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RADAR LOOP GAIN MEASUREMENTS

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ABSTRACT

This document proposes a single method to be used by all support ranges for determining C-band radar loop gain, permits uniformity for reported loop gain values, and allows for a direct performance capability comparison between like kinds of radars. A brief discussion of the derivation of the radar equation is presented. A standard procedure using sky noise as a reference is then presented. Examples of loop gain test results, based on the described procedure, are provided for a number of Western Range radars.

This document was prepared for the Range Commanders Council (RCC) through a joint effort of the Joint Range Instrumentation Accuracy Improvement Group (JRIAIG) and the Electronic Trajectory Measurements Group (ETMG).

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1.0 Introduction, Scope, and Specific Objectives

Perhaps more than any other measure, loop gain is indicative of a radar system's capability to detect and to track targets. The loop gain is a constant for a radar in a given configuration. When the radar range equation is written in logarithmic form, important fixed radar parameters such as transmitter power, antenna gain and others may be combined for convenience into a single constant, often referred to as the radar loop gain or "C." Although this constant provides a theoretical loop gain, tracking tests are necessary to measure the actual loop gain. Under ideal conditions loop gain estimates based on tracking test results will agree with estimates obtained by summation of the fixed radar parameters.

Historically, various techniques have been used at different DOD test ranges to determine radar loop gain. In some cases, several methods are used at the same test range resulting in inconsistent loop gain estimates for similar type radars.

The objectives of this document are to

- briefly describe radar loop gain so that it is uniformly understood,
- provide a standard procedure, suitable for C-band tracking radars, to produce a uniform method for estimating loop gain at all test ranges,
- provide an acceptable method for establishing the 0-dB signal-to-noise ratio (SNR), which is relatively hardware independent, and
- show results of loop gain tests for a number of western range radars based on using the standard measurement procedure.

2.0 Radar System Loop Gain and the Radar Range Equation

One form of the radar range equation commonly used for calculation is

$$\frac{S}{N} = \frac{P_T\, G_R^2\, \lambda^2\, \sigma}{(4\pi)^3 R^4 K\, T_0 B\, N_F\, L_T}$$

By changing the units normally used in the above equation and grouping the constants, the equation becomes

$$\frac{S}{N} = \frac{P_T\, G_R^2\, \lambda^2\, \sigma}{R^4 B\, N_F\, L_T} \left(\frac{m}{cm}\right)^2 \left(\frac{nmi}{m}\right)^4 \left(\frac{1}{4\pi}\right)^3 \frac{1}{290 \times 1.38 \times 10^{-23}}$$

$$\frac{S}{N} = \frac{P_T\, G_R^2\, \lambda^2\, \sigma}{R^4 B\, N_F\, L_T} \quad x \quad 1.07$$

Using the approximation of 2000 yards = 1 nautical mile (nmi) reduces the factor of 1.07 closer to unity and thus it may be eliminated to further simplify the equation. Typically, these parameters are expressed using decibels. For this reason and to simplify calculation, the above equation may be expressed in the logarithmic form shown as

$$\frac{S}{N} = P_T + 2G_R + 2\lambda + \sigma - 4R - B - N_F - L_T$$

Where

$\frac{S}{N}$ – Signal-to-noise ratio in dB.

P_T - Transmitter peak power in dB referenced to 1 watt.
For 1 megawatt. P_T = 60-dB

G_R - Antenna gain in dB.
For MPS 36 or FPS-16 with 12-foot antenna. G_R = 43 dB

λ - Wavelength in dB referenced to 1 centimeter.
For 5765 MHz, λ is 5.20 cm. λ = 7.2 dB

σ - Effective target reflective area in dB referenced to square meter.
For a 6 inch sphere σ is 0.0182 square meter. σ = -17.39 dB

R - Range in dB referenced to 1 nautical mile.
For a range of 20 nautical miles R = 13.01 dB

B - Receiver bandwidth in dB referenced to 1 Hz.
For 1.6 MHz. B = 62.0-dB

N_F - Noise Figure in dB (typically for C-band systems). $N_F \approx 2.0$-dB

L_T - Loss between transmitter and antenna, receiver and antenna, and other unexplained losses (loss for this example). $L_T \approx 4.0$-dB

$(4\pi)^3kT_0$ = Boltzmann's constant (k = 1.38 X 10-23 W per Hz per degree Kelvin) and T_0 = 290° is the reference temperature.

EXAMPLE: Using the logarithmic form repeated below and assuming the values given in the description above, the signal-to-noise ratio (SNR), while tracking a 6-inch sphere at 20-nautical miles (13.01 dB), will be

$$\frac{S}{N} = P_T + 2G_R + 2\lambda + \sigma - 4R - B - N_F - L_T$$

$$\frac{S}{N} = 60 + 2(43) + 2(7.2) + (-17.39) - 4(13.01) - 62 - 2 - 4$$

$$\frac{S}{N} = 22.97 \text{ Db}$$

2.1 Radar Loop Gain

The parameters associated with a particular radar, including losses and operating frequency, may be combined using the logarithmic form to provide an estimate of the theoretical loop gain for the radar. Using the values provided in the previous example, $P_T + 2G_R + 2\lambda - B - N_F - L_T$ combines for a value of 92.4 dB/nmi. This value is the radar loop gain, commonly referred to as "C." If the loop gain of a radar is known, calculation of SNR at any range, expressed in decibels, is simplified to:

$$\frac{S}{N} = C + \sigma - 4R$$

or using the numbers from the previous example, SNR = 92.4 - 17.39 - 4(13.01) = 22.97 dB for a 6-inch sphere at a range of 20-nautical miles.

Since the SNR in the radar receiver can be directly related to expected system performance/data quality, analysts and engineers who prepare radar support scenarios often use this compact form of the radar range equation when the radar's loop gain is known.

2.2 Practical Use of Loop Gain Equations

As described earlier, the signal level at any range on a target of known radar cross section (RCS) is calculated using

$$\frac{S}{N} = C + \sigma - 40\ Log\ (R_{nmi})$$

While loop gain may be estimated by combining radar parameters, it is better to measure it by tracking a spherical target with known RCS. This tracking of a spherical target is often made to ensure that the radar's system sensitivity or transmitter output power has not degraded over time. The SNR and range are monitored during the tracking period and the loop gain may calculated by using

$$C = \frac{S}{N} - \sigma + 40\ Log\ (R_{nmi})$$

The practical use and meaning of loop gain is shown in this equation. Note that if the target's RCS σ and the SNR are both 0-dB, then $C = 40 \log R_{nmi}$. This result implies that C indicates the approximate range at which a radar will lose or provide marginal track (SNR = 0) of a 1-square-meter target (0-dB_{sm}). Therefore, C is a direct indication of overall radar transmit and receive performance. In the previous example, C was determined to be 92.4 dB/nmi which, when converted from dB to range, provides a maximum range of 204.2 nautical miles. This range is the approximate loop gain for the FPS-16 radar with 1-megawatt transmitter and 12-foot antenna operating with 1-microsecond transmitter pulse. Loop gain values always refer to how far a system will marginally track (assuming SNR = 0) a target with a 1-square-meter effective cross section. Therefore, loop gain can be used as a standard for comparing a given system with past performance or for comparing different systems with each other.

Although the above equations use the nautical mile for a range reference, a reference of 1 yard is more common when comparing radar system loop gain values. Since a nautical mile is equal to 2025 yards, the last equation (for a 1-square-meter target and 0-dB SNR) becomes

$$C = 40 \log (R * 2025) = 40 \log R + 40 \log 2025 = 40 \log R + 132.25$$

Therefore, it is necessary to add 132.25 to C to convert the original equation to work in yards as opposed to nautical miles. The loop gain for the FPS-16 expressed in yards becomes 224.64. If range is expressed in meters, the value to be added is 130.71. Note the loop gain for a particular system is approximately 1.55 dB greater for yards as compared with meters.

Reported loop gain values for MPS-36 and FPS-16 radars range between 221-225. Standard missile precision instrumentation radars (MIPIRs) range between 241-249. The MIPIRs equipped with wide pulse capability and larger transmitters have loop gains over 260 providing a maximum range capability of over 3,162,277 yards for a 1-square-meter cross section.

3.0 Loop Gain Measurements

Loop gain measurements are routinely made at most, and perhaps all, DOD test ranges where tracking radars are used to produce data for range users or for range safety. The general procedure, as described next, is believed to be the most commonly used. Although there may be some variation in the way data are collected and processed at the different ranges, the principles are basically the same. While the basic procedure is similar, the method for determining 0-dB SNR is not. Various methods used to establish the 0-dB reference level are discussed in section 4.0.

Loop gain is measured by tracking a target with known effective radar cross sectional area, while recording SNR and range at multiple points during the tracking interval. After completion of track, loop gain is then calculated from the data recorded using the equation

$$C = \frac{S}{N} + 40\ Log\ (R_{yd}) - \sigma$$

For a target with a nonfluctuating RCS, the loop gain should remain relatively constant at every range setting. Typical measurements consist of a series of range and SNR estimates taken on a 6-inch aluminum sphere suspended below a six-foot meteorological balloon. The following steps are based upon the use of a 6-inch sphere as the target. Satellites can also be used at radars with larger antennas.

3.1 Recommended Pre-Operational Checks

Loop gain measurements are made for the purpose of estimating system performance and to ensure that performance has not degraded since the last measurement. Therefore, it is important that the system operate at peak performance. Checks to determine that the system is operating normally should be accomplished. Receiver noise figure and transmitter output power should be routinely measured since these directly affect loop gain test results. Although these parameters are not used in calculation of loop gain from track data, both are easily measured and directly affect the test results. It is recommended that transmitter power be constantly maintained from test to test to reduce variability.

3.2 AGC Recorder Calibration

The automatic gain control (AGC) channel must be recorded on the radar function recorder because this is the primary source for determining signal-to-noise ratio while tracking. While other means for recording AGC are available at some ranges, the strip chart recording with its graphical display is highly recommended. The strip chart can be easily annotated with range during the tracking period, and loop gain can be determined from this record alone.

It will be necessary to identify the 0-dB SNR level to be used as a reference point on the strip chart. The procedure described here uses sky noise plus a signal obtained by use of the boresight tower. The following method for determining this point should be applicable to most, if not all, radars. Other methods used in the past will be covered in section 4.0

Step 1. Lock the radar on an area of the sky where minimum noise is expected. Experience has shown that a point above 30-degree elevation with azimuth away from the sun will usually produce a minimum AGC level. If there is any doubt, move the antenna to various areas until the quietest area is located. Keep in mind that at most radars stronger signals produce more negative voltages. So minimum AGC in this case is the most positive voltage observable.

Step 2. Once a quiet area has been located, lock the radar on noise while pointed at the area and run the strip chart recorder. Label this point as the noise lock-on point and record the AGC voltage reading at the console.

Step 3. Point the antenna at the boresight tower and lock on the signal supplied by the signal generator. (It may be necessary to override the angle and range channels.) While observing the AGC, reduce the signal generator output until the AGC voltage indicates a signal 3-dB higher than that recorded for quiet sky lock on. At many radars, the change in AGC voltage is 0.1-volt per dB of signal change. For this case the desired voltage is 0.3-volts more negative than quiet sky voltage. This voltage is the 0-dB reference level to be used for loop gain measurements. Label this as 0-dB SNR on the strip chart. The change in AGC voltage versus signal (dB) may be different than 0.1-volt per dB at some radars and, in this case, 0.3 volts will not be correct. Knowledge of the AGC curve is required to establish the 3-dB above-noise point (0-dB). Note that this level may not be 3-dB above the noise observed while pointing at the boresight tower because the noise level at the boresight tower may be greater than the quiet sky level.

Step 4. Once the 0-dB level is established, the recorder must be calibrated so that signal levels above this point can be determined. One approach is to raise the signal generator output in 5-dB steps and record each point on the strip chart. In some cases (depending upon the test range), AGC is calibrated in absolute level (dBm). In this case the dBm level for the 0-dB point must be noted and 5-dB changes above this point are shown on the strip chart recorder.

3.3 Tracking and Test Data Collection

A spherical target of known RCS is tracked for collection of test data. The 6-inch sphere (-17.39 dB_{sm}) attached to a balloon is commonly used. Spherical satellites are also available to radars with sufficient loop gain to track them. After the target is acquired, the range at various distances should be annotated on the strip chart. For the balloon tracked target, intervals of 2000 yards is sufficient to provide enough points for calculation of loop gain. Although one point will produce data for calculation, several points should be recorded and averaged for loop gain determination. If a satellite is being tracked, labeling with range at 30-second intervals is recommended. After tracking is completed, the strip chart should again be calibrated to confirm that changes have not occurred.

3.4 Calculation of Loop Gain

The data collected on the strip chart are used for calculation of loop gain. Loop gain is determined by using the range (in yards), the SNR, (in dB above the 0-dB level), and the σ radar crosssection (RCS) (dB) in the following equation

$$C = S/N + 40 \log R_{yd} - \sigma$$

For example, calculated loop gain for a 6-inch sphere at 10,000 yards with a SNR of 44 dB is

$$C = 44 \div 40 \log (10000) - (-17.39) \text{ or}$$

$$C = 221.39$$

As noted earlier, several points should be calculated, and wild points edited. Remaining points should then be averaged, which will provide best use of the data collected to more accurately estimate loop gain.

4.0 Determination of 0-dB Signal-to-Noise Ratio

The 0-dB SNR is defined to be the point where signal in the receiver is equal to noise. This is not the Minimum Discernible Signal (MDS), and it is not equal to the noise lock-on level. Based on discussions with radar operations personnel at several ranges, it was found that some radar operators use MDS as the 0-dB SNR level and some use the noise lock on. The MDS is a subjective measurement and varies from operator to operator even at the same radar. It is based on estimating when the signal is equal to the noise as observed on the track display by the operator. Noise lock on was assumed to be 0-dB at some ranges. Noise lock on is just noise - nothing else. Since no signal is present, signal cannot equal noise.

An attempt was made to define the 0-dB level at various ranges during the 1960s period. All radars supporting NASA space programs used the same procedure to determine 0-dB SNR levels. The noise figure and power monitor (built as part of the radar) was first used to measure the noise power developed by the receiver with no signal input. Afterwards, signal was added until the power monitor indicated double the original value. This value was defined as the 0-dB SNR level. This procedure may still be used today at some radars.

A possible problem exists with the method used in the procedure described in section 3.0. It is only accurate if the AGC voltage developed by the receiver is linear with respect to input signal. While the AGC curve may be linear over a range of 60-65 dB, it may not be linear at the low and high levels. This nonlinearity could lead to an error since calibration is done at the low end. Even with this possible error, it is expected that 0-dB will be better established than it would be by using MDS or noise lock on because MDS does not mean the same thing at all ranges and noise lock on is just noise with no signal. The method described in section 3.0 was chosen because no special hardware or equipment setup is required; therefore standardization is possible. A method for examining the linearity of the AGC curve is provided in appendix B. This method could be used to compare the AGC voltage for sky noise plus 3 dB, determined by the procedure in section 3.2, with the 3-dB point obtained by the information in the appendix.

4.1 Notes Concerning Modern Low Noise Amplifiers (LNAs)

In the past, noise generated within the radar system itself was the predominant contribution to the noise power at the output of the receiver. Modern Low Noise Amplifiers (LNAs) result in much quieter systems. As a result, the receiver may contribute less noise power than the antenna and sky noise.

An antenna pointed at the warm Earth will exhibit a higher noise level than an antenna pointed at zenith, where only sky noise is observed. With a modern low noise receiver, this difference may be detectable. Since the signal source for noise calibrations will often be a boresight tower, the measured noise level may be higher than the actual sky noise for a typical track.

5.0 SUMMARY

Radar loop gain can be an effective measurement of radar health and performance characteristics. It is hoped that the availability and usage of the measurement procedure will promote greater uniformity within the DOD radar community.

APPENDIX A

OBTAIN A CALIBRATED SIGNAL-TO-NOISE MEASUREMENT

Obtaining a Calibrated Signal-to-Noise Measurement

1. The most important factor governing loop gain measurements is correctly determining the SNR of the received signal. One method for determining the SNR is to use the Automatic Gain Control (AGC) circuitry in the radar's receiver.

2. Relative measurements of the change in received signal power can be measured precisely by using the AGC signal within the radar receiver. A calibration table is used to map AGC voltage readings into corresponding changes in signal power levels. Absolute measurement of the SNR ratio requires a precise determination of the receiver noise floor.

3. The AGC calibration table is constructed by comparing the receiver's AGC setting to a known input power level. Normally, a calibrated power source is either injected into the radar's receive path or a synthetic target is generated at a boresite tower external to the radar. The range of signal power injected into the radar should cover at least the power levels expected for the test. Normally, the signal power levels range from near saturation of the radar receiver down to the noise floor of the receiver.

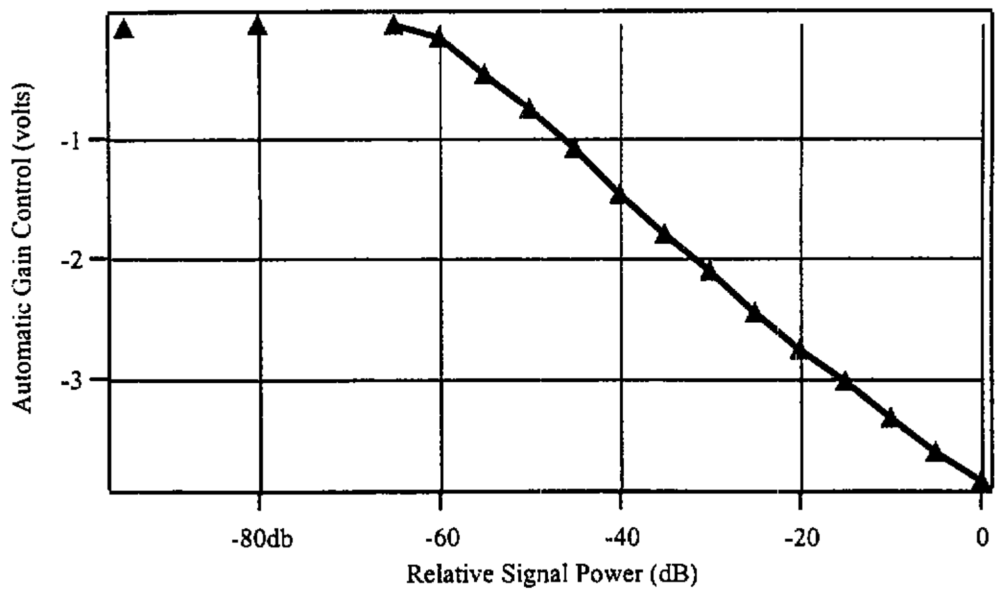
4. A sample AGC calibration table is illustrated in table A-1 showing voltage readings at 5 dB steps in the source signal power.

Signal Power	AGC Voltage	
-80	-0.072	Noise Point
-75		
-70		
-65	-0.065	
-60	-0.183	
-55	-0.48	
-50	-0.774	
-45	-1.092	
-40	-1.465	
-35	-1.789	
-30	-2.105	
-25	-2.459	
-20	-2.761	
-15	-3.032	
-10	-3.338	
-5	-3.612	
0	-3.864	

Table A-1. Injected Signal Level versus AGC Voltage

5. The desired precision of the loop gain measurement and the overall linearity of the receiver determine the table step size. Typically, 5-dB steps can be interpolated to a precision of one decibel.

6. In graphical form

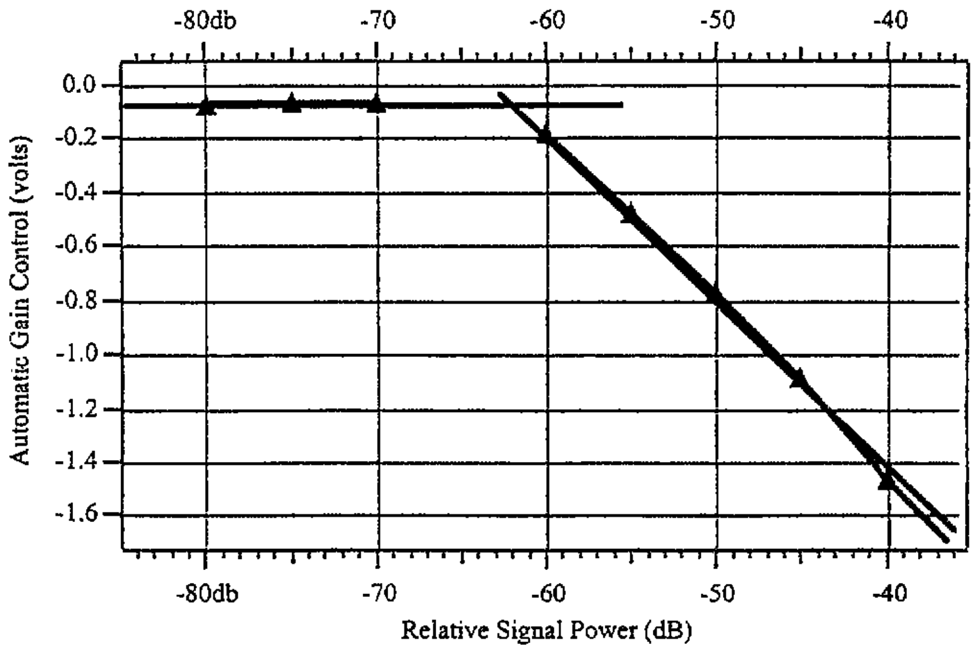


7. Tables or graphs can be used to observe relative changes in the signal power received at the radar. The AGC voltage levels are observed and compared to the indexed values in the table. The index provides a signal level relative to the signal source used in creating the table.

8. For absolute signal-to-noise measurements, a reference must be established. A unity SNR is a suitable reference. (When expressed in decibels, this SNR is zero.) Unfortunately, the AGC voltage cannot be used to observe this reference point directly. The AGC circuitry, responding to both the signal and noise, provides a nonlinear response in this region.

9. However, the table and some simple analysis procedures can be used to obtain the reference. The noise floor can be determined graphically (or numerically) by fitting lines through the noise response and the linear portion of the receiver's response. The intersection of these lines is the point where both signal and noise are equal.

10. For the example data shown, the receiver's AGC response is flat below -70-dB. In this region the receiver is responding only to the noise power. Above -55 dB, the receiver responds to the signal output in an approximately linear fashion. Fitting lines through the two sets of data yields the following pattern.



11. The intersection of the two lines is read directly from the graph. For the case shown, the receiver noise floor is -62 decibels. This is the reference point for determining absolute signal-to-noise measurements.

12. Once the AGC table is constructed and the noise floor determined, SNR measurements proceed in a straightforward manner. As a target is tracked, the AGC voltage reading is observed. The signal level can be determined by linearly interpolating the AGC table to a precision of 1dB. The reference value is used to form the SNR. Generally, the computation is performed in decibels so that only subtraction is needed to form the ratio.

$$\frac{S}{N}_{dB} = (Signal)_{dB} - (Noise\ Floor)_{dB}$$

APPENDIX B

LOOP GAIN MEASUREMENT HISTORY FOR THE FPS-16, MPS-36, MIPIR, AND MOTR RADARS AT THE AIR FORCE WESTERN RANGE

Loop Gain Measurement History for FPS-16, MPS-36, MIPIR, and MOTR Radars At Air Force Western Range (30th Space Wing)

Test results for several radars at the Air Force Western Range are shown in the following tables. The measurement of loop gain has been automated at this range. The AGC is calibrated and recorded on tape prior to tracking a spherical target. Sky noise lock-on AGC is also recorded. During the tracking period, AGC and range are recorded for post flight calculation of loop gain.

During the processing, loop gain is calculated over a range of samples using the AGC and range recorded during the tracking period. The typical number of samples, as shown on table B-1, is 200 for most tests. The sample size however, as demonstrated in table B-2, can be variable. The AGC voltage recorded during sky noise lock is averaged over the entire recording period. For these radars, a negative 0.3 volts is added to the sky noise voltage to obtain the 0-dB SNR reference level. The SNR is then computed from data recorded during the tracking period and used to calculate loop gain. Loop gain estimated for each test is shown in the column labeled "MEAS LGAIN."

Many of these radars can track in different pulse widths as indicated by the "PW" column. As expected, loop gain is dependent on pulse width since bandwidth varies with pulse width selected.

The number shown in the "OBJECT NO" column refers to the satellite ID being tracked.

Table B-1. RADAR SYSTEM LOOP GAIN RESULTS

Theoretical loop gain values are based upon the following

Antenna gain = 53 dB   Xmit Loss = 3 dB   Other Loss = 2 dB   Sys. Noise = 4 dB

SITE	DATE	MEAS LGAIN (dB/YD)	THEO LGAIN (dB/YD)	MEAS MINUS THEO (dB/YD)	STD DEV (dB/YD)	TX NO.	TX PWR (M/W)	PW (uSEC)	RCVR BW (MHz)	NO. SAMPLES	AVG SKY AGC_MEAN*10 VOLTS	T-OP	OBJECT NO.
023003	30-Sep-97	**249.49**	250.53	**-1.04**	0.35	1	**3.00**	2.4	0.58	200	-1.743	8700	5398
TPQ-18	6-Oct-97	**247.99**	248.92	**-0.93**	0.26	1	2.00	2.4	0.58	200	-1.929	8758	5398
29 FT	16-Oct-97	**250.05**	250.53	**-0.48**	0.36	1	**3.00**	2.4	0.58	200	-1.876	8802	5398
FPQ-6	2-Oct-97	**239.65**	242.29	**-2.64**	1.62	1	1.20	1.0	1.6	128	-1.984	8768	6 in sph
29 FT	15-Oct-97	**240.06**	241.50	**-1.44**	1.05	1	1.00	1.0	1.6	160	-1.964	8842	6 in sph
5765 MHz	4-Sep-97	**256.42**	254.51	**1.91**	0.16	1	2.00	CMF	0.16	200	-1.949	8579	5398
213002	30-Sep-97	**256.09**	254.05	**2.04**	0.49	1	2.00	CMF	0.16	200	-1.948	8700	5398
	20-Oct-97	**256.09**	254.51	**1.58**	0.19	1	2.00	CMF	0.16	200	-1.927	8813	5398
											-1.945		
	14-Aug-97	**257.97**	257.65	**0.32**	0.33	2	2.00	12.5	0.08	149	-1.876	8460	5398
033001	10-Sep-97	**257.94**	257.65	**0.29**	0.28	1	2.00	12.5	0.08	200	-1.774	8620	5398
HAIR	15-Sep-97	**257.81**	257.65	**0.16**	0.33	2	2.00	12.5	0.08	200	-1.751	8640	22875
29 FT	30-Sep-97	**257.54**	254.64	**2.90**	0.24	2	2.00	CMF	0.16	200	-1.789	8700	5398
	30-Oct-97	**260.75**	257.65	**3.10**	0.38	2	**4.00**	CMF	0.16	200	-1.600	8904	5398

Table 4-2. Theoretical loop gain values are based upon the following

SITE	Antenna Gain (dB)	Xmit Loss (dB)	System Noise (dB)	Other Loss (dB)	RCVR BW
FPS-16	44.00	2.00	3.00	2.00	
MPS-36	44.50	2.00	3.00	2.00	
MOTR	45.92	7.18	6.99	1.01	

SITE	DATE	MEAS LGAIN (dB/YD)	THEO LGAIN (dB/YD)	MEAS MINUS THEO (dB/YD)	STD DEV (dB/YD)	TX NO.	TX PWR (M/W)	PW (USEC)	RCVR BW (MHz)	NO. SAMPLES	AVG SKY AGC_MEAN*10 VOLTS	T-OP	OBJECT NO.
023001	9-Jun-97	**224.33**	224.66	**-0.33**	1.88	1	1.00	1.00	2.0	125	-2.216	8143	22875
FPS-16	24-Jul-97	**223.45**	224.66	**-1.21**	1.46	1	1.00	1.00	2.0	79	-2.344	8331	22875
12 FT	30-Jul-97	**224.54**	224.66	**-0.12**	1.32	1	1.00	1.00	2.0	125	-2.343	8377	22875
5725 MHz													
213003	18-Oct-95	**226.79**	226.5	**0.29**	1.12	1	1.00	1	1.6	80	-1.054	3280	22875
MPS-36	24-Jun-97	**224.98**	226.5	**-1.52**	0.78	1	1.00	1	1.6	700	-0.748	8246	6"Sphere
12 FT	2-Oct-97	**223.33**	226.5	**-3.17**	1.15	1	1.00	1	1.6	200	?	8842	6"Sphere
5765 MHz													
12 FT	23-Jun-96	**242.50**	240.40	**2.10**	0.67	6	0.80	50.00	N/A	92	N/A	1602	6"Sphere
	9-Jun-97	**241.56**	240.40	**1.16**	0.58	1	0.80	50.00	N/A	635	N/A	8143	22875
023004	13-Jul-97	**241.77**	240.40	**1.37**	0.86	1	0.80	50.00	N/A	520	N/A	8187	22875
	4-Jun-96	**236.70**	234.38	**2.32**	1.10	1	0.80	12.50	N/A	1010	N/A	4811	22875
MOTR	9-Jun-97	**234.86**	234.38	**0.48**	0.65	2	0.80	12.50	N/A	635	N/A	8143	22875
	13-Jul-97	**234.73**	234.38	**0.35**	1.67	2	0.80	12.50	N/A	520	N/A	8187	22875
5765 MHz	9-Jun-97	**228.84**	228.36	**0.48**	1.36	3	0.80	3.125	N/A	635	N/A	8143	22875
	9-Jun-97	**228.39**	228.36	**0.03**	1.29	4	0.80	3.125	N/A	2000	N/A	8156	6"sphere
	13-Jul-97	**228.74**	228.36	**0.38**	1.38	3	0.80	3.125	N/A	520	N/A	8187	22875
	23-Jun-95	**224.60**	223.41	**1.19**	0.98	3	0.80	1.00	N/A	763	N/A	1602	6"Sphere
	9-Apr-96	**223.29**	223.41	**-0.12**	1.36	3	0.80	1.00	N/A	3379	N/A	1770	6"Sphere
	9-Jun-97	**224.41**	223.41	**2.05**	2.05	3	0.80	1.00	N/A	2000	N/A	8156	6"Sphere
	23-Jun-95	**221.70**	220.40	**1.30**	0.98	2	0.80	0.50	N/A	763	N/A	1602	6"Sphere
	9-Apr-96	**220.38**	220.40	**-0.02**	1.37	2	0.80	0.50	N/A	3379	N/A	1770	6"Sphere
	9-Jun-97	**220.37**	220 40	**-0.03**	2.20	2	0 80	0.50	N/A	2000	N/A	8156	6"Sphere
	23-Jun-95	**217.90**	217 39	**0.51**	0.95	1	0 80	0.25	N/A	763	N/A	1602	6"Sphere
	9-Apr-96	**216.63**	217.39	**-0.76**	1 33	1	0.80	0.25	N/A	3379	N/A	1770	6"Sphere
	9-Jun-97	**216.56**	217.39	**-0.83**	2.20	1	0.80	0.25	N/A	2000	N/A	8156	6"Sphere

* 3dB added to the 6" sphere to match the LG in 12 5 us on obj 22875