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Technology Assessment Program

Fixed and Base Station Antennas

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Paul Cascarano, Assistant Director
National Institute of Justice

Technology Assessment Program

NIJ Standard for Fixed and Base Station Antennas

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December 1981

U.S. DEPARTMENT OF JUSTICE
National Institute of Justice

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National Institute of Justice

JAMES L. UNDERWOOD

Acting Director

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NIJ STANDARD FOR FIXED AND BASE STATION ANTENNAS

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FOREWORD

This document, NIJ Standard-0204.01, Fixed and Base Station Antennas, is an equipment standard developed by the Law Enforcement Standards Laboratory of the National Bureau of Standards. It is produced as part of the Technology Assessment Program of the National Institute of Justice. A brief description of the program appears on the inside front cover.

This standard is a technical document that specifies performance and other requirements equipment must meet to conform to the needs of criminal justice agencies for high quality service. Purchasers can use the test methods described in this report to determine firsthand whether a particular piece of equipment meets the standards, or they may have the tests conducted on their behalf by a qualified testing laboratory. Procurement officials may also refer to this standard in their purchasing documents and require that equipment offered for purchase meet the requirements, with compliance guaranteed by the vendor or attested to by an independent laboratory.

Because this NIJ standard is designed as a procurement aid, it is necessarily highly technical. For those who seek general guidance about the capabilities of fixed and base station antennas, user guides also are published. The guides explain in non-technical language how to select equipment capable of the performance required by an agency.

NIJ standards are subjected to continuing review. Technical comments and recommended revisions are welcome. Please send suggestions to the Program Manager for Standards, National Institute of Justice, U.S. Department of Justice, Washington, DC 20531.

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Lester D. Shubin
Program Manager for Standards
National Institute of Justice

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NIJ STANDARD FOR FIXED AND BASE STATION ANTENNAS

1. PURPOSE AND SCOPE

The purpose of this document is to establish minimum performance requirements and methods of test for antennas that are used at base stations or other fixed sites by law enforcement agencies. This standard is a revision of NILECJ-STD-0204.00, dated November 1977. This revision expands the standard to include antennas used in the 800–960 MHz frequency band and to include the design and construction details of two types of reference antennas.

2. CLASSIFICATION

For the purposes of this standard, fixed and base station antennas are classified by their operating frequency and their directional pattern.

2.1 Operating Frequency

2.1.1 Type I

Antennas for use in the 25–50 MHz band.

2.1.2 Type II

Antennas for use in the 150–174 MHz band.

2.1.3 Type III

Antennas for use in the 400–512 MHz band.

2.1.4 Type IV

Antennas for use in the 800–960 MHz band.

2.2 Directional Pattern

2.2.1 Omnidirectional Antennas

2.2.2 Directional Antennas

3. DEFINITIONS

The principal terms used in this document are defined in this section. Additional definitions relating to law enforcement communications are given in LESP-RPT-0203.00 [9]*.

3.1 Antenna Power Rating

The maximum continuous-wave power that can be applied to an antenna without degrading its performance.

*Numbers in brackets refer to references in appendix A.

3.2 Dipole Antenna, Resonant Half-Wavelength

A straight radiator (usually energized at the center) whose diameter is small compared to its length and whose electrical length is equal to approximately one-half the wavelength of the energizing signal. The radiator supports a line current distribution such that a current node (zero net current) exists at each of the ends, producing maximum radiation in the plane at the center of the antenna and normal to its longitudinal axis.

3.3 Effective Antenna Volume

The volume occupied by an antenna plus one-half wavelength in all directions when it is rotated through 360° as required by a particular test.

3.4 Isotropic Radiator

A hypothetical antenna radiating or receiving equally in all directions.

3.5 Major Lobe

The antenna radiation lobe that contains the direction of maximum radiation.

3.6 Pattern Recorder

A device that records the amplitude of the output signal from an antenna and receiver combination as a function of the antenna orientation.

3.7 Polarization

The orientation of the electric-field vector of the wave radiated by an antenna. Alternatively, the orientation of the electric-field vector of an incident wave which results in maximum available power at the antenna terminals.

3.8 Radiation Pattern

The magnitude of the relative electric field strength radiated from an antenna in a given plane as a function of the angle from a given reference direction.

3.9 Relative Antenna Gain

The ratio of the radiation intensity of an antenna in a given direction to the radiation intensity of a reference antenna in the same direction, with the same power input to both antennas. If the reference antenna is a lossless half-wavelength dipole antenna, the gain is expressed in decibels relative to the dipole antenna, dBd.

3.10 Scale Ratio

The ratio of the operating frequency of a scale model antenna to the operating frequency of the full size antenna.

3.11 Standard Gain Unit

The reference unit used to measure relative antenna gain. The reference unit is usually either an isotropic radiator or a lossless half-wavelength dipole. For this standard, the reference unit is the lossless half-wavelength dipole antenna.

3.12 Standing Wave Ratio (SWR)

The ratio of the maximum to the minimum voltage or current appearing along a transmission line.

3.13 Wind Velocity Rating

The maximum wind velocity that an antenna assembly can withstand without physical damage.

4. REQUIREMENTS

4.1 Performance Requirements

The antenna shall meet or exceed all the requirements of this standard as given below and summarized in table 1. These performance requirements meet or exceed those given in the Rules and Regulations published by the Federal Communications Commission [4,5].

TABLE 1. *Minimum performance requirements for fixed and base station antennas*

Antenna characteristic	Minimum requirement
Rated Power Operation	No physical damage
Relative Antenna Gain	±1.0 dB of the relative gain specified in the major lobe, ± 5.0 dB in minor lobes
Radiation Pattern	±1.0 dB of the radiation pattern specified in the major lobe, ±5.0 dB in minor lobes
Standing Wave Ratio	1.5 or less
Wind Velocity Rating	See table 2

4.2 User Information

The information supplied to the purchaser by the antenna manufacturer or distributor shall include the following:

a. Operating frequency range
b. Antenna power rating
c. Relative antenna gain vs. operating frequency in standard gain units
d. Polarization
e. Vertical radiation pattern
f. Horizontal radiation pattern
g. Nominal impedance
h. SWR vs. operating frequency
i. Connector type
j. Wind velocity rating
k. Physical dimensions
l. Weight
m. Antenna material composition
n. Operating, installation and service instructions
o. Certification of compliance with this standard.

4.3 Antenna Power Rating

The antenna shall meet the requirements of paragraphs 4.4 through 4.6 immediately after being subjected to the test described in paragraph 5.4. In addition, the antenna shall not be physically damaged by the test.

4.4 Relative Antenna Gain

The relative antenna gain, measured in accordance with paragraph 5.5, shall be within 1.0 dB of the relative gain specified by the manufacturer in accordance with paragraph 4.2.c.

4.5 Radiation Pattern

4.5.1 Vertical Pattern

The vertical radiation pattern, measured in accordance with paragraph 5.6.1, shall be within 1.0 dB of the radiation pattern specified by the manufacturer in accordance with paragraph 4.2.e.

4.5.2 Horizontal Pattern

The horizontal radiation pattern shall be measured in accordance with paragraph 5.6.2. For omnidirectional antennas, the horizontal radiation pattern variation shall be within 1.0 dB throughout a 360° variation in azimuthal angle. For directional antennas, the horizontal radiation pattern shall be within 1.0 dB of the pattern specified by the manufacturer in accordance with paragraph 4.2.f.

4.6 Standing Wave Ratio

The SWR of the antenna, measured in accordance with paragraph 5.7, shall be 1.5 or less referenced to a 50-ohm system.

4.7 Wind Velocity Rating

The antenna shall be capable of withstanding wind velocities of 114 km/h (71 mph), without ice loadings. If mounted more than 90 m (295 ft) above the ground or if located in zones B or C (see fig. 1), the antenna shall be capable of withstanding the appropriate wind velocity, as listed in table 2.

4.8 Materials

The materials used in the antenna and in auxiliary items such as support members, feed harnesses, connectors and mounting hardware shall provide a high strength-to-weight ratio and good resistance to corrosion.

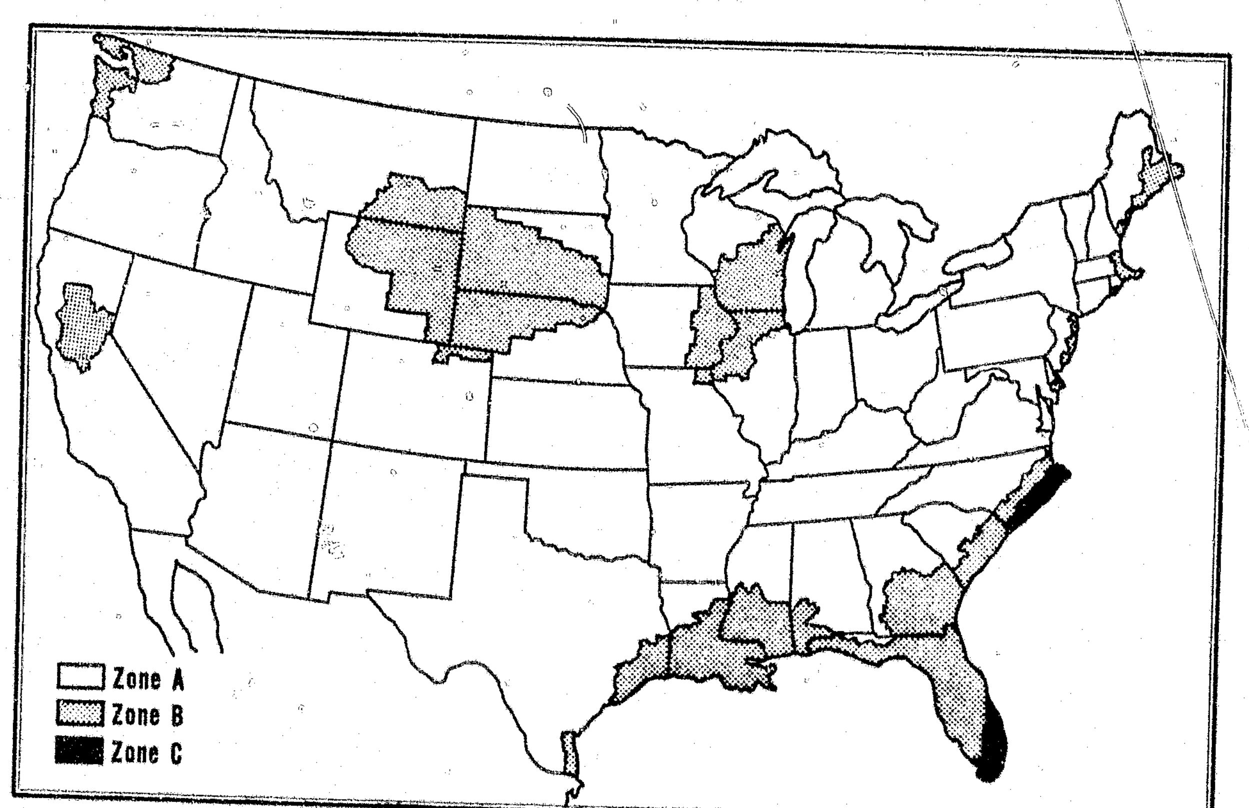

FIGURE 1. Location of wind loading zones based on 50 yr mean recurrence interval [15].

TABLE 2. *Wind velocity ratings [2]*

Antenna base height above ground	Wind loading zone A	B	C
	Wind velocity km/h (mph)		
Less than 90 m (295 ft)	114 (71)	132 (82)	145 (90)
90–200 m (295–656 ft)	123 (76.5)	144 (89.5)	161 (100)
More than 200 m (656 ft)	145 (90)	168 (104)	193 (120)

5. TEST METHODS

5.1 Standard Test Conditions

Unless otherwise specified, perform all measurements at the standard test frequencies under standard test conditions. Allow all measurement equipment to warm up until the system has achieved sufficient stability to perform accurate measurements.

5.1.1 Standard Test Frequencies

The standard test frequencies shall be three frequencies, one each at the low end, middle and high end of the operating frequency range (par. 4.2.a).

5.1.2 Standard Radiation Test Site

The standard radiation test site shall be located on level ground which has uniform electrical characteristics (i.e., ground constants). Reflecting objects (especially large metal objects), trees, buildings, and other objects which would perturb the electromagnetic fields to be measured should be no closer than 90 m (295 ft) to any measuring instrument or the equipment under test. All utility lines and any control circuits within the test site should be buried underground to a depth of 0.3 m (approximately 1.0 ft). The ambient electrical noise level shall be carefully monitored to insure that it does not interfere with the test being performed. The ambient noise level should be 14 dB or more below the minimum signal levels being measured.

5.1.3 Standard Test Range

Either a slant range, a ground level range or an elevated range may be used to measure relative gain and/or vertical and horizontal radiation patterns. In each, the distance between the two antennas, R, shall be ten wavelengths or $2d^2/\lambda$ (where d is the largest dimension, in meters, of the antenna under test, and λ is the free space wavelength, in meters, of the test frequency), whichever is greater. After turning on the signal source, the resultant electromagnetic field shall be probed using a half-wavelength dipole antenna over the effective antenna volume (par. 3.3) of the antenna to be tested to insure that the field strength variation is less than ±3/4 dB. If the field strength variation exceeds ±3/4 dB, the range should be considered unsatisfactory. If a slant range is used, the source antenna should be positioned within a few centimeters of the ground, and the antenna under test should be located about 20–30 m (66–99 ft) above ground level. If a ground level range is used, both antennas shall be positioned close to the ground such that the first maximum of the interference pattern of the source antenna and its image shall be placed at the center of the test antenna. If an elevated test range is used, both the antenna under test and the source antenna shall be elevated sufficiently that the reflected signal from the source antenna is negligible at the center of the antenna under test when the major lobes of both antennas are aligned.

5.2 Test Equipment

The test equipment described in this section is limited to the equipment that is most critical in making the required measurements. All other test equipment shall be of comparable quality.

5.2.1 Receiver

The receiver shall be well-shielded, capable of operating over the frequency range of the antenna under test and shall be calibrated such that it can measure voltages of 1 to 10 mV with an accuracy of 6% and a resolution of 2%. It shall have an input impedance of 50 ohms and an SWR of 1.05 or less.

5.2.2 Antenna Pattern Recorder

The stability of the antenna pattern recorder shall be such that it can reproduce patterns to within 0.2 dB.

5.2.3 Reference Antennas

Either of two types of reference antennas may be used, namely, the EIA standard antennas or the standard dipole antennas. Details of their design and construction are given in appendix B.

5.2.4 Power Meter

The power meter shall measure both forward and reflected power in a 50-ohm system with a full-scale uncertainty of 5% or less. It may be a through-line directional wattmeter, or directional couplers with power meters on the side arms.

5.3 Scale Model Measurements

Accurate radiation pattern and relative antenna gain measurements are difficult to obtain for type I antennas because of the antenna size. For type I antennas, scale model techniques may be used, provided certain precautions are observed. The scale model shall be constructed to the following accuracy:

$$L_S = (L \pm 1\%)/R$$

where R is the scale ratio, L_S is any significant linear dimension of the scale model, and L is the corresponding linear dimension of the full-size antenna. The scale ratio shall not exceed six. The parts of the scale model shall be constructed of the same materials as the corresponding parts of the full-size antenna. If the supporting tower or mast is an electrically essential part of the antenna or affects the electrical performance of the antenna, it also shall be constructed to scale.

5.4 Rated Power Operation Test

If authorized by the Federal Communications Commission to do so, mount the antenna on an outside range at a temperature of at least 20 °C (68 °F) and apply rated power (par. 4.2.b) for 4 h at one of the standard test frequencies. If not authorized to transmit at rated power into free space, place the antenna in a chamber that will provide 60 dB or more of shielding and perform the same test.

5.5 Relative Antenna Gain Test

Mount the source antenna and the antenna under test in accordance with paragraph 5.1.3 so that their major transmitting/receiving lobes are positioned for horizontally polarized signals, and connect the equipment as shown in figure 2. Tune the signal source to one of the standard test frequencies, and adjust its output until a convenient reading is obtained on the pattern recorder. Position and align both antennas for the maximum indication on the pattern recorder and record this reading, P_A, in decibels. Do not adjust the signal source for the remainder of this test. Remove the antenna under test and replace it with the reference antenna. Position and align the reference antenna for the maximum received signal and record the reading, P_R, in decibels. The relative antenna gain, in decibels, is $P_A - P_R + G_R$, where G_R is the gain of the reference antenna, in dBd, relative to that of the standard gain unit. Repeat for each of the other two standard test frequencies.

5.6 Radiation Pattern Tests

5.6.1 Vertical Pattern Test

Use the same measurement setup as described in paragraph 5.5 and figure 2. Align and position both the source and test antennas for maximum signal strength. Adjust the signal source for full scale indication on the pattern

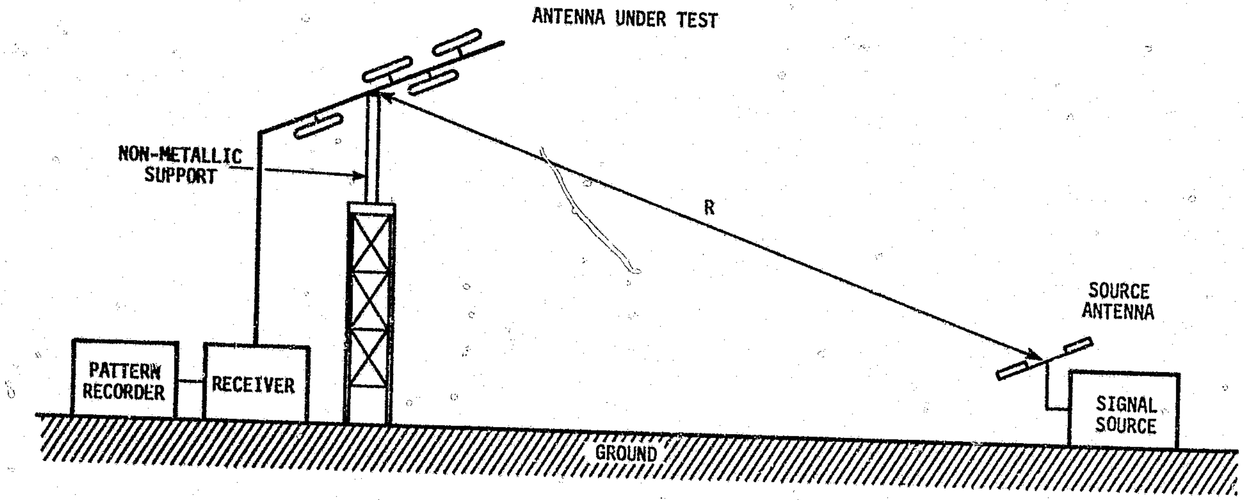

FIGURE 2. Test setup for measuring relative antenna gain and vertical radiation pattern.

recorder. Do not adjust either the pattern recorder or the signal source for the remainder of this test. Obtain the vertical radiation pattern of the antenna under test by rotating it through 360° in the plane defined by its major axis and that of the source antenna. The starting and ending points on the pattern record should be the same. If they are not, repeat the measurement. Repeat for each of the other two standard test frequencies.

5.6.2 Horizontal Pattern Test

Position the two antennas as shown in figure 3, with their major axes parallel to each other and perpendicular to the imaginary line that connects their midpoints. Adjust the signal source and the pattern recorder controls so that the pattern recorder indicates full scale. Do not make adjustments for the remainder of this test. Rotate the antenna under test through 360° about its major axis to obtain the horizontal radiation pattern of the antenna under test. The starting and ending points on the pattern record should be the same. If they are not, repeat the measurement. Repeat for each of the other two standard test frequencies.

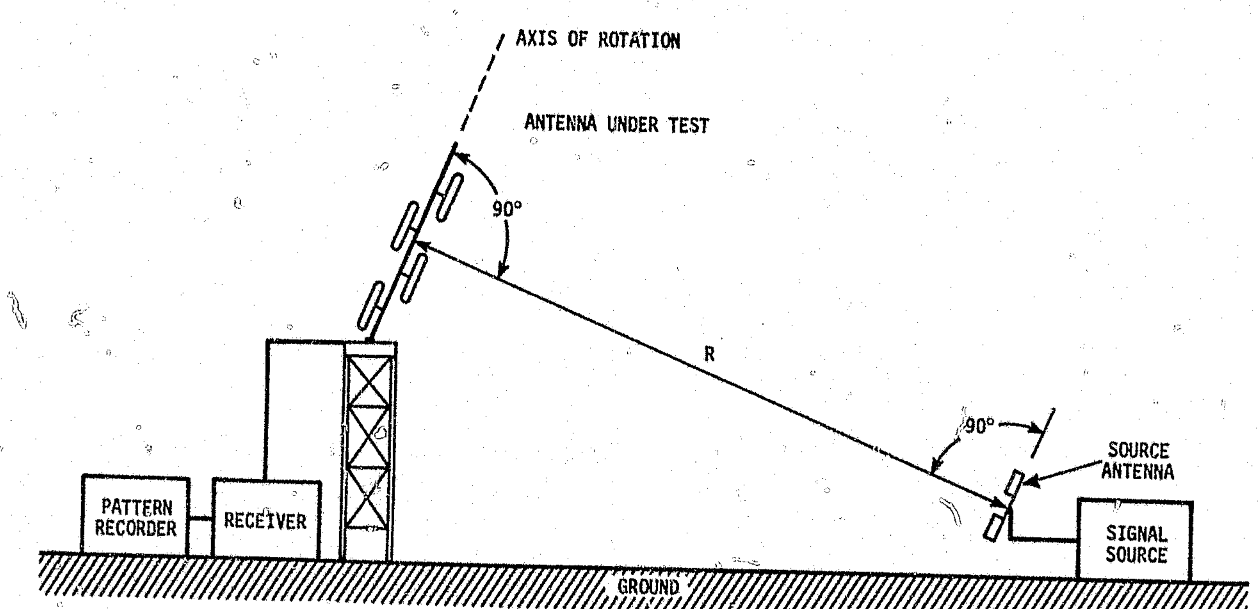

FIGURE 3. Test setup for measuring horizontal radiation pattern.

5.7 Standing Wave Ratio Test

Although SWR is defined in terms of voltage or current, the measurement procedure described herein uses a power measurement technique to determine the SWR.

Mount the antenna under test on a tower, in the same manner in which it is normally used, with its base at least 3 m (10 ft) above ground. This is important for mountings where the antenna supporting structure is in the field of the antenna. Connect the measuring instruments as shown in figure 4. Place the power meter right at the antenna input terminals, if possible. If it is necessary to use an rf transmission line to connect the power meter to the antenna input terminals use a transmission line with an SWR of 1.05 or less.

Use the power meter to measure the incident power delivered to the antenna and the reflected power from the antenna. Calculate the SWR from the following relationship, where P_i is the measured incident power in watts and P_r the measured reflected power in watts.

$$\mathrm{SWR} = \frac{\sqrt{P_i} + \sqrt{P_r}}{\sqrt{P_i} - \sqrt{P_r}}$$

If the line loss in the rf transmission line connecting the power meter to the antenna input terminals exceeds 0.5 dB, correct the measured SWR to eliminate the effect of the line loss. This correction can be applied by dividing the measured incident power, P_i, by the power ratio of the transmission line loss and multiplying the measured reflected power, P_r, by the power ratio of the transmission line loss.

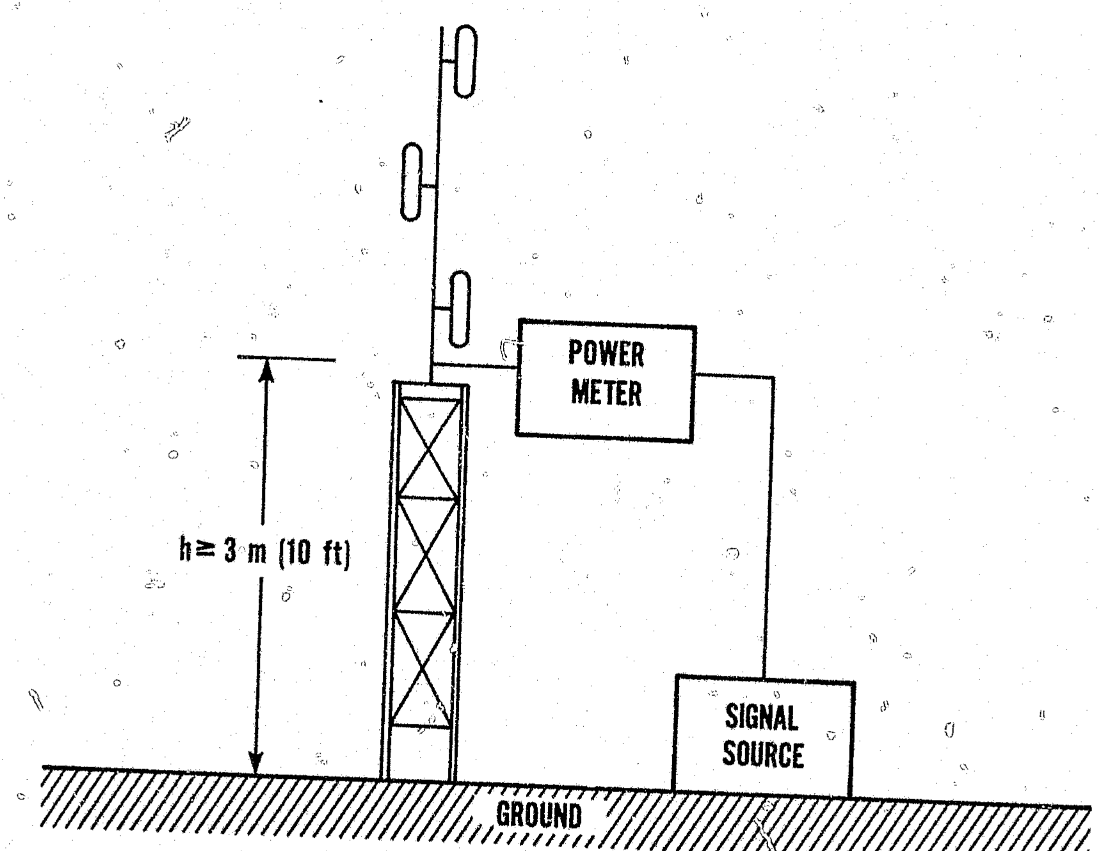

FIGURE 4. Test setup for measuring SWR.

APPENDIX A—BIBLIOGRAPHY

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APPENDIX B—REFERENCE ANTENNAS

EIA Reference Antennas

The basic configuration of the EIA reference antenna is illustrated in figure B-1. It consists of two parallel half-wavelength dipoles connected in parallel by two symmetrical sections of balanced open-wire transmission line. The dipoles are one-half wavelength apart, and are located one-quarter wavelength away from the conducting ground plane which is one wavelength by one wavelength in size.

There are four antennas, each designed to operate over a given frequency band. These frequency bands are: 148–174 MHz, 406–450 MHz, 450–512 MHz, and 800–960 MHz. The dimensions and detailed construction of each antenna are shown in figures B-2 through B-5. The antennas should be constructed of a lightweight highly conductive material such as aluminum or other comparable materials.

The antenna impedance should be tuned at each frequency by adjusting two tuning slugs and the tuning assembly. This can be accomplished by terminating the antenna coaxial connector in the desired impedance (usually 50 ohms) and, while measuring the SWR, adjusting the two tuning slugs for minimum SWR. This may take several adjustments. Then move to the tuning assembly and adjust it for minimum SWR. It may be necessary to repeat the entire process several times in order to achieve the lowest SWR.

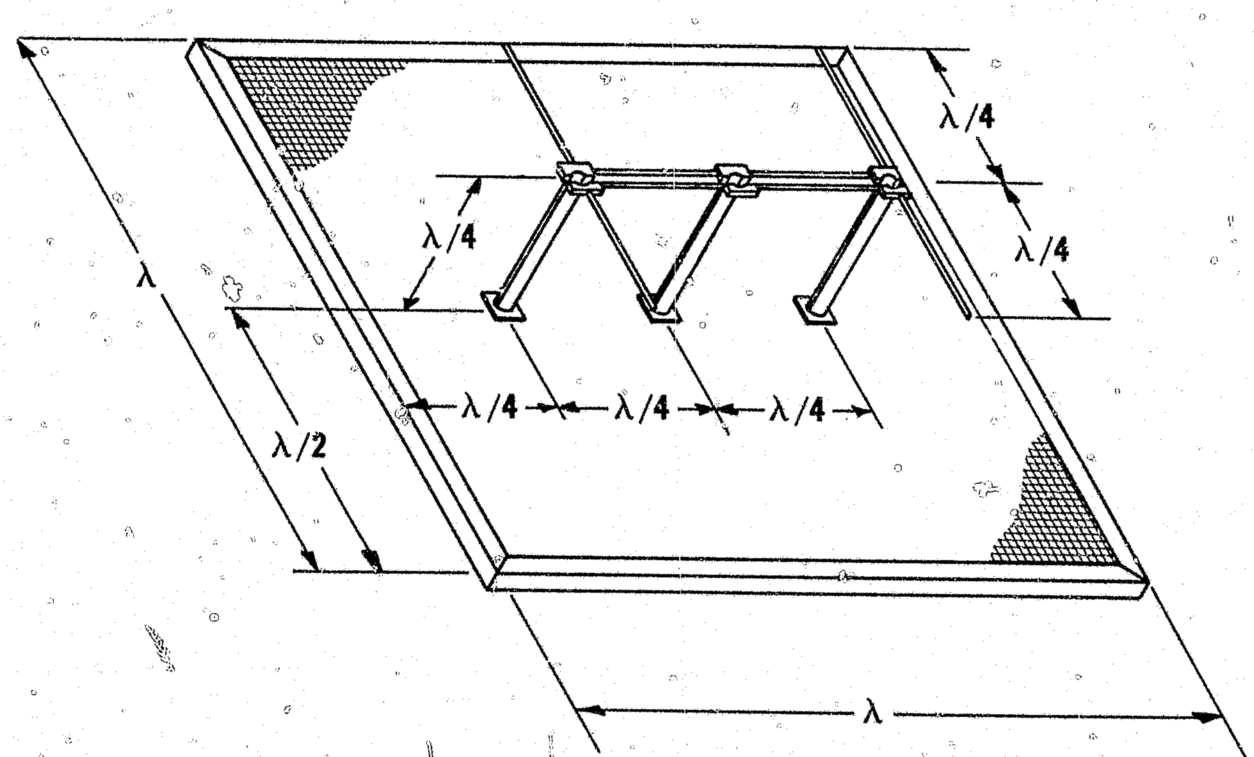

FIGURE B-1. Basic EIA reference antenna.

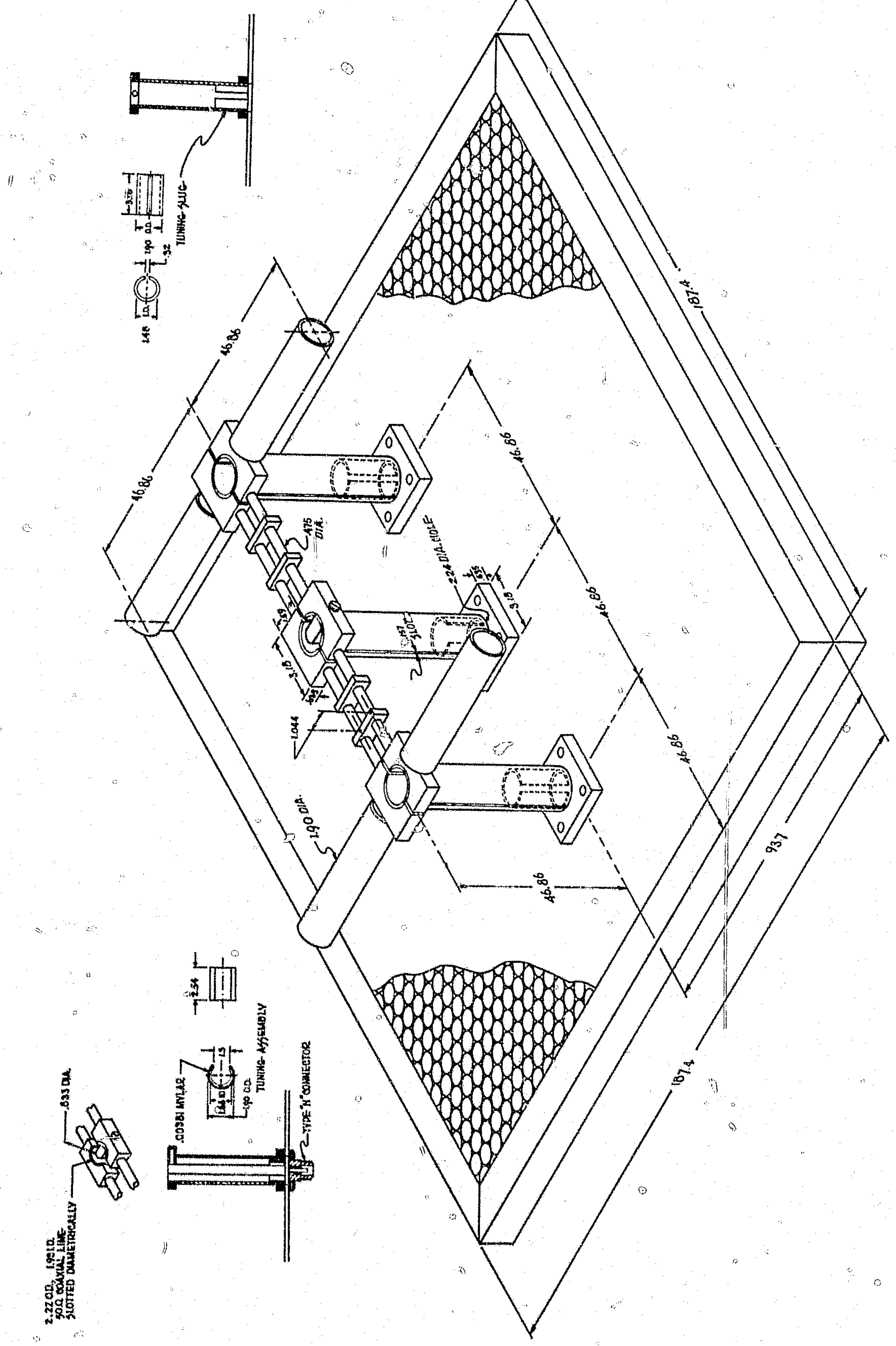

FIGURE B-2. 148 to 174 MHz EIA reference antenna (all dimensions in centimeters).

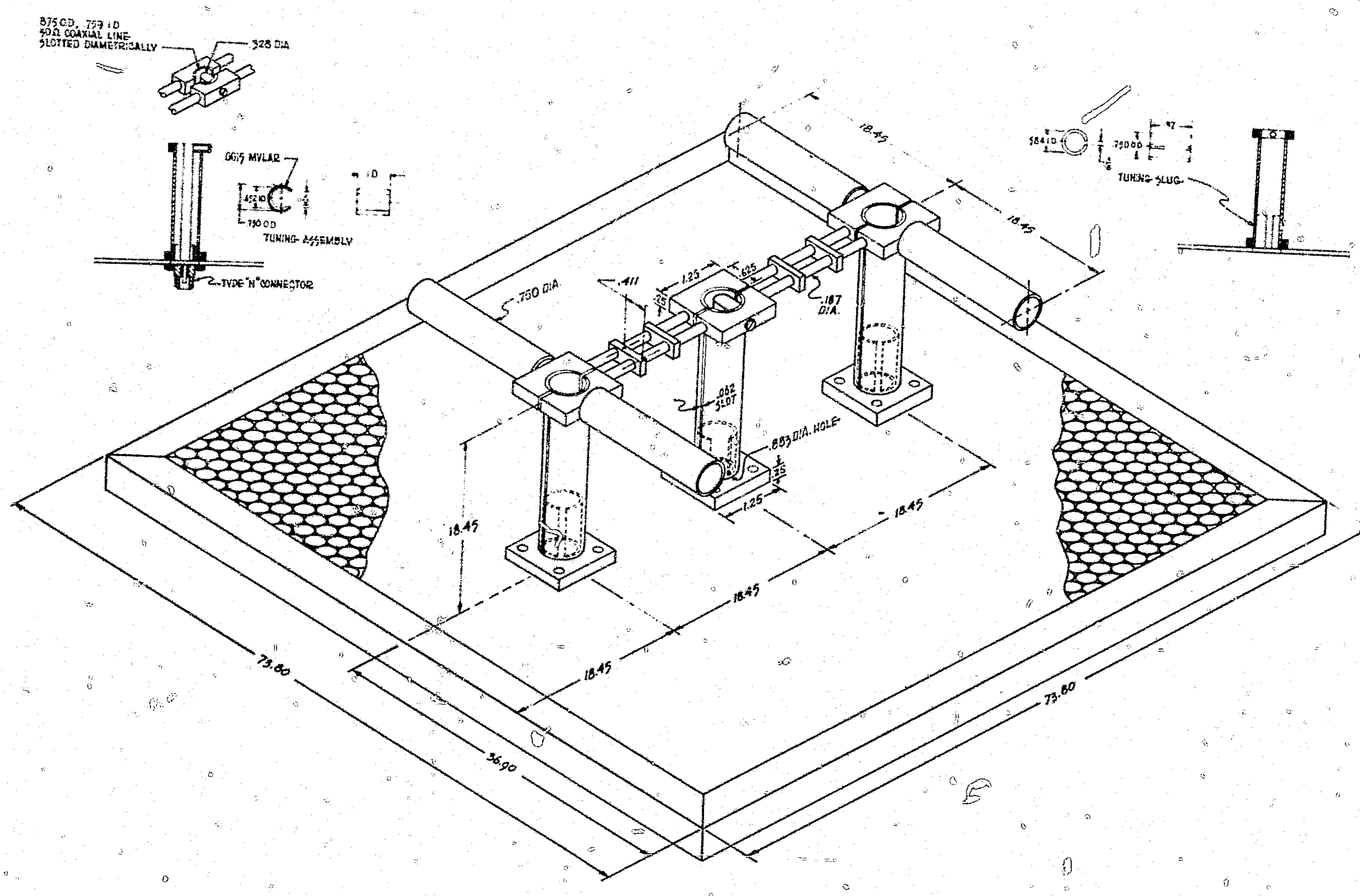

FIGURE B-3. 148 to 174 MHz EIA reference antenna (all dimensions in inches).

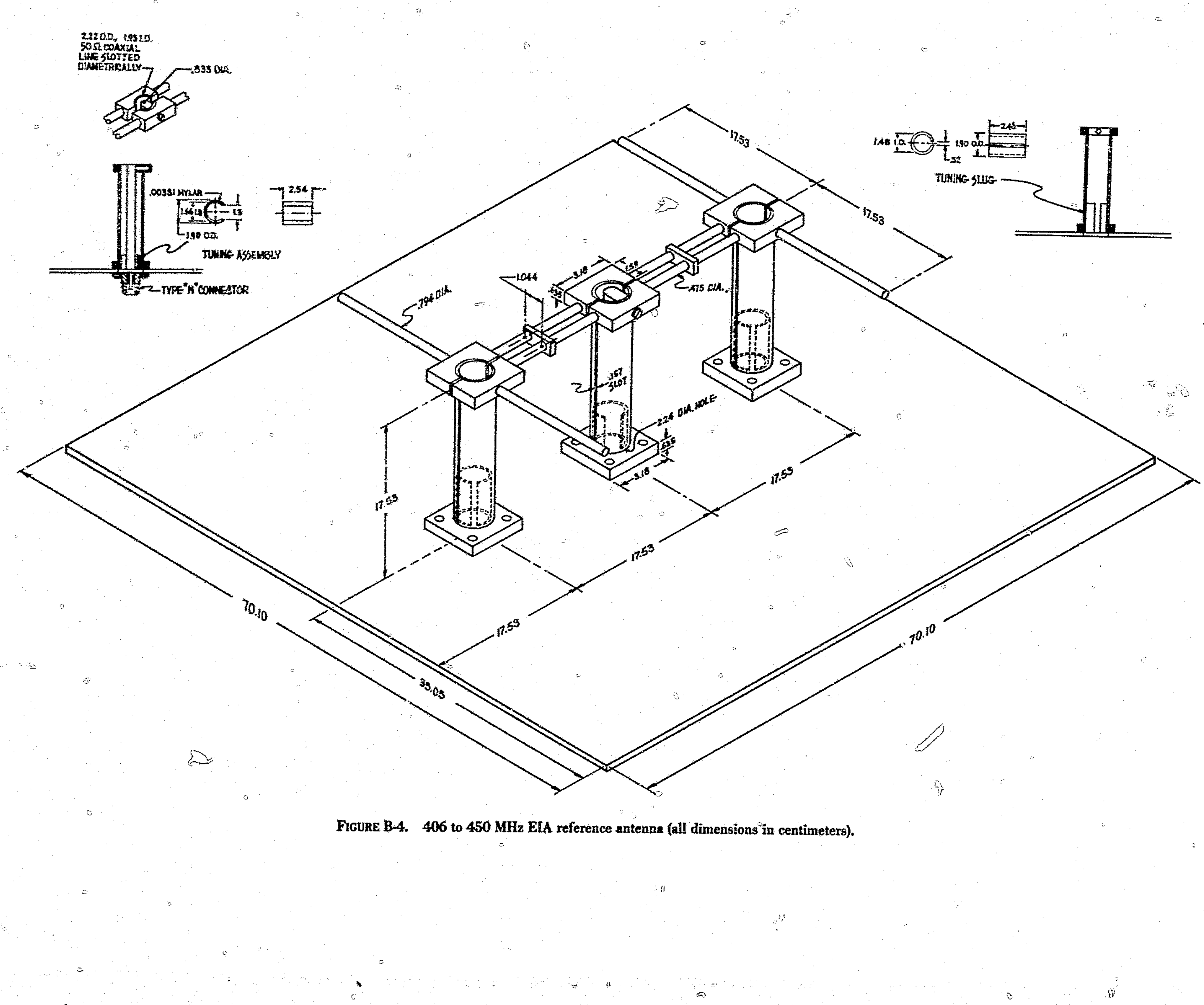

FIGURE B-4. 406 to 450 MHz EIA reference antenna (all dimensions in centimeters).

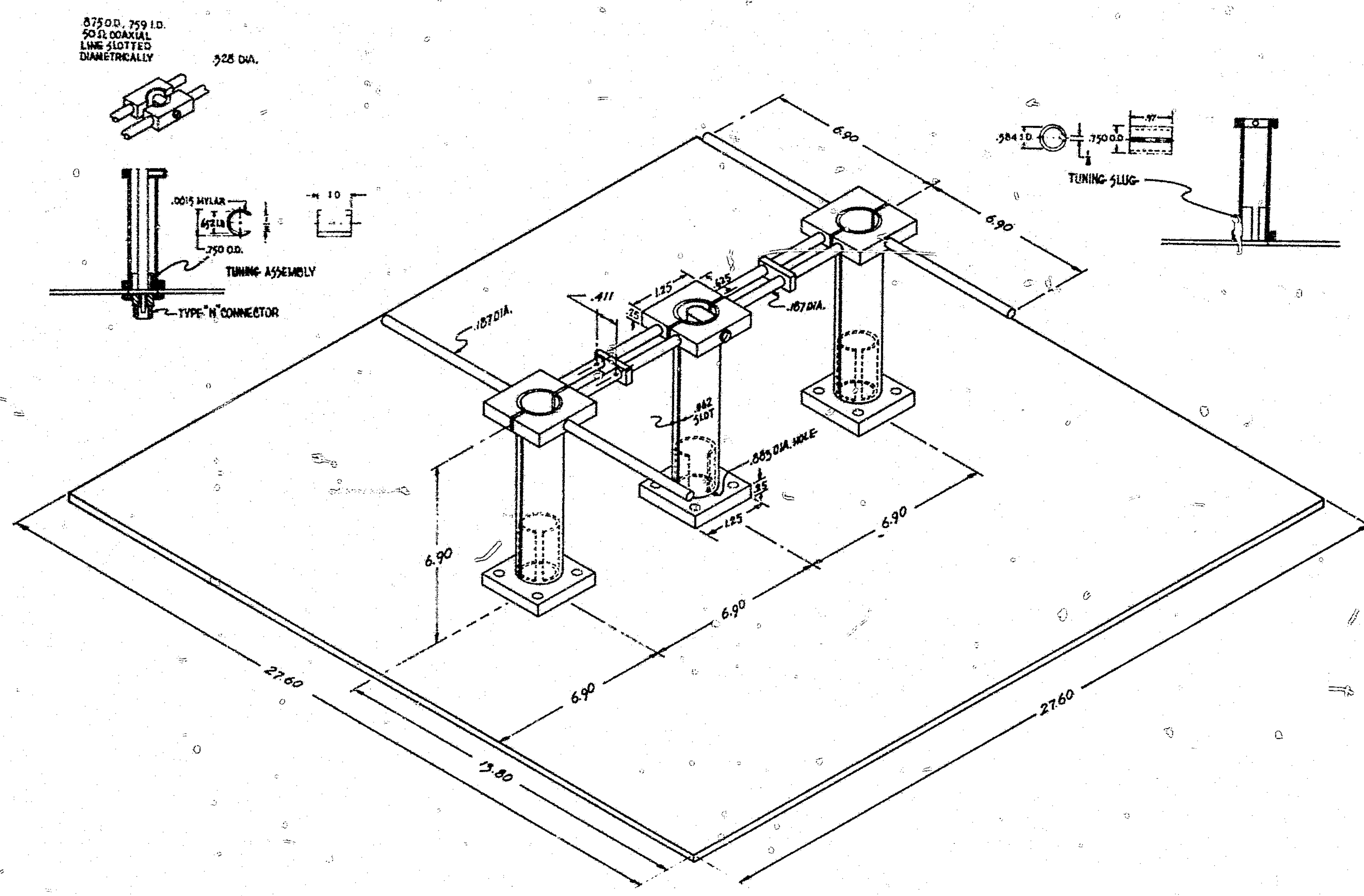

FIGURE B-5. 406 to 450 MHz EIA reference antenna (all dimensions in inches).

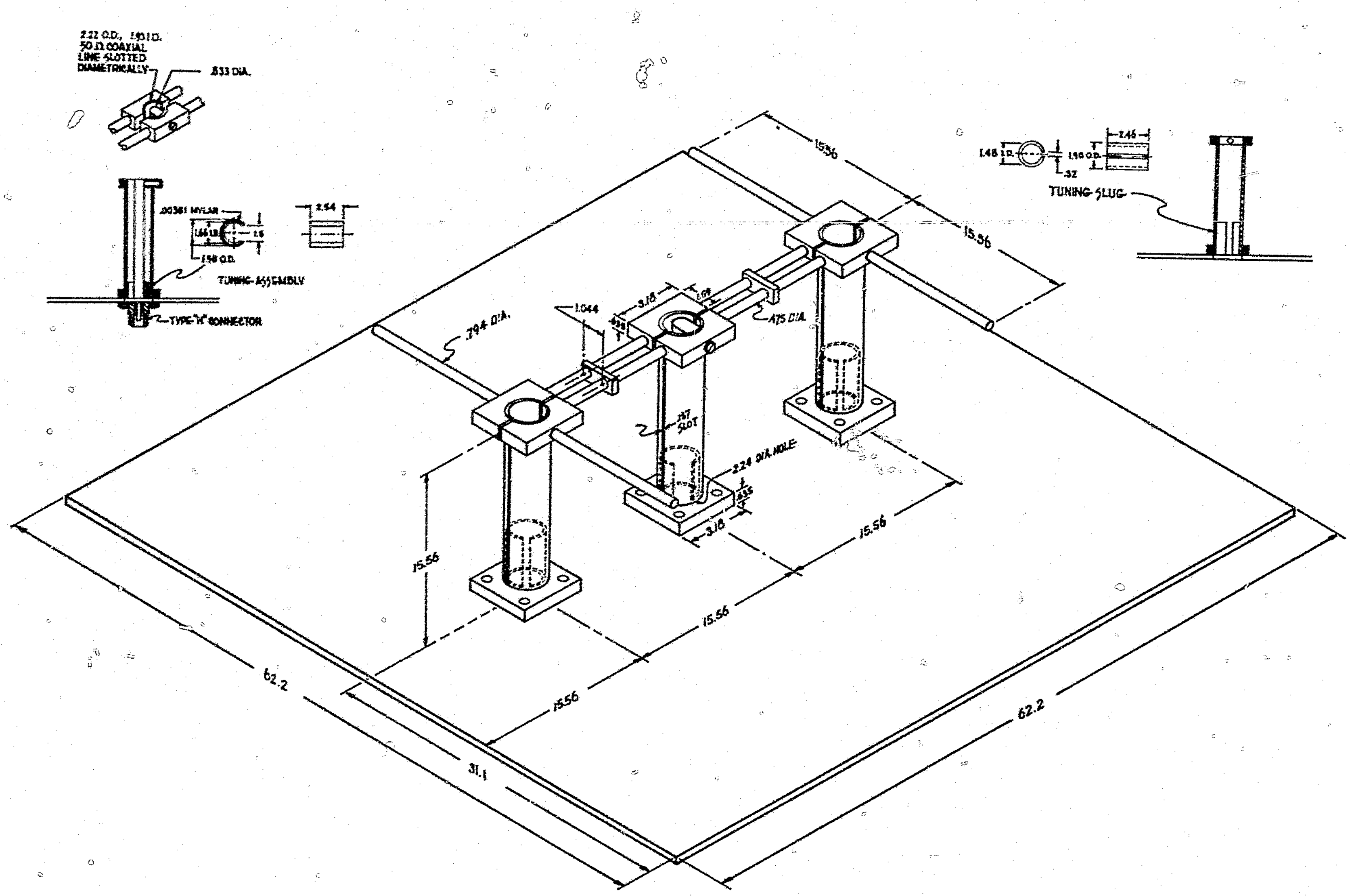

FIGURE B-6. 450 to 512 MHz EIA reference antenna (all dimensions in centimeters).

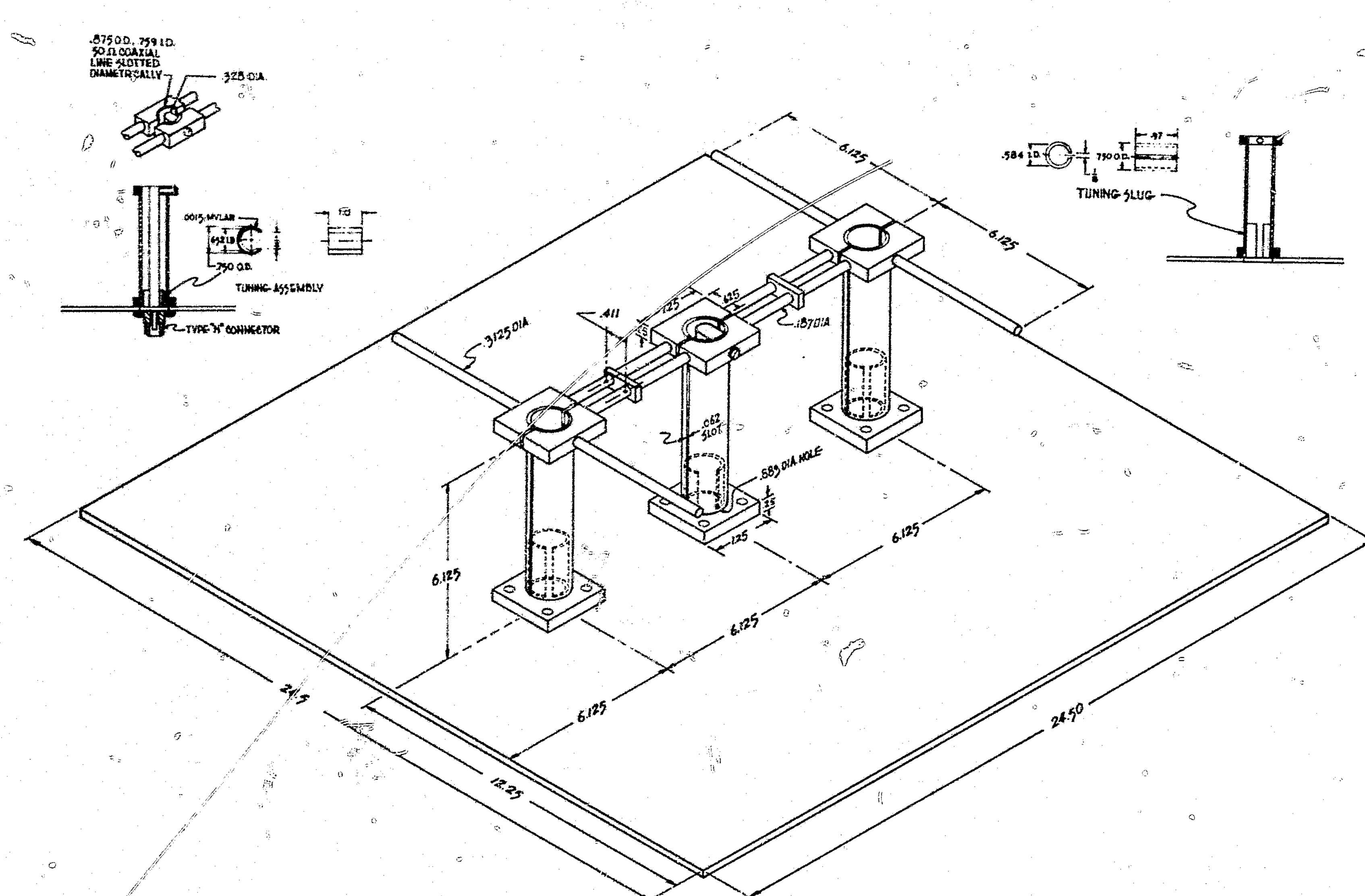

FIGURE B-7. 450 to 512 MHz EIA reference antenna (all dimensions in inches).

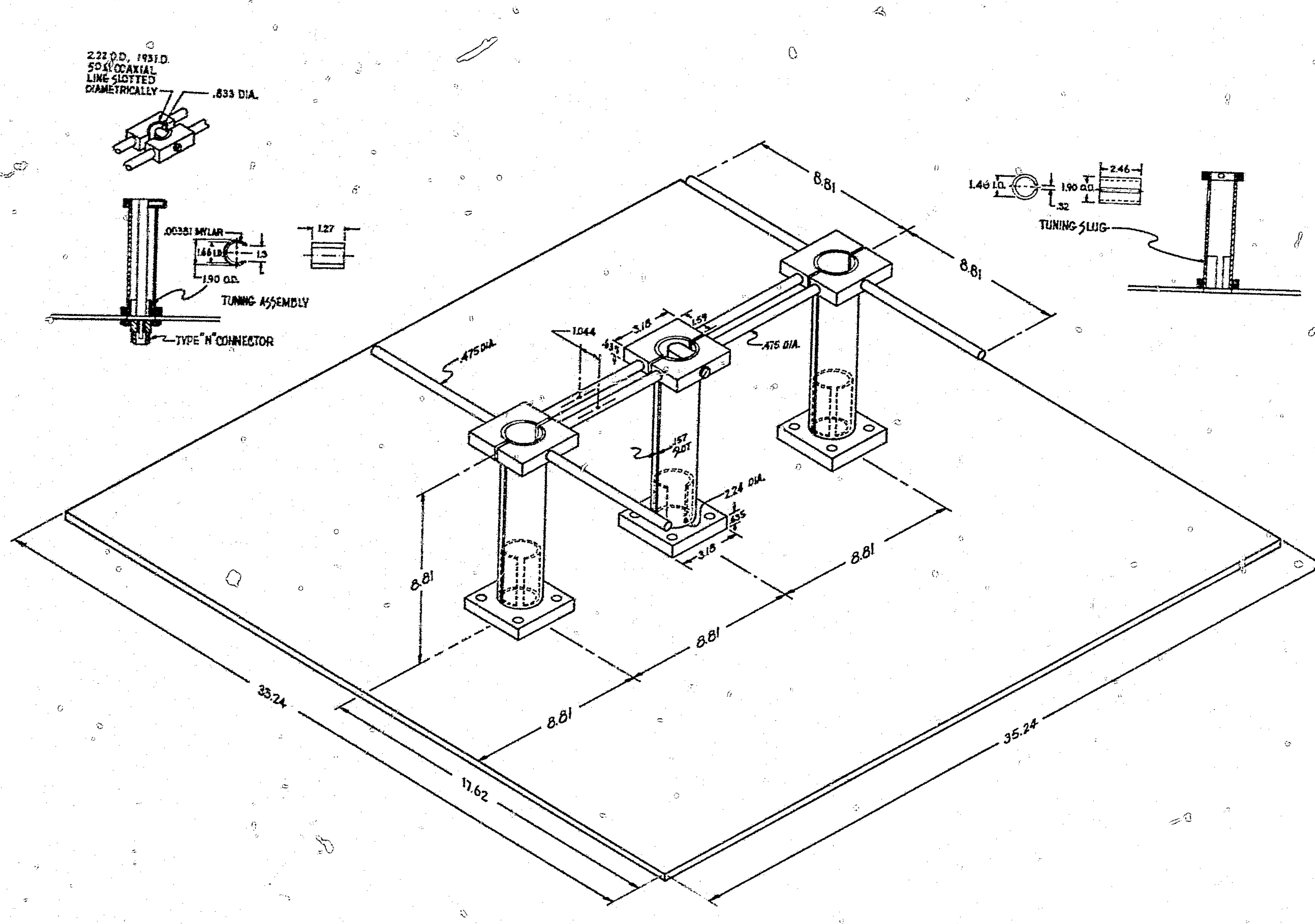

FIGURE B-8. 800 to 960 MHz EIA reference antenna (all dimensions in centimeters).

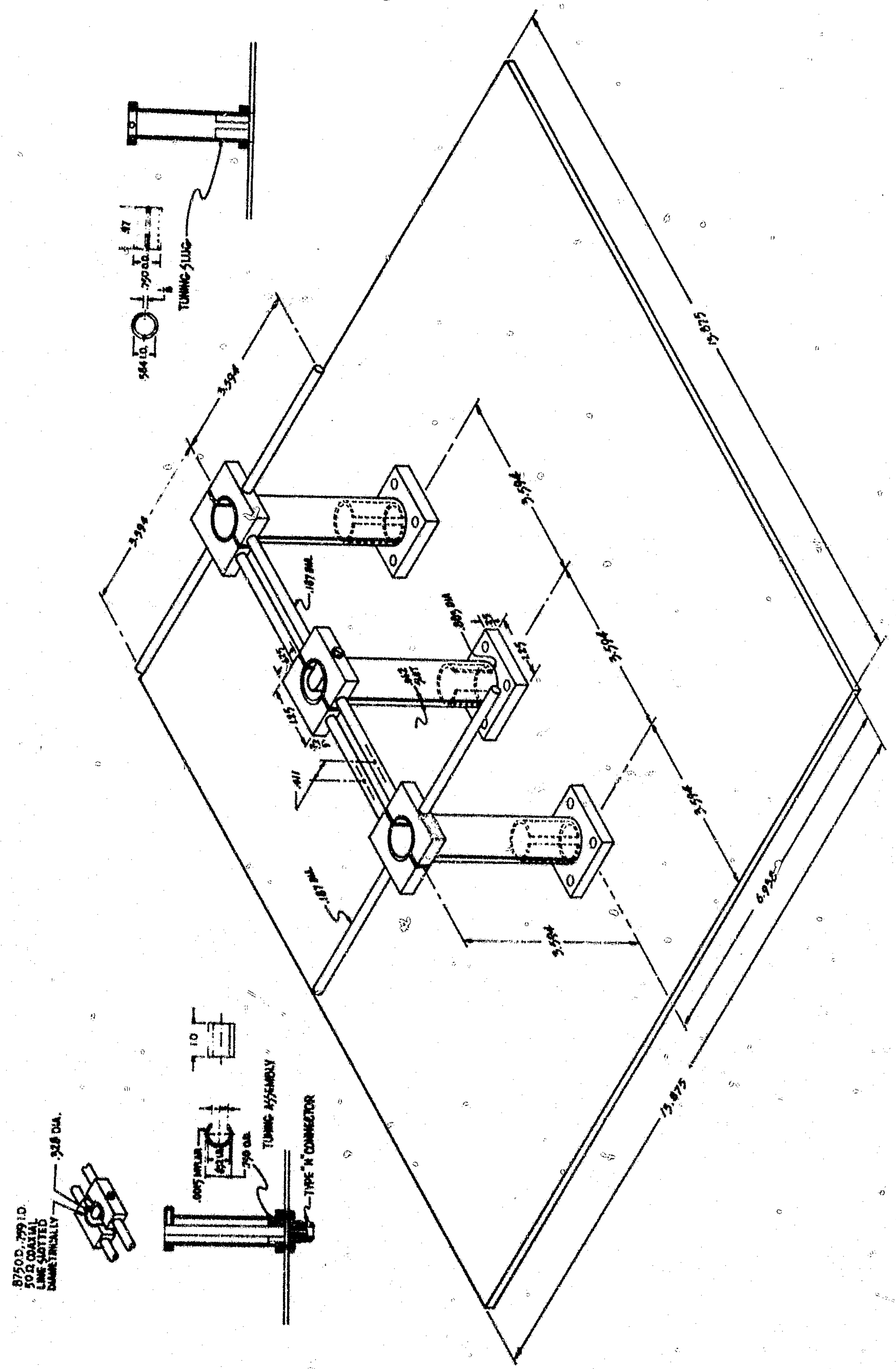

FIGURE B-9. 800 to 960 MHz EIA reference antenna (all dimensions in inches).

The gains of these reference antennas are listed in table B-1. A series of measurements were made at the National Bureau of Standards [12] on several antennas of this design to determine typical gain figures. Measurements were made at selected frequencies and selected bands on antennas that were similar in construction and supposedly identical to each other in electrical performance. However, the measured gains of these antennas varied, apparently because of minor differences in construction. The gain figures listed in table B-1 should be accurate within ±0.6 dB.

TABLE B-1. *Gains of EIA reference antennas relative to the standard gain units*

Band (MHz)	Frequency (MHz)	Gain (dBd)
148–174	148	7.5
148–174	160	7.7
148–174	174	8.0
406–450	406	7.6
406–450	428	7.7
406–450	450	7.9
450–512	450	7.5
450–512	481	7.7
450–512	512	7.9
800–960	800	7.5
800–960	882	7.7
800–960	960	8.0

Dipole Reference Antennas

The standard dipole antenna is a self-resonant half-wavelength dipole straight radiator as described in paragraph 3.2.

In order to achieve a self-resonant, half-wavelength dipole antenna, it is necessary to make the overall length of the antenna less than a half-wavelength. The shortening is a function of the antenna rod diameter and frequency. The percent shortening is determined by the following equation:

$$\%\ \text{shortening} = \frac{2708}{K_o},$$

where

K_o = 120 $\log_e (\lambda/d)-1$,

d = antenna rod diameter in centimeters, and

λ = free space wavelength in centimeters.

The balanced transmission line of a dipole antenna must usually be transformed to an unbalanced coaxial transmission line in order to connect it to the measuring system. This can be accomplished in several ways, such as by using a balun transformer or quarter-wavelength transformation stubs.

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