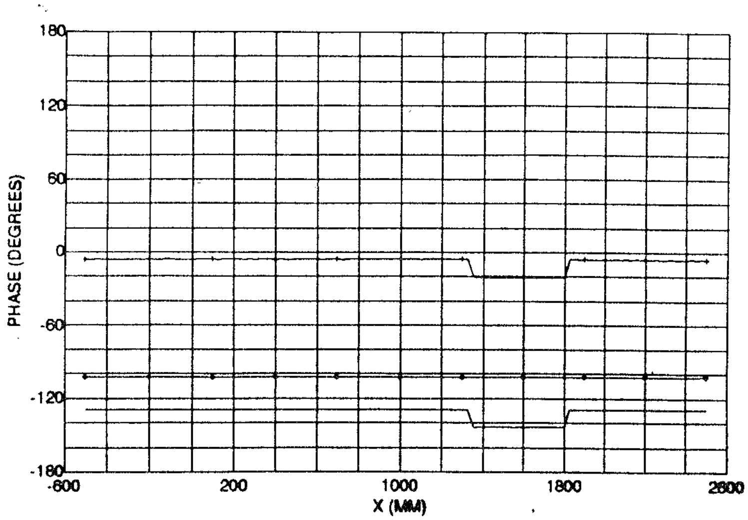


FIGURE 6 - THREE CABLE PHASE

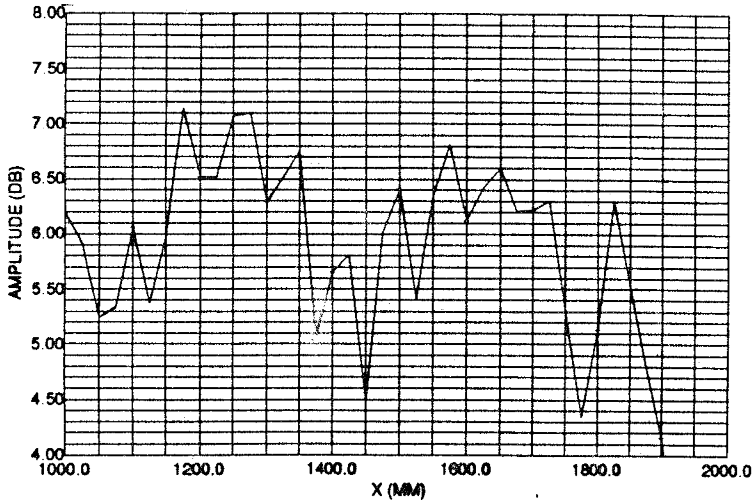


FIGURE 7 - ORIGINAL & CORRECTED NEAR-FIELD AMPLITUDE

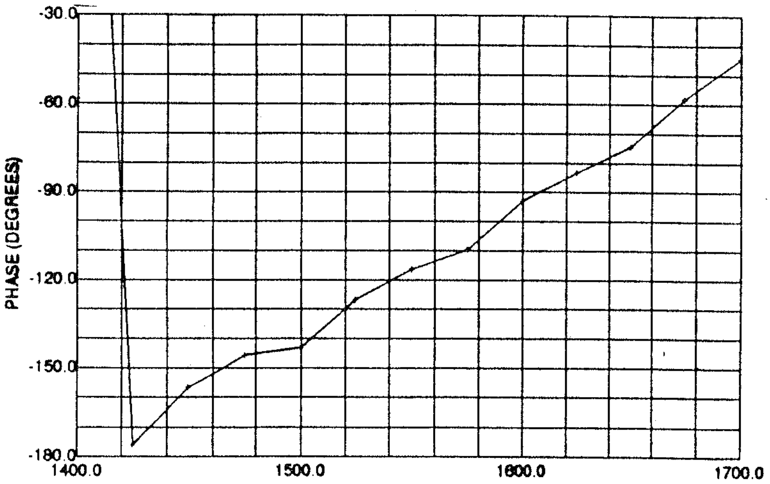


FIGURE 8 - ORIGINAL & CORRECTED NEAR-FIELD PHASE