CHAPTER II

DOUBLE DOUBLET ANTENNA'S CONSTRUCTION AND MEASUREMENTS

2-1 Introduction

The purpose of this experiment is to find the practical way of setting up the double doublet antenna with reflectors for use in domestic point-to-point communication circuit (about 500 Km). The frequencies which involved in the experiment are 7.607 Mc for day frequency and 3.370 Mc for night frequency. These frequencies are taken according to the present in use frequencies of circuit between Bangkok and Ubol which is about 500 Km apart.

2-2 The Required Characteristics for Point-to-Point Communication Antenna

In operating as a point-to-point communication antenna, the double doublet antenna should have the following properties.

1. The antenna should operate equally well for both day and night time.

2. The antenna should be an unidirectional one, with gain over dipole around 3 to 4 db at both frequencies, as shown in Sec. 6-3.

3. The front-to-back ratio should be more than 2 : 1[2].

4. The input impedance should be constant when operating at both frequencies.

5. The angle of departure of the main lobe should be in the

direction which gives the efficient propagation.

2-3 Theoretical Properties of Double Doublet Antenna

Before construction of the antenna, the theoretical properties of dipole antenna are determined as a guide.

2-3a Antenna's Height. The antenna's height from the ground effects the characteristics of itself such as the input impedance and the polar diagram.

From the driving-point resistance chart of a horizontal $\frac{1}{2}$-wave length antenna as a function of its height above ground in Fig. 6-5, if the dipole are 0.22λ, 0.48λ, 0.72λ, 1λ,..... high from ground, then its driving-point resistance will be the same as the resistance at infinite height; i.e., 73 ohms. So in choosing the antenna's height, the above heights should be considered.

Now examine the vertical polar diagram for horizontal dipoles above ground in Fig. 6-6. It is clearly seen that among the different heights from $h = 0.1\lambda$ to 2.5λ, the heights from $h = 0.6\lambda$ up to 2.5λ are undesirable because the patterns diverge into many lobes. The acceptable patterns are at the heights $h = 0.1\lambda$ to 0.5λ.

Since the required angle of departure, as shown in Sec. 8-4, obtained from Fig. 8-2, for day frequency is 21 degrees and for night frequency is 48.5 degrees. So the dipole with 0.5λ high from ground seems to take the best advantage of all heights, because it possesses 2 equal lobes with maximum radiation at the angle of 30 degrees. At this 0.5λ high, it is equally well suited for both day and night frequency propagations because at both angle of departures at 21 and 48.5 degrees, the field strengths are still greater than the half-power point as shown seperately in Fig. 2-1.

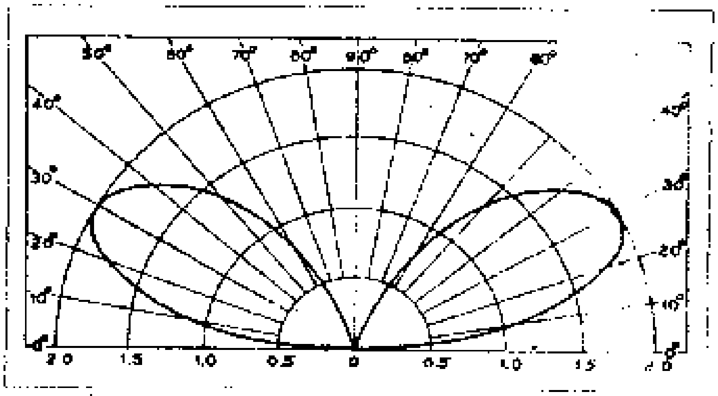


Fig. 2-1 The vertical pattern of $\frac{1}{2}$- λ dipole, 0.5 λ above ground.

But in reality, both dipoles should be suspended at the same height from ground, so the only choice is to apply this 0.5 λ high to the high frequency dipole, then at this height, the lower frequency dipole will be at about 0.225 λ high. Fortunately, at both 0.225 λ and 0.5 λ high, the driving-point resistance of the dipoles are nearly the same at 70 ohms.

Lastly, the antenna's height should be limited by the available masts, the standard masts of about 20 m high can easily be found and are cheaper in cost. At the predetermined height of 0.5 λ for high frequency and 0.225 λ for low frequency, the height in meter is 20 m.

2-3b <u>Antenna's Input Impedance</u>. Let's represent the lower frequency (night frequency), 3.370 Mc by f_1 and the corresponding dipole by # 1. Also, represent the higher frequency (day frequency), 7.607 Mc, by f_2 and the corresponding dipole by # 2.

When both dipoles are connected in parallel at the predetermined height above ground and fed with one coaxial line. With the longer dipole, # 1, operating at its resonant frequency f_1, its feed point impedance will be approximately 70 ohms, at the same time, the shorter dipole, # 2, will find its length to be $0.443 \frac{\lambda_1}{2}$ ($\beta_1 H_1 = 0.696$). From the antenna impedance chart given by Hallén in Fig. 5-4 and 5-5, taken the curve for $\frac{H}{a} = 20,000$ which is the thin antenna case. The impedance presented by antenna # 2 to the line is $10 - j1,280$ ohms. This high impedance will be in parallel with the 70 ohms of antenna # 1, and therefore will have negligible effect on the line termination, and little current will flow to the shorter dipole. This condition tends to show that the presence of the shorter dipole, # 2, has no effect on the longer dipole # 1.

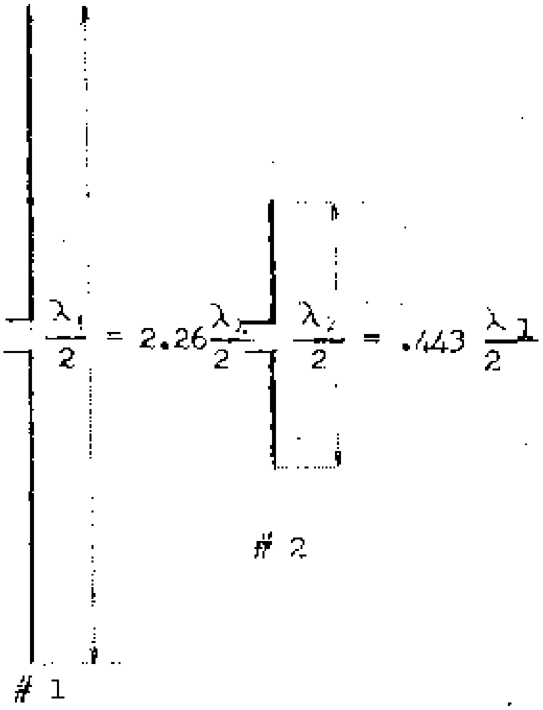


Fig. 2-2. Designate the longer dipole by # 1, and the shorter one by # 2.

Also, when the shorter dipole # 2 is operating at its resonant frequency, its feed point impedance will be approximately 70 ohms. But at the same time, the longer dipole # 1, will find its length to be $2.26 \frac{\lambda_2}{2}$ ($\beta_2 H_2 = 3.55$). From the antenna impedance chart in Fig. 5-4 and 5-5, taken the curve $\frac{H}{a} = 20,000$ for the case of thin antenna, the impedance presented by antenna # 1 to the line is $480 - j1,700$ ohms. This high impedance will be in parallel with the 70 ohms of antenna # 2, and therefore will have negligible effect on the line termination, and little current will flow to the longer dipole. This condition tends to show that the presence of the longer dipole, # 1, has no effect on the shorter dipole # 2.

From the above theoretical conditions, it is believed that when operated the antenna at either day or night frequency, the input impedance should always be constant at 70 ohms; i.e., independent of frequency.

The mutual impedance between both dipoles as a function of spacing is given in (5-37). But the calculations are tedious unless the computer is used. However, the value expected should be small as already shown that the presence of the other dipole has no effect on the characteristics of the active one. But however in reality at extremely close spacing, the mutual impedance may take part in the input impedance measurements. So it is left for the experiment to find the proper spacing between both dipoles that will give constant input impedance at both frequencies.

2-3c. Parasitic Elements. In order to make this double doublet antenna a unidirectional one, two reflectors are equipped with the antennas at the same height with them.

As already stated in Sec 6-3, there are two kinds of parasitic element; i.e., self resonant and tuned parasitic elements. In order not to let the reflector of antenna # 1 interfere or act as the director of antenna # 2, the reflector of antenna # 1 is cut as a tuned parasitic element; i.e., make it as long as possible. And with the same reason, the reflector of antenna # 2 is cut as a self-resonant parasitic element; i.e., make it as short as possible as shown in Fig. 2-3.

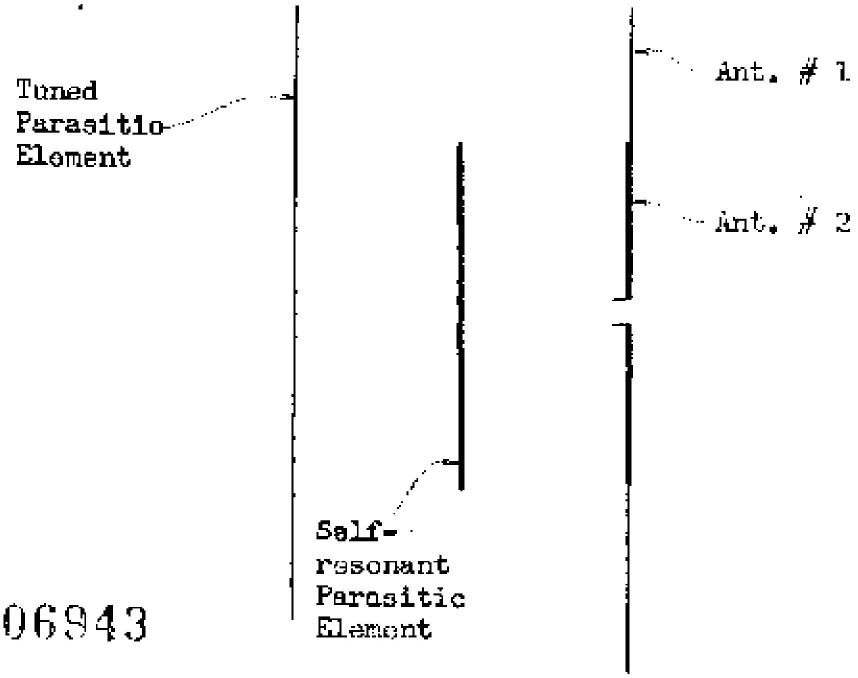


Fig. 2-3. Top view of double doublet antenna with parasitic elements.

When equipped with reflectors, the input resistance of the driven element as a function of reflectors' spacing are shown in Fig. 6-9 and 6-12 for the case of self-resonant and tuned parasitic element respectively. From the curves, at the reflectors' spacing of 0.22λ, both kinds of reflector give the input resistance of 50 ohms with the gain over dipole near maximum at 5 db for the self-resonant parasitic element and 4.75 db for the tuned parasitic element. The existence of the reflectors not only lowered the input resistance, but also produce the undesirable reactive part which could be reduced by adjusting the driven element's length.

2-4. Constructions of Antenna

In the experiment on the double doublet antenna, the antenna is scaled down with the scale ratio $\frac{1}{5}$. The measurements made on the scaled antenna are the input impedance and the relative field intensity in the direction of its maximum and minimum radiation which do not depend on power level. Then, this type of model is called a qualitative or geometrical model, with mechanical scale factor p = 5.

From Table 7-1, Sec. 7-2, the conductivity of the antenna metal be scaled according to the relation

$$\sigma' = p\sigma$$

However, if σ is large enough, the metal can be considered to be a "perfect conductor" ($\sigma = \infty$) and the conductivity need not be modeled . Thus, actual antennas of copper can usually be modeled in copper. It is assumed that ferromagnetic materials are excluded from both actual antenna and model and that the model is measured in air.

The modeled antenna has the following specifications:

The night frequency, $f_1 = 5 \times 3.370 = 16.85$ Mc

The wave length, $\lambda_1 = \frac{3 \times 10^8}{16.85 \times 10^6} = 17.8$ m

The day frequency, $f_2 = 5 \times 7.607 = 38.035$ Mc

The wave length, $\lambda_2 = \frac{3 \times 10^8}{38.035 \times 10^6} = 7.9$ m

Antenna's height $= \frac{20}{5} = 4 \text{ m} = 0.225\lambda_1 = 0.507\lambda_2$

Let's still denote the longer dipole, # 1, and the shorter dipole, # 2.

2-4a. Steps in Construction.

1. Set up four supporting masts 5 m high from ground, two of them for dipoles are 11 m apart, another two masts for reflectors are

Fig. 2-4. A $\frac{1}{5}$ scale model of double doublet antenna, using the same method of construction as the full size aerial.

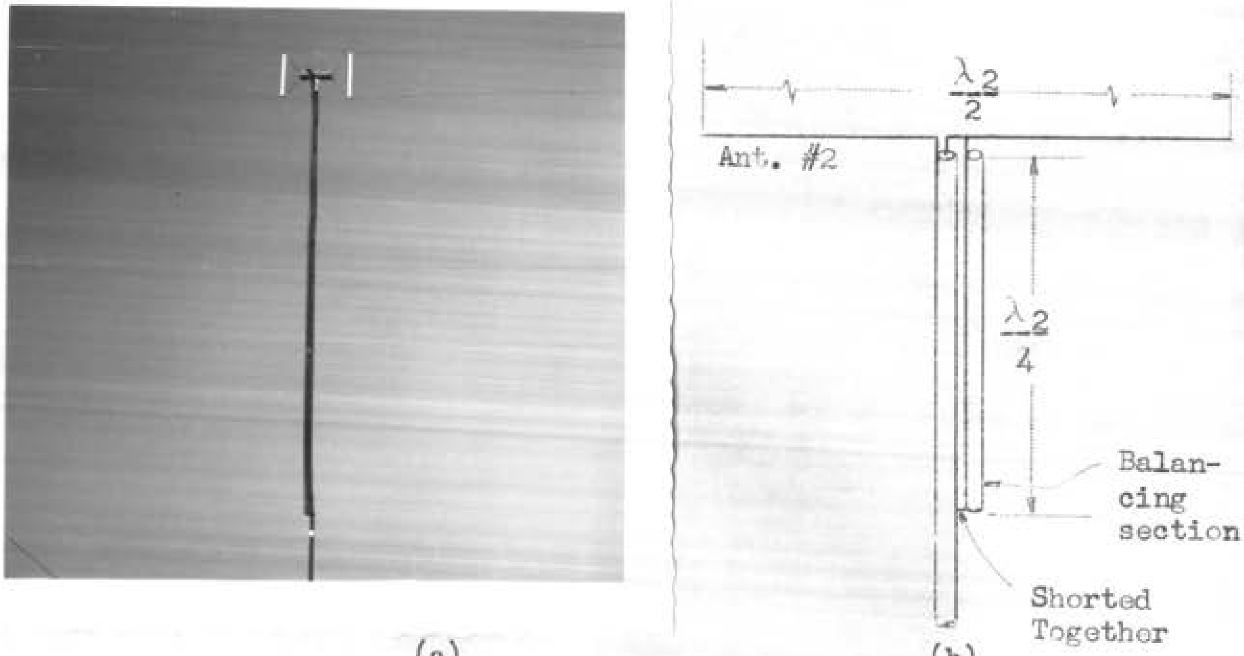
also 11 m apart and placed parallel to the first two with 4.5 m spacing. The four masts are equipped with pulleys and other facilities to adjust both the height and spacing of various elements easily. The arrangement is shown in Fig. 2-4.

2. Cut No. 12 copper wire at the length of $0.95\ \frac{\lambda_1}{2} = 8.450$ m and $0.95\ \frac{\lambda_2}{2} = 3.750$ m which are corresponded to the practical half-wavelength of f_1 and f_2 respectively to be the driven elements. Another two wires, one at a little longer than $\frac{\lambda_1}{2}$ and the other at $0.95\ \frac{\lambda_2}{2}$ long are cut as the reflectors for driven elements #1 and #2 respectively.

3. In measuring the input impedances of the antenna at both frequencies by the impedance bridge, RX Meter Type 250-A, Boonton Radio

Corporation; two coaxial feed lines are cut at the lengths which are integral multiple of $\lambda_1/2$ and $\lambda_2/2$. With these two coaxial lines, the values measured are the input impedances at the center of the antennas regardless of the characteristics of the line itself. The exact length of the coaxial lines are checked by the RX Meter itself, where the meter indicates zero reactance at balance. By taking into account the velocity constant of RG-8/U coaxial line = 0.66, the coaxial line for f_1 is cut at the length 2 X $\frac{\lambda_1}{2}$ X 0.66 = 11.748 m. The other one for f_2 is cut at 3 X $\frac{\lambda_2}{2}$ X 0.66 = 7.811 m.

4. At frequency f_1 (i.e., 16.85 Mc), the unbalance in coaxial line is rather small and can be neglected in practical use. But at f_2 (38.035 Mc), the unbalance could not be ignored, so when dealing with this frequency in the experiment, the balun is used. The balancing section as shown in Fig. 2-5b "looks like" an open circuit to the antenna,



(a) (b)

Fig. 2-5. Balun for dipole #2.

since it is a quarter-wave parallel-conductor line shorted at the far end, and thus has no effect on the normal antenna operation. The length $\lambda_2/4$ of the balancing section is checked by the RX Meter, the meter indicates zero reactance at balance.

However, for full-size antenna which operates at frequencies 3.370 and 7.607 Mc the unbalance is negligible, so the balun is unnecessary for both frequencies.

2-5. Measurements of Antenna

2-5a. Input Impedance Measurements. The input impedance of the antenna is measured with the impedance bridge, RX Meter Type 250-A, Boonton Radio Corporation. When measuring at frequency f_1, the RG-8/U coaxial line 11.748 m long is used. When measuring at frequency f_2, the RG-8/U coaxial line 7.811 m long with balun is used. The direct reading from meter is the parallel resistance, R_p, and positive or negative parallel capacitance, C_p. A positive capacitance reading indicates directly the effective parallel capacitance of a capacitive impedance. A negative capacitance reading indicates the capacitance which resonates with the effective parallel inductance of an impedance. In the latter case, the effective parallel inductance may then be determined by the simple relation

$$L_p = \frac{1}{\omega^2 C_p}$$

Extension of Results

(a) Equivalent parallel reactance (X_p)

$$X_p = \frac{1}{\omega C_p}$$

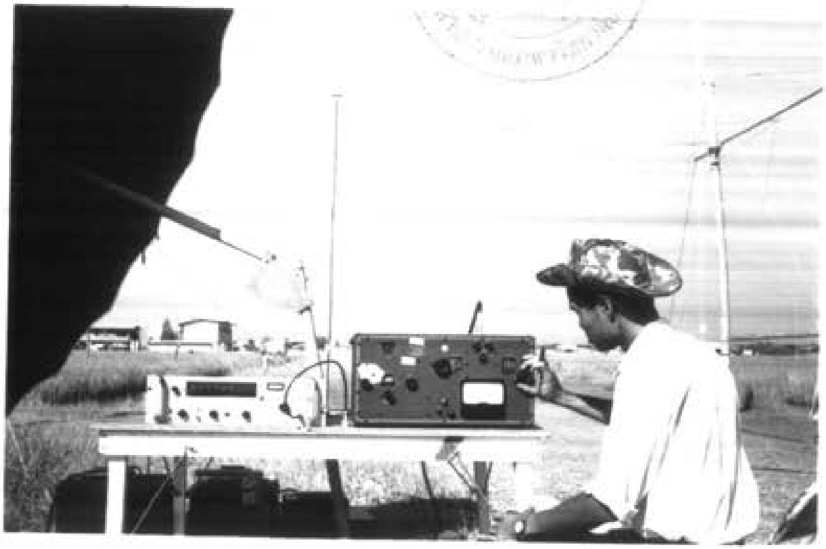


Fig. 2-6. Input impedance measurement.

(b) Equivalent parallel inductance (L_p)

$$L_p = \frac{X_p}{\omega} \quad \text{(for negative sign of } C_p \text{)}$$

(c) Q

$$Q = \frac{R_p}{X_p}$$

(d) Equivalent series resistance (R_s)

$$R_s = \frac{R_p}{1 + Q^2}$$

and, with less than 1% error

$$R_s = X_p^2/R_p \text{ , when } Q > 10$$

$$R_s = R_p \text{ , when } Q < 0.1$$

(e) Equivalent series reactance (X_s)

$$X_s = \pm\frac{X_p Q^2}{1 + Q^2}$$

and, with less than 1 % error

$$X_s = X_p \text{ , when } Q > 10$$

$$X_s = R_p^2/X_p \text{ , when } Q < 0.1$$

The input impedances as tabulated in the next pages are $R_s + jX_s$ which have already been calculated in the field measurements.

1. Input Impedance of Half-Wave Dipole Antenna

With each dipole antenna suspended at the height of 4 m from the the ground one at a time, check the input impedance with RX Meter, and a slight adjustment of the antenna's length is made. The final value obtained are:

Antenna # 1 (16.85 Mc)	74 + j3.6	ohms
Antenna # 2 (38.035 Mc)	72 + j6.8	ohms

2. Input Impedance of Double Doublet Antenna

With different ways of suspending and feeding both dipoles in parallel, the impedance of the double doublet antenna at both frequencies are measured.

The first setting is shown in Fig. 2-7, the longer dipole is suspended at the height of 4 m, the shorter one is directly below and parallel to the longer dipole. Both dipoles are connected in parallel by two parallel copper wires. The input impedances are measured at different spacing, d, but the values at both

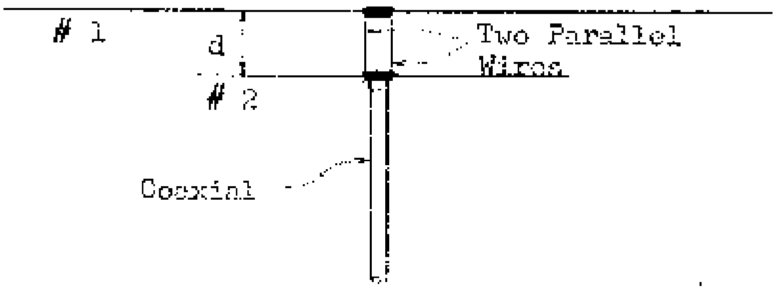


Fig. 2-7. First setting of double doublet antenna.

frequencies are much different and hard to bring them to the same value. This is because the parallel wires connected acts as a part of antenna, and made the length of the antenna change by its existance.

The second setting is shown in Fig. 2-8, the elements are fanned out either vertically, as shown, or horizontally. At the center, both dipoles are connected to the same feed point. The longer dipole # 1 is suspended at the height 4 m. The input impedances are measured at different distances d, but the values obtained at both frequencies are also much difference and hard to bring them to the same value. This is because of the mutual impedance at small d, and the false characteristic of the shorter antenna # 2 at large d, because it no longer acts as a horizontal dipole, but an inverted vee dipole instead.

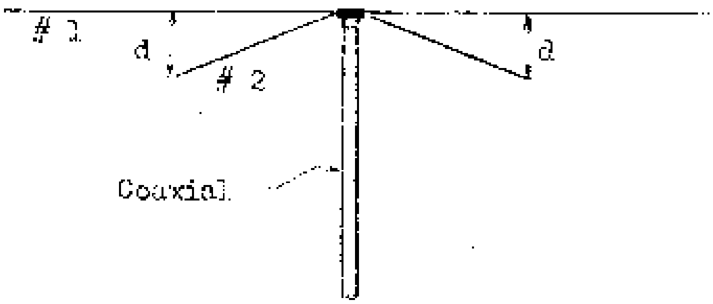


Fig. 2-8. The second setting of double doublet antenna.

The third setting is shown in Fig. 2-9, both elements are connected to the same feed point at center and are seperated from each other by two insulator spreader 6 inches long, the rest of the wires are in parallel. The longer dipole #1 is at 4 m high, the shorter dipole #2 is directly below. With this setting the condition for constant input impedance at both frequencies can be obtained as follows:

At 16.85 Mc	72 + j4.8 ohms
At 38.035 Mc	70.4 + j8.25 ohms

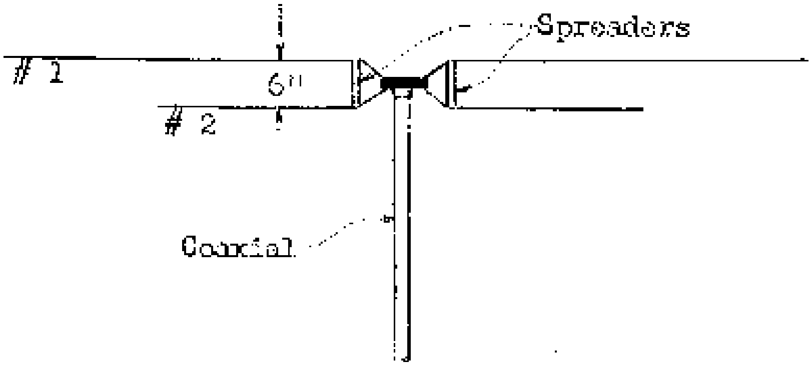


Fig. 2-9. The third setting of double doublet antenna.

The j part is small compared to the real part and can be neglected in calculating the absolute value. Although at both frequencies, the input impedances are not exactly the same, but the difference of 2 to 3 ohms can be neglected in practical use.

The above results show that the presence of other dipole has no effect on the active one; i.e., the input impedance is independent of frequency.

3. Input Impedance of Double Doublet Antenna with Reflectors

With the setting obtained, equipped the antennas with reflectors, as shown in Fig. 2-10, with the longer one at the same height as the longer dipole and the shorter one at the same height as the shorter dipole; i.e., 6 inches lower than the longer one.

Varies both reflectors to different spacings and take a series of input impedance measurements. The results shown that when operating at frequency f_1 and varied the spacing of the shorter reflector of antenna # 2, with the longer reflector fixed, the input impedance remains fixed. In the same manner, when operating at frequency f_2, with the shorter reflector of antenna # 2 fixed, and kept on varying the spacing of the longer reflector, the input impedance also remained unchanged.

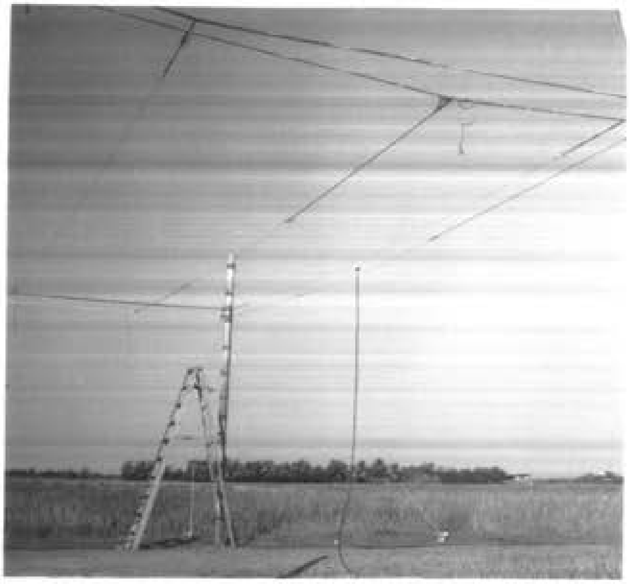


Fig. 2-10. Double doublet antenna with reflectors.

This shows that each set of dipole and reflector works independently.

Now concentrate on antenna # 1 with its reflector, first of all the reflector is fixed at the spacing of 0.22 λ and vary the reflector's length until the RX Meter reads real part of approximately 50 ohms accompanied with a number of j part. The next step is to reduce j part by varying the length of the driven element. With both elements fixed in length, then the input impedance at different reflector's spacing are taken. The results obtained are as follows:

<u>Night Frequency</u> (16.85 Mc)

Driven element # 1 length 8.66 m = 0.924 $\lambda_1/2$

Tuned parasitic element length 8.9 m = $\lambda_1/2$

Reflector's Spacings (meters)	Input Impedances (ohms)
2.00	26.7 - j1.516
2.50	33.0 - j1.05
3.00	39.65 + j.875

Reflector's Spacings (meters)	Input Impedances (ohms)
3.50	46.6 + j3.26
3.70	49.6 + j3.74
4.00	53.2 + j3.93
4.50	59.0 + j3.03
5.00	63.2 + j1.66
5.45	66.6 + j0.235

Now concentrate on antenna # 2 and its self-resonant reflector. At first, the reflector is fixed at the spacing of 0.22 λ , the driven element's length is adjusted until the RX Meter's reading is near resistive at 50 ohms. With both elements fixed in length, then the input impedances at different reflector's spacings are taken as follows:

<u>Day Frequency</u> (38.035 Mc)

Driven element # 2, length 3.65 m = 0.924 $\lambda/2$

Self-resonant reflector, length 3.750 m = 0.95 $\lambda/2$

Reflector's Spacings (meters)	Input Impedances (ohms)
1.30	35.85 - j3.33
1.40	39.7 - j1.31
1.50	44.4 + j0.354
1.60	46.6 - j1.86
1.70	52.0 - j1.216
1.80	58.0 + j2.01

Reflector's Spacings (meters)	Input Impedances (ohms)
1.90	64.0 + j1.47
2.00	66.0 + j0.16

2-5b. Field Strength Measurements. The antenna's gain is defined as:

$$\text{Power gain, } G = \frac{\text{maximum radiation intensity}}{\text{maximum radiation intensity from a reference antenna with same power input}} \qquad (\ 2\text{-}1\ )$$

$$\text{Gain in field intensity, } G_f = \frac{\text{maximum electric field intensity}}{\text{maximum electric field intensity from the reference antenna with same power input}} \qquad (\ 2\text{-}2\ )$$

$$G = G_f^2 \qquad (\ 2\text{-}3\ )$$

$$\text{db gain} = 10 \log_{10} G \qquad (\ 2\text{-}4\ )$$

$$\text{db gain} = 20 \log_{10} G_f \qquad (\ 2\text{-}5\ )$$

In this experiment, a dipole at the same effective height is used as the reference antenna.

The front-to-back ratio is also the ratio at maximum field intensity to the electric field intensity in the opposite direction.

Then, in measuring the gain over dipole and the front-to-back ratio of the antenna, the electric field intensity both in the direction of maximum radiation and in the opposite direction are measured.

The transmitter is the VHF Signal Generator, Model 608 C, Hewlett-Packard Company, with C-W output. The carrier field intensity is measured with the Noise and Field Intensity Meter, Model NF-205, Empire Devices, Inc. The meter is equipped with dipole receiving antennas and the tuning units for the desired frequency range. The arrangements are shown in Fig. 2-11.

Fig. 2-11. Field strength measurements.

The far field of the double doublet antenna can be found as follows:

The far field is usually regarded as the region beyond the critical radius given by:

$$R = \frac{2D^2}{\lambda} \quad (2\text{-}6)$$

where D is the aerial aperture (or maximum linear dimension of antenna).

At frequency f_1 (16.85 Mc), taking the maximum reflector's spacing d = 4.50 m.

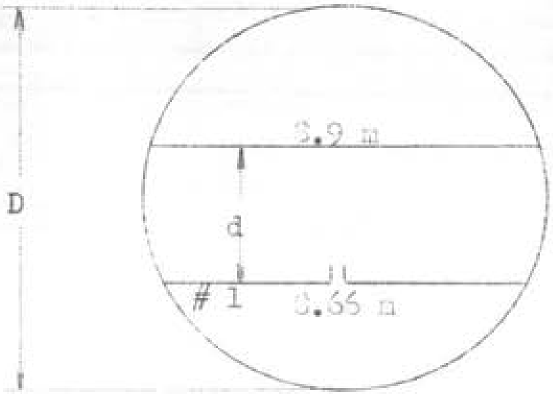


Fig. 2-12. Antenna aperture at frequency 16.85 Mc.

From Fig. 2-12,

$$\left(\frac{D}{2}\right)^2 = X^2 + 4.45^2$$

$$\left(\frac{D}{2}\right)^2 = (4.5 - X)^2 + 4.33^2$$

$$19.9 = 20.3 - 9X + 18.8$$

$$9X = 19.2$$

$$X = 2.13$$

$$\left(\frac{D}{2}\right)^2 = 4.55 + 19.9 = 24.45$$

$$D^2 = 97.8$$

$$D = 9.875 \text{ m} = 0.555\,\lambda_1$$

$$R = 0.62\,\lambda_1 = 11.03 \text{ m}$$

At frequency f_2, 38.035 Mc, taking the maximum reflector's spacing 2.00 m. From Fig. 2-13 we obtain:

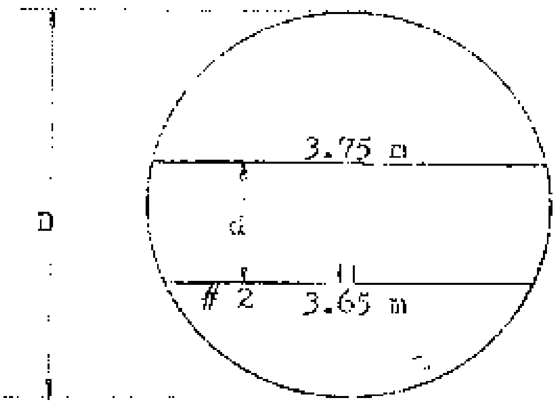


Fig. 2.13. Antenna aperture at frequency 38.035 Mc.

$$\left(\frac{D}{2}\right)^2 = X^2 + 1.875^2$$

$$\left(\frac{D}{2}\right)^2 = (2 - X)^2 + 1.825^2$$

$$3.53 = 4 - 4X + 3.34$$

$$X = \frac{3.81}{4} = 0.953$$

$$\left(\frac{D}{2}\right)^2 = 0.91 + 3.53 = 4.44$$

$$D^2 = 17.76, \quad D = 4.2 \text{ m, or}$$

$$D = 0.532\,\lambda_2$$

Then ,

$$R = 0.57\,\lambda_2 = 4.5 \text{ m}$$

The field strength of the antenna when operating at frequency 16.85 Mc is measured in the direction of maximum and minimum radiation at the distance of 64.7 m = 3.13 λ_1 from the center of antenna. At this distance, the field obtained should certainly be the far field. The receiving dipole is at the height of 2.86 m from ground, so the field strength obtained is the field strength at an elevation angle of 2° 32'. The meter reading is taken at different reflector spacings, and the results are tabulated as follows:

Reflector's Spacings (meters)	Field Strength (in db above 1 $\mu v/m$)	
	Front	Back
2.00	70.80	63.50
2.50	71.35	63.75
2.80	71.55	64.02
3.00	71.80	64.15
3.20	71.75	64.40
3.30	71.65	64.14
3.40	71.85	64.20
3.50	71.90	64.65
3.70	71.80	64.90
4.00	71.40	64.90
4.50	71.26	64.95
5.00	70.90	65.20

Also, the field strength of the antenna when operating at frequency 38.035 Mc is measured in both directions of max. & min. radiation at the distance of 33 m = 4.175 λ_2 from center of antenna. The receiving antenna is at the height of 2.68 m from ground, so the field strength obtained is the field strength at an elevation angle of 4° 39'. The meter reading is taken at different reflector's spacings, and the results are tabulated as follows:

Reflector's Spacings (meters)	Field Strength (in db above 1 μv/m)	
	Front	Back
1.00	68.25	61.90
1.10	68.40	62.10
1.20	68.60	62.05
1.30	68.70	61.95
1.40	68.65	61.95
1.50	68.70	61.70
1.60	68.70	61.40
1.70	68.50	61.40
1.80	68.30	61.45
1.90	68.30	61.25

The field strength of the dipoles at the same effective height are measured as follows:

At frequency 16.85 Mc	67.05 db above 1 μv/m
At frequency 38.035 Mc	63.95 db above 1 μv/m

Since only relative values of field strength are required in this experiment, so no calibration of meter is needed.

2-5c. <u>The Standing Wave Ratio Measurements</u>. The S.W.R. of antenna at both frequencies are measured at the point where the input impedances are 50 ohms resistive.

The equipments used are arranged as shown in the block diagram in Fig. 2-14 and the field measurements are also shown in Fig. 2-15.

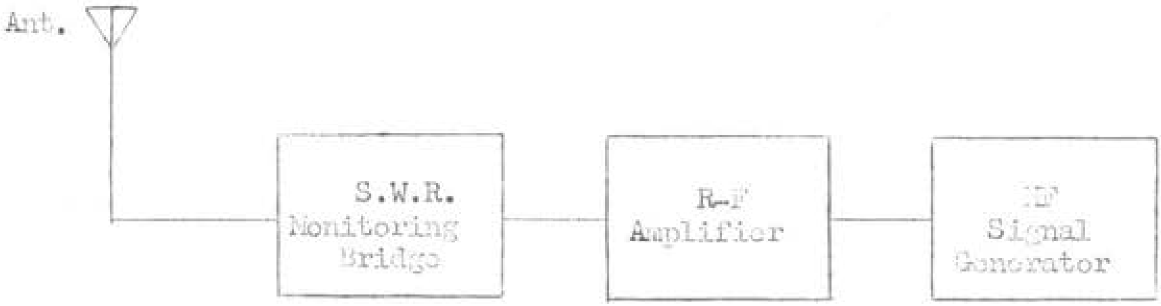


Fig. 2-14. Block diagram of s.w.r. measurements.

The HF Signal Generator, Model 606 A, Hewlett-Packard Company, is used at both frequencies, its signal is amplified by the Signal Generator Power Amplifier, Type 230-A, Boonton Radio Corporation. The s.w.r. monitoring bridge used is the Micro Match, Model 262, Microwave Devices Inc., with R-F Power and VSWR Meter Coupler Unit, Model 261.1, The Bendix Corporation.

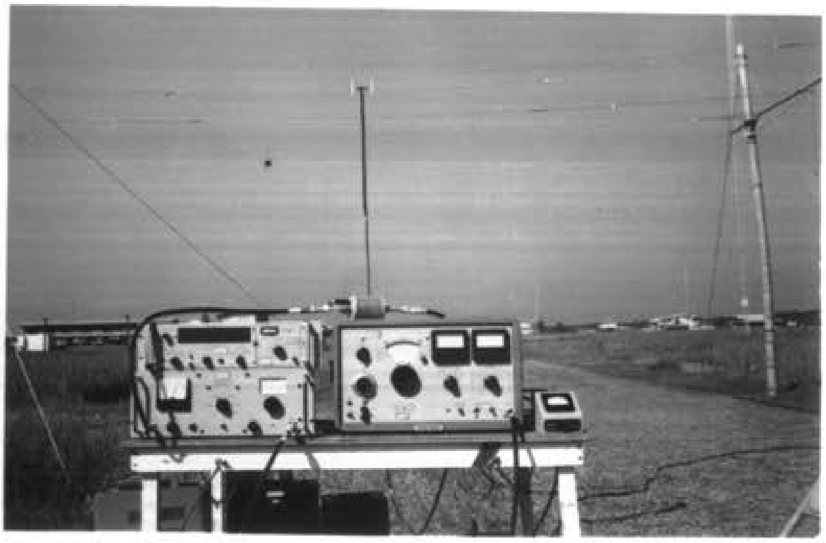


Fig. 2-15. The standing wave ratio measurements.

In measuring VSWR at both frequencies, the forward power flows are adjusted to give full scale meter reading.

At Night Frequency (16.85 Mc)

Forward Power, $\overset{F}{W}$ = 10

Reflected Power, $\overset{R}{W}$ = 0.035

Percent Reflected Power, ϕ = $\frac{0.035}{10} \times 100 = 0.35\ \%$

VSWR, ρ , From chart in Fig. 2-16 = 1.125

At Day Frequency (38.035 Mc)

(Without Balun)

$\overset{F}{W}$ = 10

$\overset{R}{W}$ = 0.425

Φ = $\frac{0.425 \times 100}{10} = 4.25\ \%$

VSWR , ρ , From chart in Fig. 2-17 = 1.525

(With Balun)

$\overset{F}{W}$ = 10

$\overset{R}{W}$ = 0.13

Φ = $\frac{0.13 \times 100}{10} = 1.3\ \%$

VSWR, ρ , From chart in Fig. 2-17 = 1.27

The VSWR measured at both frequencies are small which shown that the antennas present a good match to the transmission line.

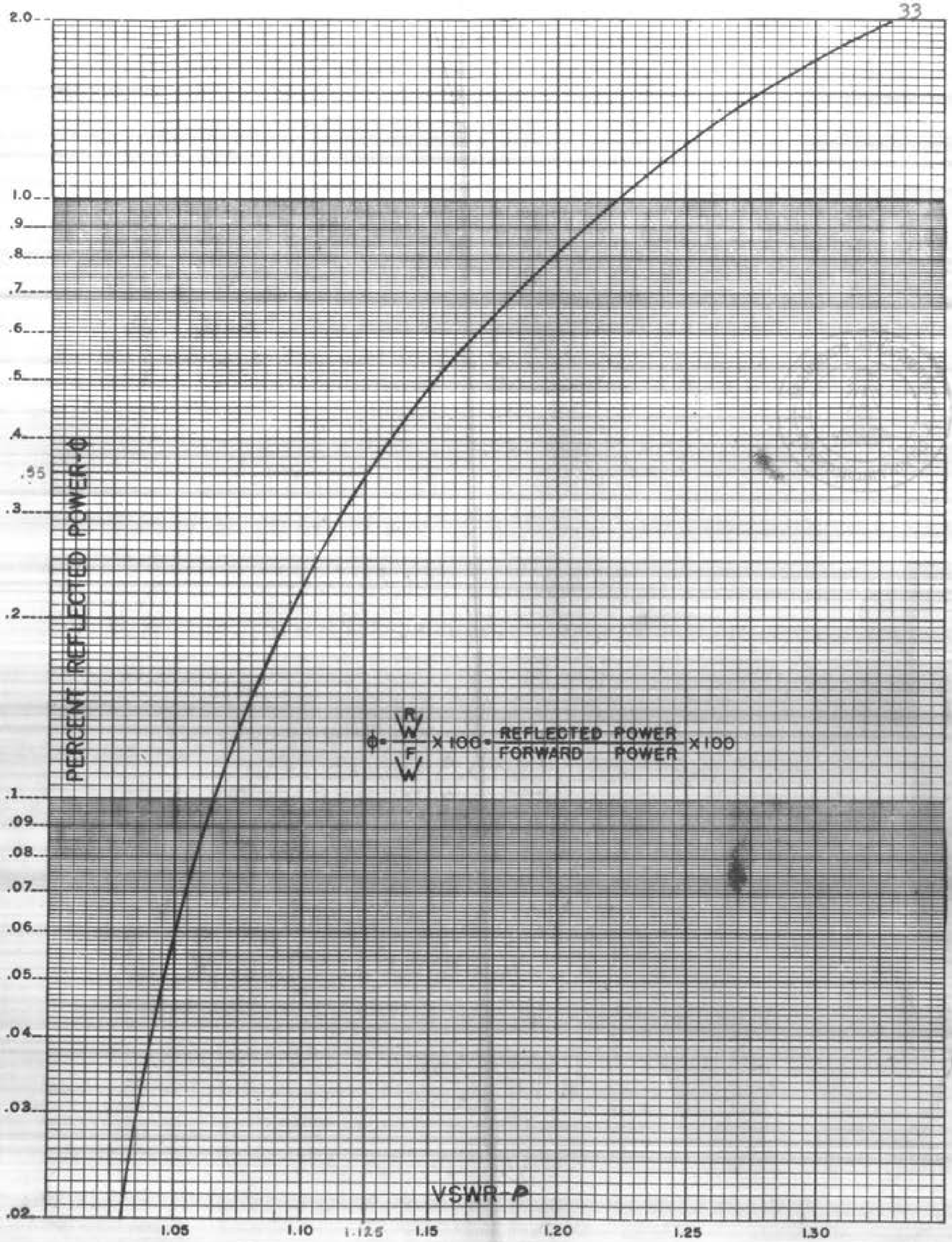


Fig. 2 - 16. Graph. - Percent Reflected Power vs. VSWR (1.0 to 1.3).

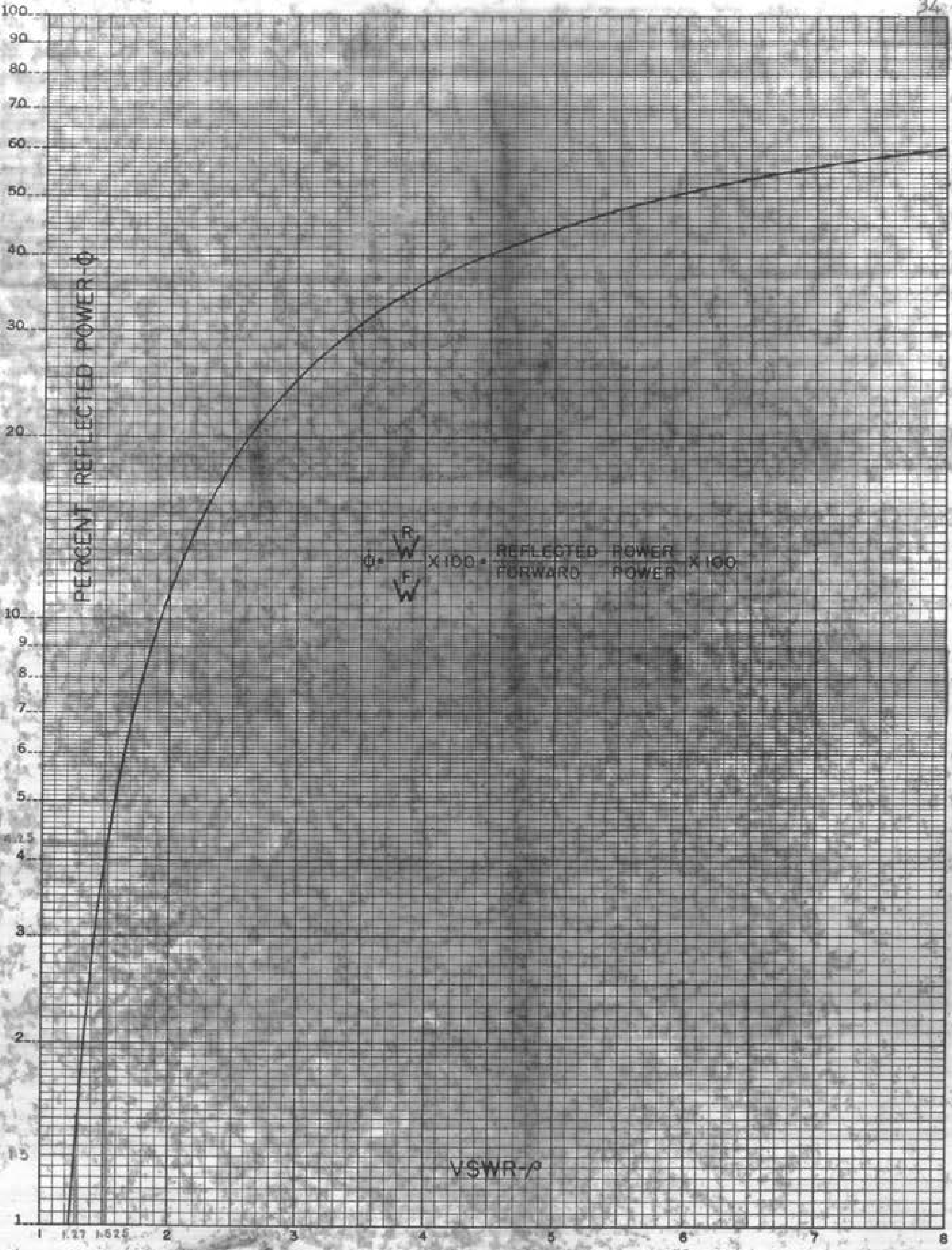


Fig. 2 - 17. Graph. - Percent Reflected Power vs. VSWR (1.0 to 8.0).

2-6. Analyzing the Data

The data for each frequency may be analyzed seperately, and the final results compared to get the most advantage setting.

Night Frequency (16.85 Mc)

The input resistance as a function of reflector's spacings are plotted in Fig. 2-18. The spacing that gives the input resistance of 50 ohms is 3.7 m or 0.208 λ_1.

The electric field strength in μ v/m can be calculated from the meter reading in db above 1 μ v/m as follows:

$$\text{db above } 1\ \mu\text{v/m} = 20 \log_{10} \frac{E_1}{E_o} \qquad (\ 2\text{-}7\ )$$

when $E_o = 1\ \mu\text{v/m}$

$$\text{Then, db above } 1\ \mu\text{v/m} = 20 \log_{10} E_1 \qquad (\ 2\text{-}8\ )$$

$$\text{and, } E_1 = \text{antilog} \frac{\text{db above } 1\ \mu\text{v/m}}{20} \qquad (\ 2\text{-}9\ )$$

Field strength of a dipole at the same effective height with the double doublet antenna = 67.05 db above 1 μv/m

$$\text{Gain over dipole in db} = (\text{ db above } 1\ \mu\text{ v/m of double doublet antenna }) - (\ 67.05 \text{ db above } 1\ \mu\text{ v/m }) \qquad (\ 2\text{-}10\ )$$

$$\text{Front-to-back ratio} = \frac{\text{Front electric field strength in } \mu\text{v/m}}{\text{Back electric field strength in } \mu\text{v/m}} \qquad (\ 2\text{-}11\ )$$

The calculated values of electric field strength in μv/m, gain over dipole, and front-to-back ratio are tabulated below.

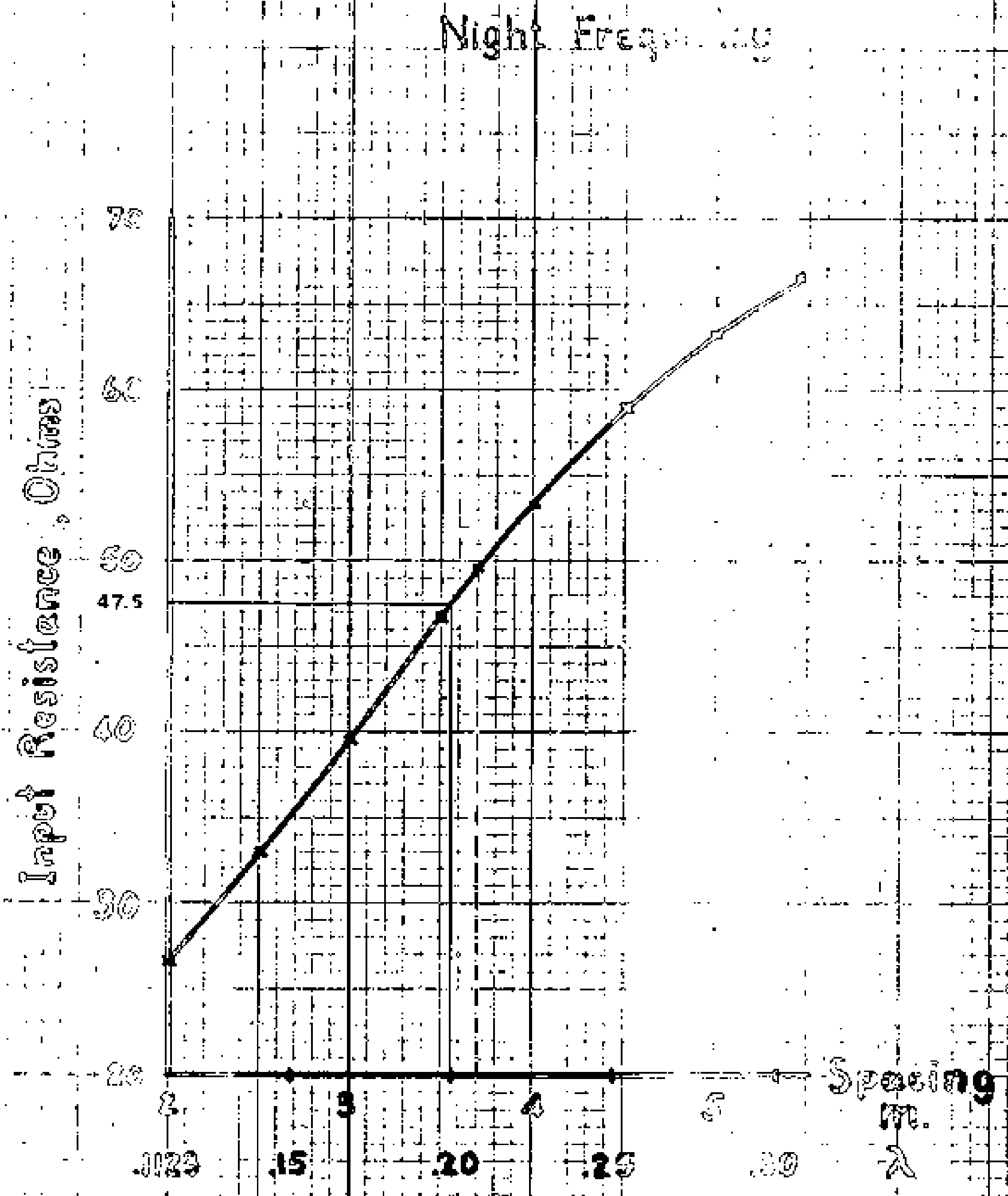


Fig.2 - 18. Curve of Input Resistance vs. Reflector's Spacing

Reflector's Spacings (meters)	Electric Field Strength		Gain Over Dipole (db)	Front-to-Back Ratio
	Front (μv/m)	Back (μv/m)		
2.00	3,467	1,510	3.75	2.3
2.50	3,694	1,540	4.30	2.4
2.80	3,823	1,588	4.60	2.41
3.00	3,890	1,613	4.75	2.41
3.20	3,868	1,660	4.70	2.33
3.30	3,868	1,610	4.70	2.40
3.40	3,890	1,622	4.75	2.40
3.50	3,936	1,708	4.85	2.385
3.70	3,868	1,758	4.70	2.2
4.00	3,715	1,758	4.35	2.11
4.50	3,652	1,768	4.20	2.06
5.00	3,508	1,820	3.85	1.93

The gain over dipole as a function of reflector's spacings are plotted in Fig. 2-19, and the front-to-back ratio as a function of reflector's spacings are also plotted in Fig. 2-20. The maximum gain, 4.85 db, occurs at the reflector's spacing of 3.50 m (0.197 λ_1), but the maximum front-to-back ratio, 2.41, occurs at the spacing of 3 m (0.1685 λ_1). However, the front-to-back ratio curve does not change too much in the vicinity of 3 ± 0.5 m. If selecting the spacing that gives maximum gain; i.e., 3.5 m (0.197 λ_1) be the point of interest, then this spacing will give the front-to-back ratio of 2.385 which is still near the maximum value, but at this spacing will give the input

Night Frequency

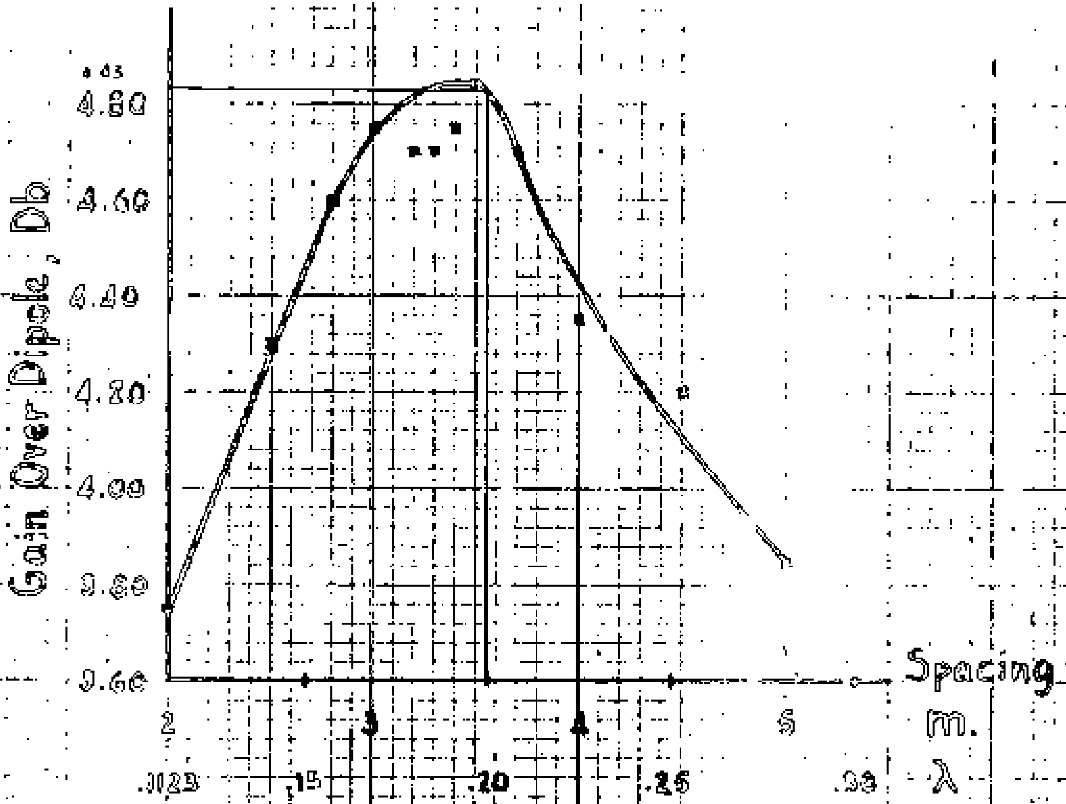


Fig. 2-19. Curve of Gain Over Dipole vs. Reflector's Spacing.

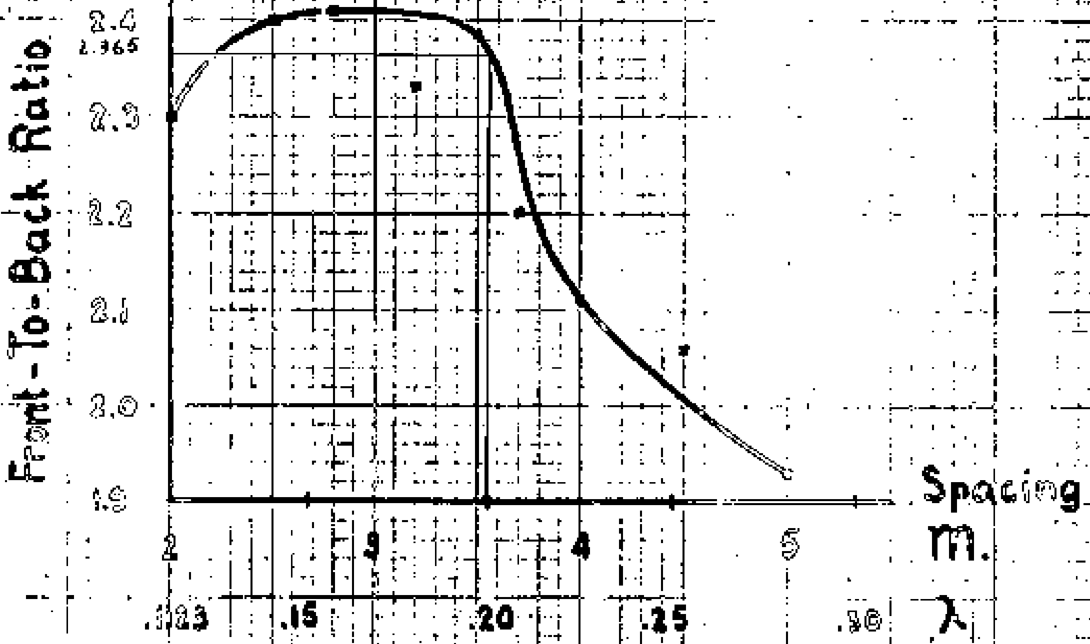


Fig. 2-20. Curve of Front-To-Back Ratio vs. Reflector's Spacing.

resistance of 46.5 ohms. If the input resistance is increased one more ohm; i.e., at the spacing of 3.56 m (0.2 λ_1), the gain will be at 4.83 db and the front-to-back ratio will be at 2.365. So this new spacing obtained by compromising gives better advantages than the former one.

Day Frequency (38.035 Mc)

The input resistances as a function of reflector's spacings are plotted in Fig. 2-21. The spacing that gives the input resistance of 50 ohms is 1.64 m (0.208 λ_2).

The electric field strength in μv/m can be calculated from (2-9). The field strength of a dipole at the same effective height with the double doublet antenna = 63.95 db above 1 μv/m.

$$\text{Gain over dipole in db} = (\text{ db above 1 } \mu\text{v/m of double doublet antenna }) - (63.95 \text{ db above 1 } \mu\text{v/m}) \qquad (2\text{-}12)$$

The front-to-back ratio also can be calculated from (2-11).

The calculated values of electric field strength in μv/m, gain over dipole in db, and front-to-back ratio are tabulated below.

Reflector's Spacings (meters)	Electric Field Strength		Gain Over Dipole (db)	Front-to-Back Ratio
	Front (μv/m)	Back (μv/m)		
1.00	2,585	1,245	4.30	2.08
1.10	2,630	1,274	4.45	2.06
1.20	2,692	1,266	4.65	2.13
1.30	2,723	1,251	4.75	2.18

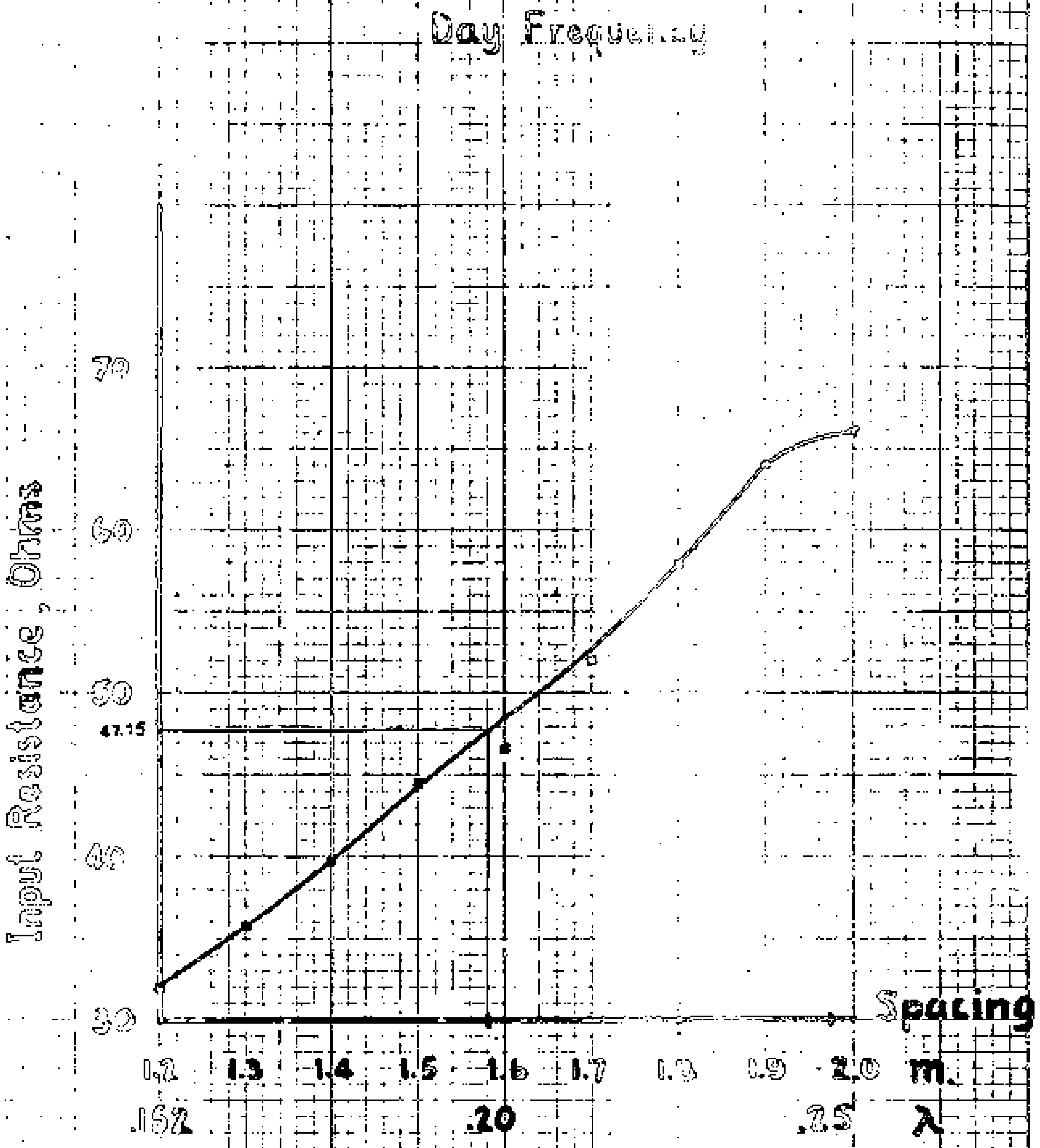


Fig. 2-21. Curve of Input Resistance vs. Reflector's Spacing.

Reflector's Spacings (meters)	Electric Field Strength		Gain Over Dipole (db)	Front-to-Back Ratio
	Front (μv/m)	Back (μv/m)		
1.40	2,703	1,251	4.70	2.16
1.50	2,723	1,216	4.75	2.24
1.60	2,723	1,175	4.75	2.32
1.70	2,661	1,175	4.55	2.26
1.80	2,600	1,181	4.35	2.20
1.90	2,600	1,154	4.35	2.25

The gain over dipole as a function of reflector's spacings are plotted in Fig. 2-22, and the front-to-back ratio as a function of reflector's spacings are also plotted in Fig. 2-23. The maximum gain; i.e., 4.75 Db, occurs at the reflector's spacing of 1.3 to 1.6 m (0.1645 λ_2 to 0.203 λ_2), but the maximum front-to-back ratio occurs at the spacing of 1.6 m (0.203 λ_2). If selecting the spacing that gives maximum front-to-back ratio as the point of interest, the gain still remains at its maximum value but the input resistance is at 48 ohms. If the spacing where the input resistance is 50 ohms; i.e., 1.64 m (0.208 λ_2), is considered, the gain will drop to 4.60 db and the front-to-back ratio will be at 2.31. Then, the former spacing is better. If simply consider the spacing at 0.2 λ_1 (1.58 m) as in the case of frequency 16.85 Mc, the gain and front-to-back ratio are still in the vicinity of their maximum values. The input resistance drops down a little to about 47.75 ohms.

Then for both frequencies the reflector's spaced approximately

Day Frequency

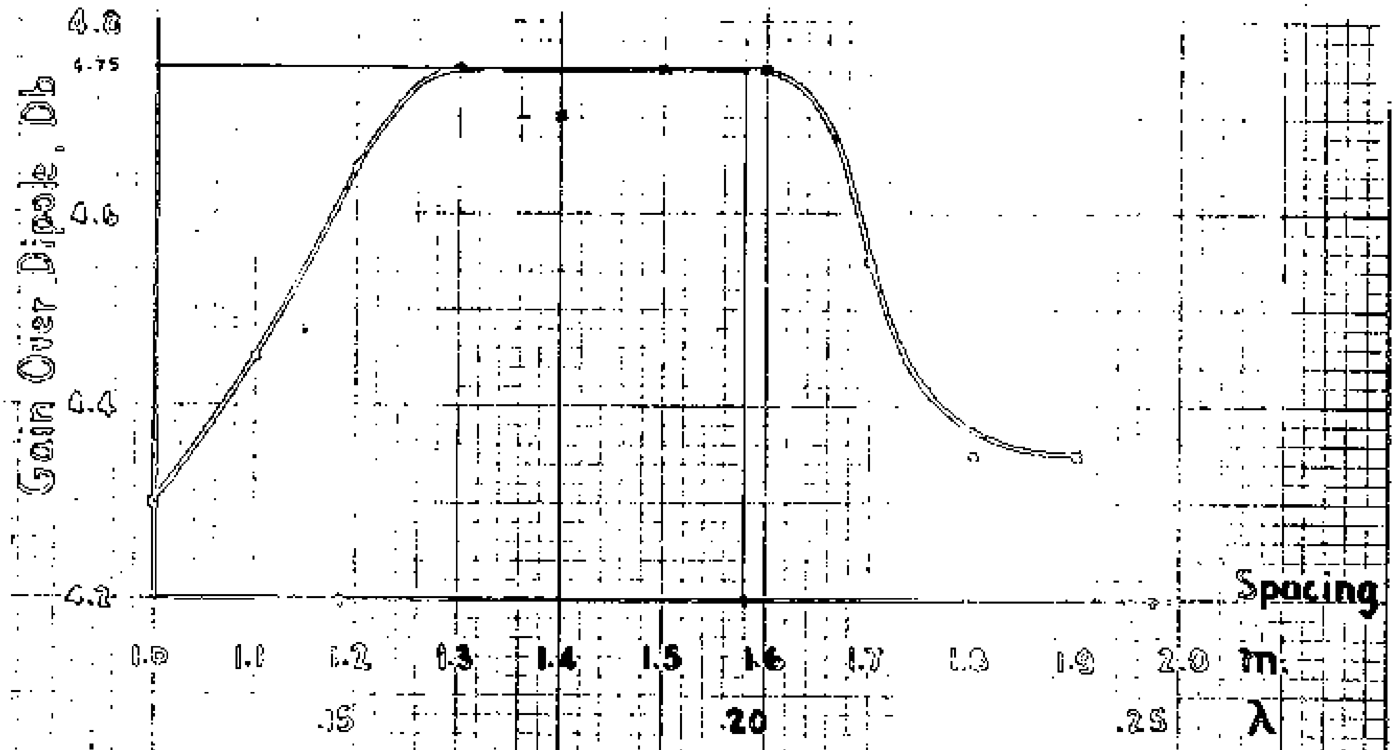


Fig. 2 - 22. Curve of Gain Over Dipole vs. Reflector's Spacing.

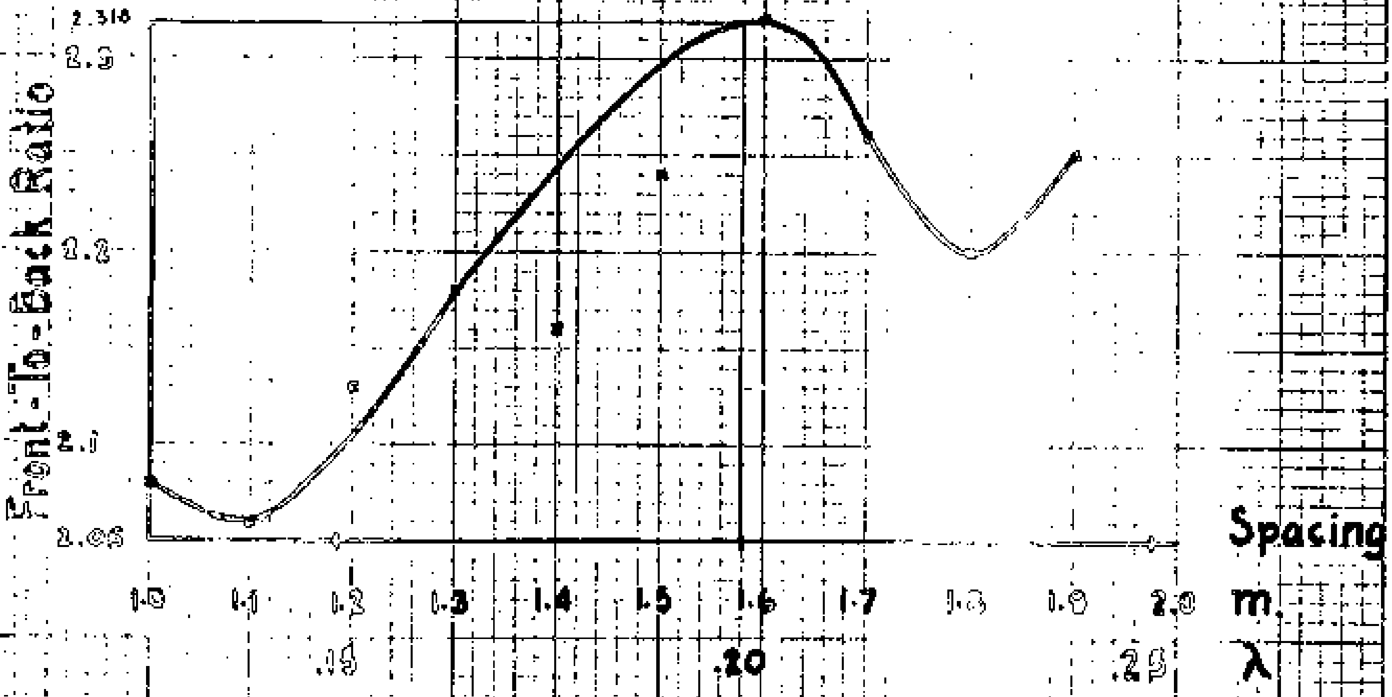


Fig. 2 - 23. Curve of Front-To-Back Ratio vs. Reflector's Spacing.

0.2 λ from the driven elements will give better operation than other spacings. The gain and front-to-back ratio are in the optimum ranges and the input resistances are nearly constant; i.e., at 47.5 ohms for frequency 16.85 Mc, and 47.75 ohms for frequency 38.035 Mc. At these values, the antennas can be well matched with the coaxial lines with characteristic impedance 48 ohms such as RG-26A/U, RG-27/U, RG-64A/U, RG-25A/U, RG-28/U, or the general-purposes, 51 ohms, RG-8/U coaxial line can be used in practical operation without appreciable mismatch.

2-6a. The Vertical Polar Diagram. As shown in Sec. 6-3, the electric field intensity at a large distance from the array as a function of ϕ according to (6-21) is:

$$E(\phi) = kI_1 \left(1 + \left| \frac{Z_{12}}{Z_{22}} \right| \underline{/\pi + \theta_{12} - \theta_{22} + d_r \cos \phi} \right) \qquad (2\text{-}13)$$

where ϕ is related to the antenna as shown in Fig. 2-24.

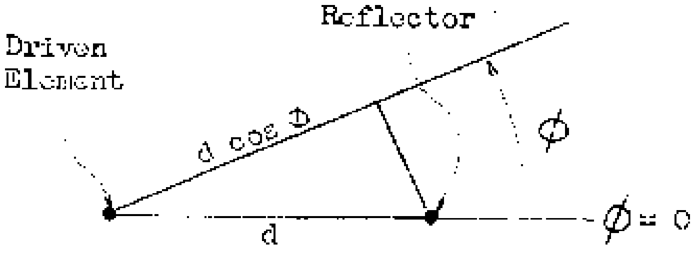


Fig. 2-24. Relation of vertical angle ϕ to antenna's elements.

Z_{12} = mutual impedance between both elements.

Z_{22} = self-impedance of parasitic element.

$d_r = \frac{2\pi d}{\lambda}$

$\theta_{12} = \text{arc tan} \frac{X_{12}}{R_{12}}$, $\theta_{22} = \text{arc tan} \frac{X_{22}}{R_{22}}$

The above pattern given in (2-13) is called the array factor, the total pattern will be the pattern of array factor multiplied by the pattern of the $\lambda/2$ driven antenna.

For Night Frequency Antenna

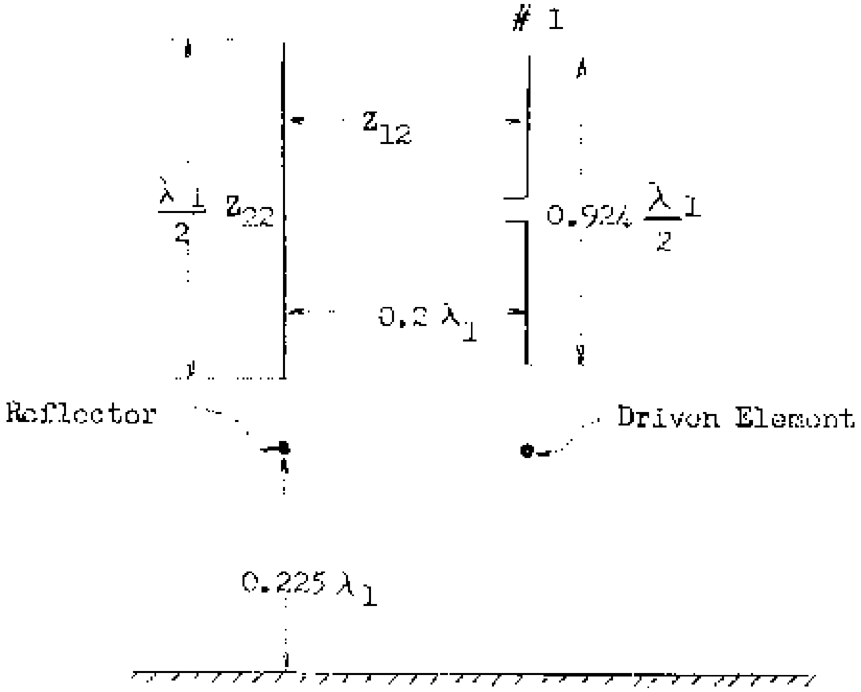


Fig. 2-25. Relation of antenna and ground.

The array factor of the antenna operating at night frequency can be calculated as follows:

Since the tuned parasitic element is exactly $\lambda_1/2$ long, then Z_{22}, from Sec. 5-2, is 73 + j42.5 ohms. Even though the length of both elements are not exactly the same at $\lambda_1/2$, but we may assume that they are, and take the approximate value of the mutual impedance between both elements at $0.2\lambda_1$ spacing from Fig. 5-10, to be:

$$Z_{12} = 52 - j22 \text{ ohms}$$

$$d_r = \frac{2\pi \times 0.2\lambda_1}{\lambda_1} = 0.4\pi = 72^\circ$$

$$\theta_{12} = -23^\circ$$

$$\theta_{22} = 30.25^\circ$$

$$\left|\frac{Z_{12}}{Z_{22}}\right| = \frac{56.5}{84.4} = 0.67$$

Then the array factor as a function of ϕ can be calculated from

$$E(\phi) = kI_1(1 + 0.67 \underline{/126.75^\circ + 72^\circ \cos\phi})$$

assuming unity current in the driven antenna, hence

$$E(\phi) = k(1 + 0.67 \underline{/126.75^\circ + 72^\circ \cos\phi})$$

let $Q = (1 + 0.67 \underline{/126.75^\circ + 72^\circ \cos\phi})$

then $E(\phi) = kQ$

The calculated values of Q at various angles ϕ are tabulated below.

ϕ (deg.)	Q	ϕ (deg.)	Q
0	0.424	100	0.96
10	0.42	110	1.10
20	0.40	120	1.20
30	0.37	130	1.30
40	0.33	140	1.37
50	0.35	150	1.423
60	0.40	160	1.45
70	0.5225	170	1.47
80	0.62	180	1.49
90	0.805		

The array factor is plotted in polar coordinate in Fig. 2-26. The vertical pattern of half wave dipole above ground can be calculated from (6-14); i.e.,

$$F(\phi) = \cos\left(\frac{2\pi h}{\lambda} \sin\phi \pm 90^\circ\right) \qquad (2\text{-}14)$$

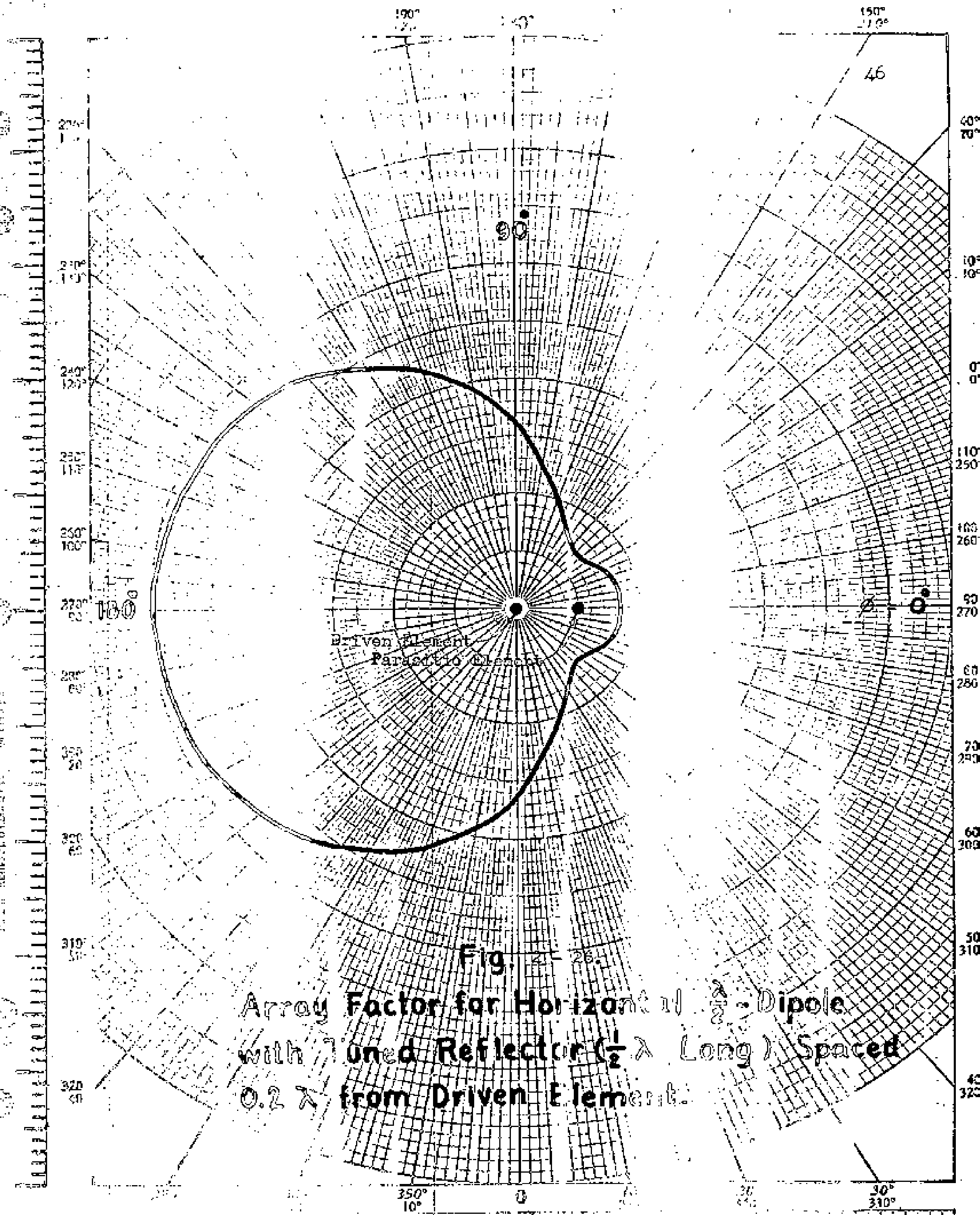


Fig. 2C-26.

Array Factor for Horizontal $\frac{\lambda}{2}$ - Dipole with Tuned Reflector ($\frac{1}{2}\lambda$ Long), Spaced 0.2 λ from Driven Element.

for $h = 0.225\lambda$

then $F(\phi) = \cos(81^\circ \sin\phi \pm 90^\circ)$

The calculated values of $F(\phi)$ at various angle ϕ are tabulated below.

ϕ (deg.)	0	10	20	30	40	50	60	70	80	90
$F(\phi)$	0	.243	.4648	.6494	.788	.883	.940	.97	.984	.988

The vertical polar diagram is shown in Fig. 2-27.

Let $E_T(\phi)$ be the total electric field as a function of ϕ. Calculated relative values of $E_T(\phi)$ at various angles ϕ are tabulated below.

ϕ (deg.)	$E_T(\phi)$	ϕ (deg.)	$E_T(\phi)$
0	0	100	.945
10	.102	110	1.067
20	.186	120	1.127
30	.24	130	1.148
40	.26	140	1.08
50	.309	150	.925
60	.376	160	.673
70	.507	170	.357
80	.61	180	0
90	.795		

The complete vertical pattern of electric field intensity of a half-wave dipole antenna 0.225λ high from ground with tuned parasitic element acts as reflector spaced 0.2λ from driven element is shown in

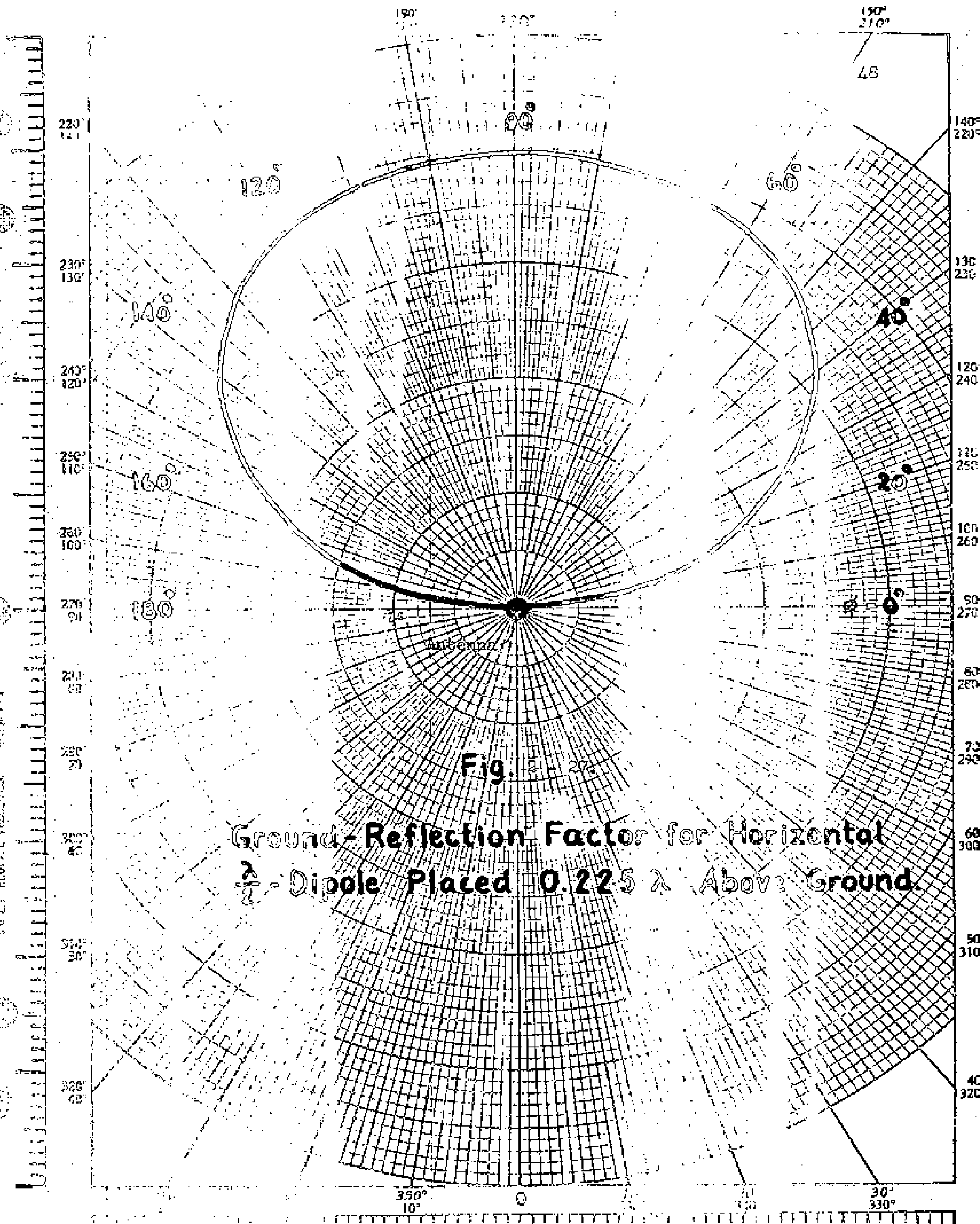


Fig. 2-27

Ground-Reflection Factor for Horizontal $\frac{\lambda}{2}$-Dipole Placed 0.225 λ Above Ground.

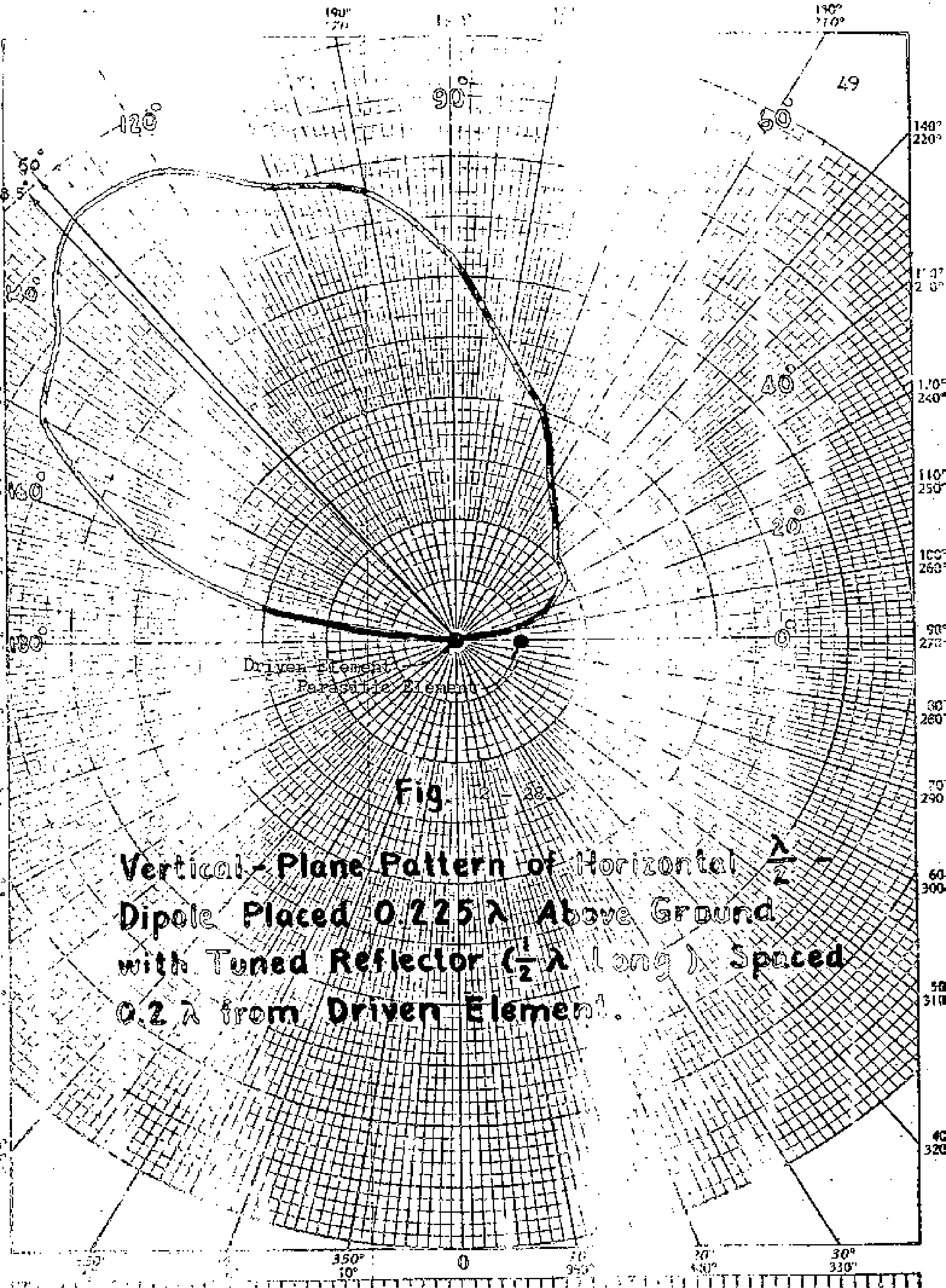


Fig. 12-28

Vertical-Plane Pattern of Horizontal $\frac{\lambda}{2}$-Dipole Placed 0.225 λ Above Ground with Tuned Reflector ($\frac{1}{2}\lambda$ long) Spaced 0.2 λ from Driven Element.

Fig. 2-28. This pattern is a theoretical one with wave angle at 50°, but in reality the pattern may be much more irregular. However, the angle of maximum radiation is believed to be more or less in the vicinity of 50°. The required wave angle for night time propagation is at 48.5°, which is quite close to the theoretical one. Thus, this antenna's setting is felt to be useful for the purpose.

For Day Frequency Antenna

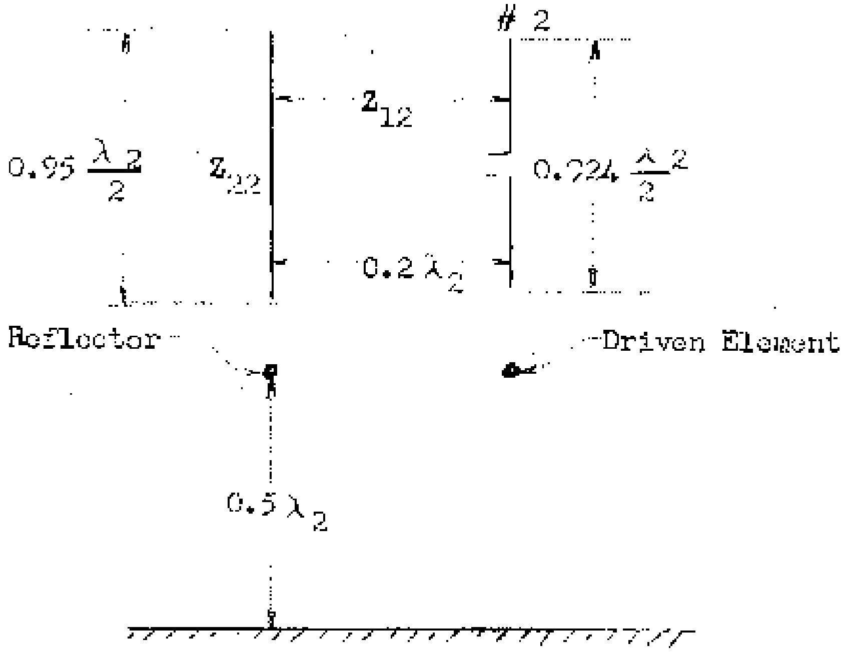


Fig. 2-29. Relations of antenna and ground.

The array factor of the antenna operating at day frequency can be calculated from (2-13) as follows:

Since the self-resonant parasitic element is $0.95\ \lambda_2/2$ long, then Z_{22} should be pure resistive, because 0.95 is the correction factor that shortened the antenna to make it a resonant one. Then,

$$Z_{22} = 73 + j0 \text{ ohms}, \quad \theta_{22} = 0^\circ$$

The approximate value of mutual impedance between both elements, taken from Fig. 5-10, Sec. 5-5, to be

$$Z_{12} = 52 - j22 \text{ ohms}, \quad \theta_{12} = -23^\circ$$

$$\left| \frac{Z_{12}}{Z_{22}} \right| = \frac{56.5}{73} = 0.774$$

Then the array factor as a function of ϕ can be calculated from

$$E(\phi) = kI_1 \left(1 + 0.774 \, \underline{/157^\circ + 72^\circ \cos\phi} \right)$$

assuming unity current in the driven antenna, then

$$E(\phi) = k\left(1 + 0.774 \, \underline{/157^\circ + 72^\circ \cos\phi} \right)$$

$$= kQ$$

where Q = value in parenthesis.

The calculated values of Q at various angles ϕ is tabulated below:

ϕ (deg.)	Q	ϕ (deg.)	Q
0	.764	100	.575
10	.74	110	.76
20	.70	120	.92
30	.61	130	1.02
40	.51	140	1.10
50	.38	150	1.18
60	.28	160	1.23
70	.22	170	1.30
80	.31	180	1.316
90	.417		

The array factor is shown in the polar plot in Fig. 2-30.

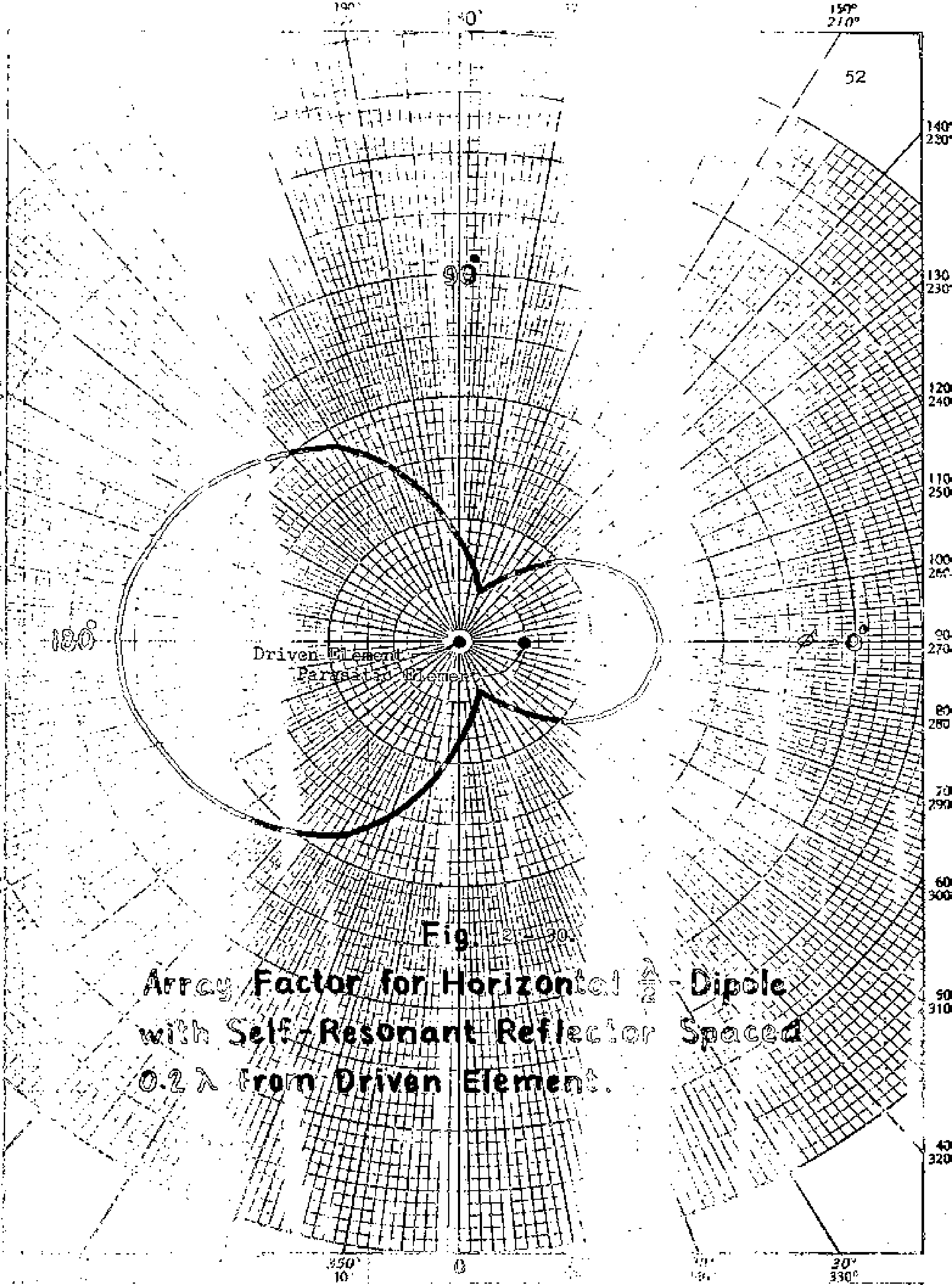


Fig. 2-30.

Array Factor for Horizontal $\frac{\lambda}{2}$ - Dipole with Self-Resonant Reflector Spaced 0.2 λ from Driven Element.

The vertical pattern of half-wave dipole above ground at the height of 0.5 λ can be calculated from:

$$F(\phi) = \cos(180^\circ \sin\phi \pm 90^\circ)$$

The calculated relative values of F(ϕ) at various angles ϕ are tabulated below.

ϕ (deg.)	0	10	20	30	40	50	60	70	80	90
F(ϕ)	0	2.25	3.4	4.0	3.6	2.7	1.6	.40	.13	0

The vertical polar diagram is shown in Fig. 2-31.

Let $E_T(\phi)$ be the total electric field as a function of ϕ . Calculated relative values of $E_T(\phi)$ at various angles ϕ are tabulated below.

ϕ (deg.)	$E_T(\phi)$	ϕ (deg.)	$E_T(\phi)$
0	0	100	.08
10	1.666	110	.17
20	2.38	120	1.472
30	2.44	130	2.75
40	1.836	140	3.96
50	1.026	150	4.72
60	.448	160	4.18
70	.17	170	2.925
80	.07	180	0
90	0		

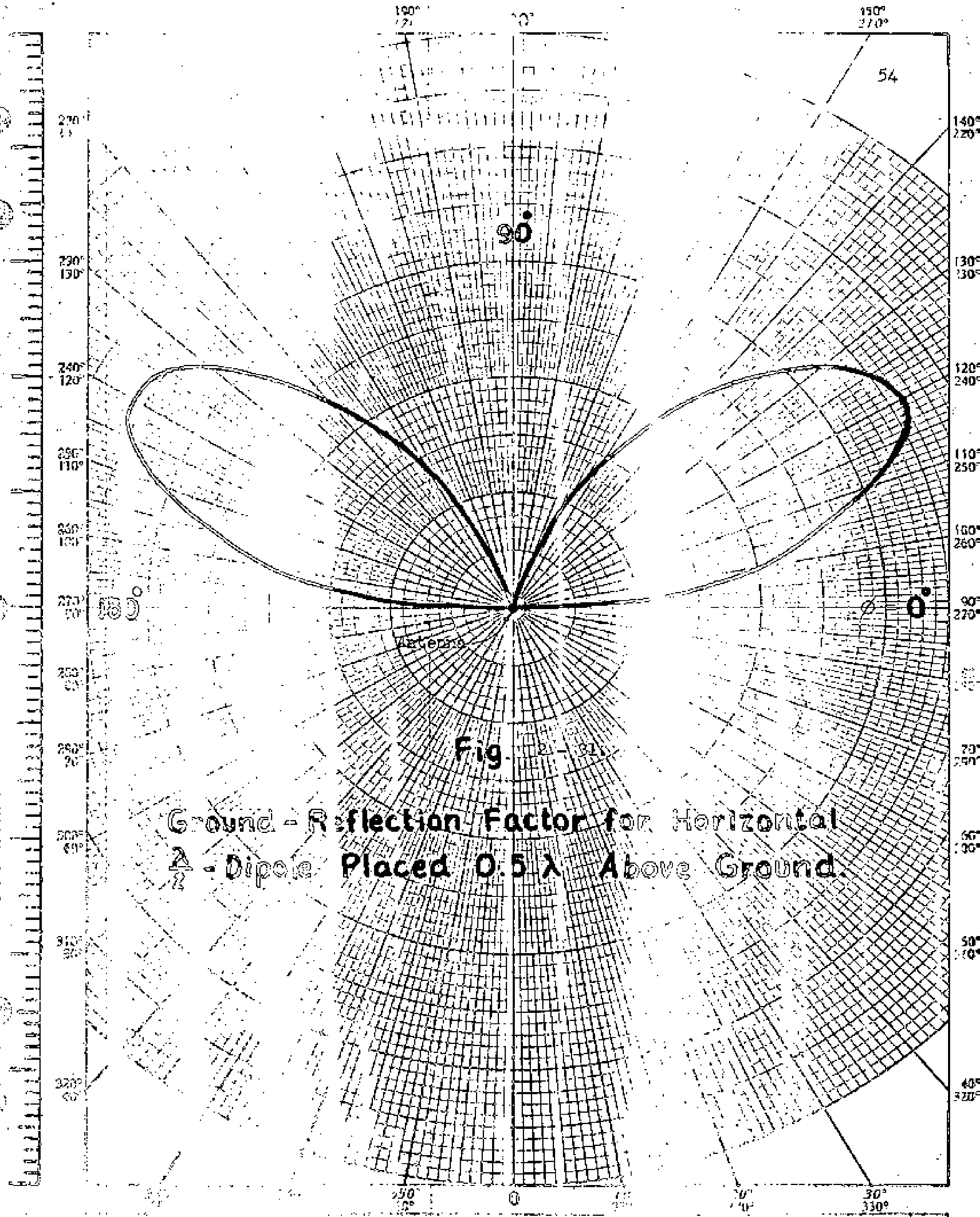


Fig 2-31.

Ground - Reflection Factor for Horizontal $\frac{\lambda}{2}$ - Dipole Placed 0.5 λ Above Ground.

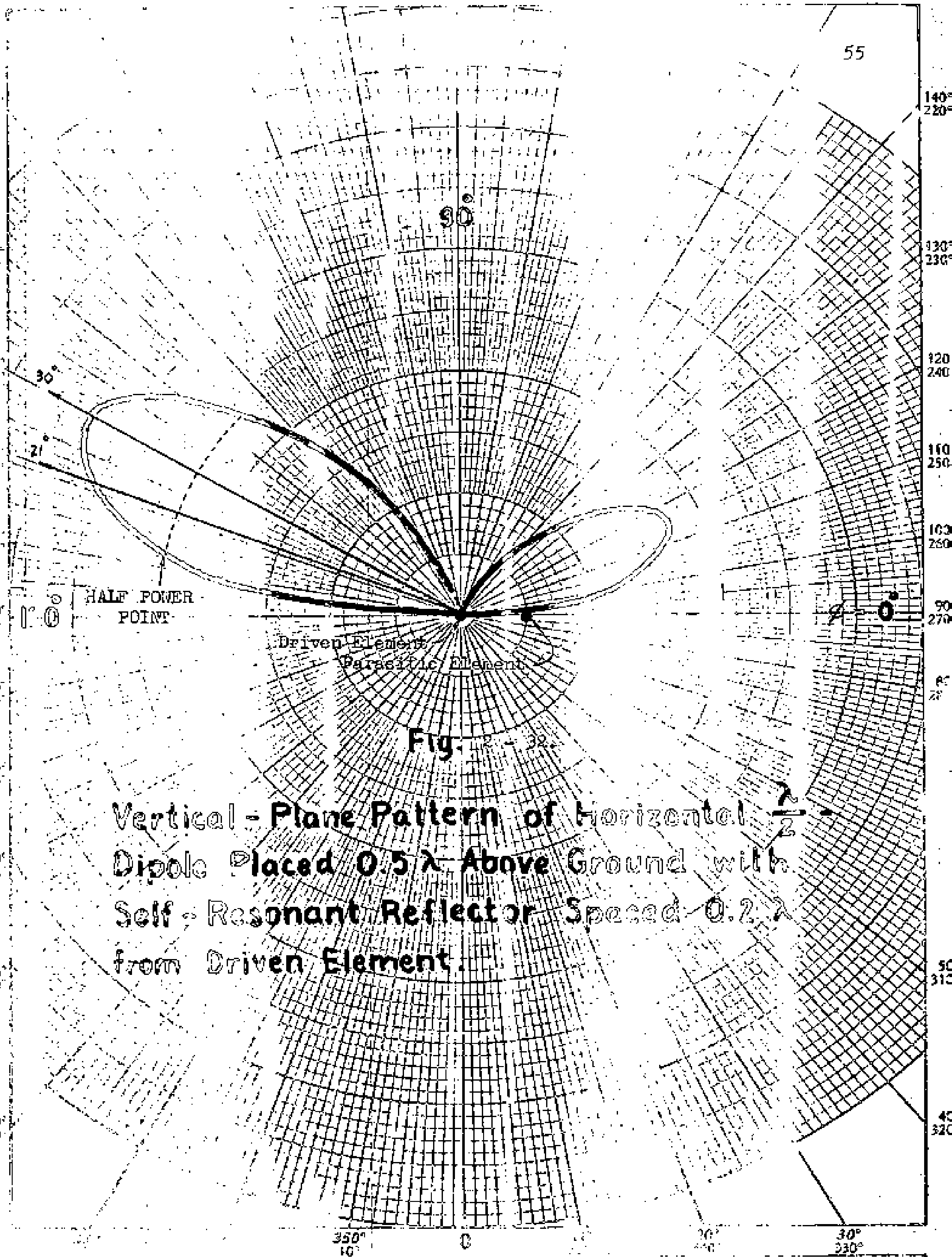


Fig. 2-32

Vertical - Plane Pattern of Horizontal $\frac{\lambda}{2}$ - Dipole Placed 0.5 λ Above Ground with Self - Resonant Reflector Spaced 0.2 λ from Driven Element.

The complete vertical pattern of electric field intensity of a half-wave dipole antenna 0.5 λ high above ground with self-resonant parasitic element acts as a reflector spaced 0.2 λ from driven element is shown in Fig. 2-32. This pattern is a theoretical one with wave angle at 30°, but in reality, the pattern may be much more irregular. However, the angle of maximum radiation is believed to be more or less in the vicinity of 30°. The required wave angle for day time propagation is 21° which is not much deviated from the theoretical one, and when considered the theoretical pattern, at angle 21° the magnitude of the field strength is still much greater than that at the half power point. Thus, it is believed that this setting of antenna is useful for the purpose.

2-7. The Design for Any Set of Frequency

In the experiment, a preselected pair of day and night frequencies (7.607, 3.370 Mc) is used. However, any set of day and night frequencies with the ratio of approximately 2 : 1 can be used with expected the same results.

2-7a. Facts about Domestic Circuits. In domestic point-to-point communication circuits which have the range of about 500 Km, the HF radio wave should be seperated into day and night frequency according to the diurnal changes of the ionospheric layers. The night frequency should have the range between 3 to 5 Mc and the day frequency should have the range between 5 to 10 Mc. The night frequency propagates by reflection at F_2 layer which has the effective height of 300 Km, the proper wave angle should be 48.5°. The day frequency propagates by reflection at E layer which has the effective height of 100 Km, the proper wave angle should be about 21°.

2-7b. Facts about Double Doublet Antennas.

1. Heights above ground of the double doublet antennas should always be at 0.2λ, 0.5λ, 0.75λ, 1λ,.... in order that the input impedance be the same as at infinite height.

2. To make the double doublet antennas as low as possible, applying the 0.5λ height to the day frequency dipole, while the night frequency dipole will be at 0.2 to 0.25λ high according to the ratio of day to night frequency. At this specified height, the input impedances at both frequencies should be around 70 ohms.

3. With the day frequency dipole equipped with self-resonant reflector ($0.95\lambda/2$ long) placed 0.2λ from the driven element, and the night frequency dipole equipped with tuned reflector ($\lambda/2$ long) placed 0.2λ from driven element. The driven elements should be shortened to $0.924\lambda/2$ long to reduce the reactive component of the input impedance. At this reflectors' spacing, the gain of the antennas are around 4.7 db, the front-to-back ratio are in the vicinity of the maximum value; i.e., at 2.3, and the input impedances are around 50 ohms, at both frequencies. The theoretical wave angles obtained at this spacing are 30° for day frequency and 50° for night frequency which are essentially suitable for propagations.

The above rules for double doublet antennas are shown in form of diagram in Fig. 2-33 as a guide for any night frequency f_1 and day frequency f_2. With the guide diagram as shown in Fig. 2-33, one should substitute the values of wavelength in hand into λ_1 and λ_2, and should

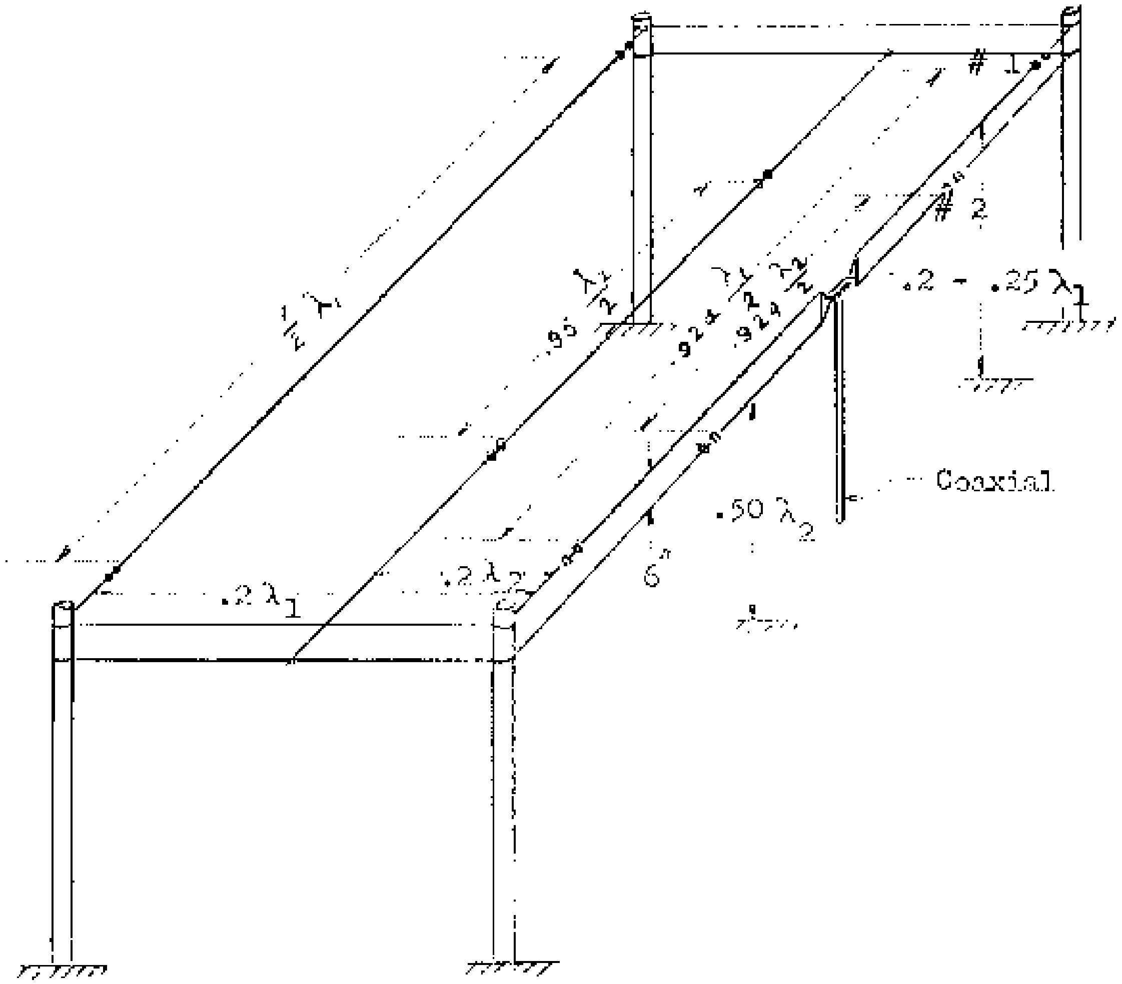


Fig. 2-33. Relations of various dimensions to wavelengths.

expect to have the same characteristics as the one in this experiment as long as the dimensions are as accurate and the site is equally unobstructed.

2-8. Conclusions

The experimental results obtained during this investigation demonstrate a promising new approach to the design of the point-to-point communication antenna by using the double doublet antennas with reflectors. Many configurations of double doublet antennas with reflectors have been built and tested. Those which give constant input impedance, high gain and high front-to-back ratio with proper wave angle for both frequencies have been reported here. The configuration obtained in setting both dipole antennas in parallel on the same support to have constant input impedance all the time is unique. The input impedance obtained are approximately 48 ohms at both frequencies, this runs closely with the established theory. The experimental results reaffirmed that even though two sets of dipole antenna with its reflector are suspended on the same support and fed with common feed line, they have no effects on each other at all.

Once the two sets of antenna are proved to be independent of each other, then the characteristics of each set can be viewed seperately as a single dipole and one reflector at each operating frequency. Thus, it is felt that a theoretical investigation of this kind of antenna would be most fruitful. The gain over dipole of about 4.5 db and the front-to-back ratio of about 2.3 for both frequencies are about what should be expected for this kind of antenna. Fortunately, the height restrictions of both antennas have an advantage on propagations. With day frequency antenna at 0.5λ high above ground, the take-off angle should be approximately 30°, and with night frequency antenna at 0.225 λ high from ground, the take-off angle should be approximately 50° which are essentially close to the required angles; i.e., at 21° and 48.5° respectively. The whole set of antenna can be constructed easily with minimum cost and with greatest economy in land area. For H·F communication between point-to-point in domestic circuit, this antenna is felt to be of great use and expected to be used popularly.