SPACECRAFT COMMUNICATIONS SYSTEM VERIFICATION USING ON-AXIS NEAR FIELD MEASUREMENT TECHNIQUES

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Determination of the readiness of a spacecraft for launch is a critical requirement. The final assembly of all subsystems must be verified. Testing of a communications system can mostly be done using closed-circuits (cabling to/from test ports), but the final connections to the antenna require radiation tests. The Tropical Rainfall Measuring Mission (TRMM) Project used a readily available "near-field on-axis" equation to predict the values to be used for comparison with those obtained in a test program. Tests were performed in a "clean room" environment at both Goddard Space Flight Center (GSFC) and in Japan at the Tanegashima Space Center (TnSC) launch facilities. Most of the measured values agreed with the predicted values to within 0.5 dB. This demonstrates that sometimes you can use relatively simple techniques to make antenna performance measurements when use of the "far field ranges, anechoic chambers, or precision near-field ranges are neither available nor practical. Test data and photographs are provided.

1.0 Spacecraft Description.

The TRMM spacecraft is shown in figures 1 and 2. The dimensions are a height (or length) of approximately 5 meters (16.5 ft) and a cross section of approximately 3.5 meters (11.5 ft). Dry mass is approximately 2,632 kilograms (5,790 pounds). Critical to mission success was contamination control, especially

Communications Antenna. The size and mass of the spacecraft as well as the need for contamination control posed serious limitations to the implementatiom of a test program to verify the uccessful mating of the "Forward" (receiving) link and "Return" (transmitting) link of the Communication circuitry to the "Hi-Gain" antenna.

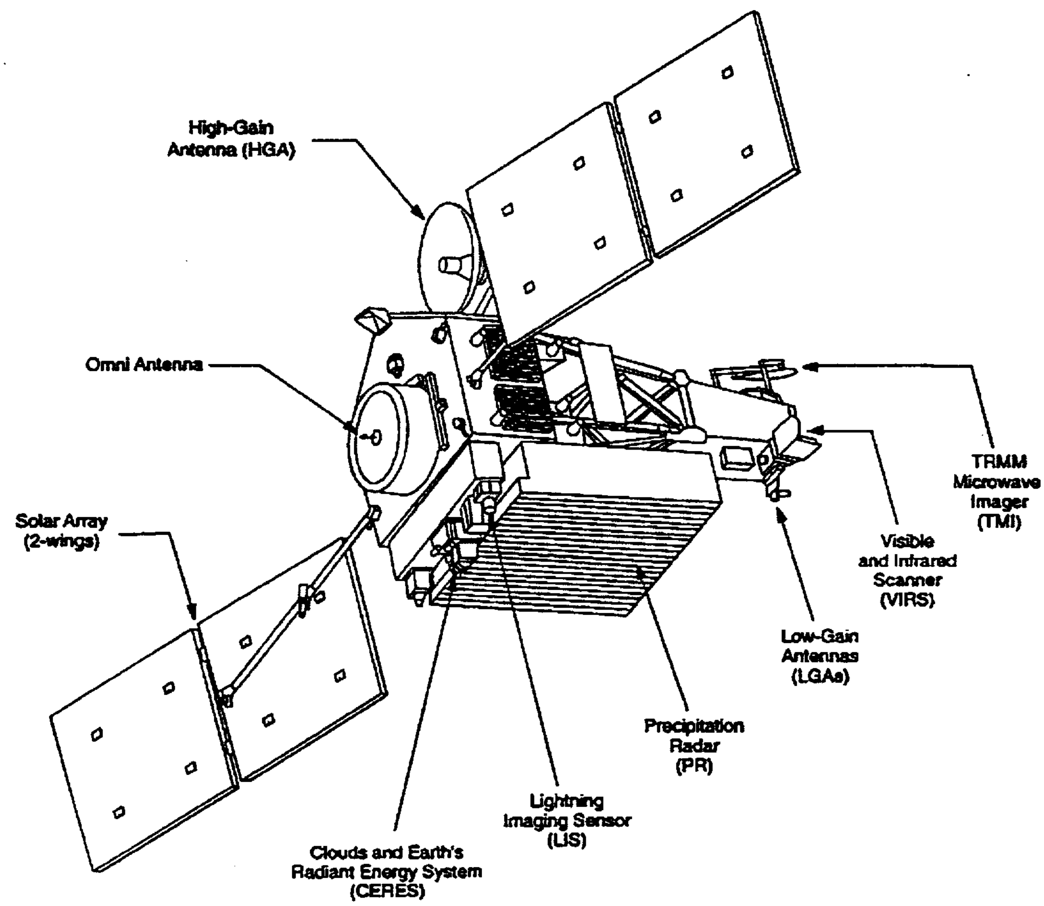

Figure 1: TRMM Drawing of the Spacecraft

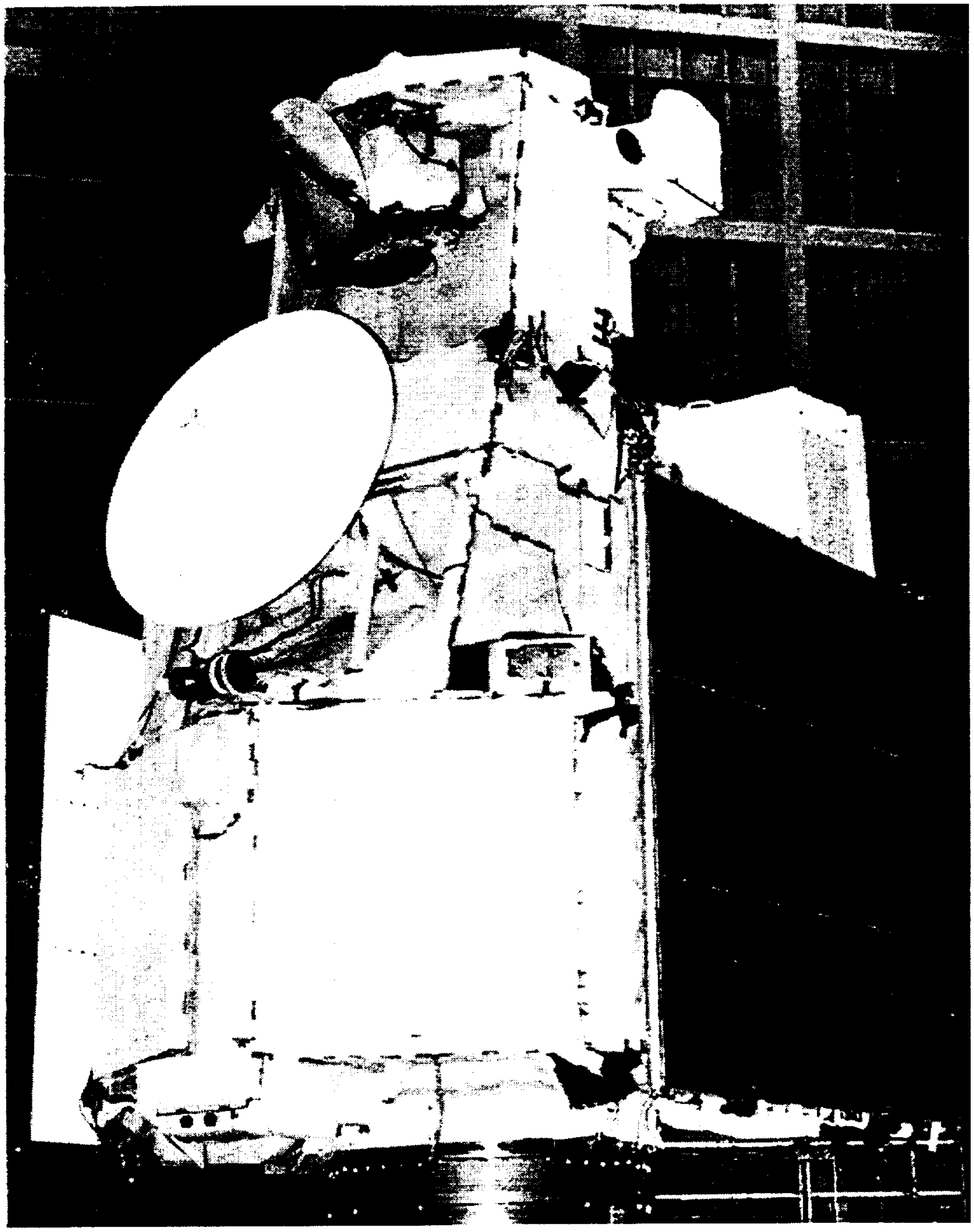

Figure 2: Photograph of the TRMM Spacecraft; the 52-Inch diameter Hi-Gain Antenna is seen in the in the upper left of the photograph.

2.0 **Communications Antenna Radio Frequency (RF) links**.

There are four RF links to the geostationary Tracking and Data Relay Satellite (TDRS); Namely:

> Left Circular Polarization (LCP) Forward (FWD) or receiving,
> Left Circular Polarization (LCP) Return (RTN) or transmitting,
> Right Circular Polarization (RCP) Forward (FWD) or receiving, and
> Right Circular Polarization (RCP) Return (RTN) or transmitting.
>
> FWD (receiving) frequency = 2076.94 MHz
> RTN (transmitting) frequency = 2255.5 MHz

3.0 **Testing Implementation**.

After much consideration of the need for actively verifying (as opposed to assuming a successful mechanical mating) by receiving and transmitting, several approaches were considered. Only two, namely; a "far-field" measurement or a "near-field " could be considered. Priority was given to the need to perform the verification at both GSFC and TnSC. The GSFC tests were needed to perform "pre-ship" tests and the TnSC were needed to demonstrate successful reassemble (the antenna was removed for shipping to Japan) and launch readiness. Far-field testing would require that the spacecraft be exposed to severe contamination conditions. Large doors would have to be opened to ordinary ambient conditions severely compromising the "clean room" environment. Thus, it was decided to perform the tests using the "on-axis near field power-density" equation shown on page 38 of Microwave Scanning Antennas, Volume I, Academic Press Inc. 1964. Figure 3 depicts the on-axis power density of a tapered circular aperture.

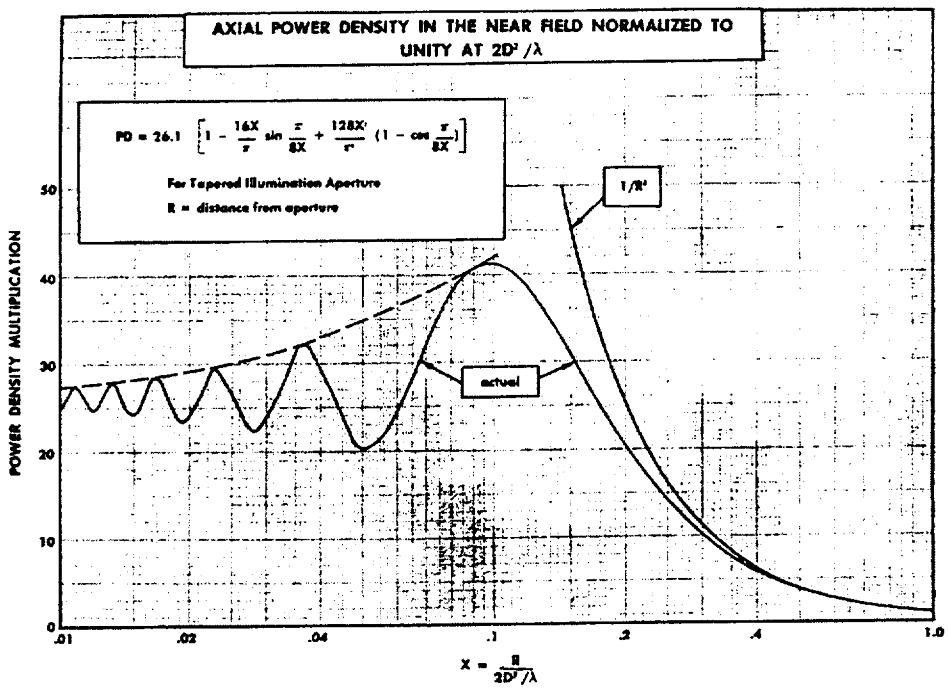

Figure 3: On-axis near field power density - tapered circular aperture

The author had used this information for estimating radiation hazard conditions. It was reasoned that if the testing program could:

(a) Accurately determine the distances from the spacecraft antenna aperture to a "probe antenna",

(b) Accurately boresight the two antennas, and

(c) Could accurately determine both the transmission and reception power levels, then testing within the confines of the "clean rooms" could be relied upon. Initially, it was initially estimated that measurements within 2 dB of predicted values would be acceptable for "verification".

4.0 **Testing Program**.

Figures 4 and 5 are two views of the test configuration. Figure 6 is a block diagram of the essential RF components of the test. All the cables were measured, the two "probe antennas" were calibrated, and power measurement meters and receiver "AGC" were accurately determined.

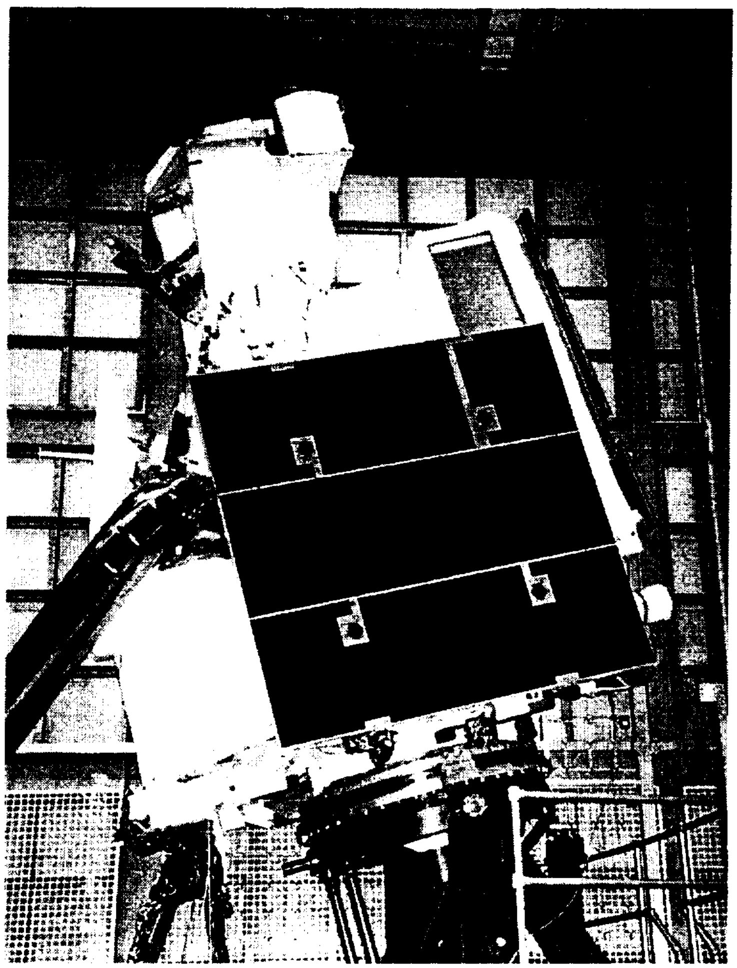

Figure 4: TRMM Spacecraft in "Clean-Room positioned for near field test of Communications Antenna

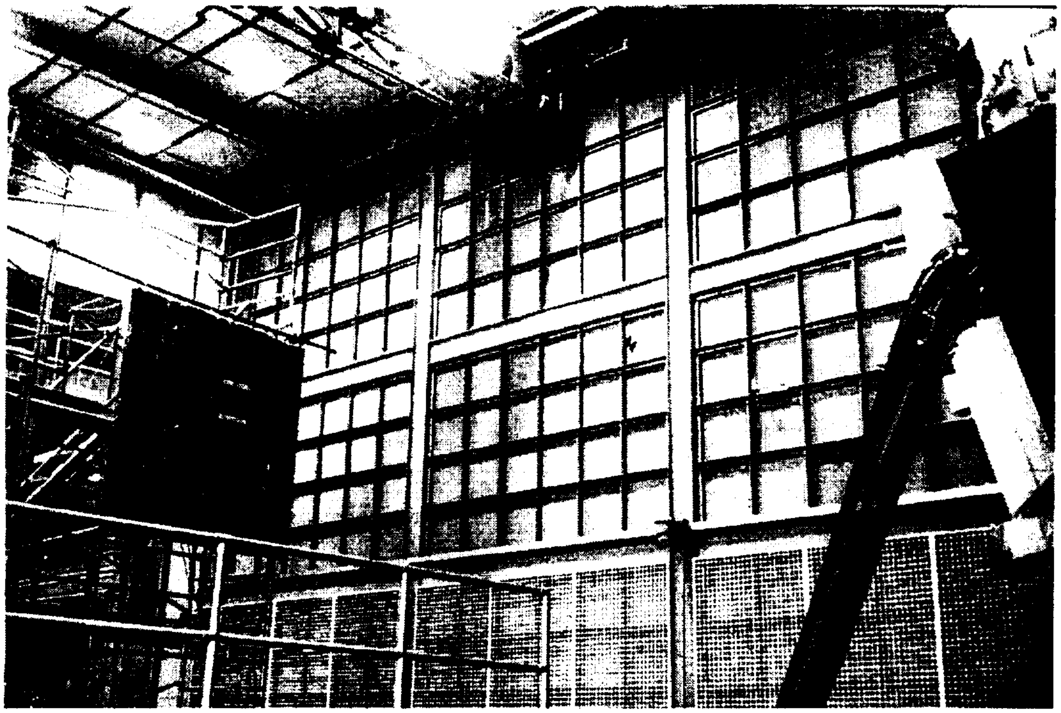

Figure 5: GSFC Range in the Environmental "Clean-Room". LCP Probe Antenna is shown on the RF absorber panel.

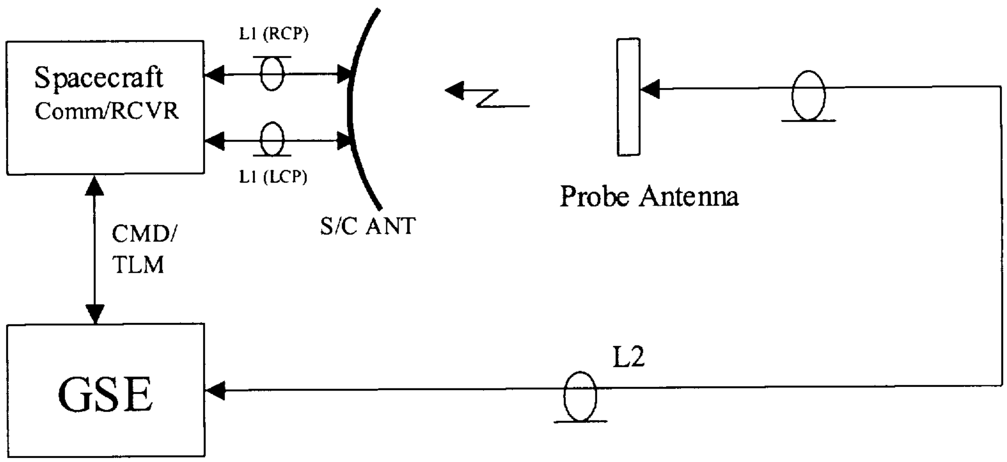

Fig. 6A Forward (Receive) link test set-up

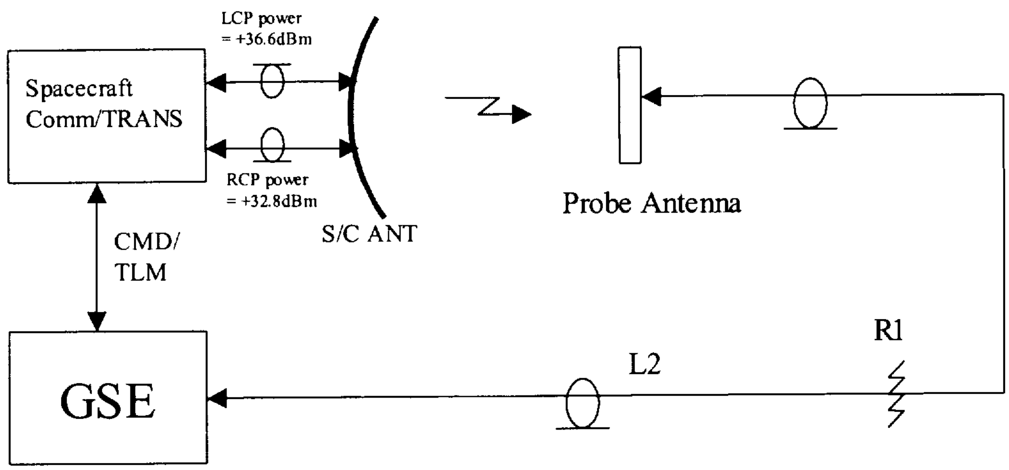

Fig. 6B Return (Transmit) link test set-up
(R1 =30dB)

Figure 6: Showing the Forward and Receive Implementation Block Diagram

The parameters used for all computations are shown in Table 1.

Table 1: Constants for Link Calculations

TABLE FOR CONSTANT FACTOR

		GSFC FWD LCP	GSFC RTN LCP	TnSC FWD LCP	TnSC RTN LCP
LINE L-1	dB	-17.3	0	-17.3	0
LINE L-2	dB	-14.6	-15.7	-22.7	-72.01
GAIN S/C Ant	dB	23.2	27.6	23.2	27.6
GAIN Probe Ant	dB	16.8	16.8	16.8	16.8
FAR FIELD SPACE LOSS	dB	-66.5	-67.9	-66.5	-67.9
FIXED REF "NET"	dB	-58.4	-39.2	-66.5	-95.51
		GSFC: FWD RCP	**GSFC RTN RCP**	**TnSC: FWD RCP**	**TnSC: RTN RCP**
LINE L-1	dB	-18.7	0	-18.7	0
LINE L-2	dB	-14.8	-15.7	-22.1	-51.41
GAIN S/C Ant	dB	23.1	27.4	23.1	27.4
GAIN Probe Ant	dB	6	6.2	6	6.2
FAR FIELD SPACE LOSS	dB	-66.5	-67.9	-66.5	-67.9
FIXED REF "NET"	dB	-70.9	-50	-78.2	-85.71

NOTES:

Forward Link: Line L-1 is from S/C Antenna ports to the S/C receiver

Return Link: Line L-1 is "zero loss" because the transmitter power is referred to the Antenna ports

Line "L-2" is to the Probe Antenna to the GSE; (TnSc L-2 includes 30 dB attenuator)

A total of five range distances were measured at GSFC and four were measured at TnSC. Table 2 compiles the Near-Field factor,which in this table, as well as the test data tables 3 and 4, is defined as the "Hansen Factor (H_f)" in dB.

Table 2
Test Ranges and Hansen Factor (H_f)

Range No.	Range (feet)	Polarization	Link	H_f (dB)
1	32.9	LCP and RCP	FWD	7.5
2	28.9	LCP and RCP	FWD	8.52
3	24.9	LCP and RCP	FWD	9.7
4	21.0	LCP and RCP	FWD	11.0
5	17.0	LCP and RCP	FWD	12.6
1	32.9	LCP and RCP	RTN	8.1
2	28.9	LCP and RCP	RTN	9.2
3	24.9	LCP and RCP	RTN	10.4
4	21.0	LCP and RCP	RTN	11.7
5	17.0	LCP and RCP	RTN	13.2

A complete set of computations for all ranges and links (frequencies) is provided in Appendix A.

6.0 **GSFC Test Results.**

Table 3 "Near-Field Gain Tests at Goddard Space Flight Center" shows the measured power (Pm) vs the power expected (Pe) for all five range settings. The differences were converted into numeric values and averaged. The numerical average was converted to dB to provide an "Average Deviation in dB".

Table 3: Near-Field Gain Tests at Goddard Space Flight Center

NEAR FIELD GAIN TESTS at GODDARD SPACE FLIGHT CENTER

RANGE Number	RANGE feet	POL	LINK	FIXED REF dB	Hf db	Pwr Inj dBm	Pwr Exp dBm	Pwr Meas dBm	Pm - Pe dB	Value Numeric
1	32.9	LCP	FWD	-58.4	7.5	-30.1	-81	-80.72	0.28	1.067
2	28.9	LCP	FWD	-58.4	8.52	-32.1	-81.98	-81.98	0	1.000
3	24.9	LCP	FWD	-58.4	9.7	-33.1	-81.8	-81.35	0.45	1.109
4	21	LCP	FWD	-58.4	11	-35.1	-82.5	-81.98	0.52	1.127
5	17	LCP	FWD	-58.4	12.6	-37.1	-82.9	-82.93	-0.03	0.993
							AVG DEVIATION (dB)		0.25	1.06
1	32.9	RCP	FWD	-70.9	7.5	-12.1	-75.5	-74.48	1.02	1.265
2	28.9	RCP	FWD	-70.9	8.52	-13.1	-75.48	-75.13	0.35	1.084
3	24.9	RCP	FWD	-70.9	9.7	-14.1	-75.3	-75.13	0.17	1.040
4	21	RCP	FWD	-70.9	11	-16.1	-76	-75.45	0.55	1.135
5	17	RCP	FWD	-70.9	12.6	-18.1	-76.4	-75.78	0.62	1.153
							AVG DEVIATION (dB)		0.56	1.14
1	32.9	LCP	RTN	-39.2	8.1	36.6	5.5	5.45	-0.05	0.989
2	28.9	LCP	RTN	-39.2	9.2	36.6	6.6	6.61	0.01	1.002
3	24.9	LCP	RTN	-39.2	10.4	36.6	7.8	7.59	-0.21	0.953
4	21	LCP	RTN	-39.2	11.7	36.6	9.1	8.95	-0.15	0.966
5	17	LCP	RTN	-39.2	13.2	36.6	10.6	10.02	-0.58	0.875
							AVG DEVIATION (dB)		-0.19	0.96
1	32.9	RCP	RTN	-50	8.1	32.8	-9.1	-8.12	0.98	1.253
2	28.9	RCP	RTN	-50	9.2	32.8	-8	-7.44	0.56	1.138
3	24.9	RCP	RTN	-50	10.4	32.8	-6.8	-6.31	0.49	1.119
4	21	RCP	RTN	-50	11.7	32.8	-5.5	-5.12	0.38	1.091
5	17	RCP	RTN	-50	13.2	32.8	-4	-3.77	0.23	1.054
							AVG DEVIATION (dB)		0.54	1.131

7.0 **TnSC Test Results.**

Table 4 "Near-Field Gain Test at Tanegashima Space flight (TnSC)" shows accuracy was not a good as GSFC. The cause is the different mechanisms available for positioning of the RF absorber structure containing the probe antennas. At GSFC the RF absorber structure was mounted on a rigid scaffold (Figures 4 and 5). The determination of the range, horizontal, and vertical positions of the Probe antenna was obtained under reasonably controlled conditions. By contrast, at TnSC, the RF absorber structure was suspended from a crane and ropes were attached to the two bottom corners to steady the structure. This led to a lesser controlled condition for positioning and pointing of the Probe antenna.

NEAR FIELD GAIN TESTS at TANEGASHIMA SPACE FLIGHT CENTER

RANGE Number	RANGE feet	POL	LINK	FIXED REF dB	Hf db	Pwr Inj dBm	Pwr Exp dBm	Pwr Meas dBm	Pm - Pe dB	Value Numeric
1	32.9	LCP	FWD	-66.5	7.5		NO TEST			
2	28.9	LCP	FWD	-66.5	8.52	-22	-79.98	-81.03	-1.05	0.785
3	24.9	LCP	FWD	-66.5	9.7	-23.2	-80	-80.72	-0.72	0.847
4	21	LCP	FWD	-66.5	11	-24.6	-80.1	-81.35	-1.25	0.750
5	17	LCP	FWD	-66.5	12.6	-26.1	-80	-80.72	-0.72	0.847
							AVG DEVIATION (dB)		-0.93	0.807
1	32.9	RCP	FWD	-78.2	7.6		NO TEST			
2	28.9	RCP	FWD	-78.2	8.52	-10.3	-79.98	-79.45	0.53	1.130
3	24.9	RCP	FWD	-78.2	9.7	-11.51	-80.01	-79.77	0.24	1.057
4	21	RCP	FWD	-78.2	11	-12.9	-80.1	-80.1	0	1.000
5	17	RCP	FWD	-78.2	12.6	-14.4	-80	-80.1	-0.1	0.977
							AVG DEVIATION (dB)		0.17	1.041
1	32.9	LCP	RTN	-95.51	8.1		NO TEST			
2	28.9	LCP	RTN	-95.51	9.2	36.6	-49.71	-51.1	-1.39	0.726
3	24.9	LCP	RTN	-95.51	10.4	36.6	-48.51	-50.2	-1.69	0.678
4	21	LCP	RTN	-95.51	11.7	36.6	-47.21	-49	-1.79	0.662
5	17	LCP	RTN	-95.51	13.2	36.6	-45.71	-47.6	-1.89	0.647
							AVG DEVIATION (dB)		-1.69	0.678
1	32.9	RCP	RTN	-85.71	8.1		NO TEST			
2	28.9	RCP	RTN	-85.71	9.2	32.8	-43.71	-42.7	1.01	1.262
3	24.9	RCP	RTN	-85.71	10.4	32.8	-42.51	-41.7	0.81	1.205
4	21	RCP	RTN	-85.71	11.7	32.8	-41.21	-40.5	0.71	1.178
5	17	RCP	RTN	-85.71	13.2	32.8	-39.71	-38.7	1.01	1.262
							AVG DEVIATION (dB)		0.89	1.227

Table 4: Near-Field Gain Test at Tanegashima Space flight (TnSC)

8.0 **Conclusions.**

Given limitations in the availability of antenna test facilities or other factors hindering the implementation of more common measurement procedures, the use of the On-axis Near-Field Power Density equation can provide a means to:

(a) Obtain a quick check of antenna gain, and/or

(b) Verify operational readiness of a completely assembled communications system.

If care is taken to control the test conditions factors of: (a) the RF transmitted and received powers, and (b) the geometric values of distance and boresight, then an accuracy of +/- 0.5 dB is obtainable.

APPENDIX A:

Spacecraft Communications System Verification using On-Axis Near-Field Measurement Techniques

F_{fwd} = 2076.5 MHz ; F_{rtn} = 2255.5 MHz

λ_{fwd} = 5.68 inches; λ_{ret} = 5.23 inches

Antenna Diameter = 52 inches = D_a

Far Field for FWD = FF_{fwd} ;   Far Field for RTN = FF_{rtn}

LCP Probe Antenna Gain = 16.8 dB (FWD and (RTN)
RCP Probe Antenna Gain = 6.0 dB (FWD) and 6.2 dB (RTN)

****

$D_a := \frac{52}{12}$ $\lambda_{fwd} := \frac{5.68}{12}$ $\lambda_{rtn} := \frac{5.23}{12}$

$D_a = 4.333$ feet $\lambda_{fwd} = 0.473$ feet $\lambda_{rtn} = 0.436$ feet

$$FF_{fwd} := \frac{2 \cdot D_a^{\,2}}{\lambda_{fwd}} \qquad FF_{fwd} = 79.343 \text{ feet}$$

$$FF_{rtn} := \frac{2 \cdot D_a^{\,2}}{\lambda_{rtn}} \qquad FF_{rtn} = 86.17 \text{ feet}$$

****

Space Loss for Far Field = L_{fffwd} and L_{ffrtn}

$$L_{fffwd} := \left[\frac{\lambda_{fwd}}{4 \cdot \pi \cdot FF_{fwd}}\right]^2 \qquad L_{fffwd} = 2.254 \cdot 10^{-7} \qquad L_{fffwdDB} := 10 \cdot \log\left(L_{fffwd}\right)$$

$L_{fffwdDB} = -66.471$ dB

$$L_{ffrtn} := \left[\frac{\lambda_{rtn}}{4 \cdot \pi \cdot FF_{rtn}}\right]^2 \qquad L_{ffrtn} = 1.62 \cdot 10^{-7} \qquad L_{ffrtnDB} := 10 \cdot \log\left(L_{ffrtn}\right)$$

$L_{ffrtnDB} = -67.905$ dB

$i := 1, 2 .. 5$ $\quad$ i = counter

$Rfwd_i :=$ $\quad$ Rfwd is the set of test ranges, Rfwd = Rrtn

$Rfwd_i$
32.86
28.9
24.93
20.97
16.99

$$Xfwd_i := \frac{Rfwd_i}{FF_{fwd}}$$

$Xfwd_i =$ $\quad$ $Xfwd_i$ is the ratio for the Hansen Factor H_f

$Xfwd_i$
0.414
0.364
0.314
0.264
0.214

$PDfwd_i$ is the Hansen formula ahown on Page 140 of the 1964 Microwave Engineers Handbook with a counter to compute for all appropriate trange values.

$$PDfwd_i := 26.1 \cdot \left[1 - \left(16 \cdot \frac{Xfwd_i}{\pi} \cdot \sin\left(\frac{\pi}{8 \cdot Xfwd_i} \right) \right) + \left[128 \cdot \left(\frac{Xfwd_i}{\pi} \right)^2 \cdot \left(1 - \cos\left(\frac{\pi}{8 \cdot Xfwd_i} \right) \right) \right] \right] \qquad (1)$$

$PDfwd_i =$

$PDfwd_i$
5.58
7.109
9.342
12.733
18.173

$PDfwdDB_i := 10 \cdot \log\left(PDfwd_i\right)$

$PDfwdDB_i =$

$PDfwdDB_i$
7.466
8.518
9.704
11.049
12.594

$Rrtn_i := Rfwd_i$

$Rrtn_i =$

2.86
28.9
4.93
0.97
6.99

$$FF_{rtn} := \frac{\left[2 \cdot D_a{}^2\right]}{\lambda_{rtn}} \qquad Xrtn_i := \frac{Rrtn_i}{FF_{rtn}}$$

$Xrtn_i =$

.381
.335
.289
.243
.197

$PDrtn_i$ is the Hansen formula ahown on Page 140 of the 1964 Microwave Engineers Handbook with a counter to compute for all appropriate range values.

$$PDrtn_i := 26.1 \cdot \left[1 - 16 \cdot \frac{Xrtn_i}{\pi} \cdot \sin\left(\frac{\pi}{8 \cdot Xrtn_i}\right) + \left[128 \cdot \left(\frac{Xrtn_i}{\pi}\right)^2 \cdot \left(1 - \cos\left(\frac{\pi}{8 \cdot Xrtn_i}\right)\right)\right]\right] \qquad (2)$$

$PDrtn_i =$

6.522
8.287
10.846
14.687
20.714

$PDrtnDB_i := 10 \cdot \log\left(PDrtn_i\right)$

$PDrtnDB_i =$

8.144
9.184
10.353
11.669
13.163