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Analysis and Test of the Reduced Height Performance of the AN/GRN-27 ILS System Course and Clearance Near Field Detector Antennas

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The report consists of three parts. The first is a computer analysis of the reduced height performance of a four-element Yagi antenna over a variety of real earth conditions. The second is a computer analysis of the Yagi antennas as near field detectors in the AN/GRN-27 ILS system. Coupled to this is an analysis and experimental check of the reduced height Yagi performance in the MRN-7 localizer antenna modification to the GRN-27 ILS system. The last part is an analysis and prediction of the Yagi performance in a second modification to the GRN-27 system that uses a log periodic type of localizer antenna.

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Preface

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Analysis and Test of the Reduced Height Performance of the AN/GRN-27 ILS System Course and Clearance Near Field Detector Antennas

1. INTRODUCTION

The AN/GRN-27 Instrument Landing System uses four-element Yagi antennas as near field sensors to detect abnormal operation of the modulation and rf power levels of the localizer antenna system. When modulation levels vary from pre-set values or rf power drops beyond some pre-set level, detector circuits connected to the Yagi antennas turn on alarm devices.

The GRN-27 electronics has been mated to localizer antennas other than the parabolic reflector designed for that system. The system presently in use at Griffiss AFB, a MRN-7, uses a colinear array of horizontal dipoles as a course antenna and three bent dipoles as a clearance array. A proposed ILS system will use an array of log periodic dipole arrays as both course and clearance antennas. Both the MRN-7 and the proposed system use the GRN-27 electronics and the question arises as to whether the Yagi detector antennas can also be used in the two systems. In the GRN-27 setup, the Yagi antennas are 72 in. above the ground while in the other systems, the detector antennas would have to be placed closer to the ground. The purpose of this report is to document the behavior of the four-element Yagi course and clearance detector antennas designed for the AN/GRN-27 ILS system as their height above the ground is varied. There are three distinct parts to the study: (1) a theoretical analysis of the antenna behavior as a function of

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height, ground conditions, and frequency of operation; (2) an experimental test program on the RADC-Griffiss MRN-7 system to verify the results found in (1), and (3) an examination of the results and a prediction of the detector antenna performance at reduced height with the GRN-29 log periodic localizer antenna.

2. COMPUTER ANALYSIS OF A FOUR-ELEMENT YAGI ANTENNA ABOVE GROUND

A generalized antenna array analysis computer program named AMP was used in this study. Physical parameters of the Yagi antennas are shown in Figure 1. The course and clearance Yagi detector antennas are identical.

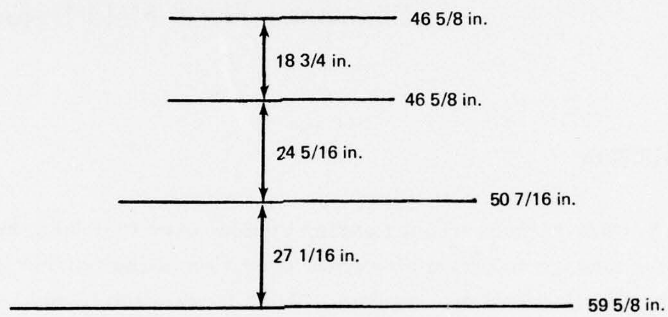

Figure 1. Yagi Antenna Physical Parameters

The antenna elements are encapsulated in plastic weather tubes about 4 in. in diameter. The computer program requires the antenna element thickness itself as an input parameter, and this could not be easily determined without destroying the weather tubes. An antenna element thickness of 0.36 in. was assumed and used in all the computations.

Since the earth beneath the detector antennas plays a major role in their performance, and also, since the ILS system could be located in a variety of geographical locations, computations were performed for three classical earth conditions. The purpose was to show up any sensitivity of the predicted results to earth conditions. The electrical parameters characteristic of the earth types used in the analysis are listed on the following page:

(a) Good Earth - defined as pastoral farm land typical of Ohio, Illinois, Nebraska, and Dallas, Texas,

$\epsilon = 14 - j\,1.8,\ \sigma = 10^{-2}$ at 100 MHz,

(b) Poor Earth - defined as desert-like, sandy areas, or very dry industrial areas,

$\epsilon = 4 - j\,0.18,\ \sigma = 10^{-3}$ at 100 MHz,

(c) Marsh Land - very wet, swampy soil,

$\epsilon = 30 - j\,20,\ \sigma = 0.11$ at 100 MHz.

These electric constants are average figures and have been previously used in the antenna literature for similar studies.[1,2]

There are some differences between the computer model of the antenna and the actual antenna, that is, the modeling does not take into account the plastic weather tubes around the antenna elements. This is not expected to produce major changes in the computer results. The computer model also assumes thin antenna elements, that is, length to width ratio of about 100. The actual antenna elements could have smaller ratios but the expectation is that even if this is so, the computer results should still provide valid comparative data.

Antenna gain, input impedance, and far-field radiation patterns for the four-element Yagi detector antennas were computed for antenna heights above ground ranging from 90 to 20 in., in 10-in. steps with special consideration at 40.8 in. (3.4 ft) the proposed new height of the detector antennas. Note that at the frequencies involved, that is, 108-112 MHz, the far-field region of the Yagi antennas begins about 5 ft from the antennas so that a radiation pattern analysis is valid. The Yagi antennas themselves are always in the near field of the course array and may or may not be in the far-field of the clearance arrays.

A Yagi antenna in free space (unaffected by the ground) has a far-field radiation pattern whose main beam lies in the same plane as the antenna, that is, parallel to the ground. Such an antenna serves in Table 1 as a point of comparison. As the antenna is placed in proximity to the ground, several significant changes in antenna performance occur. The main beam and backlobe tilt upward away from the ground, the main beam and backlobe gains increase and the antenna impedance varies.

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1. Jenkins, R.W. (1973) The effect of snow on radiation patterns: A presentation of results, IEEE Trans. AP, 21(No. 5).

2. Reed and Russell, (1966) Ultra High Frequency Propagation Boston Technical Publications, Cambridge, MA.

Table 1. Performance of a Four-Element Yagi as a Function of Height Above Ground

Height Above Ground	Mainbeam Gain	*Mainlobe* Points at Elevation Angle of	*Backlobe* Points at Elevation Angle of	Backlobe Value	Antenna Impedance
Infinity (Antenna in Free Space)	7.62 dB	0°	0°	0.3 dB	74 + j 13 Ω
Poor Earth—110 MHz					
90 in.	12.1 dB	15°	15°	4.4 dB	73 + j 15 Ω
80 in.	11.6 dB	15°	20°	4.5 dB	71 + j 14 Ω
70 in.	11.3 dB	20°	20°	4.6 dB	71 + j 10 Ω
60 in.	10.9 dB	20°	25°	4.1 dB	76 + j 8 Ω
50 in.	10.6 dB	25°	30°	3.2 dB	81 + j 13 Ω
40.8 in.	9.9 dB	30°	40°	2.7 dB	79 + j 20 Ω
30 in.	8.9 dB	30°	50°	2.8 dB	70 + j 24 Ω
20 in.	7.2 dB	45°	55°	2.0 dB	57 + j 19 Ω
Good Earth—110 MHz					
90 in.	12.8 dB	+15°	+15°	5 dB	73 + j 17 Ω
80 in.	12.3 dB	+20°	+20°	5.4 dB	69 + j 15 Ω
70 in.	11.9 dB	+20°	+20°	5.7 dB	69 + j 8 Ω
60 in.	11.6 dB	+25°	+25°	5.1 dB	77 + j 4 Ω
50 in.	11.5 dB	+25°	+35°	3.7 dB	86 + j 12 Ω
40.8 in.	11.1 dB	+30°	+40°	3.4 dB	83 + j 24 Ω
30 in.	10.2 dB	+35°	+45°	3.8 dB	68 + j 31 Ω
20 in.	8.7 dB	+40°	+47°	3.2 dB	49 + j 24 Ω
Marsh Land—110 MHz					
90 in.	13.1 dB	15°	15°	5.2 dB	73 + j 18 Ω
80 in.	12.7 dB	20°	20°	5.8 dB	68 + j 15 Ω
70 in.	12.2 dB	20°	20°	6.3 dB	67 + j 8 Ω
60 in.	12.0 dB	25°	28°	6.0 dB	77 + j 1 Ω
50 in.	12.0 dB	25°	35°	4.0 dB	89 + j 11 Ω
40.8 in.	11.7 dB	30°	43°	3.7 dB	86 + j 26 Ω
30 in.	11.0 dB	35°	45°	4.5 dB	69 + j 36 Ω
20 in.	10.0 dB	40°	45°	4.4 dB	45 + j 30 Ω

Typical results are shown in Table 1 at 110 MHz, and indicate the magnitude of the changes caused by the real earth. The important conclusion from Table 1 is the significant upward tilting of the Yagi main beam. Differences of 5° to 10° in mainlobe and backlobe tilt occur as ground parameters are varied. Peak backlobe values also change by about 2 dB with ground constants. Computations show that all the Yagi radiation patterns, regardless of ground parameters and height, have a null along the surface of the earth. Radiation levels therefore change drastically in the first few degrees of elevation. The overall receiving performance of the Yagi antennas is a function of the angular extent of the Yagi antenna pattern that is intercepted by the course or clearance transmitting arrays. As will be seen later, this angular region is usually in the 0° to 4° elevation angle region, unless the Yagi is very close to the localizer antennas. One should expect therefore, since as antenna height decreases the angular region also comes closer to zero degrees elevation angle, that Yagi performance will decrease markedly with height. The main beam gain plays little or no role in the Yagi performance.

Note that the peak backlobe levels are higher for the antenna over earth than for the antenna in free space. The Yagi antennas in the GRN-27 system are at a height of 72 inches. Table 1 shows that at about this height backlobe levels vary from about 4.6 to 6.3 dB, and these appear to cause no problems. Lowering the antennas to 40.8 in. will actually reduce backlobe levels and therefore, backlobe levels should not represent any problem in a system utilizing Yagi antennas at a height of 40.8 inches.

Changes in antenna impedance with height show no clear trend upward or downward. Since the Yagi antennas are internally matched at the factory to a 50 Ω output within a VSWR of 1.3, the changes in impedance with height can cause an increase in VSWR and hence an increase in signal loss between antenna and alarm circuits. This is effectively a loss in antenna performance. The Yagi antennas are apparently not tunable so that these signal losses will have to be accounted for. Additional data on this subject is presented in a later section.

2.1 Summary

Decreasing the height of the Yagi detector antennas causes:

(1) Increased tilt in mainlobe and backlobe for all earth types,

(2) Decreased antenna output,

(3) Possibility of decreased signal output due to mismatch of impedance values,

(4) Decrease in backlobe levels.

Quantitative information on these changes is contained in the following sections.

3. A COMPUTER ANALYSIS OF THE PERFORMANCE OF THE YAGI DETECTOR ANTENNAS IN THE GRN-27 LOCALIZER SYSTEM

The GRN-27 is the only one of the three localizer systems considered in this report that actually uses the Yagi antennas as near field detectors. Since the antenna placement in that system is successful, an analysis of that performance provides a standard against which the reduced height performance in the other systems can be compared. Ideally, if one knew the signal threshold level required to successfully operate the detector circuitry, he could simply calculate the antenna parameters needed to produce this signal level in the MRN-7 and GRN-29 systems. Such threshold information is however, not available for the GRN-27 system. It was therefore decided to calculate performance figures for the Yagi antennas in the GRN-27 system and then find heights and locations for the Yagi antennas in the MRN-7 and GRN-29 systems that produce the same performance levels. This is a basic step in the analysis of this report which can be verified in an experimental test on the MRN-7 system.

The geometry of the GRN-27 localizer system is shown in Figure 2. The Yagi antennas are 6 ft high. As mentioned earlier, Yagi performance is governed by the portion of the Yagi radiation pattern intercepted by the course and clearance transmitting antennas. The course antenna is a parabolic section of horizontal wires that is 116 ft across the opening. This means that it intercepts only that horizontal portion of the course Yagi radiation pattern that is ± 10° on either side of the center line. The horizontal wires that form the actual radiating elements in the course transmitting antenna range from 4 to 13.5 ft above the ground. These intercept only that vertical section of the course Yagi radiation pattern that lies between 0.7° and 2.4°. Note that as mentioned earlier, the main beam of the Yagi points upward at an angle of 20° and has little effect on detector performance. The vertical extent of the Yagi receiving region is only slightly higher than the radiation pattern null at 0° elevation angle. The gain of the Yagi was calculated for the 0.5° to 2.5° vertical region over a horizontal extent of 0° to + 10°. (By symmetry, the 0° to -10° region is identical.) This data is shown in Table 2.

Note the large change in antenna gain as elevation angle increases, that is, -15.3 to -1.4 dB in only 2.0° while the change in horizontal gain is much slower, that is, -1.4 to 1.7 dB in 10°, indicating that the Yagi beam is quite broad in the horizontal dimension.

The average gain over this region is -7.1 dB and it seems reasonable to assume that this one figure adequately characterizes the Yagi performance. Calculations for Poor Earth and Marsh Land showed average performance figures of -7.0 and -7.1 dB respectively. Thus, the course Yagi performance in the GRN-27 configuration is essentially independent of the ground parameters.

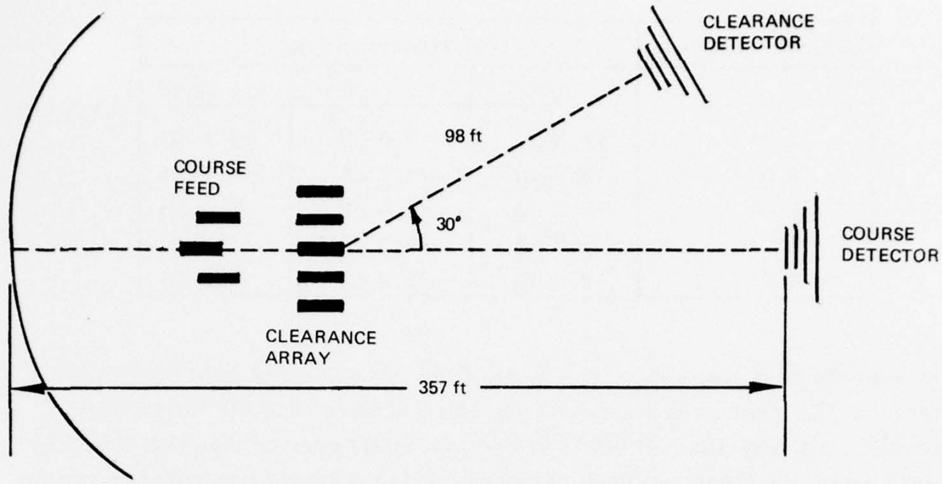


Figure 2. Location of Yagi Detector Antennas in GRN-27 System

Table 2. Course Yagi Performance GRN-27.
Good earth—110 MHz, Yagi height—72 inches

Elevation Angle	Horizontal Angle		
	0°	+5°	+10°
2.5°	-1.4 dB	-1.5 dB	-1.7 dB
2.0°	-3.3 dB	-3.4 dB	-3.6 dB
1.5°	-5.8 dB	-5.6 dB	-6.1 dB
1.0°	-9.3 dB	-9.4 dB	-9.6 dB
0.5°	-15.3 dB	-15.3 dB	-15.6 dB

Similar reasoning for the Clearance Yagi placed at a 30° angle, 98 ft from the clearance array and at a height of 6 ft, showed that the angular subtense is ± 2.5° on either side of center and from 4.7 to 6.2° in vertical extent. Because the vertical intercepts occur higher on the Yagi beam, the expectation is that gain is higher and does not change as rapidly as in the course Yagi. The figures in Table 3 verify this.

Table 3. Clearance Yagi Performance GRN-27.
Good earth—110 MHz, Yagi height--72 inches

Elevation Angle	Horizontal Angle		
	0°	+1.5°	+2.5°
6.5°	+6.3 dB	+6.3 dB	+6.3 dB
6.0°	+5.7 dB	+5.7 dB	+5.7 dB
5.5°	+5.1 dB	+5.0 dB	+5.0 dB
5.0°	+4.3 dB	+4.3 dB	+4.3 dB
4.5°	+3.4 dB	+3.4 dB	+3.4 dB

The average gain over this region is +4.9 dB. The average gain figures for the clearance Yagi over Poor Earth and Marsh Land were +4.6 dB and +5 dB respectively. Although this spread in values is slightly greater than that found for the course Yagi, the clearance Yagi performance is not highly dependent on ground parameters in the GRN-27 configuration. As the Yagi height is reduced in the remaining two localizer situations, this conclusion will have to be rechecked.

The total output power of the Yagi detector antennas, P_o, depends on both the incident power, P_i, and the average antenna gain G, over the window in the Yagi pattern intercepted by the transmitting antennas. The size of this window depends on the distance between the two antennas, R.

$$P_o = P_i \cdot G(R) \cdot K \, . \tag{1}$$

P_i is simply the transmitted power, P_t, decreased by R^2. (Since the Yagi antennas are in the near field of the transmitting antennas, one cannot use the transmitting antenna gain, a far-field concept. In this report, since time did not allow a determination of a near field patterns, we simply assume isotropic radiation in the region.)

$$P_o = \frac{P_t}{R^2} G(R) \tag{2}$$

$$P_o(\text{dB}) = P_t(\text{dB}) + 10 \log_{10} G(R) + 10 \log_{10}(1/R^2) \, . \tag{3}$$

P_t does not change as Yagi height and location vary, hence plays no role in comparisons of antenna behavior. This term is therefore neglected. The reference for measuring R and its normalization also are of no consequence in the comparative measurements that follow. Thus, at 328 ft, the course Yagi suffers a -50.3 dB loss in power while the clearance Yagi at 98 ft undergoes a -39.8 dB loss. Total

Yagi performance in the GRN-27 is therefore: course, -57.4 dB; clearance, -34.9 dB. The goal in the following sections is to find a location for a 3.4-ft high Yagi antenna in the MRN-7 and GRN-29 localizer systems that produces these same performance figures.

4. COMPUTED PERFORMANCE OF THE GRN-27 YAGI DETECTOR ANTENNAS IN THE MRN-7 LOCALIZER SYSTEM

The dimensions used for the MRN-7 localizer antenna were:

(1)	Course Array Length	89.6 ft
(2)	Course Array Height	4.0 ft
(3)	Distance from end of Runway	500.0 ft
(4)	Clearance Array Length	9.4 ft
(5)	Clearance Array Height	7.7 ft
(6)	Distance between Course and Clearance Arrays	51.0 ft

4.1 Course Detector

Computations were performed for the course Yagi placed on the center line at distances varying from 250 ft to 50 ft from the MRN-7 course antenna. Yagi performance will increase as distance decreases because at smaller distances, the MRN-7 course array subtends higher vertical and broader horizontal angles at the Yagi. The MRN-7 course antenna subtends vertical angles that range from 0.92° to 4.6° as the distance decreases from 250 to 50 feet. The corresponding horizontal angles range from ± 10° to ± 42°. The goal is to find a location for a 3.4-ft high Yagi that produces about -57 dB of average performance. The MRN-7 performance at the Yagi antennas can be expected to be worse than the GRN-27 because it is a smaller antenna both in vertical and horizontal extent. The Yagi, therefore, receives energy from a smaller region of space. The height of the Yagi was held fixed at 3.4 ft as the distance between antennas was varied. Results are shown in Table 4.

Note from the figures in Table 4 that performance equal to the GRN-27, that is, -57 dB is obtainable at distances up to about 200 feet.

Computations were also performed to document the change in Yagi performance as its height above ground is varied. Results are shown in Table 5 for a fixed distance of 100 feet.

Note that one can increase Yagi performance by about 7.4 dB simply by increasing height from 2 to 6 feet. These results are typical of the performance increases found at other distances. Note also that at a distance of 100 ft, the course Yagi can provide GRN-27 type performance even at heights as low as 25 inches.

Table 4. Performance of 3.4-ft High Course Yagi Antenna as Distance from MRN-7 Localizer Antenna is Varied. Good earth—110 MHz

Distance from Course Antenna to Yagi	Loss Due to $1/R^2$	Average Performance of Yagi	Total Yagi Performance Figure
250 ft	-47.9 dB	-14.2 dB	-62.1 dB
200 ft	-46.0 dB	-12.5 dB	-58.5 dB
150 ft	-43.5 dB	-10.1 dB	-53.6 dB
125 ft	-41.9 dB	- 8.6 dB	-50.5 dB
100 ft	-40.0 dB	- 6.9 dB	-46.9 dB
75 ft	-37.5 dB	- 4.9 dB	-42.4 dB
50 ft	-33.9 dB	- 2.6 dB	-36.5 dB

Table 5. Variation in Course Yagi Performance with Height. Good earth—110 MHz

Distance of Yagi from MRN-7 Course Antenna—100 ft	
Height	Average Performance
25 in.	-50.2 dB
40.8 in.	-46.9 dB
48 in.	-45.8 dB
60 in.	-44.3 dB
72 in.	-42.8 dB

4.2 Clearance Detector

The placement of the course Yagi is relatively straightforward. It should respond to and monitor changes in the course modulation and rf signals. Placed on the center line, it receives both course and clearance signals but since the course signal is 10 dB stronger than the clearance signal, the Yagi responds primarily to the course signal as it should. The clearance Yagi must be placed so that it responds only to the weaker clearance signal. In the GRN-27, its placement at a 30° angle from the clearance array presumably assures that the course signal, being directive because of the large parabolic course reflector, has little effect on its operation.

In the MRN-7, the radiating elements in the course array are dipoles and are not overly directive. It was felt that placing the Yagi in a region similar to that used in the GRN-27 would not assure sufficient isolation of the clearance signal.

It seemed reasonable to situate the Yagi where it could receive signals directly from the clearance array without the obstruction of the course array. The final placement was arrived at experimentally and is shown in Figure 3.

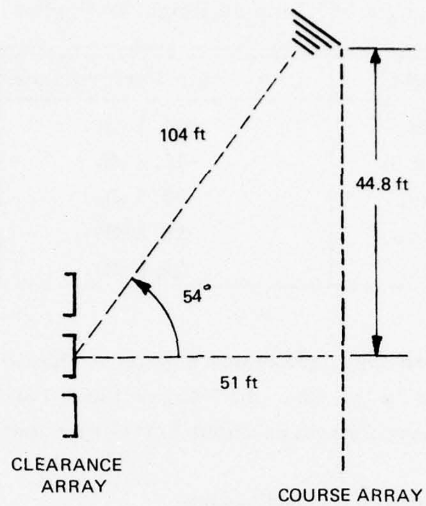


Figure 3. Placement of Clearance Yagi in MRN-7 System

Computations for distances ranging from 200 to 50 ft along the 54° line with the Yagi height held constant at 3.4 ft led to the results in Table 6.

Table 6. Performance of a 3.4-ft High Clearance Yagi Antenna as Distance from MRN-7 Clearance Antenna is Varied. 110 MHz—Good earth

Distance from Yagi to Clearance Array Along 54° Line	Loss Due to $1/R^2$	Average Performance of Yagi	Total Yagi Performance Figure
200 ft	-46.0 dB	-6.6 dB	-52.6 dB
175 ft	-44.9 dB	-5.5 dB	-50.4 dB
150 ft	-43.5 dB	-4.2 dB	-47.7 dB
100 ft	-40.0 dB	-0.8 dB	-40.8 dB
75 ft	-37.5 dB	+1.6 dB	-35.9 dB
50 ft	-33.9 dB	+4.7 dB	-29.2 dB

Performance levels about equal to those of the GRN-27 occur at about 75 feet.

Table 7 shows the variation in performance level of the clearance Yagi as its height is varied. The distance is constant at 100 feet.

Table 7. Performance of Clearance Yagi at 100 ft Along a 54° Line as Height is Varied

Height	Average Performance
25 in.	-44.1 dB
40.8 in.	-40.8 dB
48 in.	-39.6 dB
60 in.	-38.3 dB
72 in.	-36.8 dB

It appears from these figures that performance equal to the GRN-27 can be obtained only at the heights of 60 and 72 in. when the Yagi is 100 ft from the clearance array. Note that performance increases about 1.8 dB per foot of increased height.

4.3 Dependence of Computed Results on Ground Constants

Calculations showed that the results above varied only slightly with ground conditions, that is, average performance figures changed by only 0.2 dB. This was not considered significant.

4.4 Dependence of Computed Results on Frequency of Operation

Calculations were performed at 108 and 112 MHz, the limits of the ILS system operating range. Although the antenna impedance does change with frequency, the average performance of the Yagis changed only about 0.3 dB. This was not considered significant.

4.5 Signal Losses Due to Impedance Mismatch

Table 1 showed typical variations in the driving point impedance of the Yagi antennas as the height was changed. In the GRN-27 system with Yagi heights of 6 ft, calculated impedances were:

Poor Earth - $Z = 71 + j\,11$,

Good Earth - $Z = 68 + j\,10$,

Marsh Land - $Z = 66 + j\,10$.

It appears from the GRN-27 Technical Orders that each Yagi contains an internal tuning circuit that matches the antenna to the 50 Ω coaxial line. This is adjusted at the factory during manufacture and then sealed. When the Yagi height is changed from the 72 in. of the GRN-27 system, the antenna impedance varies. The tuning circuit will no longer provide a good match and signal reflections will occur between the antenna and the cabling. It is not known exactly what the tuning circuit consists of, but it seems reasonable to assume that the reactive part of the antenna impedance is cancelled and the remaining real part is changed, via a transformer, to about 50 Ω. If it is further assumed that the tuning circuit is adjusted to some median expected impedance at a 6-ft Yagi height, one can postulate what the mismatch could be when the height is reduced to 3.4 feet. Calculations show that in the worst case, with a Yagi impedance of $Z = 95 + j\,19$ (at 112 MHz), the Yagi VSWR would be in the vicinity of 1.5, meaning power losses are only about 0.2 dB. This is not considered significant.

4.6 Summary

(1) Computations show that locating the course Yagi detector antenna at a height of 3.4 ft (or higher) on the center line of the MRN-7 course antenna at distances of 200 ft or less will produce a performance equal to, or better than, the GRN-27 system. This conclusion will be tested in the experiment at Griffiss.

(2) In the location selected for analysis in this report, that is, along a 54° line from the center of the MRN-7 clearance array, heights of 60 in. or higher were required for the clearance Yagi to produce performance levels equal to the GRN-27 at the 100-ft distance. A 3.4-ft high Yagi produced satisfactory results when moved in to a 75-ft distance. These predictions will also be tested in the experiment at Griffiss AFB on the MRN-7.

(3) The conclusions above are not seriously altered by a change in ground constants or a change in frequency over the 108 to 112 MHz range.

5. EXPERIMENTAL TEST OF THE GRN-27 YAGI DETECTOR ANTENNAS IN THE GRIFFISS MRN-7 LOCALIZER SYSTEM

The goal of the test program on the Griffiss ILS system was simply to verify the accuracy of the computer analysis and the numerical results reported in the preceding section. The philosophy is to test the trends predicted by the computer for the MRN-7 system and if agreement between the experiment and the computer results is good, one can expect that results predicted for the GRN-29 antenna should similarly be correct.

There are several items to be verified in the experiment:

(1) That the variation of Yagi antenna performance with distance from the course and clearance arrays is as predicted in Tables 4 and 6.

(2) That the variation of Yagi antenna performance with height above the ground is as predicted in Tables 5 and 7,

(3) That the impedance change with height agrees with predictions, that is, no serious signal loss occurs because of mismatch,

(4) Most important, that a Yagi location that gives a performance equal to or better than the GRN-27, successfully triggers the alarm circuits in the MRN-7 setup,

(5) Since it has been assumed in all the calculations that the only vertical fall off in the fields is due to the pattern of the Yagi antennas themselves, and that the course and clearance arrays produce essentially constant vertical field strength at the Yagis, an experimental check of this assumption was planned. If the assumption is not true, then Yagi performance levels will be lower than those predicted by the computations,

(6) Another assumption in the calculations was that the clearance detector Yagi received signals only from the clearance array and similarly for the course detector. It was planned to check this assumption also. If in fact, both arrays provide signal to the detectors, signal levels will be higher than predicted but running the alarm circuits could be more difficult.

The computer model of the antenna system assumes a smooth, flat earth between the transmitting and the detector antennas. The earth surface at the experimental test site is far from smooth and flat. A level line at a 4-ft height was run from the transmitting antenna and the Yagi was placed about 7 in. below it, that is, at 3.4 feet. Because of ground dips, the Yagi was sometimes 5.5 ft above the local ground. Whenever obstructions such as landing light poles and junction boxes were encountered at a measuring point, the Yagi antennas were displaced sufficiently to provide a clear unobstructed path to the course and clearance transmitting antennas. Such interference was minimal anyway because of the horizontal polarization of the ILS signal.

In order to verify the assumption that the course Yagi responds only to course signals, the signal power levels at the Yagi were measured with both course and clearance transmitters on and then with the course transmitters alone. No change in the measured levels indicated no interference from the clearance signal. Similar measurements at the clearance Yagi indicated that at the positions chosen for the test, the course signal did not interfere with the clearance Yagi.

The output power from the Yagi antennas was measured directly with a thermistor power meter.

5.1 Course Detector Results

Output power was measured as the course Yagi, at a height of 3.4 ft, was moved from 250 ft to 100 ft along the center line of the course transmitting array (see Table 8). When the measured values are scaled and the 150 ft value is set equal to the value computed at 150 ft, the following results emerge.

Table 8. Comparison of Measured and Computed Yagi Performance in the MRN-7 System. Height—3.4 ft

Distance	Computed Performance	Measured Performance
250 ft	-62.1 dB	-62.7 dB
200 ft	-58.5 dB	-61.1 dB
150 ft	-53.6 dB	-53.6 dB (Match Point)
100 ft	-46.9 dB	-47.3 dB

Variation in Yagi performance as height increased from 38 in. to 72 in. was measured at a distance of 100 feet. After scaling and setting measured and computed values at 60 in. equal, Table 9 results.

Table 9. Comparison of Measured and Computed Yagi Performance in the MRN-7 System as Height Varies

Height	Computed Performance	Measured Performance
40.8 in.	-46.9 dB	-47.4 dB
48 in.	-45.8 dB	-46.5 dB
60 in.	-44.3 dB	-44.3 dB (Match Point)
72 in.	-42.8 dB	-42.8 dB

The comparison between measured and computed behavior of the course Yagi antenna is quite good. It was not possible to make VSWR field measurements but Tables 8 and 9 imply that, as predicted, the impedance mismatch causes no serious problems and can therefore be neglected as the Yagi height is reduced.

5.2 Clearance Detector Results

Measurements similar to those above were carried out for the clearance Yagi in the location indicated in Section 4. Results are shown in Tables 10 and 11.

Table 10. Comparison of Measured and Computed Clearance Yagi Performance in the MRN-7 System

Distance	Height	Computed Performance	Measured Performance
150 ft	22.8 in.	-51.7 dB	-51.7 dB (Match Point)
100 ft	20 in.	-45.7 dB	-46.7 dB

Table 11. Comparison of Measured and Computed Clearance Yagi Performance in the MRN-7 System as Height is Varied

Height	Computed Performance	Measured Performance
20 in.	-45.6 dB	-44.3 dB
30 in.	-42.9 dB	-43.0 dB
40 in.	-40.9 dB	-41.9 dB
50 in.	-39.4 dB	-39.4 dB (Match Point)

Again, comparison between computer predictions and measured performance is good indicating that the antenna modeling program and its attendant assumptions can be relied on to give an accurate prediction of actual Yagi detector performance.

5.3 Check of Course and Clearance Alarm Circuits

When the rf transmitter power was purposely reduced by 10 to 18 percent, the alarm circuits activated for all the Yagi locations listed in the previous section. The basic assumption of the theoretical analysis was that output power levels equal to those of the GRN-27 would guarantee successful operation of the alarm circuits in both the MRN-7 and GRN-29 systems. This is true! What was surprising was that output power levels considerably lower are also successful in running the alarm circuits. It had been expected that as soon as signal levels dropped a few dB from GRN-27 levels, the detectors would not function. The detectors appear much more versatile. Drops of about 8 to 10 dB from the GRN-27 levels can be tolerated by the alarm circuits. In fact, in the measurement program, due to cabling lengths it was not possible to put either antenna far enough away from the MRN-7 to force a failure in the alarm circuits. We feel that we approached the limit of operation however when the course detector was at 260 ft and the clearance was at 150 feet. Given the one-day time frame of the experiment, it was also not possible to determine whether the system produced any increase in false alarms due to aircraft overflights. Even though the alarm circuits work at signal levels well below GRN-27 levels, false alarms could emerge as a problem at the low signal levels.

5.4 Vertical Field Dropoff

It was not possible to measure the vertical field dropoff at the Yagi antennas over the 25-in. to 77-in. height range, due to a probe deficiency. Preliminary computer calculations had indicated that some dropoff was present in both the course and clearance transmitting array near-fields. However, the good correlation between measurements and calculations would lead one to believe that the effect was not serious.

5.5 Summary

(1) Measured performance of the course and clearance detector antennas in the MRN-7 system showed good agreement with the predicted results. This verifies the computer approach as an analysis tool for other systems such as the GRN-29 localizer.

(2) VSWR and vertical field drop-off measurements could not be made. Other measurements indicate that neither is a major problem as height is reduced.

(3) Check of the alarm circuits showed that with detector heights of 3.4 ft, successful operation was possible with the course Yagi as far as 260 ft and the clearance Yagi as far as 150 ft from the MRN-7 arrays. At these distances, it seemed that we were close to a threshold beyond which the detectors could not provide sufficient signal to run the alarm circuits. This latter conclusion was not actually tested due to length of available cabling. Alarm circuit operation at distances within the limits shown above was always possible.

(4) Placing the detectors to provide a performance level equal to the GRN-27 seems to guarantee success but it is by no means necessary to have this level of performance. Placing the detectors to provide levels of performance up to 8 to 10 dB below GRN-27 performance also seems to be successful. This means the detectors can be placed:

  (a) further away or,

  (b) lower than or,

  (c) both further away and lower than,

the heights required for GRN-27 performance, if false alarms do not show an increase.

6. COMPUTED PERFORMANCE OF THE GRN-27 YAGI DETECTOR ANTENNAS IN THE GRN-29 LOCALIZER SYSTEM

The dimensions of the GRN-29 antenna used in the computations were:

Length of Course Array—85.8 ft,

Height of Course Array—6 ft, 10 in.,

Length of Clearance Array—32.2 ft,

Height of Clearance Array—6 ft, 10 in.

6.1 Course Detector

Computations of the average performance of the Yagi detector were performed for the Yagi placed along the course array center line and varied in distance from 357 to 125 ft from the course array. The height was held fixed at 3.4 feet.

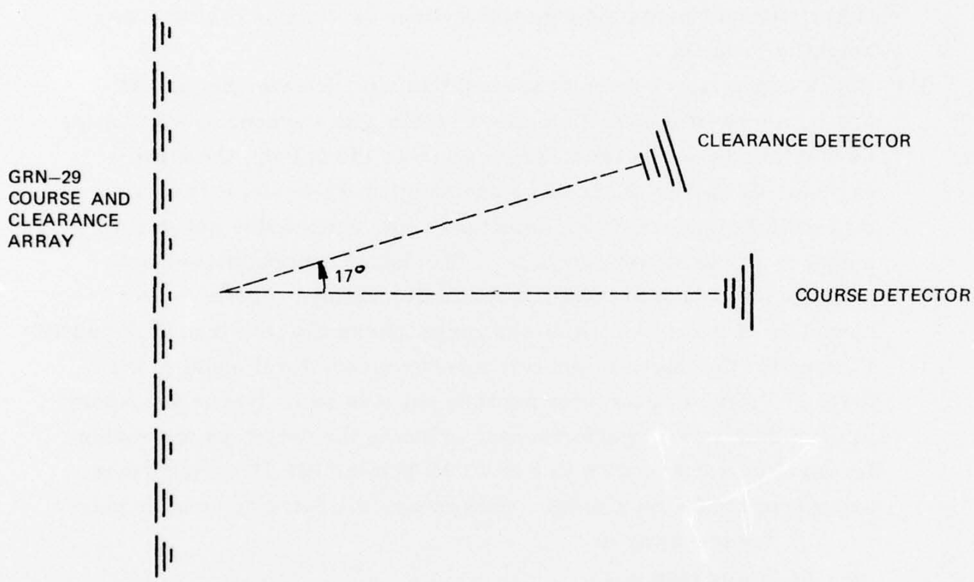


Figure 4. Geometry of the Course Detector

As the course Yagi is moved inward, the vertical extent of the pattern contributing to its performance ranges from 1.08° at 357 ft to 3.2° at 125 feet. The horizontal angles vary from ± 7° at 357 ft, to ± 19° at 125 feet. Results are shown in Table 12. Recall that the level of performance needed to equal the GRN-27 is -57.4 dB.

Table 12. Performance of 3.4-ft High Course Yagi Antenna as Distance from GRN-29 Localizer Antenna is Varied. Good earth—110 MHz

Distance from Course Antenna to Yagi	Loss Due to $1/R^2$	Average Performance of Yagi	Total Yagi Performance
357 ft	-51.0 dB	-12.7 dB	-63.7 dB
300 ft	-49.5 dB	-11.2 dB	-60.7 dB
250 ft	-47.9 dB	- 9.7 dB	-57.6 dB
200 ft	-46.0 dB	- 7.9 dB	-53.9 dB
175 ft	-44.9 dB	- 6.8 dB	-51.7 dB
150 ft	-43.5 dB	- 5.6 dB	-49.1 dB
125 ft	-41.9 dB	- 4.3 dB	-46.2 dB

A comparison of Tables 12 and 4 shows that simply because the GRN-29 array is a higher antenna than the MRN-7, that is, 6.8 ft vs 4 ft, the Yagi detector antenna performs better at further distances. One needs to place a 3.4-ft high Yagi at about 250 ft in the GRN-29 system to obtain a performance that duplicates the GRN-27 behavior. In contrast, the distance required in the MRN-7 system is about 200 feet. The trends and tradeoffs are obvious here. If the GRN-29 antenna is lower than 6.8 ft, the 3.4-ft Yagi must be moved closer than the 250 ft quoted above. This is also true if the GRN-29 antenna remains at 6.8 ft but the Yagi is lower than 3.4 feet. In the case that both the GRN-29 and the Yagi are lowered simultaneously, the Yagi would have to be moved in considerably from 250 ft to duplicate the GRN-27 performance.

Just as in the MRN-7 case, it is possible to vary the height of the Yagi (at a given distance from the course array) and alter its performance. This is shown in Table 13. Note that an increase in height from 3.4 to 6 ft produces an increase in Yagi performance of about 4 dB, a gain of about 1.5 dB per ft of increased height. This is about the same increase noted with the MRN-7. Note also that at distances closer than 200 ft, Yagi height can be as low as 25 in. while providing levels equal to or better than GRN-27 performance figures.

Table 13. Variation in Course Yagi Performance with Height

Height	Average Performance
Distance of Yagi from GRN-29 Course Antenna—200 ft	
25 in.	-57.2 dB
40.8 in.	-53.9 dB
48 in.	-52.7 dB
60 in.	-51.3 dB
72 in.	-49.8 dB
Distance of Yagi from GRN-29 Course Antenna—175 ft	
Height	Average Performance
25 in.	-55.1 dB
40.8 in.	-51.7 dB
48 in.	-50.6 dB
60 in.	-49.1 dB
72 in.	-47.6 dB
Distance of Yagi from GRN-29 Course Antenna — 150 ft	
Height	Average Performance
25 in.	-52.5 dB
40.8 in.	-49.1 dB
48 in.	-48.0 dB
60 in.	-46.5 dB
72 in.	-45.1 dB

6.2 Clearance Detector

The Yagi was placed in a location similar to that used in the GRN-27 system, that is, at an angle of 17° to the clearance array. It is not clear that this location assures that the course array causes no interference. The easiest way to check for such interference is experimentally as was outlined in Section 5 but time did not allow this. The calculations that follow therefore, assume no interference at the clearance array. Distance between the two antennas was varied from 167 to 50 ft, while the height of the Yagi was held fixed at 3.4 feet. The vertical angles subtended by the clearance array at the Yagi varied from 2.1° at 167 ft to 8.6° at 50 ft, while the horizontal angles varied from ± 5° to ± 19° over the corresponding distances. Results are shown in Table 14. Recall that the desired performance level is about -35 dB.

Table 14. Performance of 3.4-ft High Clearance Yagi as Distance from GRN-29 Clearance Array is Varied. Good earth—110 MHz

Distance from Clearance Antenna to Yagi	Loss Due to $1/R^2$	Average Performance of Yagi	Total Yagi Performance
167 ft	-44.4 dB	-6.3 dB	-50.7 dB
150 ft	-43.5 dB	-5.5 dB	-49.0 dB
125 ft	-41.9 dB	-3.9 dB	-45.8 dB
100 ft	-40.0 dB	-2.2 dB	-42.2 dB
75 ft	-37.5 dB	0 dB	-37.5 dB
50 ft	-33.9 dB	+2.8 dB	-31.1 dB

A 3.4-ft high Yagi placed at about 75 ft or closer along a 17° line from the center of the GRN-29 antenna should provide a performance level about equal to that of the GRN-27.

The increase in performance that occurs with height change is shown in Table 15.

Table 15. Performance of Clearance Yagi at 75 ft Along a 17° Line as Height Changes. Good earth—110 MHz

Height	Average Performance
25 in.	-40.8 dB
40.8 in.	-37.5 dB
48 in.	-36.4 dB
60 in.	-35.0 dB
72 in.	-33.5 dB

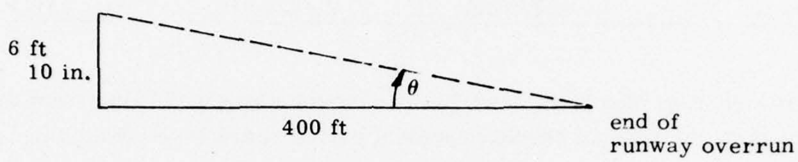
At this distance, almost all of the antenna heights provide satisfactory performance.

6.3 Operating Frequency and Earth Type Variations

As in the MRN-7, computations showed that neither frequency nor earth produced more than 0.2 to 0.3 dB change in average performance level of the course and clearance Yagis.

6.4 Detector Placement Restrictions Due to Siting Considerations

The final location of the Yagi antennas is governed both by performance limits and also by ILS system aircraft clearance requirements. The allowable height for the course and clearance detector antennas depends on the exact placement of the localizer antenna and the aircraft clearance angles required. If, for example, the GRN-29 localizer antenna is placed 400 ft from the end of the runway overrun, and if the antenna is 6 ft, 10 in. high, then the takeoff clearance angle would be:



$$= \tan^{-1} \times \frac{6.8333}{400} = 0.978°\ ,$$

compared to the usual 1.14° found in ILS systems, that is, a ratio of 1-ft height increase to 50 horizontal feet. If it is assumed that both course and clearance detector antennas must be placed to maintain this 0.978° angle, then 3.4-ft high detector antennas must be no further than 201 ft from the localizer antenna. As the antennas are moved in closer to the localizer, they can get higher while still maintaining the 0.978° angle.

Detector Distance	Maximum Allowable Height to Preserve 0.978° Angle
175 ft	46 in.
150 ft	51 in.
125 ft	56 in.
100 ft	61 in.
50 ft	72 in.

All of these results are of course, heavily dependent on the exact distance and height that is selected for the GRN-29 antenna. With the calculations reported earlier, one has the assurance that the Yagi antennas can in fact perform as required.

6.5 Summary and Specific Recommendations for Use of the GRN-27 Yagi Detector Antennas in a GRN-29 Type Localizer System

(1) The GRN-27 Yagi antennas appear suitable for use in the GRN-29 system without modification or any internal retuning.

(2) The course Yagi detector antenna when placed on the center line and in front of the GRN-29 array at 3.4-ft height, will provide adequate signal to run the alarm circuits as long as its distance is 250 ft or less. If the results found in the MRN-7 experiment hold true, that is, that the detector alarm circuits will operate even when signal levels are up to 10 dB below GRN-27 levels, then the 3.4-ft high Yagi could be placed as far as 350 ft from the GRN-29 antenna and still trip the alarm circuits when rf power is reduced.

(3) The actual height of the course Yagi depends on the siting geometry and the aircraft clearance angles required. These factors seem to demand distances less than 200 ft for a 3.4-ft antenna, hence successful operation of the course detector alarm circuits seems to be well within the capabilityof the Yagi antenna.

(4) The clearance Yagi should be located (in angle) such that it is unaffected by the course array. It is easiest to determine this location experimentally and a few simple tests with one of the Yagis and the GRN-29 array should lead to a proper location for the Yagi. The calculations in this report assume that the clearance Yagi is located along a line 17° from the array center. Angles in the 30° to 60° range would seem to offer better isolation if the 17° angle proves troublesome.

(5) The clearance Yagi, when placed 75 ft away from the localizer antenna along a 17° line at 3.4-ft height will provide sufficient signal strength to activate the alarm circuits. Again, assuming that the MRN-7 results apply, the antenna could be moved to distances as great as 125 to 150 ft and still activate the alarm circuitry.

(6) The results reported above are not dependent on frequency changes within the 108 to 112 MHz ILS band or changes in the electrical parameters of the earth beneath the antennas. These and the signal losses due to mismatch between the antenna and the detector circuits each contribute only a fraction of a dB and are therefore not considered important.

6.6 Some Considerations

(1) It has been assumed that the GRN-29 system will use the same power levels as the MRN-7 system. If this is not so, that is, if power levels are reduced, the Yagi distances quoted above would have to be reduced from 350 and 125 feet.

(2) It has been assumed that in spite of antenna design differences, the GRN-29 and MRN-7 arrays produce essentially the same distribution of energy in their near fields, that is, the area where the Yagis are located. This assumption can be checked via the computer, but it entails a considerable computation and for that reason, was not amenable to the time frame of this study.

(3) The computer results do not account for any high grass or vegetation between the localizer and Yagi antennas. The experiment at Griffiss was performed with such vegetation cover well trimmed. It is not clear exactly how such ground cover would affect the performance of the Yagi antennas, but it is recommended that such cover be kept to a minimum in ILS installations.

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