A STUDY OF THE REFLECTION CHARACTERISTICS OF SMALL CONDUCTING ELEMENTS

By

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PREFACE

The majority of the experiments and published data about the actions of parasitic elements have been for elements being used as directors and reflectors spaced in the near vicinity of the driven element. Very little work has been done on the effect of these same elements spaced many wave lengths away from the source of power. The purpose of this study is to make an investigation of the field intensity patterns with such a spacing.

The author wishes to extend thanks to Paul A. McCollum and Edmund W. Schedler, Jr. for their assistance in assembling and testing the experimental equipment and moving it to the testing location. In particular the author is indebted to Prof. Betts for his help, advice, and instruction throughout the course of this study.

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A STUDY OF THE REFLECTION CHARACTERISTICS OF SMALL CONDUCTING ELEMENTS

INTRODUCTION

Familiarization

Parasitic elements and flat conducting sheets in conjunction with receiving antenna systems have been used for some time to obtain different degrees of gain and directivity. Such elements have no transmission-line connection to a transmitter but are excited by currents induced by the fields of some remote driven elements. The magnitude and phase relation of the current in the parasitic element to the current in the driven element depends on the tuning of the parasitic element. The tuning is most usually accomplished by changing the length of the element, however, it is also possible to change the tuning by inserting lumped reactances in series with the antenna at its center point. If the parasitic element is longer than one-half wave length it will be inductively tuned. When tuned in this way and placed in the near field it will act as a reflector. Conversely, if the electrical length is shorter than a half-wave length it will be capacitively tuned and will act as a director when placed in the near field.

It has been a relatively short time since Brown[1] did his

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[1] G. R. Brown, "Directional Antennas," Proceedings of the I.R.E., (January, 1937).

work on the parasitic array, using spacings of less than a quarter wave length. However, with the advent of radar during World War II, long strides have been made in the field of parasitic antenna systems. Since most of the published data on these parasitic elements have been for spacings of the order of less than a half-wave length, it was decided that a series of investigations would be made to determine the reflection characteristics of these elements when spaced in the far field of the driven element. The far field being defined here as a distance greater than ten wave lengths. With this definition the assumption is made that the transmitting and receiving antennas are sufficiently remote from the reflecting elements that no appreciable phase difference exists between the waves striking the center and edge of the reflector. That is, the reflector is uniformly illuminated by the incident wave.

Objective

The objective of this thesis is to make an investigation of the reflection properties of resonant elements when excited parasitically by a driven element which is located at least ten wave lengths away.

THEORY

Fundamentals

To understand the reflection properties of parasitic elements it is necessary to first become acquainted with the characteristics of the basic dipole antenna.

In the fundamental treatment of the field of radiation from a current carrying conductor, it is assumed that the current is the same throughout the whole length of the conductor.[1] This is, of course, impossible in a practical antenna. However, it may be assumed that it is a part of a longer antenna wire in which case there will be radiation from each part of the longer wire. The total radiation from the antenna is then found by summation, or integration, of the components of radiation from the many short sections of the antenna. In this manner it is found that the radiation

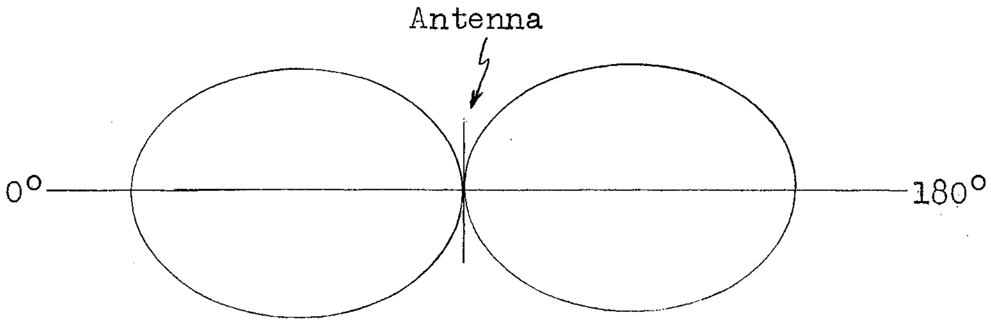

Figure 1

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[1] H. H. Skilling, <u>Fundamentals of Electric Waves</u>, pp. 164-169.

intensity from an elementary dipole is greatest at right angles to the line of the conductor, and decreases as the direction becomes more nearly in line with the conductor until, right off the ends, the intensity is zero. This field pattern of the half-wave dipole[2] is illustrated in Figure 1, with a sample calculation in Appendix A.

Absorption and Scattering by a Dipole

Consider a plane wave falling on a dipole and setting it into vibration so that it both absorbs and scatters energy. This problem necessitates making assumptions about the behavior of a dipole. It must act like a resonant circuit, so that when it is acted on by a sinusoidal force, it is set into forced vibrations with a definite amplitude and phase. This amplitude and phase is determined by the effective inductance, resistance, and capacity of the dipole.

The incident wave strikes the dipole, and a certain amount of the energy is stopped by the dipole and removed from the beam. The energy removed from the beam is divided into two parts. One part is reradiated or scattered, in a spherical wave. The other part is absorbed, going into the heating of the resistance. To determine the relative amounts of the energy scattered and absorbed we must assume the resistance of the antenna being comprised of two parts: the ordinary ohmic resistance of the conductor and the radiation resistance of the antenna. The radiation resistance is a fic-

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[2] E. C. Jordan, Electromagnetic Waves and Radiating Systems, pp. 393.

titious term defined as the average radiated power divided by the square of the effective value of current in the antenna.[3] If these two terms are called R_o and R_r, the total resistance will be the sum of R_o and R_r. The power input to the dipole from the external wave then will be $1/2i^2(R_o+R_r)$, of which the part $1/2i^2R_o$ goes into absorption, and $1/2i^2R_r$ into scattering. It can now be seen that the amount of absorption and scattering will depend on the relative amounts of R_o and R_r.

If the dipole is to be used for absorption (receiving) the R_o term should be made as large as possible. This is accomplished when R_o equals R_r. In the case at hand where reradiation is of prime importance it is necessary to make the R_o term as small as possible since the radiation resistance R_r is a relatively fixed amount. Assuming the antenna is being fed at the center then, as a receiving antenna, R_o would be a minimum when the center points were shorted.[4] This is the case with the half-wave conducting elements used in the experimental work preceding this Thesis.

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[3] H. H. Skilling, Fundamentals of Electric Waves, pp. 179.

[4] J. C. Slater, Microwave Transmission, pp. 239.

EXPERIMENTAL ANALYSIS

Equipment

The equipment for this experiment consisted of three major pieces:

1. A power source in the 10 centimeter range.
2. A receiver and detector to cover the same frequency range.
3. A plywood board for supporting the conducting elements.

The power source was obtained by using a General Electric R-F oscillator. The oscillator used a single 2C40 lighthouse tube.[1] The frequency of the oscillator may be changed over a small range by changing the effective length of the plate line of the tube.

A method for pulse modulating the R-F oscillator was designed by Paul A. McCollum, Assistant Professor, Technical Training. Briefly, this section consisted of a master oscillator, a clipper circuit, and the modulator stage as shown in the block diagram in Figure 2. A complete schematic diagram of the Oscillator-Modulator unit will be found in Appendix B.

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[1] Zeluff and Markus, Electronics Manual for Radio Engineers, 1st Edition, pp. 466-469.

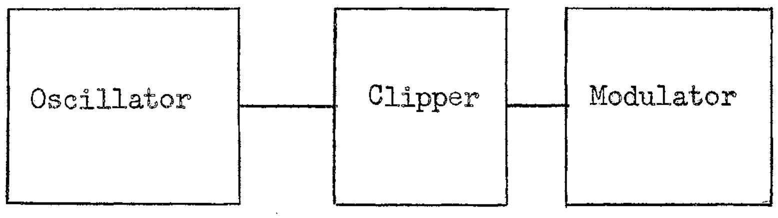


Figure 2

The master oscillator for the modulation signal is a plate coupled multivibrator with the time constant of the coupling condensers and resistors made small enough to obtain a good square wave output. A repetition rate of 240 pps was chosen. A potentiometer was used for R_5 in the circuit so that the output pulse width could be varied. This method enables the operator to vary the duty cycle of the oscillator from about 20% to 65%.

A two stage clipper circuit was used after the master oscillator to sharpen the leading edge of the square wave.

The modulator stage uses a 6Y6 screen grid tube which grid modulates the R-F oscillator. The action of the system is to apply a bias beyond cutoff to the grid of the 2C40 R-F oscillator. Then when a positive modulation pulse hits the grid it will drive it above cutoff and will deliver R-F power for the duration of the pulse.

An SCR 545 search receiver was modified to meet the requirements of the frequency range by E. W. Schedler, Jr., Instructor, Electrical Engineering Department. Major modifications consisted of changing the power supply circuit so that only one rack was required and the addition of a detector circuit for output to a VTVM and oscillograph. A balance circuit was also built so that background noise could be balanced out. The I-F amplifier operated at 60 mc. Mixing was accomplished by a 1N21B crystal diode.

A plywood board was made for suspending the conducting elements. The board was constructed so that it could rotate in a horizontal plane. All joints were connected by dowels and glued. The board was fitted to a table so that it would be approximately the same height as the transmitting antenna.

Method of Measurement

The tests were undertaken at a frequency of 3,000 mc. The wave length of 10 cm permitted convenient proportions in the physical set-up, and much of the required equipment was already available. The arrangement of equipment is shown in Figure 3. The transmitting antenna and the reflection board were in the same horizontal plane while the receiving antenna was slightly lower. Horizontal polarization was used in all tests. The transmitting and receiving antennas were located about 10 feet (approximately 30 wave lengths) from the reflection board assembly.

Actual measurements were taken with the equipment set up in an open field near the edge of town. Sixty cycle power was brought to the equipment by a #8 stranded cable. The

Figure 3 Arrangement of Equipment

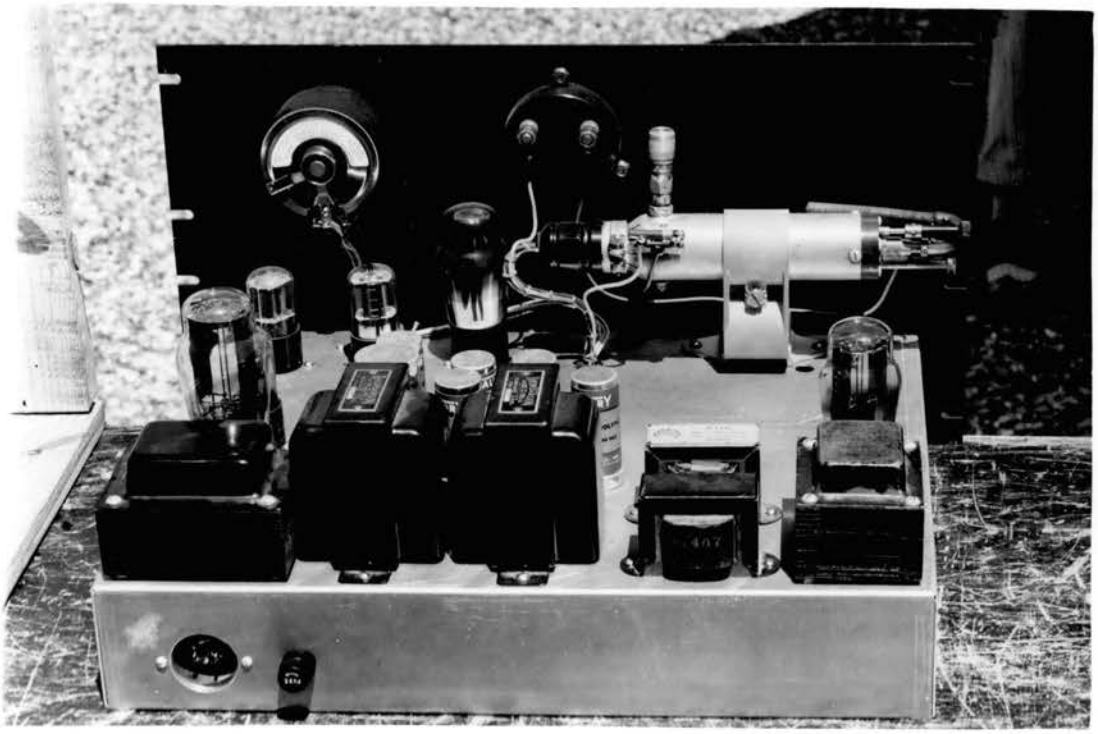


Figure 4 (A) Transmitter Unit

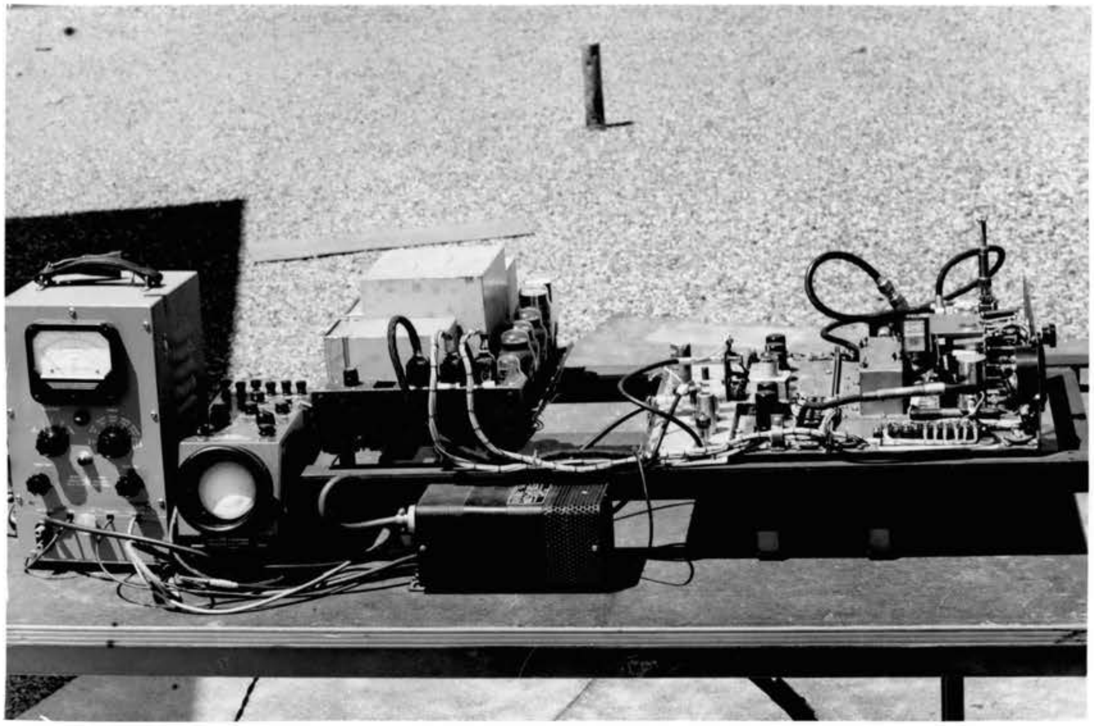


Figure 4 (B) Receiver and Detector Unit

Figure 5 (A) Transmitting and Receiving Antennas

Figure 5 (B) Reflection Board

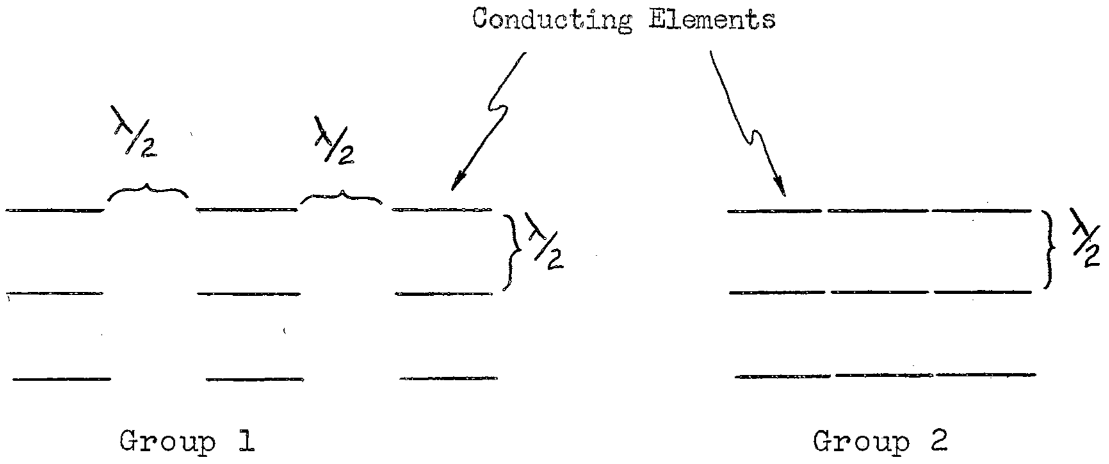


Figure 6

Experimental Results

The results of these tests are presented in the curves in section IV. The observed readings and adjusted (actual) values are given in the data tables of the same section. The adjusted values are obtained by subtracting the corresponding reading of the empty board. The accuracy of these readings are inestimable. Small power-line voltage fluctuations and random frequency drift due to temperature changes are believed to have caused some uncertainty. A major item in obtaining accurate results seemed to be the spacing between the transmitter-receiver location and the reflecting board location. It was noticed that the pressure of the wind against the board would cause enough variation in distance to give large variations in recorded readings. It was assumed that this was due to ground reflections causing standing waves to exist on the return signal. Due to this difficulty most of the measurements were made at night while the wind was low. Even though this precaution was taken, changes in amplitude of the return signal persisted. It was found that this was due to slight changes in the board setting while making the manual rotation of the board during readings. This source of error had to be accepted since it was impossible to make the angular adjustments necessary on the board without moving it a few millimeters. If the table had been mounted rigidly on a concrete base it seems likely that this difficulty could have been eliminated. It is suggested also that some of the signal on the return trip is being reflected or "bounced" off the ground which is arriving out of phase with the "direct" signal return. This phase relationship is causing a difference in reading which could be less than the same reading of the previous run.

TEST DATA AND GRAPHS

Experimental and Calculated Data for Vertical and Horizontal Element Spacings of One-Half Wave Length

θ	Board	9 Elements		15 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.33	.33	.00	.33	.00
88	.33	.33	.00	.33	.00
86	.33	.34	.01	.34	.01
84	.30	.31	.01	.31	.01
82	.27	.27	.00	.31	.04
80	.27	.27	.00	.31	.04
75	.29	.29	.00	.34	.05
70	.34	.32	.00	.37	.03
65	.30	.30	.00	.33	.03
60	.24	.26	.02	.28	.04
55	.33	.35	.02	.42	.09
50	.25	.32	.07	.40	.15
45	.25	.32	.07	.41	.16
40	.28	.36	.08	.42	.14
35	.23	.26	.03	.29	.06
30	.35	.35	.00	.37	.02
25	.13	.19	.06	.21	.08
20	.17	.26	.09	.27	.10
15	.44	.49	.05	.52	.08
10	.83	.96	.13	.99	.16
5	1.35	1.60	.25	1.50	.15
0	1.80	2.10	.30	2.00	.20

Experimental and Calculated Data for Vertical and Horizontal Element Spacings of One-Half Wave Length

Θ	Board	21 Elements		25 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.33	.33	.00	.34	.01
88	.33	.33	.00	.34	.01
86	.33	.34	.01	.34	.01
84	.30	.31	.01	.31	.01
82	.27	.27	.00	.28	.01
80	.27	.27	.00	.30	.03
75	.29	.30	.01	.31	.02
70	.34	.34	.00	.33	.00
65	.30	.31	.01	.31	.01
60	.24	.28	.04	.27	.03
55	.33	.39	.06	.34	.01
50	.25	.39	.14	.34	.09
45	.25	.39	.14	.37	.12
40	.28	.41	.13	.34	.06
35	.23	.30	.06	.26	.03
30	.35	.36	.01	.37	.02
25	.13	.22	.09	.20	.07
20	.17	.27	.10	.22	.05
15	.44	.49	.05	.35	.00
10	.83	.98	.15	.65	.00
5	1.35	1.55	.20	1.50	.15
0	1.80	1.95	.15	2.00	.20

Experimental and Calculated Data for Vertical and Horizontal Element Spacings of One-Half Wave Length

θ	Board	27 Elements		35 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.33	.33	.00	.36	.03
88	.33	.34	.01	.36	.02
86	.33	.35	.02	.35	.02
84	.30	.32	.02	.32	.02
82	.27	.27	.00	.30	.03
80	.27	.27	.00	.31	.04
75	.29	.30	.01	.33	.04
70	.34	.34	.00	.35	.01
65	.30	.32	.02	.32	.02
60	.24	.27	.03	.31	.07
55	.33	.41	.08	.39	.06
50	.25	.41	.16	.40	.15
45	.25	.42	.17	.43	.18
40	.28	.45	.17	.40	.12
35	.23	.30	.07	.31	.08
30	.35	.36	.01	.41	.06
25	.13	.20	.07	.24	.11
20	.17	.27	.10	.31	.14
15	.44	.51	.07	.51	.07
10	.83	1.10	.27	1.00	.17
5	1.35	1.65	.30	1.55	.20
0	1.80	2.20	.40	2.10	.30

Experimental and Calculated Data for Vertical and Horizontal Element Spacings of One-Half Wave Length

θ	Board	45 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.33	.34	.01
88	.33	.34	.01
86	.33	.33	.00
84	.30	.31	.01
82	.27	.28	.01
80	.27	.30	.03
75	.29	.31	.02
70	.34	.32	.02
65	.30	.29	.01
60	.24	.28	.04
55	.33	.33	.00
50	.25	.35	.10
45	.25	.42	.17
40	.28	.35	.08
35	.23	.25	.02
30	.35	.33	.00
25	.13	.21	.08
20	.17	.26	.09
15	.44	.57	.13
10	.83	1.00	.17
5	1.35	1.58	.23
0	1.80	2.13	.33

Experimental and Calculated Data for Element Spacings of One-Half Wave Length Vertical and Zero Horizontal

θ	Board	9 Elements		15 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.66	.66	.00	.66	.00
88	.66	.66	.00	.66	.00
86	.69	.68	.00	.71	.02
84	.76	.76	.00	.81	.05
82	.85	.89	.14	.91	.11
80	.79	.99	.20	1.00	.21
75	.69	.89	.20	.91	.22
70	.70	.89	.19	.91	.21
65	.86	1.09	.23	1.16	.30
60	.82	1.04	.22	1.06	.24
55	.63	.79	.16	.81	.18
50	.91	1.29	.38	1.41	.50
45	.82	1.14	.32	1.21	.39
40	.69	.99	.30	1.00	.31
35	1.10	1.44	.34	1.56	.46
30	.67	.89	.22	.86	.19
25	1.10	1.39	.29	1.21	.11
20	1.35	1.79	.44	1.76	.41
15	1.55	1.99	.44	1.96	.41
10	1.55	2.04	.49	2.01	.46
5	1.70	2.29	.59	2.41	.71
0	2.00	2.74	.74	3.26	1.26

Experimental and Calculated Data for Element Spacings of One-Half Wave Length Vertical and Zero Horizontal

θ	Board	25 Elements		35 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.66	.66	.00	.66	.00
88	.66	.61	.00	.61	.00
86	.69	.58	.00	.58	.00
84	.76	.61	.00	.61	.00
82	.85	.69	.00	.70	.00
80	.79	.72	.00	.78	.00
75	.69	.72	.03	.78	.09
70	.70	.78	.08	.86	.16
65	.86	.95	.09	1.06	.20
60	.82	.87	.05	.96	.14
55	.63	.67	.04	.74	.11
50	.91	.91	.00	1.00	.09
45	.82	.79	.00	.86	.04
40	.69	.75	.06	.85	.16
35	1.10	1.22	.22	1.31	.31
30	.67	.73	.06	.85	.18
25	1.10	1.00	.00	1.06	.00
20	1.35	1.32	.00	1.16	.00
15	1.55	1.57	.02	1.41	.00
10	1.55	1.72	.17	1.81	.26
5	1.70	2.22	.52	2.21	.51
0	2.00	2.72	.72	2.76	.76

Experimental and Calculated Data for Element Spacings of One-Half Wave Length Vertical and Zero Horizontal

θ	Board	45 Elements		63 Elements	
Axis Angle Degrees	Reflection Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts	Total Field Strength-Volts	Difference Field Strength-Volts
90	.66	.66	.00	.65	.00
88	.66	.66	.00	.56	.00
86	.69	.67	.00	.48	.00
84	.76	.70	.00	.47	.00
82	.85	.81	.00	.57	.00
80	.79	.82	.03	.78	.00
75	.69	.84	.15	.94	.25
70	.70	.95	.15	1.15	.45
65	.86	1.20	.34	1.20	.34
60	.82	1.15	.32	1.00	.18
55	.63	.79	.16	.76	.03
50	.91	1.05	.14	1.20	.29
45	.82	.85	.03	1.20	.38
40	.69	.79	.10	.95	.26
35	1.10	1.45	.35	1.30	.20
30	.67	.91	.24	1.15	.48
25	1.10	1.10	.00	1.85	.75
20	1.35	1.30	.00	2.00	.65
15	1.55	1.50	.00	1.85	.30
10	1.55	1.80	.25	2.20	.65
5	1.70	2.40	.70	3.30	1.60
0	2.00	3.20	1.20	3.90	1.90

REFLECTION PATTERN
OF EMPTY PLY-
WOOD BOARD

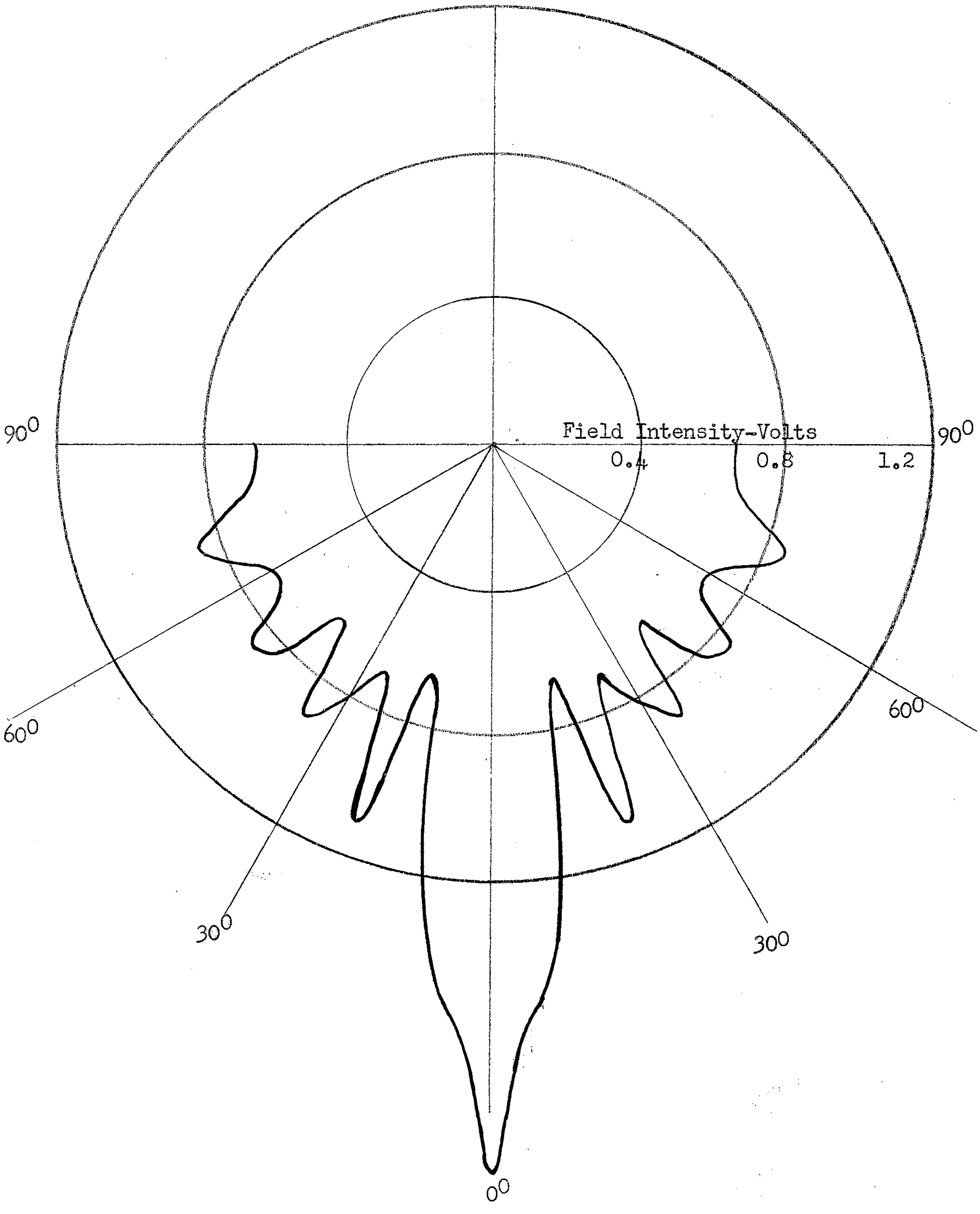
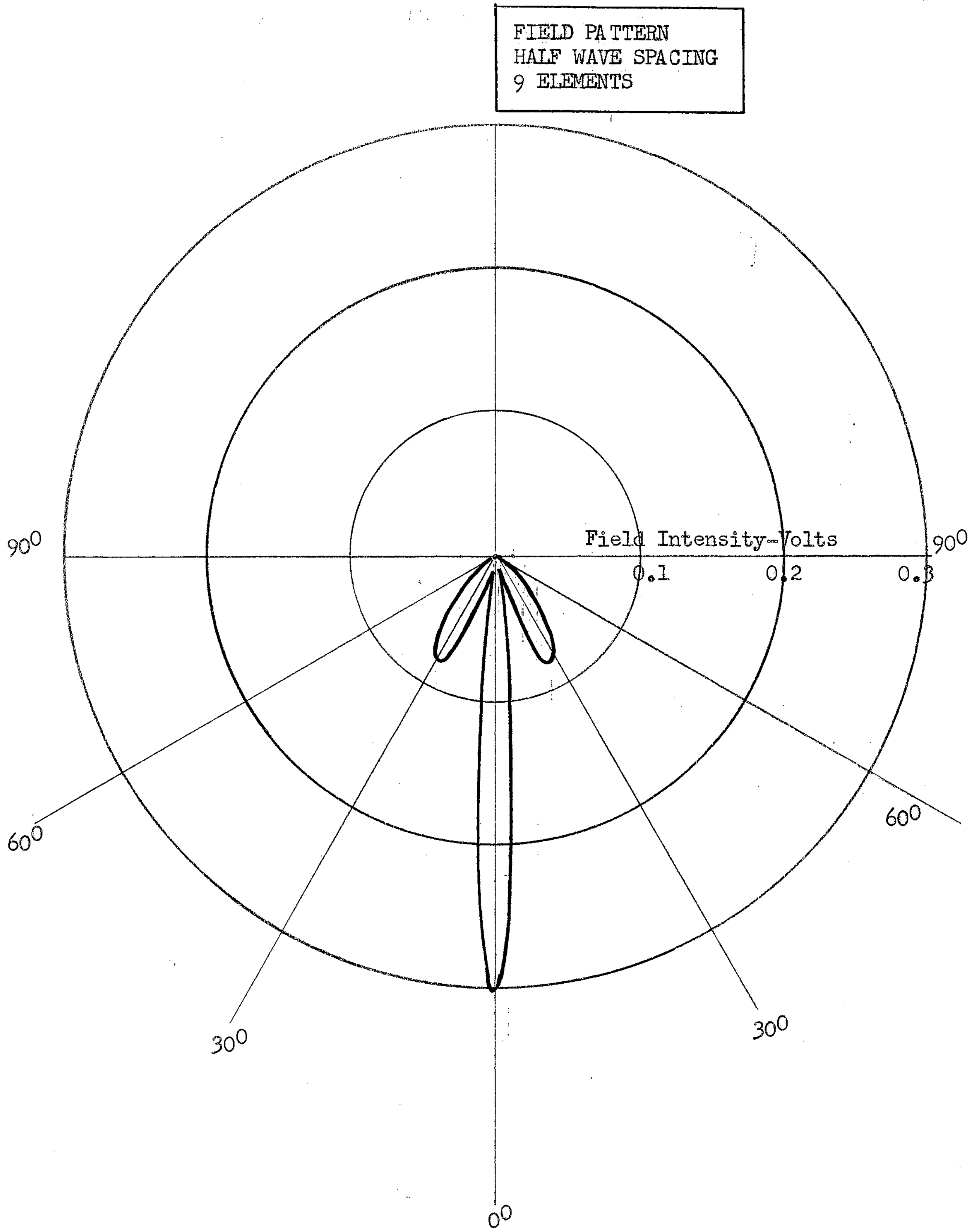


Figure 7


FIELD PATTERN
HALF WAVE SPACING
9 ELEMENTS
Field Intensity-Volts
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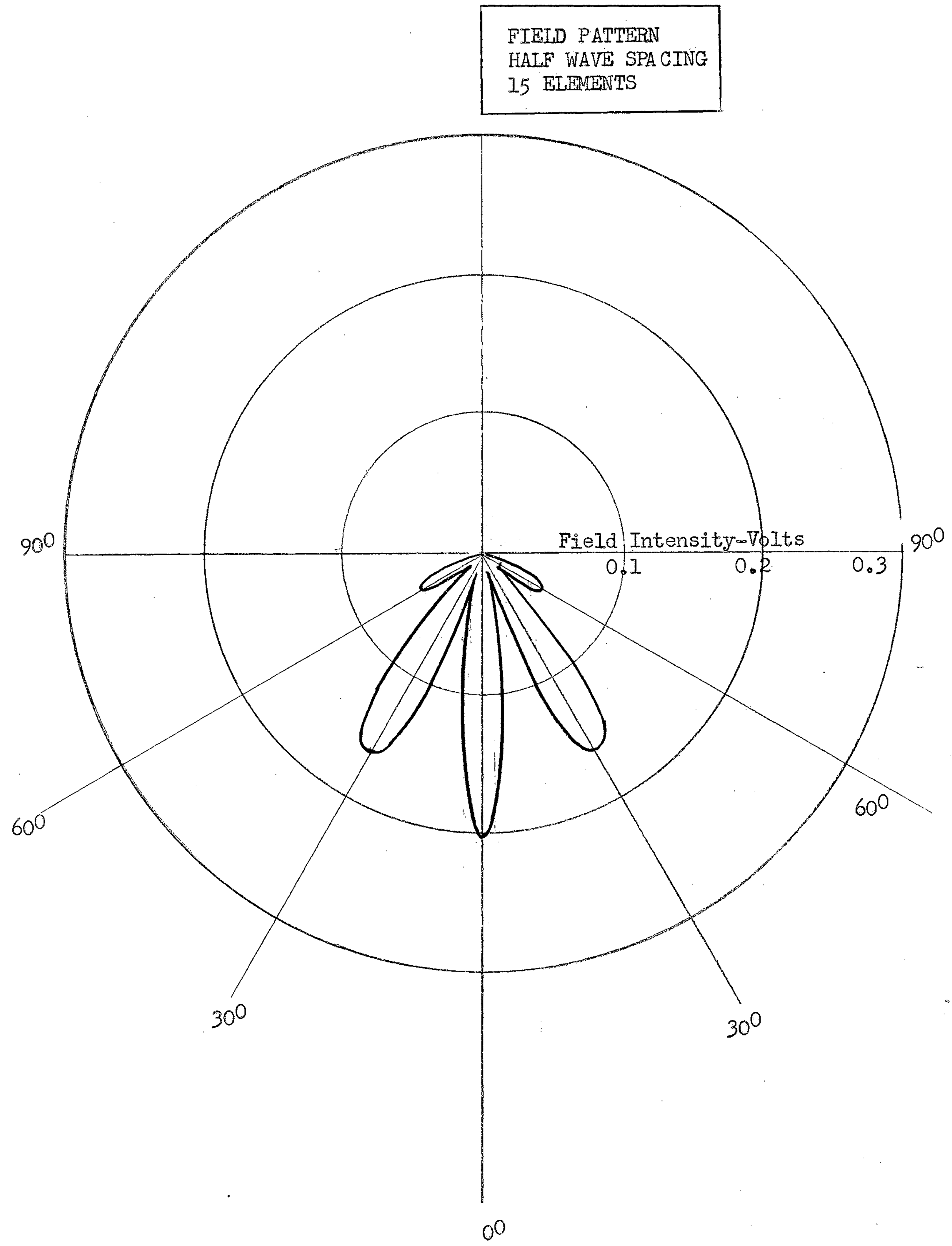
0.2
0.3
90°
90°
60°
60°
30°
30°
0°

Figure 8



FIELD PATTERN
HALF WAVE SPACING
15 ELEMENTS

Figure 9

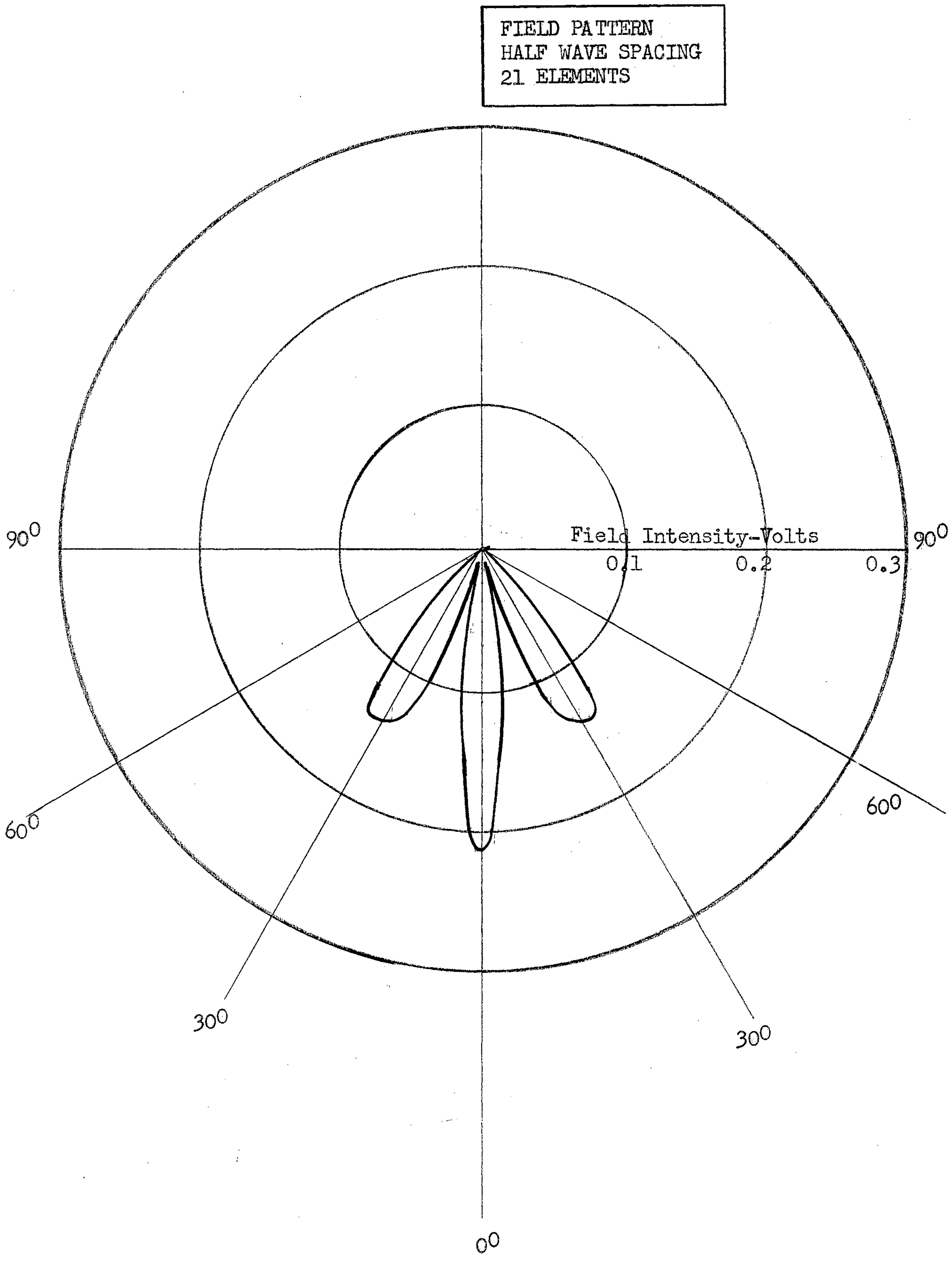

FIELD PATTERN
HALF WAVE SPACING
21 ELEMENTS
Field Intensity-Volts
0.1
0.2
0.3
90°
90°
60°
60°
30°
30°
0°

Figure 10

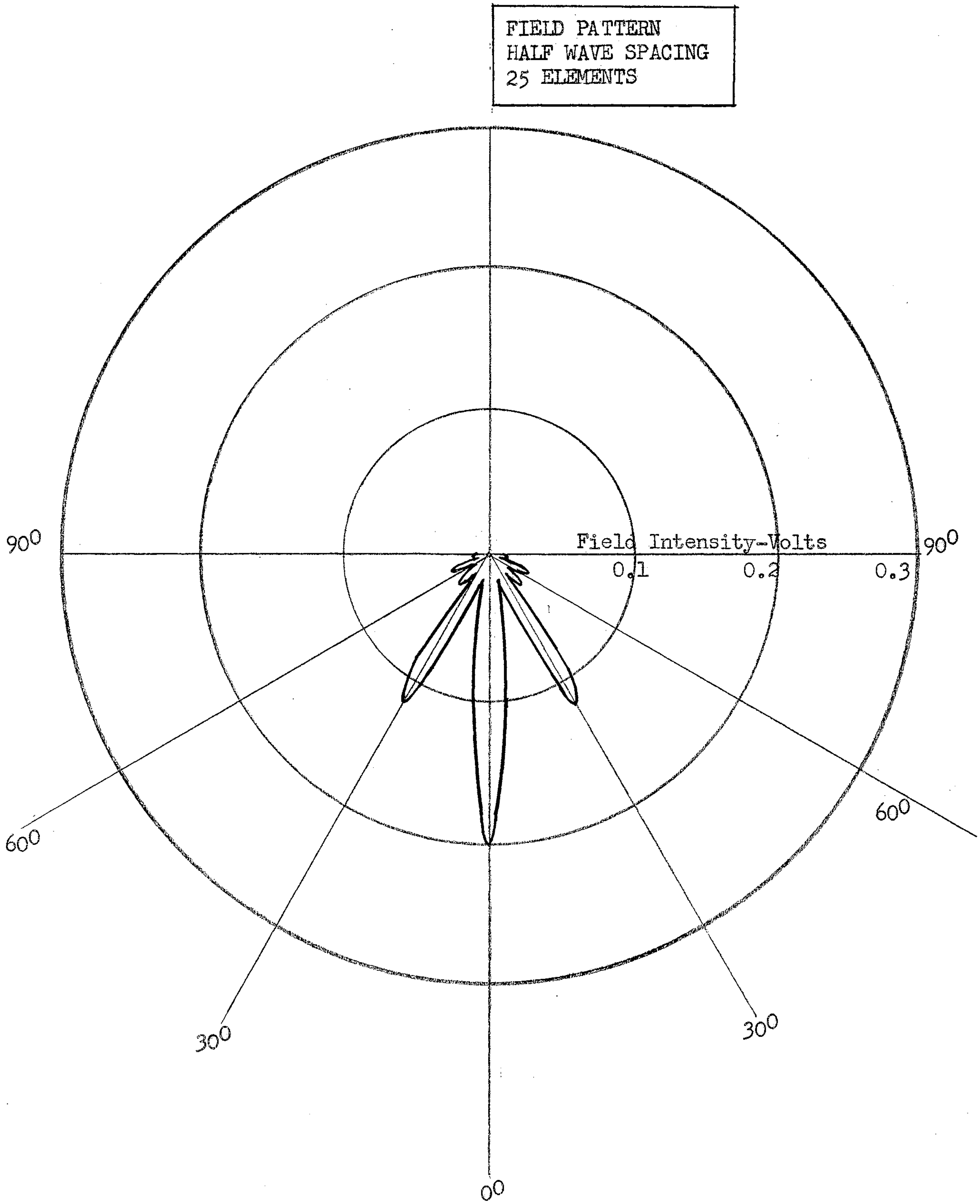

FIELD PATTERN
HALF WAVE SPACING
25 ELEMENTS
Field Intensity-Volts
0.1
0.2
0.3
90°
90°
60°
60°
30°
30°
0°

Figure 11

FIELD PATTERN
HALF WAVE SPACING
27 ELEMENTS

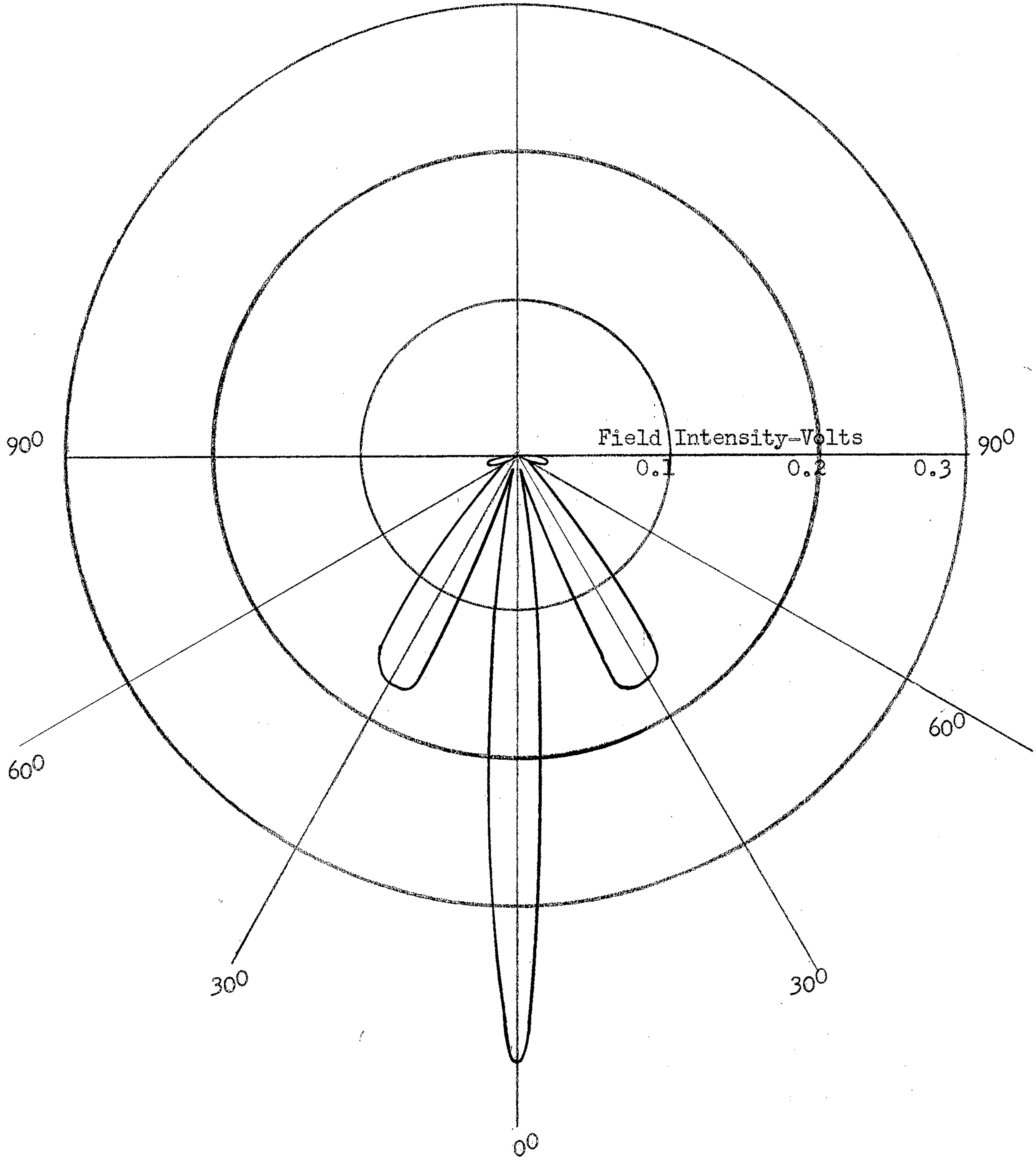


Figure 12

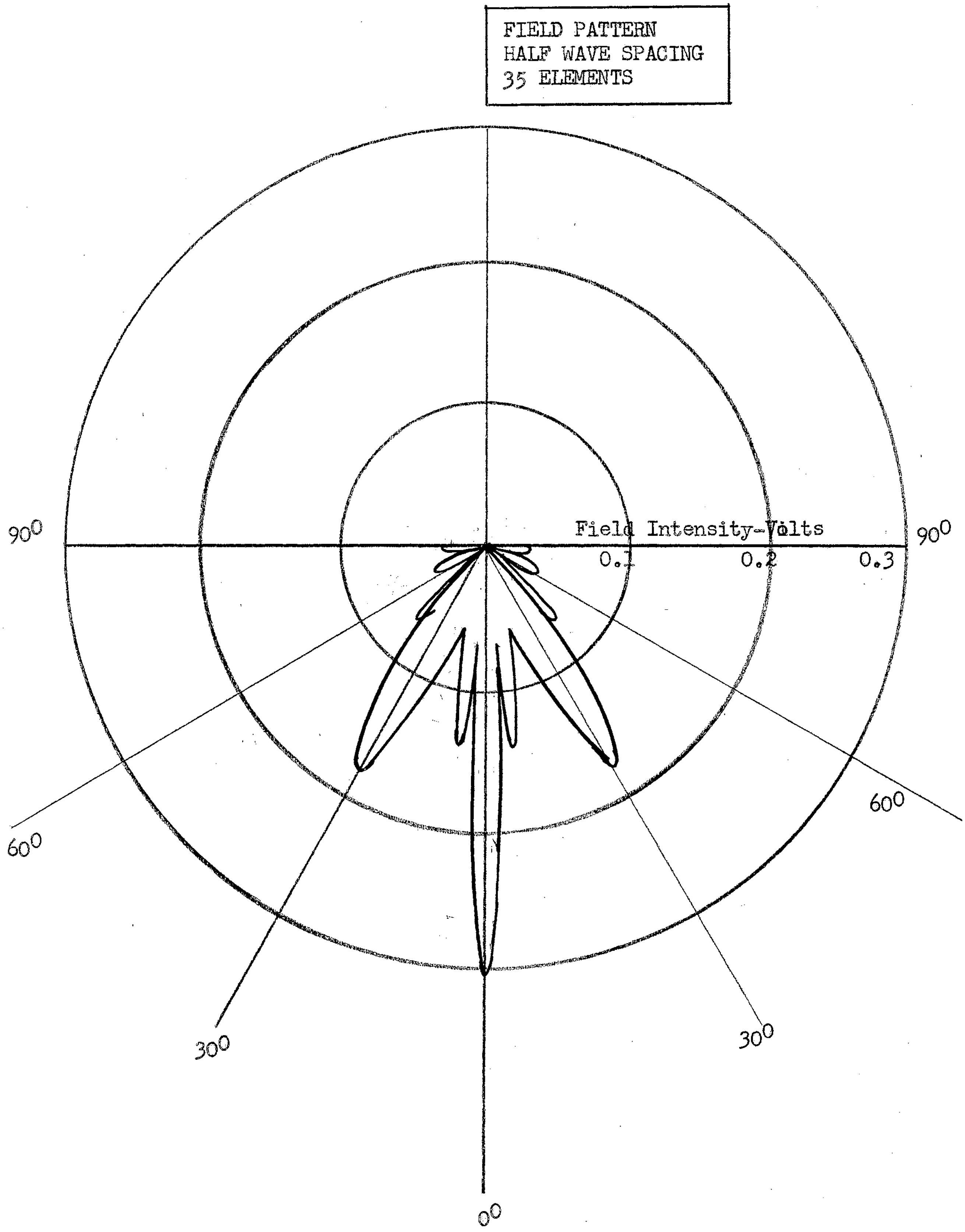
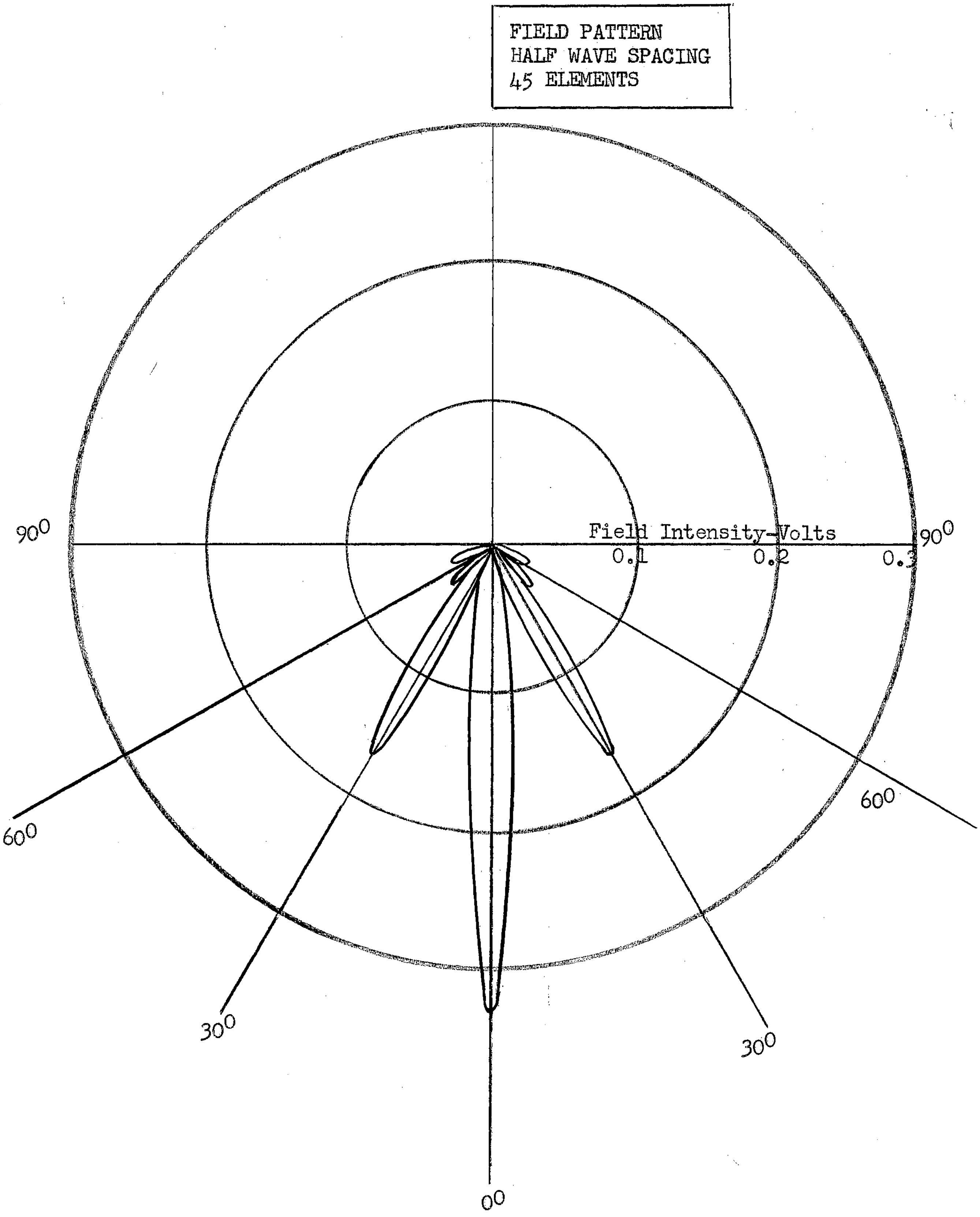

FIELD PATTERN
HALF WAVE SPACING
35 ELEMENTS
Field Intensity-Volts
0.1
0.2
0.3
90°
90°
60°
60°
30°
30°
0°

Figure 13



FIELD PATTERN
HALF WAVE SPACING
45 ELEMENTS

Figure 14

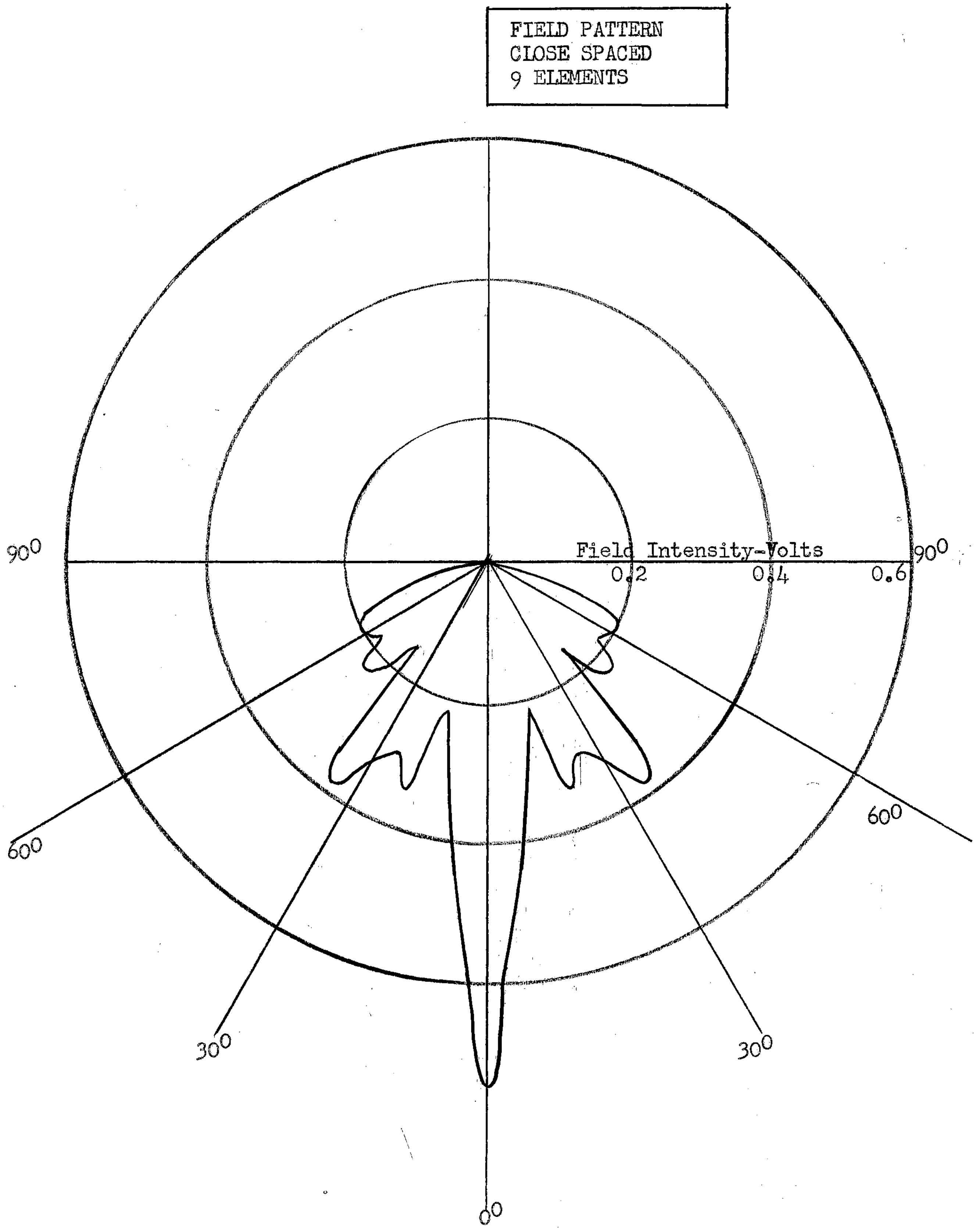

FIELD PATTERN
CLOSE SPACED
9 ELEMENTS
Field Intensity-Volts
0.2
0.4
0.6
90°
90°
60°
60°
30°
30°
0°

Figure 15

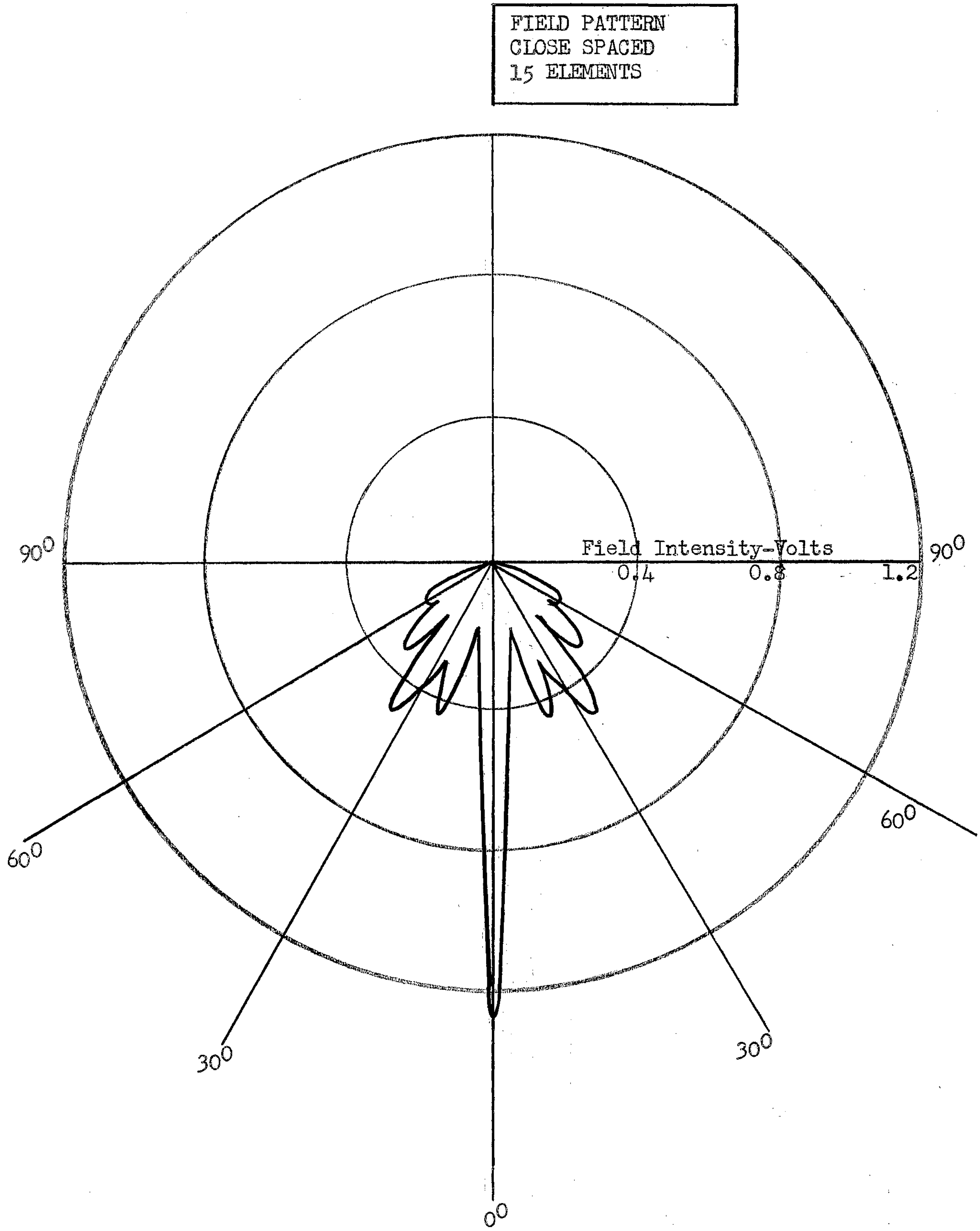

FIELD PATTERN
CLOSE SPACED
15 ELEMENTS
Field Intensity-Volts
0.4
0.8
1.2
90°
90°
60°
60°
30°
30°
0°

Figure 16

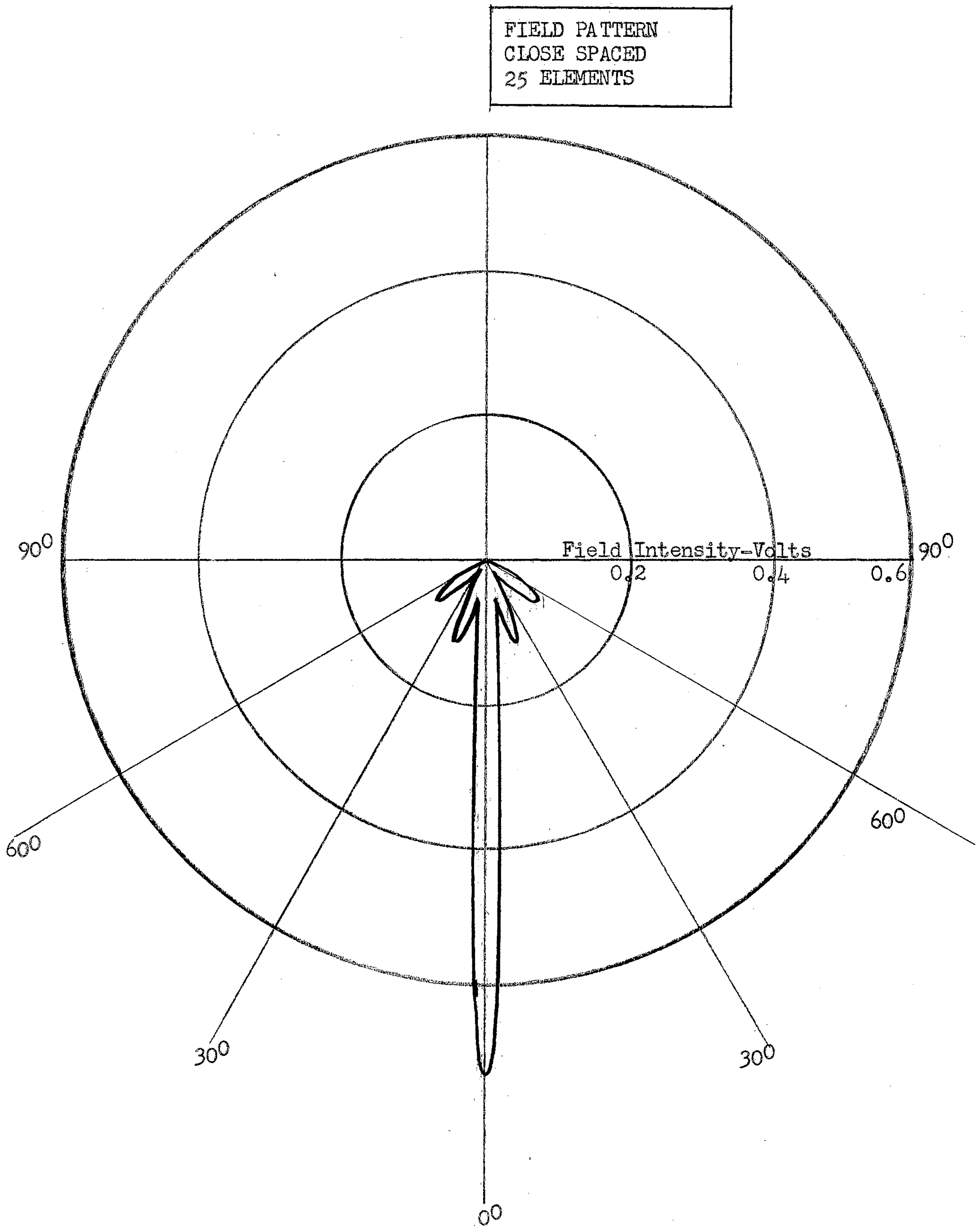

FIELD PATTERN
CLOSE SPACED
25 ELEMENTS
Field Intensity-Volts
0.2
0.4
0.6
90°
90°
60°
60°
30°
30°
0°

Figure 17

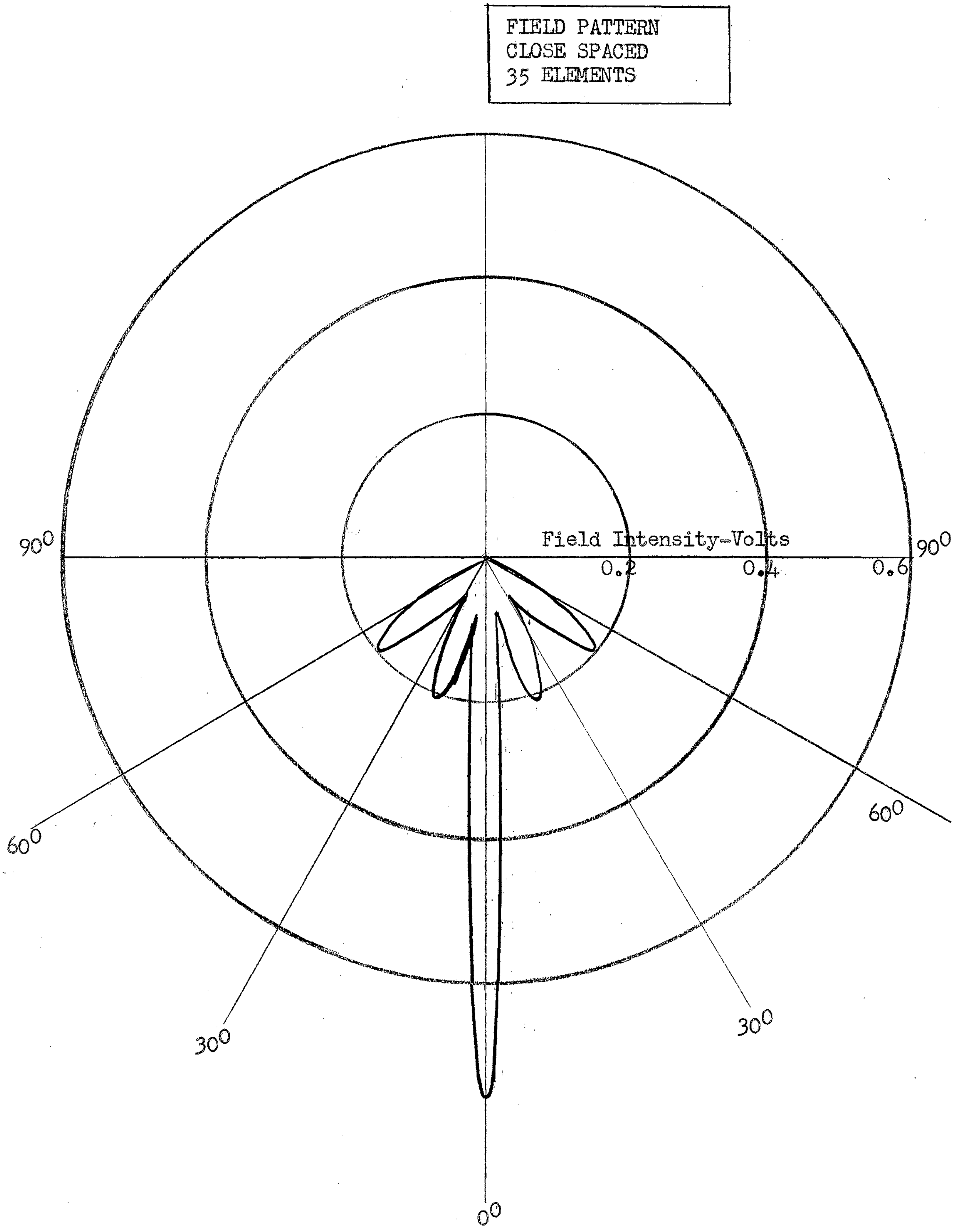

FIELD PATTERN
CLOSE SPACED
35 ELEMENTS
Field Intensity-Volts
0.2
0.4
0.6
90°
90°
60°
60°
30°
30°
0°

Figure 18

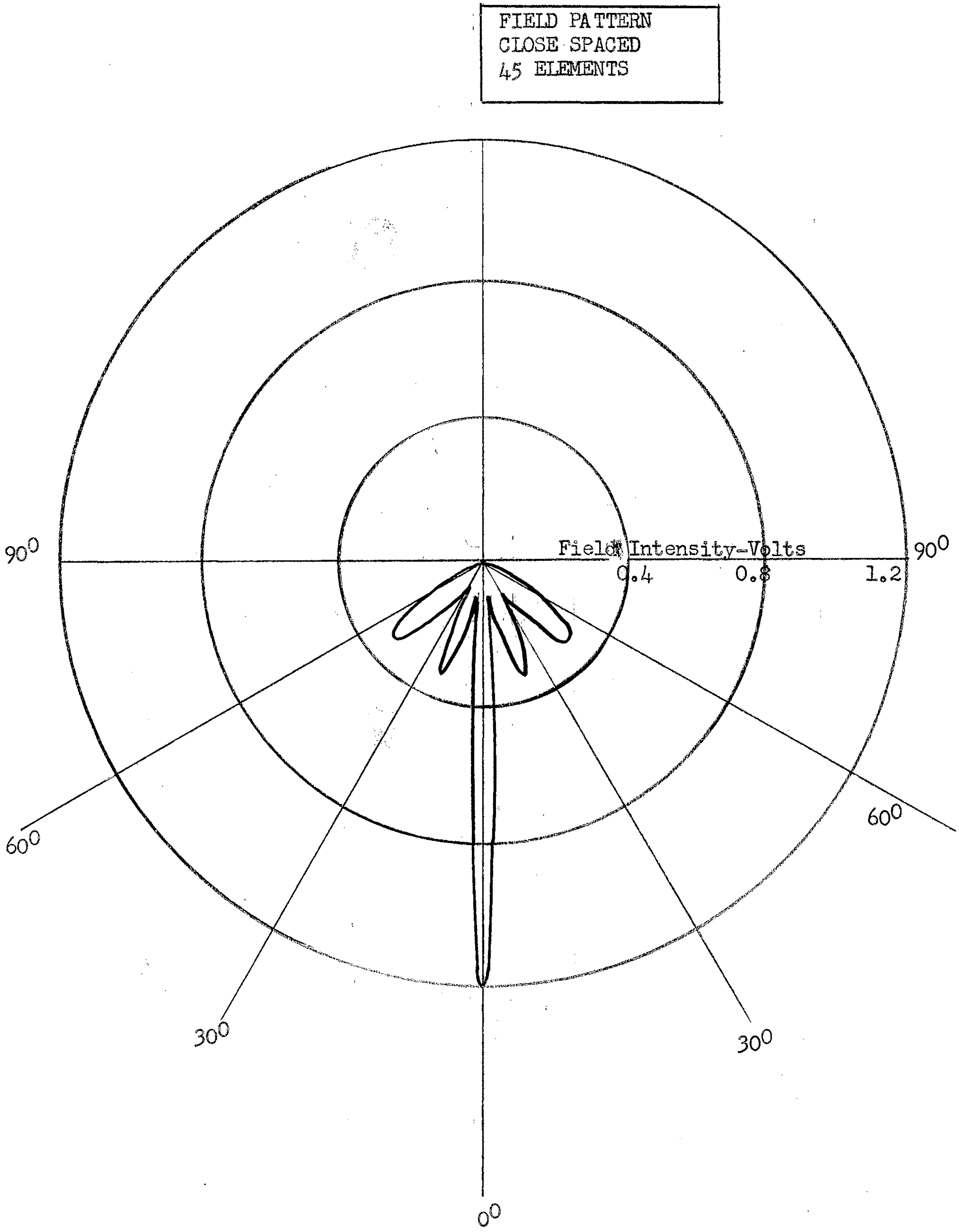

FIELD PATTERN
CLOSE SPACED
45 ELEMENTS

Figure 19

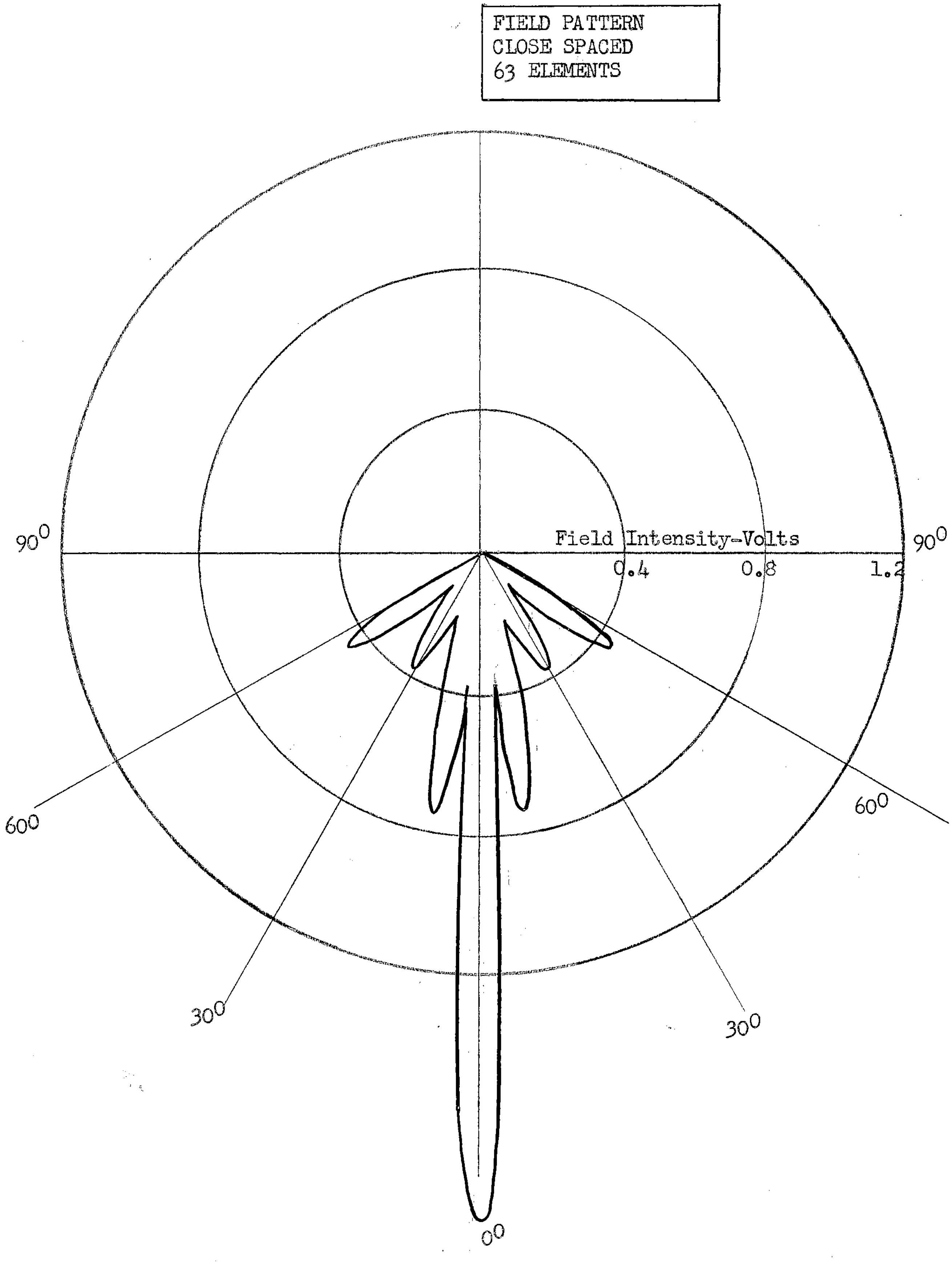

FIELD PATTERN
CLOSE SPACED
63 ELEMENTS
Field Intensity-Volts
0.4
0.8
1.2
90⁰
90⁰
60⁰
60⁰
30⁰
30⁰
0⁰

Figure 20

SUMMARY

As will be noticed in the curves in section IV, the magnitudes of the peaks for one curve, relative to the peaks of another curve, are meaningless. This was due to lack of rigidity of the mounting board as explained before. Thus, no conclusions can be drawn as to whether one array is better or worse than another in its reflecting properties. All arrays gave the same general type of reflected field pattern with the major lobe appearing at 0°. This major lobe was in all cases very narrow. At 3 db. down from peak value the widest lobe was approximately 7°. This extremely narrow lobe seems to indicate that the majority of the energy is being reflected in a manner analogous to light being reflected from a mirror. The rest of the energy then being reradiated similar to a driven dipole, due to current flow in the conductors. The total field pattern then is a summation of these two types of reflection, direct reflection and reradiation.

It can be seen that a thorough knowledge of the reflecting properties of conducting elements would be very useful in the field of microwave relay. In instances where it is necessary to transmit a signal from a downtown location to a remote station, it would be very costly if a coaxial relay system were used. The objective of this study, of course, is only one of the many problems present when working with reflecting elements. The arrangement of the elements in this study is only one of a number that should be investigated. Future studies of this problem should try to determine the optimum number of elements needed for greatest reflection with any given configuration of elements. Also, it would be interesting to compare the reflecting properties of conducting elements with dielectric materials or flat conducting sheets.

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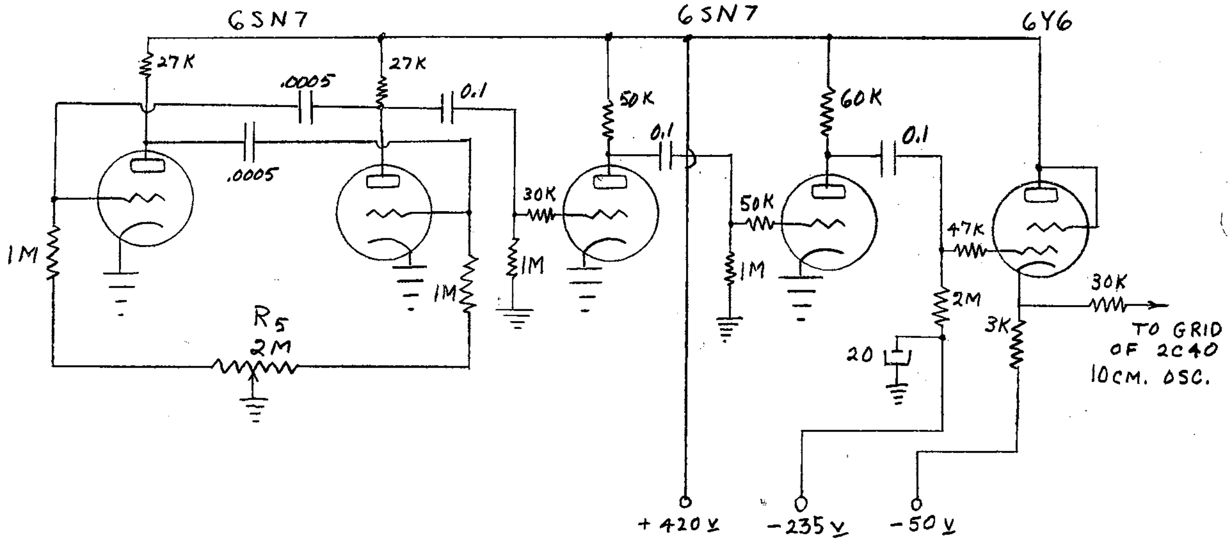
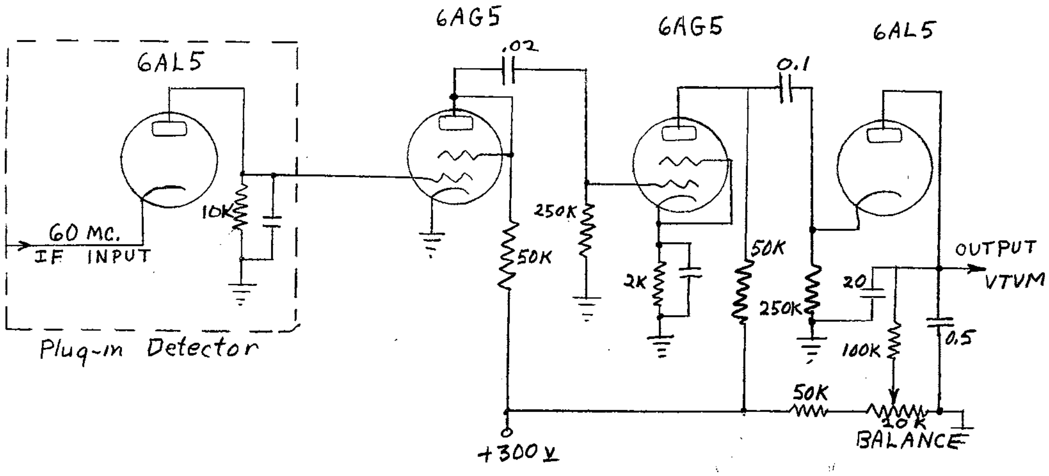
APPENDIX A



Pulse Modulator



Video and Indicator Circuit

APPENDIX B

Sample Calculation. The expression for the magnitude of the radiation field intensity to a half wave dipole is:[1]

$$E = \frac{60\ I}{r} \left[\frac{\cos(\pi/2 \cos \theta)}{\sin \theta} \right] \quad \text{volts/meter}$$

For simplicity let I = 1 amp and r = 3 meters.

Then for 30°:

$$E = \frac{60(I)}{3} \left[\frac{\cos(\pi/2 \cos 30^\circ)}{\sin 30^\circ} \right] \quad V/M$$

$$E = 20 \left[\frac{\cos 78^\circ}{\sin 30^\circ} \right] = 40\ (.28) = 11.2 \quad V/M$$

Making the calculation completely around the dipole will give the field intensity pattern as listed in the table below.

θ	E V/M
0	0
30	11.2
60	16.3
90	20
120	16.3
150	11.2
180	0
210	11.2
240	16.3
270	20
300	16.3
330	11.2
360	0

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[1] E. C. Jordan, Electromagnetic Waves and Radiating Systems. pp. 394.

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THESIS TITLE: A Study of the Reflection Characteristics of Small Conducting Elements

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