Near-Field Test Challenges of High Frequency Digital Phased Array Antennas

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***Abstract* – A hemispherical near-field test system that allows for the AUT to remain stationary is described. Typical structural test data is presented to illustrate the applicability of this type of test system for high frequency (mmWave) cases. Digital data rates for a typical AUT are also presented and it is shown to become restrictive in terms of the maximum throughput achievable during testing.**

***Keywords* — Spherical near-field testing, antenna measurement, digital beamforming.**

I. INTRODUCTION

Digital beamforming antennas and the technology enabling their implementation required the development of unique test systems in the late '90s [1]. Since that time, these antennas have found wide application in the defense industry, and test systems had to keep pace with more challenging requirements [2]. Today, these types of antennas are used commercially and are being implemented at ever higher frequencies of operation.

The testing of these large digital phased arrays presents some unique challenges. These typically include keeping the Antenna Under Test (AUT) stationary during testing and contending with very high digital data rates. The need to keep the AUT stationary can be driven by aspects like the complexity of cabling or cooling systems, minimizing facility high power absorber usage, or the desire to minimize risk to the hardware. Although this can be achieved readily by using a planar near-field test approach, low directivity elements and the need to test these as individual radiators often preclude that solution and dictates a Spherical Near-Field (SNF) test system. Such a solution is described in Section II.

Near-field solutions typically rely on the capability to accurately measure phase. For higher frequency AUT's, this determines not only RF system fidelity but also the structural integrity of the scanner. Being able to maintain this structural integrity during motion is crucial and measured data for the system described here is presented in Section III.

Finally, output from these digital phased array antennas can be overwhelming when compared to traditional analog-based receiver systems. Ensuring the acquisition subsystem is capable of these data rates is essential and this aspect is addressed in Section IV.

II. SPHERICAL NEAR-FIELD SYSTEM

A spherical near-field scanner allowing an AUT to remain stationary is depicted in Fig. 1. Steel columns support an upper rotation stage that forms the vertical ϕ axis of a spherical coordinate system. Attached to this rotator is an arch structure that allows for 95° of probe carriage motion and forms the θ axis of the SNF acquisition system. The scanner specifications are shown in Table I.

Fig. 1 Hemispherical near-field scanner allowing AUT to remain stationary

TABLE I HEMISPHERICAL SCANNER SPECIFICATIONS

Parameter	Specification
Probe radial distance	1.2 m
Maximum probe weight	22.6 kg
Angular scan area	0 - 360° in ϕ and 0 – 95° in θ
Position accuracy (RMS)	0.01° in ϕ and 0.002° in θ
Rotational Speed	30°/s in ϕ and 6°/s in θ

III. STRUCTURAL DATA

Near-field testing requires very tight spatial tolerances for probe location to ensure accurate near-field data and associated far-field performance. Two production systems (as depicted in Fig. 1) were built and subsequently characterized for position accuracy. A summary of this data is presented in Table II. The three relevant spherical coordinate variables (θ,ϕ,r) were evaluated. Native (uncorrected) and corrected (through structure positioning adjustment) test results are shown.

Also shown in Table II are probe radial distance variations during rotation of the ϕ stage at three different angular velocities. At the highest angular velocity, a value of 0.04 mm RMS is measured, which is an indication that these structures would allow for testing up to a frequency of 75 GHz if a 1/100λ radial tolerance is assumed acceptable.

TABLE II SNF SCANNER STRUCTURAL TEST DATA SUMMARY

Parameter	**Unit 1 [+/-]**	**Unit 1 [RMS]**	**Unit 2 [+/-]**	**Unit 2 [RMS]**
ϕ accuracy [deg]	0.033	0.009	0.040	0.011
θ accuracy [deg]	0.022	0.010	0.017	0.010
r deviation at grid points only [mm]	0.176	0.070	0.219	0.084
ϕ corrected accuracy [deg]	0.012	0.004	0.024	0.008
θ corrected accuracy [deg]	0.007	0.001	0.010	0.002
r corrected deviation at grid points only [mm]	0.029	0.006	0.059	0.024
r corrected deviation at 6°/s	0.075	0.014	0.102	0.032
r corrected deviation at 18°/s	0.141	0.022	0.117	0.031
r corrected deviation at 30°/s	0.232	0.040	0.205	0.044

IV. DIGITAL ACQUISITION DATA RATE

Digital phased array antennas that have a receiver embedded on each receiving element typically generate a data stream of I and Q pairs. As an example, we consider an antenna with 1500 elements (variable N_e), each with its own receiver, and each receiver performs its own integration over multiple samples but provides a single IQ combination per measurement point. We assume that during the measurement there are 100 frequencies (variable N_f) to be measured; and for each frequency, there is a near-field probe to AUT measurement, a reference measurement (where the RF signal is injected directly into the AUT through a separate coax connection) and a leakage measurement (no signal at the probe, nor through the reference channel). Using a dual-polarized probe, the reference and leakage measurement can be done simultaneously for the two polarizations, resulting in a total of four measurements (variable N_m) for two polarizations, reference signal, and leakage signal. This leads to

$$(N_e+1)N_fN_m = 600{,}400 \qquad (1)$$

samples per AUT/probe measurement. With each IQ sample consisting of 32 bits, this dictates about 20 Mb per AUT/probe measurement. If we now consider an angular sampling density of 2° (based on the electrical size of the AUT) and calculated as outlined in [3], and the scanning axis is the ϕ axis and this rotates at 30°/s, a sustained data stream of 20 Mb x 30/2 = 300 Mb/s needs to be supported.

For a 2° sampling density, assuming we use the full scan range of the scanner, an SNF measurement will contain 8,688 probe/AUT measurements, which in turn will yield a total of 5,216,275,200 IQ pairs to be recorded. This leads to a measurement file of roughly 21 GB in size.

Of the numbers mentioned, the 300 Mb/s data rate may be problematic and will certainly require components that support Gigabit rates. This example illustrates how digital phased arrays and the data stream emanating from them can dictate the instrumentation required to support the mechanical acquisition system. If this is not feasible, slowing down the scanning axis may be required and is often done in practice.

V. CONCLUSION

This paper addresses unique challenges that one encounters when testing large digital phased arrays. These include the restriction of not being able to move the antenna during testing, measuring elements of low directivity, the structural challenges that high frequencies impose, and the data rate one has to contend with when testing such arrays.

An example is presented of an SNF scanner with high structural fidelity that meets these needs. Structural data of actual production scanners, as measured for two units, are presented.

The paper also addresses the question of digital data acquisition rate that can be limiting when measuring such arrays and highlights the challenges by presenting typical numbers.

REFERENCES

[1] M. Tanabe & D. S. Fooshe, “Digital Beam-Forming Antenna Range”, AMTA 22nd Annual Meeting & Symposium, Philadelphia, Pa., USA, Nov. 2000.

[2] S. T. McBride, “An interface between a near-field acquisition system and active arrays with digital beamformers”, AMTA 34th Annual Meeting & Symposium, Seattle, WA, Oct. 2012.

[3] C. Parini, S. Gregson, J. McCormick & D. Janse van Rensburg, Theory and Practice of Modern Antenna Range Measurements, London, UK: The Institute of Engineering and Technology, 2014.