Fig. 4. Test automobile body in anechoic chamber with roof-mounted receiving and transmitting antennas (technician is measuring antenna VSWR with slotted line).

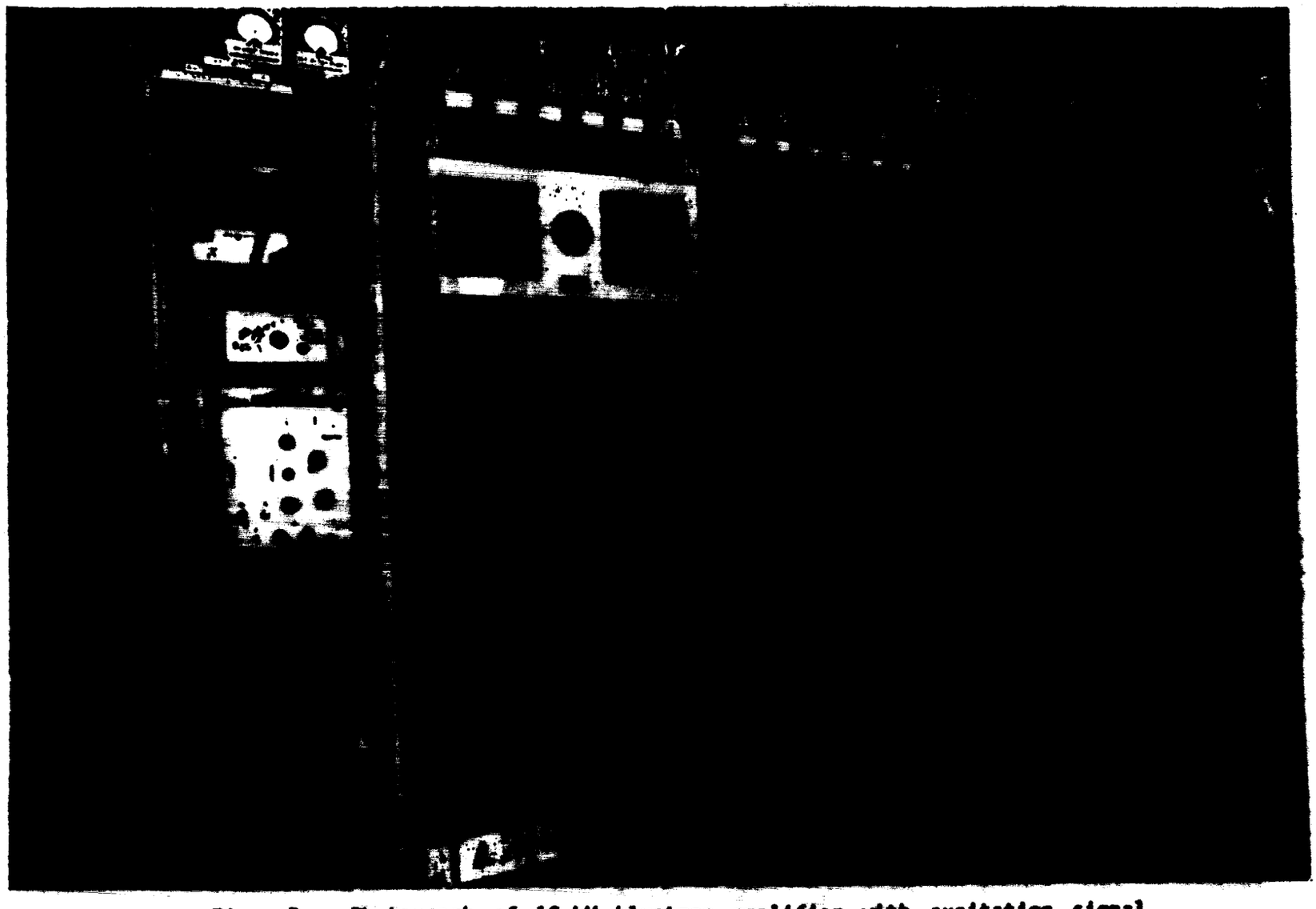


Fig. 5. Photograph of 10-kW klystron amplifier with excitation signal generator, amplifier, liquid-dummy load control system, output power meter and reflected power meter.

Modification of Antennas

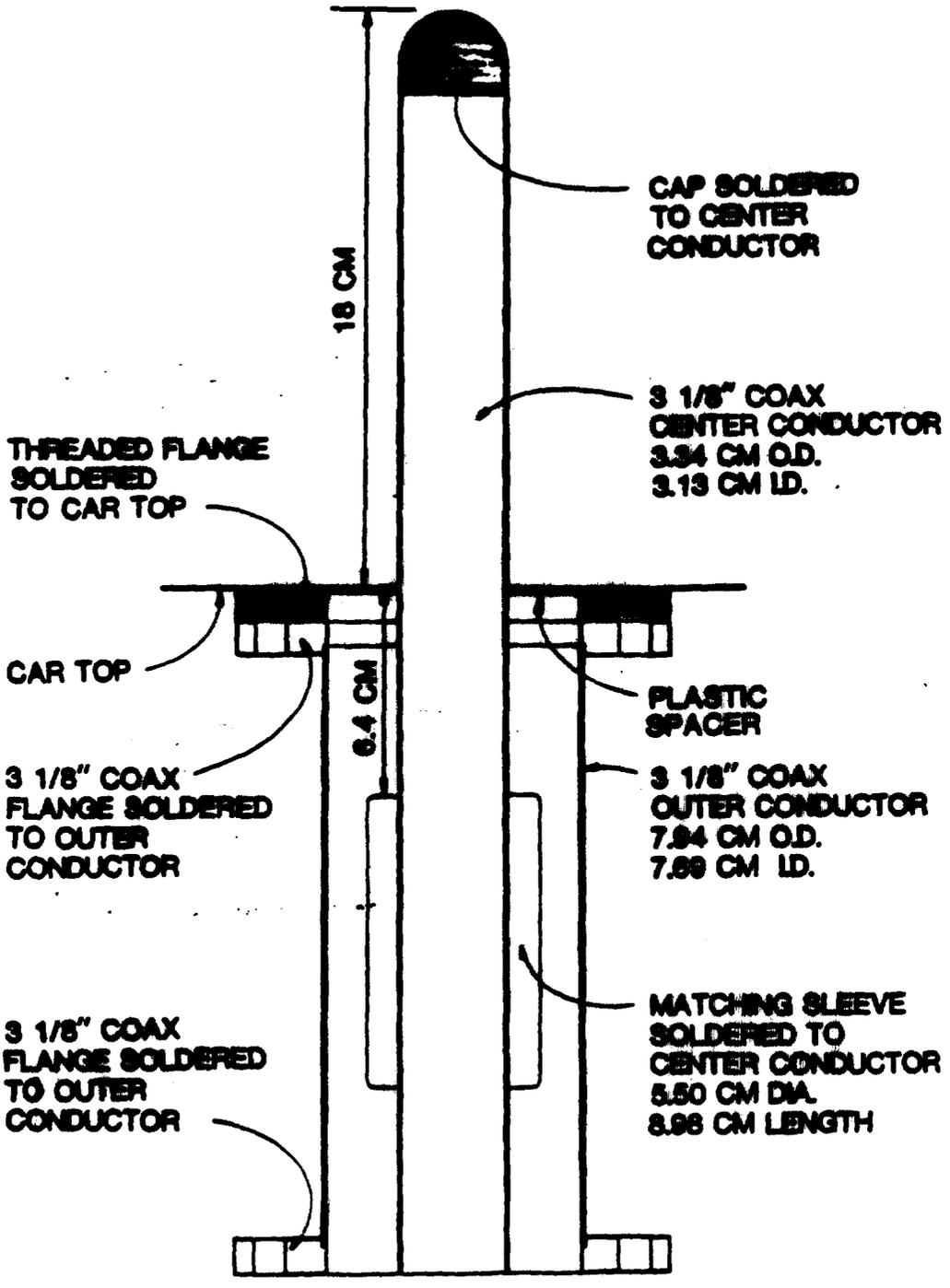
The original roof- and trunk-mounted antennas shown in Fig. 3, as supplied by Bell Laboratories, were designed for operation of a low-power, 3- to 10-W mobile telephone system. In applying the thermographic technique, one must use considerably greater power than that used for operation of a mobile telephone system to heat the model during a very short exposure time. Since the original antennas could not handle such a high power, an equivalent set of antennas with the same radiation pattern as the original antennas had to be developed.

The roof-mounted antenna consisted of a half-wavelength antenna approximately 17.5 cm long with an 8-cm-long base coil mounted on an insulator designed to allow power to be fed through the roof of the automobile. The trunk-mounted antenna consisted of a similar radiator-coil-combination mounted on a 23-cm-high skirt.

For high-power operation the roof-mounted antenna (shown in Fig. 6) was simulated by a half-wavelength-long (18-cm) stub extension of the center conductor of a standard EIA, 3-1/8"-diameter coaxial line with a flange in the outer conducter designed to interface to the underside of the automobile roof. A slotted line was initially connected to the unmatched antenna for determination of its input impedance. On the basis of the antenna input impedance, a quarter-wave transformer was fabricated as shown in the sketch and photograph in Fig. 7 to match the antenna to the 3-1/8-inch-diameter, 50-ohm EIA coaxial cable.

Upon completion of the design of the antenna, its performance in comparison to the original Bell Laboratories antenna was evaluated. For this evaluation, the receiving antenna was terminated with a 50-ohm load and the transmitting antenna was energized with 2-5 W of 835-MHz power with the incident and reflected powers measured by Hewlett-Packard 430B power meters. A National Bureau of Standards (NBS) EDM-1C meter was set up as shown in Fig. 8, with its sensor placed at 57.5 cm from the transmitting antenna. The probe of the NBS meter was mounted on a styrofoam hollow

Fig. 6. High-power, roof-mounted antenna and slotted line for measuring impedance.



HIGH POWER ROOF ANTENNA

Fig. 7a. Sketch of high-power, 835-MHz, roof-mounted mobile antenna.

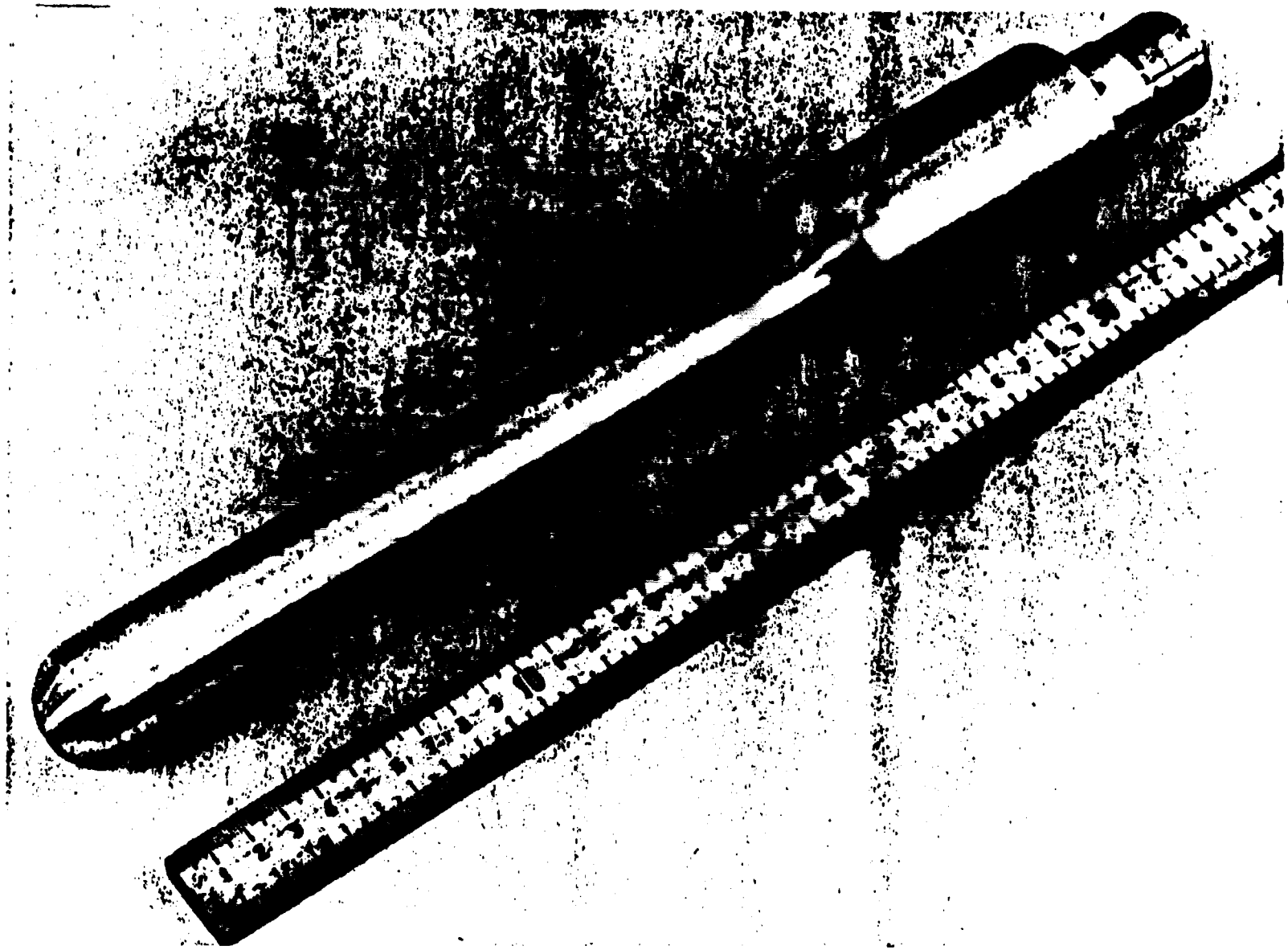


Fig. 7b. Photograph of center conductor with quarter-wave matching transformer.

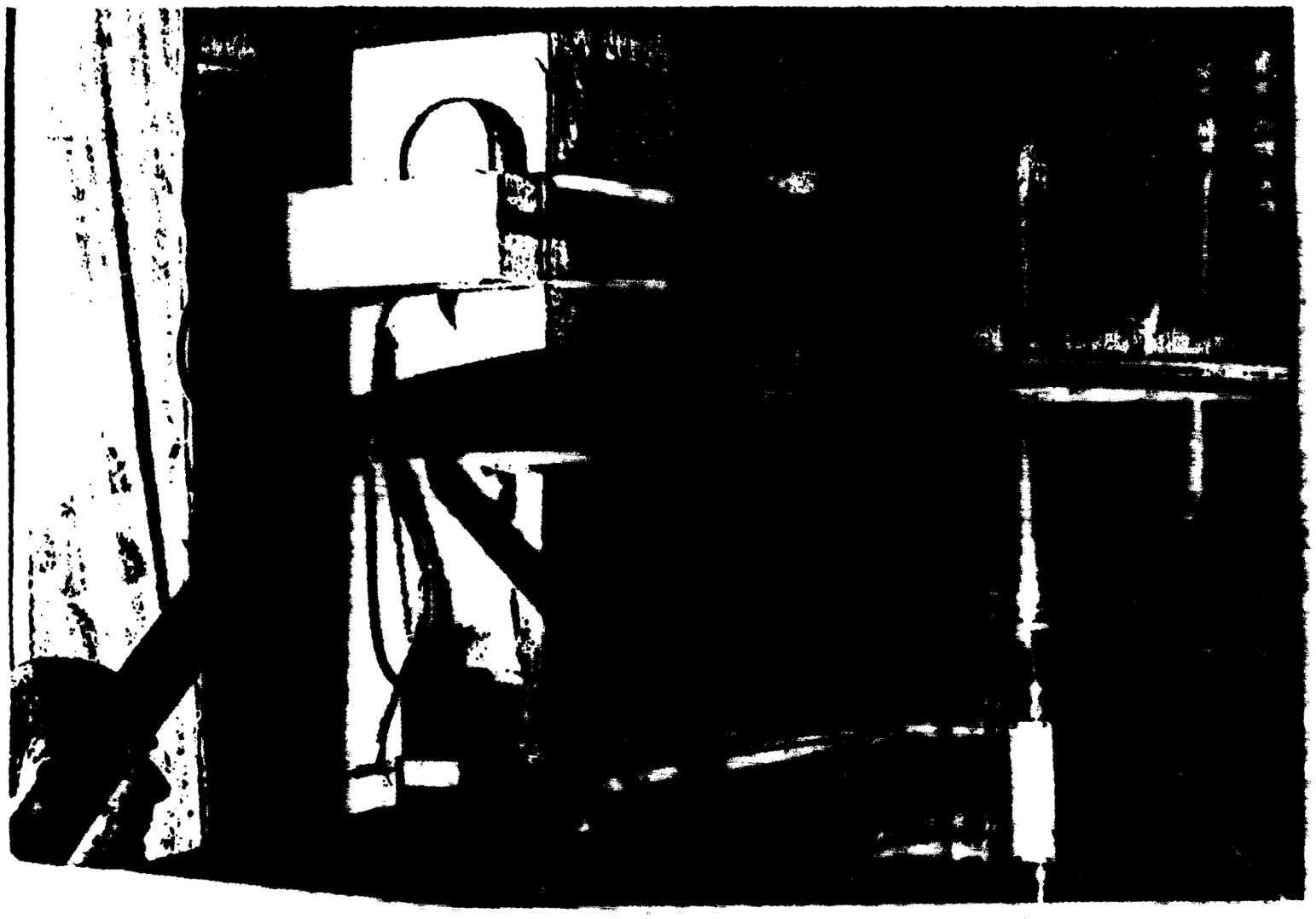


Fig. 8. Measurement of performance of high-power, roof-mounted antenna with National Bureau of Standards EDM-1C energy density meter.

form, which was designed to hold the synthetic tissue for simulating the woman model. Measurements of power density were done for both the high-power antenna and the low-power Bell Laboratories antennas; the results are shown in Table 1. The measured values indicate that the performance characteristics in the antennas were similar.

The sketch and photograph of the high-powered trunk-mounted antenna are shown in Fig. 9. The antenna originally consisted of an 18"-long halfwave stub section, similar to the roof-mounted antenna, protruding from a 3-1/8"-diameter coaxial line containing a quarter-wave-shorted transmission-line skirt for decoupling the transmission line from the antenna. The quarter-wave transformer was used to match the impedance of the antenna to 50 ohms. Originally, the antenna was designed so that the stub could be changed in length; a telescoping section and the quarter-wave skirt could be moved up and down with respect to the opening of the transmission line. The radiation pattern of the antenna in a plane containing the antenna and perpendicular to the side of the automobile was measured for a number of different antenna designs and compared with the radiation pattern of the original Bell Laboratories trunk-mounted antenna. The closest match between the patterns was obtained with the dimensions shown in Fig. 9a.

A comparison of the patterns of the Bell Laboratories and the high-power trunk antennas is shown in Fig. 10. The power intensities were measured over distances of 15-45 cm from the antenna by means of the NBS EDM-1C energy density meter. To minimize the influence of instrumentation and the operator on the fields, we used absorbing materials to shield the meter and probe cable with the probe inserted through the absorbing material. The power density was measured in 5-cm increments vertically (1/7 wave-lengths).

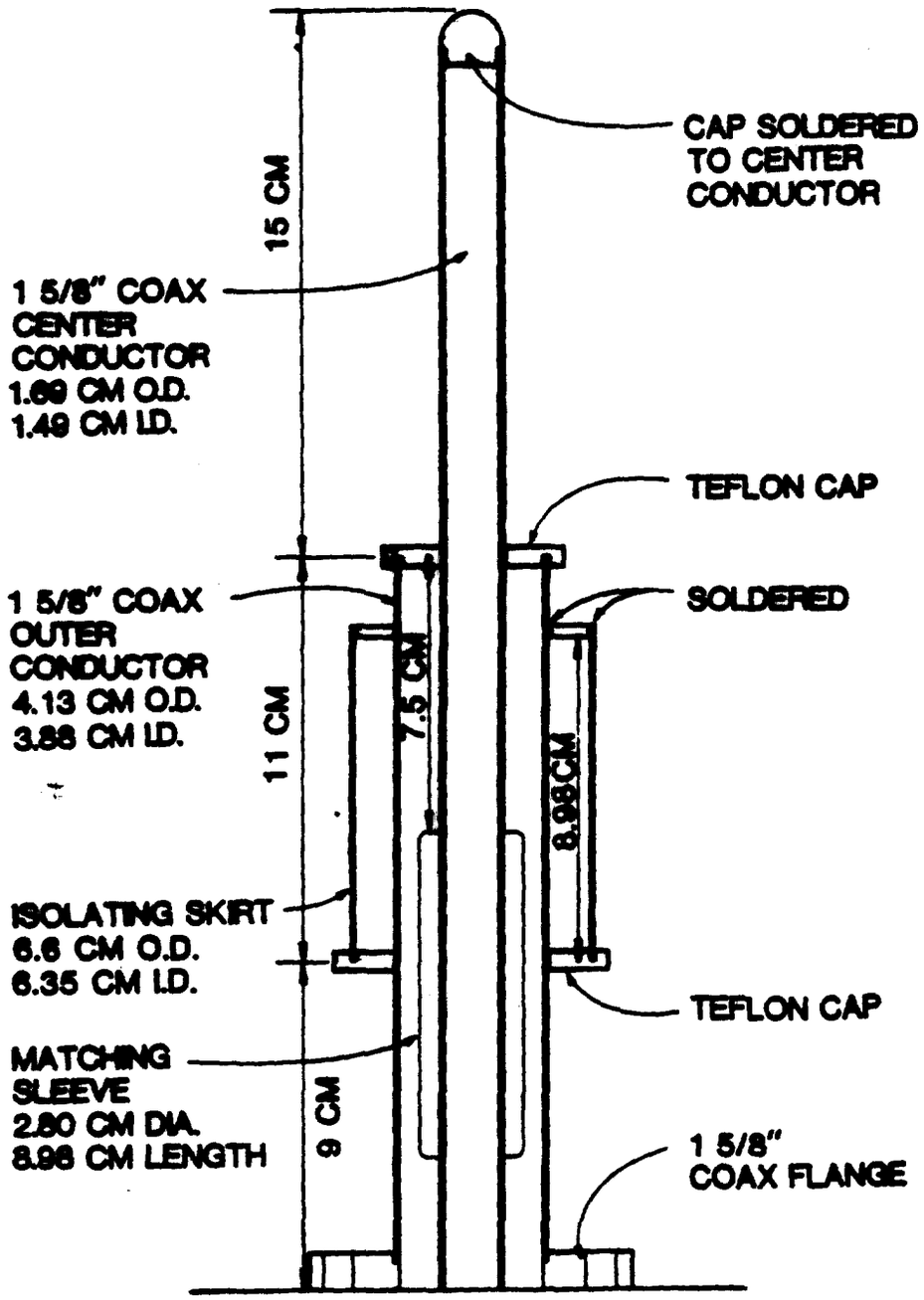
Phantom Models

The full-scale phantom models used in this research were of a man, a woman, and a child and consisted of hollow foam or fiberglass shells of

TABLE 1. COMPARISON OF PERFORMANCE OF BELL LABORATORIES LOW-POWER, ROOF-MOUNTED ANTENNA WITH THAT OF HIGH-POWER ANTENNA

Antenna	Frwd. Pwr. (W)	Refl. Pwr. (W)	Net Pwr. (W)	NBS Meter Reading (nJ/m)	Normal Pwr. Dens. (mW/cm per Watt)
Bell	2.51	0.123	2.39	1	0.088
Lab	4.83	0.242	4.59	2	0.091
High	2.53	0.022	2.51	1	0.084
Pwr.	4.96	0.042	4.92	2	0.084

Location = Side of car, 2 cm below and 57.5 cm away from antenna tip
Frequency = 835-MHz



HIGH POWER TRUNK ANTENNA

Fig. 9a. Schematic of high-power, 835-MHz, trunk mounted antenna.

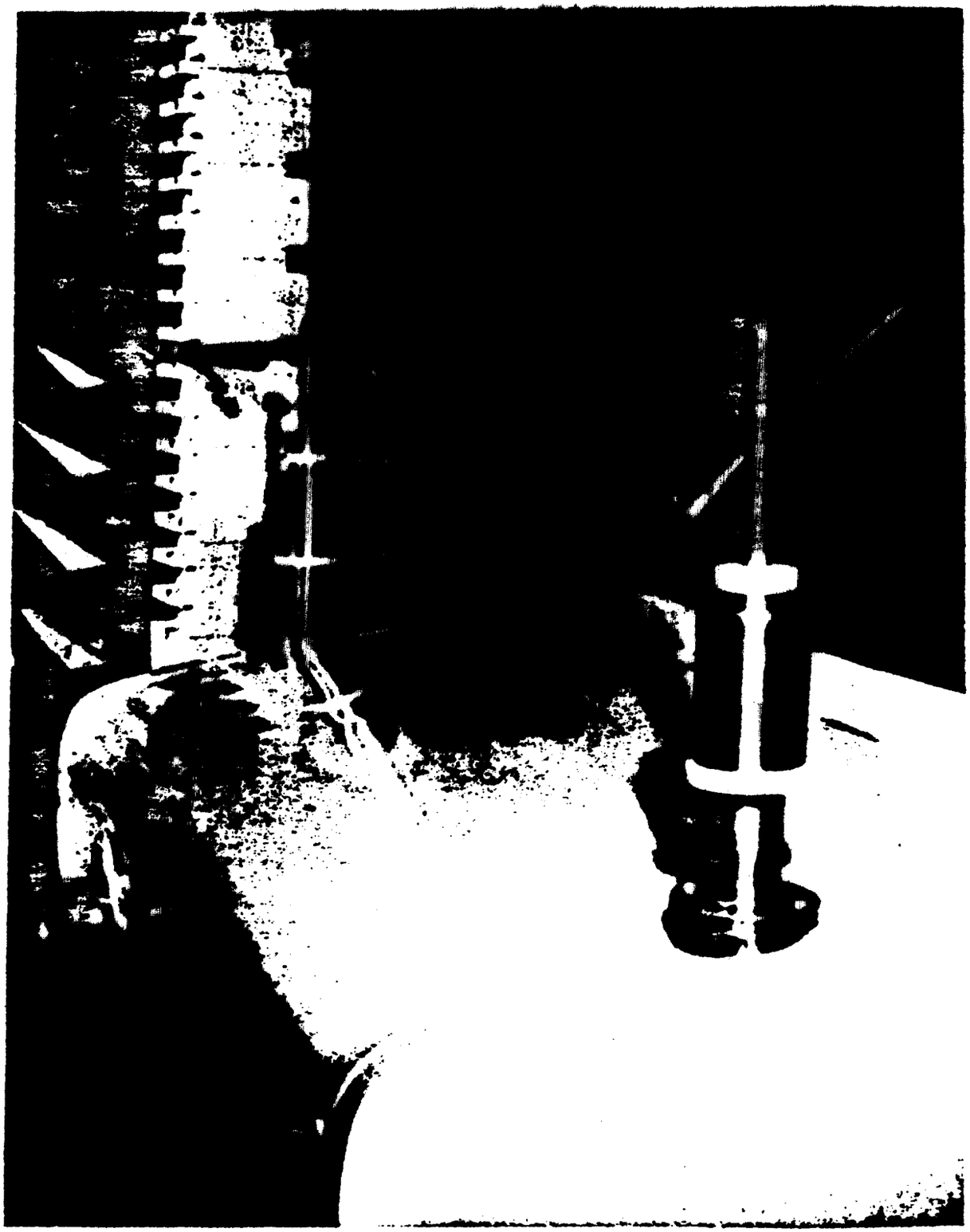


Fig. 9b. Photograph of high-power, trunk-mounted antenna and EDM-1C energy-density probe for measuring antenna fields.

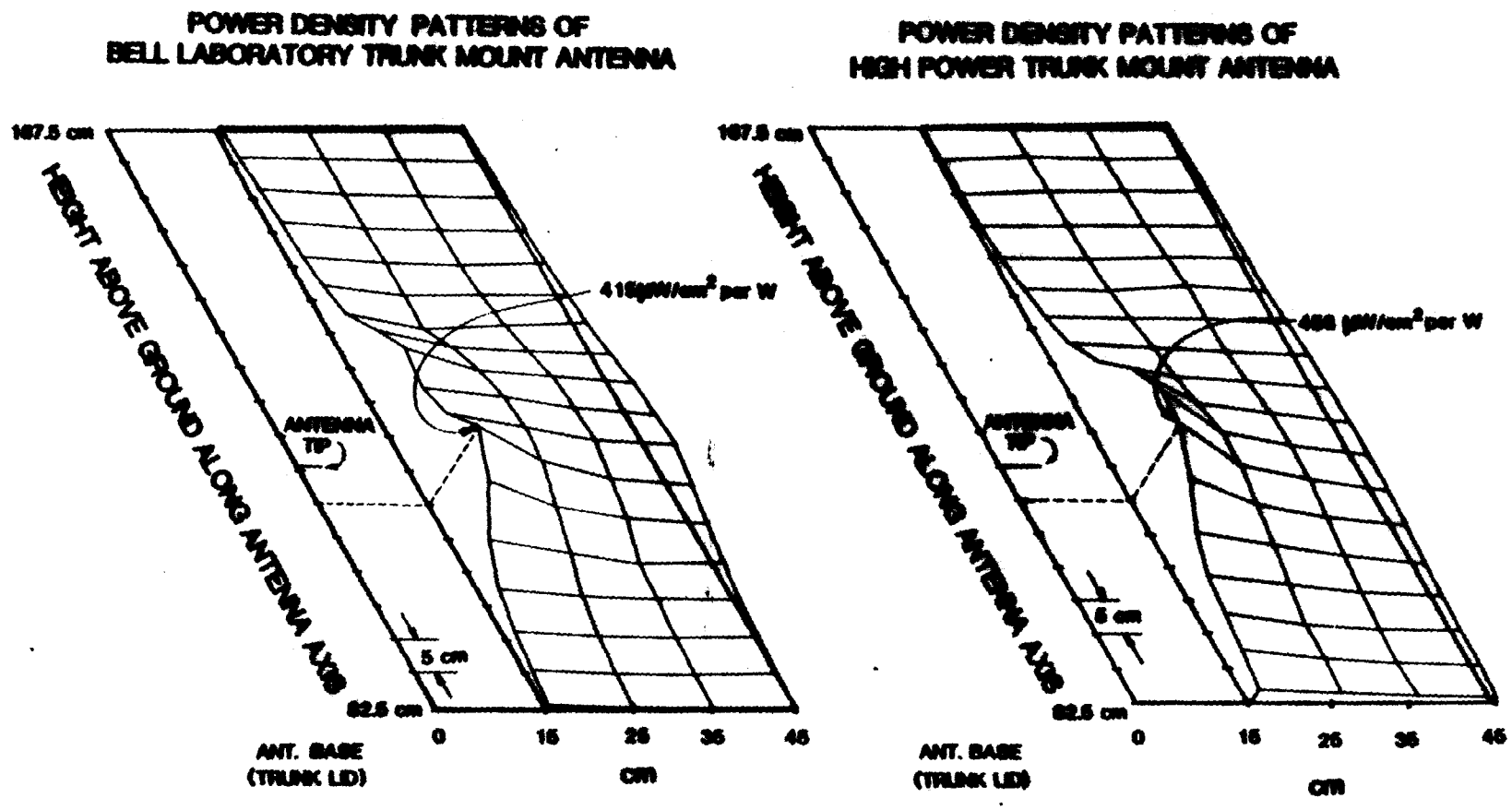


Fig. 10. Comparison of power-density patterns of Bell Laboratories antenna and high-power trunk mounted antenna.

human shape filled with a synthetic gell having the same dielectric properties as human muscle. No attempt was made to simulate skin, fat, bone, or internal organs. The styrofoam models used in the research were previously developed for a microwave-leakage study (Guy et al., 1976a). The woman model shown in Fig. 11 (with absence of muscle equivalent material) was designed to separate along a sagittal plane and also along a horizontal plane through the torso. The model corresponded to an adult female 1.63 m tall, weighing 59 kg. In Fig. 12 is a photograph of a half-section of the child model filled with synthetic muscle and separated along a sagittal plane. This model simulated a child .94 m tall, weighing 15 kg. The models could also be sectioned transversely through the level of the eyes, where high SAR levels were expected for facial exposures. These models were used for measuring the SAR patterns in an adult female and a child exposed to the roof-mounted antenna fields, in addition to a child exposed to the trunk-mounted antenna fields.

Because of the age of the models and their history of long use, the surfaces of separation were somewhat worn, so an additional set of models were constructed, consisting of hollow fiberglass shells from off-the-shelf clothing store "mannequins". The hollow models were first fabricated as shown in Fig. 13 for the erect man and Fig. 14 for the sitting man (hollow shells). The hollow shells were bisected along the planes of interest, and flanges were attached to enable rapid assembly or disassembly of the model over the selected plane. The completed man, woman, and child models are shown in standing positions in Fig. 15. We covered the woman model in Fig. 15 with metal foil to demonstrate the applicability of the models for measuring body currents resulting from exposure to electric fields at extra-low through medium frequency ranges. For this application the foil sections of the model, such as the arm, may be insulated from the rest of the body so that an ammeter may be used to measure the total current flowing across the particular cross section. Although such measurements are of no interest in this study, this does demonstrate the superiority of the fiberglass-shell model over the older, foam model for wider applications to nonionizing-radiation dosimetry studies.

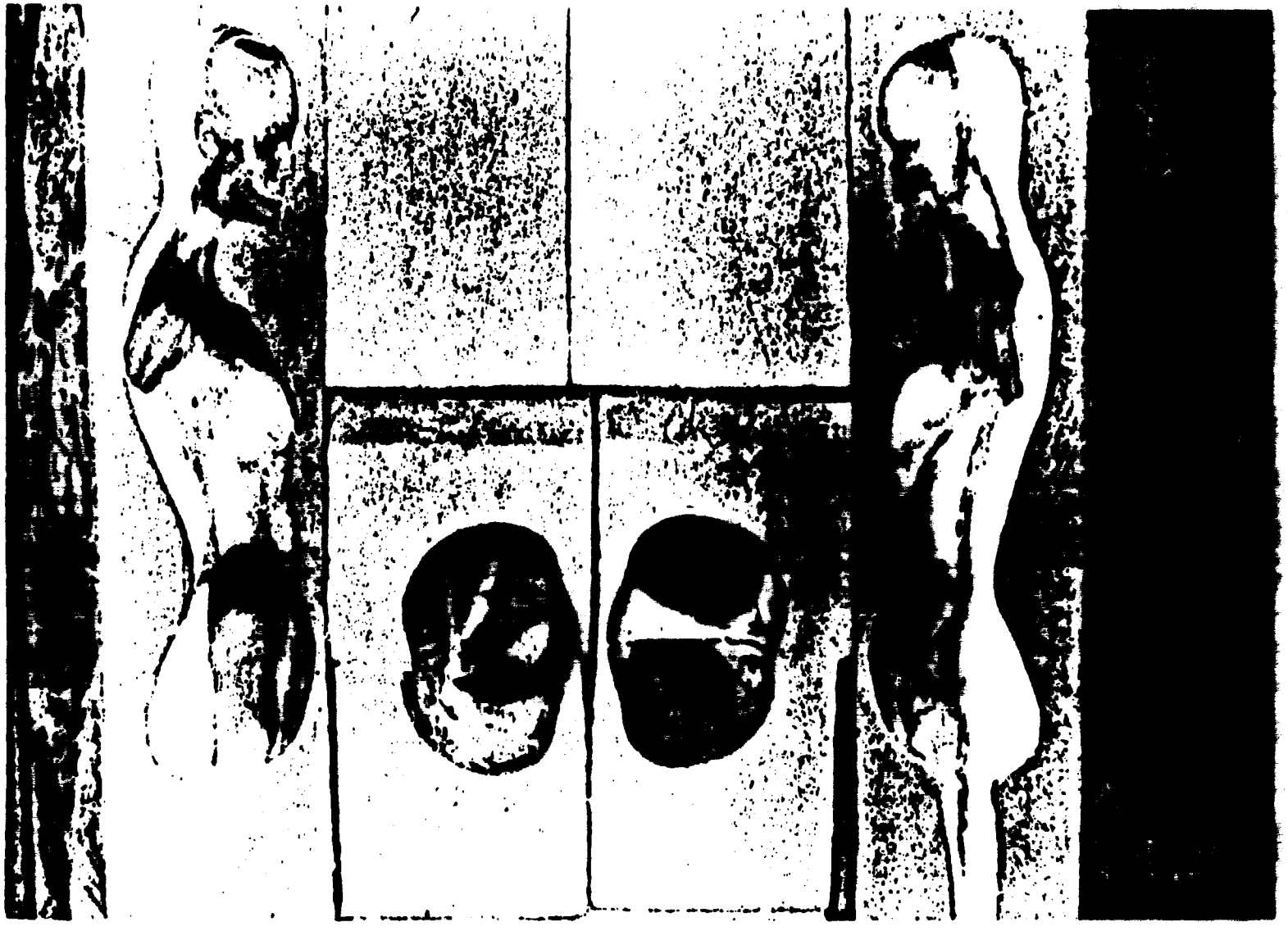


Fig. 11. Foam shells used for fabricating woman models, designed for separation along sagittal plane and horizontal plane through torso.

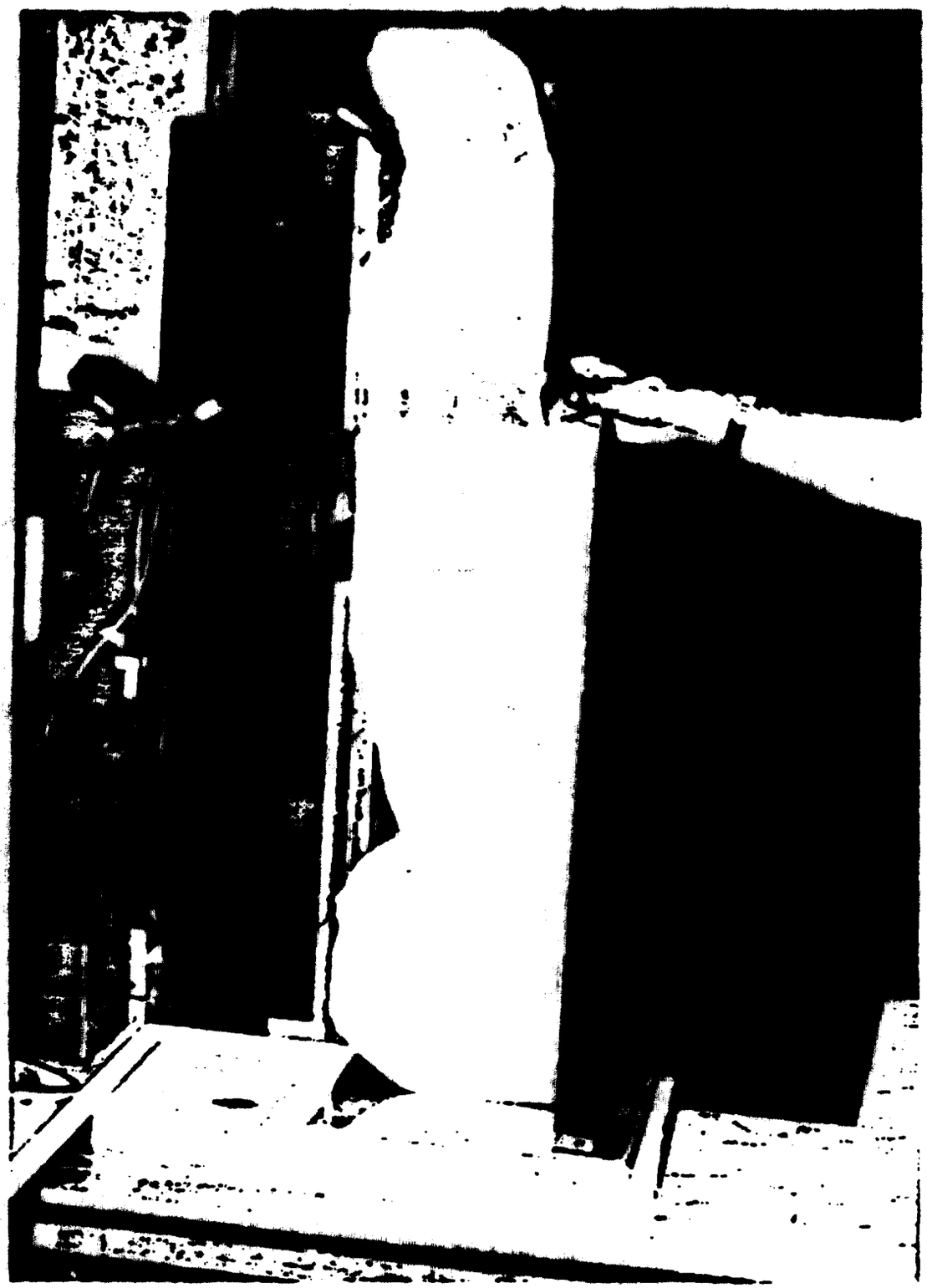


Fig. 12. Foam child model filled with synthetic muscle and separated along sagittal plane.

Fig. 13. Construction of fiberglass shell for phantom model of erect man.

Fig. 14. Fiberglass shell for phantom model of sitting man.

Fig. 15. Completed fiberglass shells with flanges at separation planes for man, woman, and child models. Woman model covered with metal foil shows applicability of models for measuring body currents due to exposure to electric fields at ELF through medium-frequency range.

With the fiberglass-shell models filled with synthetic muscle tissue, the weights and heights of the models were as follows: man 83.4 kg, 178 cm; woman 51.7 kg, 166 cm; and child 27.8 kg, 149 cm.

The composition and the electrical and physical properties of the phantom muscle used to fill the shells of the model are tabulated in Table 2. Prior to filling each half of a bisected model, we covered the open shell at the plane of the bisection with a 60-threads-per-inch mesh, 7N6XX polyester silk screen (NBC Silk, Nagoya, Japan) stretched tightly over the flanges at the plane of separation. The model was then filled with the synthetic muscle through a hole at the top of the head of each half. The purpose of the silk screen was to ensure electrical contact between the halves of the model when they were joined and allow easy separation of each half of the model along the smooth plane, as shown in Fig. 16.

Exposure Conditions

A number of possible exposure conditions were modeled in the study. Attempts were made to simulate worst-case exposure conditions resulting from the closest approaches of human subjects to the radiating antennas. These included an adult woman standing in close proximity to the side of the automobile as shown in Fig. 17, and a child in close proximity to the radiating roof-mounted antenna, closest possible approach if carried by an adult as shown in Fig. 18. Other exposures included a child (Fig. 19), a woman (Fig. 20), and a man (Fig. 21) standing next to the trunk-mounted antenna; a man sitting in the back seat of the automobile (Fig. 22); and a child peering out the back window of the automobile (Fig. 23). In most instances the subjects were exposed under conditions where 5- to 10-kW power was fed into the antennas from the traveling-wavetube-amplifier for periods of 20 to 90 sec. In all exposure conditions a high-powered load was placed at the feedpoint of the receiving antenna to absorb any of the power coupled to it from the transmitting antenna.

TABLE 2. COMPOSITION AND ELECTRICAL AND PHYSICAL PROPERTIES OF THE PHANTOM MUSCLE

Composition	TX150	PEP	H_2O	NaCl
(% By Weight)	8.45	15.20	75.44	0.9069

	Dielectric constant ε	Conductivity σ (S/m)
Electrical properties (915 MHZ)	51	1.24
	Specific heat (kcal/kg ^{o}C)	Specific density (g/cm^3)
Physical properties	0.86	0.97

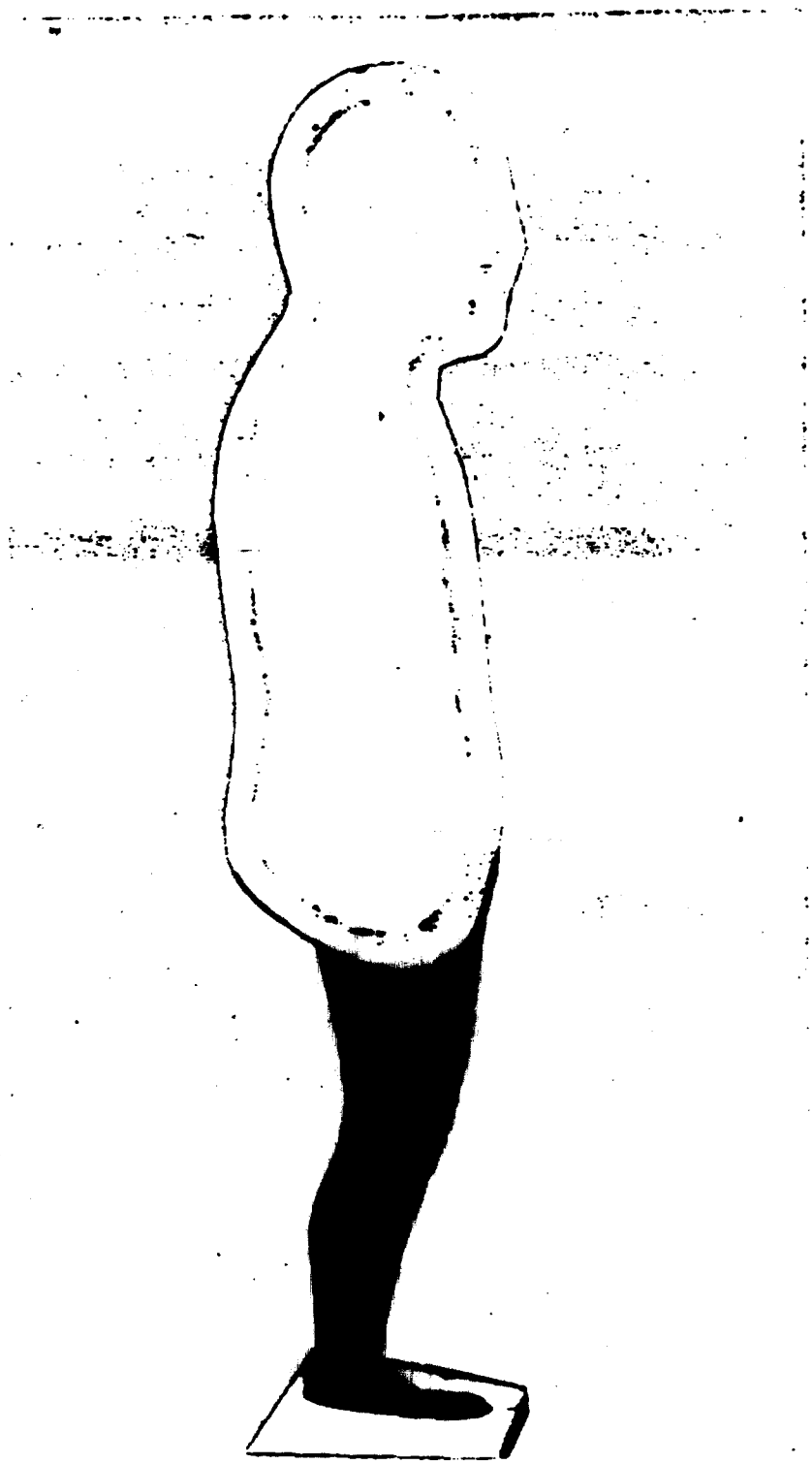


Fig. 16. Erect man model separated along sagittal plane.

Fig. 17. Woman model (separated along sagittal plane for illustration) exposed to roof-mounted mobile antenna.

Fig. 18. Child model exposed to roof-mounted antenna (carried position).

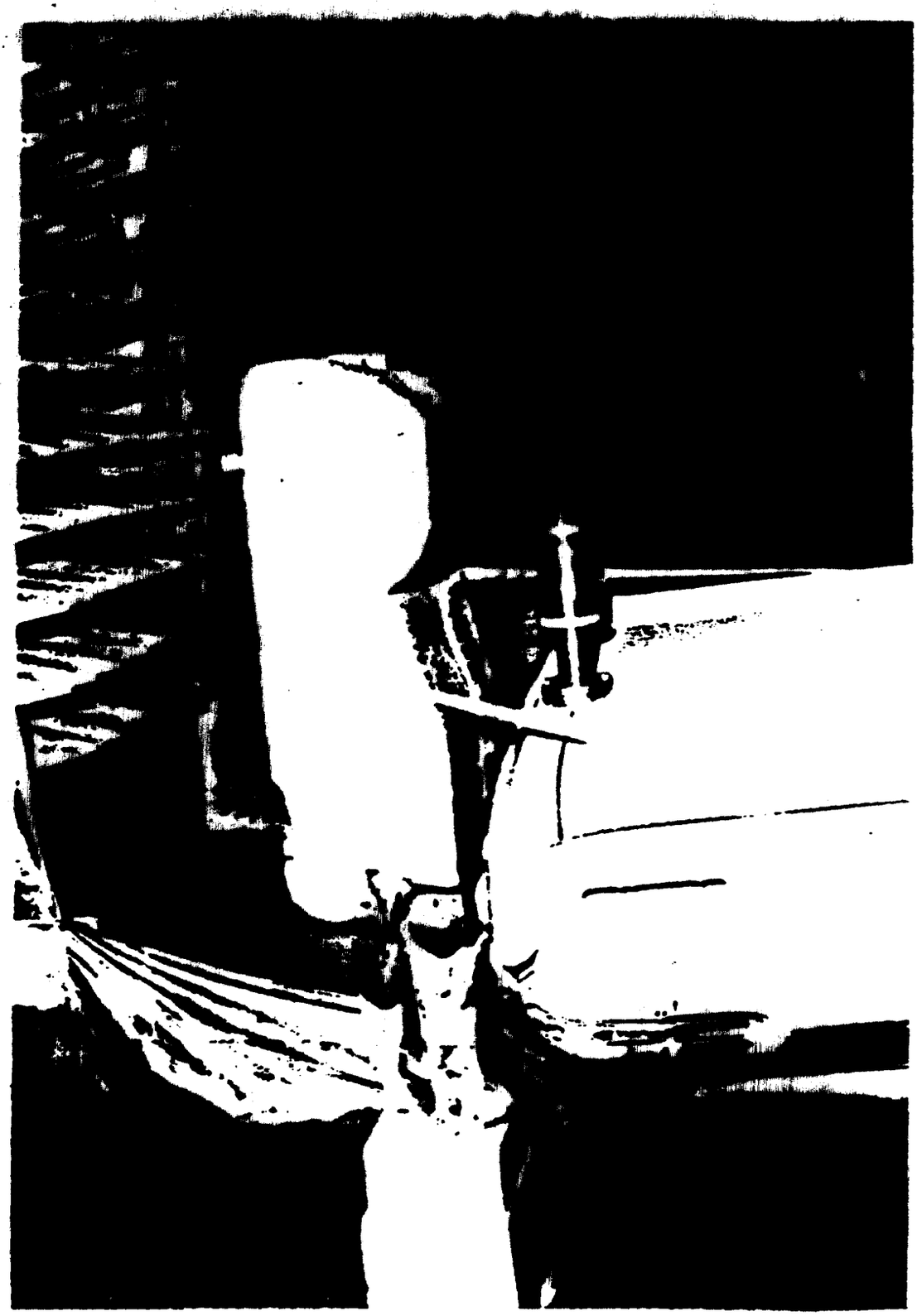


Fig. 19. Erect child model exposed to trunk-mounted antenna.

Fig. 20. Erect woman model exposed to trunk-mounted antenna.

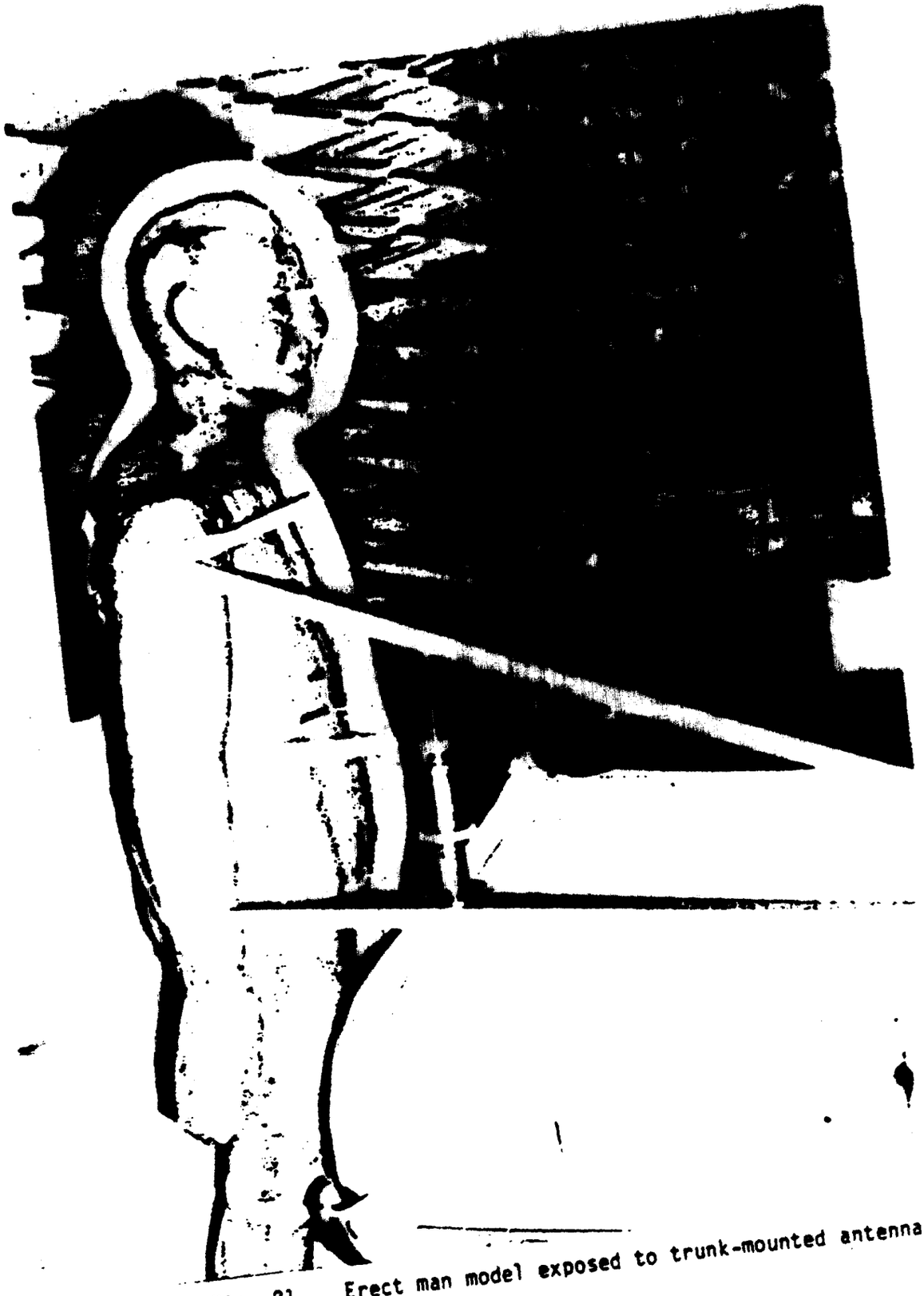


Fig. 21. Erect man model exposed to trunk-mounted antenna.