A TECHNIQUE TO EVALUATE THE IMPACT OF FLEX CABLE PHASE INSTABILITY ON mm-WAVE PLANAR NEAR-FIELD MEASUREMENT ACCURACIES

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ABSTRACT: The impact of flex cables on mm-wave planar near-field measurements is considered. It is demonstrated how to estimate measurement errors due to these effects and an example is presented. The techniques shown here allows one to evaluate existing antenna test facilities to assess their suitability for mm-wave testing and also shows that flex cables provide very accurate results despite their imperfections.

1.0 INTRODUCTION

It is well known that planar near-field measurements are impacted by flex cable induced amplitude and phase instabilities. Many different techniques have been proposed in the past to counter this problem and these techniques have had various degrees of success. In this paper three methods to evaluate the impact of these amplitude and phase instabilities on measurement accuracy are investigated. These methods are used as evaluation techniques for determining the suitability of an existing measurement setup for doing mm-wave measurements.

In this paper measured amplitude and phase stability data is presented and it is shown how LO phase stability data will impact the RF phase measurement. Using this measured data, it is demonstrated by example what the impact of the phase error is on an antenna radiation pattern in terms of directivity, side lobe level and boresight error uncertainty. These errors are compared to those obtained using an existing error estimate formulation [1] and other simpler approaches (ie. by comparison to a fictitious constant amplitude and phase aperture distribution).

The paper does not focus on techniques to improve phase stability in planar near-field systems but demonstrates how to evaluate the performance of an existing facility.

2.0 MM-WAVE MEASUREMENT SYSTEMS

Since the impact of flex cables are most pronounced for very high frequency applications, the example considered here is that of a V or W-band RF system as shown in Figure 1. In this system there is an RF source, an LO source and two mixers as shown. This diagram represents systems as used on many NSI planar near-field scanners and the antenna under test (AUT) (which in this case is the transmitter) is connected to an RF source that contains a frequency multiplier to provide the required RF signal. The LO source drives both test and reference mixers and is phased locked to the RF source.

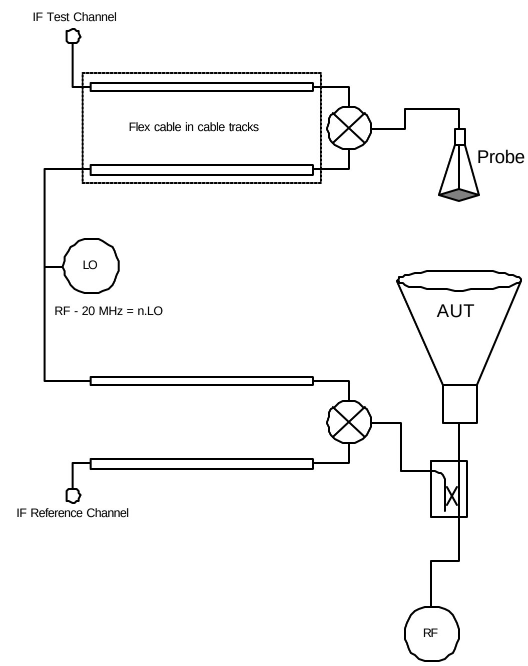

Figure 1: Schematic diagram of the RF system and flex cables.

The test mixer is mounted on the scanner probe carriage and therefore the LO and IF cables as shown in Figure 1 are flexed during scanner motion. Note that in most applications these cables are combined as a single cable carrying both signals which are separated via a diplexer. This cable is routed through the x-axis and y-axis cable tracks and is the object of this discussion. Note that for higher order harmonic mixers, of order *n*, the LO frequency is related to the RF frequency as RF - n.LO = IF.

3.0 MEASURED CABLE DATA

In order to assess the impact of the flex cables described above, loop back cable tests are performed using a very stable coiled semi-rigid feedback cable. This approach introduces the possibility of adding extra cable errors due to movement of the feedback cable, but since this cable is not inserted in the cable track and is hung directly from the probe carriage for the test and therefore is almost not flexed at all during testing, it has been found that the flex cable behavior during movement is dominant. For this test the loop back cable is not taken from the AUT port to the probe port (due to the mm-wave frequencies and associated losses). The approach taken is to measure the effect of the flex cable at the LO frequency of interest, since this would be transmitted on the cable during operation. The higher order harmonic mixing is therefore not used during the cable test and simply fundamental mixing and the test performed at the LO frequency of roughly 4 GHz relevant for the V-band test considered.

The data presented below was obtained for the test setup as described. Cable phase and amplitude data was measured at a frequency of 4 GHz. Further; since the cable flexure is the same along the y-axis for any x position of the scanner and vice-versa, only single axis cuts were taken. Figure 2 shows the amplitude response for both movement along the x-axis (y-axis stationary) and for movement along the y-axis (x-axis stationary). As expected the result is close to 0 dB. Figure 3 shows the phase response for both movement along the x-axis (y-axis stationary) and for movement along the y-axis (x-axis stationary) corresponding to the data shown in Figure 2.

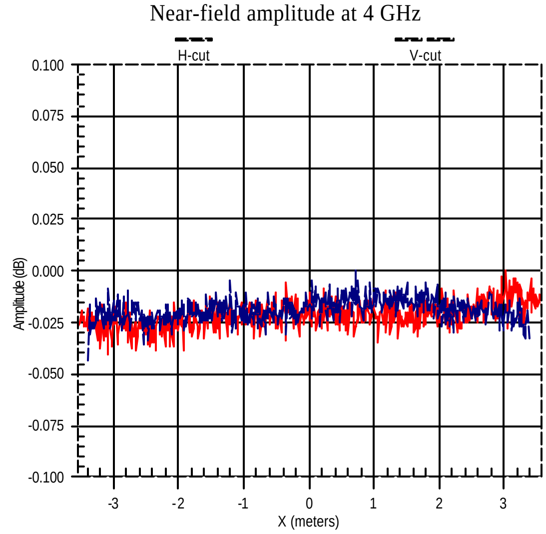

Figure 2: X-axis & Y-axis cable amplitude response at 4 GHz.

These curves should ideally be flat and the effect of the y-axis cable (bottom curve) is clearly visible.

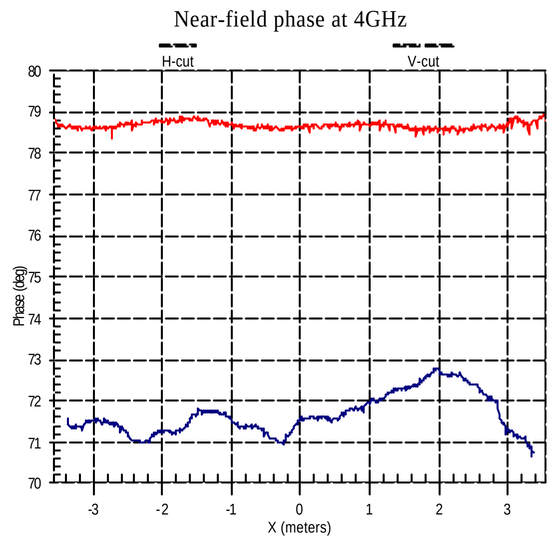

Figure 3: X-axis & Y-axis cable phase response at 4 GHz.

The data shown is for movement of the scanner along the full extent of both axes.

Note that during these tests the effect of the LO cable is most important since it's phase response determines the phase response of the measured signal. The same can of course be said of the IF cable (which may of course be the same cable), but since the IF frequency is at 20 MHz (the difference in frequency between the LO frequency times the harmonic number and the RF frequency) the effect of the cable is much less significant than for the LO cable. The data shown in Figures 2 & 3 therefore demonstrate the importance of cable phase response. (This statement is true for systems where remote mixers are used. When a near-field system uses local mixing (normal VNA approach) the flex cable amplitude response becomes very important and may in some instances be a much tougher problem to solve.)

When one now considers the impact of higher order harmonic mixing (say n'th order), it becomes clear that the phase variation of the LO cable is amplified by factor n. The implication of this is that the phase response as shown in Figure 3 must be amplified by a factor of n to determine the flex cable phase effect at the actual RF measurement frequency.

4.0 ERROR ANALYSIS TECHNIQUES

To now assess the impact of the phase and amplitude variation as shown, three separate approaches are considered here.

Uniform Aperture Comparison

In this technique the impact of the cable amplitude and phase variation is estimated by comparing the far-field data (obtained by transforming the measured loop-back data) to the far-field data of the ideal (no amplitude or phase variation) cable data. One disadvantage of this approach is that for electrically large scan areas a very fine side-lobe structure results and this makes data interpretation and relation to actual measured antenna patterns difficult. In the results shown here, the data area of interest is plotted over a small angular region to amplify pattern differences. A pattern subtraction is also performed to obtain the residual error level shown in Figure 4. Figure 4 therefore shows the far-field radiation pattern in the vertical plane (since this is where one would expect the worst case error due to the y-axis cable phase variation) for the cable data transformed to the far-field at the mm-wave frequency of interest. The two patterns shown are for the ideal case and the measured cable data. Error values of up to –30 dB can be seen close to boresight (note that this number is typically in the order of –40dB to –60dB on a near-field system).

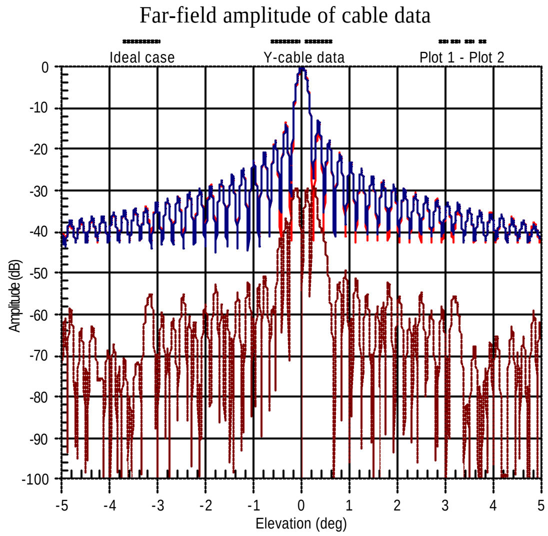

Figure 4: Cable phase response vs. ideal cable response.

Measured Aperture Comparison

Based on the results obtained above, a second more realistic approach to the problem is to evaluate the impact of the cable amplitude and phase variation to the data obtained from an antenna measured in the facility. Since the raw near-field data is available for the antenna, the impact of the cable response can be accounted for before transformation to obtain the far-field data. This is done by adding the cable amplitude response to that of the AUT and multiplying the cable phase response by the harmonic number and then adding that to the phase data of the AUT. In Figures 5 & 6 below the impact of this process is demonstrated on the near-field data for a measured antenna. From the amplitude comparison it is clear that there is no significant change. From the phase data a slight change is detectable (note that the antenna was centered in the facility and therefore the corresponding section of the cable data was used).

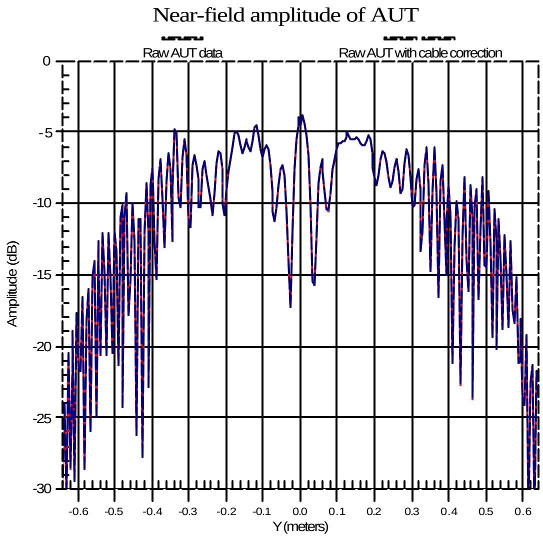

Figure 5: Measured near-field amplitude of AUT with and without cable effect.

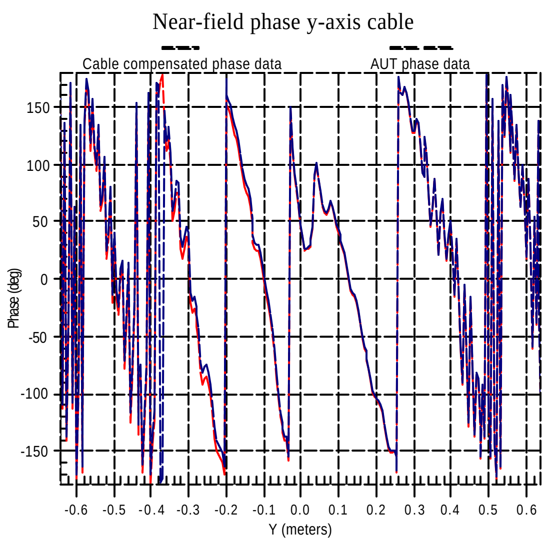

Figure 6: Measured near-field phase of AUT with and without cable effect.

Transforming this data to a far-field elevation pattern results in the data shown in Figure 7 and to a far-field azimuth pattern to that shown in Figure 8. From these patterns (and their corresponding error curves) it becomes clear that the error estimate using this approach seems to be comparable to that shown before in the elevation plane. Error levels of roughly –30 dB are noted in the region of boresight in the elevation plane. The boresight error noted in elevation for the cable effect is 0.01 degrees.

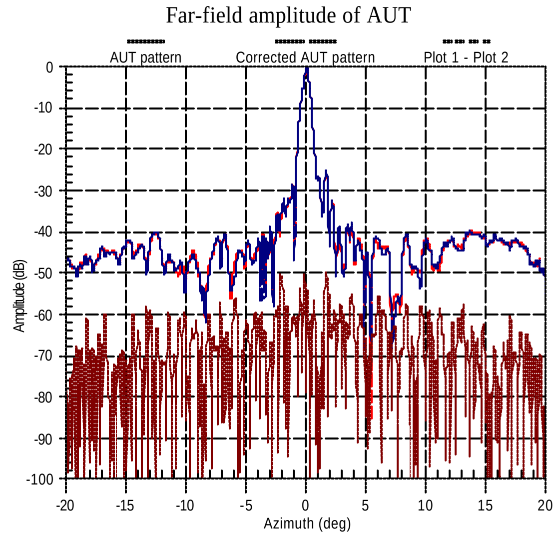

Figure 7: AUT azimuth patterns.

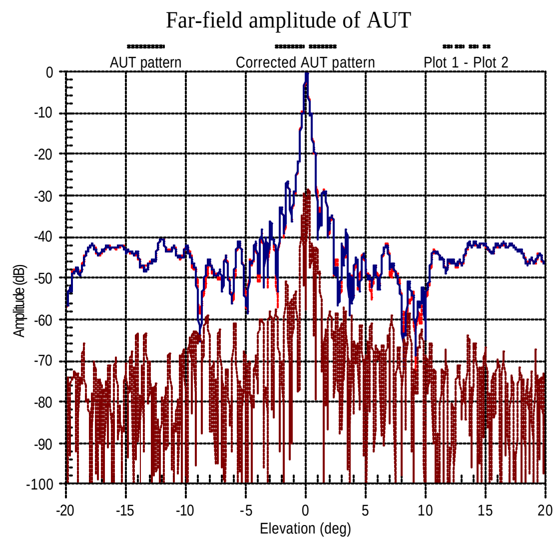

Figure 8: AUT elevation patterns.

NIST 18-Term Error Formula [1]

In [1] the impact of the flex cable on a measurement is also considered. The approach taken there is to do a Fourier analysis of the phase behavior of the cable as a function of probe movement and to obtain an estimate of dominant periodic components. The reasoning being that these components will then produce errors in the sidelobe regions of the antenna. RMS phase errors will then contribute to antenna directivity errors in the far-field. From Eq. 51 in [1] the angle in the elevation plane at which the periodic phase errors will affect the pattern, can be calculated. That equation is:

$$\sin f = \frac{l}{t}$$

Where λ is the wavelength, ϕ is the elevation angle and τ is the period of the component. Performing such an analysis on the phase data for the y-axis cable an RMS phase error of about 8.5 degrees is found, a periodic component of magnitude 6 degrees and period 6.8m, a periodic component of magnitude 6 degrees and period 3.4m and another periodic component of magnitude 0.5 degrees and period 0.1m. Using the equation above, it can be seen that all of these components affect the elevation pattern close to boresight. It is found that these components translate to a worst case error signal level of –37 dB at 0.04 and –37 dB 0.08 degrees off of boresight. (Note that these error signal values are at the RF frequency of interest and not the LO frequency at which the cable test was performed.) This data ties in with what we saw from the previous analyses.

5.0 CONCLUSION

The results presented in this paper demonstrate that mm-wave planar near-field measurements are feasible using flexible coaxial cables. Two methods are presented which allow the evaluation of these cables to determine their suitability for such applications. In this study it was found that flex cable routing and stress free operation is of great importance for accurate and repeatable performance. The results also indicate that accurate far-field data can be obtained at these high frequencies using imperfect coaxial flex cables.

6.0 ACKNOWLEDGEMENT

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7.0 REFERENCES

[1] A C Newell, "Error Analysis Techniques for Planar Near-Field Measurements", IEEE Trans. Antennas & Propagation, Vol 36, No. 6, pp 754-767, June 1988.