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A BROADBAND, ISOTROPIC, REAL-TIME, ELECTRIC-FIELD SENSOR (BIRES) USING RESISTIVELY LOADED DIPOLES

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A Broadband, Isotropic, Real-Time, Electric-Field Sensor (BIRES) Using Resistively Loaded Dipoles

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A broadband, isotropic, real-time, electric-field sensor (BIRES) developed by the National Bureau of Standards (NBS) consists of three resistively loaded dipoles mounted orthogonally to each other. It has the capability of measuring a complete description of frequency, polarization, magnitude, and phase information of the incident electromagnetic (EM) field. The typical tangential sensitivity of the BIRES is 13 to 16 μV/m with a usable dynamic range of 125 to 144 dB for various bandwidths in the frequency range of 10 MHz to 1 GHz. The isotropic response, isotropy, of the BIRES is obtained by calculating the Hermitian magnitude of the incident electric field, and its variation is found to be less than ± 1 dB.

Key words: Broadband; dynamic range; electric-field sensor; Hermitian magnitude; isotropy; resistively loaded dipole; tangential sensitivity.

1. INTRODUCTION

Recently, there has been a steady increase in the use of microwave energy for commercial, industrial, consumer, and military applications. This has created a need to measure the electromagnetic (EM) field strength in near- and far-field regions over a broadband frequency range of any polarization emanating from various sources operating at many different frequencies and traveling in any direction. For this reason, various types of EM sensors have been developed.

The National Bureau of Standards (NBS) has developed several energy density meters (EDMs), which consist of three orthogonal dipoles with diode detectors connected between the arms of the dipoles. There are also several kinds of commercially available radiation monitors (RMs), composed of three orthogonal elements consisting of thin-film thermocouples deposited on a plastic substrate. In these devices, the detected signals from the orthogonal elements of the field sensor (a dipole with a diode or with a thermocouple) are proportional to the square of the corresponding electric-field strengths, which can then be readily converted into units of mW/cm^2.

However, EDMs and RMs measure only the Hermitian magnitude of an electric-field strength and destroy its frequency and phase information. Frequency, phase, and magnitude information of an EM field are particularly essential for short duration, impulsive EM measurements. Since an EDM with a beam lead Schottky barrier diode and an RM with a high input impedance voltmeter consist of electrically short dipoles with high impedance loads, their responses are relatively flat over the frequency range below the first dipole resonance frequency [1]. However, near the first dipole resonance frequency, the responses of these devices generally increase, and accurate EM-field-intensity measurements will not be possible. For this reason, a broadband, isotropic, real-time, electric-field sensor (BIRES) using resistively loaded dipoles was considered.

A resistively loaded dipole developed by NBS has several unique properties which make this antenna useful as a BIRES. The dipole has linear magnitude and phase response over a broadband frequency range typically between 10 MHz and 1 GHz. These characteristics provide the unique capability for measuring fast, time-varying EM fields with minimal pulse-shape distortion due to nonlinear amplitude or phase characteristics. The dipole also has a relatively effective filtering action so that EM signals outside the frequency range from 10 MHz to 1 GHz will be rejected. This characteristic prevents any outband response.

This antenna system provides a substantial improvement over the previous antennas used for EM energy density measurements. The antenna will provide magnitude, phase, polarization, and frequency information of the EM environment. It has the ability to measure electric-field strengths (i.e., magnitude, phase, polarization, and frequency) over 10 MHz to 1 GHz in quick succession, a procedure prohibited until now because of the need to physically change antennas.

The purpose of this paper is to discuss the basic characteristics of a BIRES using resistively loaded dipoles. Section 2 discusses briefly the theoretical concepts and the characteristics of a resistively loaded dipole. The design considerations for a BIRES using resistively loaded dipoles are then given in section 3. The calibration of the BIRES in terms of its antenna factor is given in section 4.

2. A RESISTIVELY LOADED DIPOLE

2.1 Theoretical Considerations

If a cylindrical antenna has a tapered resistive loading such that the internal impedance per unit length $Z^i(z)$ is a particular function of position along the antenna, Wu and King [2,3] found that a pure outward traveling wave can exist on an antenna of finite length, h, and radius, a. That is, if the impedance loading is given by:

$$Z^i(z) = \frac{60\psi}{h - |z|} \quad , \tag{1}$$

where:

$$\psi \cong 2\left[\sinh^{-1}\frac{h}{a} - C(2ka,2kh) - jS(2ka,2kh)\right] + \frac{j}{kh}\left(1 - e^{-j2kh}\right) \quad ,$$

and C(a,x) and S(a,x) are the generalized cosine and sine integrals, then the approximate current distribution for the one-dimensional wave is a traveling wave such that:

$$I_z(z) = \frac{V_o}{60\psi(1 - j/kh)} \left(1 - \frac{|z|}{h}\right) e^{-jk|z|} \quad . \tag{2}$$

The solution $e^{+jk|z|}$ does not satisfy the original wave equation. Since the frequency dependence of $Z^i(z)$ appears only in the form of a logarithm for small kh, the antenna has much broader frequency characteristics than an antenna with lumped resistors located at quarter-wavelengths from the ends of the antenna [4,5].

In the present study, the resistively loaded dipole was analyzed theoretically using the method of moments [6]. Detailed theoretical analyses on this subject are given elsewhere by the first author [7,8,9].

2.2 Fabrication of Continuously Tapered, Resistively Loaded Antennas

The resistive antenna elements are made by depositing, starting at the center and proceeding outward toward the ends, a thin alloy film of varying resistivity as shown in figure 1. This alloy, which consists of approximately 70 percent nickel, 15 percent chromium, 10 percent iron, and 2 percent titanium, has a very high resistivity and a very low temperature coefficient. A glass rod, 15 cm long and 0.7 cm in diameter, was chosen as a substrate for the deposited element. This becomes a half-wave dipole; i.e., $kh = \pi/2$ at 1 GHz. The desired resistive loading profile, which turns out to be a relatively weak function of frequency, is calculated and is shown in figure 1. Typically, the resistive loading required is about $5\ k\Omega/m$ at the driving point, about $10\ k\Omega/m$ at the midpoint, and infinite at the end of the antenna. Knowing the resistivity of the alloy used, it is possible to calculate the required thin-film thickness of the alloy. Typically, this thickness is about 240 nm at the driving point, 100 nm at the midpoint, and zero at the end of the antenna. The photograph of the resistively loaded dipole antenna is shown in figure 2.

2.3 Receiving Characteristics of the Resistively Loaded Dipole

The theoretical results for the receiving transfer function of the resisitvely loaded dipole were obtained using the method of moments [6] in the frequency domain. Figure 3 shows these results along with the experimental results. Here, the receiving transfer function is defined as a ratio of the output voltage of the antenna to the normal incident electric-field strength. It is found from figure 3 that the resistively loaded dipole has a frequency response that is flat to ± 3 dB from 200 MHz to over 3 GHz, whereas its frequency response rolls off at -6 dB per octave below 200 MHz.

The transient response of the resistively loaded antenna was also evaluated experimentally on the time-domain antenna range with a time-domain automatic network analyzer (TDANA). The TDANA measures the time-domain waveform of the impulse response of the antenna. The duration of the impulse used in the theory and the experiments is typically 100 ps. The time-domain waveform is then digitized and stored in a minicomputer memory. By acquiring an ensemble of many waveforms, it is possible to perform signal averaging within the minicomputer to improve the signal-to-noise ratio in the measurements. The minicomputer then computes the spectrum amplitude from the digitized, averaged waveform using the fast Fourier transform (FFT). The frequency response thus obtained experimentally is also shown in figure 3. The theoretical and experimental results are in generally good agreement. Figure 3 indicates that the receiving characteristic of the resistively loaded dipole is well behaved. The antenna should find very wide application as a standard receiving antenna for the measurements of fast, time-varying, transient EM fields.

2.4 Far-Field Radiation Patterns

The electric field of the resistively loaded antenna for the far-field regions is rigorously given by:

$$E_\theta(r) = j\omega \sin\theta \, A_z$$

$$= \frac{j\omega\mu_o \sin\theta}{4\pi} \int_{-h}^{h} I_z(z') \frac{e^{-jk\sqrt{r^2 + z'^2 + 2rz'\cos\theta}}}{\sqrt{r^2 + z'^2 + 2rz'\cos\theta}} dz' \; . \qquad (3)$$

This integration is carried out numerically using the current distribution $I_z(z)$ obtained by the method of moments.

Using the current distribution given by the Wu-King approximation in eq (2), the far-field radiation patterns can also be calculated analytically, yielding [2]:

$$E_\theta^f(r) = \frac{jV_o}{\psi(1 - j/kh)} \cdot \frac{F(kh,\theta)}{r} \qquad (4)$$

where:

$$f(kh,\theta) := \frac{-jkh \sin^2\theta + (1+\cos^2\theta) - [j2\cos\theta \sin(kh\cos\theta) + (1+\cos^2\theta)\cos(kh\cos\theta)]e^{-jkh}}{kh \sin^3\theta} \; .$$

The experiments to obtain the radiation pattern were performed using a near-field calibration range for the frequency range between 700 MHz and 5 GHz. The experimental and theoretical results of the far-field radiation patterns are shown in figures 4(a), 4(b), 4(c), 4(d), and 4(e) for several frequencies. As shown in figures 4(a) and 4(b), the radiation patterns of the resistively loaded antenna are well behaved at frequencies below 1 GHz, $kh < \pi/2$, and are very similar to those of a metal dipole with the same electrical length, $2h = 15$ cm. As frequency increases above 1 GHz, $kh > \pi/2$, the radiation patterns of a 15 cm long, metal dipole split and result in many sidelobes as shown in figures 4(c), 4(d), and 4(e). However, figure 4(c) indicates that the 15 cm long, resistively loaded dipole still has a well-behaved electric-field pattern up to 2.5 GHz, $kh = 2.5(\pi/2)$. At 5 GHz, $kh = 5(\pi/2)$, the radiation pattern of the resistively loaded dipole splits and results in sidelobes as shown in figure 4(d). For further reference, the radiation pattern of the resistively loaded antenna at 10 GHz, $kh = 10(\pi/2)$, is shown in figure 4(e). It was thus found that the 15 cm long, resistively loaded dipole discloses a well-behaved, radiation pattern up to 2.5 GHz, $kh = 2.5(\pi/2)$; whereas a 15 cm long, metal dipole has a well-behaved electric-field pattern only up to 1 GHz, $kh = \pi/2$, as expected.

3. BROADBAND, ISOTROPIC, REAL-TIME, ELECTRIC-FIELD SENSOR (BIRES)

3.1 Design Configurations

A BIRES consists of three resistively loaded dipoles. The protective mount is made of a polycarbonate core, nylon dipole holders, and epoxy fiber glass tubing for the main support. The housing provides for mounting orthogonally the three dipoles, a set of three baluns, and a set of three coaxial cables in a fixed, relative direction as shown in figure 5.

In order to provide an output voltage of at least 2 μV at the BIRES output for an electric-field strength of 15 μV/m meter, a shaping amplifier, a booster amplifier, and a 30-dB attenuator are incorporated in a coaxially switched system. A block diagram of the BIRES switching system is shown in figure 6. For the BIRES frequency response to be flat over the frequency range from 10 MHz to 1 GHz, a shaping amplifier is always used. This amplifier provides additional gain at those frequencies where the frequency response of the resistively loaded dipole falls off.

For measurements of low-level, electric-field strengths below 300 mV/m, both shaping and booster amplifiers are used to provide a proper output, at least 2 μV at an electric-field strength of 15 μV/m. For the measurement of high-level, electric-field strengths above 300 mV/m, a shaping amplifier with a 30-dB attenuator is used in the switching system. The entire setup is shown in figure 6.

3.2 Frequency Response

It is found that the frequency response of each resistively loaded dipole has a 6-dB roll-off below 200 MHz as shown in figure 3. For the overall frequency response of the BIRES to be flat over a frequency range from 10 MHz to 1 GHz, a shaping amplifier is used to compensate a 6-dB roll-off below 200 MHz. The typical power gain of the shaping amplifier is shown in figure 7. The detailed frequency response of the BIRES at low- and high-level settings is given in terms of the antenna factor section 4.

3.3 Tangential Sensitivity

It is common practice to make performance comparisons among various antenna systems based upon input signal sensitivity. One common criterion is tangential sensitivity, usually defined as that input signal which increases the antenna output power by a factor of 2 (i.e., (S+N)/N = 2 or S/N = 1). The signal-to-noise ratio, S/N, of the antenna system can be estimated as:

$$\frac{S}{N} = \frac{V_L^2/Z_L}{k[T_{ant}\,\eta + (1 - \eta)T_o + T_{amp}]B} \; . \tag{5}$$

The symbols have the following meanings: k is Boltzmann's constant ($1.38 \times 10^{-23} JK^{-1}$), T_{ant} is the antenna temperature in kelvins, η is the antenna radiation efficiency, T_o is the ambient temperature in kelvins, T_{amp} is the effective input noise temperature of a field effect transistor (FET) amplifier in kelvins, and B is the bandwidth in hertz. Here, $T_{ant}\eta+(1-\eta)T_o$ is the noise contribution due to the antenna system. If the antenna is surrounded by a 290-K environment, the noise temperature contributed by the antenna system would be 290 K regardless of its radiation efficiency, η.

To estimate the the tangential sensitivities of the BIRES at various frequencies, the noise figures of the broadband, shaping amplifier were measured using an automated noise figure meter and are shown in figure 7. At the same time, the losses due to the balun and the 7.6 m long RG 8A/U cable were also measured using an automated network analyzer. The tangential sensitivities of the BIRES with various bandwidths and frequencies are calculated using eq (5) and are summarized in table 1. The typical tangential sensitivities of the BIRES are 13 to 16μV/m for various bandwidths in the frequency range from 10 MHz to 1 GHz.

3.4 Dynamic Range

The dynamic range of the BIRES is limited by the broadband, shaping amplifier. Typical power gain variations and the output power at the 1-dB gain compression point are shown in figure 7. The output power at the 1-dB gain compression point of the shaping amplifier essentially limits the dynamic range of the BIRES and decreases approximately 20 dB per decade from 20 MHz to 200 MHz. This 20-dB decrease results because the amplifier gain is specially tailored to provide additional gain (20 dB per decade) at those frequencies where the antenna response falls off. To achieve a 20-dB gain roll-off for 20 MHz to 200 MHz, a

20-dB per decade, low-pass filter was added at the final stage of the amplifier so that the noise figure (typically 4 dB) is not degraded. The filter does, however, degrade the output power at the 1-dB gain compression point to approximately -20 dBm. The low amplifier output at the 1-dB gain compression point limits the maximum measurable electric field to about 8 V/m at 30 MHz and 1 V/m at 200 MHz as indicated in table 2. To increase the maximum electric field that can be measured by the BIRES, a 3-dB attenuator is added for the high-level, electric-field measurements. The maximum electric field that can be measured by the BIRES with a 30-dB attenuator (high level) at various frequencies is given in table 2. The relation between the incident electric-field strength and the output of the BIRES at 750 MHz is shown in figure 8. The overall dynamic range of the BIRES with and without a 30-dB attenuator (high level and low level) as a function of bandwidth is given below:

- 152 db (100 Hz BW)
- 142 dB (1 kHz BW)
- 132 dB (10 kHz BW)
- 125 dB (50 kHz BW)

3.5 Isotropy

To achieve isotropy of response for EM radiation measurements, the resistively loaded dipoles are mounted orthogonally to each other. Three separate rf signal outputs from mutually orthogonal dipoles are then fed into a receiver, e.g., a field intensity meter, a spectrum analyzer, etc. The Hermitian magnitudes are meaningful measures of the intensity of complicated electric fields having reactive near-field components, multipath components, and arbitrary polarization. In isotropic media, the Hermitian magnitude of the electric-field strength is defined as:

$$|E| = (|E_x|^2 + |E_y|^2 + |E_z|^2)^{1/2}, \tag{6}$$

in a rectangular coordinate system.

The radiation patterns of each resistively loaded dipole are measured in an anechoic chamber at frequencies between 450 MHz and 1 GHz and are shown in figures 9(a), 9(b), 9(c), 9(d), 9(e), 9(f), and 9(g). The overall radiation patterns of the BIRES are calculated using eq (6) and are also shown in these figures. The overall variation in isotropic response with respect to angle is within ± 1 dB.

4. CALIBRATION OF ANTENNA FACTOR

4.1 Calibration Technique

The BIRES is immersed in a calculable, standard EM field in order to calibrate it. Calibrating fields above 450 MHz are produced in an anechoic chamber by a series of standard-gain pyramidal horns.

To establish a standard field at frequencies above 450 MHz, the radiated field intensity is calculated in the near zone of standard-gain horn antennas. These antennas consist of a series of rectangular pyramidal horns. It is desirable to calibrate the BIRES in far-zone, plane-wave fields. To keep the proximity correction to less than 0.05 dB, the separation distance required between a rectangular pyramidal horn and the BIRES must be on the order of $32\ D^2/\lambda$ where D is the largest dimension of the pyramidal horn and λ is the wavelength. The anechoic room available for the measurements does not, however, meet this requirement. Therefore, a complication known as near-zone gain reduction arises when field strength is calculated near a transmitting antenna. Unlike a field traveling in a waveguide, the EM field across a horn aperture has a somewhat spherical (rather than planar) wavefront. The phase at the rim of the horn lags that at the center, causing a nonequiphase front across the aperture, which reduces the effective gain in the near-field (Fresnel) region. A further reduction occurs, even for an equiphase aperture, due to the difference in distance between the various elements in the radiating aperture and the on-axis field point in question. Both of these "defects" reduce the power density to less than that predicted by the simple far-zone, inverse-square relation of a distant point source.

Larsen [10] has generated simple polynomial expressions, similar to the various algebraic equations which have been published for approximating the Fresnel integrals, to determine the near-zone gain reduction factors, R_H and R_E, for pyramidal horns. The pertinent horn dimensions used in the equations are shown in figure 10, where the dimensions have been normalized to wavelengths by letting:

$$A = \frac{a}{\lambda}, \quad B = \frac{b}{\lambda}, \quad L_H = \frac{\ell_H}{\lambda}, \quad L_E = \frac{\ell_E}{\lambda}, \quad \text{and } D = \frac{d}{\lambda} .$$

Here:

a, b, ℓ_H and ℓ_E = horn dimensions (meters) given in figure 10, d = distance in front of the horn aperture to an on-axis field point (meters), and λ = free-space wavelength (meters).

After defining:

$$\alpha = A^2 \left(\frac{1}{L_H} + \frac{1}{D}\right) \quad \text{and} \quad \beta = B^2 \left(\frac{1}{L_E} + \frac{1}{D}\right) ,$$

the two gain reduction factors, R_H due to the H-plane flare of horn and R_E due to the E-plane flare of horn, expressed in dB, are given by:

$$R_H = (0.01\alpha)\ (1 + 10.19\alpha + 0.51\alpha^2 - 0.097\alpha^3) \tag{7}$$

and

$$R_E = (0.1\beta^2)(2.31 + 0.053\beta) . \qquad (8)$$

Finally, the theoretical gain of the horn (near zone or far zone), expressed in dB, is given by:

$$\text{GAIN} = 10 \log(AB) + 10.08 - R_H - R_E . \qquad (9)$$

4.2 Antenna Factors

The antenna factors of the BIRES are determined by immersing the antenna in the known field generated with standard-gain pyamidal horns in an anechoic chamber for the frequency range from 450 MHz to 1 GHz as described in subsection 4.1, and are shown in figure 11.

The antenna factor K, expressed in dB, is defined as:

$$K = 20 \log(E_s/V) , \qquad (10)$$

where:

E_s = standard electric-field strength (volt/m) generated by a standard-gain pyramidal horn in an anechoic chamber, and

V = rf voltage at the output of the BIRES into a 50-Ω load (receiver).

An unknown field strength, E in dB above 1 μV/m, may be measured with the calibrated BIRES by using the expression:

$$E = K + M \qquad (11)$$

where:

K = antenna factor (dB), and

M = metering circuit indication (dB above 1 μV) of a calibrated 50-Ω receiver.

It is estimated that the standard fields can be established in an anechoic chamber by rectangular pyramidal horns over the frequency range from 450 MHz to 1 GHz with an uncertainty less than ± 1.0 dB [10] by carefully measuring the power delivered to the horns. By estimating the mismatch error between the BIRES and a 50-Ω load receiver to be ± 1.0 dB, the antenna factors of the BIRES given thus have a ± 3-dB uncertainty, including ± 1-dB variation in its isotropic response.

5. CONCLUSIONS

The prototype development and evaluation of a BIRES have been discussed in this paper. The BIRES, which consists of three resistively loaded dipoles mounted orthogonally to each other, allows measurement of three polarization components of broadband electric fields for the frequency range from 10 MHz to 1 GHz. The three separate rf signal outputs from these dipoles provide a complete description of frequency, polarization, magnitude, and phase information of the incident electric field.

The typical tangential sensitivity of the BIRES is 13 to 16 μV/m with a typical usable dynamic range from 125 to 144 dB for various bandwidths at a frequency range from 10 MHz to 1 GHz. The isotropy of response of the BIRES can be obtained by arithmetically evaluating the Hermitian magnitudes of the incident electric field. The variation with respect to angle in isotropy of response is found to be less than ± 1 dB. The antenna factors of the BIRES are determined by immersing the antenna in the standard electric fields produced in the anechoic chamber by rectangular, pyramidal horns for the frequency range from 450 MHz and 850 MHz. The antenna factors below 450 MHz were not determined due to experimental difficulties. However, the evaluation of each component of the BIRES, namely the resistively loaded dipoles, baluns, 30-dB attenuator, shaping and booster amplifiers, and coaxial switches, indicates that the antenna factors of the BIRES are estimated to be flat to within ± 3 dB, and to have a ± 3-dB uncertainty, including the nonisotropic response.

Since the BIRES has a linear magnitude and phase response over a broadband frequency range from 10 MHz to 1 GHz, it has the unique capability to measure fast, time-varying, complicated EM fields.

VII. ACKNOWLEDGMENT

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Table 1. Tangential sensitivities of BIRES.

FREQUENCY IN MHz	TRANSFER FUNCTION IN dB	NOISE CONTRIBUTION: SHAPING AP NF IN dB	NOISE CONTRIBUTION: BALUN LOSS IN dB	NOISE CONTRIBUTION: CABLE LOSS IN dB (7.6m RG 8A/U)	TOTAL NOISE FIGURE IN dB (EFFECTIVE NOISE TEMPERATURE IN K)	V_L IN mV AT 15μV/m	BANDWIDTH IN KHz S/N=1 AT 15μV/m	MINIMAL V_L IN V (TYPICAL BANDWIDTH IN KHz)	TANGENTIAL SENSITIVITY IN μV/m (BANDWIDTH IN KHz)
10	-66	3.5	0.5	0.1	4.1(455)	7.5×10^{-9}	0.11	7.2×10^{-9}(0.1)	14(0.1)
30	-56	3.5	0.5	0.2	4.2(473)	2.4×10^{-8}	1.09	2.3×10^{-8}(1)	14(1)
50	-52	4	0.5	0.4	4.9(606)	3.8×10^{-8}	2.34	3.5×10^{-8}(2)	14(2)
100	-46	4	0.5	0.6	5.1(648)	7.5×10^{-8}	8.69	8.1×10^{-8}(10)	16(10)
300	-38	4	0.7	1.2	5.9(838)	1.9×10^{-7}	46.4	2.0×10^{-7}(50)	16(50)
500	-35	4.5	1.0	1.4	6.9(1130)	2.7×10^{-7}	74.4	2.2×10^{-7}(50)	13(50)
1000	-33	5	1.0	2.1	8.1(1582)	3.4×10^{-7}	89.5	3.6×10^{-7}(100)	16(100)

Table 2. Dynamic ranges of BIRES.

FREQUENCY IN MHz	SHAPING AP GAIN IN dB	MAXIMUM OUTPUT POWER* IN dB	MAXIMUM INPUT POWER* IN dB	MAXIMUM INPUT RF VOLTAGE AT 50Ω LOAD IN V	TRANSFER FUNCTION IN dB	BALUN AND CABLE LOSS IN dB	TOTAL TRANSFER FUNCTION** AT LOW LEVEL	MAXIMUM ELECTRIC FIELD STRENGTH* AT LOW LEVEL IN V/m	DYNAMIC RANGE AT LOW LEVEL IN dB (BANDWIDTH IN KHz)	TOTAL TRANSFER FUNCTION*** AT HIGH LEVEL	MAXIMUM ELECTRIC FIELD STRENGTH* AT HIGH LEVEL IN V/m	DYNAMIC RANGE AT HIGH LEVEL IN dB (BANDWIDTH IN KHz)
20	32.2	1.0	-31.2	6.2×10^{-3}	-60	1.8	-61.8	7.6	114(1)	-91.8	241	144(1)
100	19.5	-11.7	-31.2	6.2×10^{-3}	-46	2.9	-48.9	1.7	99(10)	-78.9	55	129(10)
200	13.5	-17.8	-31.3	6.1×10^{-3}	-41	5.0	-46	1.2	95(50)	-76	38	125(50)
500	11.3	-18	-29.3	1.1×10^{-2}	-35	6.6	-41.6	1.3	96(50)	-71.6	48	126(50)
1000	12.6	-12	-24.6	1.3×10^{-2}	-33	9.0	-42	1.6	97(50)	-72	51	127(50)

* AT 1 dB GAIN COMPRESSION POINT

** TRANSFER FUNCTION OF RESISTIVELY LOADED DIPOLE WITH BALUN AND CABLE (7.6m RG 8A/U)

*** TRANSFER FUNCTION OF RESISTIVELY LOADED DIPOLE WITH BALUN, CABLE (7.6m RG 8A/U) AND 30 dB ATTENUATOR

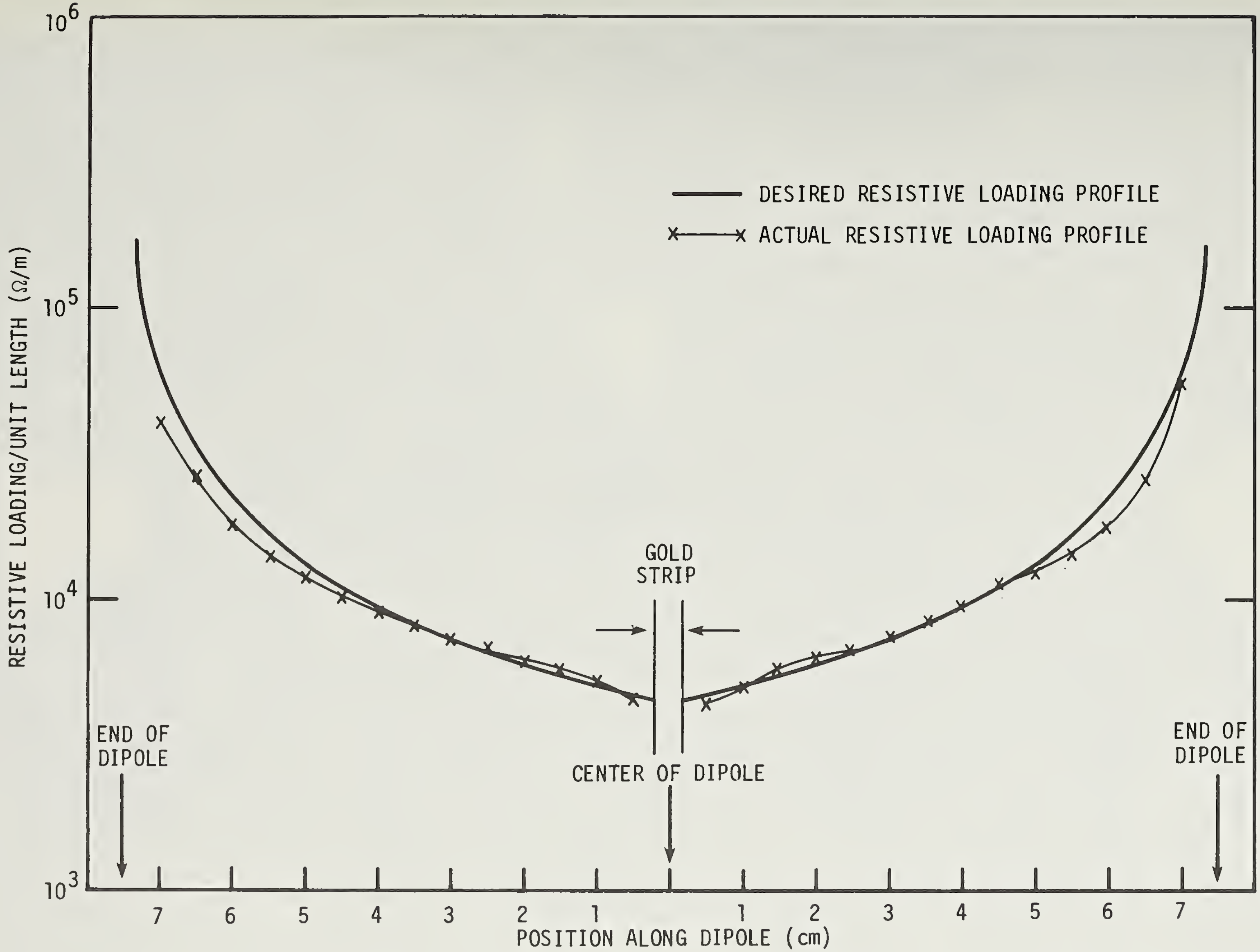

Fig. 1. Resistive loading profile.

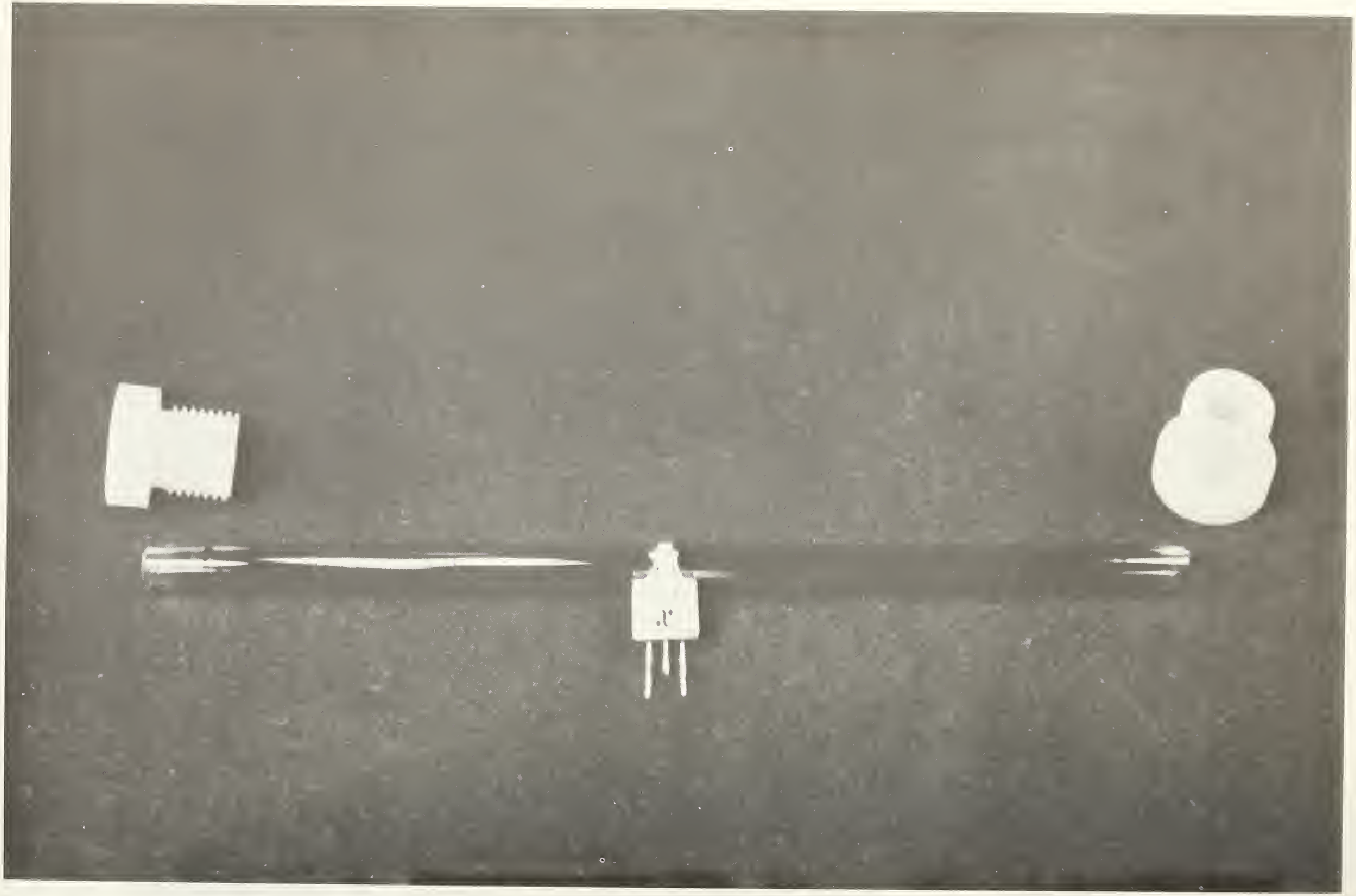

Fig. 2. Resistively loaded dipole.

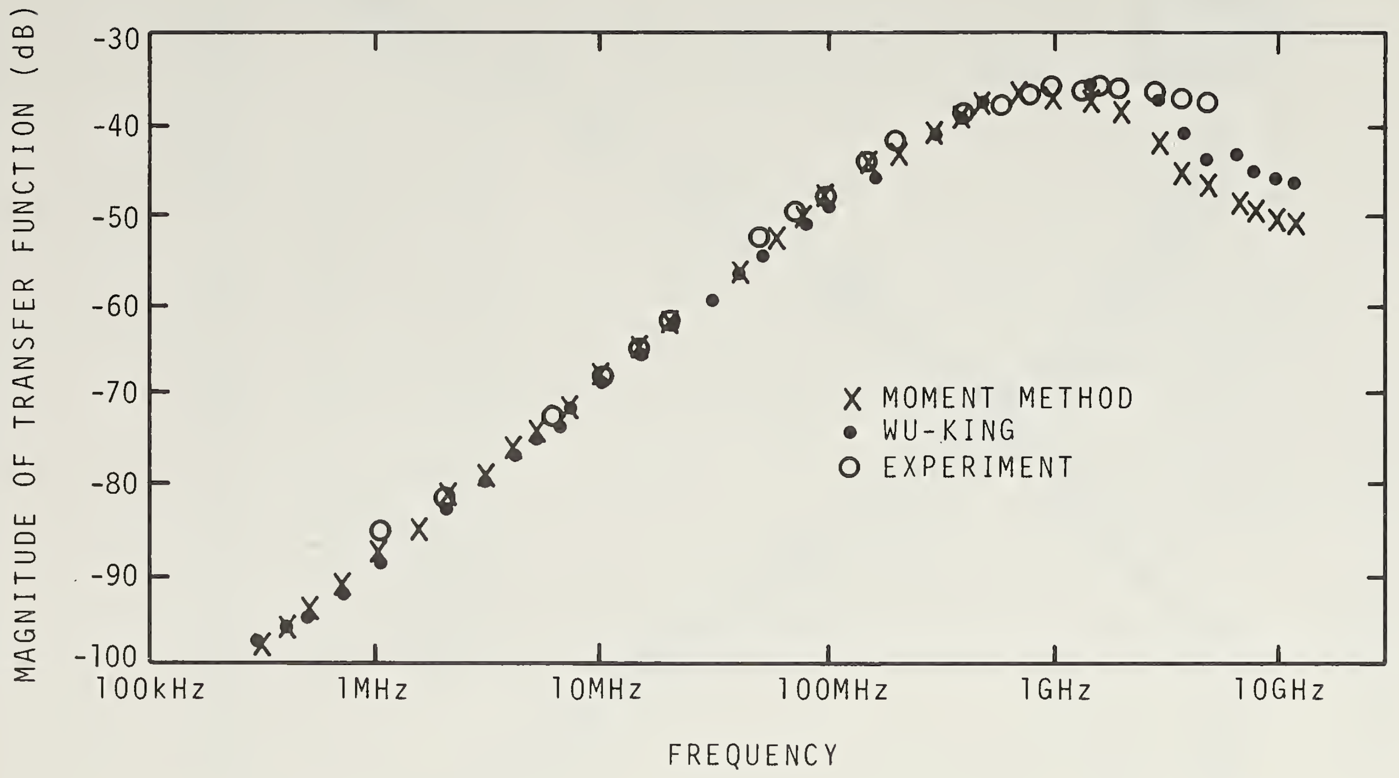

Fig. 3. Receiving transfer function of resistively loaded dipole.

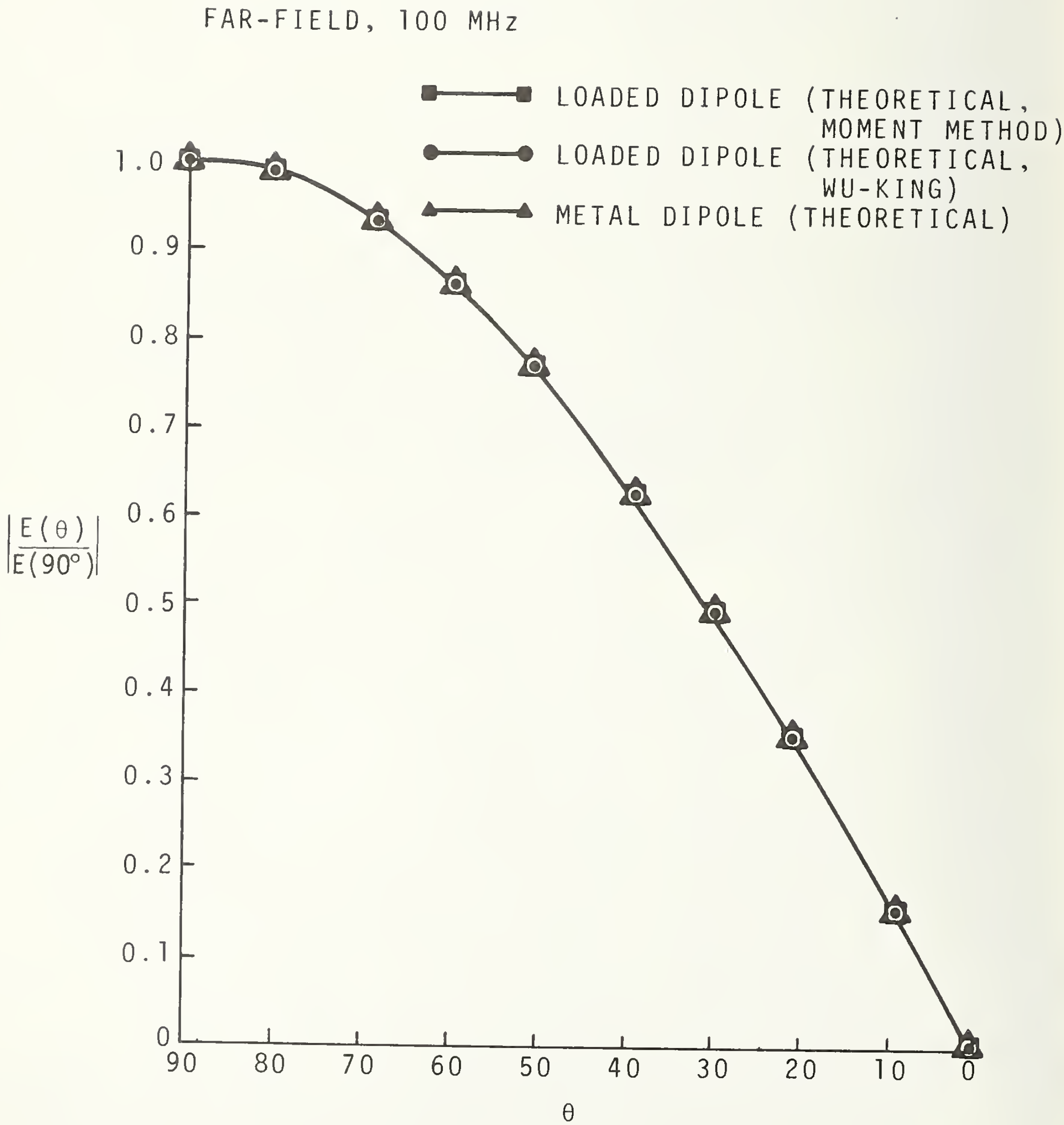

Fig. 4(a). Radiation patterns of resistively loaded dipoles at 100 MHz.

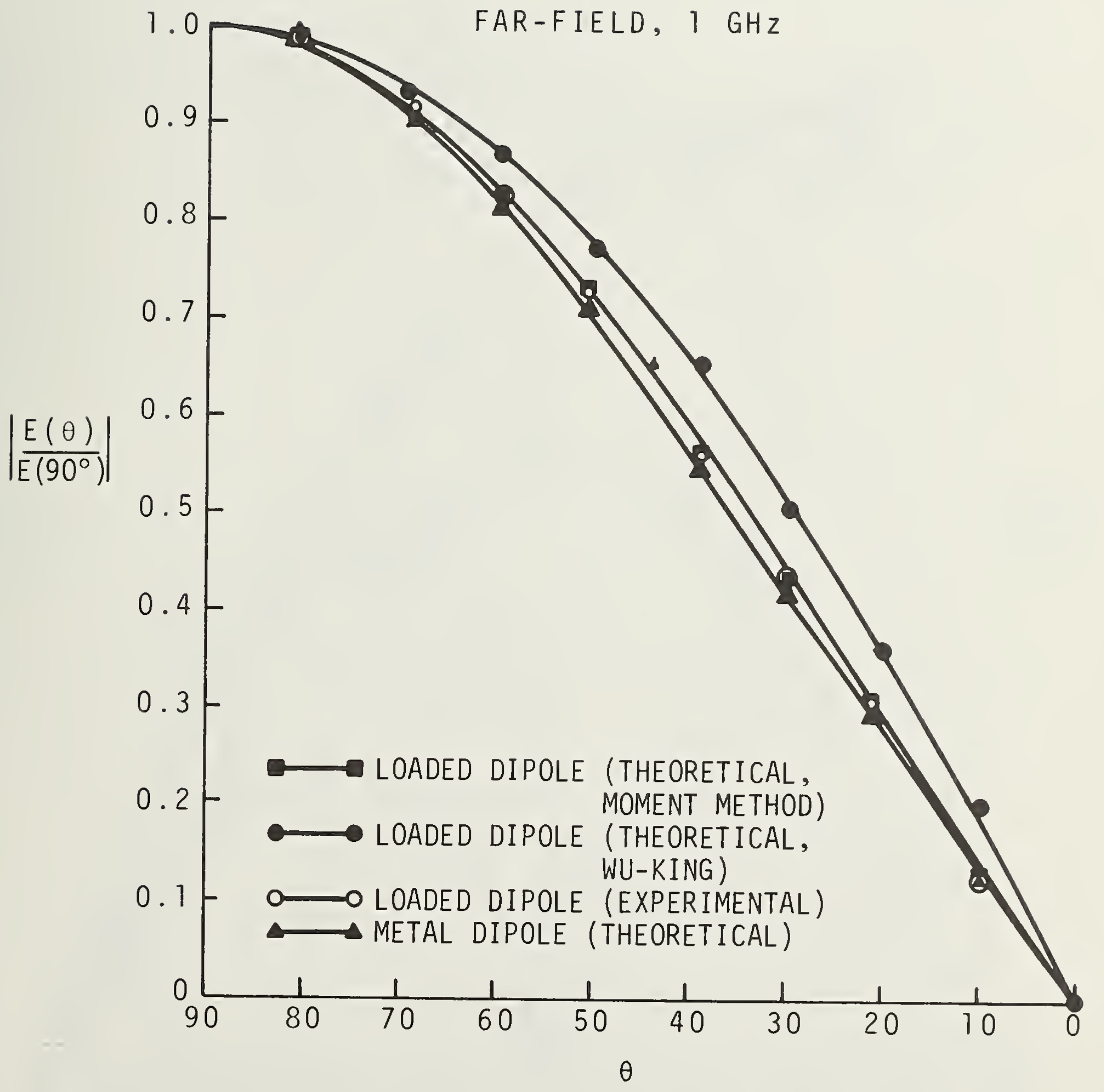

Fig. 4(b). Radiation patterns of resistively loaded dipoles at 1 GHz.

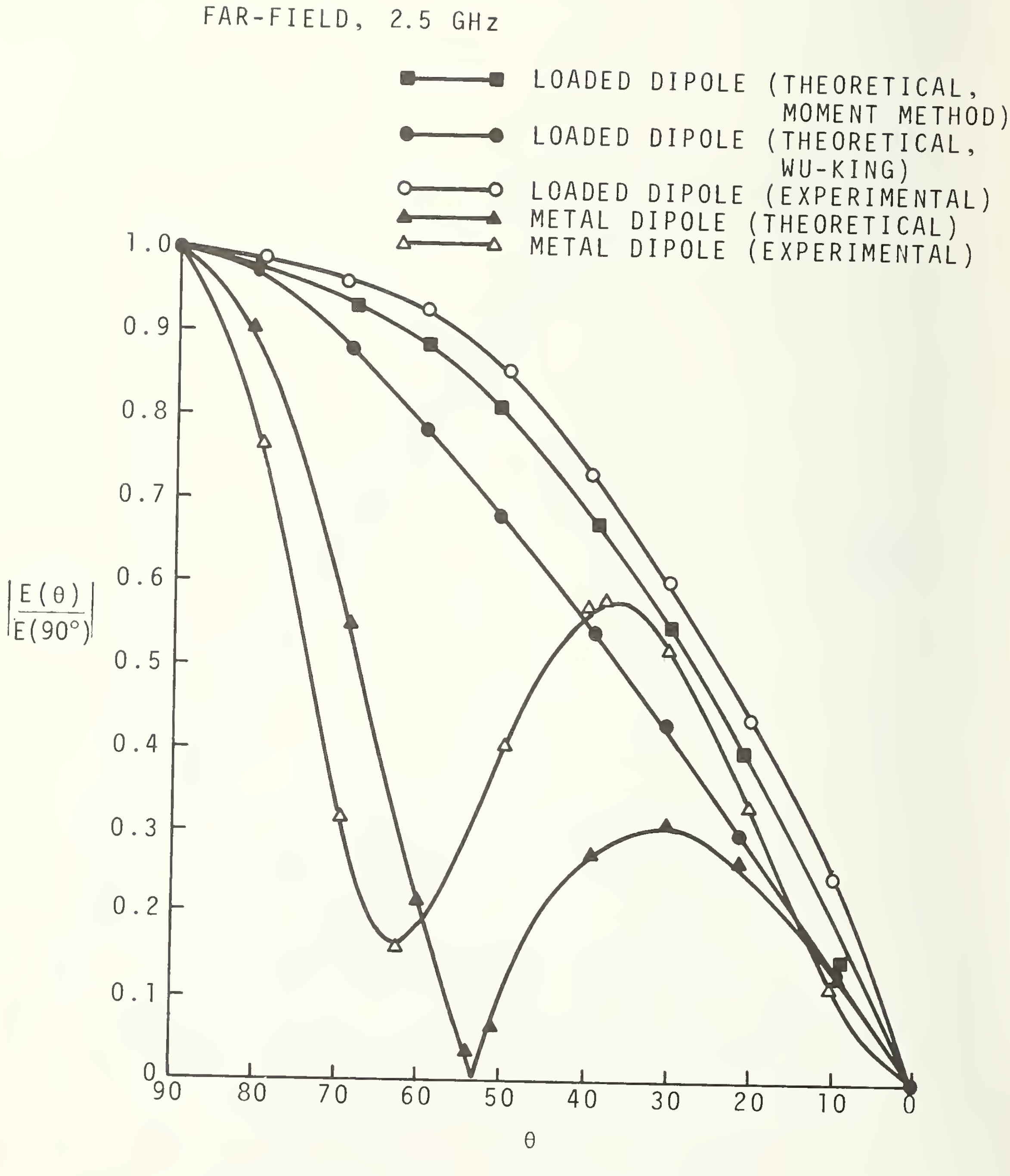

Fig. 4(c). Radiation patterns of resistively loaded dipoles at 2.5 GHz.

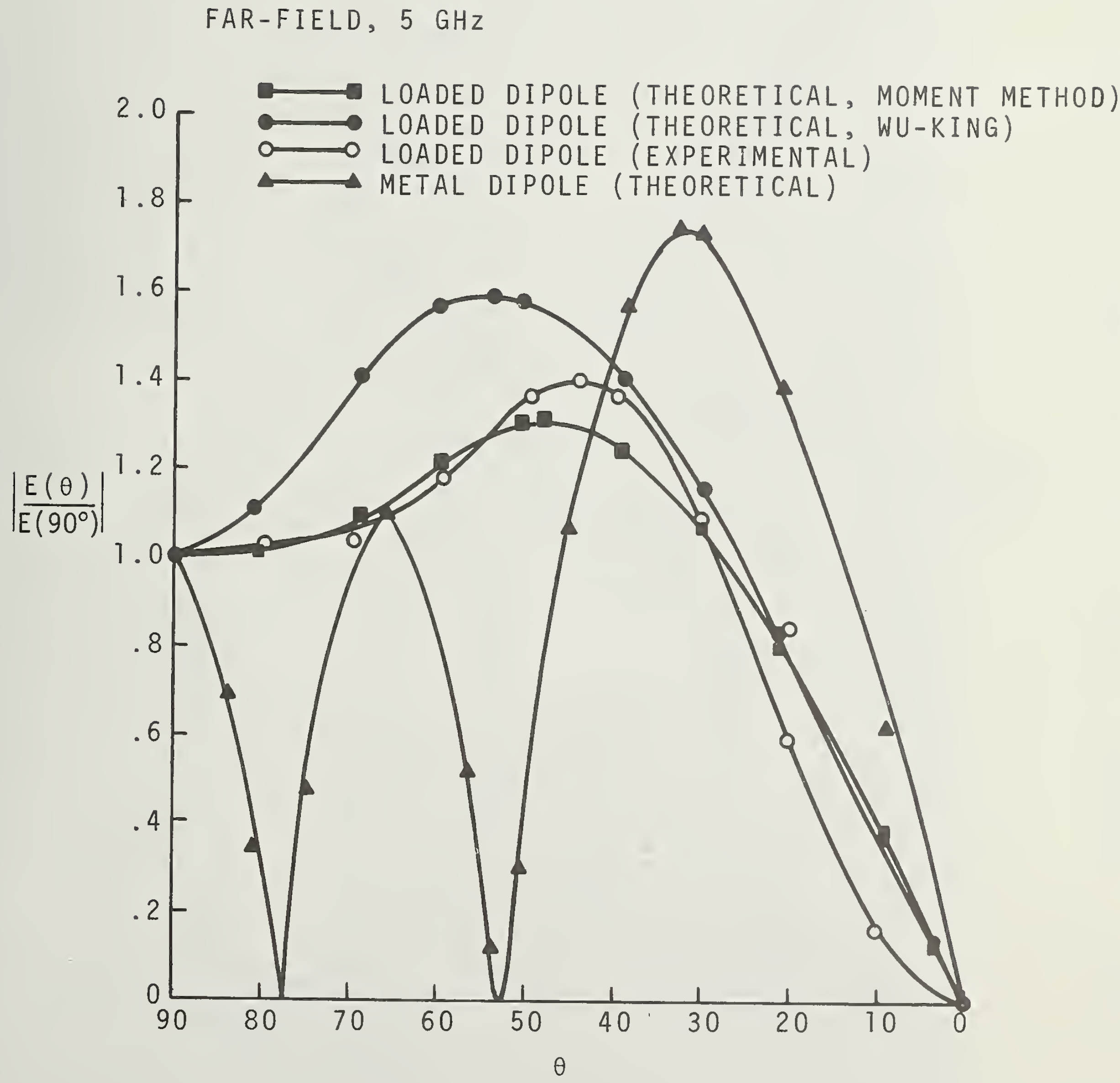

Fig. 4(d). Radiation patterns of resistively loaded dipoles at 5 GHz.

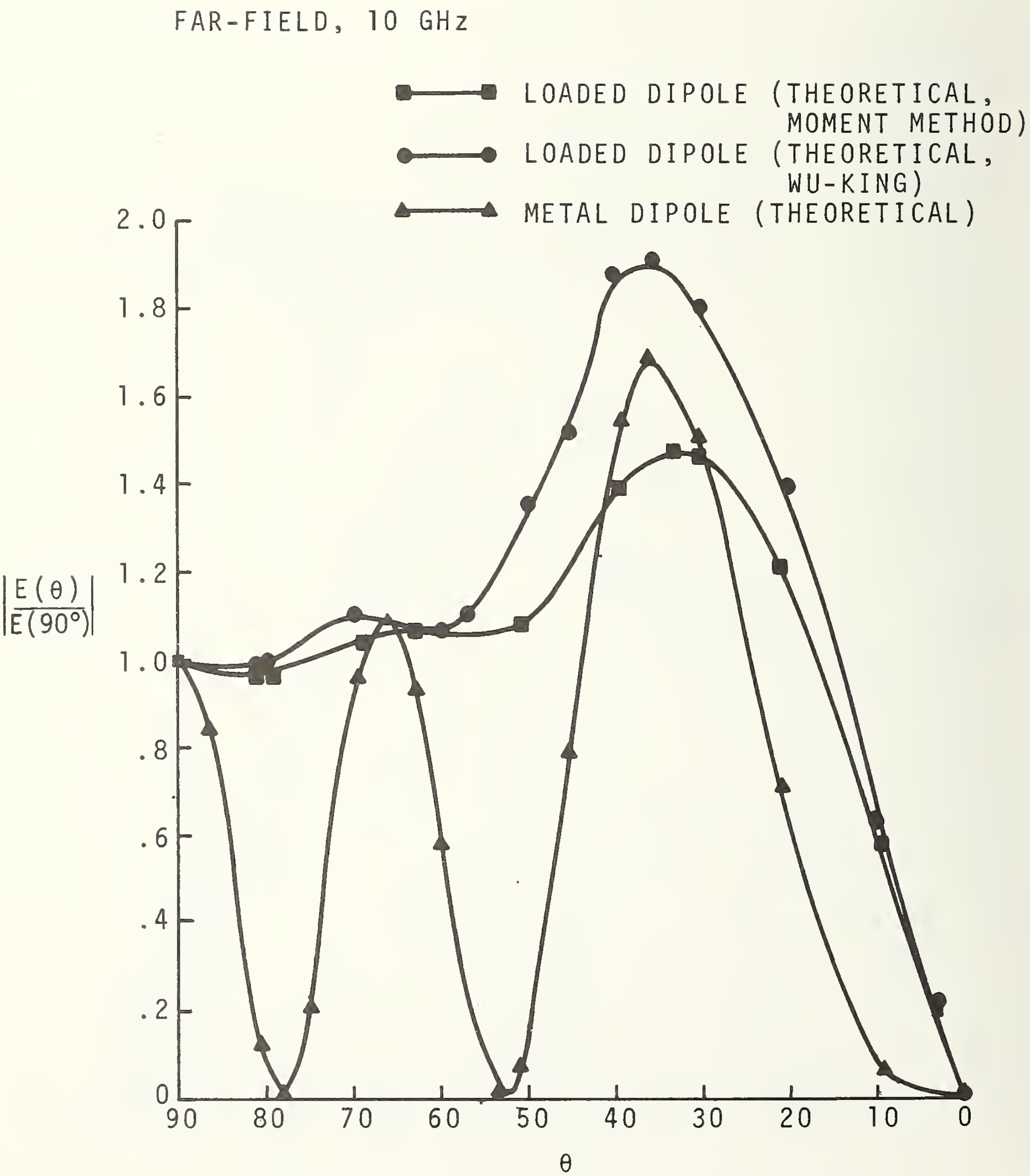

Fig. 4(e). Radiation patterns of resistively loaded dipoles at 10 GHz.

Fig. 5. Broadband, isotropic, real-time, electric-field sensor (BIRES).

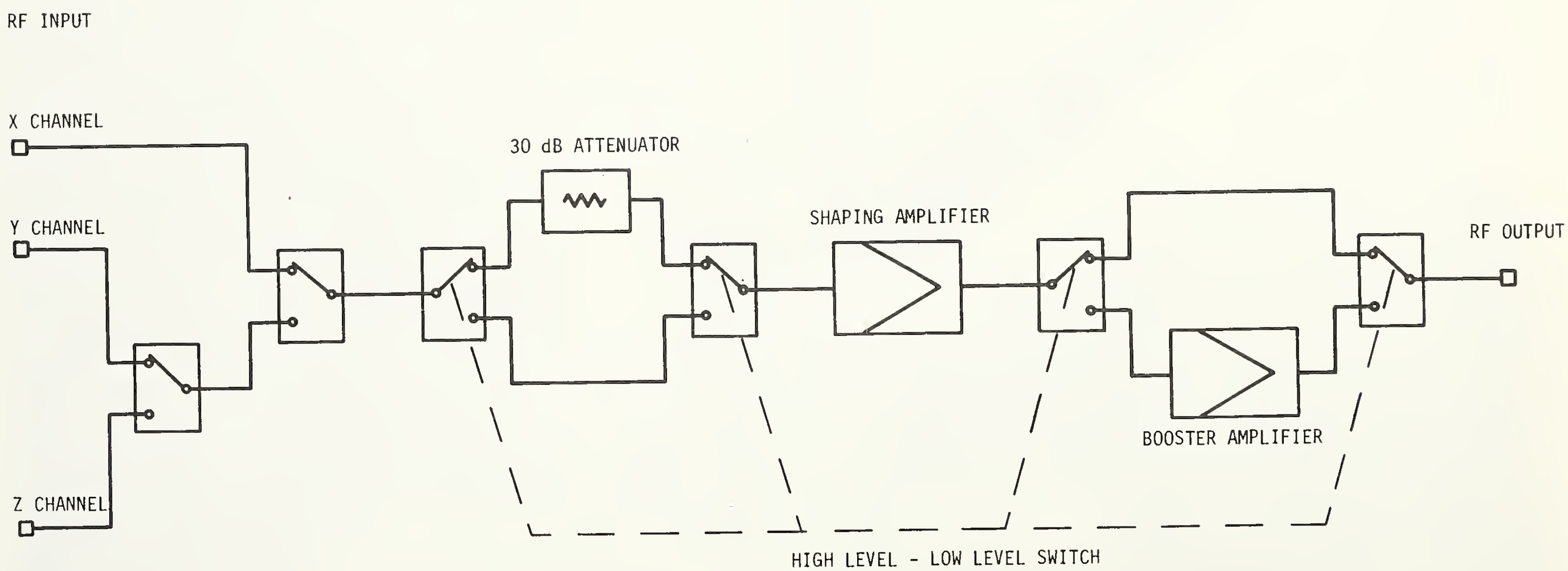

Fig. 6. Block diagram of BIRES switching system.

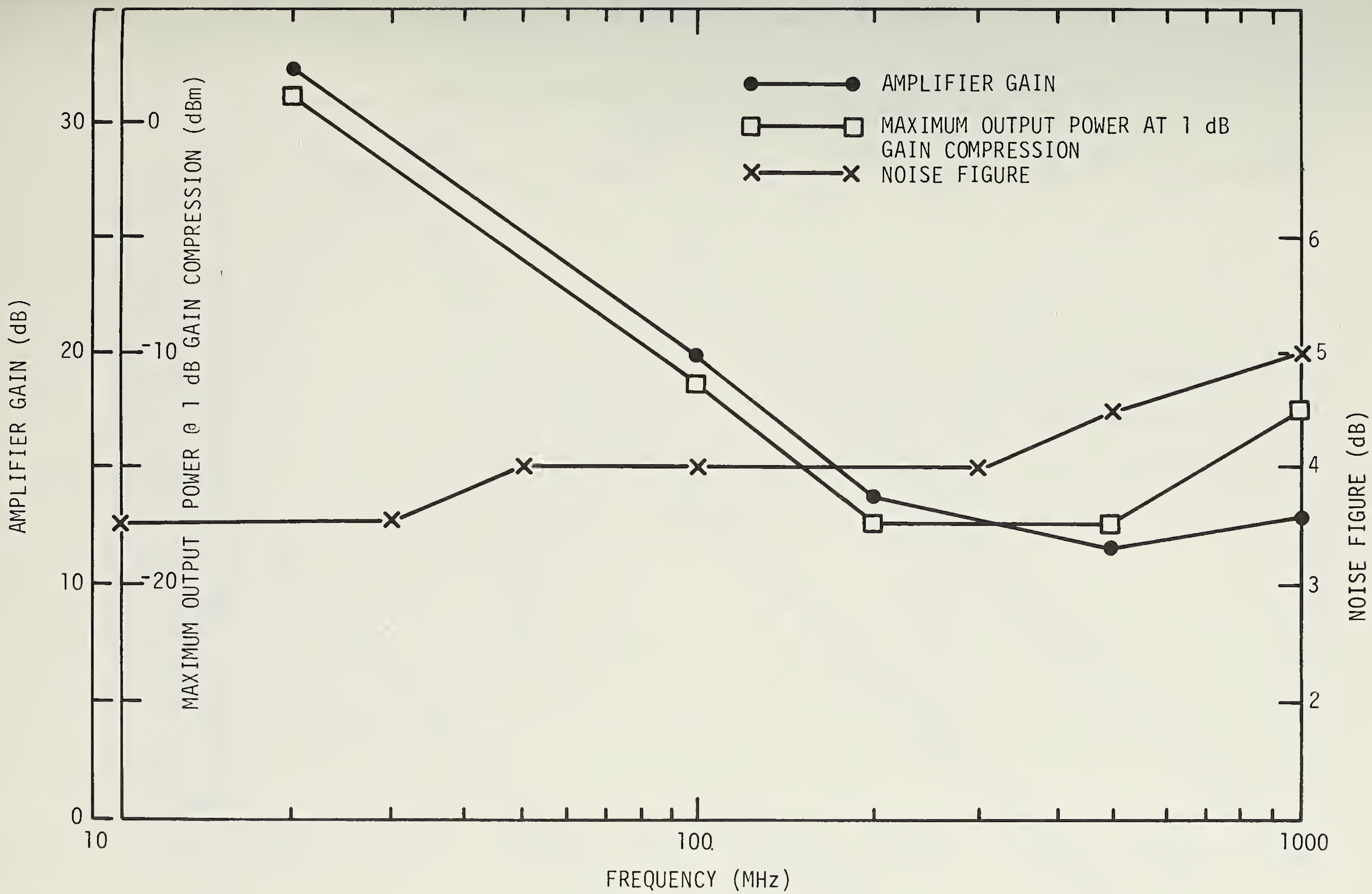

Fig. 7. Power gain, noise figure, and output power at 1 dB gain compression point of the broadband shaping amplifier.

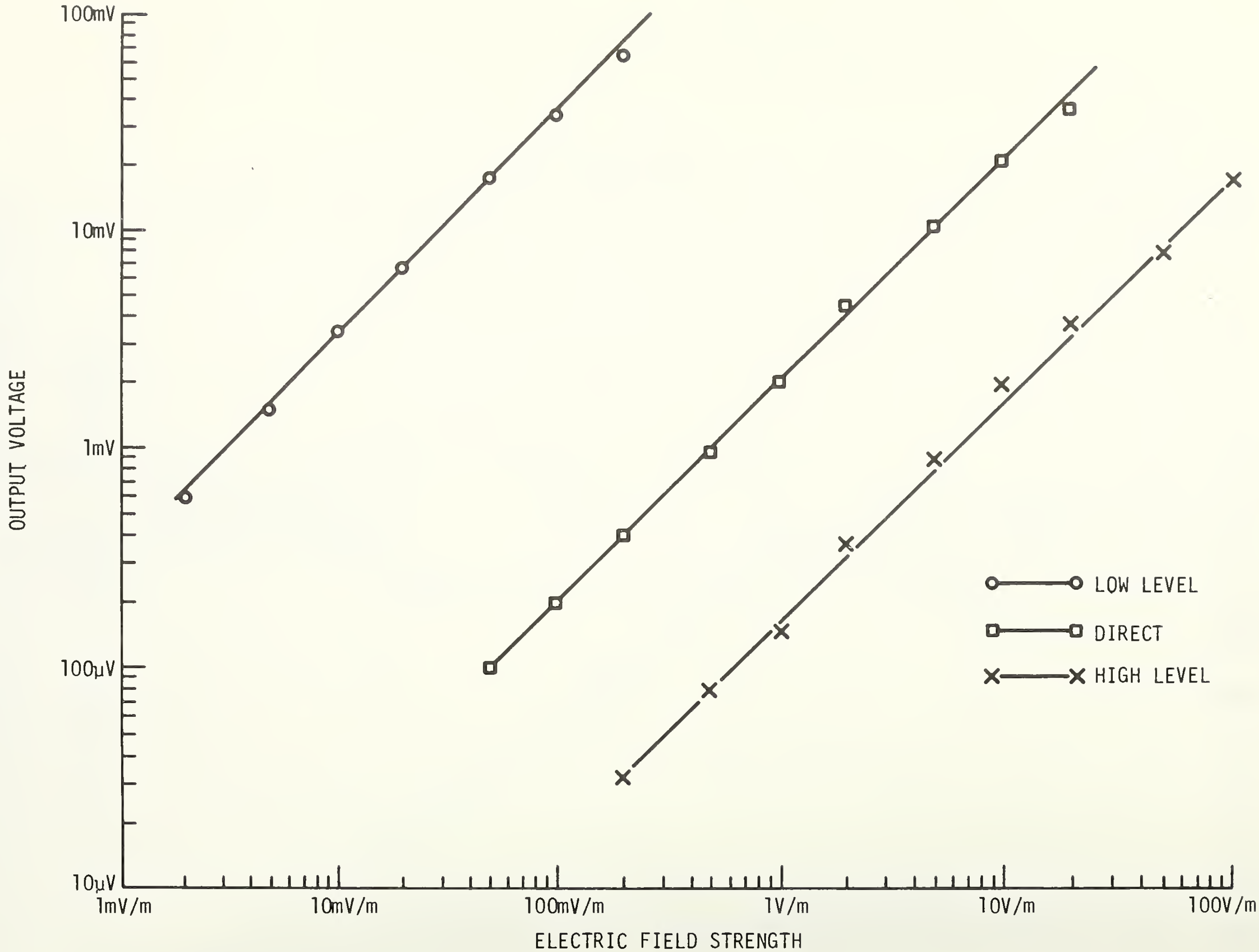

Fig. 8 Linearity of BIRES at 750 MHz.

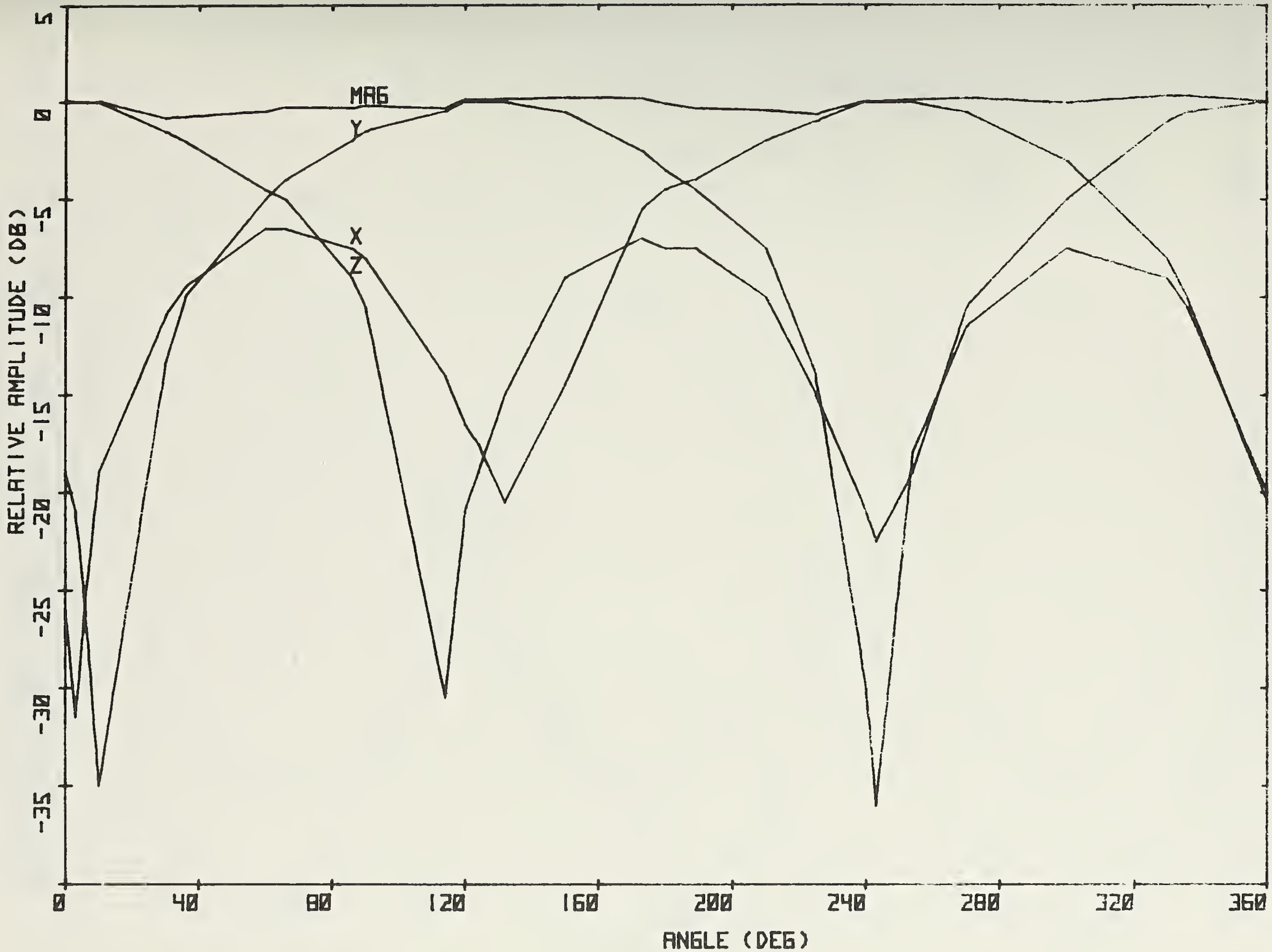

Fig. 9(a). Isotropy of BIRES at 450 MHz.

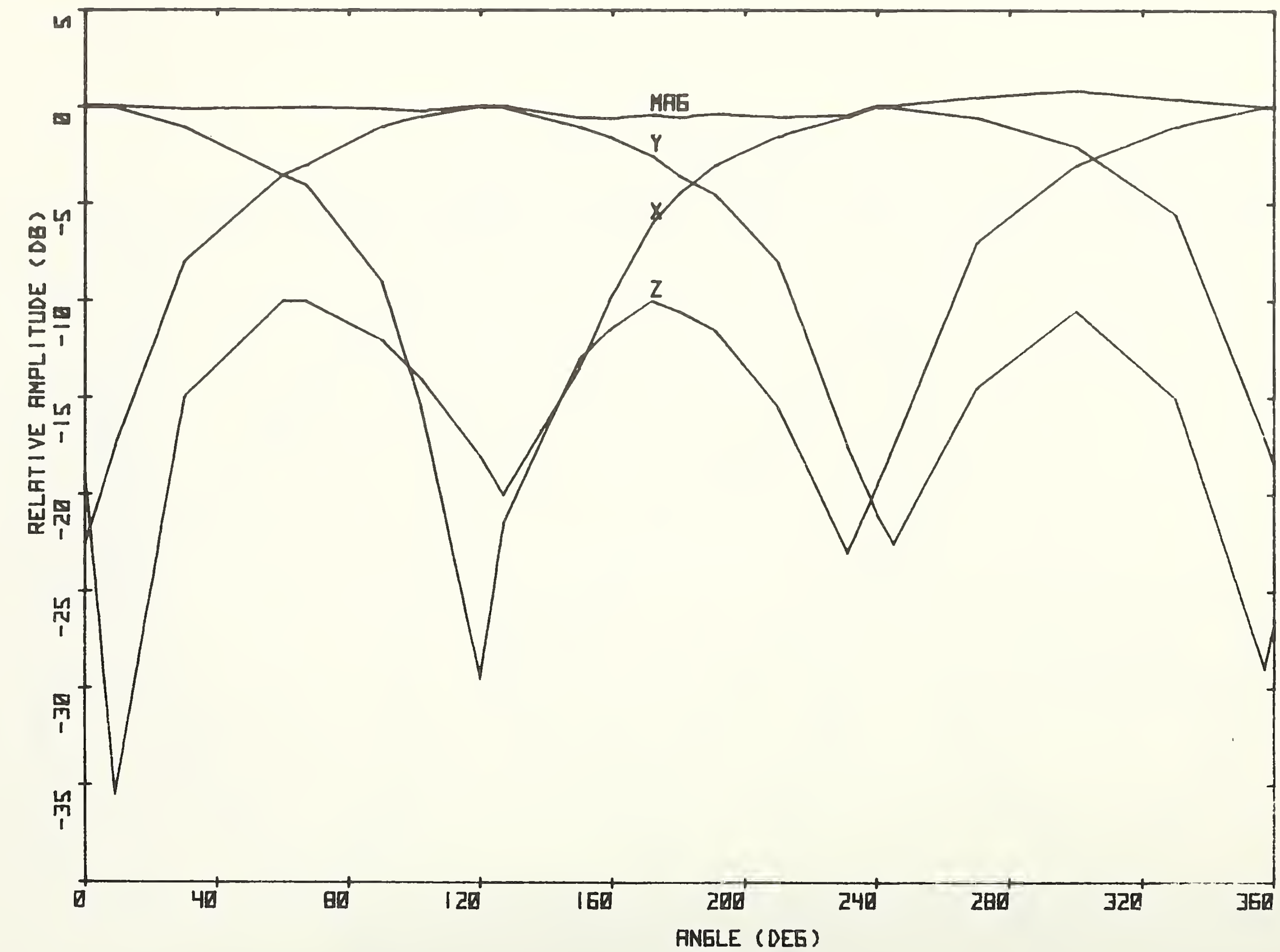

Fig. 9(b). Isotropy of BIRES at 550 MHz.

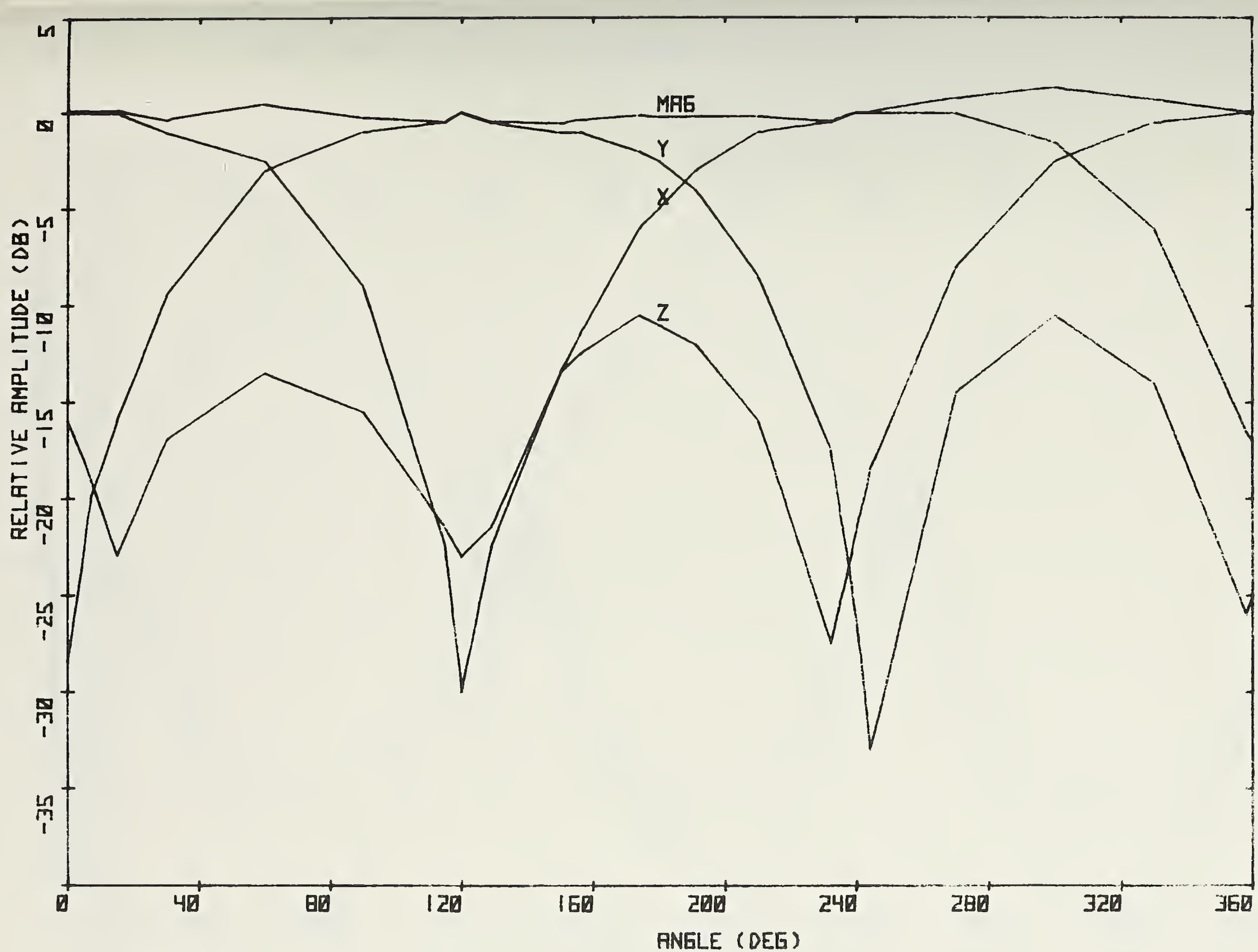

Fig. 9(c). Isotropy of BIRFS at 650 MHz.

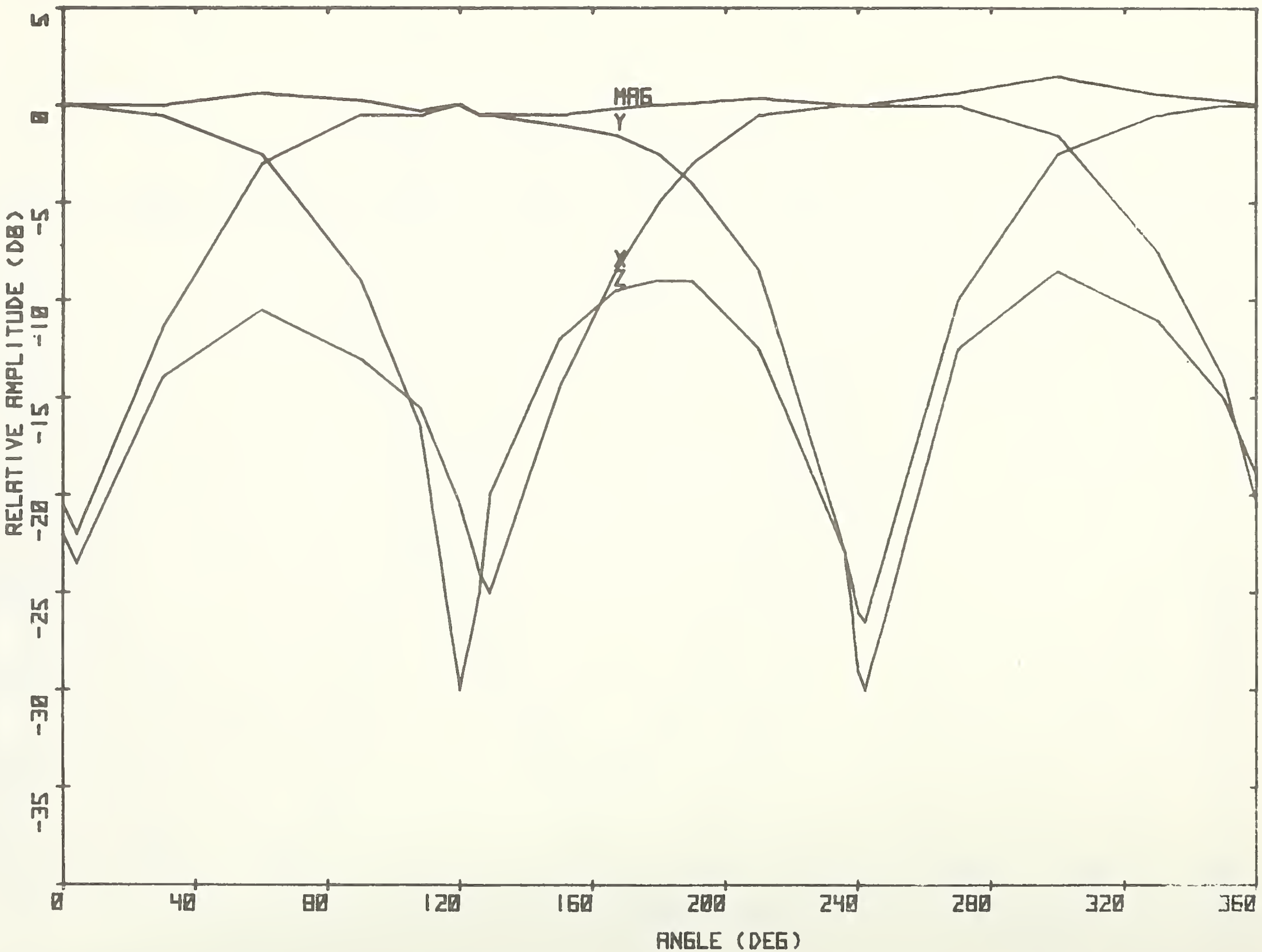

Fig. 9(d). Isotropy of BIRES at 750 MHz.

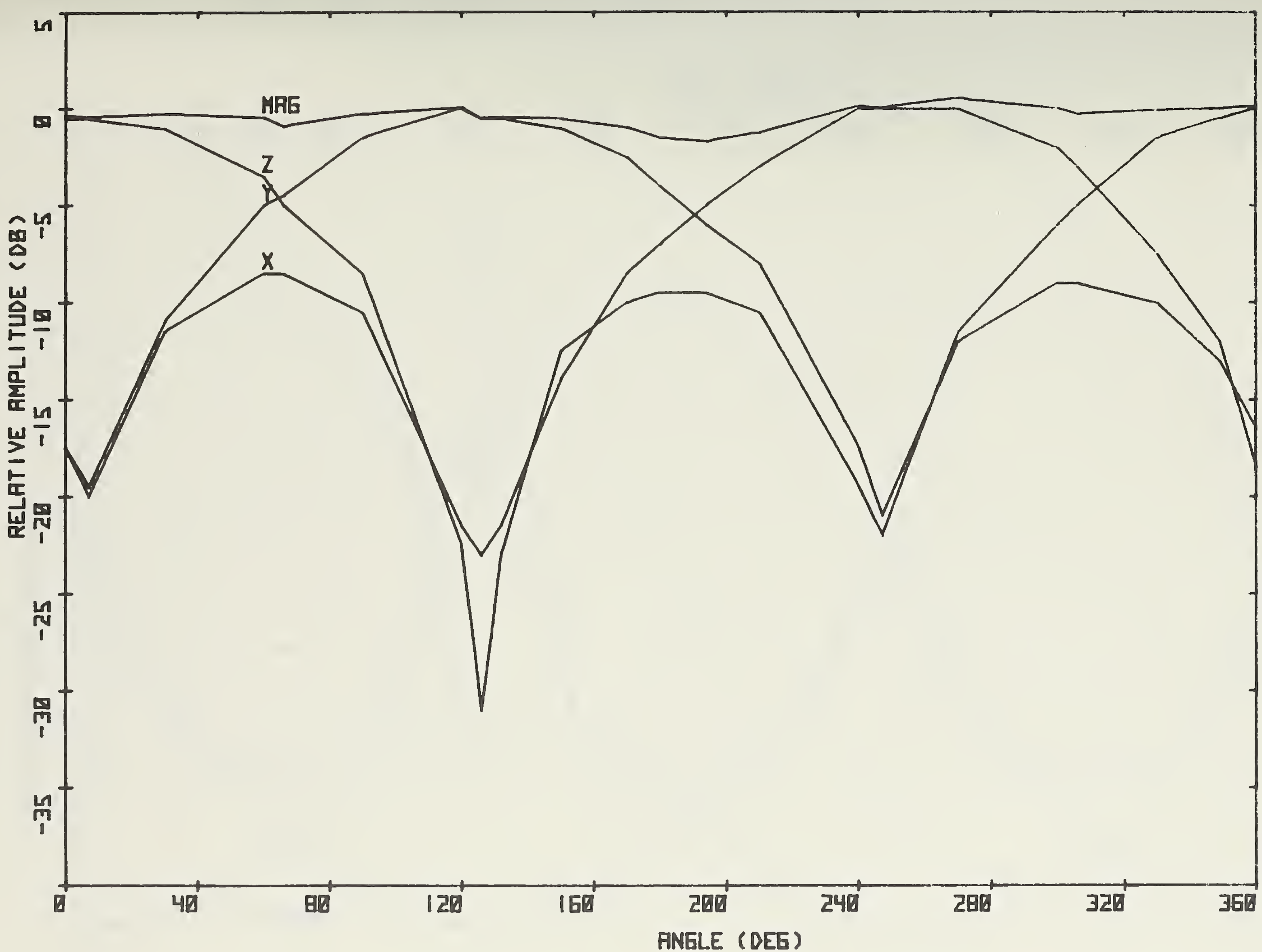

Fig. 9(e). Isotropy of BIRES at 850 MHz.

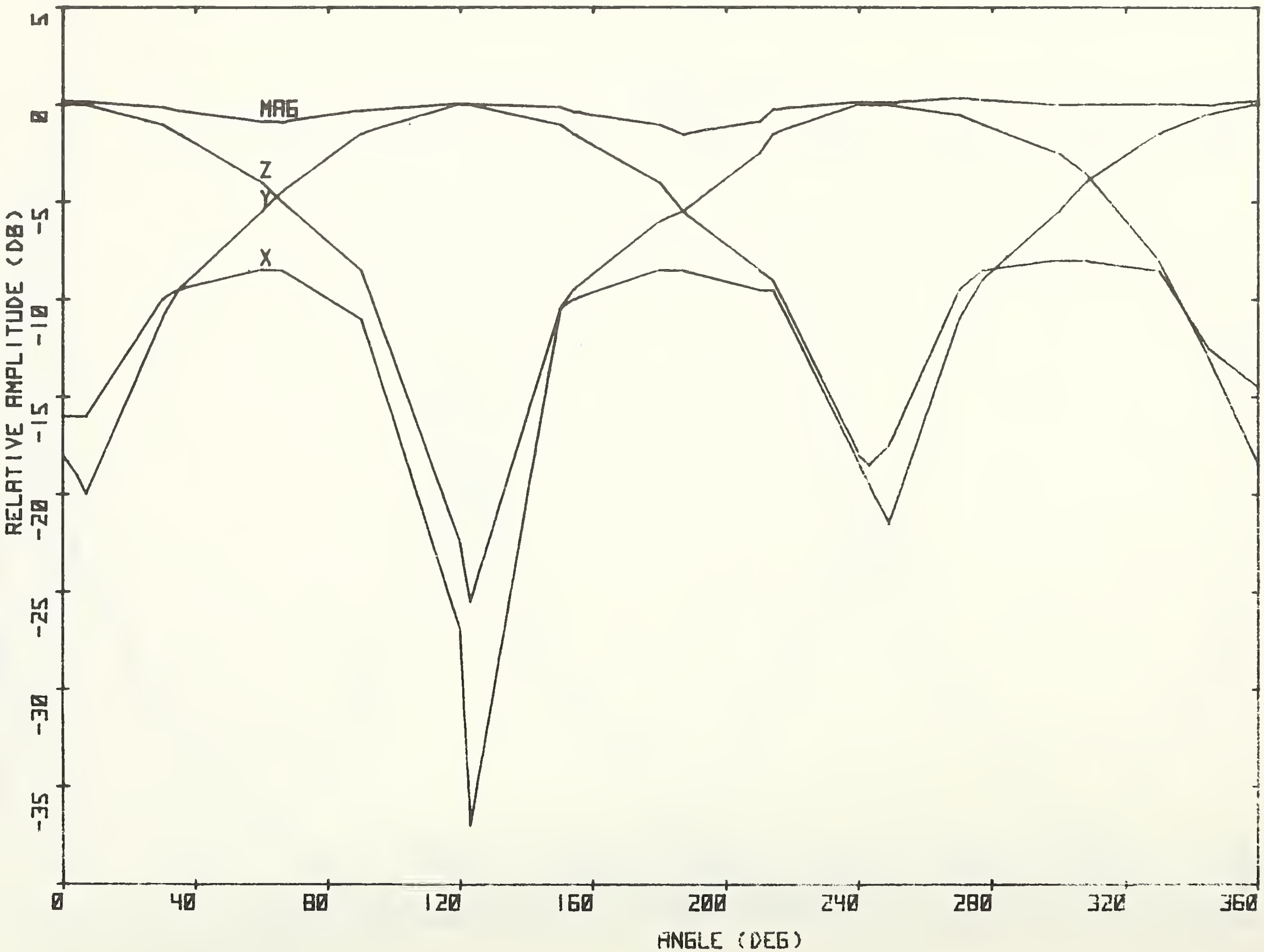

Fig. 9(f). Isotropy of BIRES at 950 MHz.

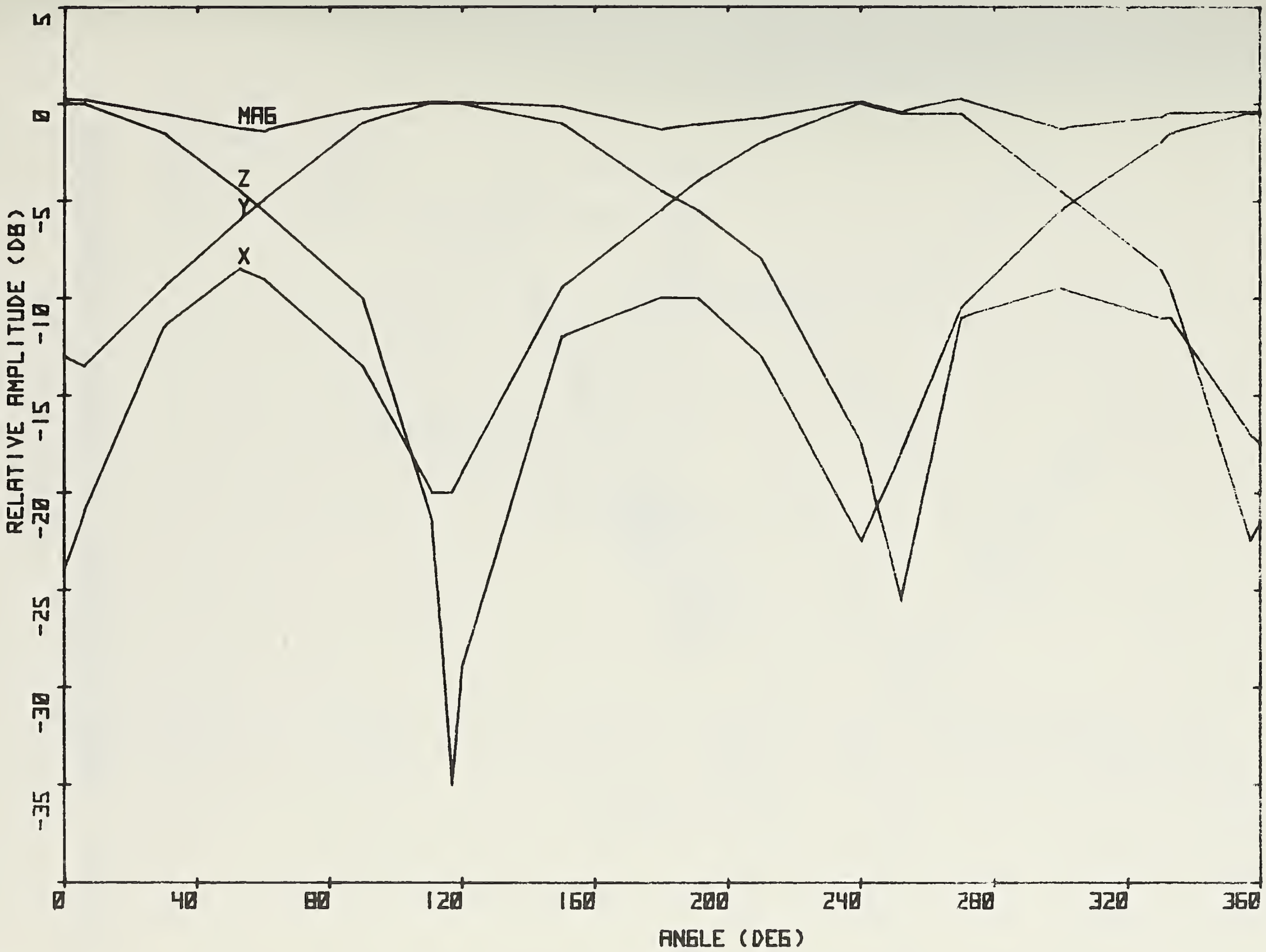

Fig. 9(q). Isotropy of BIRES at 1 GHz.

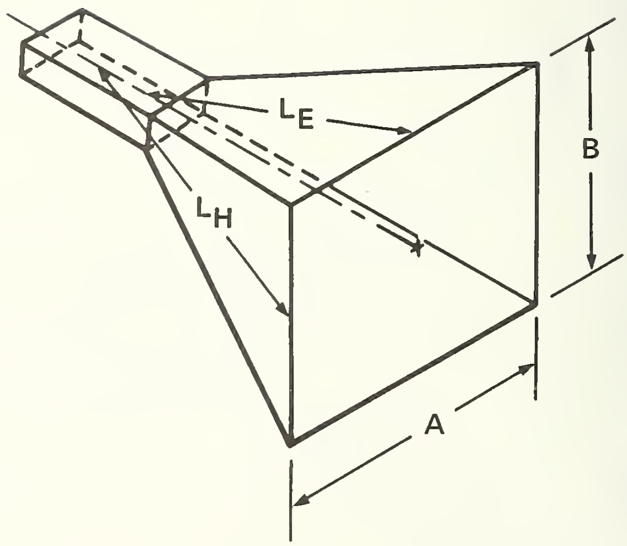

Fig. 10. Sketch of pyramidal horn dimensions in wavelengths.

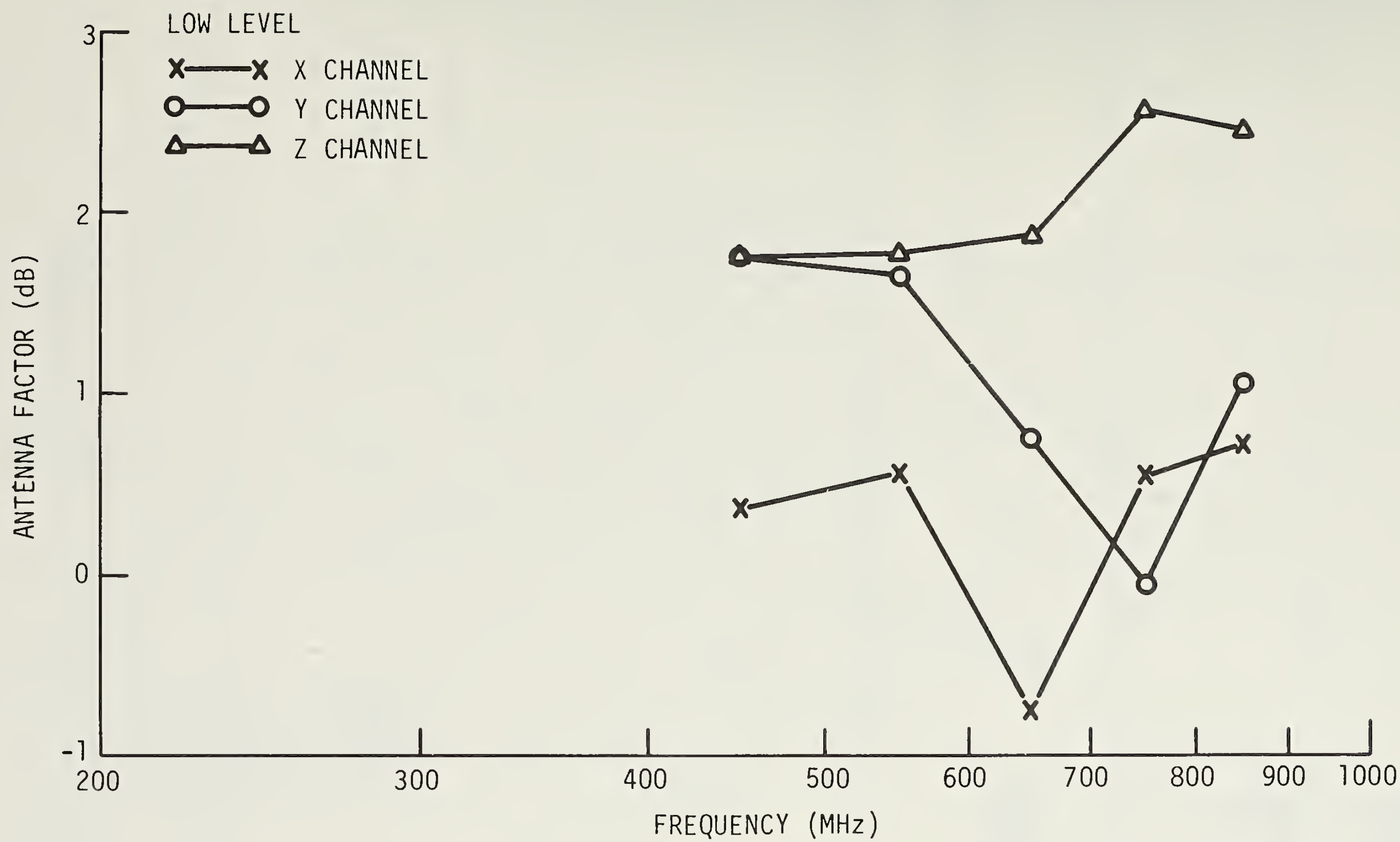

Fig. 11(a). Antenna factors of BIRES for low-level measurements.

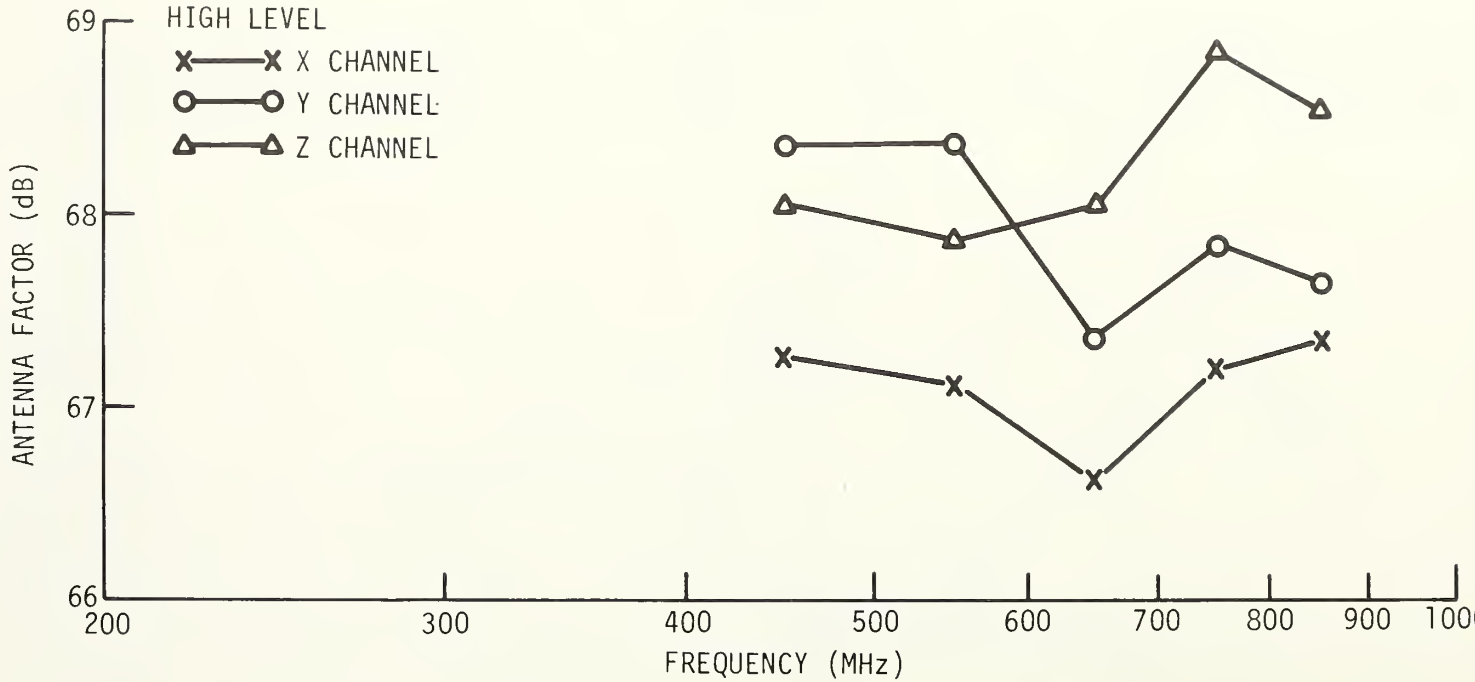

Fig. 11(b). Antenna factors of BIRES for high-level measurements.

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

A broadband, isotropic, real-time, electric-field sensor (BIRES) developed by the National Bureau of Standards (NBS) consists of three resistively loaded dipoles mounted orthogonally to each other. It has the capability of measuring a complete description of frequency, polarization, magnitude, and phase information of the incident electromagnetic (EM) field. The typical tangential sensitivity of the BIRES is 13 to 16 μV/m with a usable dynamic range of 125 to 144 dB for various bandwidths in the frequency range of 10 MHz to 1 GHz. The isotropic response, isotropy, of the BIRES is obtained by calculating the Hermitian magnitude of the incident electric field, and its variation is found to be less than ± 1 dB.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Broadband; dynamic range; electric-field sensor; Hermitian magnitude; isotropy; resistively loaded dipole; tangential sensitivity.

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