NBS TECHNICAL NOTE 688

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Yagi Antenna Design

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Yagi Antenna Design

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Issued December 1976

NATIONAL BUREAU OF STANDARDS TECHNICAL NOTE 688
Nat. Bur. Stand. (U.S.), Tech Note 688, 27 pages (December 1976)

CODEN: NBTNAE

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1976

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
(Order by SD Catalog No. C13.46:688) Price 65 cents (Add 25 percent additional for other than U.S. mailing).

FOREWORD

This work was carried out by the National Bureau of Standards at antenna test ranges located in Sterling, Virginia, and at Table Mountain near Boulder, Colorado.

These measurements were carried out by the Antenna Research Section of the Radio System Division, National Bureau of Standards.

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YAGI ANTENNA DESIGN

Peter P. Viezbicke

This report presents data, using modeling techniques, for the optimum design of different length Yagi antennas. This information is presented in graphical form to facilitate the design of practical length antennas--from 0.2λ to 4.2λ long--for operation in the HF, VHF, and UHF frequency range. The effects of different antenna parameters on realizable gain were also investigated and the results are presented. Finally, supplemental data are presented on the stacking of two or more antennas to provide additional gain.

Key words: Antenna, director, driven element, gain, radiation pattern, reflector, Yagi.

1. INTRODUCTION

The Yagi-Uda antenna [1], commonly known as the Yagi, was invented in 1926 by Dr. H. Yagi and Shintaro Uda. Its configuration normally consists of a number of directors and reflectors that enhance radiation in one direction when properly arranged on a supporting structure.

Since its discovery, a large number of reports have appeared in the literature relative to the analysis, design, and use of the Yagi antenna [2, 3, 4, 5, 6, 7, 8, 9]. However, little or no data seem to have been presented regarding how parasitic element diameter, element length, spacings between elements, supporting booms of different cross sectional area, various reflectors, and overall length affect measured gain.

This report presents the results of extensive measurements carried out by the National Bureau of Standards to determine these effects and gives graphical data to facilitate the design of different length antennnas to yield maximum gain. In addition, design criterion is also presented on stacking--one above the other and in a columnar configuration. The gain is given in decibels (dB) relative to a dipole (reference antenna) at the same height above ground as the test (Yagi) antenna.

2. METHOD OF MEASUREMENT

The measurements were carried out at the NBS antenna range when it was located at Sterling, Virginia, and at Table Mountain, Colorado, after the antenna research group was relocated to Colorado. All measurements were conducted at a modeling frequency of 400 MHz. The antenna under test was used as a receiving antenna and was located approximately 320 meters from a target transmitter and antenna. The transmitting antenna was located at a height above ground so that the receiving antennas were illuminated at grazing angles. The Yagi under test was mounted 3λ (wavelength) above ground and its gain was compared to a reference dipole antenna located approximately 5λ to one side and at the same height as the test antenna. Each antenna was matched precisely to 50 ohms and switched alternately to an attenuator and associated receiving and detecting equipment located in a nearby wooden building. In comparing the attenuator readings of the two antennas to produce a constant receiver output level, line losses to each were measured and compensated for in arriving at final values of gain. The values of gain were reproducible to within 0.2 dB over the period when measurements were being carried out. The values presented are those measured in a forward direction compared to the maximum response of a dipole at the same height above ground and are believed accurate to within 0.5 dB. If referenced to an isotropic source, the values must be increased by 2.16 dB.

3. RESULTS

The results of the measurements carried out in this study are presented in graphical form. They are intended to provide a simple means of designing a Yagi antenna of practical dimensions with maximum gain for the configuration under consideration. The purpose of these tests was to determine the following:

a. Effect of reflector spacing on the gain of a dipole antenna

b. Effect of different equal length directors, their spacing and number on realizable gain

c. Effect of different diameters and lengths of directors on realizable gain

d. Effect of the size of a supporting boom on the optimum length of parasitic elements

e. Effect of spacing and stacking of antennas on gain

f. Measured radiation patterns of different Yagi configurations

3.1 EFFECT OF REFLECTOR SPACING ON MEASURED GAIN

These tests as well as all others were carried out on a non-conducting plexiglass boom mounted 3λ above ground. With the exception of measurements stated in sections 3.3 and 3.4, all parasitic elements were constructed of 0.63 cm (one-fourth inch) diameter aluminum tubing. The driven element used in the Yagi as well as in the reference dipole was a half-wave folded dipole matched to 50 ohms using a double-stub tuner.

The gain of a dipole and reflector combination for different spacings between the two elements is shown in figure 1. Maximum measured gain was 2.6 dB and was realized at a spacing of 0.2λ behind the dipole. This reflector spacing was used in all subsequent measurements. However, for the different Yagi configurations the reflector length was optimized to yield maximum gain. An additional 0.75 dB gain was realized using the reflector configuration shown in figure 2.

Although this arrangement was used only on the 4.2λ long Yagi, comparable benefits would be realized with other antenna lengths. A photograph of the experimental set-up for this configuration is shown in figure 3.

Various arrangements and spacings of reflector elements were tested on the 4.2λ Yagi using the drilled plexiglass support as shown. The reflecting elements were arranged in shapes of plane reflecting surfaces, parabolas and corner reflectors. In addition, different shaped solid reflecting surfaces placed at various distances behind the driven element were also used. Of the combinations tested, the one shown in figure 2 yielded the largest increase in gain over that of the single reflecting element.

3.2 EFFECT OF DIFFERENT EQUAL LENGTH DIRECTORS AND SPACING ON MEASURED GAIN FOR DIFFERENT YAGI LENGTHS

These measurements were conducted using the same non-conducting boom as mentioned in the preceding section. The driven element consisted of a $\lambda/2$ folded dipole; the reflector was 0.482λ in length and spaced 0.2λ behind the driven element. The diameter of all elements was 0.0085λ (0.25 inches = 0.63cm).

The gain of the Yagi was measured as a function of antenna length (number of directors) for different equal length directors and spacing between them. The director lengths were varied from 0.304λ to 0.423λ and spacings from 0.01λ to 0.40λ. The Yagi length, measured from the driven element to the last director, was varied from an overall length of 0.2λ to 10.2λ. The reflector in all cases was fixed. Although many measurements were carried out, only those results and associated graphs are presented that show the effects of these parameters on measured gain.

Figures 4, 5, and 6 show the relative gain of a Yagi as a function of length for different spacings between director elements using director lengths of 0.382λ, 0.411λ, and 0.424λ. Figure 4 shows that for relatively short directors at a spacing of 0.3λ, the gain of the Yagi increased to a maximum value of 14.5 dB when the antenna length was increased to approximately 10λ. Note, however, that as the spacing between elements was

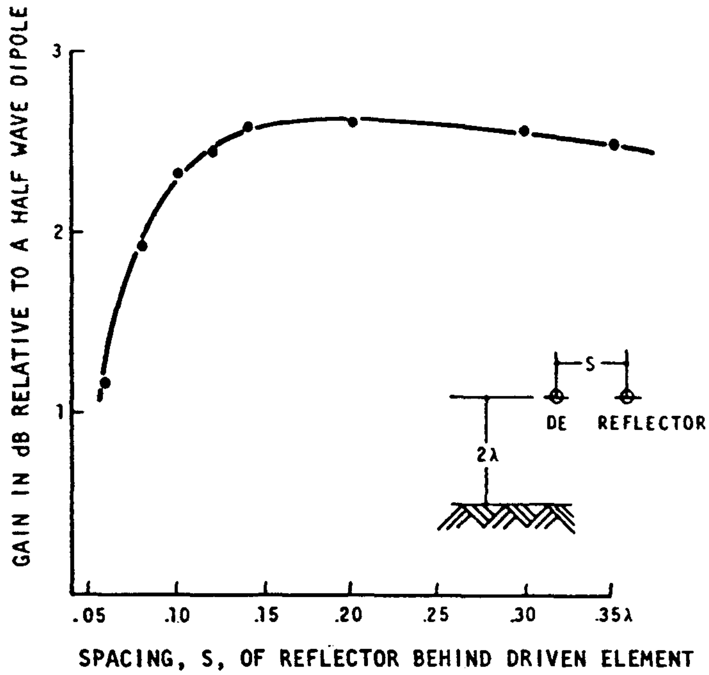

FIG. 1 GAIN IN dB OF A DIPOLE AND REFLECTOR FOR DIFFERENT SPACINGS BETWEEN ELEMENTS

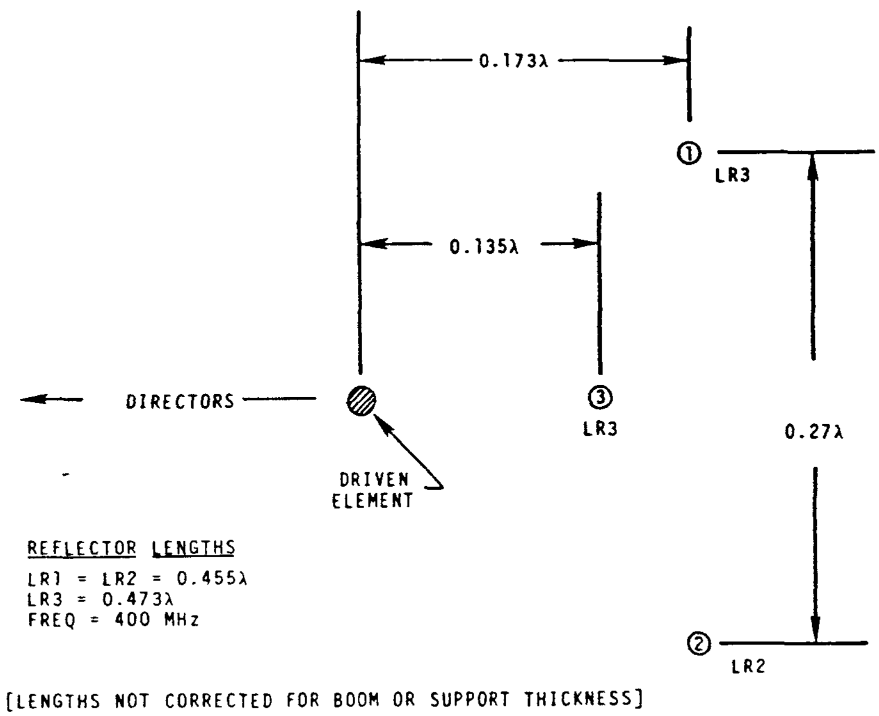

FIG. 2 ARRANGEMENT OF THREE REFLECTING ELEMENTS USED WITH THE 4.2λ YAGI

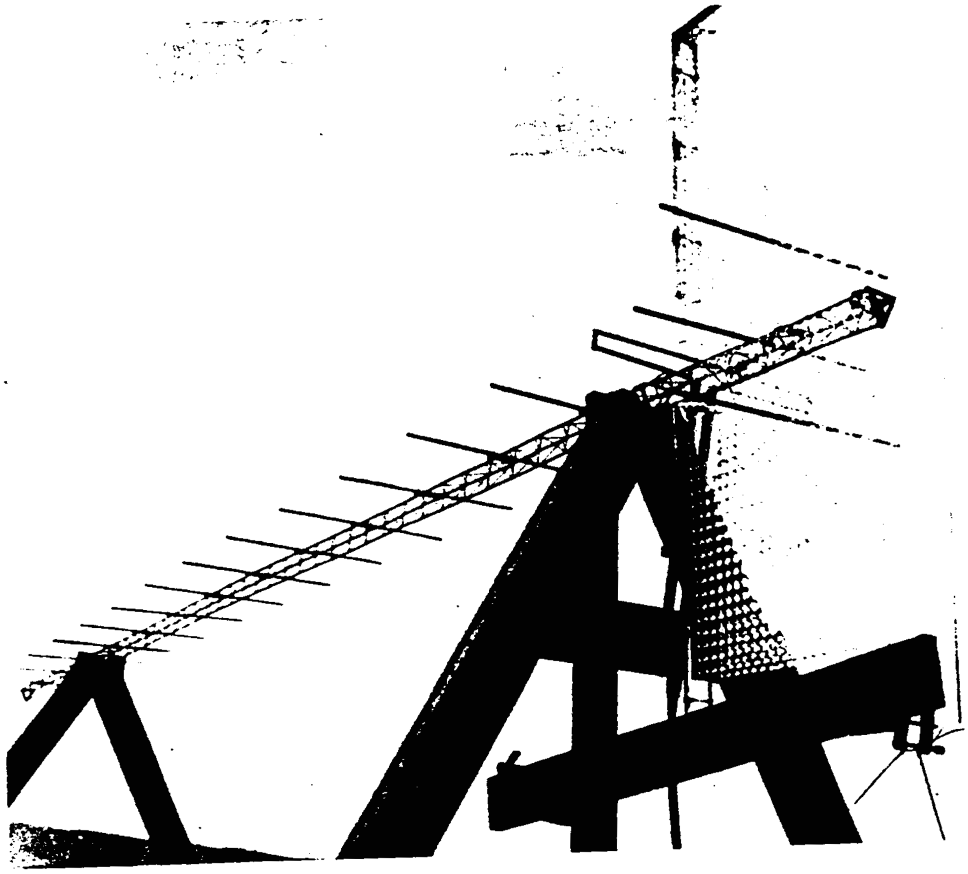

FIG. 3 PHOTOGRAPH OF THE TRIGONAL REFLECTOR EXPERIMENTAL SET-UP USED WITH THE 4.2λ YAGI

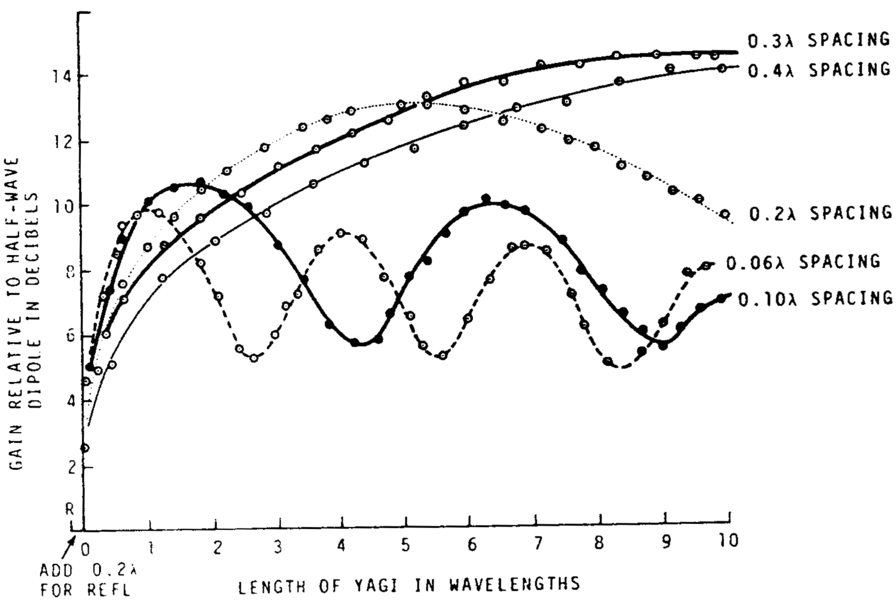

FIG. 4 GAIN OF A YAGI AS A FUNCTION OF LENGTH (NUMBER OF DIRECTORS) FOR DIFFERENT CONSTANT SPACINGS BETWEEN DIRECTORS OF LENGTH EQUAL TO 0.382λ

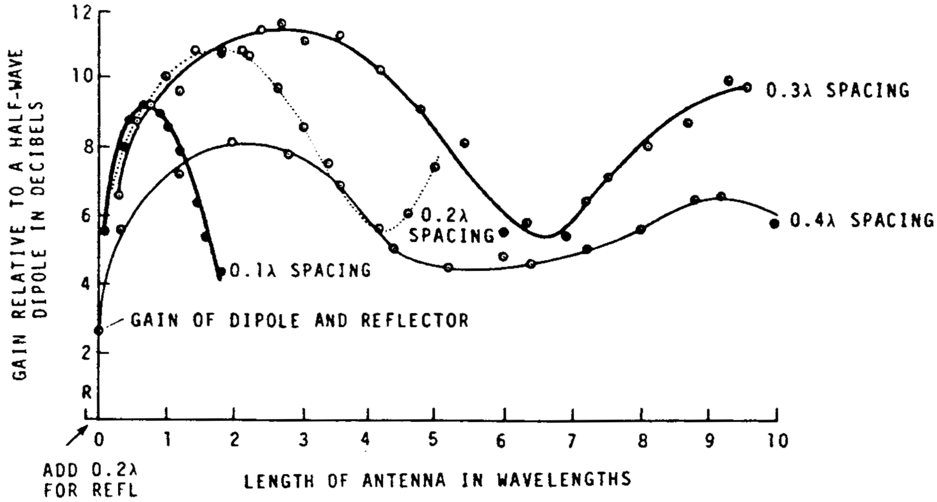

FIG. 5 GAIN OF A YAGI AS A FUNCTION OF LENGTH (NUMBER OF DIRECTORS) FOR DIFFERENT CONSTANT SPACINGS BETWEEN DIRECTORS OF LENGTH EQUAL TO 0.411λ

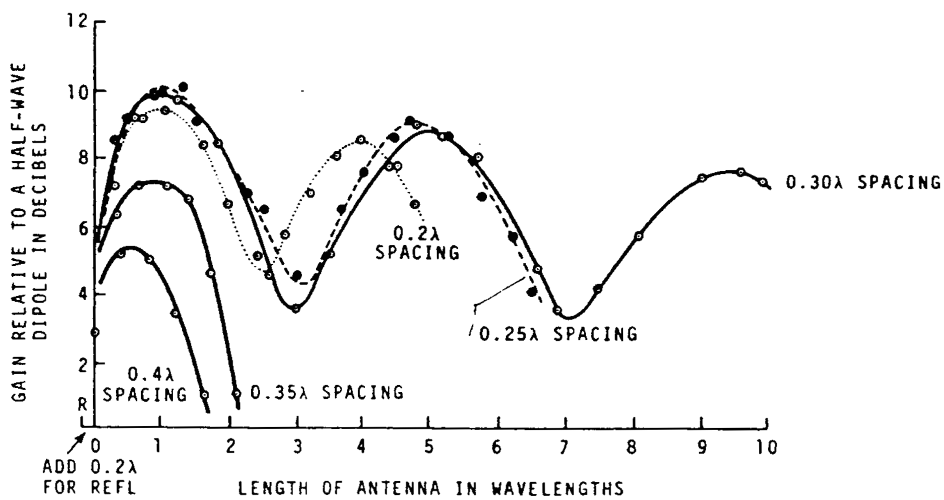

FIG. 6 GAIN OF A YAGI AS A FUNCTION OF LENGTH (NUMBER OF DIRECTORS) FOR DIFFERENT CONSTANT SPACINGS BETWEEN DIRECTORS OF LENGTH EQUAL TO 0.424λ

decreased, an oscillatory wave pattern resulted wherein the maximum gain occurred at a shorter Yagi length and varied between a maximum and minimum value as the length of the Yagi was changed. As the length of the directors was increased, the variations in the wave pattern were also enhanced together with a reduction in gain as shown in figures 5 and 6.

The curves presented in figure 7 show a comparison of realized gain vs Yagi length up to 4.2λ for antennas using directors of equal length and those optimized in length. For the optimized length configurations the gain increased from 0.5 dB for the 2.2λ antenna to approximately 1.5 dB for the 4.2λ Yagi. Table 1 gives details of antenna parameters for the different optimized design lengths tested and measured.

3.3 EFFECT OF DIFFERENT DIAMETERS AND LENGTHS OF DIRECTORS ON MEASURED GAIN

This effect was determined by measuring the gain of different Yagi configurations for different director lengths of various diameters. Curves showing the results of measurements carried out on the 1.25λ long Yagi are given in figure 8. As expected, the maximum gain for the different combinations remained unchanged. The larger diameter elements yielded maximum gain at shorter lengths while the smaller diameter elements yielded maximum gain at correspondingly greater lengths. Results of a series of measurements, noting these effects, were carried out on the different length Yagis and, together with results presented in Table 1, a set of design curves was produced and is presented in figure 9. These data provide the basic design criterion of the Yagi antenna and are valid over a large frequency range provided the selected element diameter to wavelength ratio d/λ falls within the limits shown.

3.4 EFFECT OF THE SIZE OF A SUPPORTING BOOM ON THE OPTIMUM LENGTH OF A PARASITIC ELEMENT

Round and square supporting booms of different cross-section area were employed in Yagi antennas of different lengths to determine what effect the boom diameter had on the optimum length of the parasitic elements. The round and square booms yielded similar results. The effect of a round supporting boom on the length of a parasitic element is represented by the curve in figure 10. This experimental response can be used in applying the boom correction for the final Yagi design.

3.5 EFFECT OF SPACING AND STACKING OF YAGI ANTENNAS ON REALIZABLE GAIN

As shown in figure 11, additional gain is realized when antennas are stacked one above the other or in broadside. Not only is gain increased but the beamwidth is reduced appreciably depending upon the configuration employed.

Figure 11 (A) shows the effects of stacking two antennas, one above the other. These responses show similar mutual effects between two seven-element Yagis and between two fifteen-element Yagis. At close spacing, approximately 0.8λ, the gain was reduced due to high mutual impedance effects but increased to a maximum of 2.5 dB as the spacing was increased to approximately 1.6λ. Similar effects were measured with the combination shown in figure 11 (B). Maximum gain in this case was realized with the two antennas spaced at approximately 2.0λ.

A combination of the above two configurations using spacings as shown yielded an additional 2.5 dB gain and a corresponding reduction in beamwidth. For example, four 0.8λ Yagi antennas, appropriately stacked, spaced and fed in phase yielded a gain of 14.2 dB relative to a dipole located at the same height above ground. In contrast, a combination of four 4.2λ Yagi antennas yielded a gain of 19.6 dB relative to a dipole, as shown by the graph in figure 12.

3.6 MEASURED RADIATION PATTERNS OF DIFFERENT LENGTH YAGI ANTENNAS

Radiation patterns measured in the E (horizontal-solid curves) and H (vertical-dashed curves) planes for different Yagi designs are presented in figures 13 through 19. The radiation patterns of the simplest yagi array (which consists of a reflector and driven

TABLE 1. OPTIMIZED LENGTHS OF PARASITIC ELEMENTS FOR YAGI ANTENNAS OF SIX DIFFERENT LENGTHS

		LENGTH OF YAGI IN WAVELENGTHS					
		0.4	0.8	1.20	2.2	3.2	4.2
LENGTH OF REFLECTOR, λ		0.482	0.482	0.482	0.482	0.482	0.475
LENGTH OF DIRECTOR, λ	1st	0.424	0.428	0.428	0.432	0.428	0.424
	2nd		0.424	0.420	0.415	0.420	0.424
	3rd		0.428	0.420	0.407	0.407	0.420
	4th			0.428	0.398	0.398	0.407
	5th				0.390	0.394	0.403
	6th				0.390	0.390	0.398
	7th				0.390	0.386	0.394
	8th				0.390	0.386	0.390
	9th				0.398	0.386	0.390
	10th				0.407	0.386	0.390
	11th					0.386	0.390
	12th					0.386	0.390
	13th					0.386	0.390
	14th					0.386	
	15th					0.386	
SPACING BETWEEN DIRECTORS, IN λ		0.20	0.20	0.25	0.20	0.20	0.308
GAIN RELATIVE TO HALF-WAVE DIPOLE IN dB		7.1	9.2	10.2	12.25	13.4	14.2
DESIGN CURVE (SEE FIG. 9)		(A)	(B)	(B)	(C)	(B)	(D)

ELEMENT DIAMETER = 0.0085

f = 400 MHz

REFLECTOR SPACED 0.2λ BEHIND DRIVEN ELEMENT

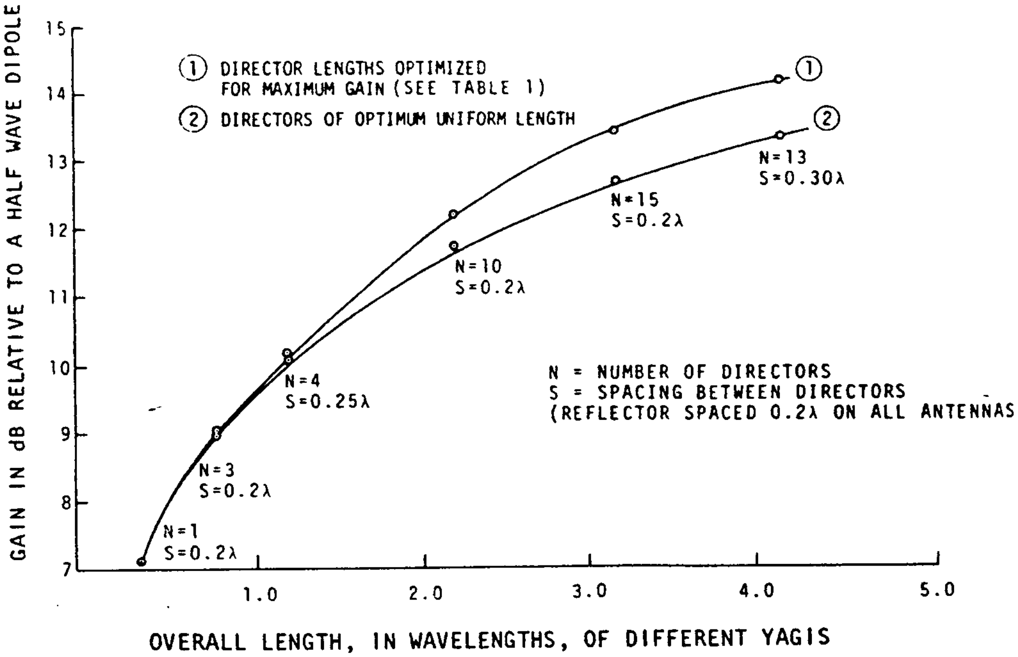

FIG. 7 COMPARISON OF GAIN OF DIFFERENT LENGTH YAGIS SHOWING THE RELATIONSHIP BETWEEN DIRECTORS OPTIMIZED IN LENGTH TO YIELD MAXIMUM GAIN AND DIRECTORS OF OPTIMUM UNIFORM LENGTH

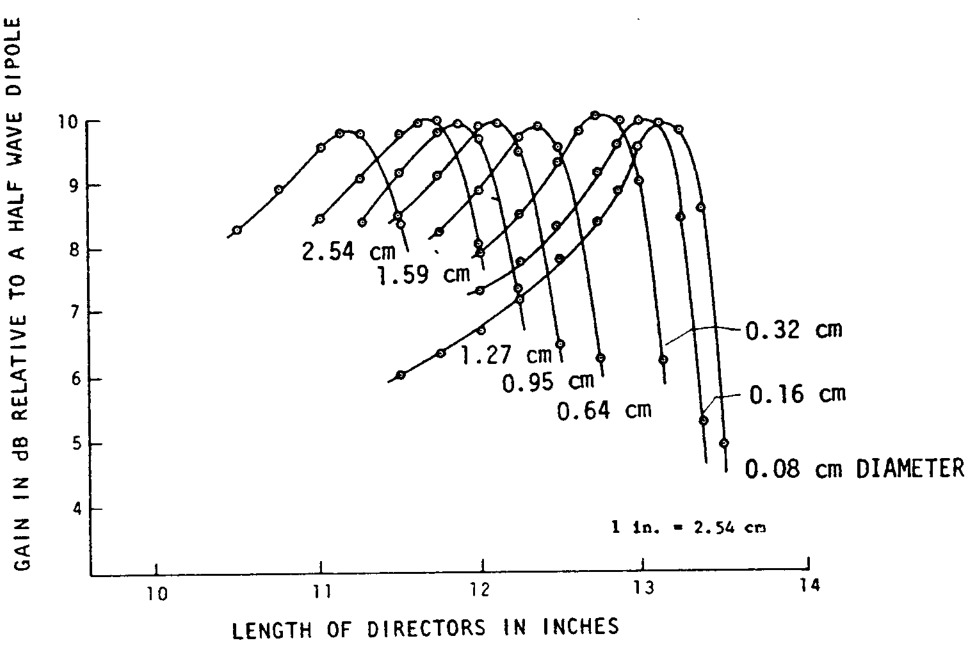

FIG. 8 MEASURED GAIN VS DIRECTOR LENGTH OF A 1.25λ YAGI ANTENNA USING THREE DIRECTORS OF DIFFERENT LENGTH AND DIAMETER SPACED 0.35λ

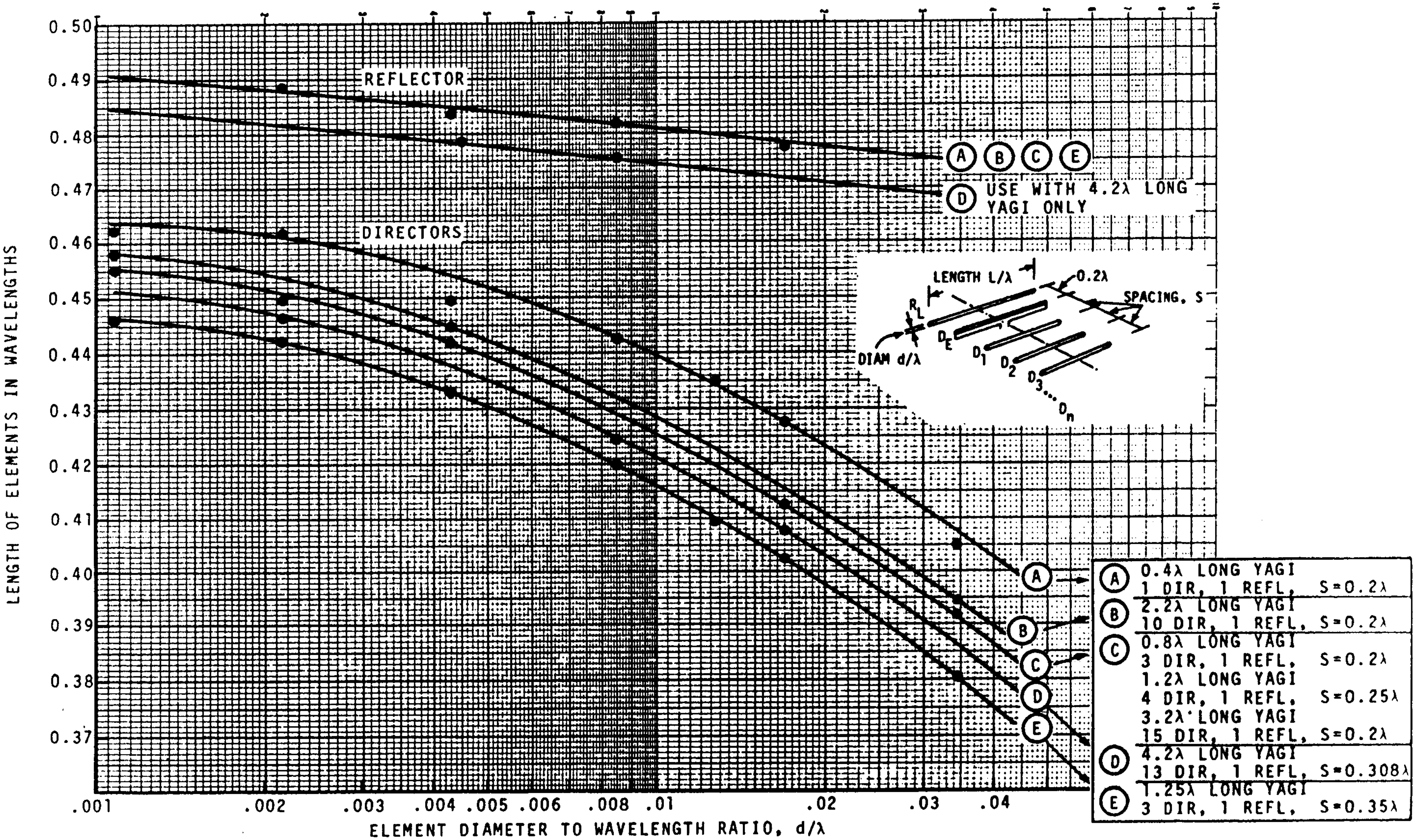

FIG. 9 YAGI ANTENNA DESIGN DATA SHOWING THE RELATIONSHIP BETWEEN ELEMENT DIAMETER TO WAVELENGTH RATIO AND ELEMENT LENGTH FOR DIFFERENT ANTENNAS

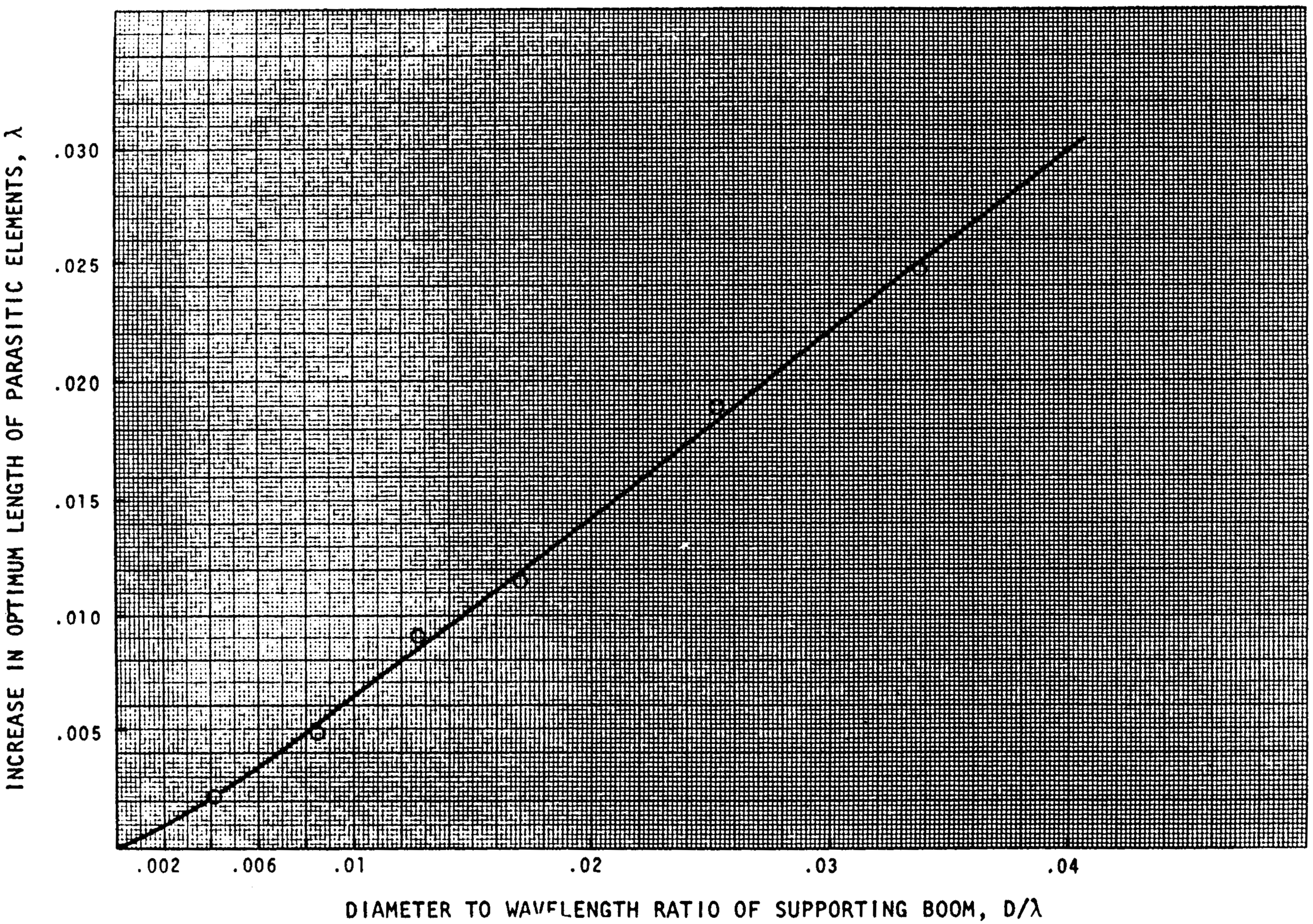

FIG. 10 GRAPH SHOWING THE EFFECT OF A SUPPORTING BOOM ON LENGTH OF ELEMENTS

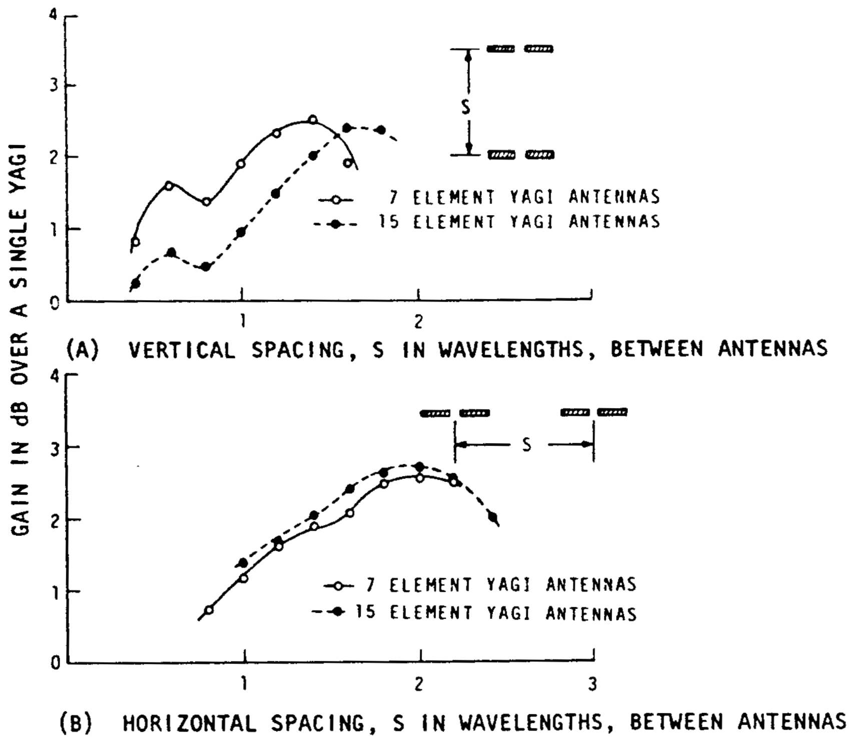

FIG. 11 GAIN OF AN ARRAY OF YAGIS, STACKED ONE ABOVE THE OTHER AND IN BROADSIDE, AS A FUNCTION OF SPACING

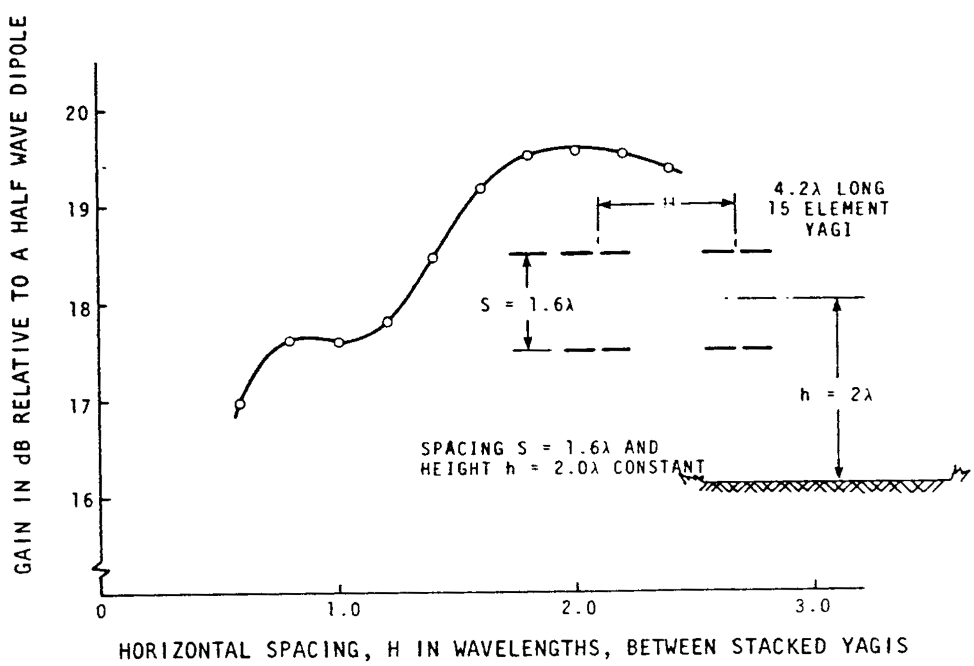

FIG. 12 GAIN OF AN ARRAY OF TWO SETS OF STACKED YAGIS SPACED 1.6λ AS A FUNCTION OF HORIZONTAL DISTANCE BETWEEN THEM

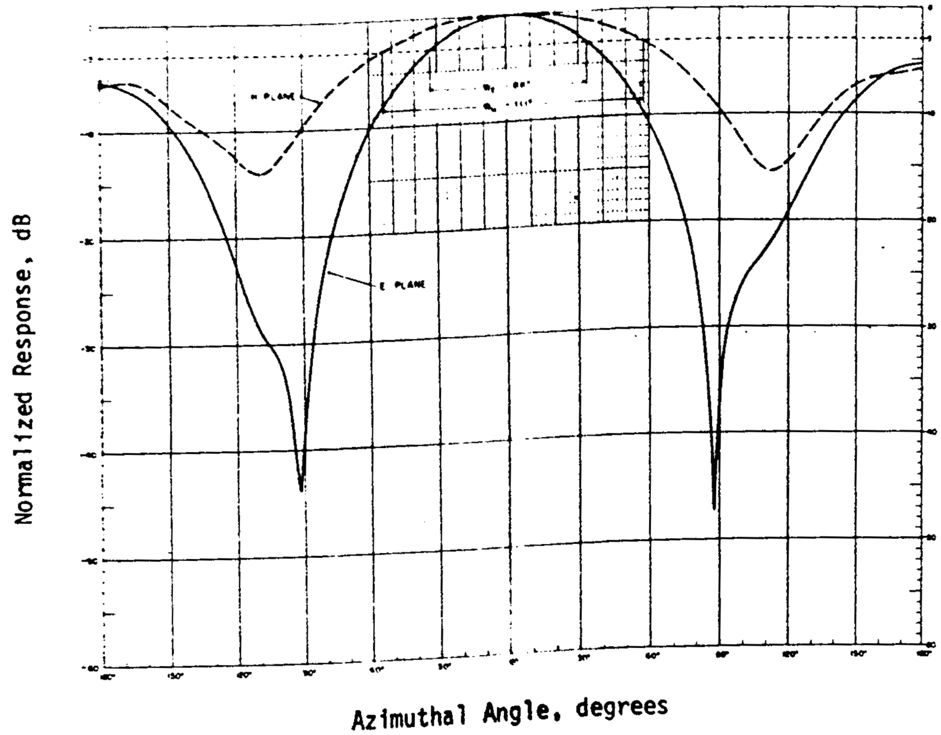

FIG. 13 RADIATION PATTERNS OF A DIPOLE AND REFLECTOR WITH 0.2λ SPACING

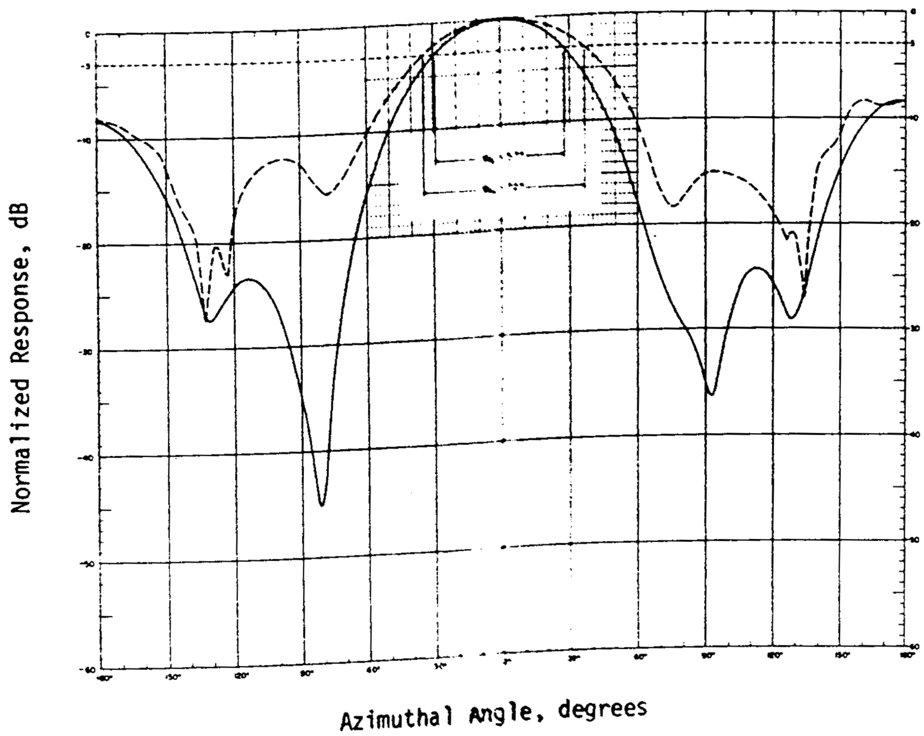

FIG. 14 RADIATION PATTERNS OF A 3-ELEMENT, 0.4λ LONG YAGI

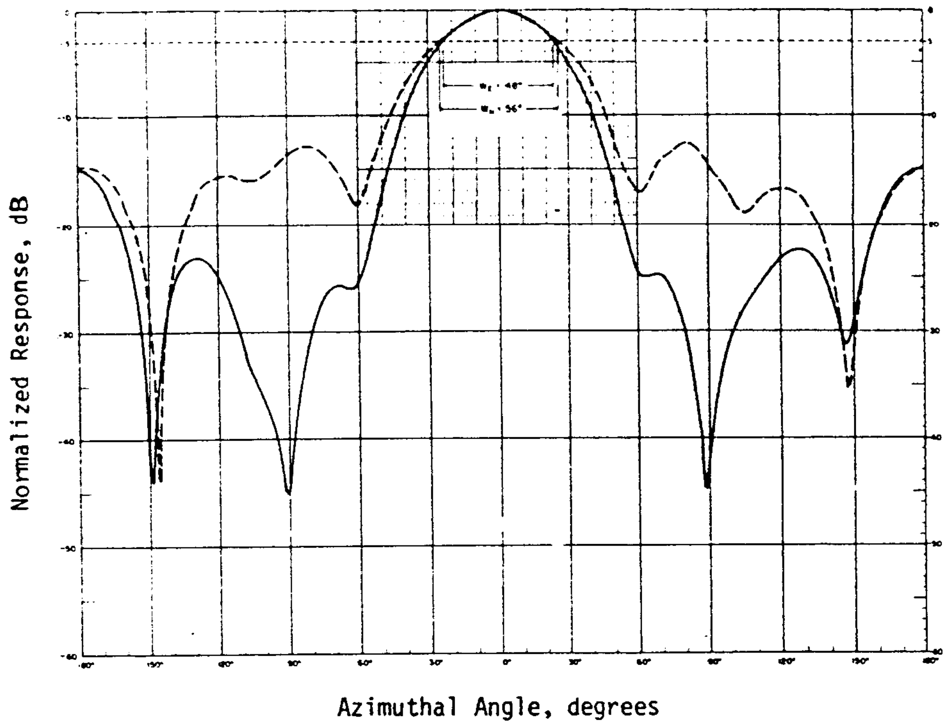

FIG. 15 RADIATION PATTERNS OF A 5-ELEMENT, 0.8λ LONG YAGI

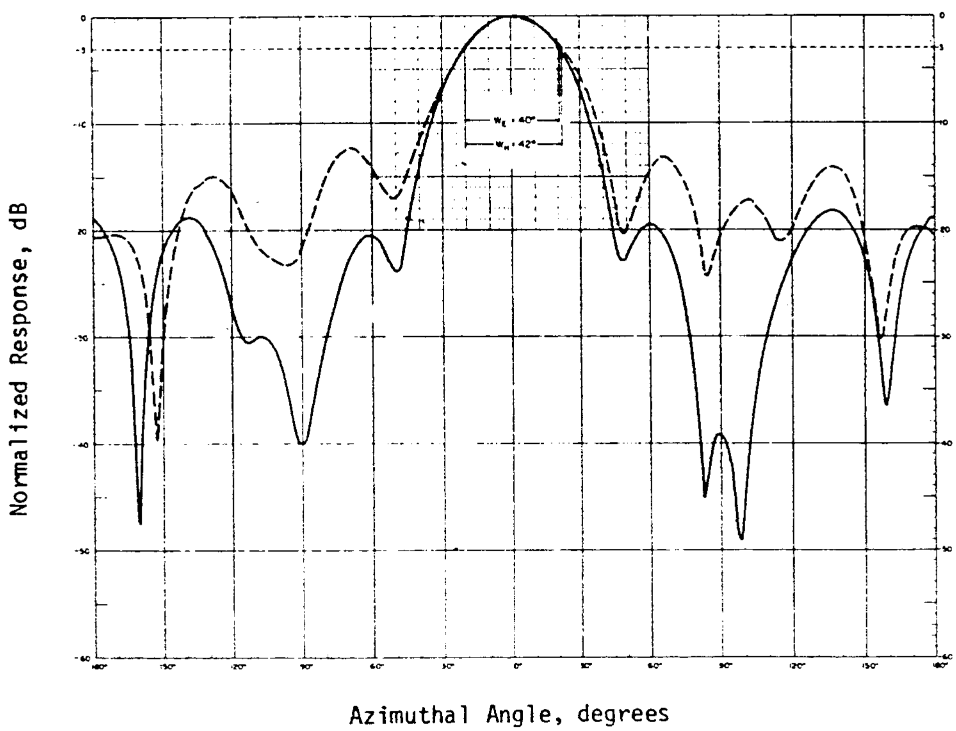

FIG. 16 RADIATION PATTERNS OF A 6-ELEMENT, 1.2λ LONG YAGI

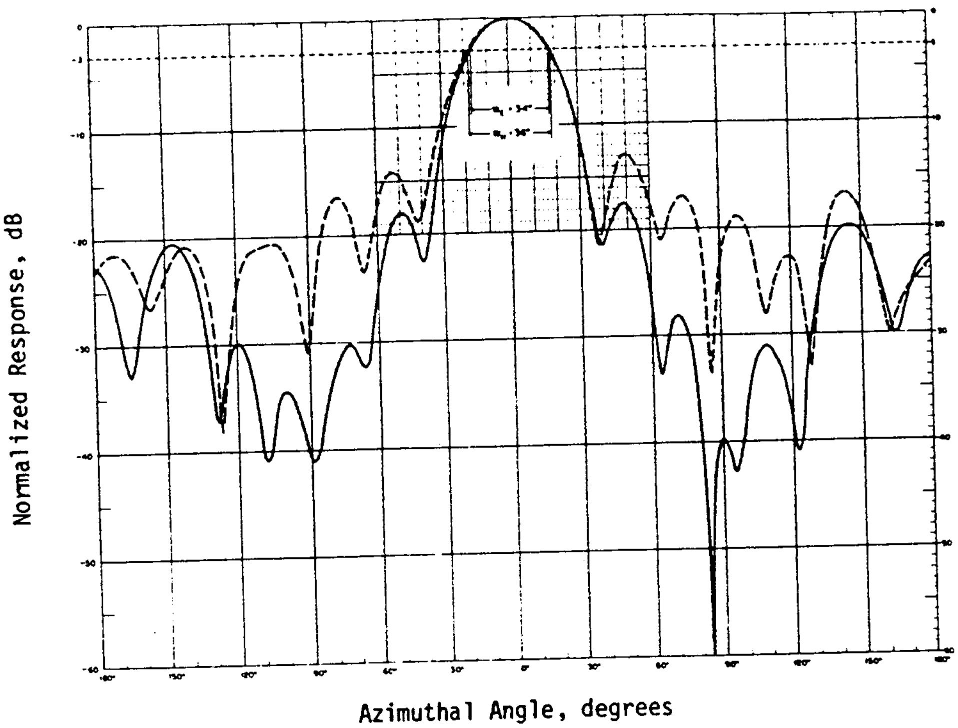

FIG. 17 RADIATION PATTERNS OF A 12-ELEMENT, 2.2λ LONG YAGI

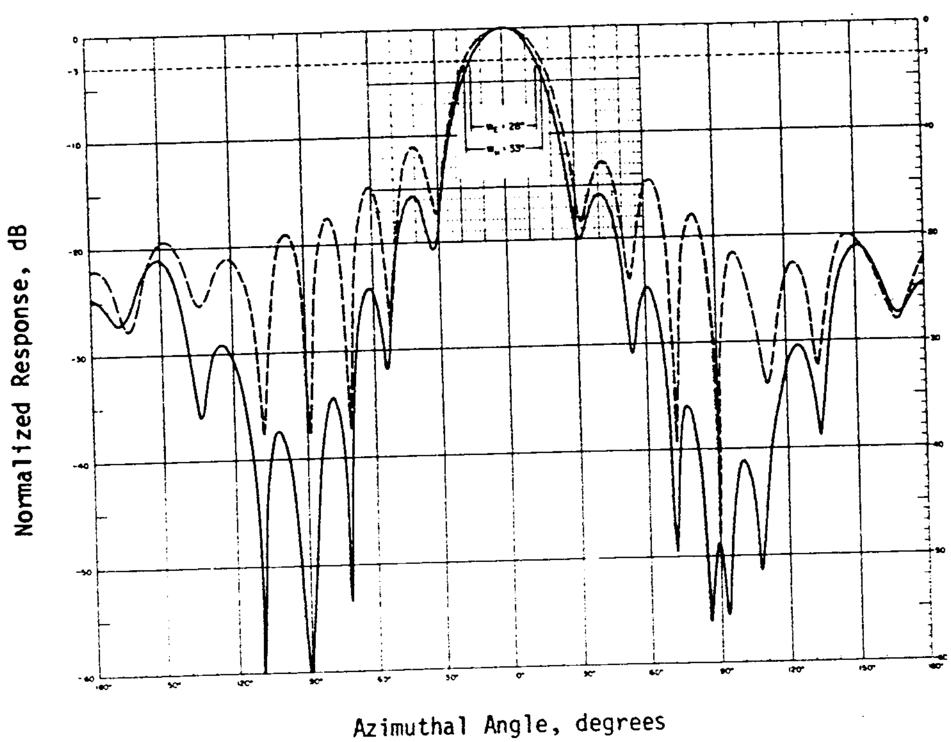

FIG. 18 RADIATION PATTERNS OF A 17-ELEMENT, 3.2λ LONG YAGI

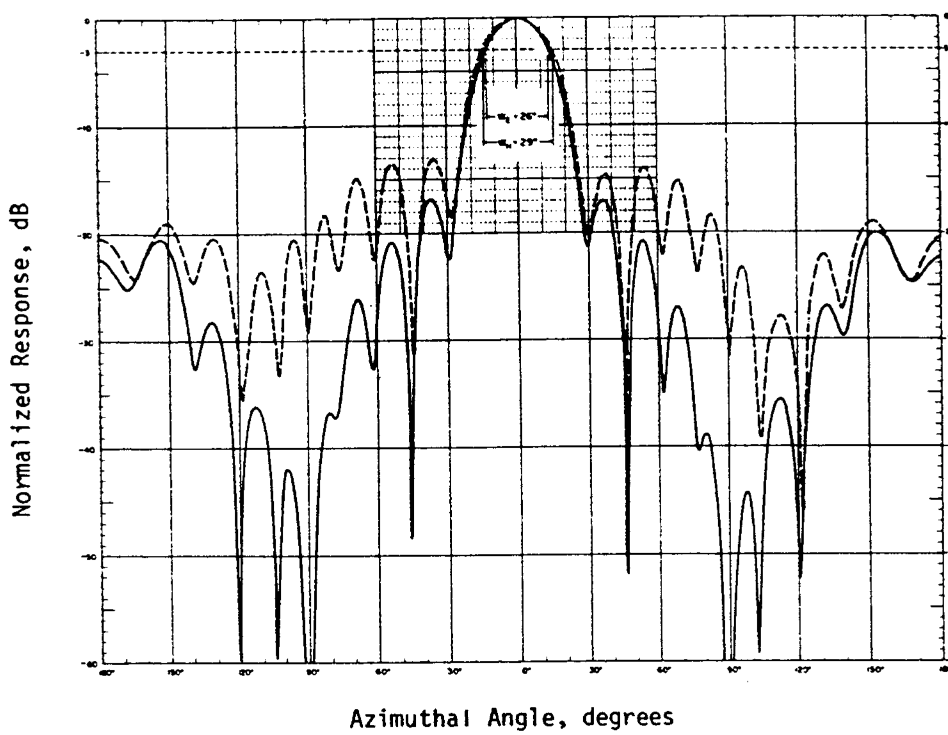

FIG. 19 RADIATION PATTERNS OF A 15-ELEMENT, 4.2λ LONG YAGI

element) are presented in figure 13. The 3-dB E and H plane beamwidths measured 66° and 111° respectively. The beamwidth of the 3-element 0.4λ antenna, as shown in figure 14, measured 57° and 72° in the E and H planes respectively. The E plane, front-to-side ratio is in the order of 24 dB, while the radiation to the rear was only 8 dB down from that in the forward direction.

The radiation pattern of the 5-element 0.8λ Yagi presented in figure 15 is characterized by a 3 dB beamwidth of 48° and 56° in the E and H planes respectively. The E plane, front-to-side ratio remained comparable to the 3-element antenna; however, the front-to-back ratio was improved considerably and measured 15 dB. In radiation patterns of 6, 12, 17 and 15-element Yagis as shown in figures 16 through 19, the beamwidths became progressively smaller as was expected with increased gain.

4. DESIGNING THE YAGI ANTENNA

To facilitate the design of an antenna of practical dimensions and yet realize maximum gain, refer to the curves shown in figure 9. These data were developed from results of model measurements carried out at 400 MHz using elements of different diameters. Only those curves are presented which will enable the user to design the 0.4, 0.8, 1.2, 2.2, 3.2 and 4.2λ long Yagis that yield gains of 7.1, 9.2, 10.2, 12.3, 13.4 and 14.2 dB respectively over that of a dipole mounted at the same height above ground.

In designing a Yagi antenna, the following basic information is required and, of course, will depend upon individual requirements.

1. Frequency of operation, f (wavelength, λ)

2. Antenna gain required, G (dB)

3. Diameter of parasitic elements (directors-reflectors) used in construction, d/λ

4. Diameter of supporting boom used in construction, D/λ

Careful consideration should also be given to selection of the diameter of the elements and boom at the wavelength or frequency of operation. This is important since smaller diameter and lighter materials can be used at the higher frequencies in contrast to larger and heavier materials needed for support at the lower frequencies. Note also that the selected element diameter-to-wavelength ratios used in the design of the chosen antenna must fall within the limits shown.

If maximum gain is to be realized using the data presented, it is essential to follow very closely the procedure described here. In addition, the element lengths should be measured and cut to a tolerance of about 0.003λ with respect to the calculated values. To aid the user in the design of this antenna and to familiarize him in use of the design data, two specific examples are presented. The first considers the design of a 5-element, 0.8λ Yagi; the second example presents a step-by-step procedure for the design of a 15-element, 4.2λ Yagi. In the first example, consider the design of a 0.8λ Yagi antenna to operate at a frequency of 50.1 MHz in the amateur radio band and yield a gain of 9.2 dB relative to a dipole. The elements shall be constructed of 2.54 cm (1 in.) diameter aluminum tubing with the boom of 5.08 cm (2 in.) diameter aluminum tubing.

GIVEN:	Frequency 50.1 MHz, λ	= 597 cm. (235 in.)
	Element Diameter, d	= 2.54 cm. (1 in.)
	d/λ	= 0.0042
	Boom diameter, D	= 5.1 cm. (2 in.)
	D/λ	= 0.0085
	Element spacing	= 0.2λ = 119 cm. (47 in.)
	Overall length	≃ 0.8λ = 478 cm. (188 in.)

STEP 1: Plot the lengths of the parasitic elements obtained from Table 1 for 0.8λ long Yagi on the corresponding curve in figure 9. For clarity, these curves are reproduced in figure 20. Establish points $L_{D_1} = L_{D_3}$, L_{D_2}, L_R and determine the parasitic element lengths for $d/\lambda = 0.0085$.

Thus $L_{D_1} = L_{D_3} = 0.428\lambda$

$L_{D_2} = 0.424\lambda$

$L_R = 0.482\lambda$

STEP 2: For our design, where the element diameter to wavelength ratio $d/\lambda = 0.0042$, plot and establish this point on the director curve and indicate by a check mark (✓). This is the uncompensated director length of $D_1 = D_3 = 0.442\lambda$.

STEP 3: For the same d/λ ratio, determine the uncompensated length of the reflector $L_R = 0.485\lambda$.

STEP 4: With a pair of dividers, measure the distance along the curve between the initial points $D_1 = D_3$ to D_2 determined in Step 1. Transpose this distance from the point established in Step 2 downward along the curve and determine the uncompensated length of director $L_{D_2} = 0.438\lambda$.

From the foregoing, the uncompensated parasitic element lengths for the 50.1 MHz Yagi are:

$$L_{D_1} = L_{D_3} = 0.442\lambda$$

$$L_{D_2} = 0.438\lambda$$

$$L_R = 0.485\lambda$$

To these values, a correction must be added to compensate for the boom diameter.

STEP 5: Refer to figure 10. For a boom diameter-to-wavelength ratio $D/\lambda = 0.0085$, determine the fractional increase in wavelength by which each of the parasitic elements must be increased. From the chart this length = 0.005λ. Thus, for this design the exact lengths of the parasitic elements should be measured and cut to the following lengths.

$$L_{D_1} = L_{D_3} = 0.442\lambda + 0.005\lambda = 0.447\lambda = 267 \text{ cm.}$$

$$L_{D_2} = 0.438\lambda + 0.005\lambda = 0.443\lambda = 264.5 \text{ cm.}$$

$$L_R = 0.485\lambda + 0.005\lambda = 0.490\lambda = 293 \text{ cm.}$$

The driven element is designed so that the Yagi can work either into a 50 or 200 ohm load impedance. For a 50 ohm impedance, a folded dipole and a quarter-wave balun can be employed. Precise matching to 50 ohms can be accomplished by using a double-stub tuner connected into the feed line.

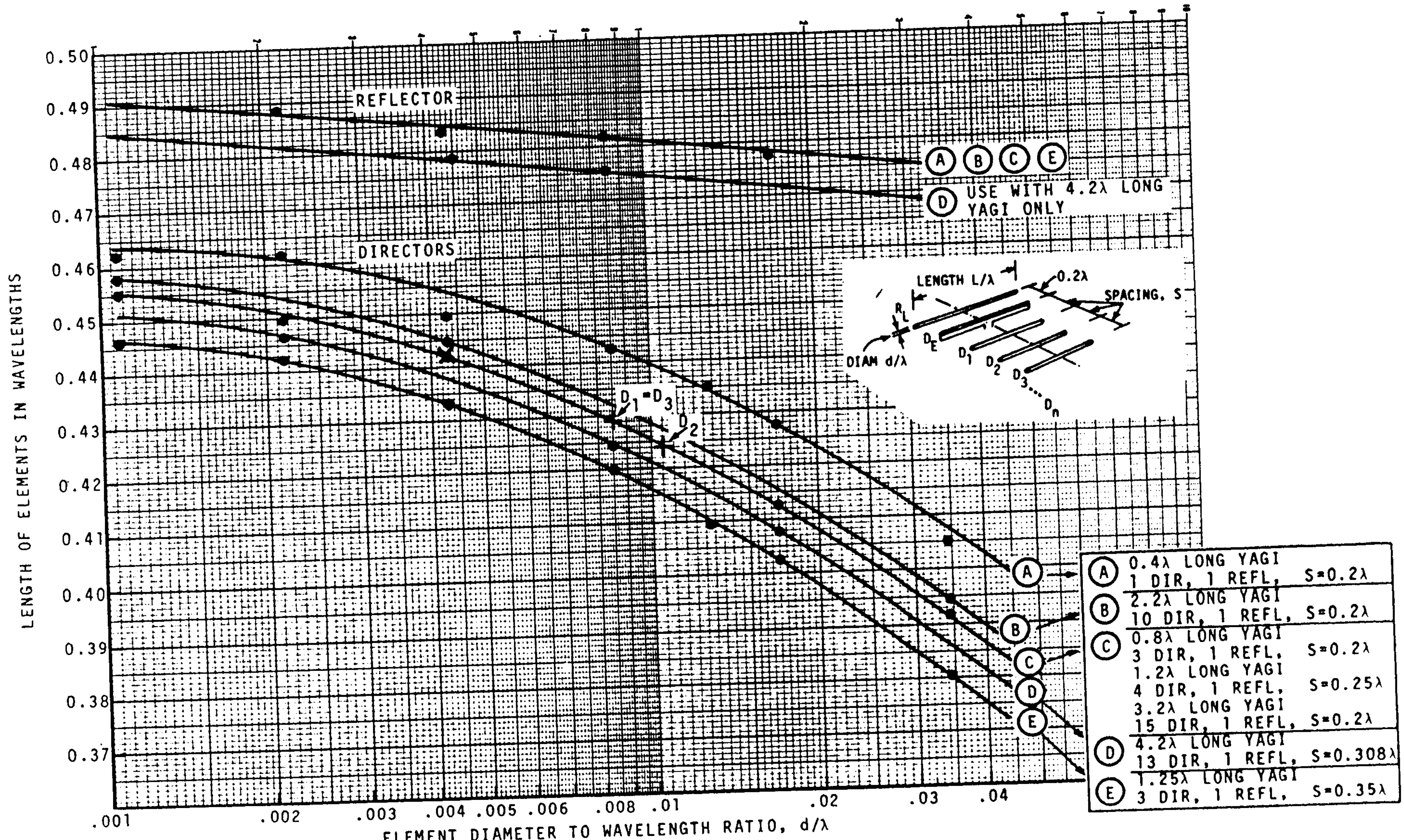

FIG. 20 USE OF DESIGN CURVES IN DETERMINING ELEMENT LENGTHS OF 0.8λ YAGI CONSIDERED IN EXAMPLE 1

If the antenna is designed with a 200 ohm balanced input impedance, then the driven element should be designed to provide an impedance step-up ratio of 12. For this configuration, a $\lambda/2$ balun section and stubs can be used to provide proper impedance transformation and matching. Other matching methods can also be employed such as Gamma or T match [10, 11, 12].

As a second example, consider the design of a 4.2λ long Yagi to provide a gain of 14.2 dB relative to a dipole to operate on 827 MHz in the center of TV Channel 73. For the construction of this antenna let us select and use a 1/2-inch diameter boom with 3/16-inch diameter elements using thin wall brass tubing.

GIVEN: Frequency 827 MHz, λ = 36.34 cm. (14.3 in.)

Element diameter, d = 0.48 cm.

d/λ = 0.013

Boom diameter, D = 1.27 cm. (1/2 in.)

D/λ = 0.035

Element spacing = 0.308λ = 11.2 cm.

Overall length $\simeq 4.2\lambda$ = 152 cm.

STEP 1: Plot the lengths of parasitic elements from Table 1 for the 4.2λ long Yagi on the corresponding curve in figure 9. For clarity, these curves are reproduced and presented in figure 21. Establish points $L_{D_1} = L_{D_2}, L_{D_3} \ldots L_{D_{13}}$ and locate the parasitic element lengths on the curve as in the previous example for the $d/\lambda = 0.0085$ case.

STEP 2: For our particular design, however, where the element diameter to wavelength ratio $d/\lambda = 0.013$, plot and establish this point on the 4.2λ long Yagi curve and indicate this starting point with a check (✓). This is the uncompensated director length of $D_1 = D_2 = 0.414\lambda$.

STEP 3: For the same d/λ ratio, determine the uncompensated length of the reflector, $L_R = 0.473\lambda$; from curve D, figure 21.

STEP 4: With the use of a pair of dividers, establish and measure the distance between the points $D_1 = D_2$ to D_3. Transpose this distance from the initial (✓) mark downward along the director curve and determine $L_{D_3} = 0.409\lambda$.

Measure the distance from $D_1 = D_2$ to D_4. Transpose this distance from initial (✓) point and determine length of $D_4 = 0.395\lambda$. Similarly, determine remaining director lengths. $L_{D_5} = 0.391\lambda$, $L_{D_6} = 0.385\lambda$, $L_{D_7} = 0.381\lambda$, L_{D_8} to $L_{D_{13}} = 0.377\lambda$.

To these values a correction must be added to compensate for boom diameter.

STEP 5: Again, refer to figure 10. For a boom diameter-to-wavelength ratio D/λ = 0.035, determine the fractional amount by which each element must be increased to compensate for boom. From the curve, determine this length = 0.026λ.

Thus, to realize maximum gain from this antenna, measure and cut the parasitic elements to the following lengths:

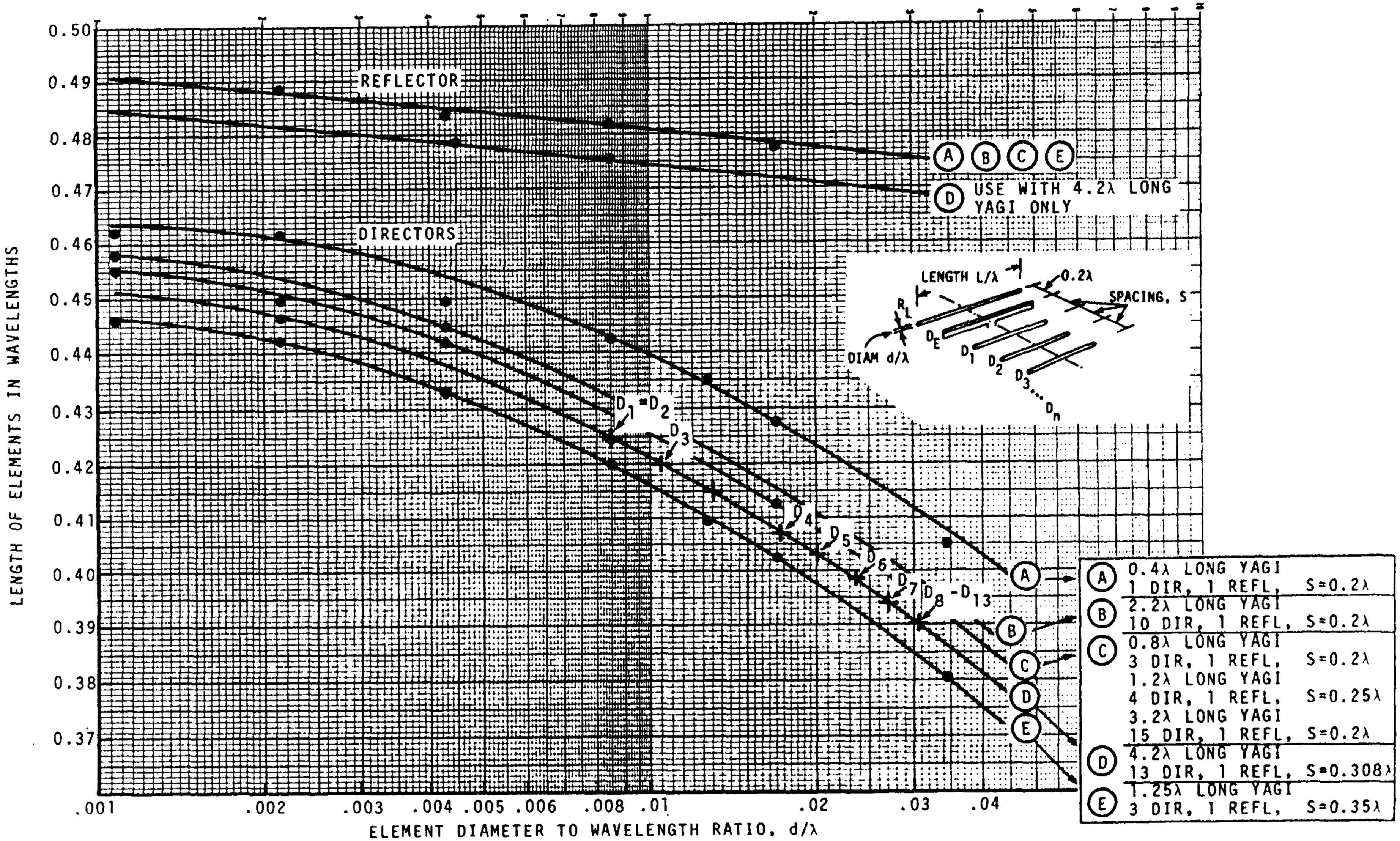

FIG. 21 USE OF DESIGN CURVES IN DETERMINING ELEMENT LENGTHS OF 4.2λ YAGI CONSIDERED IN EXAMPLE 2

$$L_{D_1} = L_{D_2} = 0.414\lambda + 0.026\lambda = 0.440\lambda = 16.0 \text{ cm.}$$

$$L_{D_3} = 0.409\lambda + 0.026\lambda = 0.435\lambda = 15.8 \text{ cm.}$$

$$L_{D_4} = 0.395\lambda + 0.026\lambda = 0.421\lambda = 15.3 \text{ cm.}$$

$$L_{D_5} = 0.391\lambda + 0.026\lambda = 0.417\lambda = 15.1 \text{ cm.}$$

$$L_{D_6} = 0.385\lambda + 0.026\lambda = 0.411\lambda = 14.9 \text{ cm.}$$

$$L_{D_7} = 0.381\lambda + 0.026\lambda = 0.407\lambda = 14.8 \text{ cm.}$$

$$L_{D_8} - L_{D_{13}} = 0.377\lambda + 0.026\lambda = 0.403\lambda = 14.6 \text{ cm.}$$

$$L_R = 0.473\lambda + 0.026\lambda = 0.499\lambda = 18.1 \text{ cm.}$$

The driven element can be of a variety of designs and will depend upon individual requirements. It is usually measured and cut to one-half wavelength less a shortening factor to compensate for end-effects and matched to the characteristic impedance of the feed line.

5. CONCLUSIONS

The data presented in this report provide the necessary information for the design of Yagi antennas ranging in length from 0.2λ to 4.2λ. These data allow the user to design antennas to yield maximum gain for seven different design configurations. In addition, stacking of antennas, side by side and one above the other--all fed in phase--provides an additional gain up to 5.2 dB over that of the single array.

6. ACKNOWLEDGMENTS

The author wishes to extend sincere appreciation to William Gorboczieski for his assistance in the fabrication of test set-ups and in carrying out of the measurements. Also, sincere appreciation and thanks to Alvin Wilson for providing the radiation patterns.

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