RESULTS OF A NEW RF CABLE CORRECTION METHOD

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ABSTRACT

As an RF cable is moved during data acquisition, its insertion loss will often change [1-3]. Techniques have been published [1-3] that measure and compensate those changes in insertion loss. Each of these techniques, however, requires stable access to both the signal source and the receiver at one end of the cable bundle. This requirement poses a challenge when trying to compensate a moving RF cable between a receive antenna and a mixer where there are additional axes below the mixer. This paper will show measured results of a new technique developed by MI Technologies to do similar compensation where the source and receiver are at opposite ends of the moving (or otherwise changing) cable bundle. The technique was developed for transmission efficiency measurements on radomes, but also has applicability for quiet-zone field probing or any other scenario where a strong signal is always being received. It requires the use of multiple identical RF cables in the cable bundle, and measures multiple cable combinations to determine the cable characteristics.

Keywords: radome, field probe, cable correction, measurement errors

1. Introduction

The measurement of a radome's transmission efficiency often requires system-level repeatability measured in the hundredths of a dB. This extreme level of fidelity is never easy to achieve.

One of the numerous error sources that can impact this repeatability is a flexing RF cable. Any change in the cable's insertion loss directly affects system repeatability. This paper concentrates on this particular error source, since it proved to dominate in one example radome test facility.

In this example facility, space constraints and required testing capability caused the mixer to be separated from the system antenna by three rotary axes, none of which had rotary joints. In order to scan the radome while keeping the system antenna aligned with the range axis, all three of these axes, plus the azimuth axis below the mixer, were in motion during each scan [4]. Figure 1 below is a conceptual range layout showing the routing of multiple flexible RF cables from the monopulse system antenna, across the antenna positioner axes, to the multiplexer and the mixer. Figure 1 also attempts to convey that the mixer is separated from both the source and the receiver by moving positioner axes.

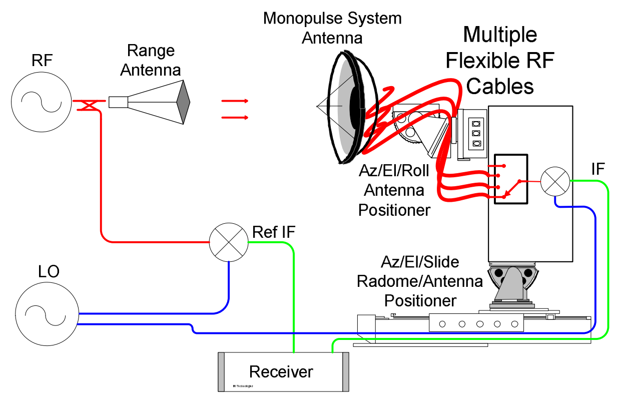

Figure 1 – Conceptual Cabling Diagram

The needs of the system also constrained the RF cables to be very slender and very flexible. Due to the large angular range and the lack of rotary joints on each antenna axis, the cables undergo a tremendous amount of flexure in the course of a radome test. These conditions combine to promote unwanted change in the RF cable characteristics as the positioner axes move.

Even after carefully routing and managing the cable motion, the system repeatability was many times the required level of ±0.04 dB. The dominant error source was the change in the flexing RF cable's loss. Other error sources were present, of course, but could not initially be resolved due to the magnitude of the cable error.

2. Options for Compensation

As indicated in Figure 1, there are multiple flexible RF cables between the monopulse system antenna and the mixer. Only the Sum channel of the monopulse antenna is measured for transmission efficiency, such that all but one of the cables are unused during these measurements. The system antenna is always facing the range antenna during each transmission-efficiency scan, so that there is always a high signal level present.

Several factors prevented the ready implementation of existing methods of cable compensation [1-3]. A new correction method was therefore devised and implemented. As will be shown below, this new method was very effective.

3. Overview of the New Correction Method

Since none of the existing cable-compensation mechanisms were readily applicable to this facility, a new mechanism was required. MI Technologies is not yet ready to disclose the implementation details of this new mechanism. This paper concentrates on the assumptions that must be met, and on the results of the technique.

In order for this new correction method to be appropriate, several conditions or assumptions must be met:

- Multiple identical RF cables are available.
- Perturbation of the multiple cables with motion, temperature, etc., is the same
- Extra RF plumbing is connected so that the necessary measurements can be performed to determine the cables' changing insertion loss
- The characteristics of the extra RF plumbing remain acceptably constant between measurements on the device under test (DUT) and the relevant calibration or reference measurements
- A high signal-to-noise ratio is always present

The data on the multiple cable configurations are obtained at each record increment, so that a new estimate of the cable's complex insertion loss is generated for each point in the scan. The time required for acquisition and processing of the extra data is negligible.

Transmission efficiency of a radome is often computed simply as the point-by-point ratio of data with the radome on to data at the same positioner angles with the radome off [4, 5]. The 'reference acquisition' as defined here indicates the data set containing the denominators of those ratios. The uncorrected (measured) transmission efficiency (TXE) can therefore be expressed as

$$TXE_{Meas}(\theta,\varphi) = \frac{DUT(\theta,\varphi)L(\theta,\varphi,t_{DUT})\varepsilon_2(\theta,\varphi)}{R(\theta,\varphi)L(\theta,\varphi,t_R)\varepsilon_1(\theta,\varphi)}$$

where

the numerator represents the contents of the uncorrected DUT acquired data file

the denominator represents the contents of the uncorrected reference acquired data file

DUT represents power received at the antenna with the radome on

R represents power received at the antenna without the radome, or the reference power level

$(\theta,\ \varphi)$ is the coordinate pair representing an antenna-to-radome aspect (the antenna is always pointing along the range axis)

DUT / R is the true transmission efficiency, which is the ratio of power received by the system antenna with the radome to the power received with no radome

L is the insertion loss of the RF cables

ε represents all other measurement errors

t_{DUT} represents the span of time when the DUT measurements were taken

t_R represents the span of time when the reference measurements were taken

The goal of this compensation is to reduce the contribution of the varying cable loss *L* in each of the DUT and reference measurements. This compensation therefore performs measurements and estimates the value of *L* for each $(\theta,\ \varphi)$ pair, then divides that estimate out of the corresponding point in the measured DUT or reference data as appropriate.

This compensation is not intended to directly address the other measurement errors lumped into the ε terms above. A secondary goal, however, is to reduce the level of the cable-loss errors *L* enough to resolve, if necessary, other error sources in the ε terms.

4. Data

Three data sets are shown below. The first data set was taken over a six-hour duration. The second data set was taken many days later over a 15-hour duration. The final data set was taken just prior to final system acceptance, and was measured over a 13-hour span. Only the corrected output of the final 13-hour data set is shown. In each data set, all DUT data are compared to a single set of reference data taken at or before time zero on each plot.

Figure 2 below shows the system drift measured in the six-hour test without cable correction and without a radome mounted. When transmission efficiency is measured without mounting a radome, the theoretical result is always zero dB. Any non-zero result indicates measurement errors, and any trends in the results represent system drift.

Each dot in Figure 2 represents the average transmission efficiency of the several hundred values in a single DUT acquisition. The reference acquisition for this six-hour data set was the DUT measurement at time zero. The drift at time zero is, therefore, exactly zero dB. Figure 2 clearly shows that errors were present, and also clearly indicates long-term system drift.

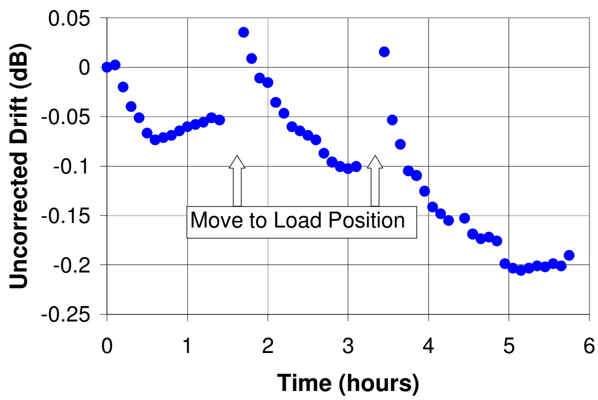

Figure 2 – Drift in Six-Hour Measurement

The acquisition sequence performed several identical acquisitions, and then sent the positioning system to the orientation used for loading or unloading a radome. The positioner was then returned to the test position, and the sequence repeated. The simulated load operations occurred at t=1.5 and t=3.3 in Figure 2. These events coincide with pronounced features in the measured data.

The HVAC system was manipulated during the six-hour test above so that the chamber temperature was cycled through its full normal range, and those temperatures were measured. There is no evidence of clear correlation to the measured temperature in Figure 2.

The general trends of long-term decay and rapid recovery after a loading sequence were repeatable. Figure 3 below shows data taken on a different day over a span of 15 hours. Note that the drift appears not to have stabilized even after 15 hours. Also note that a two-hour delay is not enough to permit the system to return to its initial state after four hours of testing. The reference data set was obtained some time prior to the start of the 15-hour test.

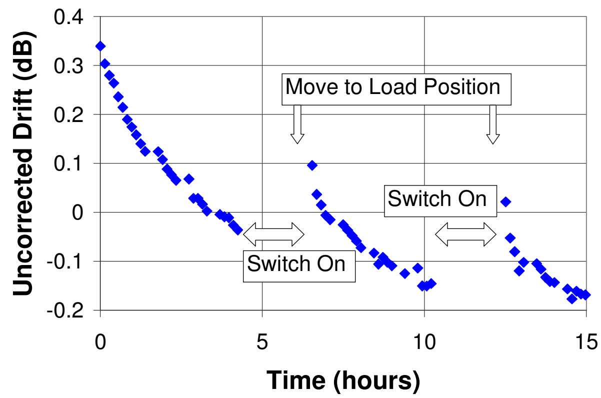

Figure 3 – Drift in 15-Hour Measurement

The chamber temperature was fairly constant during the 15-hour test above. Instead of exercising temperature, this test examined the effects of energizing a fail-safe switch during the two-hour pause prior to the move to the load position. Again, there is no clear indication about the impact of that switch's self heating in Figure 3.

5. Results

The data shown in Figures 2 and 3 above were collected with the extra RF plumbing in place to compensate for cable variations, but the compensation had not yet been performed. Figure 4 below shows the estimate from the six-hour sequence of the change in insertion loss in each flexible RF cable. Each dot in Figure 4 is independent, except that all are relative to the one reference data set at time zero.

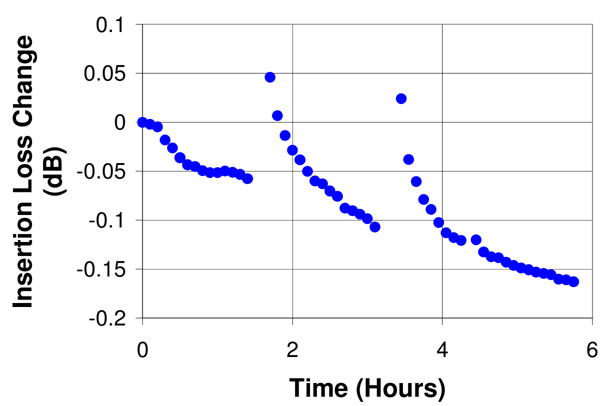

Figure 4 – Change in Cable's Insertion Loss During Six-Hour Test

Figure 5 below shows the transmission efficiency computed after removing the appropriate cable-loss estimates from the DUT and reference data for the six-hour test. Each dot in Figure 5 again represents the average of the drift seen in one acquisition. Recall that the theoretical result is zero for all time, and the requirement was ±0.04 dB. Note that the correction brings this data set nearly within specifications, improving repeatability from a span of 0.24 dB to 0.068 dB. Note also that the sharp features that followed a transition to the radome-load position do not appear in the corrected data, but rather were completely contained in the measured data associated with the cable.

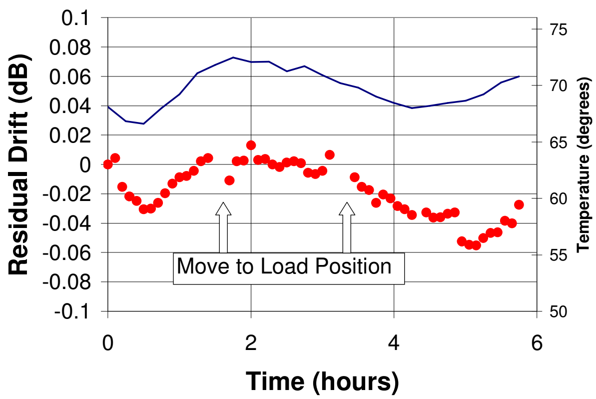

Figure 5 – Residual Drift for Six-Hour Test

The solid line in Figure 5 represents the measured chamber temperature. The residual drift seen in Figure 5 has a component that appears correlated to measured temperature in the range. That apparent temperature dependence was found to be the mixers, and was later improved in hardware to bring the facility within specifications. The correlation to temperature is not nearly so evident in Figure 2's uncorrected data, and has therefore been successfully unmasked by removing the cable characteristics.

The change in insertion loss associated with the 15-hour data in Figure 3 is shown in Figure 6 below. Note the similarity to both the 15-hour data being corrected and the six-hour cable characteristics shown in Figure 4.

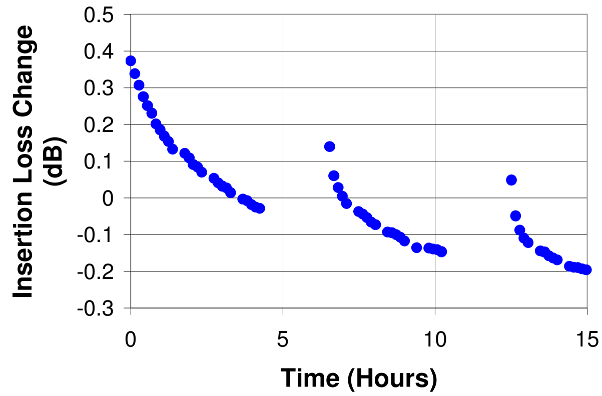

Figure 6 – Change in Cable's Insertion Loss During 15-Hour Test

Figure 7 below shows the residual drift in the 15-hour measurement of Figure 3 after removing the effects of the cable's changing insertion loss. In this case, the correction has improved the repeatability of the data from a span of over 0.5 dB to 0.083 dB. The removal of the cable fluctuations also unmasks the change in the switch's insertion loss due to self-heating. This change appears to be about a 0.05 dB increase in loss that returns to normal about 30 minutes after power is removed from the switch.

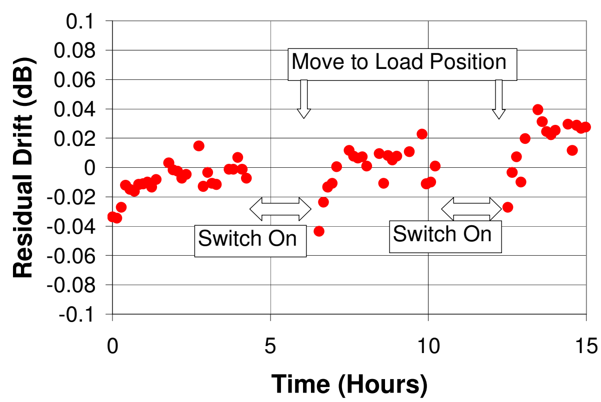

Figure 7 – Residual Drift for 15-Hour Test

Figure 8 below shows the level of drift in the system's final configuration, including automated cable correction. This data set spanned more than 13 hours and included 55 repeated acquisitions. The system was moved to the radome-load position three times during the sequence, an operation that had a very visible and adverse effect prior to the correction. The peak-to-peak fluctuation of the average transmission efficiency over that interval was less than 0.05 dB, or had a range less than ±0.025 dB.

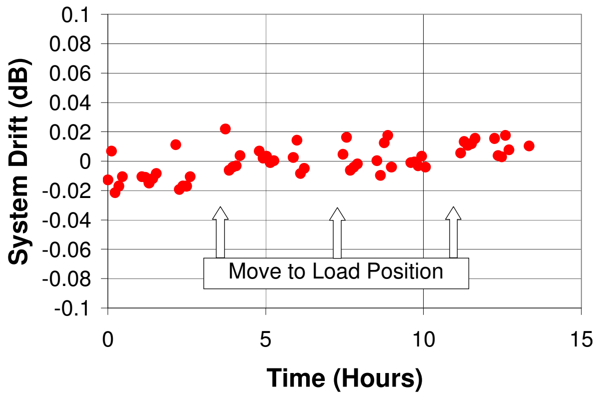

Figure 8 – Final System Stability Achieved

6. Extension to Other Applications

Any application that demands high fidelity and has one or more RF cables in flexure will likely benefit from some form of RF cable correction. The detrimental effects of a changing RF cable remain the same whether the RF cable is at the transmit end or the receive end of the range. Existing mechanisms [1-3] are well suited for cables at the transmit end, with access to both the source and receiver from one side of the moving RF cable.

The new correction mechanism, which was employed in the example system, is intended for configurations where the source and receiver are attached at opposite ends of the RF cable. This new mechanism requires that the received signal always (or at least usually) has sufficient signal-to-noise ratio to avoid injecting noise as cable characteristics. Since the received signal goes through the DUT during DUT measurements, this requirement may exclude some applications.

One application that meets the constraints of this technique is a field probe whose mixer is not located at the probe. A field probe is always pointed at a strong signal, and the moving RF cable (if any) is generally located between the receive antenna and the mixer.

This method might also have applicability for the receive end of a near-field range. Care would be needed in the correction algorithm when measuring portions of the near field with low signal strength. Likewise, this method could be used for general antenna-pattern measurements provided either that the pattern has nulls of sufficiently shallow depth or that care is again taken in the algorithm when the signal level is low.

The measurement of radome transmission efficiency only requires amplitude stability. This new technique should also be able to compensate changes in the cable's insertion phase.

7. Summary

A new technique has been implemented that estimates and compensates the insertion loss of a flexing RF cable. The new technique performs extra measurements involving additional cables with identical characteristics. A key assumption made by this technique is that the multiple RF cables undergo the same change in insertion loss when the cable bundle is flexed. Care must therefore be taken in the cable management to minimize the likelihood of inducing changes in one cable but not the others. The data presented above indicate that this assumption can be met.

This technique has been implemented and fielded. The repeatability and accuracy of the measurements was dramatically improved. This compensation was a primary contributor in meeting the ambitions repeatability requirement of ±0.04 dB, and also unmasked additional error sources for further improvement.

8. REFERENCES

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