SPHERICAL NEAR-FIELD ANTENNA MEASUREMENT NOTE: INSERTION LOSS GAIN MEASUREMENT

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ABSTRACT

This note highlights the connection of antenna gain to the measurement of insertion loss based on established SNF formulations, relating directly among antenna transmission coefficients, antenna gain, acquired SNF raw scan data and the parameters acquired during a range insertion loss measurement. It shows how the measured insertion loss parameters are applied in normalizing raw SNF scan data in determining antenna gain.

Keywords: Gain, Spherical Near-Field, Range.

1. Introduction

Spherical near-field (SNF) antenna measurement theory supports antenna gain determination through range insertion loss measurement. As an absolute antenna gain measurement method, temptation of its application in routine antenna measurement grows stronger with proliferation of SNF antenna measurement. For many end users of a SNF system, however, the connection between antenna gain and measurement of scan data and insertion loss may not always be immediately obvious, given the complexity of SNF theory and formulations involved. This may results in confusion, misunderstanding, even misuse when applying this method in the practice of antenna gain measurement.

This note highlights the connection of antenna gain to the measurement of insertion loss, relating directly among antenna transmission coefficients, antenna gain, acquired SNF raw scan data and the parameters acquired during a range insertion loss measurement. It shows how the measured insertion loss parameters are applied in normalizing raw SNF scan data in determining antenna gain. To achieve the above, we first review in the first part of this paper some of the formulas derived in [1] by Hansen. This review serves as a necessary basis for discussing the relationship of gain and insertion loss parameters, as well as their measurement practice introduced in the following sections.

2. Review of the Formulation

In [1], SNF transmission formula is given by Hansen in his equation 3.10 as,

$$\frac{w(A,\chi,\theta,\varphi)}{v} = \frac{1}{2}\sum_{\substack{smn\\ \sigma\mu\upsilon}} T_{smn} e^{im\varphi} d^{n}_{\mu m}(\theta) e^{i\mu\chi} C^{sn(3)}_{\sigma\mu\upsilon}(kA) R^{p}_{\sigma\mu\upsilon} \qquad (1)$$

where w is the outgoing wave received at the probe port. v is the incoming wave transmitted at the port of the antenna under test (AUT). Both w and v are marked in Figure 1. T_{smn} is the transmitting coefficients of the AUT. Refer to [1] for definitions for the rest of the variables in the transmission formula.

An AUT's transmit characteristics are completely described by T_{smn}[1]. From it, one can derive all common antenna parameters, including antenna patterns, directivity and gain. Once the left side of equation (1), $\frac{w}{v}$, is known, T_{smn} can be computed through a series of mathematical transformations and manipulations.

AUT directivity D_T can be computed using Hansen's equation 2.208 [1]

$$D_T(\theta,\varphi) = \frac{\left|\sum_{smn} T_{smn}\vec{K}_{smn}(\theta,\varphi)\right|^2}{\sum_{smn}\left|T_{smn}\right|^2} = \frac{\left|\sum_{smn} (CT_{smn})\vec{K}_{smn}(\theta,\varphi)\right|^2}{\sum_{smn}\left|(CT_{smn})\right|^2} \qquad (2)$$

where C is a constant, and $\vec{K}_{smn}$ is the far-field pattern functions. Equation (2) shows that directivity can be obtained not only from T_{smn}, but also CT_{smn}.

Multiplying both sides of equation (1) with C, we have

$$C\frac{w(A,\chi,\theta,\varphi)}{v} = \frac{1}{2}\sum_{\substack{smn\\ \sigma\mu\upsilon}} (CT_{smn}) e^{im\varphi} d^{n}_{\mu m}(\theta) e^{i\mu\chi} C^{sn(3)}_{\sigma\mu\upsilon}(kA) R^{p}_{\sigma\mu\upsilon} \qquad (3)$$

Equation (3) shows that, when only interested in directivity or relative antenna patterns, one needs to

[1] Equation (1) characterizes AUT's transmit properties only. Scattering and reflection are ignored.

measure $\frac{w}{v}$ accurate only to a proportional factor C, that is, $C\frac{w}{v}$.

Using the input-output probe concept, one can find the output probe's far fields response $w_{farfield}$ with sufficiently large output radius A_{out} [1],

$$\begin{aligned} w_{farfield}(A_{out},\chi,\theta,\varphi) &= w_{out}(A_{out},\chi,\theta,\varphi) \\ &= v\sum_{\substack{smn\\ \mu}} T_{smn} e^{im\varphi} d^n_{\mu m}(\theta) e^{i\mu\chi} P^{out}_{s\mu n}(kA_{out}) \end{aligned} \quad (4)$$

Hansen's equation 3.67 [1] relates $w_{farfield}$ to antenna gain G_T,

$$\frac{\frac{1}{2}\left|w_{farfield}\right|^2}{\frac{1}{2}\left|v\right|^2} = \frac{G_T G_{p(out)}}{4(kA_{out})^2} \quad (5)$$

Or

$$\frac{\frac{1}{2}\left|w_{out}\right|^2}{\frac{1}{2}\left|v\right|^2} = \frac{G_T G_{p(out)}}{4(kA_{out})^2} \quad (6)$$

where $G_{p(out)}$ is the output probe's gain. Substitute (4) into (6), we obtain

$$\left|\sum_{\substack{smn\\ \mu}} T_{smn} e^{im\varphi} d^n_{\mu m}(\theta) e^{i\mu\chi} P^{out}_{s\mu n}(kA_{out})\right|^2 = \frac{G_T G_{p(out)}}{4(kA_{out})^2}$$

or

$$G_T = 4\frac{(kA_{out})^2}{G_{p(out)}}\left|\sum_{\substack{smn\\ \mu}} T_{smn} e^{im\varphi} d^n_{\mu m}(\theta) e^{i\mu\chi} P^{out}_{s\mu n}(kA_{out})\right|^2 \quad (7)$$

Equation (7) shows that, to determine gain, one must know T_{smn}, which in turn requires an absolute measurement of $\frac{w}{v}$ according to equation (1).

3. Measurement of $C\frac{w}{v}$, $\frac{w}{v}$ and Insertion Loss

It is obvious that $C\frac{w}{v}$ and $\frac{w}{v}$ can be obtained through measurement of w and v. It is however rarely a good practice to determine a ratio by measuring its denominator and numerator separately, as it tends to introduce excessive uncertainties. Besides, in a typical SNF measurement setup, it may not be practical to directly measure either w or v. Instead, routine measurement is made of V_{RX}, the RF signal at the receiver located further down from w, as shown in Figure 1. Separating between w and V_{RX} are cables, connectors, and possibly other RF components such as rotary joint, attenuators, couplers and amplifiers etc. In Figure 1, we lump them all into one single constant c_2. The value of c_2 does not have to be known, as long as it remains constant over RF levels of interest. We then have

$$V_{RX}(A,\chi,\theta,\varphi) = c_2 w(A,\chi,\theta,\varphi) \quad (8)$$

Substitute w in (8) into (1), we get

$$\frac{V_{RX}(A,\chi,\theta,\varphi)}{vc_2} = \frac{1}{2}\sum_{\substack{smn\\ \sigma\mu\upsilon}} T_{smn} e^{im\varphi} d^n_{\mu m}(\theta) e^{i\mu\chi} C^{sn(3)}_{\sigma\mu\upsilon}(kA) R^p_{\sigma\mu\upsilon} \quad (9)$$

Usually, v remains unchanged during a measurement. We can then lump the two unknown constants, c_2 and v, into a single constant C where $C=vc_2$. Multiplying both sides of equation (9) with C, we obtain

$$V_{RX}(A,\chi,\theta,\varphi) = \frac{1}{2}\sum_{\substack{smn\\ \sigma\mu\upsilon}} (CT_{smn}) e^{im\varphi} d^n_{\mu m}(\theta) e^{i\mu\chi} C^{sn(3)}_{\sigma\mu\upsilon}(kA) R^p_{\sigma\mu\upsilon} \quad (10)$$

As we can see, un-normalized SNF scan data V_{RX} is sufficient for the determination of CT_{smn}, which is in turn sufficient for the determination of relative antenna pattern and directivity, as we saw earlier.

On the other hand when antenna gain is of interest, one must measure $\frac{w}{v}$. Determination of $\frac{w}{v}$ may be facilitated via a so-called insertion loss measurement, where $V_{RX}o$ is measured. Referring to Figure 1, $V_{RX}o$ is the RF signal at the receiver when the AUT, the space and the probe is substituted with a known attenuation IL_o. In essence, in an insertion loss measurement, one obtains the values for both $V_{RX}o$ and IL_o.

Let's see in the following how these two values $V_{RX}o$ and IL_o make it possible to determine antenna gain. Refer to Figure 1, we see that

$$V_{RX}o = c_2 IL_o v \quad (11)$$

Or

$$v = \frac{V_{RX}o}{c_2 IL_o} \quad (12)$$

Divide (8) by (12), we have

$$\frac{w(A,\chi,\theta,\varphi)}{v} = IL_o\frac{V_{RX}(A,\chi,\theta,\varphi)}{V_{RX}o} \quad (13)$$

Note that c_2 has been divided out. Substitute the above into (1), we obtain

$$IL_o \frac{V_{RX}(A,\chi,\theta,\varphi)}{V_{RX}o} = \frac{1}{2}\sum_{\substack{smn\\ \sigma\mu\upsilon}} T_{smn} e^{im\varphi} d^{n}_{\mu m}(\theta) e^{i\mu\chi} C^{sn(3)}_{\sigma\mu\upsilon}(kA) R^{p}_{\sigma\mu\upsilon} \tag{14}$$

This equation shows that the raw SNF scan $V_{RX}(A,\chi,\theta,\varphi)$, normalized with values of $V_{RX}o$ and IL_o, allows for the determination of T_{smn}, therefore the determination of gain using equation (7).

4. Conclusion

Equation (14) together with (7) establishes that a simple normalization of raw SNF scan data with $V_{RX}o$ and IL_o changes an antenna measurement from a relative to an absolute measurement, and in particular, enables an absolute antenna gain determination. With the probe and the AUT being in close proximity in a SNF range, measurement of $V_{RX}o$ and IL_o is not only practical but also convenient. Further more, for a given range, at least in theory, such measurement only needs to be performed once. The insertion loss measurement technique therefore affords potentially simple, convenient and powerful technique for determining absolute antenna gain.

One should be mindful however that, despite its simplicity and elegance offered by the theory, harnessing full potential of insertion loss antenna gain measurement in practice can be quite challenging. Those challenges may manifest in many different ways, in particular, when one is pursuing a high accuracy antenna gain measurements. Many common, otherwise innocuous, measurement errors can hinder one's effort in achieving the desired gain accuracy. Some of the measurement errors are associated with the insertion loss measurement, which includes those in attenuation measurement, additional mismatches, cable flexing, rotary joint repeatability, repeatability associated with operation in connection, disconnection and reconnection, and so on [2]. Other errors come from a SNF model that may not take into account antenna-probe multiple reflections and scattering. Therefore, an accurate determination of antenna gain using a range insertion loss measurement requires both a qualified SNF model including its probe model, and meticulous measurement practice.

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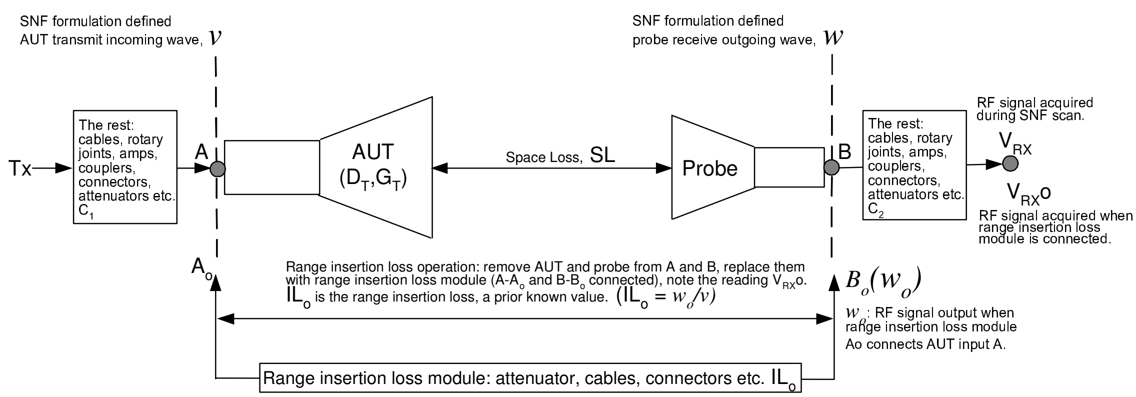

Figure 1 Illustrate parameters involved in SNF antenna measurement and range insertion loss measurement