# THE PRINCIPAL FEATURES OF LONG YAGI ANTENNAS AND METHODS OF OBTAINING MAXIMUM GAIN

by

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ABSTRACT

The object of this thesis is to develop a method of obtaining maximum gain and improving the sidelobe ratio of a 10 wavelengths long Yagi antenna.

The conventional analysis which considers the Yagi as a resonant antenna is only adequate for the practical design of a short Yagi antenna consisting of three or four director elements. In this analysis, the optimum performance of a Yagi antenna depends upon the array length, height, diameter and spacing of directors and reflectors.

In the case of a long Yagi antenna, where the number of elements may be very large, the analysis of the antenna according to the conventional method becomes very complicated, if not impossible.

Long Yagi antennas can be analyzed by introducing the notion of a surface wave traveling along the array. Assuming that a traveling wave is launched along the array length, it is then possible to demonstrate experimentally the relationship between the different parameters of the antenna. With this idea, the gain of the antenna then depends only on the phase velocity of the surface wave (which in turn is a function of the height, diameter and spacing of the directors) and the choice of the reflectors. Therefore, maximum gain

for a given array length, for any spacing less than 0.5 wavelength, can be obtained by suitable variation of the parameters to yield the desired phase velocity.

## ACKNOWLEDGMENT

The author wishes to express his thanks and appreciation to Dr. Robert A Hessemer Jr. for his very helpful suggestions and his patient guidance throughout the experimental and the theoretical studies in the preparation of this thesis.

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CHAPTER 1

# INTRODUCTION

Yagi antennas are commonly used for directional reception of linearly polarized electromagnetic waves at VHF and UHF. They are the cheapest and simplest of the directional antennas and they can be used successfully in both high and low frequencies as well. The conventional analysis which considers the Yagi strictly as a resonant antenna is only adequate for the practical design of very short Yagi antennas. Long Yagi antennas are almost impossible to analyze by this method. However, long Yagi antennas can be analyzed in a much simpler way by considering them as traveling wave antennas.

The application of traveling wave ideas to Yagi antennas is a relatively new concept. The analysis of Yagi as a traveling wave antenna was first suggested and the physical actions of different elements of the Yagi antenna explained by Smith.[1] According to his explanation and suggestion, the physical action of the director elements in

[1] R. A. Smith, Aerial for Metre and Decimetre Wavelength, Cambridge University Press, Cambridge, England, pp. 150-151; 1950.

the Yagi is to reduce the phase velocity of the traveling wave which is launched along the length of the antenna by the driven elements.

The long Yagi antennas attracted the attention of the microwave engineers after the application of the traveling wave principle to the antenna problems. Extensive experimental investigations have been made by Ehrenspeck and Poehler,[2] Kearns[3] and Reynolds,[4] on the properties of the uniform long Yagi as a traveling wave antenna. Simmon and Biggi[5] and Sengupta[6,7] have done both analytical and experimental work on the method of tapering of the length and spacing of the director elements.

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[2]H. W. Ehrenspeck and H. Poehler, "A New Method for Obtaining Maximum Gain from Yagi Antenna," IRE Trans. on Antennas and Propagation, vol. AP-7, pp. 379-385; October, 1959.

[3]W. J. Kearns and H. W. Ehrenspeck, "Two Dimensional Endfire Array with Increased Gain and Sidelobe Reduction," 1957 IRE Wescon Convention Record, pt. 1, pp. 217-230.

[4]D. K. Reynolds, "Broadband Traveling Wave Antenna," 1957 IRE National Convention Record, pt. 1, pp. 99-107.

[5]J. C. Simmon and V. Biggi, "Un Nouveau Type D'Aerien et son Application a la Transmission de Television a Grand Distance," L'Onde Electrique, vol. 34, pp. 883-896; November, 1954.

[6]D. L. Sengupta, "On Uniform and Linearly Tapered Long Yagi Antennas," IRE Trans. on Antennas and Propagation, vol. AP-8, pp. 11-16; January, 1960.

[7]D. L. Sengupta, "On the Velocity of Wave Propagation along an Infinite Yagi Structure," IRE Trans. on Antennas and Propagation, vol. AP-7, pp. 234-239; July, 1959.

This thesis involves a long Yagi antenna 10 wavelengths long at a frequency of 10 Kmc. In this thesis three types of long Yagi arrays are used. The first type of array is a one dimensional uniform long Yagi, the second one is a two dimensional uniform long Yagi with two parasitic side arrays, and the last one is the tapered form of the second type. The works of different authors are combined, thus the experiments reported here are new. The work of Sengupta[8] involves a one dimensional uniform and tapered long Yagi antenna of 6.0 wavelengths at 3.0 Kmc. Ehrenspeck and Poehler[9] made investigations on the properties of the uniform long Yagi as a traveling wave antenna. They also found the relationship between the various parameters of a long Yagi antenna for optimum gain in a forward direction. This work gives very practical information for optimum design of a long Yagi antenna. Kearns and Ehrenspeck[10] made experimental works on one and two dimensional uniform long Yagi antennas of 6.0 wavelengths at 10 Kmc. Using the near field radiation pattern of Yagi, they found out that it was possible to increase the gain and improve the sidelobe ratio of a one dimensional long Yagi simultaneously by adding parasitic side

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[8]Sengupta, op. cit., 1960.

[9]Ehrenspeck and Poehler, op. cit.

[10]Kearns and Ehrenspeck, op. cit.

arrays on either side of the center array. In this thesis, the works of Sengupta, Ehrenspeck, Poehler and Kearns are combined and as a new feature, tapering is done in two dimensional array. The authors mentioned above did not perform any experiment with the tapered two dimensional long Yagi antenna which is the third type of array considered in this thesis.

The details of the method of analysis of the antenna are presented in Chapter 2 and Chapter 3.

# CHAPTER 2

# DEFINITION, DESIGN, CONSTRUCTION AND EXPERIMENTAL ARRANGEMENT OF LONG YAGI ANTENNA

## 2.1 Definition and General Description

A Yagi antenna consists of a number of linear elements parallel to each other along a straight line. Fig. 2.1a, b represent two types of Yagi antenna. The first one is called a conventional Yagi; the other one consists of a row of monopoles imaged in a ground plane. The latter is the type under investigation in this thesis. Only one of the monopoles is excited. This element is called feeder; all others are parasitic. The elements in the direction of increased gain are called directors and the ones in the opposite direction are called reflectors. As mentioned in the introduction, one can obtain an increase of gain in the endfire direction of the array by choosing the correct combination of the dimensions of the different parameters of the Yagi antenna.

Yagi antennas are essentially unidirectional and can be assumed as some kind of endfire antennas with increased gain. These antennas are very easy to construct both mechanically and electrically and they can be used practically in all frequency ranges.

## 2.2 Discussion of Design of 10 Wavelength Yagi and the Symbols Used in Design

In designing a Yagi antenna the problem is to find the correct combinations of the dimensions of the parameters. For this purpose, it is necessary to discover how these parameters are related to each other under the conditions of optimum gain. Up to now, a rigorous theoretical solution to the Yagi antenna problem has not been discovered. Consequently, the solution given to the Yagi antenna problem in this section will be partly theoretical and partly experimental.

The goal here, is to find a general design method for Yagi antennas with optimum gain. First, the investigation is restricted to a consideration of Yagis with three reflectors and directors of equal height, spacing and diameter. The design criteria, here are based on achieving maximum forward gain.

It can be shown that the maximum gain of a Yagi antenna of given length L occurs at a definite value of the phase velocity of the traveling wave which is launched along the axis of the antenna. It has long been recognized that the maximum directivity is obtained from this kind of antenna when

$$(\beta - k)L = \pi$$

$$\text{or} \quad \frac{v}{c} = \frac{L/\lambda}{L/\lambda + 0.5} \qquad (2.1)$$

where

$\beta$ is the propagation constant in the antenna,

k is the propagation constant in the free space for lossless case,

L is the length of the antenna,

v is the phase velocity in the antenna,

c is the phase velocity in free space,

(2.1) is the well-known Hansen-Woodyard condition which predicts that the phase velocity should be less than free-space velocity in order to satisfy the condition. Therefore, it is predicted that this antenna works as a slow wave structure to get the maximum gain in the desired direction. Fig. 2.2 shows the required values of the normalized phase velocity (v/c) in the antenna as a function of the antenna length in wavelength. Once the necessary phase velocity is chosen for a given antenna length, the radiation pattern of the antenna may be analyzed by using the following expression[11]

$$S(\theta) \quad L. \left\{ \frac{\sin\left[\pi L/\lambda\ (\beta/k - \cos\theta)\right]}{\left[\pi L/\lambda\ (\beta/k - \cos\theta)\right]} \right\} \qquad (2.2)$$

where

$S(\theta)$ is the space factor for Yagi antenna

$\theta$ is the angle measured from the axis of the antenna

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[11] Sengupta, op. cit., 1960.

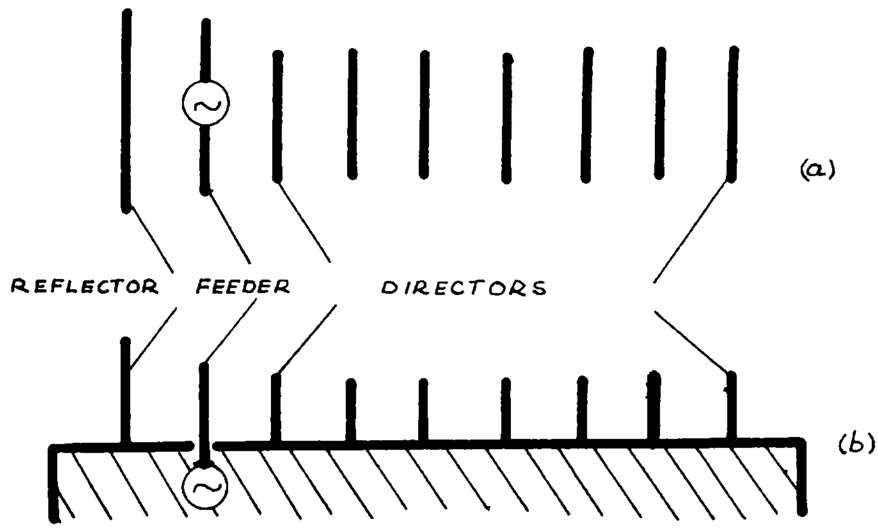


Fig. 2.1 _ (a) CONVENTIONAL YAGI STRUCTURE
(b) YAGI CONSISTING OF MONOPOLES IMAGED IN A GROUND PLANE

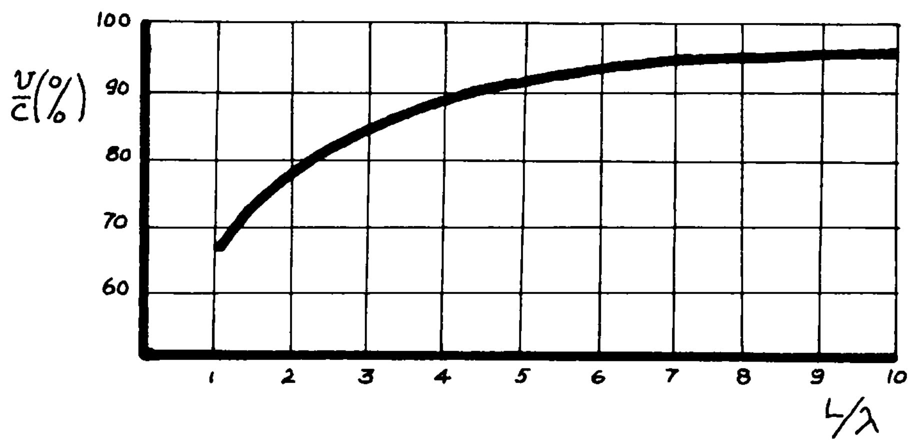


Fig. 2.2 _ OPTIMUM PHASE VELOCITY AS A FUNCTION OF ANTENNA LENGTH

This equation is an approximate one. It gives sufficient accuracy for practical purposes to explain the characteristics of the mainlobe and the sidelobe.

The symbols used for antenna parameters throughout this thesis, are shown in Fig. 2.3. In that figure,

$h_f$ is the height of the feeder

2R is the diameter of the copper rods

$h_r$ is the height of the reflectors

$h_d$ is the height of the directors

$S_{rf}$ is the distance between the feeder and the reflector

$S_{fd}$ is the distance between the feeder and the director

$S_d$ is the distance between two adjacent directors

The following discussion will present a clear picture of the design ideas and the interrelationships between the different parameters. For infinitely long Yagi antennas, it can be shown[12] that the phase velocity on the antenna satisfies the following expression in addition to the Hansen-Woodyard condition:

$$\frac{v}{c} = \frac{\lambda z}{4\pi S_d X} + 1 \qquad (2.3)$$

where

z is any length along the axis of the antenna

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[12]Sengupta, _op_. _cit_., 1959.

X is the reactance presented by the elements and is given as[13]

$$X = -jZ_c \operatorname{Cot} \frac{2\pi h_f}{\lambda} \tag{2.4}$$

Since the phase velocity on the antenna is almost independent of the length of the structure after a certain length of the antenna, (2.3) can also be used for calculating the phase velocity in a long but finite long Yagi antenna.

The following general comments can be made from a critical study of (2.3) and (2.4):

1. The phase velocity is less than the free-space velocity as long as $h_f < \lambda/4$. This is the range of practical interest, since the antenna utilizes the slow-wave nature of the propagation.

2. The phase velocity decreases continuously with increase of $h_f$ and decrease of $S_d$. Its value is very close to free-space phase velocity for small value of $h_f$ and large value of $S_d$.

3. The phase velocity increases with decrease of R and its value approaches the free-space value in the ideal case of $R = 0$. This property cannot be seen directly from the above equations. Jordan[14] explains it in detail.

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[13] L. Tourel, The Antennas, John Willey & Sons Inc., N. Y., 1960, p. 140.

[14] E. C. Jordan, Electromagnetic Waves and Radiating Systems, Prentice-Hall, Inc., N. Y., 1950. PP. 359-364.

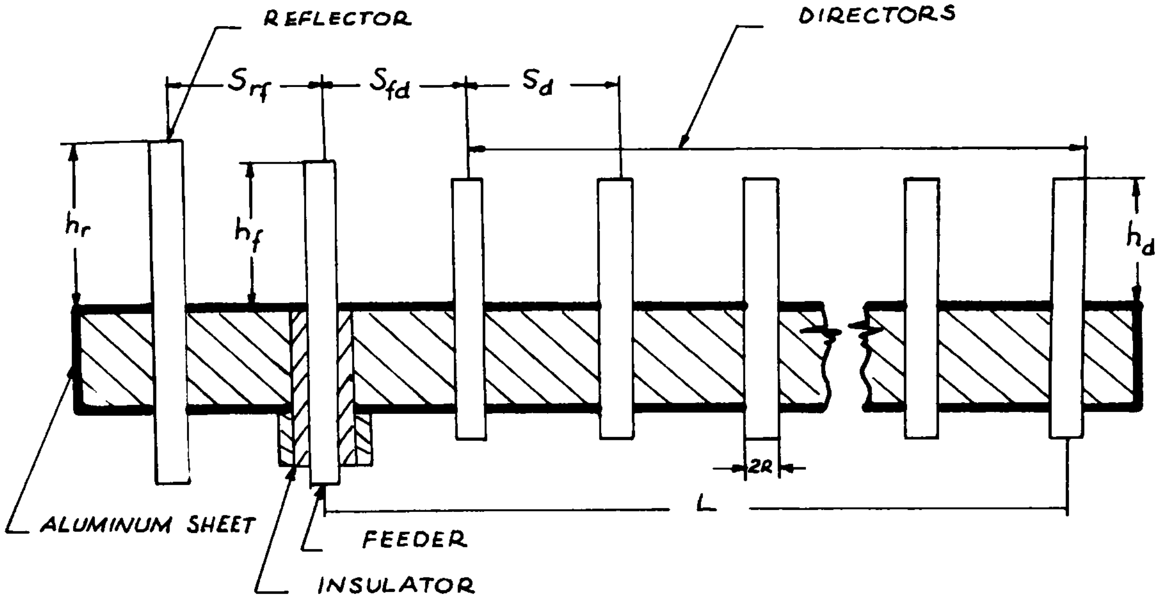


Fig. 2.3 _ YAGI PARAMETER SYMBOLS

4. The phase velocity decreases continuously with increase of frequency.

Consequently, one can say that for a given value of phase velocity, the values of different parameters of the uniform long Yagi antenna can be chosen by consulting the published experimental and theoretical curves.

## 2.3 Optimum Design Procedure

By following the technique presented in the previous section, a uniform long Yagi antenna of length $L = 10\lambda$ at the frequency of 10 Kmc. has been designed. The design values of different parameters are given below:

Operating frequency $f_o = 10$ Kmc.

Relative phase velocity according to the Hansen-Woodyard condition $\frac{v}{c} = \frac{10}{10.5} = 0.952$

Radius of the elements $R = 0.0335\lambda$

Spacing between the two adjacent directors $S_d = 0.2\lambda$

The height of each director $h_f = \lambda/4$

It should be noted that for a given length L of the antenna, the optimum phase velocity may be obtained for different combinations of the parameters mentioned above. Consequently, one can say that the design values given above are not unique. However, from a critical study of the variation of the phase velocity with the different parameters, it is possible to find suitable ranges for the values of the parameters. The value of R should be chosen between $kR \approx 0.05$ and $kR = 0.15$. This choice of R is given by Sengupta[15] considering the variation of the self reactance of any wire with its radius. It can also be shown experimentally that the directivity of the antenna becomes less frequency sensitive for values $S_d = \lambda/4$. The main consideration on choosing the value of $S_d$ is the idea stated above; for practical interest, a possible range for $S_d$ may be taken as between $0.1\lambda$ and $0.25\lambda$. Once R and $S_d$ are chosen, $h_f$ can be fixed automatically by consulting the published experimental and theoretical curves similar to the curves given by Reynolds[16] and Ehrenspeck and Poehler.[17]

## 2.4 On the Types of Antenna Arrays Under Investigation:

Measurements of antenna patterns were performed on two different types of endfire arrays. The first type is a one dimensional long Yagi antenna of 10 wavelengths. This array is discussed in sections 2.2 and 2.3 in detail. The second type is a two dimensional long Yagi antenna with two parasitic side rows of the same length. The most important physical dimensions of these array types are shown in Fig. 2.4. This second type of array has been explained in detail

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[16] Reynolds, *op. cit.*

[17] Ehrenspeck and Poehler, *op. cit.*

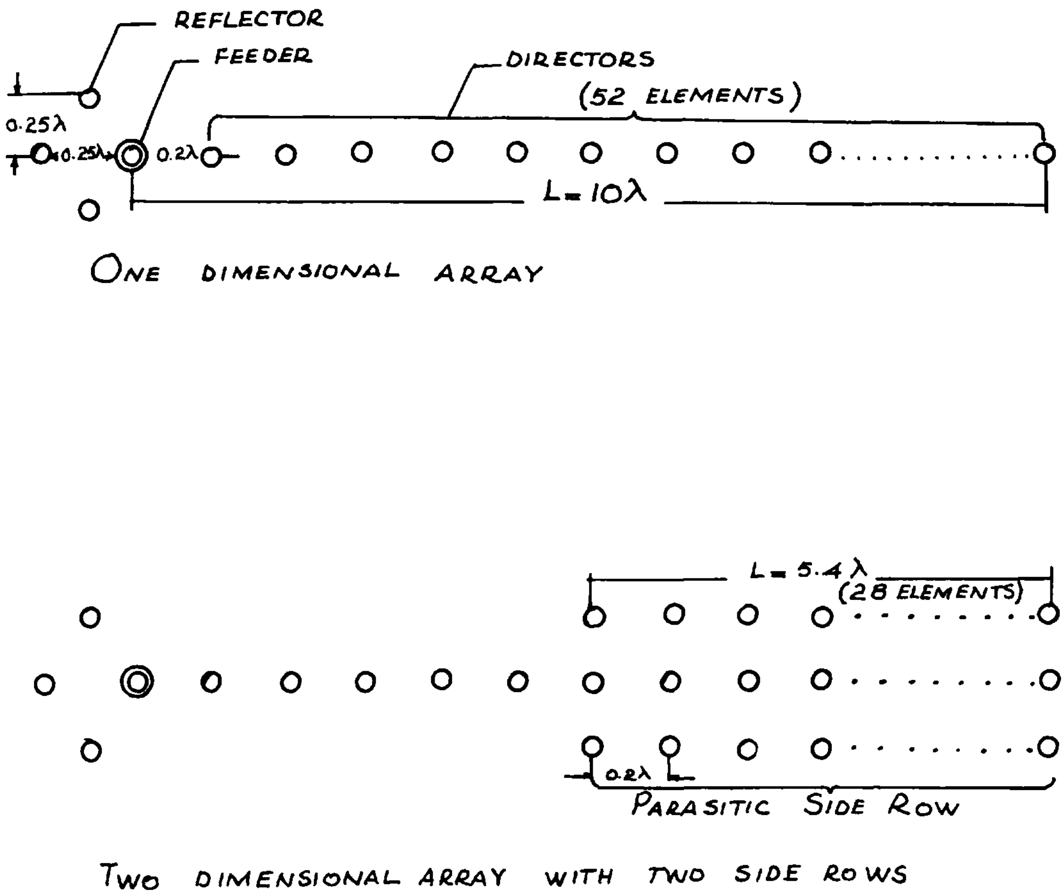


Fig. 2.4 — PHYSICAL DIMENSIONS OF THE ONE AND TWO DIMENSIONAL ARRAYS

by Kearns and Ehrenspeck[18] using the near field radiation pattern of the antenna. They showed that all the energy travels along the array in a virtual wave channel which has an overall width of about 2 wavelengths and the energy, transported through the channel, is radiated at the open end from a virtual aperture just as from the open end of a wave guide.

The field propagating along the axis of the structure is very complicated to analyze because of the multiple effect of the elements among themselves.

The virtual aperture which is assumed to exist at the radiation end of the array can be increased by symmetrically placing one or more shorter rows of parasitic elements on either side of the center array because these parasitic side rows act as smaller wave channels fed by coupling from the main array.

Examining the near-field radiation of the antenna, Kearns and Ehrenspeck[19] decided to place the side rows at a distance where the phase had deviated most from the main array axis. They found that the best location for the parasitic array is at a distance of $2/3\ \lambda$ from the array axis. They also discovered that if one places the side rows exactly symmetrical on either side of the center director elements

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[18] Kearns and Ehrenspeck, op. cit. [19] Ibid.

and with heights equal to the heights of the directors, it is possible to get a reduced sidelobe level compared to the first type array. The addition of the parasitic side rows changes the amplitude and the phase distribution in the vitual aperture. Therefore, change of gain and sidelobe level becomes simultaneous. Furthermore, the length of the side rows has to be adjusted for maximum gain, but there is no rigorous way of finding an exact answer to this problem, because of the very complicated influence of the side rows on the main array. The correct length of the side rows can only be found experimentally. According to the experimental result, it is found that the length of the side rows should be about the half of the length of the whole array. From the above explanation one can conclude that it is possible to get higher gain and lower sidelobe level just by adding parasitic side rows on either side of the center array of a long Yagi antenna.

## 2.5 Construction and the Experimental Arrangement

It was decided to perform the experiment above a ground plane. This is very advantageous for several reasons, one of which is that the feeder arrangement can be excited from beneath.

An aluminum sheet was selected as ground plane which, in turn, furnishes mechanical support for the elements. A series of holes was drilled and individual copper rod radiators were press fit inserted into the holes and their heights and the spacing between two adjacent elements were experimentally adjusted instead of finding these values from the published experimental and theoretical curves.

As the pattern and the gain had to be measured in the far field, the ground plane was extended as far out as feasible. Because of the directive nature of the Yagi antennas a width of 50 wavelengths and a length of 100 wavelengths were chosen.

The experimental arrangement is shown in Fig. 2.5. As mentioned above, the set of holes that held the elements was drilled in a piece of rectangular aluminum plate and it was in turn connected to an antenna mount in such a fashion that the array under observation could be rotated while a receiving antenna, which was fixed to the far end of the ground plane, detected the signal and relayed it to an antenna pattern analyzer.

All experiments were conducted in the Microwave Laboratory of the University of Arizona. The ground plane was further surrounded by absorbing material to reduce the reflection to a minimum. During the experiments, the VSWR on the Yagi feed was kept in the range 1.12-1.2. Both the incident and reflected power were measured using powermeters on both sides of a double sided directional coupler. The reflected power was minimized by using an E-H tuner. On the

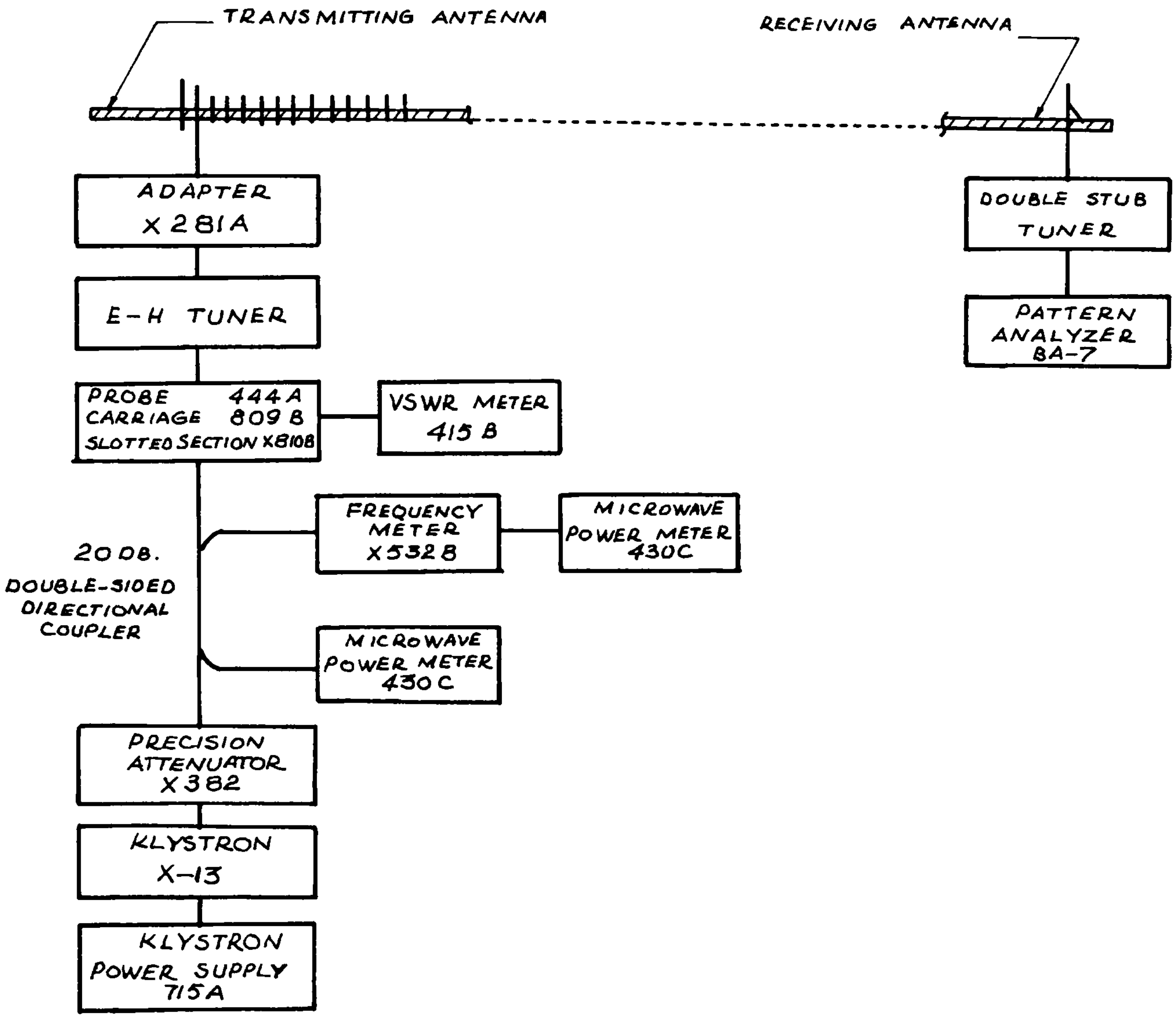



Fig. 2.5 — EXPERIMENTAL ARRANGMENT

receiving antenna side a double stub tuner was used to maximize the receiving power.

The experiments were carried out as follows: first, the dipole to dipole measurement was made and found to be 3.5 db above the noise level. This was very important because all gain measurements were taken in terms of the power gain of the reference dipole feeder and all gain figures include the ohmic losses.

Second, the Yagi antenna was considered as consisting of two parts: the combination of feeder-reflectors, and the row of director elements.

The experiment was started by adjusting the combination of feeder-reflectors for maximum gain in the forward direction for different values of $S_{rf}$ and $h_r$ which remained optimum even after the row of directors was added. The same result occurred in successive experiments involving different rows of directors. After obtaining the maximum gain condition, the directors were added and the gain of the long Yagi antenna was measured as a function of $S_d$ and $h_d$. Then the gain of Yagi was measured as a function of the array length under the maximum gain adjustment condition.

All the values about the maximum gain adjustment experiments are shown in Figs. 2.6a & b, 2.7a & b, 2.8.

Next, the ground plane radiation pattern of the one dimensional array was measured and the result is produced in

Fig. 2.9. It can be seen from Fig. 2.9 that the sidelobe ratio in the pattern is about 9.0 db down as expected from theory. As mentioned before, a better sidelobe ratio and a higher gain can be obtained by placing two parasitic side rows symmetrically on either side of the center directors of the above antenna. A radiation pattern of the antenna, with two additional side rows, was measured; the gain increased 2.5 db and the sidelobe ratio improved 3.5 db compared to the original Yagi antenna. The results are produced in Fig. 2.10.

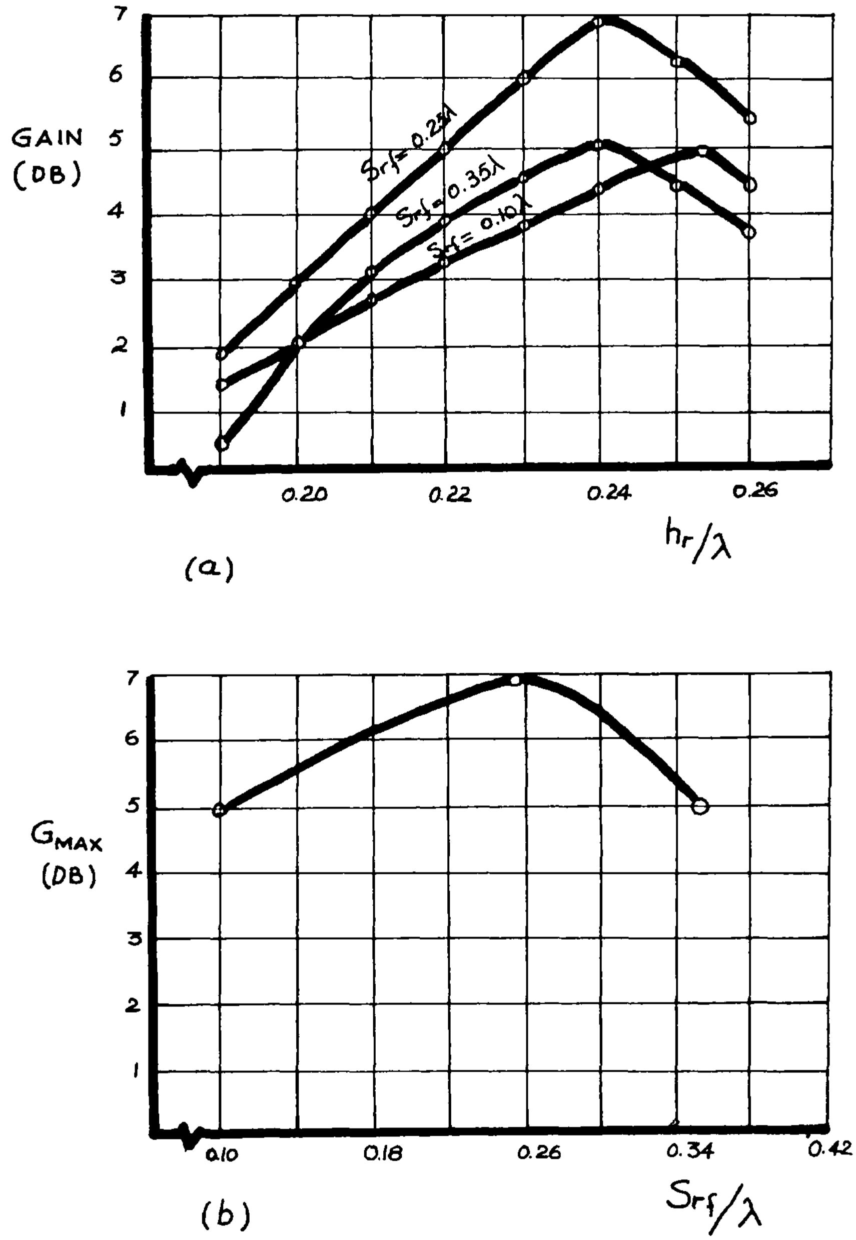
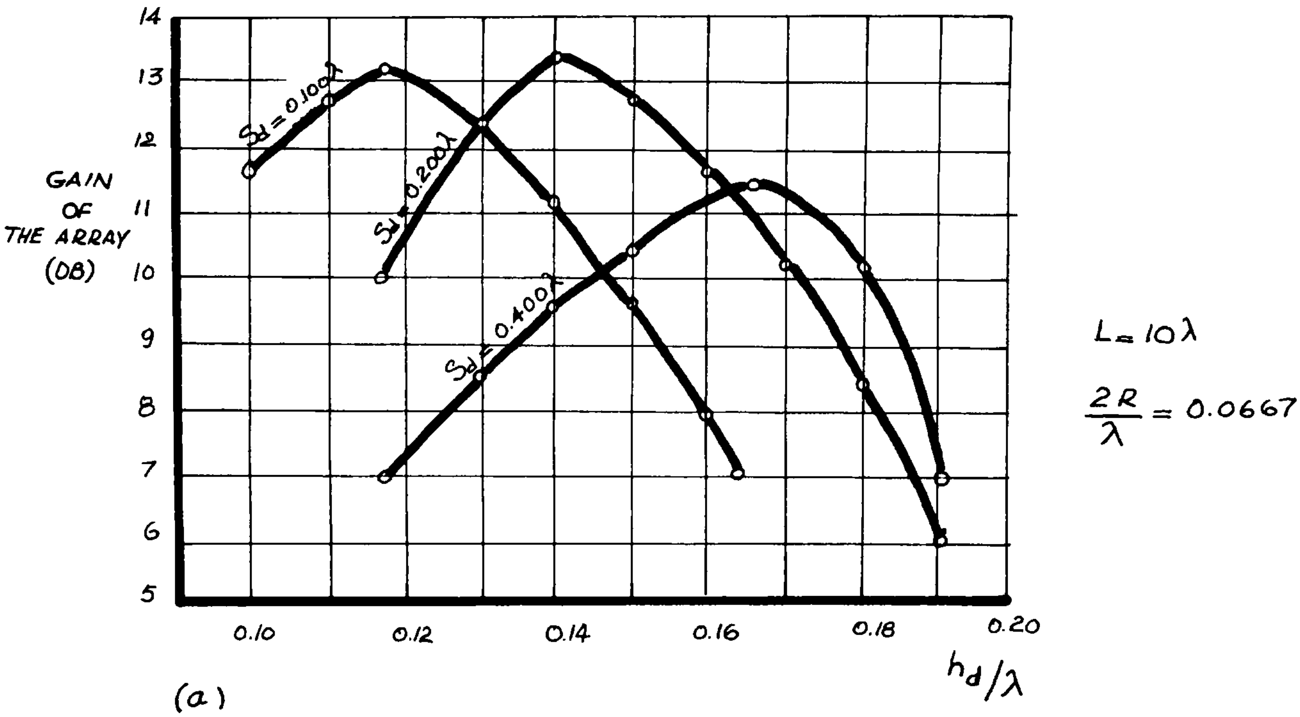



Fig. 2.6 — (a) GAIN OF FEEDER-REFLECTOR COMBINATION AS A FUNCTION OF $h_r$ FOR VARIOUS $S_{rf}$

(b) MAXIMUM GAIN OF FEEDER-REFLECTOR COMBINATION AS A FUNCTION OF $S_{rf}$



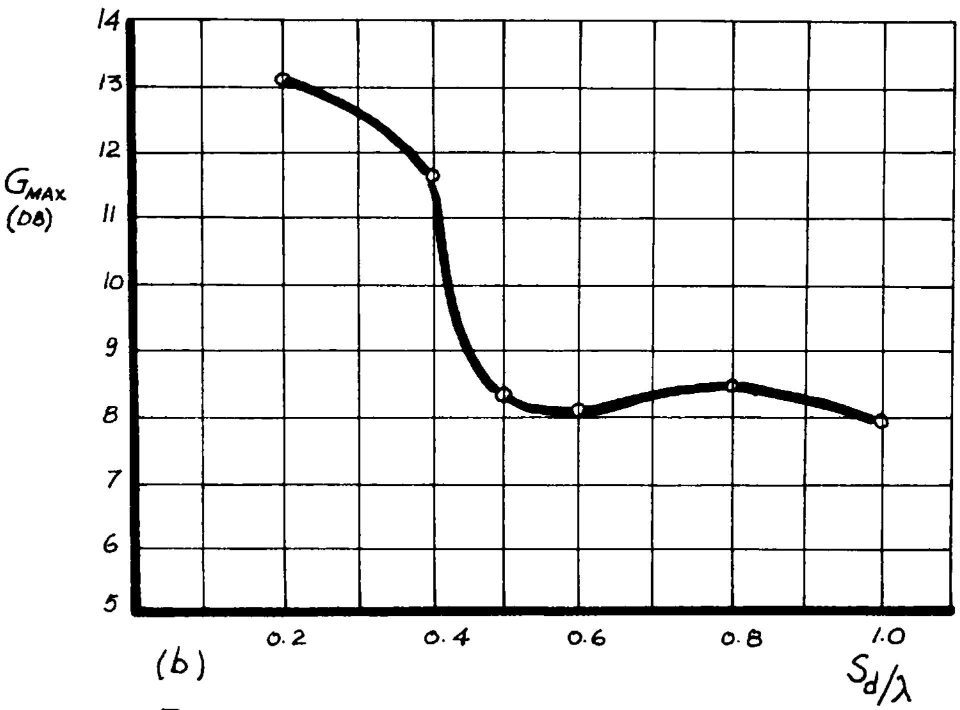




Fig. 2.7— (a) GAIN OF YAGI ARRAY AS A FUNCTION OF $h_d$ AND $S_d$ FOR $L = 10\lambda$

(b) MAXIMUM GAIN OF YAGI ARRAY AS A FUNCTION OF $S_d$

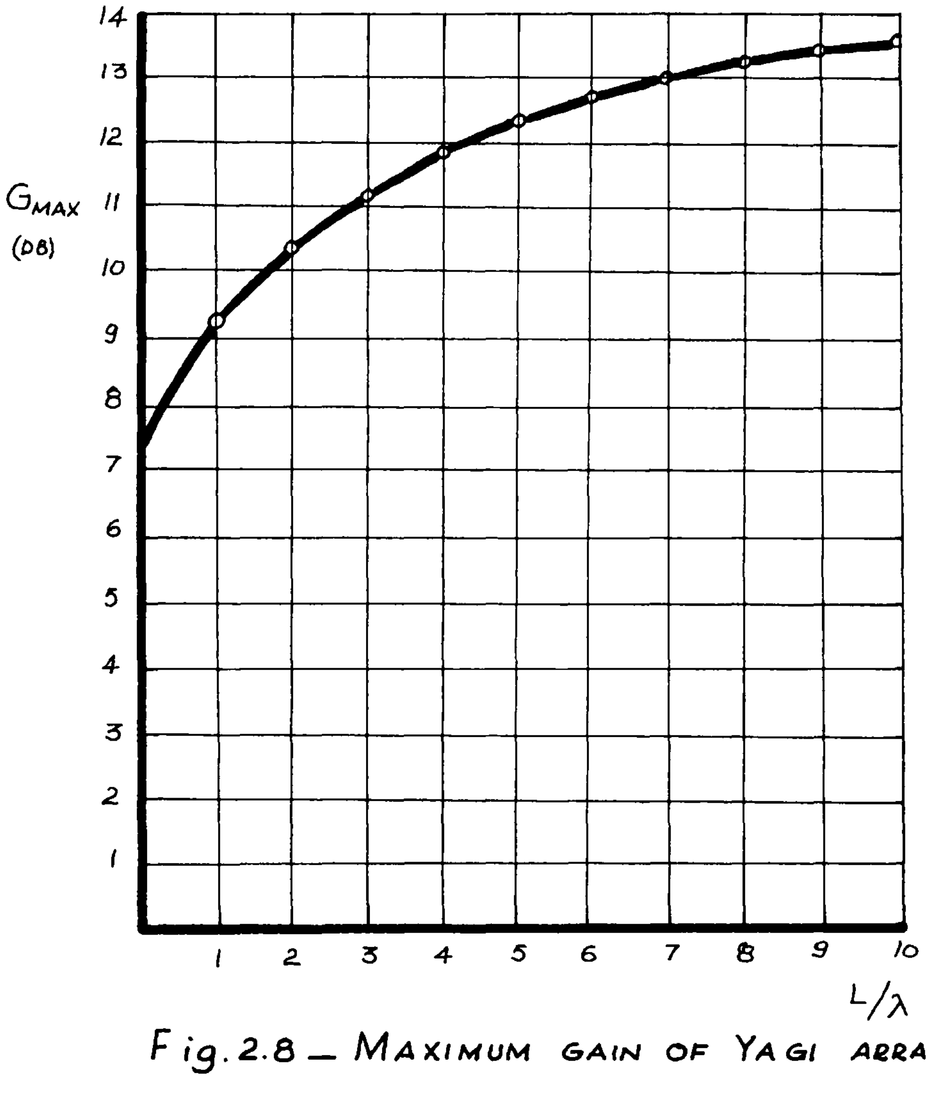



Fig. 2.8 — MAXIMUM GAIN OF YAGI ARRAY AS A FUNCTION OF ARRAY LENGTH

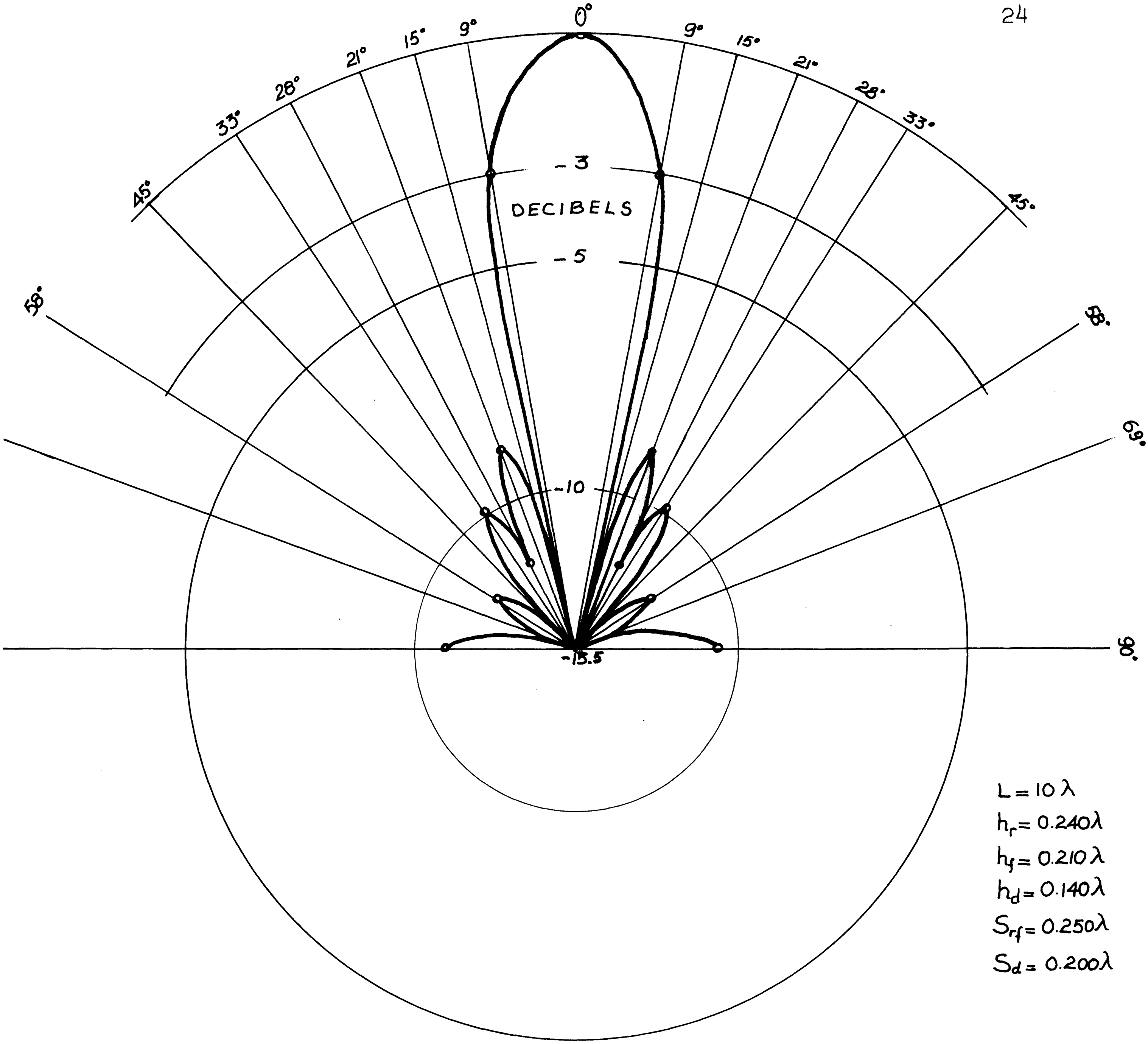



Fig. 2.9 – Ground Plane Radiation Pattern of One-Dimensional Array

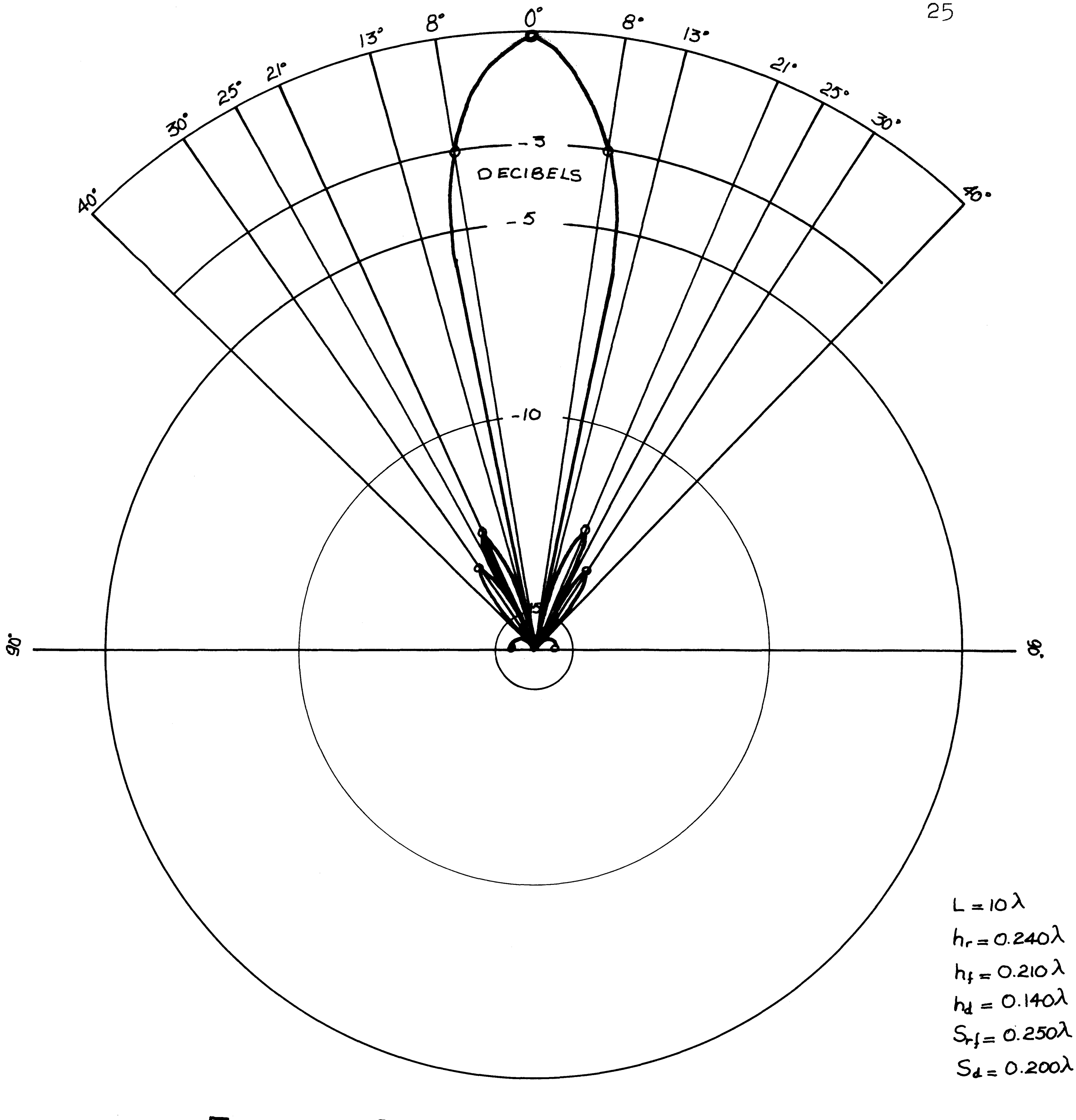



Fig. 2.10 – Ground Plane Radiation Pattern of the Two-Dimensional Array

## CHAPTER 3

## TAPERING OF LONG YAGI ANTENNA

### 3.1 Physical Explanation of the Tapering Action

The sidelobe level of a long Yagi antenna can be improved considerably without sacrificing much of the directivity by just using a linear variation of the propagation constant along the length of the antenna. The variation of the propagation constant should be distinguished from the arbitrary periodic variation. The theory and method which explain the effect of tapering on the variation of the phase constant is given by Sengupta.[20]

According to the discussion given in Sec. 2.2, the normalized phase velocity and therefore the phase constant on the antenna structure can be varied with the variation of $h_f$ and $S_d$. Consequently, one may easily think that it is possible to control the value of the phase constant along the length of the antenna structure by tapering the heights of the directors or the distance between the director elements in a predetermined fashion. The effect of varying phase constant is to produce a nonuniform field distribution along the antenna structure. It is a well-known fact in antenna

[20]Sengupta, *op. cit.*, 1960.

theory that a proper nonuniform source distribution produces better sidelobe ratio in the radiation pattern than that produced by a uniform distribution. Moreover, if the propagation constant is decreased slowly and linearly toward the end of the array, then the effect of any possible reflection at the end of the antenna will be reduced. Therefore, one can reasonably expect that the sidelobe level in the radiation pattern of a long Yagi antenna may be improved by tapering the propagation constant along its length. However, the amount of tapering should be kept very small so that the average value of the phase constant in the antenna may not be too different from that required by the Hansen-Woodyard condition. Otherwise, the advantage of tapering will be lost due to too much broadening of the main beam of the radiation pattern.[21]

## 3.2 Method of Tapering

The required phase constant may be obtained by varying either the director height or the director spacing or a combination of both. In this thesis, the variation of the element length is used because of its simplicity. Later, the effect of the combined tapering is explained briefly.

It should be remembered that this variation of the

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[21] J. D. Kraus, Antennas, McGraw-Hill Book Company, Inc., New York, 1950, pp. 93-109.

element length and spacing or both should be a very slowly varying function of the antenna length so that the propagation constant at any point along the structure may be assumed to have the value equal to what is required with the Hansen-Woodyard condition.

### 3.3 An Approximate Theory of Tapering

If one assumes that the propagation constant along the array varies linearly from $\beta_1$, at the feed end of the antenna to a value of $\beta_2$ at the open end, then propagation constant at any point z along the antenna may be written as follows:

$$\beta(z) = \beta_1 - \alpha z \tag{3.1}$$

where

$\alpha = (\beta_1 - \beta_2)/L$ is the average variation of the phase constant per unit length along the antenna.

After solving some differential equations and making some mathematical manipulation, Sengupta[22] shows that the space factor for the tapered Yagi antenna can be represented in the following expression: (3.2)

$$S(\theta) = \left\{ \left(\frac{\sin(bL/2)}{bL/2}\right)^2 + \left[\frac{\alpha L}{2b}\left(I + \frac{b}{2_{av}}\right)\frac{\cos(bL/2)}{bL/2}\right]^2 \right\}^{\frac{1}{2}}$$

[22]Sengupta, op. cit., 1960.

where

$$b = \beta_{av} - k \cos \theta \qquad (3.3)$$

$$\beta_{av} = \frac{\beta_1 + \beta_2}{2} \qquad (3.4)$$

$\theta$ is the angle measured from the axis of the antenna; it may be seen that for $\alpha \rightarrow 0$, (3.2) reduces to the radiation pattern for the uniform case. This space factor equation is an approximate one but it is quite satisfactory for practical purposes.

## 3.4 Experimental Procedure to find the Tapering Parameters

Before giving the details of the experimental attempts made, it will be useful to define some parameters used in this chapter.

$h_{d_{max}}$ represents the height of the director element at the feed end of the antenna,

$h_{d_{min}}$ represents the height of the director element at the open end of the antenna,

$h_{d_{av}}$ represents the height of the director element which is located at the middle of the directors row and it is taken exactly equal to $h_d$ defined in Chapter 2.

These parameters satisfy the inequality

$$h_{d_{max}} > h_{d_{av}} > h_{d_{min}}$$

The main purpose, here, is to find the values of the above parameters experimentally which will improve the sidelobe level without sacrificing much of the gain and without broadening the mainlobe. This was done in the following manner:

First, several values of $(h_{d_{max}}/h_{d_{min}})$ were tried to produce the smallest sidelobe level in the radiation pattern. It was found that for $(h_{d_{max}}/h_{d_{min}}) = 1.2$, the lowest sidelobe level was obtained. For this value of $(h_{d_{max}}/h_{d_{min}})$ and assuming $h_{d_{av}}$ is equal to unity, it is possible to calculate numerical values of $h_{d_{max}}$ and $h_{d_{min}}$ as follows:

$$h_{d_{max}} = 1.09\ h_{d_{av}}$$
$$h_{d_{min}} = 0.91\ h_{d_{av}} \qquad (3.4)$$

These values of director elements are important. Knowing these numerical values, it is possible to find the values of the phase constants at both ends of the antenna structure; and from the two values of the phase constant it is easy to get the average variation of the phase constant per unit length which is represented by $\alpha$. The numerical values are:

$$\frac{\beta_1}{k} = 1.145$$
$$\frac{\beta_2}{k} = 0.95 \qquad (3.5)$$
$$\alpha = 0.019$$

These values can be used in the evaluation of the space factors given in (3.2), but no attempt is made to evaluate the space factor here. It was found by Sengupta[23] that the theoretical and experimental values agree when the sidelobe level is kept to a minimum by finding the suitable tapering ratio.

### 3.5 Experimental Arrangement and the Procedure of the Experiment

The experimental arrangement shown in Fig. 2.5 was also used in the experiment of this chapter. It was found that the maximum gain condition remained unchanged even after the tapering was made.

The experiment was carried out in the following manner: the center director elements and two side parasitic rows of the second type array of Chapter 2 were tapered linearly with different tapering ratios as mentioned in the previous section. The value of 1.2 was found to be the most suitable tapering ratio as explained before. It was found that the directivity of the antenna was not reduced appreciably as compared with the uniform case for this particular value of tapering ratio. The only experiment which was performed with this tapered array was the far-field measurement of the antenna. The results of the measurement are

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[23]Sengupta, op. cit., 1960.

produced in Fig. 3.1. From this figure, it is seen that the gain of the whole array is reduced only about 0.5 db; however, the sidelobe level is improved some 2.0 db as compared with the uniform case.

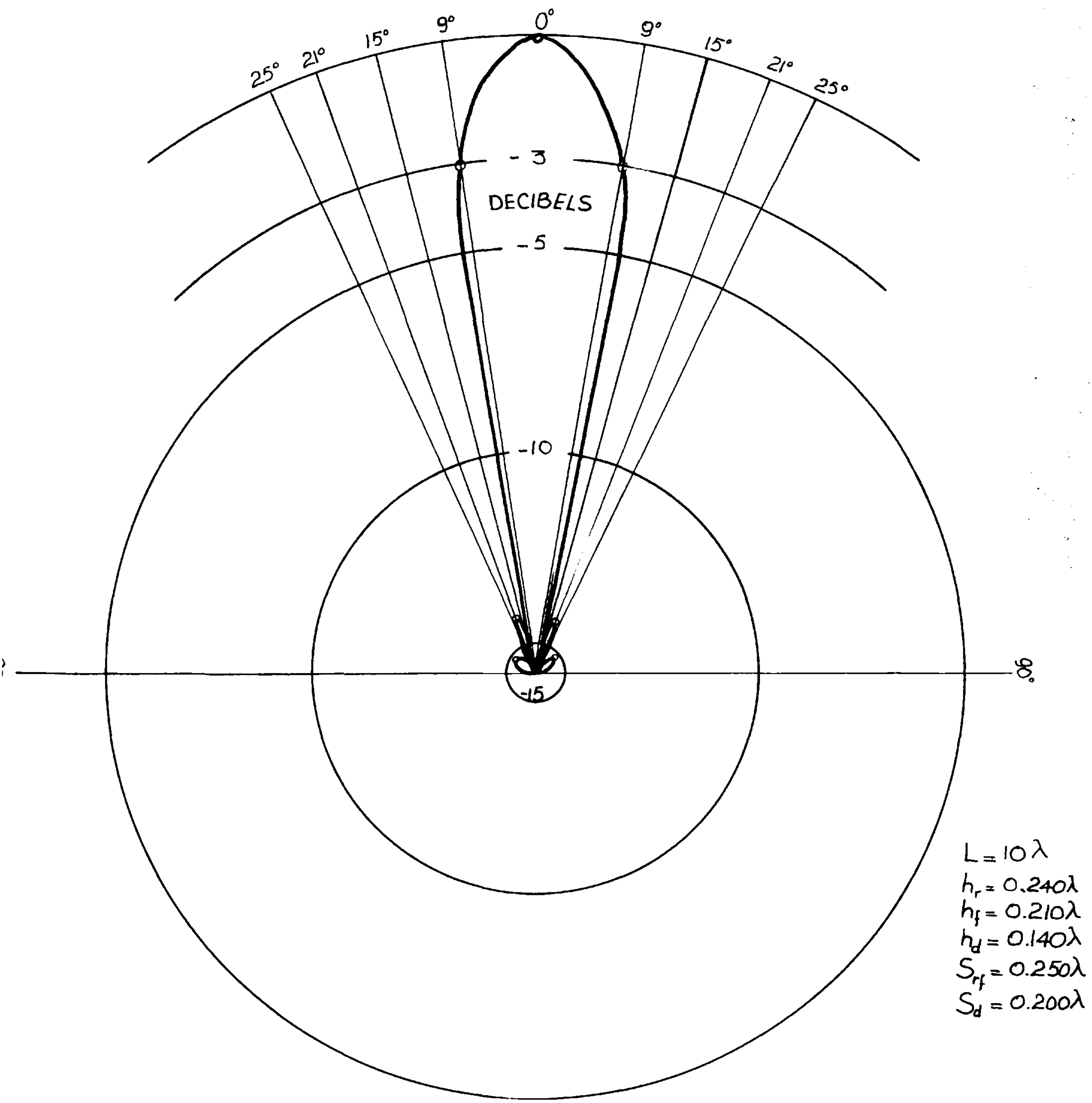


Fig. 3.1 – Ground Plane Radiation Pattern of the Tapered Long Yagi Array

# CHAPTER 4

## SUMMARY OF THE RESULTS

## DISCUSSION AND CONCLUSIONS

In this chapter, the results of all experiments given in Chapters 2 and 3 are summarized, and the different values are discussed and compared with the theoretical and experimentally expected values.

In the first experiment of Chapter 2, a dipole to dipole gain measurement was performed. Although it was the reference gain figure of all experiments, there is nothing to discuss about it because there is no experimental and theoretical gain figure to compare with it. Consequently, the 3.5 db gain above the noise level which is found for this experiment will be accepted as a reference gain figure.

The second experiment was the feeder-reflectors adjustment for three different feeder-reflectors separation. The goal of this experiment was (after deciding a value, for feeder element, which is less than 0.25 wavelengths) to find the maximum gain arrangement for feeder-reflector combination. A maximum 7.0 db gain was obtained with values of $h_f = 0.21\lambda$, $h_r = 0.24\lambda$ and with a separation of $S_{rf} = 0.25\lambda$. Ehrenspeck and Poehler[24] obtained a 4.0 db gain with values $h_f = 0.20\lambda$, $h_r = 0.225\lambda$ and $S_{rf} = 0.25\lambda$. Since in the experiment of this thesis, three reflectors were used instead of one as in the case of the experiment of Ehrenspeck and Poehler,[25] the figures of this experiment seem quite reasonable.

Next, the director elements were added to the structure and the gain measurements were made for different values of $h_d$ and $S_d$. It is realized that the same maximum gain can be obtained as long as the value of $S_d$ remains less than 0.4 wavelength. The maximum gain attained in this experiment was 13.5 db for $L = 10$ wavelengths. The authors mentioned above found a maximum of 14.8 db gain for $L = 6$ wavelengths. It is obvious that the maximum gain attained in our case is lower than the expected experimental value. It is also possible to check the degree of correctness of these two gain figures with a formula. A theoretical formula due to Reid and an experimental formula to calculate the gain of a long Yagi antenna are given by Tourel[26] as follows:

$$\begin{aligned} G &= 9.2\ L \quad \text{(Theoretical)} \\ G &= 5\ L \quad \text{(Experimental)} \end{aligned} \tag{4.1}$$

The second formula will be used to calculate the gain figures for different values of the antenna length.

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[24] Ehrenspeck and Poehler, *op. cit.* [25] *Ibid.*

[26] Tourel, *op. cit.*

From the formula given above for the experimental case, the gain of the Yagi antenna for different values of the length of arrays, can be calculated as follows:

for $L = 6.0$ wavelengths,

$$G = 10 \log_{10} (5 \times 6) = 14.78 \text{ db}$$

for $L = 10$ wavelengths,

$$G = 10 \log_{10} (5 \times 10) = 16.96 \text{ db}$$

From the above results it is seen that the result of the authors in question agrees with the result of the formula; on the other hand, there is 3.5 db difference between our result and the result of the formula. This 3-3.5 db difference from the optimum expected experimental results has been realized throughout the experiments in this thesis. The reasons for getting less gain than the expected value are explained at the end of this chapter.

The next experiment was the measurement of the radiation pattern of the long Yagi antenna with two parasitic side rows. From the experimental values given by Kearns and Ehrenspeck,[27] a 19-19.5 db gain can be expected. Our maximum gain figure for this array is 16 db. The value is again 3-3.5 db less than the expected value. According to the theory presented in Chapter 2, the sidelobe level of the two dimensional array has to be better than the sidelobe level

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[27] Kearns and Ehrenspeck, op. cit.

of the one dimensional uniform long Yagi array. From the radiation pattern, it can be realized that the sidelobe ratio is about 12.5 db which is 3.5 db better than that of the one dimensional array.

In Chapter 3, some experiments were made to find the proper value of the tapering ratio. For tapering ratios larger than the one which gives the desired gain, it is realized that the main beam in the radiation pattern broadens considerably, and the directivity of the antenna is reduced. This broadening of the main beam for larger values of tapering ratios may be explained if one considers that for a larger tapering ratio, the element lengths, near the open end of the antenna, become too short, thereby reducing the effective radiating length of the antenna. From this consideration, one might expect a better result by using a combination of tapering in length and spacing, because this will enable one to achieve the desired tapering of $\beta$ without making the element length near the open end of the antenna too short. The tapering of spacing is not a linear one, therefore it can only be made experimentally. An extensive experimental work on this kind of tapering has been done by French scientists Simmon and Biggi.[28] They first performed the space tapering, placing every individual

[28] Simmon and Biggi, op. cit.

director element at a point where it increases the gain most along the axis of the antenna, starting from the feed end and going in the open end direction. With this arrangement they got even better sidelobe level as compared with the result of the length tapering only. The tapering of the spacing can also indriectly explain one important situation in long uniform Yagi antenna cases. It was mentioned earlier that the maximum gain along the array can be obtained as long as the value of $S_d$ remains less than 0.4 wavelength. If $S_d$ is increased beyond this value, the phase velocity on the antenna array also increases. This increase of the phase velocity makes it difficult to trap the wave along the antenna structure, and the gain of the antenna drops considerably. This is why the restriction statement about the value of $S_d$ was mentioned on page 35.

After finding a proper value for tapering ratio, the radiation pattern measurement of the tapered long Yagi antenna was performed. The maximum gain of this array was found to be 15.5 db and the sidelobe level at 14.5 db down which was 2.0 db better than that of the two dimensional uniform long Yagi array, as expected. The maximum gain figure of this experiment was again 3.0-3.5 db less than the expected value.

The most serious sources of errors in getting less gains than the expected ones are from the reflections of the walls. Experiments of this type should be conducted in a microwave darkroom which is built for this special purpose to minimize the reflections.

It is quite probable that the mechanical precision of the antenna structure for the maximum gain condition was not satisfactory because of the smallness of the element dimensions.

# CHAPTER 5

## SUGGESTIONS FOR FURTHER STUDIES

Although the experiments which are carried out in this thesis give some satisfactory conclusions, further investigations using this same approach or preferably a new approach, might well lead to a better solution to the long Yagi antenna problem.

Pattern measurements for different arrays can be carried out at different frequencies and from the distortion of the patterns at these frequencies, the directivity and the sidelobe level comparisons can be made. This will certainly indicate the importance of working exactly at the resonance frequency. The bandwidths of different arrays of long Yagi antennas can also be investigated by the above measurements.

Long Yagi antenna measurements in two dimensions can be carried out and the characteristics of the arrays can be explained by another method which is called the virtual aperture method. To be able to use this method in antenna measurements, it is necessary to have the near-field radiation pattern of the array in E and H planes. For this purpose, a near-field radiation pattern analyzer has to be used. In this analysis, the problem is to find a way of increasing the virtual aperture. This can be done by adding one or more parasitic side rows on either side of the center array where the phase deviates most from the main array. The increase of the virtual aperture can be seen from the near-field measurements of the new array. The array with one side row on each side of the center array is examined in this thesis with another method, taking the results of the experiments of Kearns and Ehrenspeck[29] for granted. Placing only one side row on each side increases directivity and improves the sidelobe level of the array simultaneously. Placing the first side row a closer distance and adding more side rows, it is possible to increase further the directivity of the array but, in this case, the sidelobe level is not as good as the first case; however, it is better than the sidelobe level of the array without side rows. If the length of every additional row is made one half of the preceeding row, the sidelobe level does not increase appreciably. If a moderate sidelobe level and a higher directivity is preferred, this array can be suggested for this purpose. The number of the side rows on each side of the antenna depends on the construction possibilities of the antenna.

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[29]Kearns and Ehrenspeck, op. cit.

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