

# EIRP & SFD MEASUREMENT METHODOLOGY FOR PLANAR NEAR-FIELD ANTENNA RANGES

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## ABSTRACT

**EIRP (Equivalent Isotropically Radiated Power) and SFD (Saturating Flux Density) are two system level parameters often sought during test campaigns. Measurement of these under far-field conditions is well defined and common. Although valid techniques for measuring these parameters on near-field ranges exist, these techniques are not commonly used. This paper presents measurement techniques for both parameters in detail in an attempt to illustrate the process. The techniques presented are also valid if the source (in the EIRP case) or receiver (in the SFD case) ports of the device under test are inaccessible.**

**Keywords:** Planar near-field, EIRP, Satellite, SFD

## 1. Introduction

Equivalent Isotropically Radiated Power (EIRP) and Saturating Flux Density (SFD) are two system level parameters often measured during characterizing of spacecraft systems. EIRP is of interest for transmitters and SFD for receivers. Although measurement of both parameters is simple if one has access to the source or receiver ports respectively, this is often not the case with integrated systems. In such instances the Friis transmission equation [1, p. 62] is used and if the separation distance and the receiving antenna gain values are known, the EIRP or SFD can be calculated. However, this approach requires far-field conditions to be met and since many spacecraft are tested in near-field ranges, measurement techniques for both parameters are desired.

A solution to this problem for the planar near-field (PNF) case was presented in [2 & 6] and an implementation for the EIRP portion thereof was reported on in [3]. Despite this information being available, the measurement of both parameters in PNF ranges has not found wide-spread application. This may be partly due to the complexity of the mathematical formulations and the fact that their implementation is not immediately obvious.

In what follows we attempt to demystify the expressions for both EIRP and SFD as presented in [2 & 6] and also offer step by step measurement processes as they would apply to commercially available antenna measurement software [4].

In Sections 2 and 3 below, we review the formal definitions of these two parameters and the associated far-field measurement approaches. We then present the specific near-field formulations for both EIRP and SFD. In Section 4 we present step by step measurement procedures for both of these terms and in Section 5 verification results for both parameters are presented.

## 2. EIRP

EIRP is a system power parameter and is obtained from the product of the antenna gain and the net input power accepted by the antenna [1]. Alternatively we can state that the EIRP quantity is the power that an isotropic radiator will have to transmit to lead to the same power density that the AUT will affect at a specific angle of interest. If we consider the polarisation matched case of the Friis transmission equation, we can write

$$\frac{P_r}{P_t} = (1 - |\Gamma_t|^2)(1 - |\Gamma_r|^2) \left(\frac{\lambda}{4\pi R}\right)^2 G_t G_r$$

Where,  $P_r$  denotes the power received,  $P_t$  denotes the power transmitted, and  $G_{t/r}$  are the gains of the transmit and receive antennas. When we assume that our AUT is the transmitter, then we can write the EIRP as,

$$EIRP = P_t G_t (1 - |\Gamma_t|^2) = \left(\frac{4\pi R}{\lambda}\right)^2 \frac{P_r}{(1 - |\Gamma_r|^2) G_r}$$

Thus, a very convenient measurement technique is to set up a standard gain antenna as receiver in the far-field of our AUT and to then determine EIRP by measuring the power at the port of the standard gain receiving antenna. Since the distance is known, the EIRP can be calculated. The convenience of this approach is that the AUT can remain intact and no port disconnection is needed. A near-field EIRP technique as it applies to the planar coordinate system is presented in [2, eq. 32 & 6, eq. 171] repeated here for convenience (version from [6]),

$$EIRP(\overline{K}_0) = \left(\frac{4\pi}{\lambda^2}\right)^2 \frac{|1 - \Gamma_t \Gamma_r|^2}{(1 - |\Gamma_t|^2)(1 - |\Gamma_r|^2)} \frac{P_0(x_0, y_0) \left| \delta_x \delta_y \sum B'_0(\overline{P}_i) e^{j\overline{K}_0 \cdot \overline{P}_i} \right|^2}{G_r(\overline{K}_0)} \left(\frac{k_z}{k}\right)^2$$

$$S_0 = \frac{P_i G_S}{4\pi d^2}$$

In this equation  $\overline{K}_0$  is a vector indication the direction in which the EIRP is sought (usually orthogonal to the scan plane). Variable  $P_0(x_0, y_0)$  is a power value measured with a power meter connected to the near-field probe, located at the reference position  $(x_0, y_0)$ . The reflection coefficients  $\Gamma_t$  &  $\Gamma_r$  are for the power meter and the probe respectively and the term above containing these coefficients simply serves as a mismatch correction term. The variable  $G_r$  denotes the probe gain as it would apply in the direction  $\overline{K}_0$ . The summation in this equation represents a discrete Fourier transform of all near-field sample points  $B'_0(\overline{P}_i)$  normalized with respect to the data point at the reference location. The near-field data point spacing in  $x$  and  $y$  are denoted by  $\delta_x$  and  $\delta_y$  respectively.

It is worthwhile to also note that:

- The factor  $(k_z/k)^2$  is not shown in [2, eq. 32] indicating that the expression only applies to the common case where the EIRP is sought in the direction normal to the scan plane, that is when  $(k_z = k)$ .
- Only one spectral component in direction  $\overline{K}_0$  is extracted in the Fourier transform.
- This expression for the EIRP assumes a PNF probe that is nominally polarization matched to the AUT. This expression and the associated test procedure outlined below, need to be modified if an AUT is considered with principal polarization other than that of the probe being used.

The derivation of this equation relies on two fundamental expressions for the gain and the equivalent surface of an antenna in terms of a plane wave expansion given in [5, p. 74 - 76]. Through substitution of the expressions for the probe corrected AUT spectra and the probe spectra this expression for the EIRP is derived [6].

We proceed to outline a measurement procedure in Section 4.

### 3. SFD

SFD is the flux required to saturate the receiver of the AUT and is determined on a far-field range as,

where  $P_i$  is the input power accepted by the source antenna (in what follows this will be our near-field probe),  $G_S$  is the gain of that source antenna and  $d$  is the distance separating the AUT and the source antenna [2 & 6]. The philosophy of this measurement is to determine the saturation level of the receiver and this is typically achieved by gradually increasing the input power level  $P_i$ . This process continues as long as the receiver response linearly tracks the increase in power of the transmitter and is terminated once the receiver is saturated. Thus, SFD can be thought of as being the receive system parameter counterpart of the transmit system parameter EIRP.

A near-field SFD technique as it applies to the planar coordinate system is presented in [2, eq. 39 & 6, eq. 178] repeated here for convenience (version from [6]),

$$SFD = \left(\frac{\lambda^2}{4\pi}\right) \frac{P_i G_r(\overline{K}_0)}{\left| \delta_x \delta_y \sum B'_0(\overline{P}_i) e^{j\overline{K}_0 \cdot \overline{P}_i} \right|^2} \left(\frac{k}{k_z}\right)^2$$

In this equation the variables have the same significance as before, with  $P_i$  now denoting the power accepted (corrected for port mismatch) by the probe (in this case the transmitter) and radiated to the AUT. The summation in this equation still represents a discrete Fourier transform across all normalized near-field sample points, as before.

We again note that:

- The factor  $(k_z/k)^2$  is not shown in [2, eq. 39] indicating that the expression only applies to the common case where the SFD is sought in the direction normal to the scan plane when  $(k_z = k)$ .
- Only one spectral component in direction  $\overline{K}_0$  is extracted in the Fourier transform.
- This expression for the SFD assumes a PNF probe that is nominally polarization matched to the AUT.

We proceed to outline a measurement procedure in Section 4.

### 4. EIRP & SFD Measurement Procedures

As was shown above, in order to measure EIRP in a PNF range the gain of the near-field probe has to be known. A power meter is also required for measuring

the signal at the near-field probe output when located at the reference position  $(x_0, y_0)$ .

A typical measurement setup is shown in Figure 1. It is a regular PNF test setup as one would employ for an

AUT-transmit measurement, with the addition of a power meter sensor at the probe side. The power meter and sensor will be used to measure the power received by the probe after completion of the PNF scan at the desired reference location  $(x_0, y_0)$ .

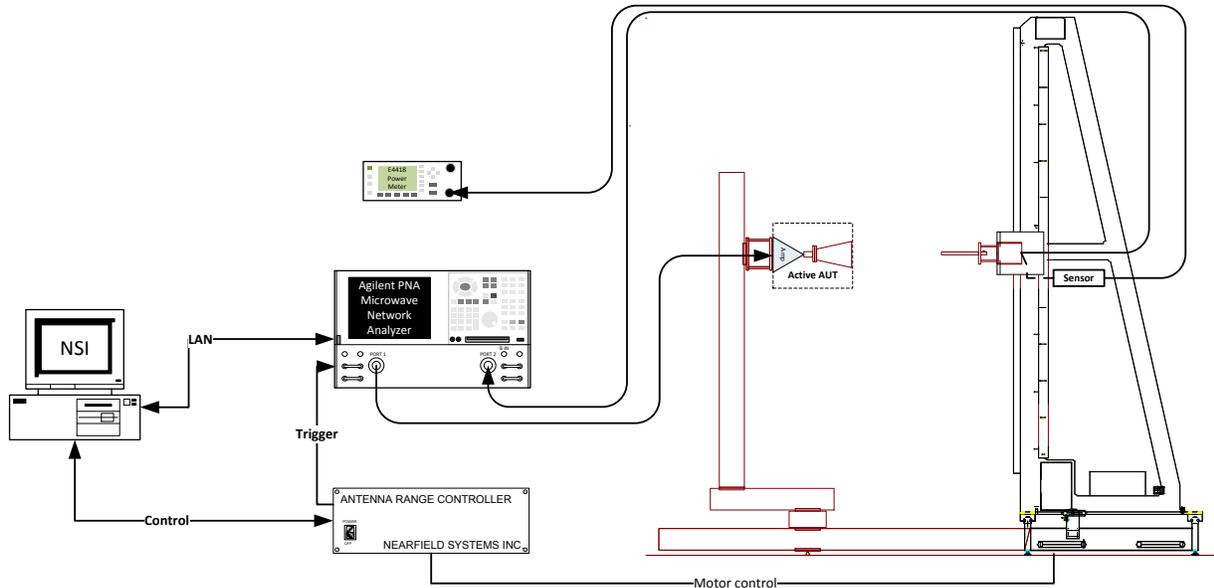


Fig. 1: Typical Block Diagram (AUT Tx) for EIRP testing.

From a practical perspective [7], the power meter sensor cable should be long enough to reach the probe when located at the reference location (typically the scan plane center). For large systems, remote operation of this process may be required using automation with an RF switch.

The procedure for making this measurement is:

- 1) Setup, align and connect AUT.
- 2) Perform complete PNF acquisition.
- 3) Upon completion of the acquisition, determine region of maximum energy based on PNF data set and establish reference position<sup>1</sup>  $(x_0, y_0)$ .
- 4) Record the un-normalized near-field value from the measured PNF data set at this reference position  $(x_0, y_0)$ .
- 5) Connect power meter sensor to the output connector of the probe and record the power meter reading at reference position  $(x_0, y_0)$ .

The procedure for doing the processing to determine EIRP is:

<sup>1</sup> It is important to state that this location does NOT need to be at the maximum value of the near-field data set. It is desirable that it be close to the maximum value.

- 1) Calculate the far-field from the measured PNF data set.
- 2) Select the “Direct method” of gain calibration [4] as shown in Figure 2.
- 3) Specify the “Network offset” value as the negative of the un-normalized near-field value (2.261 dB in Fig. 2) recorded at reference position  $(x_0, y_0)$ . (This takes care of normalizing the PNF data set.)
- 4) Enter the pre-measured probe gain value (5.672 dB in Fig. 2).
- 5) Enter the negative of the power meter measurement at reference position  $(x_0, y_0)$  (0.0667 dB in Fig. 2) as the “Bypass measurement” value.
- 6) The “Calculated AUT gain” value now represents the EIRP (30.201 dB in Fig. 2).

As for EIRP, in order to measure SFD in a PNF range the gain of the near-field probe has to be known and a power meter is required for measuring the signal level at the near-field probe input port. Some form of variable attenuator is also required to adjust the transmit power into the probe. The power level will be adjusted from a signal low enough to not saturate the receiver/amplifier to a signal high enough to cause the receiver/amplifier to saturate (usually determined by the 1 dB compression

point). A remotely controlled step attenuator with 1 dB steps over a wide enough range to determine the saturation point is required.

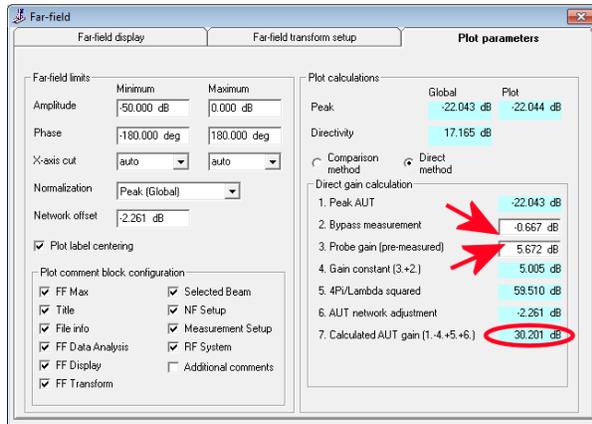


Fig.2: NSI2000 menu [4] for “Direct method” gain calibration – EIRP case.

The measurement setup is a regular PNF test setup as one would employ for an AUT-receive measurement, with the addition of a power meter sensor and step attenuator at the probe side. The step attenuator is used to determine the saturation point and the power meter and sensor will be used to measure the power injected into the probe port.

The procedure for making this measurement is:

- 1) Setup, align and connect AUT.
- 2) Perform complete PNF acquisition at a power level where the receiver is not saturated.
- 3) Upon completion of the acquisition, determine region of maximum energy based on PNF data set and establish reference position  $(x_0, y_0)$ .
- 4) Record the un-normalized near-field value from the measured PNF data set at this reference position  $(x_0, y_0)$ .
- 5) While observing the AUT output, adjust the attenuator from a point below saturation to a point where saturation occurs. (It is helpful to plot the “attenuator value” vs. “AUT power out” to determine the saturation point).
- 6) Connect the power meter to the cable that connects to the probe and record the power level.

The procedure for doing the processing to determine SFD is:

- 1) Calculate the far-field from the measured PNF data set.
- 2) Select the “Direct method” of gain calibration [4] as shown in Figure 3.

- 3) Specify the “Network offset” value as the negative of the un-normalized near-field value (-15.433 dB in Fig. 3) recorded at reference position  $(x_0, y_0)$ . (This takes care of normalizing the PNF data set).
- 4) Enter the pre-measured probe gain value (5.672 dB in Fig. 3).
- 5) Enter the power meter measurement for receiver saturation (-13.673 dB in Fig. 3) as the “Bypass measurement” value.
- 6) To now obtain the SFD value the “Calculated AUT gain” value is subtracted from half the value in the box labelled “4Pi/Lambda squared”<sup>2</sup> ( $59.510 / 2 - 43.121 = -13.456$  dB in Fig 3).

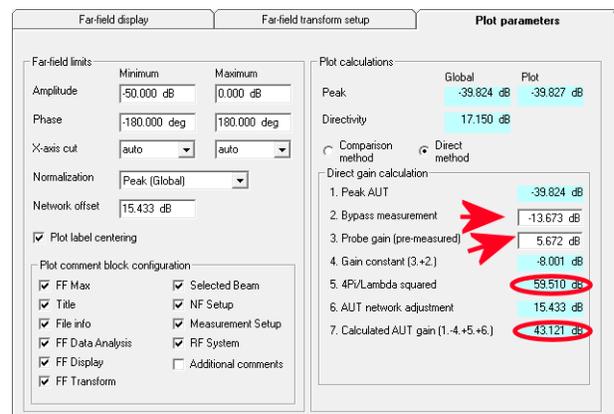


Fig.3: NSI2000 menu [4] for “Direct method” gain calibration calculation – SFD case.

## 5. Verification Tests

The following tests were performed as a verification test of the procedures described above. The tests were performed on an NSI PNF scanner using a WR 284 standard gain horn and a WR 284 OEWG near-field probe. An Agilent N1913A power meter with N8487A sensor was used for power meter measurements.

The standard gain horn and an NSI-RF-5968 RF amplifier were used to simulate an active antenna for SFD measurements. The step attenuator was characterized on the bench in 1 dB steps across a total range of 60 dB. A 6 dB attenuator was inserted before the step attenuator to prevent exceeding the operating range of the power meter sensor and other 6 dB attenuators were placed on the probe side of the cable connecting to the probe, and the AUT side of the cable connecting to the AUT to minimize mismatch errors.

<sup>2</sup> This contortion is required to extract the SFD parameter from this standard gain calibration menu.

Using the EIRP measurement procedure as described in Section 4, measurements were made from 2.6 to 3.9 GHz in 0.1 GHz steps. The power at the port of the AUT was also measured in order to calculate the EIRP and used for verification purposes. The results are shown in Table 1.

Table 1 contains all the frequencies of measurement, the measured power at the AUT port, the measured power at the probe port when located at the reference location  $(x_0, y_0)$  and the two calculated EIRP values. The right most column shows the difference between the two EIRP values and these are seen to be less than 0.71 dB.

Freq [GHz]	SGH284 Gain [dBi]	Power in [dBm]	Probe Gain [dBi]	Probe Power [dBm]	NF at @ $(x_0, y_0)$ [dB]	EIRP Calc [dBm]	EIRP Meas [dBm]	Delta [dB]
2.6	16.921	13.685	5.672	0.667	2.261	30.607	30.201	0.406
2.7	17.184	13.559	5.583	-0.062	1.700	30.743	30.225	0.518
2.8	17.433	13.438	5.890	0.062	1.934	30.871	30.419	0.452
2.9	17.668	13.345	6.458	0.232	1.993	31.013	30.667	0.346
3.0	17.891	13.273	5.925	-1.075	0.525	31.164	30.845	0.319
3.1	18.101	13.032	6.344	-0.989	0.610	31.133	30.655	0.478
3.2	18.300	12.885	6.694	-0.824	0.714	31.185	30.727	0.458
3.3	18.488	12.860	6.682	-1.178	0.055	31.348	30.830	0.518
3.4	18.666	12.818	6.984	-2.038	-0.814	31.484	30.778	0.706
3.5	18.834	12.682	7.016	-2.281	-1.200	31.516	30.830	0.686
3.6	18.992	12.628	7.233	-2.169	-1.304	31.621	30.983	0.638
3.7	19.142	12.668	7.402	-2.294	-1.676	31.810	31.259	0.551
3.8	19.283	12.619	7.460	-2.898	-2.494	31.901	31.212	0.689
3.9	19.415	12.490	7.609	-2.955	-2.533	31.905	31.307	0.598

Table 1: EIRP calculated vs EIRP measured using the procedure outlined in Section 4.

A measurement in the SFD configuration was also performed and since the standard gain antenna with amplifier was used as simulated active antenna, it was possible to separate the AUT and amplifier and make a power measurement at the AUT port in order to calculate an SFD value to construct a verification process. (This power value is converted to a flux value by dividing by the AUT effective area.)

With the probe in the reference location  $(x_0, y_0)$  the power injected at the probe port was adjusted using the step attenuator. The 1 dB compression point was determined by projecting a best fit of the linear (non-saturated) power levels and finding where the measured output fell from the projected by 1 dB. The results are

shown in Table 2. Table 2 contains all the frequencies of measurement, the measured 1 dB compression power (not used in any calculation), the attenuator setting for which this was achieved, the power measured at the AUT port (between the AUT and amplifier) and the power injected at the probe port. The table also shows the near-field data set normalization constant at the reference location  $(x_0, y_0)$ , the calculated effective area of the AUT and the calculated SFD as well as that obtained with the process described in Section 4. In this calculation the AUT gain and probe gain values shown in Table 1 were used. The right most column shows the difference between the two derived SFD values and these are seen to be less than 0.95 dB.

Freq [GHz]	1 dB compression [dBm]	Attenuator [dB]	AUT port [dBm]	Probe port [dBm]	NF at @ (x0,y0) [dB]	AUT Effective area [m <sup>2</sup> ]	SFD Calc [dBm/m <sup>2</sup> ]	SFD [dBm/m <sup>2</sup> ]	Delta [dB]
2.6	-5.472	23	-27.110	-13.763	-15.443	0.052	-14.276	-13.466	0.811
2.7	-5.812	23	-27.902	-13.889	-15.739	0.051	-15.004	-14.062	0.941
2.8	-5.001	22	-26.702	-12.971	-15.659	0.051	-13.736	-12.888	0.848
2.9	-5.001	22	-26.524	-13.016	-15.453	0.050	-13.488	-12.669	0.819
3.0	-5.725	22	-27.771	-12.892	-16.853	0.049	-14.663	-13.789	0.875
3.1	-5.484	22	-27.372	-13.051	-16.482	0.048	-14.190	-13.337	0.853
3.2	-4.775	21	-26.168	-12.170	-16.448	0.047	-12.909	-13.114	-0.205
3.3	-4.915	21	-26.323	-12.049	-16.936	0.046	-12.985	-12.212	0.773
3.4	-5.170	21	-26.720	-11.880	-17.816	0.046	-13.301	-12.563	0.738
3.5	-5.356	21	-27.039	-11.990	-18.390	0.045	-13.536	-12.780	0.756
3.6	-5.252	21	-26.993	-12.061	-18.476	0.044	-13.403	-12.605	0.798
3.7	-5.327	21	-27.178	-12.021	-18.946	0.043	-13.500	-12.707	0.793
3.8	-5.078	20	-26.860	-11.255	-19.627	0.042	-13.091	-12.290	0.801
3.9	-5.677	21	-27.746	-12.174	-19.884	0.041	-13.884	-13.100	0.784

Table 2: SFD calculated vs SFD measured using the procedure outlined in Section 4.

## 6. Concluding Remarks

This paper provides two detailed near-field measurement procedures for determining EIRP and SFD as presented in [2 & 6] for the case where the AUT is integrated with the transmitter/receiver. These procedures are given as step-by-step instructions and hopefully allow the reader to gain more insight into the complex formulations describing them.

Verification data is presented for a standard gain antenna, which is combined with an amplifier (for the SFD case) as measured on a planar near-field range to confirm the techniques. This test setup is simple enough to allow a third party to readily repeat the verification process if desired. The EIRP verification results presented here agree to within 0.71 dB and the SFD results to within 0.94 dB.

Both of these results can probably be improved through careful gain calibration of both the gain antenna and near-field probe used as well as performing port mismatch correction at all measurement ports.

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