A LOG PERIODIC ANTENNA FOR FREQUENCIES TWO TO EIGHT KMC/S

by

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ABSTRACT

This thesis is a study of a log periodic antenna of the frequency range, two to eight KMc/s. The object of the thesis was to develop a satisfactory feed for the antenna from an impedance standpoint. Two types of feed were tried.

The first type was coaxial cable connected directly to the antenna. Since tests showed a large impedance mismatch between the cable and the antenna, it was concluded that coaxial cable alone is not a satisfactory feed. While testing the coaxial cable feeds, however, it was found that the input impedance of the antenna varied periodically with the log of the frequency.

The second type of feed was a balun transformer. Tests of the original antenna fed with the balun transformer displayed VSWR, as follows: From 8.0 down to 6.6 KMc/s, the VSWR remained below 2:1; between 6.6 and 4.1 KMc/s, the VSWR was less than 3.5:1; below 4.1 KMc/s, the impedance match deteriorated entirely. A modification of the antenna was developed which extended the useful frequency range from 4.1 down to 2.7 KMc/s. VSWR at frequencies above 4.1 KMc/s remained essentially unchanged.

ACKNOWLEDGMENT

The author expresses thanks to Professor Robert A. Hessemer, Jr. for his patient guidance which was most helpful in the preparation of this thesis.

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CHAPTER 1

INTRODUCTION

The log periodic concept of antenna design was discovered recently by R. H. DuHamel and his associates.[1] The concept has drawn considerable interest due to its potential to produce antennas with exceptionally large bandwidths. A bandwidth of 10:1 is readily achieved with log periodic antennas, while unlimited bandwidth is theoretically possible.[2] The log periodic design described by DuHamel combines his log periodic concept with another concept of antenna design developed by Rumsey.[3] This concept is that the characteristics of antennas described completely by angles are independent of frequency. If infinite antennas described entirely by angles were possible, they would be frequency-independent. However, in general, end effects limit the usefulness of this concept alone. An excellent example is the finite, biconical antenna, the bandwidth of which is limited by reflections from the ends of the cones. It is the addition of log periodic variations along a finite, angular antenna that eliminates the end effects within the pass-band. Hence, the addition of log

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[1] R.H. DuHamel and D.E. Isbell, "Broadband Logarithmically Periodic Antenna Structures," 1957 IRE Nat. Conv. Rec., part 1, pp. 119-128.

[2] R.H. DuHamel and F.R. Ore, "Logarithmically Periodic Antenna Designs," 1958 IRE Nat. Conv. Rec., part 1, pp. 139-151.

[3] V.H. Rumsey, "Frequency Independent Antennas," 1957 IRE Nat. Conv. Rec., part 1, pp. 114-118.

periodic variations to the angular design allows practical, broad-banded antennas to be developed.

This thesis involves a log periodic antenna of the trapazoidal tooth variety with a 150-ohm input impedance and a 4:1 bandwidth over frequencies from 2 to 8 KMc/s. The design of this antenna is the same as an antenna developed for the frequency range, 0.6 to 6 KMc/s by DuHamel and Ore.[4] However, the antenna studied here is scaled to higher frequencies than DuHamel and Ore's or any other log periodic antenna reported in the past. The higher the frequency, the smaller the antenna, and with decreasing size, the antenna becomes increasingly difficult to feed.

Both the radiation pattern and the input impedance are essentially constant over the antenna's frequency range. The feed to the antenna must provide a constant impedance match to the input impedance over the antenna's entire frequency range. Two methods of feeding log periodic antennas have already been developed.

One method of feeding is by a directly connected, coaxial cable.[5] This type of feed has been used successfully on antennas for frequencies in or below the UHF range. In general, the input impedance match has not been of major concern, and impedance mismatches of 2:1 or 3:1 have been considered acceptable for test purposes.

The second method of feeding is the use of a balun transformer.

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[4] R.H. DuHamel and F.R. Ore, "Log Periodic Feeds for Lens and Reflectors," 1959 IRE Nat. Conv. Rec., part 1, pp. 128-137.

[5] F.R. Bean, "An Investigation of a Log-Periodic Antenna Structure," Master's Degree thesis, Univ. of Arizona, 1960, p. 13.

An antenna for frequencies above UHF is a relatively small device since it is scaled to a fraction of the wavelength involved. Feeding this higher-frequency antenna generally requires a more sophisticated method than a directly connected, coaxial cable. Standard, coaxial cable is comparable in size to the antenna dimensions. When the cable is led over the antenna plates, it can join in mutual effects with the antenna, disterting the radiation pattern and input impedance over the whole of parts of the frequency range. A balun transformer was used successfully by DuHamel and Ore in feeding a log periodic antenna at frequencies up to 6 KMc/s.[6] In addition to advantages discussed later, one clear advantage of the balun transformer is that it provides an impedance match between the antenna and the source or feed line.

This thesis is directed toward developing a satisfactory feed to the 2-to-8-KMc/s, log periodic antenna from an impedance standpoint. The methods tested for feeding the antenna are the following: directly by a coaxial cable and by a 50- to 150-ohm Tchebycheff tapered balun transformer. The transformer projects a two-conductor transmission line to the antenna. Each method is evaluated for its relative merits and is compared to published results of tests upon a lower-frequency, log periodic antenna.

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[6] R.H. DuHamel and F.R. Ore, "Log Periodic Feed for Lens and Reflectors," loc. cit., p. 136.

CHAPTER 2

DEFINITION, DESIGN AND CONSTRUCTION OF THE LOG PERIODIC ANTENNA

2.1 Definition

A log periodic antenna is an antenna whose electrical properties repeat with the logarithm of the frequency. The ratio of two adjacent frequencies, f_1 and f_2, at which the antenna exhibits the same electrical properties, is τ, a design factor of the antenna plates (Fig. 2.1).

$$\tau = \frac{f_1}{f_2} \qquad (f_1 < f_2) \qquad (2.1)$$

A concise definition of a log periodic antenna is available through transformation in the real plane, W, with coordinates, r and ϕ, to a logarithmic plane, Z, with coordinates, x and y.[7] Where Z and W are both complex,

$$Z = \ln W \ . \qquad (2.2)$$

Then, where

$$W = r\, e^{j\phi}, \qquad (2.3)$$

and

$$Z = x + jy, \qquad (2.4)$$

it is true that

$$x = \ln r \qquad (2.5)$$

and

$$jy = j\phi \ . \qquad (2.6)$$

The "bow tie" antenna transforms into horizontal strips in the Z-plane (Fig. 2.2a). To reduce end effects of such an antenna, periodic variations are formed in the Z-plane strips. These variations

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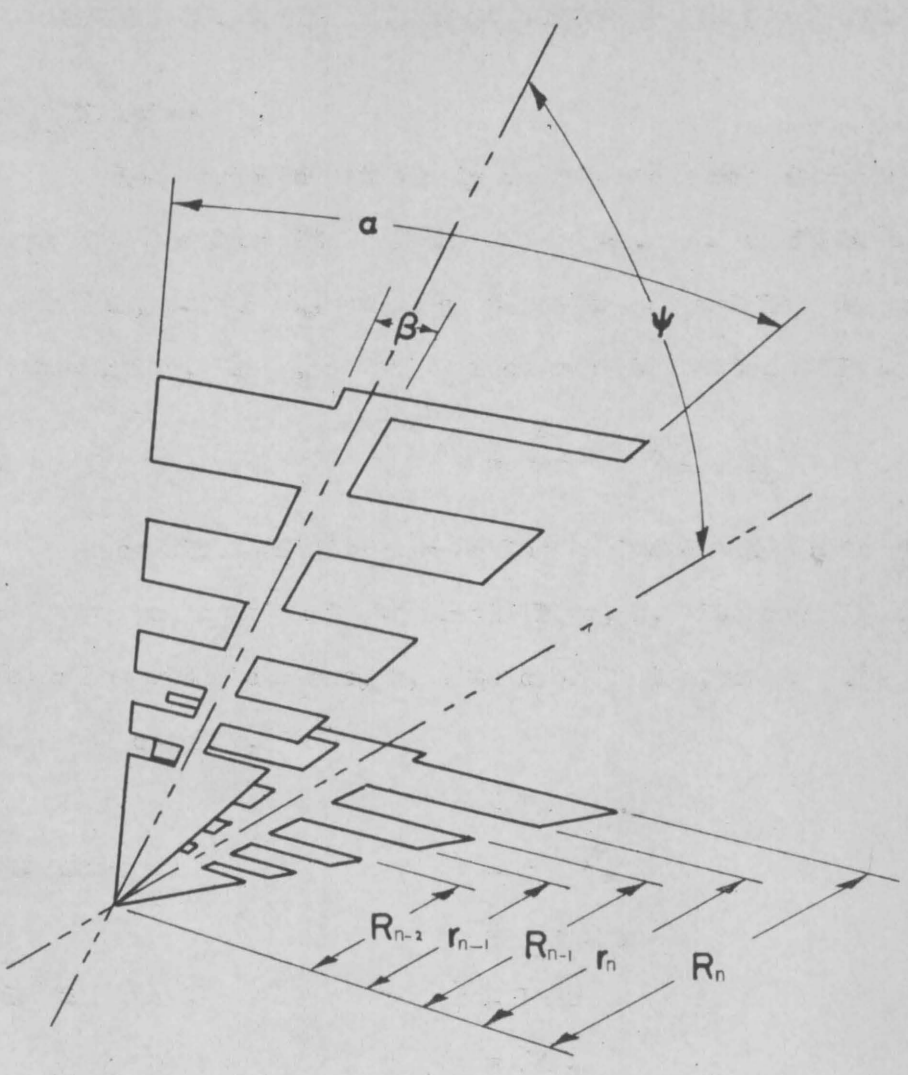
[7] R.H. DuHamel and D.E. Isbel, loc. cit.



$$\frac{R_{n-1}}{R_n} = \tau$$

$$\frac{r_n}{R_n} = \sqrt{\tau}$$

Fig. 2.1 — DESIGN PARAMETERS

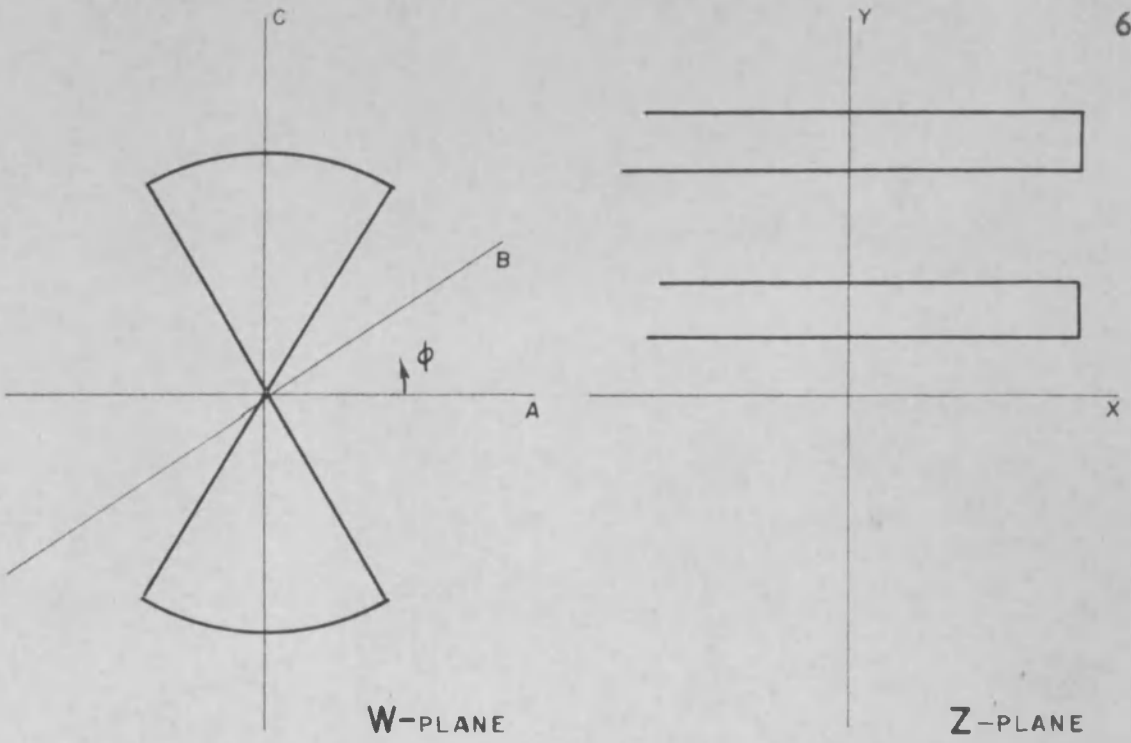


Fig. 2.2a—"BOW TIE" ANTENNA

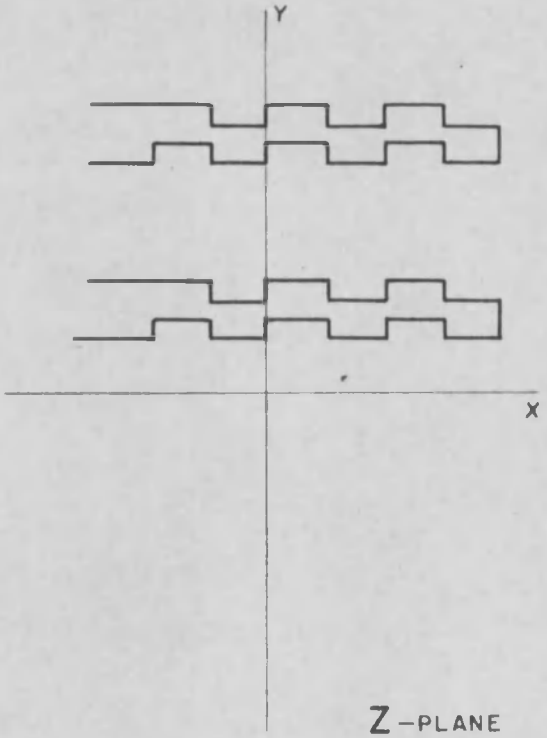


Fig. 2.2b—LOG PERIODIC "BOW TIE" ANTENNA

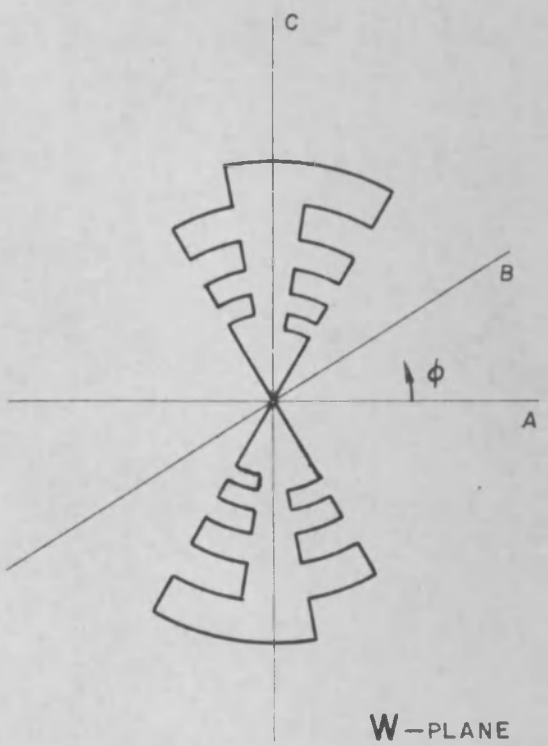


Fig. 2.2c—LOG PERIODIC "BOW TIE" ANTENNA

are transformed back into the W-plane to produce log periodic teeth (or log periodic variations) on the "bow tie" antenna.[8,9] Many types of log periodic antennas are conceivable. However, for the antenna studied in this thesis, the periodic variations are square indentations alternating between the top and bottom of the strips in the Z-plane (Fig. 2.2b). Both the spacing and the width of the indentations are equal to the constant,

$$x = \frac{\ln \tau}{2} . \qquad (2.7)$$

The depth of each indentation is

$$y = \frac{\alpha - \beta}{2} . \qquad (2.8)$$

The "bow tie" log periodic antenna which is transformed from the Z-plane in Figure 2.2b, is shown in Figure 2.2c. It has teeth of constant radii. These teeth, however, can be approximated satisfactorily by trapazoidal teeth.[10]

The uniplane, trapazoidal antenna radiates a bidirectional pattern. By folding the antenna about its a-axis, its pattern is made

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[8] A pair of Z-plane strips inclined from the x-axis transform into an equiangular spiral. Normally, log periodic variations are not needed since end effects in the equiangular spiral are not appreciable.

[9] The teeth facilitate energy radiation thereby attenuating the standing wave of current at the antenna input caused by reflections from the end of the antenna. Thus, the teeth help eliminate end effects. Each tooth is resonant over its own part of the antenna's bandwidth. At its resonant frequency, the currents on any particular tooth are larger than the currents on neighboring teeth. As the frequency increases or decreases from resonance, the current decreases rapidly. See R.L. Bell and C.T. Elfring, "Near-Field Measurements on a Logarithmically Periodic Antenna," IRE Trans. on Ant. and Prop., Vol. AP-8, pp. 260-267; May, 1960.

[10] R.H. DuHamel and F.R. Ore, "Logarithmically Periodic Antenna Designs," loc. cit.

essentially unidirectional. Forward radiation is in the positive b direction.

2.2 Design

R. H. DuHamel and F. R. Ore investigated several trapazoidal tooth, log periodic antennas for the frequency range 0.6 to 6 KMc/s.[11] Below are the particular parameters which they found to give a suitable radiation pattern and an input impedance of 150 ohms. The same parameters were used in constructing the 2-to-8-KMc/s antenna studied in this thesis. These parameters are the following:

$$\tau = 0.707$$
$$\beta = 10^\circ$$
$$\alpha = 60^\circ \qquad (2.9)$$
$$\psi = 45^\circ$$

The size of a log periodic plate (two plates form an antenna) depends entirely upon the design parameters and the frequencies involved. The lower cutoff occurs when the longest tooth is approximately a quarter wavelength long. The upper cutoff occurs when the shortest tooth is slightly longer than a quarter wavelength. A diagram of the plates with all dimensions is shown in Figure 2.3.

2.3 Construction

The log periodic plate design of Figure 2.3 was scribed onto the "blued" surface of 1/32 inch, sheet copper. Special care was used in preserving dimensions and smooth edges when the plate was cut from the copper. Assembly of the plates with a feed is described later,

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[11] Ibid.

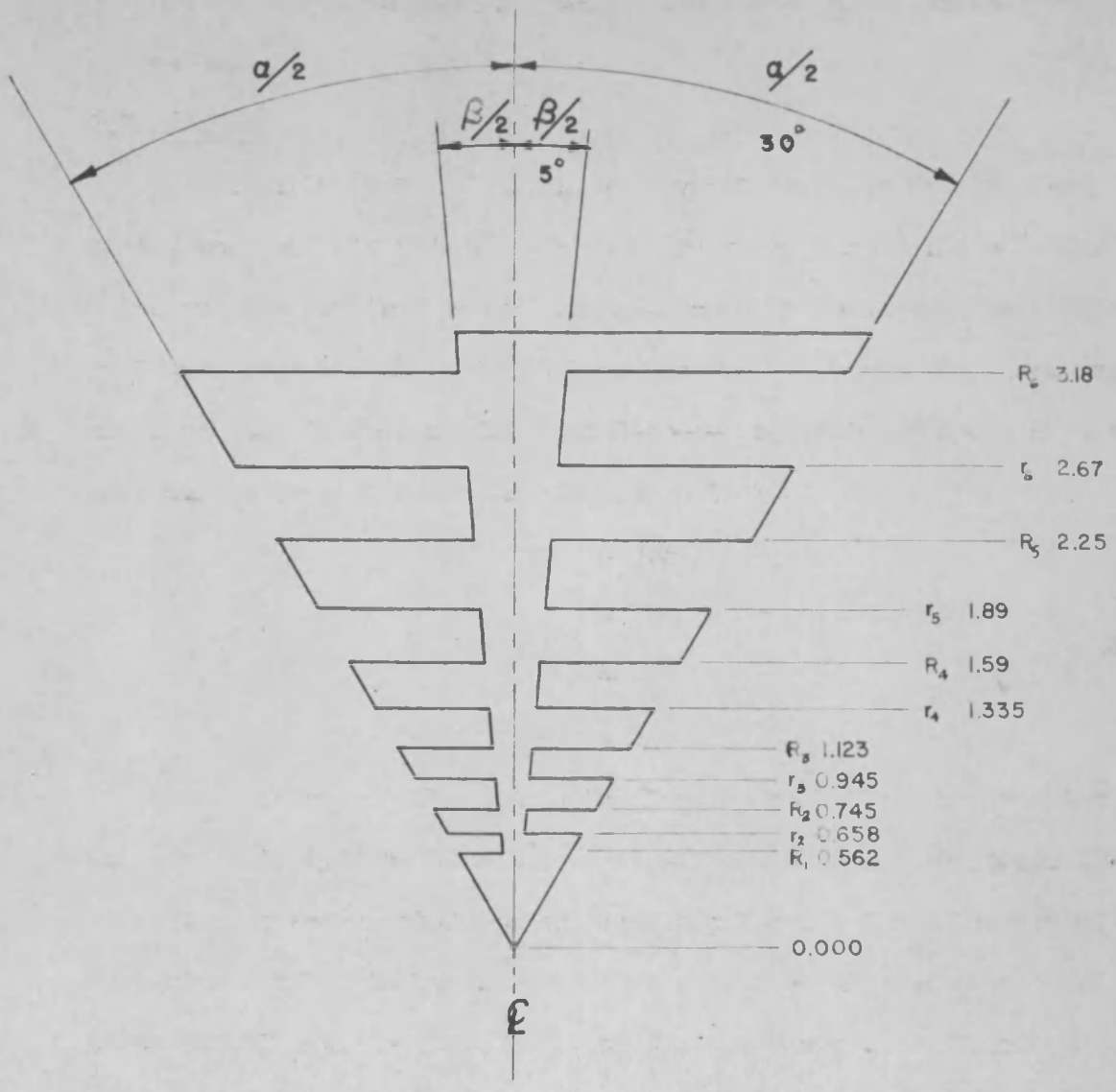

Fig. 2.3 — ANTENNA PLATE DIAGRAM

although a photograph of the plates assembled with the balun transformer (mentioned in Chapter 1 and described in Chapter 3) is shown in Figure 2.4.

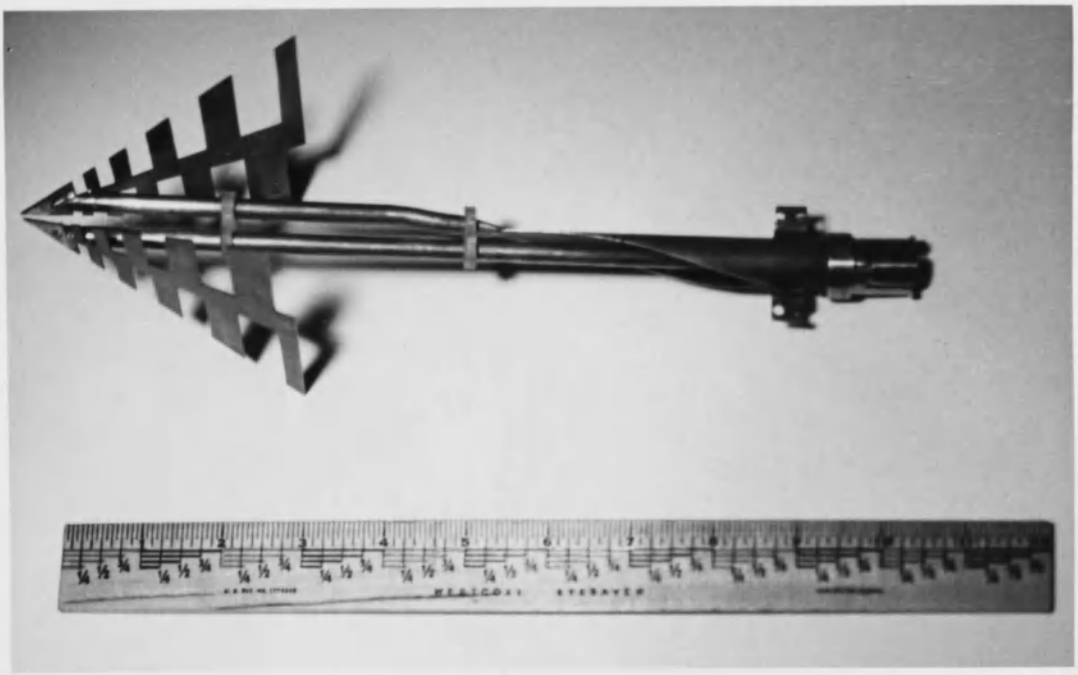

Fig. 2.4—TRANSFORMER–ANTENNA ASSEMBLY

CHAPTER 3

TCHEBYCHEFF TAPERED BALUN TRANSFORMER

3.1 Advantages of the Transformer

The Tchebycheff tapered balun transformer ideally satisfies the feed requirements of the log periodic antenna. Conventional power sources and laboratory equipment require 50-ohm, coaxial connections. Since the antenna input is 150 ohms, a transformer is necessary. Besides the impedance transformation, the balun transformer projects a balanced, two-conductor line between the log periodic plates of the antenna. This avoids bringing a coaxial cable over the plates distorting the impedance and radiation pattern at the higher end of the frequency band. Also the balun transformer affords a rigid, symmetric and convenient mounting for the antenna plates.

3.2 Design

The Tchebycheff impedance transformation can be designed to cause arbitrarily small reflections or VSWR. The theory of such a transformation incorporated in a balun transformer is presented by Duncan and Minerva.[12,13] A balun transformer is a transition from rigid, coaxial cable to a two-conductor line of higher impedance. The transition between the two types of transmission lines is made by

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[12] J.W. Duncan and V.P. Minerva, "100:1 Bandwidth Balun Transformer," Proc. of the IRE, Vol. 48, pp. 156-164; Feb., 1960.

[13] The balun transformer was originally conceived by R. H. DuHamel.

cutting away the outer conductor of the coaxial cable such that the impedance matches a Tchebycheff curve at every point along the transition. The Tchebycheff curve for an impedance differential of 50-150 ohms and a maximum reflection coefficient of 0.055 is presented in Figure 3.1. The impedance of the line with an outer opening angle, 2ϕ (Fig. 3.2), is presented in Figure 3.3.[14] The opening angle as a function of distance along the axis is computed from Figures 3.1 and 3.3 and is presented in Figure 3.4.

Standard copper tubing was chosen for the coaxial line. The inner conductor is 0.250 inch OD; the outer conductor is 0.625 inch OD with 0.031 inch walls giving an ID of 0.563. The impedance of a coaxial line is

$$Z = 60 \ln \frac{a}{b} \qquad (3.1)$$

where a is the outer conductor diameter, and b is the inner conductor diameter. The above choice gives an impedance of 48 ohms for the coaxial line. The two-conductor line consists of 0.250 inch copper tubing. The impedance of a parallel wire line in air is

$$Z = 120 \ln \frac{2D}{d} \qquad (3.2)$$

where D is the separation, center to center, and d is the wire diameter.

$$Z = 150\,\Omega = 120 \ln \frac{2D}{0.250} \qquad (3.3)$$

$$D = 0.125\, e^{1.25} = 0.458'' \qquad (3.4)$$

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[14] J.W. Duncan and V.P. Minerva, loc. cit., p. 161.

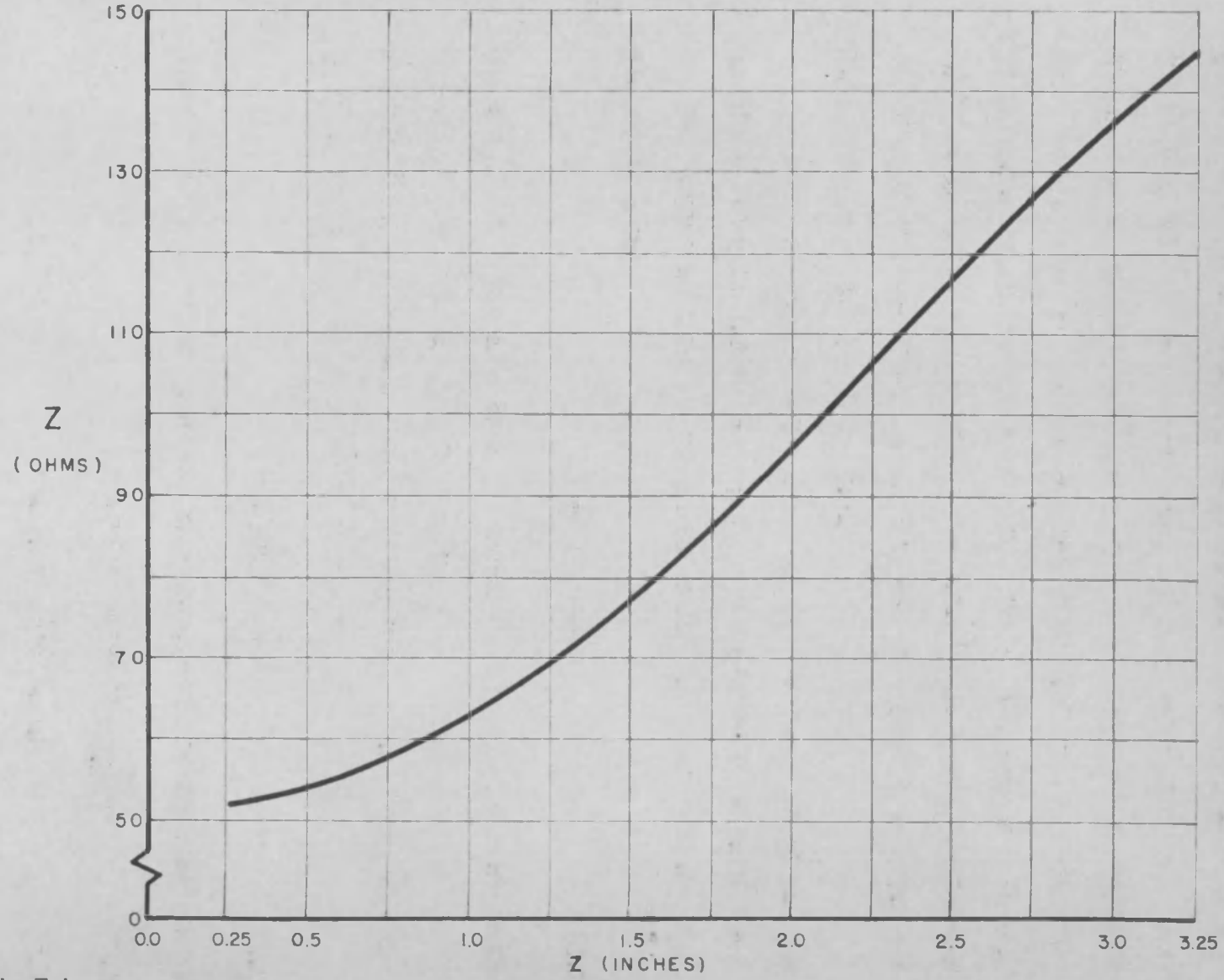

Fig.3.1 —— 50- TO 150-OHM TCHEBYCHEFF IMPEDANCE TAPER (IMPEDANCE VS AXIAL DISTANCE OF BALUN TRANSFORMER)

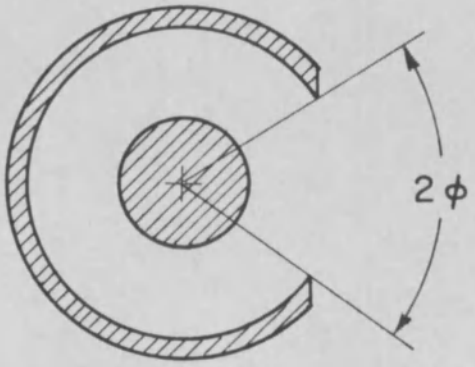

Fig. 3.2 — BALUN CROSS SECTION

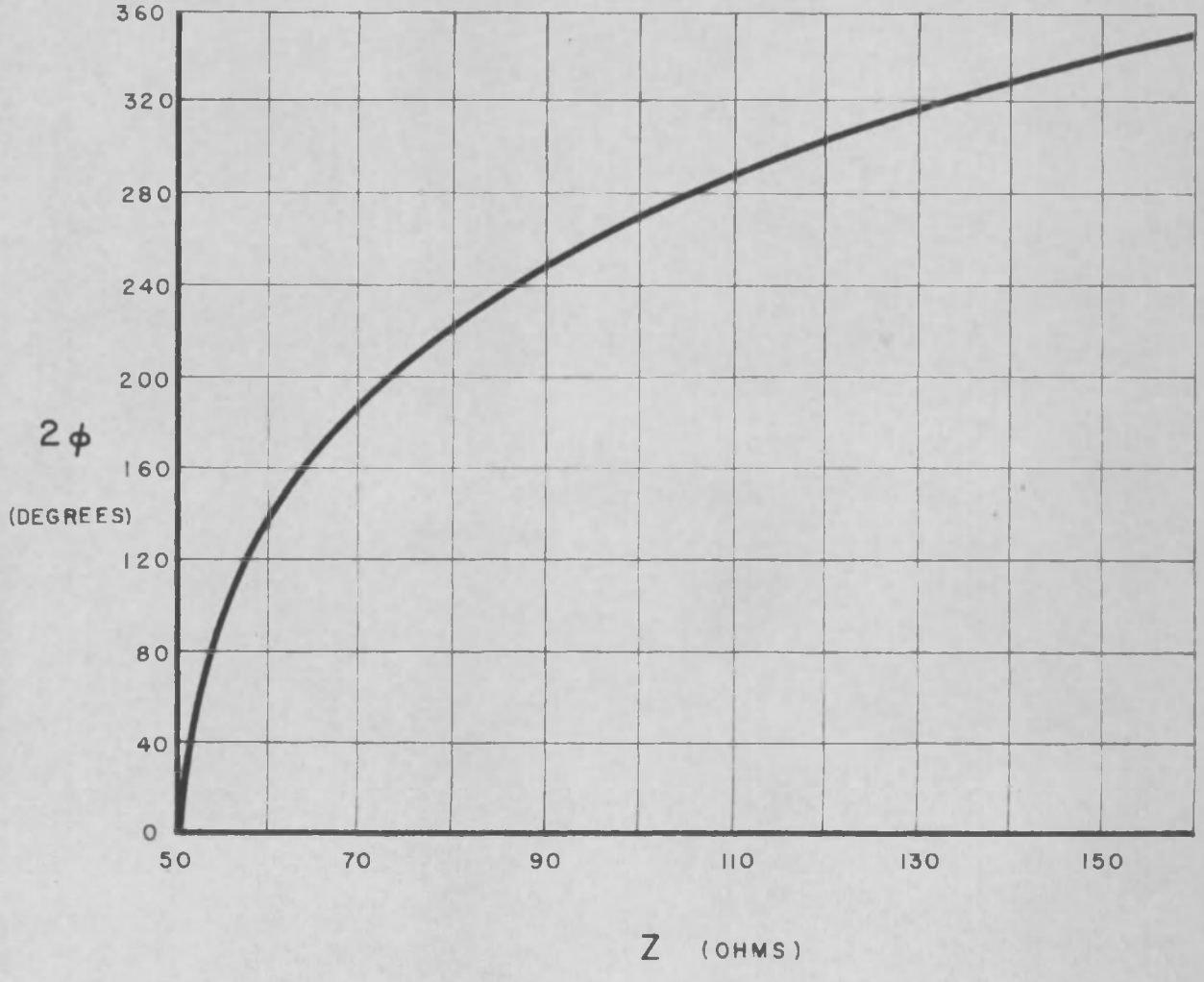

Fig. 3.3 — OPENING ANGLE (2φ) VS IMPEDANCE OF BALUN TRANSFORMER

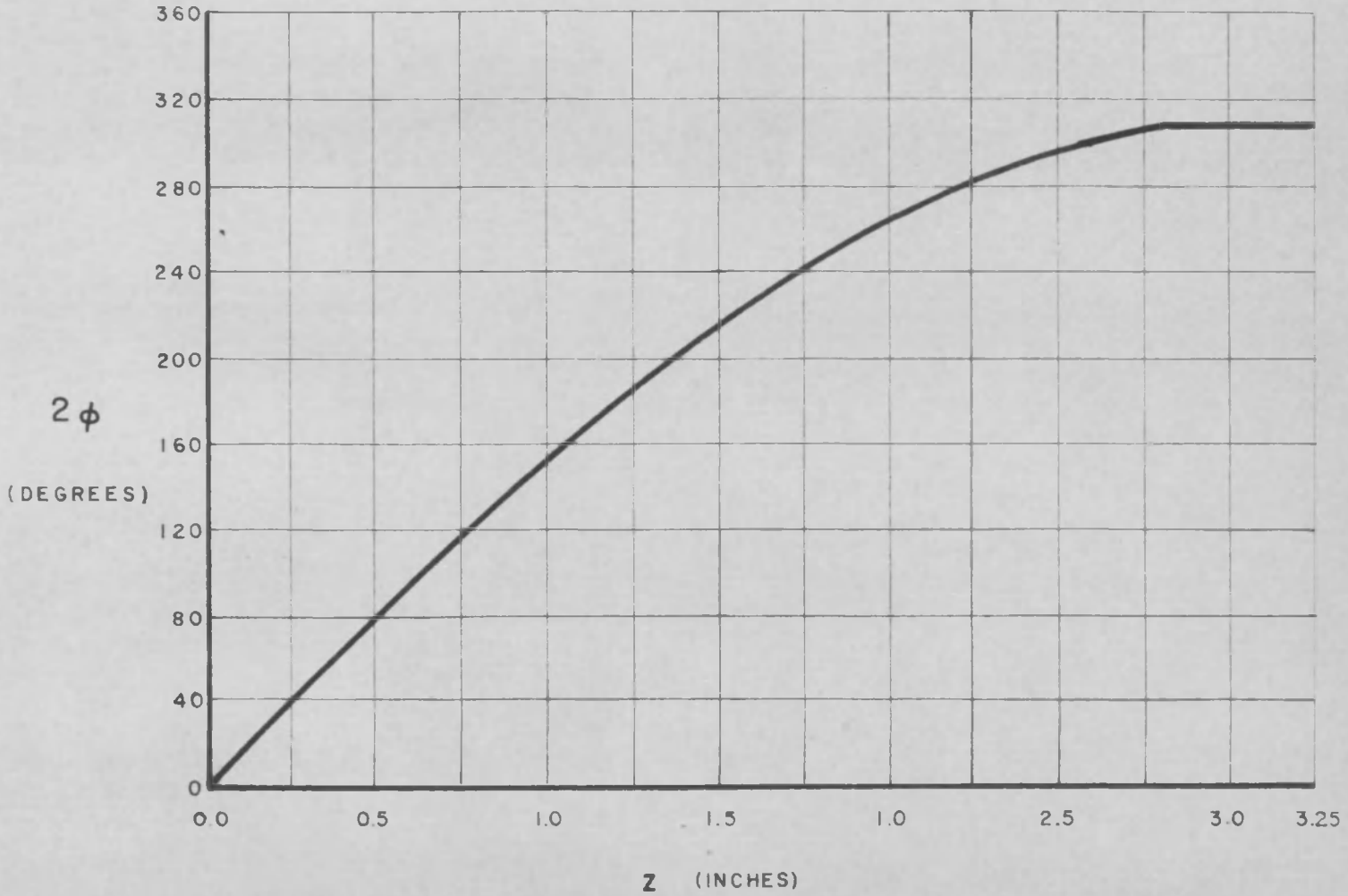

Fig. 3.4—OPENING ANGLE (2φ) VS AXIAL DISTANCE OF BALUN TRANSFORMER

The separation of a 150-ohm, two-conductor line (cylindrical conductors) is 0.458 inch center to center.

Cutoff occurs when the length of the transition is equal to 0.478 wavelength. The lowest frequency at which the transformer must operate is 2000 Mc/s. Since the corresponding wavelength is 6 inches, the transformation must be extended over a distance greater than 2.78 inches. A length of 3.25 inches yields a reasonably small device, yet it does not narrow the operating band of the log periodic antenna (Fig. 3.5).

At the point where $2\emptyset = 312^{\circ}$, the outer conductor is a concave strip of width equal to the diameter of the center conductor. The impedance at this point is 131 ohms; axial position, z, is 2.82 inches. Here the transition from the concave strip to a cylindrical conductor identical to the center conductor begins. This transition takes place between the axial positions z = 2.82 inches and 3.25 inches of the transformer. Physically this is difficult to do in such a short length. The Tchebycheff impedance curve must be followed, and, at the end of the transformer, the two-conductor line must have the correct spacing such that its characteristic impedance is 150 ohms.

3.3 Construction

Copper tubing about 6 inches long was used for the outer conductor, while the inner conductor was about 12 inches long. The coaxial line was assembled using a type GR 874-B connector. The GR connector is advertised as having a VSWR of less than 1.03 for frequencies below 5 KMc/s. However, tests described in the next section show that the connector is acceptable for use with the balun transformer up to 8 KMc/s.

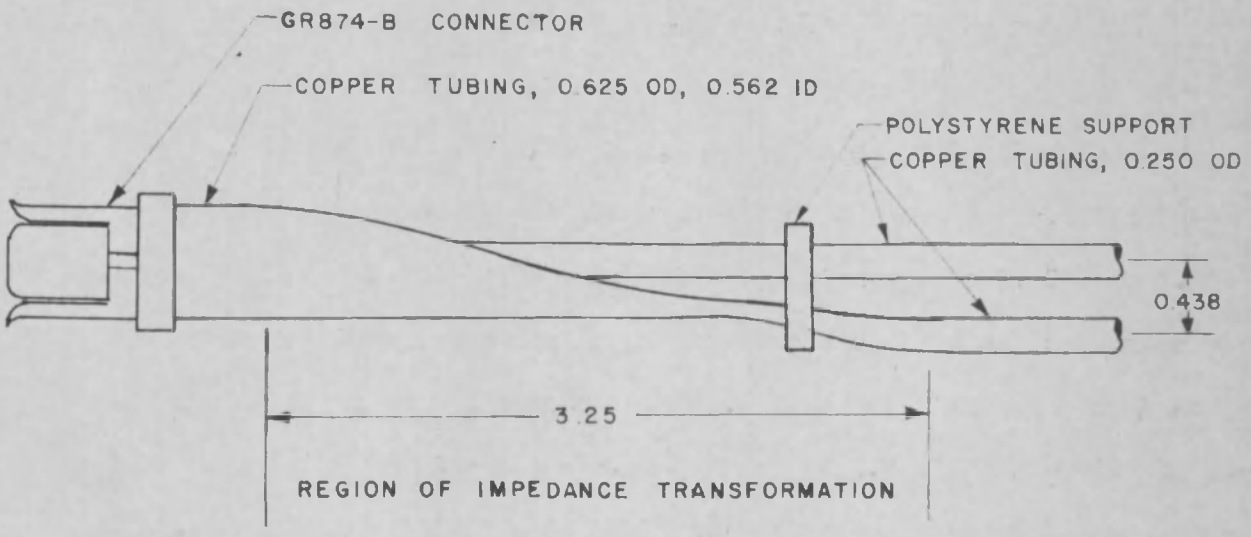

Fig. 3.5—BALUN TRANSFORMER

In cutting the balun taper, a dowel was used. The profile height of the taper was geometrically related to the opening angle of the outer conductor. A hardwood dowel was turned to fit into the outer conductor exactly. Then the dowel was cut such that its cross section matched the desired Tchebycheff shape at every point. The dowel was inserted into the outer conductor, and the conductor was filed to match the dowel. It is estimated that this process produced a taper of a tolerance of less than 0.015 inch.

Attaching the quarter-inch tubing to the end of the taper was the next step. The taper was extended slightly beyond the point, $z = 2.82$ inches. This extension was notched into the quarter-inch tubing and soft-soldered. The tubing was bent out such that the distance between it and the center conductor was 0.478 inch, center to center. The transition from strip to tubing and the bending of the tubing should both be confined to the same 0.43-inch length. The author found this difficult to do with the available tools and extended this distance by about 50%, thus departing from the Tchebycheff impedance curve.

Two polystyrene supports were used in the assembly. The supports were 1/8 inch thick with properly spaced, $\frac{1}{4}$-inch holes for the conductors. One was placed at the point, $z = 2.95$ inches; the other was placed 2 3/4 inches farther along the axis and on the two-conductor line (Fig. 3.5). These supports will necessarily cause small reflections.

3.4 Measurements of Transformer Assembly Reflections

The balun transformer is designed to have a maximum reflection coefficient of 0.055. However, there are reflections due to the

imperfections of the taper and the transition from the concave strip to the cylindrical tubing; there are reflections from the GR connector, the polystyrene supports and the mismatch of the laboratory, 50-ohm cable to the 48-ohm input of the transformer. Conceivably, all of the foregoing reflections could add at some frequencies to produce a large VSWR in the feed lines to the transformer. Any maximum tolerable VSWR is purely arbitrary, but the VSWR from the balun, alone, certainly should be less than 2 which represents a 33% reflection.

The method for testing the transformer is similar to Deschamps' method. Here, the loss coefficient was not measured; only the reflection coefficient was found. The two-conductor line was terminated in a large copper sheet perpendicular to the line. The sheet was moved along the line to allow maximum and minimum VSWR to be measured on a slotted line in series with the input line (Fig. 3.6). The two VSWR were measured at 300 Mc/s intervals over the operating range, 2 to 8 KMc/s. From the two VSWR, a reflection coefficient was calculated.[15] This reflection coefficient represents the net reflection of the transformer assembly minus only the second polystyrene support. This support was removed to give room to the sliding sheet of copper. Results in the form of VSWR (calculated from the reflection coefficient) are presented in Figure 3.7.

Limitations of the above method lie mainly in the measurement of the maximum VSWR on the slotted line. However, even errors as large as 20% in the maximum VSWR measurement can cause errors of only about

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[15] Appendix

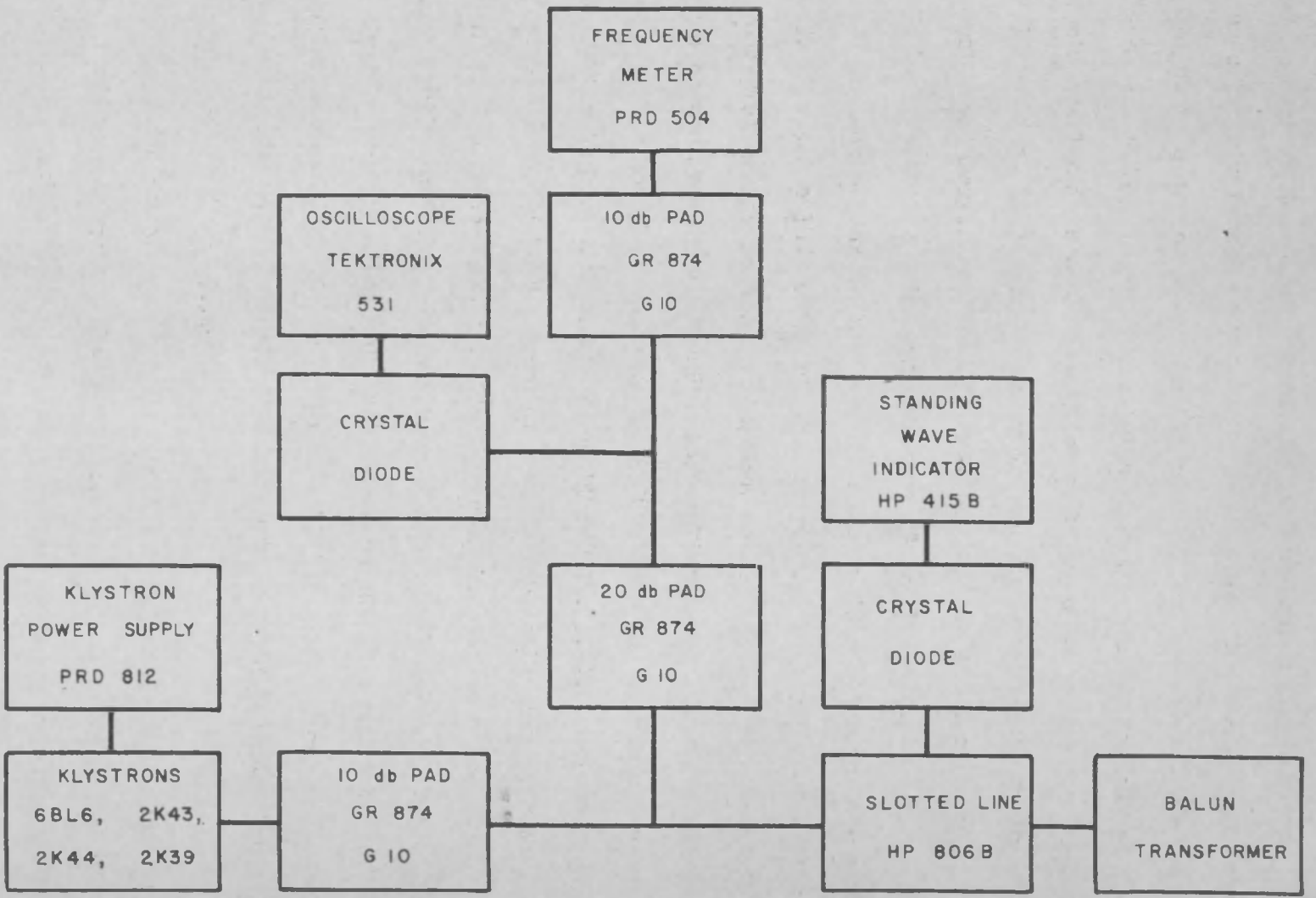

Fig. 3.6 — EXPERIMENTAL SETUP

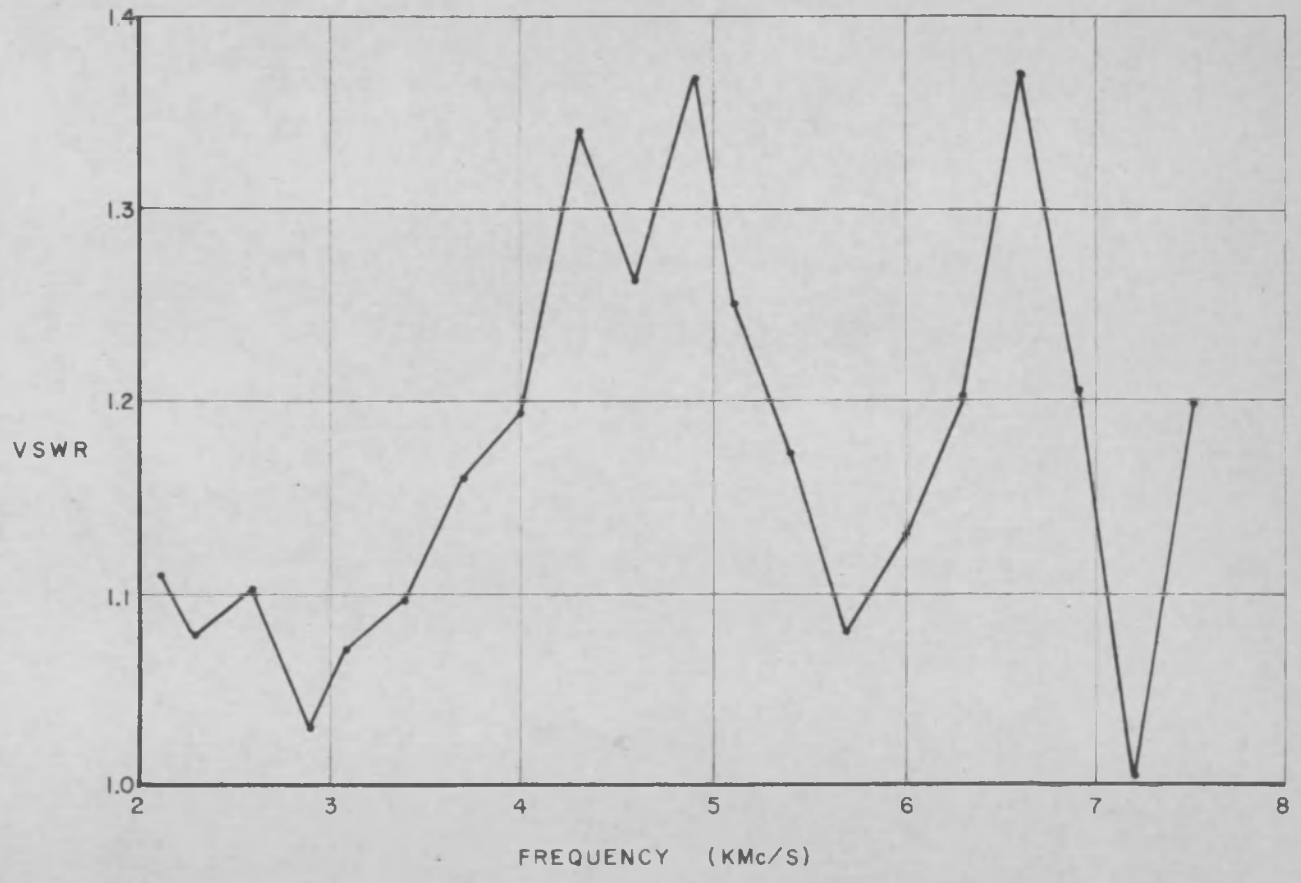

Fig. 3.7—EXPERIMENTAL PERFORMANCE OF BALUN TRANSFORMER

6% in the resulting reflection coefficient for the transformer. Errors in the minimum VSWR measurements are negligible. The other source of error lies in the damping effects of loss between the slotted line and the sliding plate. The maximum VSWR which were measured all indicate a total reflection greater than 94%. Thus, attenuation (due mainly to radiation loss) was less than 6% and need not be considered in this first order examination.

The transformer produces a maximum VSWR of 1.37 at two frequencies. The possible error in this value is expected to be less than 6%. Though a refined transformer would be desirable, the transformer as tested was used in feeding the log periodic antenna described in the next chapter.

CHAPTER 4

FEEDING THE LOG PERIODIC ANTENNA

Three basic types of feeds and their expected qualities are discussed in the following three sections. The first two types have been tested experimentally in this thesis. The tests and results are described in sections 4.4 and 4.5.

4.1 Coaxial Feeds

Antennas similar in design but for lower frequencies than the one tested here are generally fed with directly-connected cable. The antennas being large, the presence of a small coaxial cable has negligible effect. The flexible cable is led over one plate to the tip of the antenna. The outer conductor is attached to the first plate, and the inner conductor is led across the insulating gap to the second plate.

The antenna tested here is small enough such that a feed as described above would appreciably change the physical shape of the antenna. Distortion in both impedance and pattern would be expected.

Two coaxial feeds were tested experimentally in this thesis. As described in section 4.4, both depart from the above design in order to keep the cable as remote from the antenna plates as possible. Both were tried with two purposes in mind.

The first purpose was to establish a control feed with which the balun transformer feed (next section) could be compared. The second purpose was to discover any periodicity which could exist in

the quality of the impedance match. This expected periodicity is described below.

A log periodic antenna is an aggregate of a series of radiating elements whose frequency bands are consecutive. The overall bandwidth of the antenna may be increased with addition of more elements. The relative bandwidths of the elements are equal due to the design of the antenna.[16] Each element's bandwidth is inversely proportional to the design factor, τ, discussed in Chapter 2. A maximum standing wave of current exists upon the part of the antenna whose dimension is approximately equal to a half-wavelength (the resonant element), or where a tooth is approximately equal to a quarter-wavelength.[17]

It is expected that the input impedance will vary in a certain pattern over each element's bandwidth. This pattern should repeat periodically with the log of the frequency. DuHamel chose the parameter, τ, to be 0.707 on the basis of some maximum allowable impedance and radiation pattern variation. Thus, if log periodic variations are apparent, they should not be excessive in magnitude.

4.2 Balun Transformer Feed

The advantages of feeding with a two-conductor line projected from a balun transformer are discussed in Chapter 3. It is sufficient to repeat that the object in using the transformer is to attain a good

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[16] The relative bandwidth is the highest frequency divided by the lowest frequency in the band. For example, the bandwidth of the log periodic antenna for frequencies, 2 to 8 KMc/s, is 8/2 = 4 (a 4:1 bandwidth).

[17] R.L. Bell and C.T. Elfring, loc. cit.

impedance match over the whole frequency range, 2 to 8 KMc/s. The bandwidth of the transformer as described in Chapter 3 should not be a limiting factor. One difficult point expected is attaching the 150-ohm, two-conductor line to the antenna without distorting the antenna's input impedance.

4.3 Proximity Feed

Proximity transmission lines are used for feeding ladder antennas.[18] A strip line is placed near the ladder elements, although it is insulated from the elements. A similar arrangement might be suitable for feeding the log periodic antenna. Difficulty would be expected in obtaining a strip line with the diverging nature required to follow the antenna plates. Proximity feeds were not experimentally investigated in this thesis.

4.4 Description of Coaxial Arrangements and Test Results

Two arrangements using coaxial cable were tried. Neither proved entirely satisfactory. The first is shown in Figure 4.1a. RG 55/U cable was fed between the plates to the tip of the antenna. This arrangement exhibited much greater VSWR than the expected 3:1. Two reasons are cited: a satisfactory connection at the antenna tip could not be attained; also the available RG 55/U-to-type-N connectors were not satisfactory for operation at the required frequencies.

The second arrangement was more satisfactory (Fig. 4.1b). A larger, RG 8/U cable was fed from outside the antenna plates. The

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[18] A.F. Wickersham, Jr., "Recent Developments in Very Broad-Band End Fire Arrays," Proc. of the IRE, Vol. 48, pp. 794-795; April, 1960.

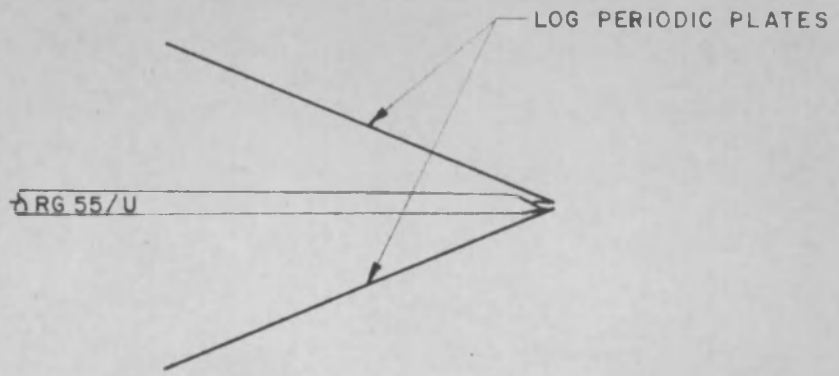

Fig. 4.1a — FIRST COAXIAL FEED

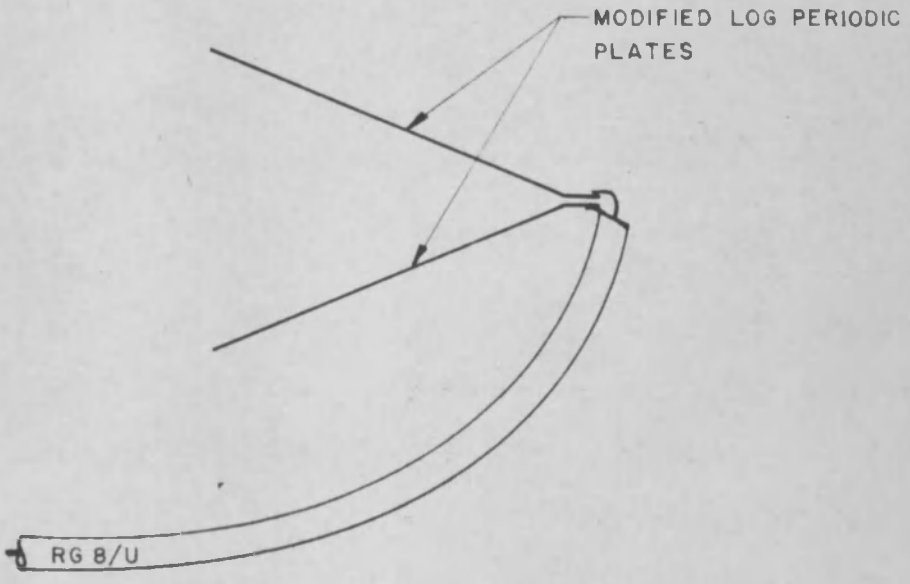

Fig. 4.1b — SECOND COAXIAL FEED

larger cable was used to escape the connector problem. The plates, in this case, were modified as described in the next section. The cable was brought in perpendicular to the tips. The outer conductor was soft-soldered to the tip of one plate, and the inner conductor was led across the gap and soft-soldered to the tip of the other plate. A polystyrene support at the rear of the antenna held the plates in their correct position. A UG-21B/U (type N) connector was attached to the free end of the cable.

The experimental setup used to test the second coaxial arrangement is shown in Figure 4.2. This setup is the same as used to test the balun transformer with the exception that the antenna replaces the transformer. The setup is standard for this type of measurements and needs no further explanation.

The test results are presented by the solid curve in Figure 4.3. (The dashed curve is the result of a test, described later, with the balun transformer.) Data for frequencies below 2.6 KMc/S and between 4.4 and 6.0 KMc/s were not taken. Reflex klystrons for generating these frequencies were not available to the author at the time the test was made. Note that in Figure 4.3, superimposed upon the graph is a distorted shape of one side of a log periodic plate. Each tooth of the antenna is aligned with the band of frequencies which has corresponding free-space wavelengths equal to 4 times the length of the tooth. Each tooth is tapered such that it covers a band of frequencies. Also note that the relative bandwidths of the teeth are equal.

Between frequencies, 2.7 and 4.4 KMc/s, there is a small but definite correspondence of the VSWR plot to that of the superimposed

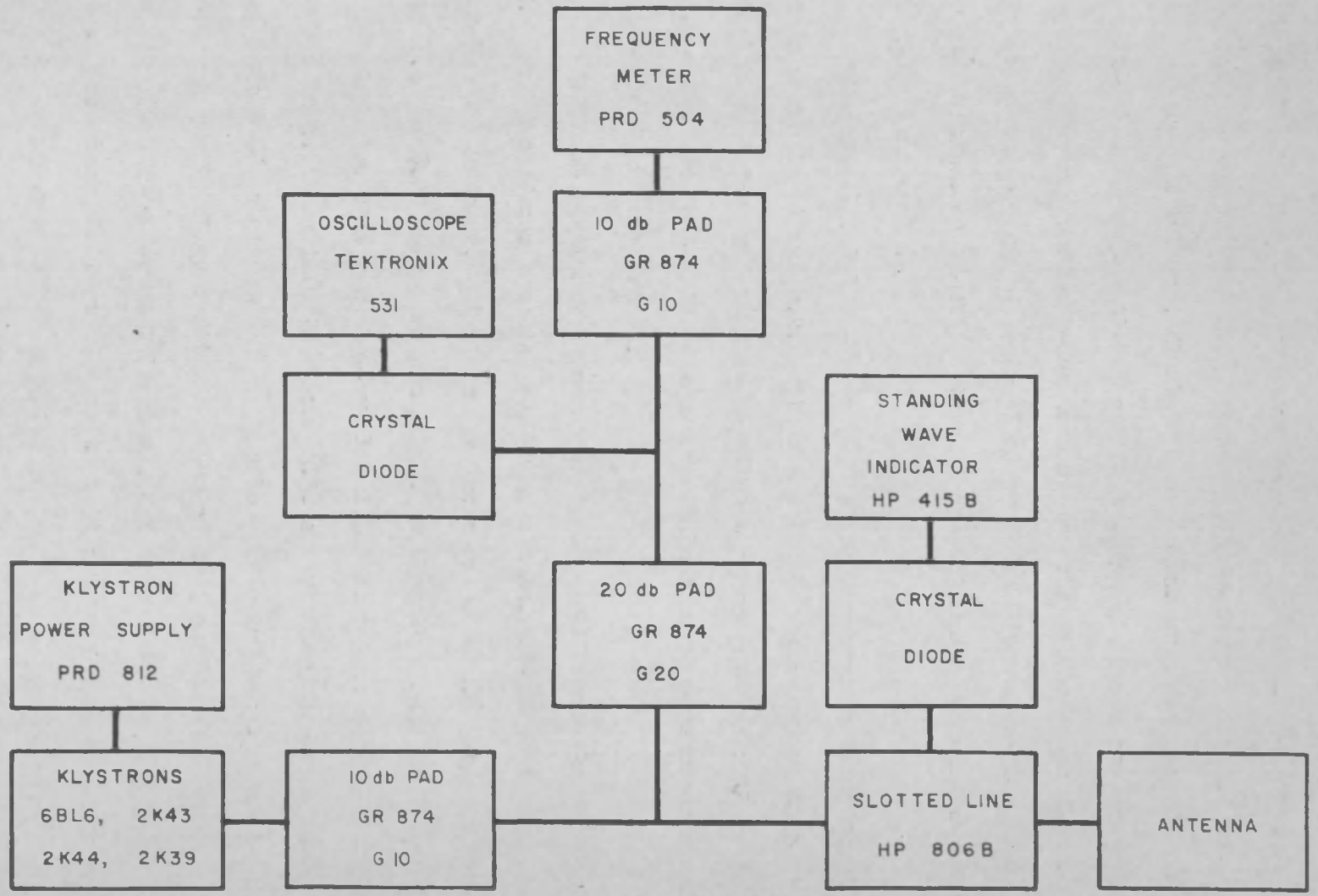

Fig. 4.2 — EXPERIMENTAL SETUP

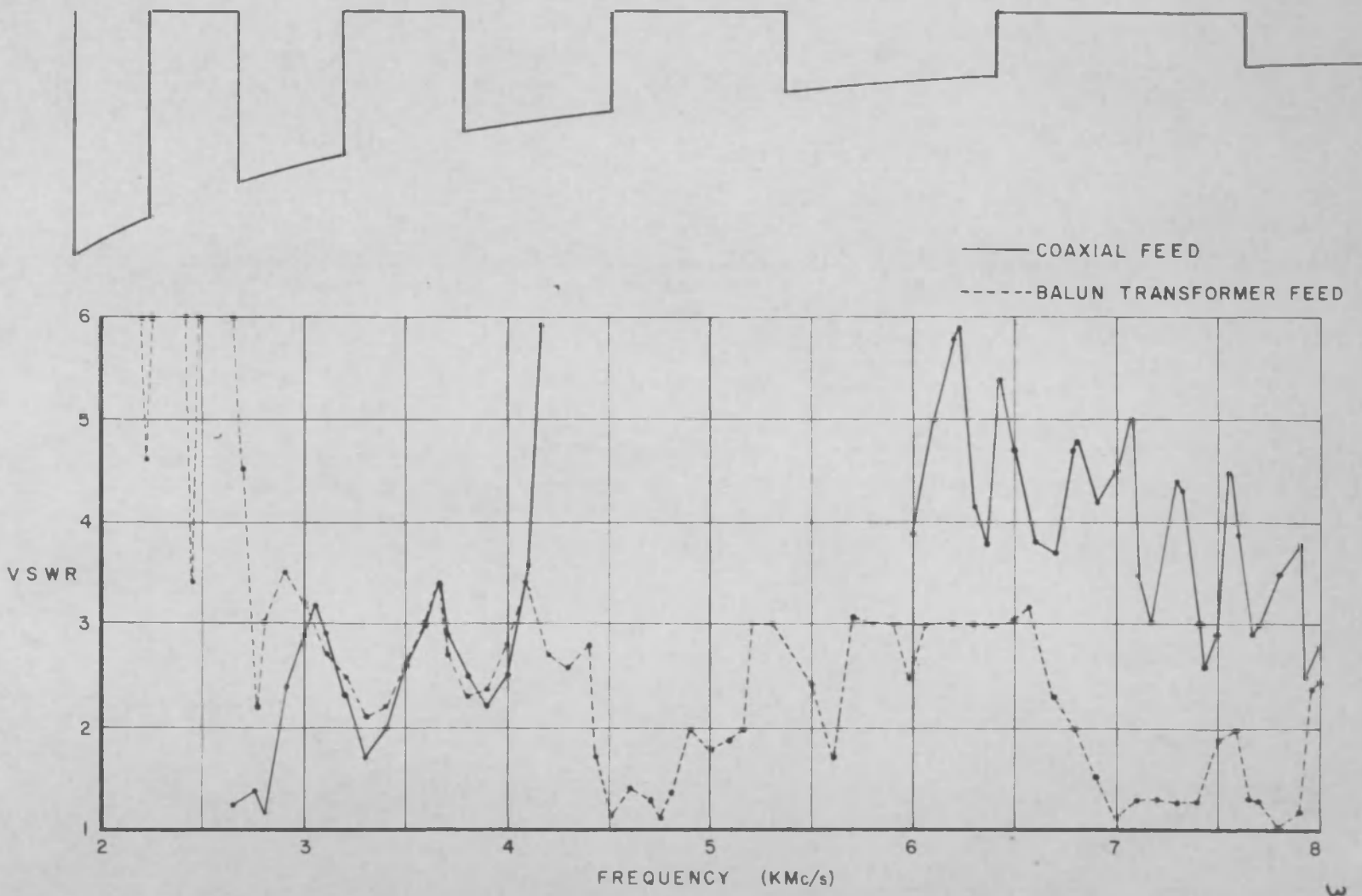

Fig. 4.3 — COAXIAL FEED PERFORMANCE

antenna plate. However, the periodicity disappears for frequencies above 6.0 KMc/s. The value of this coaxial feed for use as a control feed is questionable. In general, the tests of feeds using directly-fed, coaxial cable were at best, moderately successful and, thus, serve mainly in exemplifying the need for a more sophisticated type of feed.

4.5 Description of Balun Transformer Feed and Test Results

A two-conductor line projects from the 150-ohm end of the balun transformer of Chapter 3. The two conductors were cut 4 inches from the end of the region of transformation and beveled at $22\frac{1}{2}^{\circ}$ to the z axis. See Figure 4.4. The antenna plates as described in Chapter 2 were then soldered to the beveled ends of the two conductor line. A small gap was left at the tip. Since each plate was inclined to transmission line axis at a $22\frac{1}{2}^{\circ}$ angle, the angle, ψ, between the plates was the chosen 45° (Fig. 4.5a). The plates were supported entirely by the transmission line.

Again the experimental setup used was that of Figure 4.2. The VSWR caused by the transformer-antenna assembly were measured at 50 Mc/s intervals throughout the 2-to-8-KMc/s band. The results are shown by the solid curve in Figure 4.6. The impedance match of this antenna deteriorates completely near and below 4.1 KMc/s. It was discovered that by bending the plates toward the transmission line, the performance below 4.1 KMc/s was improved. Reducing the angle, ψ, increases the capacitance between the plates and reduces the impedance.

Since it was desired not to change the major design parameters in this investigation, an alternate way of reducing the impedance was

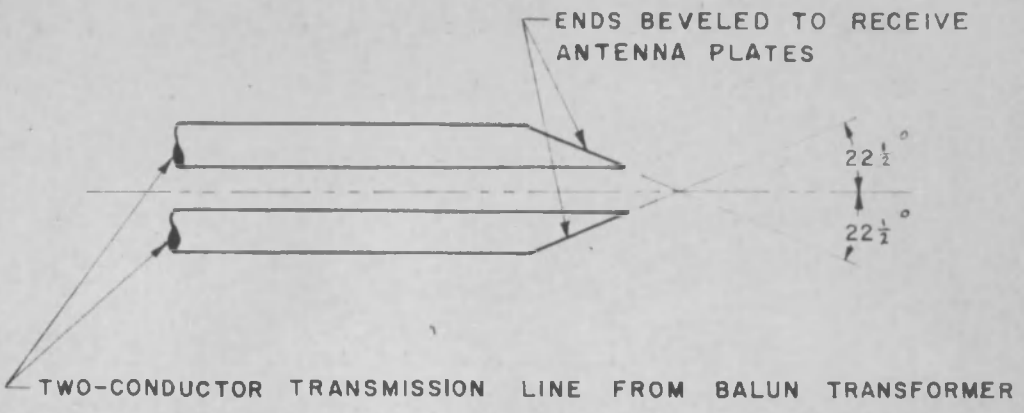

Fig. 4.4 — DETAIL OF TRANSFORMER—ANTENNA CONNECTION

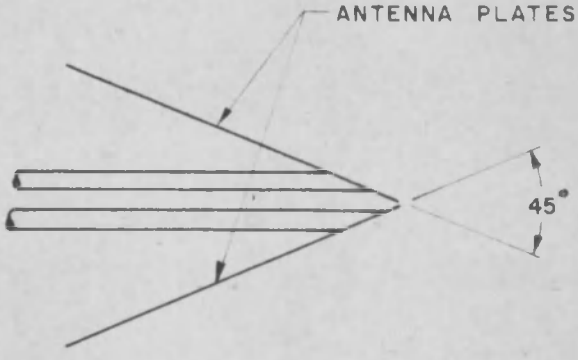

Fig. 4.5a — ORIGINAL ANTENNA ASSEMBLY

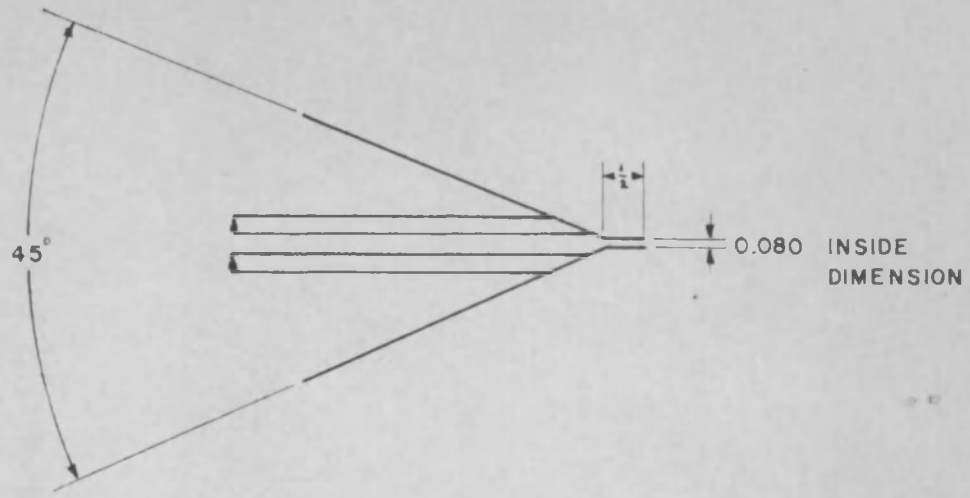

Fig.4.5b — FIRST MODIFICATION OF ANTENNA

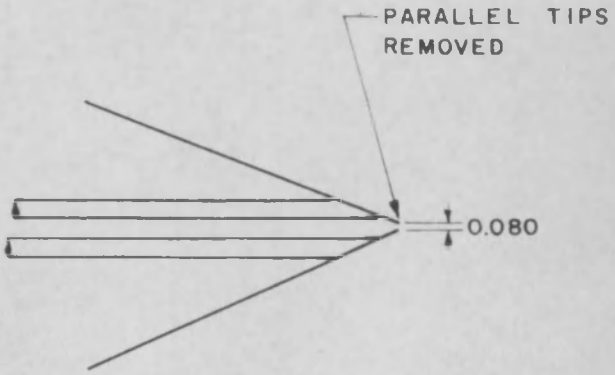

Fig.4.5c — SECOND MODIFICATION OF ANTENNA

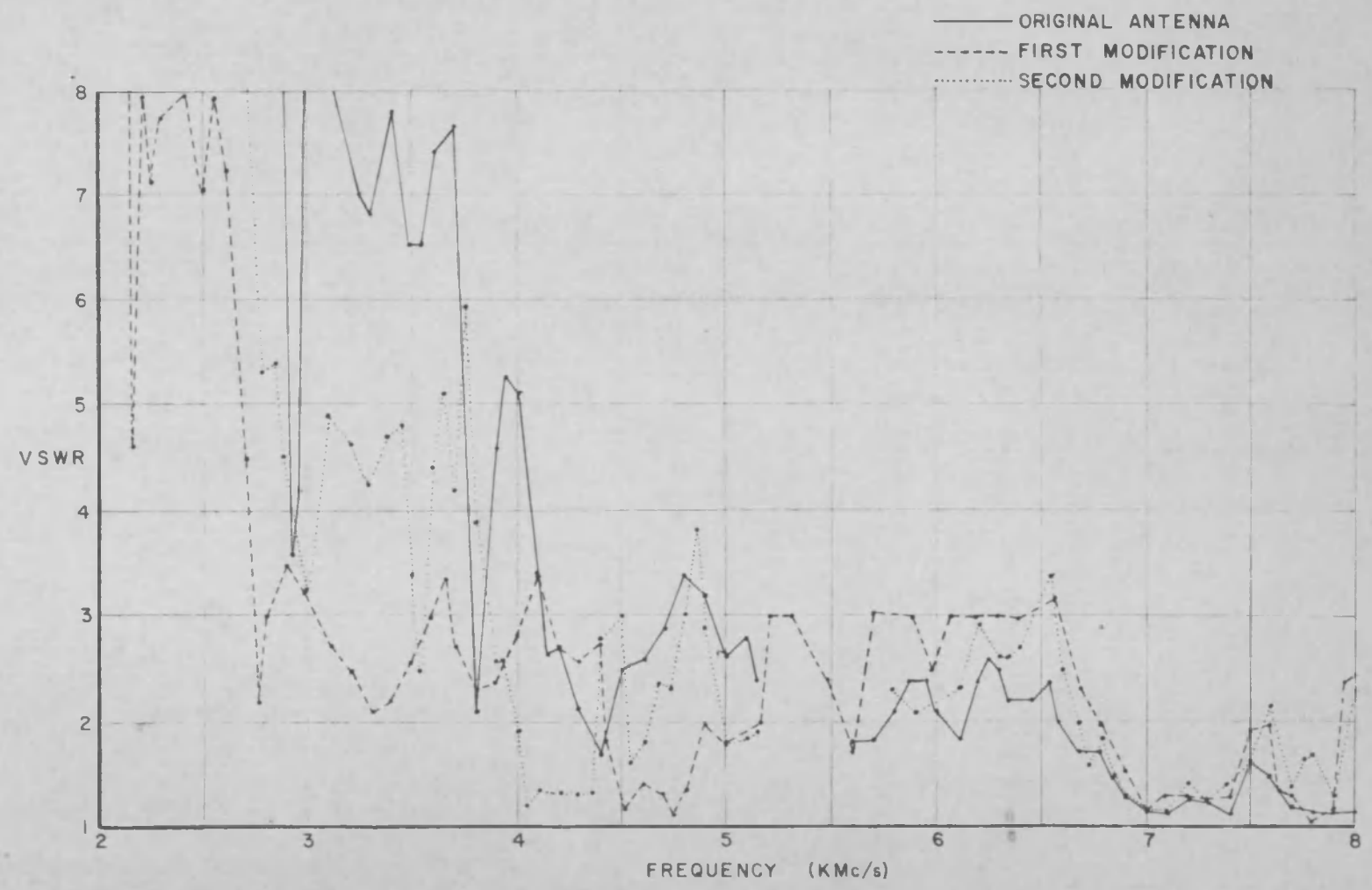

Fig. 4.6 — EXPERIMENTAL PERFORMANCE OF TRANSFORMER-ANTENNA ASSEMBLIES

devised. The last half inch of the tip was bent parallel to the axis of the transmission line. The plates were then resoldered such that the parallel tips were 0.080 inch apart. See Figure 4.5b. This effectively moves the plates together without changing ψ. Also, in effect, a parallel plate capacitor has been added in parallel with the antenna plates. Tests results of this arrangement are displayed by the dashed line in Figure 4.6.

Considerable improvement was obtained in the low frequency performance. The feed remained acceptable down to the frequency, 2.7 KMc/s. This is an addition of 1.4 KMc/s to the useful bandwidth of the antenna. The sacrifice required to obtain this improvement is very small. At the high frequencies (above 5.6 KMc/s) the VSWR are only slightly larger than those measured of the unmodified antenna of Figure 4.5a.

Test results of the modified antenna (Fig. 4.5b) are also presented in Figure 4.3 for comparison to the test results of the coaxial feed. The variations in each VSWR curve are similar for frequencies below 4.2 KMc/s. It again appears that the cause of the variations is the log periodicity of the antenna itself.

A second modification was tried. To determine the effect of the parallel tips, tests were made of the antenna of Figure 4.5c. Without moving the plates, the parallel tips were cut off. Test results in Figure 4.6 (dotted curve) show VSWR which, in general, lie between those of the original antenna and the first modification. Again no significant change was made at frequencies above 5.6 KMc/s.

CHAPTER 5

RESULTS AND CONCLUSIONS

The principal objective of this thesis was to develop a satisfactory feed for a log periodic antenna with particular design parameters presented in Chapter 2.

Coaxial feeds and a balun transformer feed were tried. With one coaxial feed, it was found that there is some log periodic variation of impedance of the antenna, though the variation is not excessive. Its exact magnitude was not determined. Since the impedance match using 50-ohm, coaxial cable was generally poor, it is concluded that the coaxial cable alone is not a suitable feed.

The other type of feed tried is the balun transformer. Using this feed, the antenna as originally described in Chapter 2, and one important modification were tested. Tests of the original antenna fed with the balun transformer displayed VSWR as follows: From the upper limit of the antenna band (8 KMc/s) down to 6.6 KMc/s, the VSWR remained below 2:1; between 6.6 and 4.1 KMc/s, the VSWR was less than 3.5:1; below 4.1 KMc/s, the impedance match deteriorated entirely.

With the improved antenna of Figure 4.5b (the parallel tip modification of Chapter 4), the impedance match was improved at low frequencies. At frequencies above 4.1 KMc/s, the match was not appreciably affected. However, the useful bandwidth of the antenna was extended down from 4.1 to 2.7 KMc/s. Although the modification represented considerable improvement, a satisfactory feed was not obtained

to cover the intended frequency band of the antenna (2 to 8 KMc/s). Published results are available for a similar antenna for frequencies up to 6 KMc/s.[19] The modified antenna compares favorably with these results for frequencies above 2.7 KMc/s.

The results obtained in this thesis were contrary to expectations. It was expected that trouble would be incurred at the higher end of the band and not at the lower end of the band. One possible explanation is that this antenna cuts off when its longest tooth is considerably longer than a quarter wavelength. This is contrary to information presented by DuHamel.[20] However, this explanation seems to be borne out by R. L. Bell and C. T. Elfring.[21] They indicated that appreciable currents exist on two teeth on either side of the resonant tooth. If the teeth on one side of the resonant tooth were missing, adverse effects would be expected (this is the case near 2 KMc/s). This explanation leads one to expect trouble at the upper end of the frequency band also. The impedance match there was good. This fact tends to discredit the above explanation. Hence, a completely satisfactory explanation of the mismatch at the lower frequencies is not immediately evident.

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[19] R.H. DuHamel and F.R. Ore, "Log Periodic Feeds for Lens and Reflectors," loc. cit.

[20] Ibid.

[21] R.L. Bell and C.T. Elfring, loc. cit.

CHAPTER 6

SUGGESTIONS FOR FURTHER STUDY

Further investigation of the antenna studied here is necessary for its complete evaluation. Pattern measurements should be carried out with the antenna as first presented in Chapter 2 and with the first innovation presented in Chapter 4. Other suggestions are that the bandwidth be extended upward in frequency and that the balun be refined. The size of the coaxial line leading into the transformer and the size of the two-conductor line attached to the antenna both could be reduced considerably. This change should reduce any disturbing effects which the presence of the feed has upon the antenna's pattern. Such a modification is absolutely necessary for feeding antennas of any higher frequencies than the one tested here. With this modification, it probably would be necessary to develop new methods of supporting the antenna plates and to construct a constant-impedance taper to be used between the new coaxial line and that of standard laboratory equipment.

A more challenging problem is to calculate the input impedance of a log periodic antenna from its design parameters. This problem might involve calculating the impedance from the antenna's transformed, three-dimensional shape in log coordinates. A suggested transformation is from the antenna in spherical coordinates, $W(r,\phi,\theta)$, to its transformed shape in rectangular coordinates, $Z(x,y,z)$, where

$$x = \ln r, \tag{6.1}$$

$$y = \phi \tag{6.2}$$

and $$z = \theta \text{ .} \qquad (6.3)$$

The xy plane is the same transformation of r and ϕ coordinates as found in Chapter 2. The addition of the third coordinate allows the antenna to be designed completely in the log coordinate system. Thus, the addition of the new dimension creates a new and more powerful design tool than the one discussed in Chapter 2.

A recently published article by C. C. Eaglesfield describes an intuitive approach to the design of a balun.[22] It might be interesting to compare Eaglesfield's balun (when coupled with an impedance transformation) and the balun transformer of Chapter 3 for their relative merits as feeds to the log periodic antenna.

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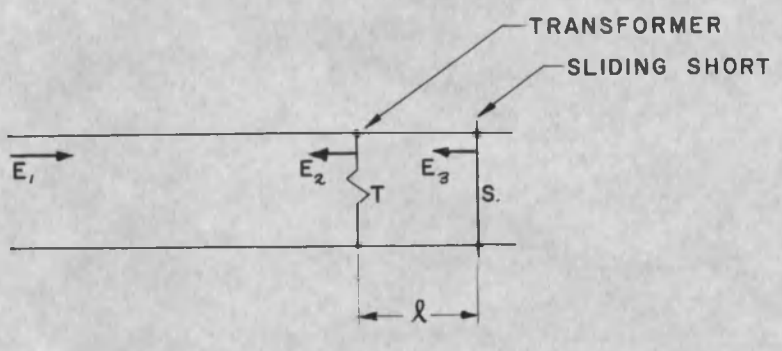
[22] C.C. Eaglesfield, "Note on a Balun: Solution by a Tapered Potential," Proc. of the IRE, Vol. 49, pp. 810-811; April, 1961.

APPENDIX

DETERMINING THE REFLECTION COEFFICIENT, ρ_2, OF THE BALUN TRANSFORMER USING A SLIDING SHORT



E_1 = incident wave.

$E_2 = \rho_2 E_1$ = wave reflected from transformer (T).

$E_3 = \rho_3 E_1$ = wave reflected from short (S).

ρ_2, ρ_3 = reflection coefficients of T, S.

λ = free-space wavelength.

At any frequency, when ℓ is $\frac{n}{2}\lambda$, n = 1,2,3,..... , the reflected waves add causing a maximum VSWR equal to S_{max}. When ℓ is $\frac{2n-1}{4}\lambda$, n = 1,2,3,..... , the reflected waves subtract causing a minimum VSWR equal to S_{min}.

$$S_{max} = \frac{E_1 + (E_3 + E_2)}{E_1 - (E_3 + E_2)} = \frac{1 + \rho_3 + \rho_2}{1 - \rho_3 - \rho_2} \qquad (A.1)$$

$$S_{min} = \frac{E_1 + (E_3 - E_2)}{E_1 - (E_3 - E_2)} = \frac{1 + \rho_3 - \rho_2}{1 - \rho_3 + \rho_2} \qquad (A.2)$$

$$(S_{max} + 1)\rho_2 + (S_{max} + 1)\rho_3 = S_{max} - 1 \qquad (A.3)$$

$$-(S_{min} + 1)\rho_2 + (S_{min} + 1)\rho_3 = S_{min} - 1 \qquad (A.4)$$

$$\rho_2 = \frac{S_{max} - S_{min}}{(S_{max} + 1)(S_{min} + 1)} \qquad (A.5)$$

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