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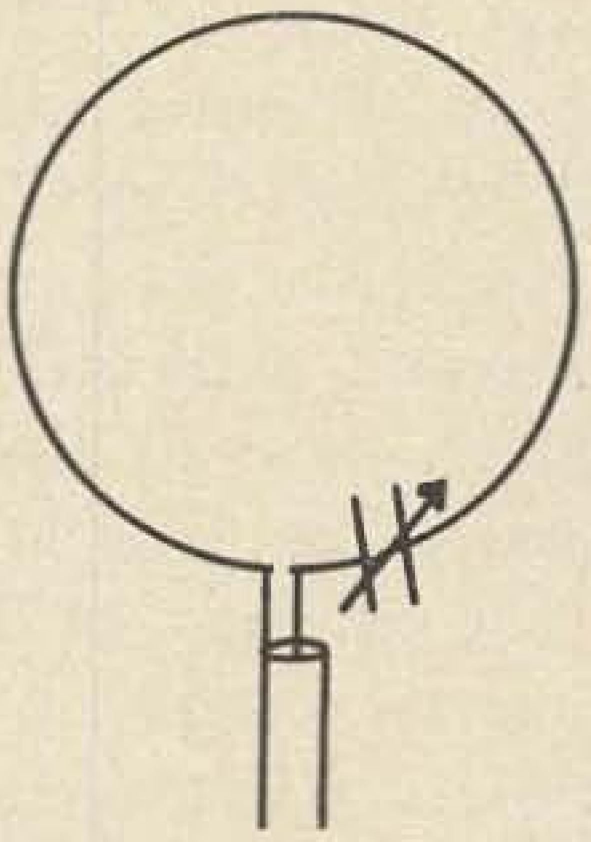
Can A 7 foot 40m Antenna Work?

. . . the Small Lop

In attempting to operate an amateur radio station while living in an apartment on the top floor of a three story frame house, it was desirable to use the smallest antenna possible. Since in the interests of social harmony it was virtually mandatory that the antenna be concealed from the landlady who lived one floor below, the antenna had to be restricted indoors to the confines of the apartment. In the course of trying to match a number of different shapes of wire to a coaxial transmission line it was noticed that when the loop forming the gamma match in the center of an 'S' shaped antenna was made large enough, a close match to the transmission line could be obtained. While the first surprise was that the loop forming the gamma match was as large as it was, the second was that the match to the line was little affected when the arms of the 'S' were shortened and even removed. That the loop that remained was of a useful size for an antenna was evident since at 7.15 MHz the length of wire in the loop was about 6.7 meters (22 feet) and the total height when erected vertically was about 2.1 meters (7 feet). An antenna this size was easily manageable while there was simply not enough room to put up a half wavelength antenna 20 meters long.

At first it seemed to be a bit strange that a loop antenna this small would have as high a radiation resistance as it did. In a number of books the radiation resistance of a loop antenna with a uniform current distribution is calculated (as in ref. 1) and a loop with a circumference of about .7 wavelength is needed to obtain a radiation resistance of 50 ohms. Since this would mean the calculated loop circumference would be some 4.5 times the actually measured size a qualitative check was made of the current distribution in the loop. As can be seen in Fig. 1, the current distribution was certainly not uniform. Indeed it was not even symmetric about the two points where the antenna was fed; a much greater current flowed in the side connected to the capacitor. This held true with the connections to the coax braid and center conductor switched. Once it is established the current is not uniform it is to be expected that the radiation resistance will be higher than the uniform current model would predict. Thus it appears that a more accurate physical model would have to be used to explain why the current flow assumes the form it does. (These measurements are not precise but are probably accurate enough to ascertain the antenna current. They were made with a loop of wire a couple inches in diameter held several inches from the antenna. This test loop and a four germanium diode bridge were mounted on the end of a four foot piece of plastic pipe and the dc output was fed through a coax line to a galvanometer.)

It needs to be said that the above mentioned and all the following measurements were made with the antenna indoors on the ground floor of a two story frame apartment building in San Diego, California. The concrete floor, which is essentially at ground level, was covered with at least two layers of regular aluminum foil. This gave a solid ground plane roughly 6.7 by 4 meters and .0032 cm thick (which is about the skin depth of a 7 MHz rf current in aluminum). The antenna was made of 19 strands of aluminum wire in a loose bundle. Each strand was slightly less than 1/16 inch in diameter. The antenna was erected in a vertical plane and fed with RG-58/U at its lowest point which was 20 cm (8 inches) above the ground plane. The ground plane was not directly connected to the antenna, feed line or signal source. A Galaxy V transceiver was used as the rf source and the swr readings were taken on the swr meter in a Galaxy Deluxe Accessory Console which gave a 1.0 to 1.0 reading for a 51 ohm load. The antenna was about 3.5 meters from the transceiver.

The small loop antenna, as might be expected, is inductive and from Fig. 3 it can be seen that the inductive reactance increases as the length increases. This can be contrasted with the short linear dipole which looks capacitive and whose reactance goes to and crosses through zero as its length is increased. The radiation resistance of the loop as a function of its length is given in Fig. 2. Comparing the points on the graphs where the radiation resistance equals 51 ohms it can be seen that the reactance is almost eight times as large as the resistance which indicates that the setting of the capacitor in series with the antenna will in practice be critical. Adding to this problem is the very rapid change in resistance as the length increases, which indicates that the length of the antenna will also be a critical factor. Experience confirms that only small variations in the length and in the capacitance can be tolerated if a close match to a transmission line is sought. These readings were taken at low power with a calibrated 100 ohm carbon potentiometer inserted in series between the coax inner conductor and the variable capacitor.

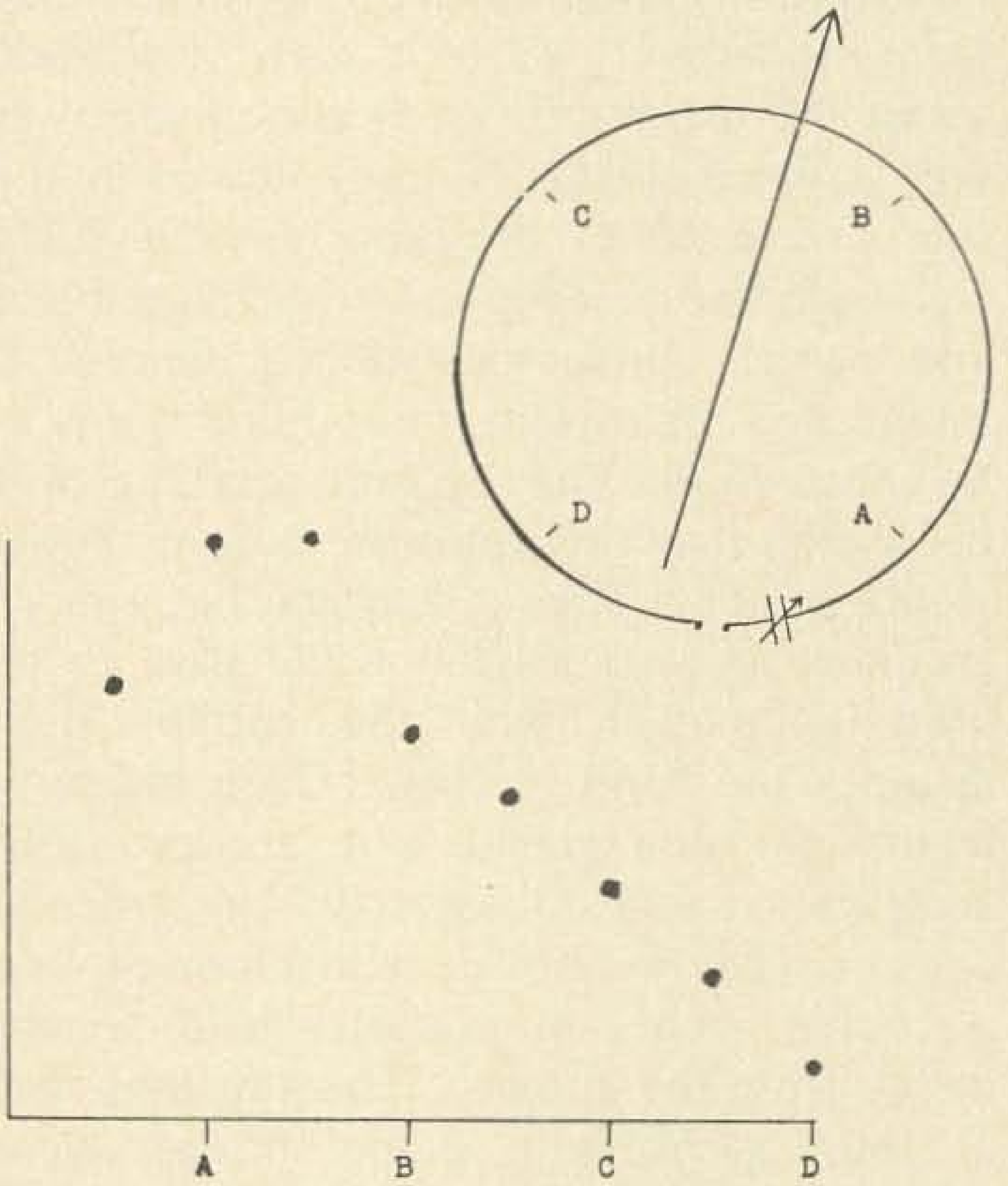


Fig. 1. A plot of the approximate current flowing in the antenna. Current is plotted on the vertical axis in arbitrary units. The slanted arrow indicates the general radiation polarization of the antenna positioned as shown.

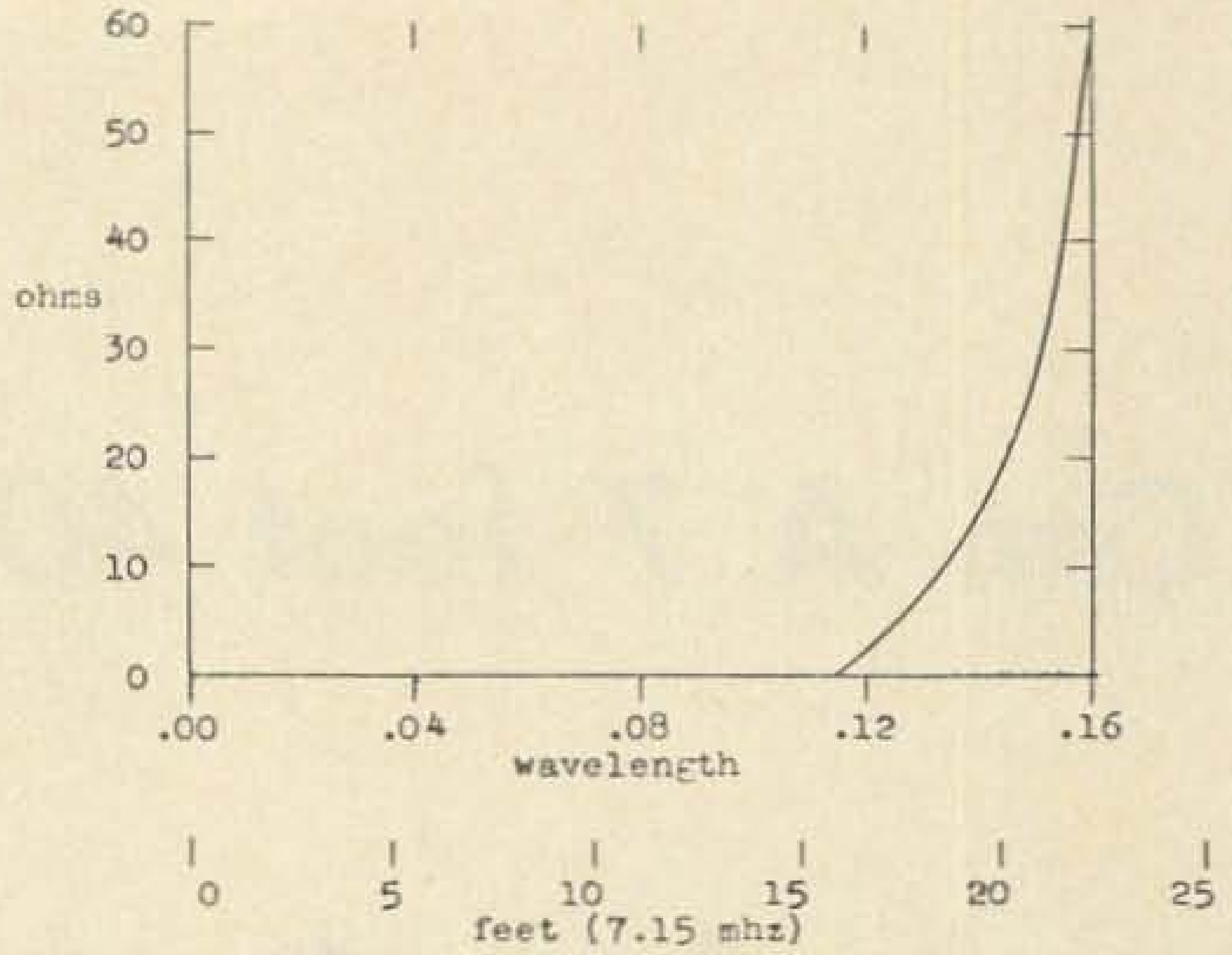


Fig. 2. The radiation resistance of the loop antenna versus the length of the circumference measured in fractions of a wavelength. The bottom scale gives the circumference in feet for a signal frequency of 7.15 MHz.

The swr of the loop antenna across the entire 40 meter band is shown in Fig. 4. Here the length of the antenna and the setting of the capacitor were chosen to give the best match at 7.15 MHz. As can be seen the swr is less than 1.6 to 1 even at the band edges. In Fig. 5 the length of the antenna was not changed but the capacitor was adjusted to give the lowest swr at each frequency. One can see that for a fixed length the antenna can be tuned to keep the swr below about 1.2 to 1 even at the band

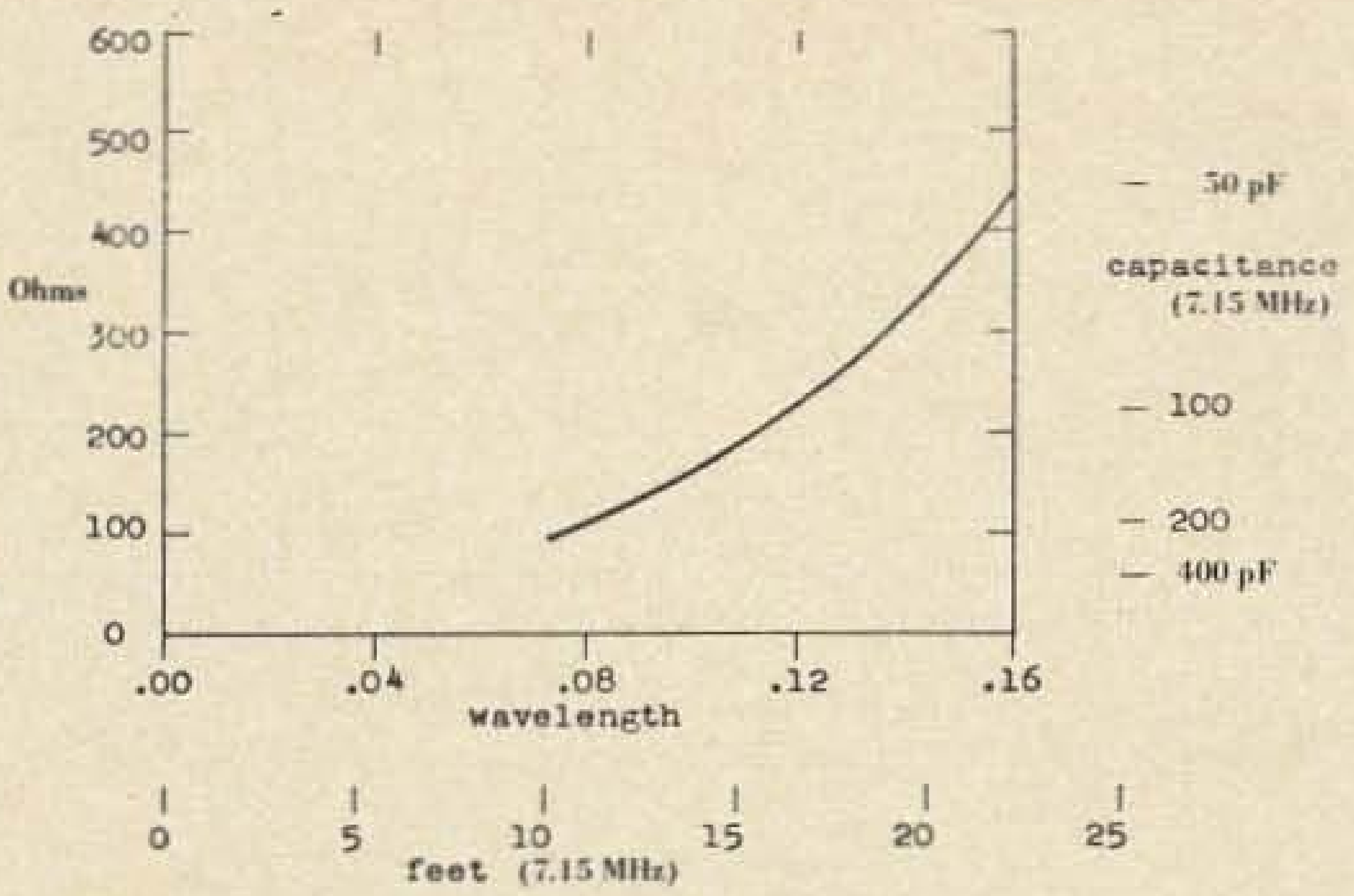


Fig. 3. The inductive reactance of the loop antenna versus the length of the circumference. The scale on the right indicates the value of the series capacitor needed to tune out the antenna's reactance for a signal frequency of 7.15 MHz.

edges. In Fig. 6 swr plots are given for several different capacitor settings.

Some Important Practical Aspects of Small Antennas

While a loop antenna that is .05 wavelength high can radiate as well as any simple dipole antenna, there are a number of very important practical considerations that have to be kept in mind. Indeed, these considerations apply to any short antenna whether it is a dipole, loop or whatever, even though the discussion here will focus on the loop. The first concern is with tuning out the reactance and obtaining the proper radiation resistance while the second involves minimizing nonradiative energy losses.

1. Tuning out the reactance and obtaining the proper radiation resistance.

Most short antennas will be reactive and the loop is especially so. For maximum operating efficiency in most situations, it is desirable to have the feedline see a purely resistive load. It is also usually desirable that this resistive load be of a particular value. Since in most short antennas a small change in the length will have a profound effect on both the resistance and the reactance, the length has to be determined rather accurately. One difficulty here is that the "right" length is going to depend on such things as the proximity of conducting bodies, antennas, feedlines, towers, etc., as well as the height above ground and the nature of the ground itself. The reactance needed to tune the antenna will be similarly affected. What this means in practice is that the length of the antenna and the value of the tuning reactance will have to be adjusted in each situation to make sure a reasonable match is being obtained. Thus it is essential that an swr meter, antenna bridge or other accurate device be used to determine that the antenna does indeed provide a close match to the feedline being used.

In connection with tuning the antenna there is another detail to consider. Since the loop antenna has much inductive reactance, the capacitor used to tune it will also have a high reactance which means that the voltage appearing across the capacitor will be large. For the loop antenna under consideration here it means that 100W of rf fed into a 50 ohm loop will produce about 800V peak across the capacitor, which indicates that even at this power level there are few capacitors other than air or vacuum dielectric ones which can be used that will not arc through or burn out. For an rf power level of 2 kw PEP into the loop it means that something like 3600V appears across the plates, which indicates that the capacitor will have to be chosen with some care.

2. Minimizing nonradiative energy losses.

In principle the ability of an antenna to radiate does not change as the antenna is made smaller since the current goes up as the length is reduced. The problem is that as the current rises the energy lost to heating the antenna wire increases as the current squared so that what may have been built to be a

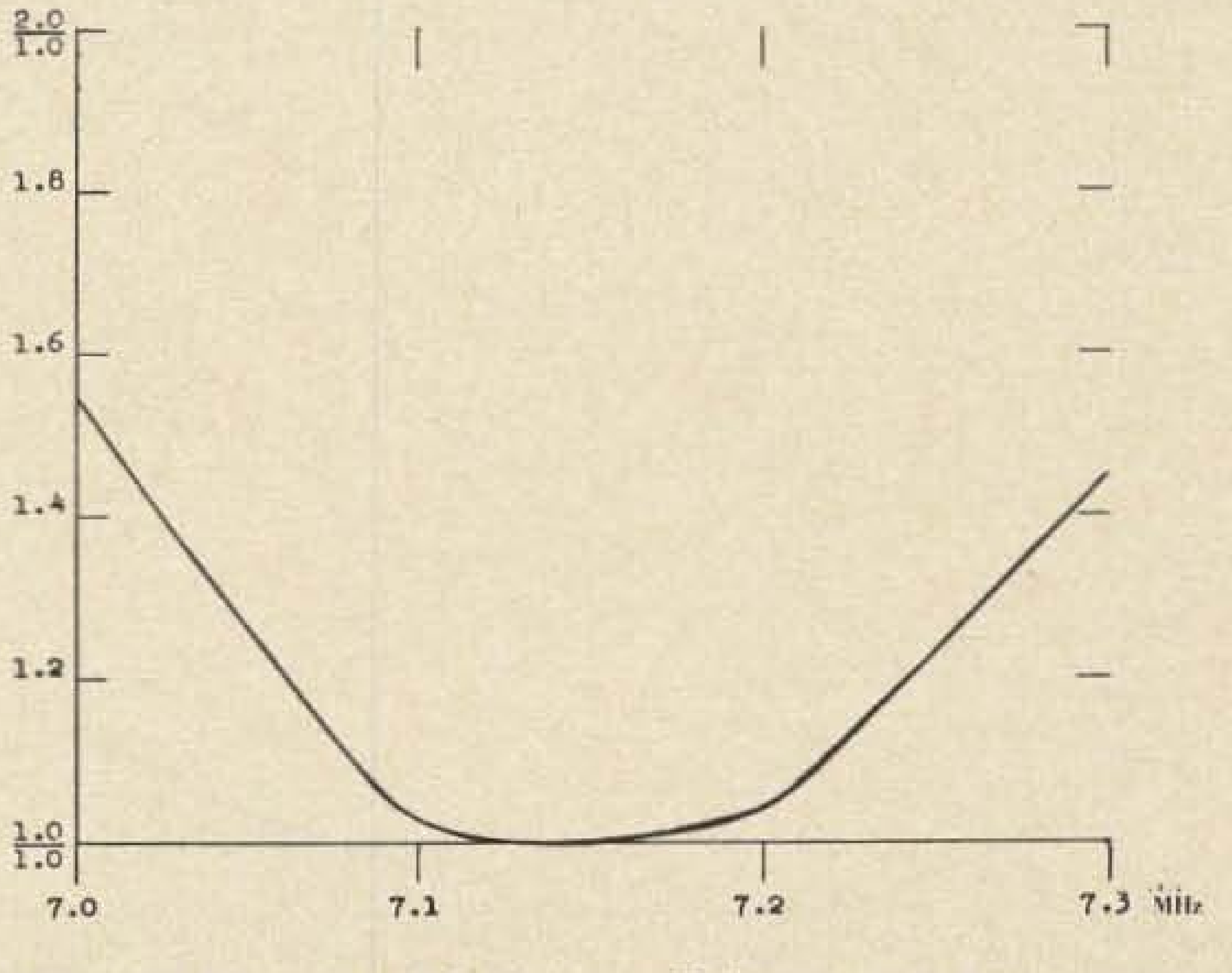


Fig. 4. The swr of the small loop antenna across the 40 meter band. The antenna was matched to a 51 ohm coaxial transmission line at the band center.

small antenna may in fact be a big resistor that generates a lot of heat and radiates little rf. If the probably not unreasonable assumption is made that the loop antenna electrically looks like an antenna that is .05 wavelength high with a nonuniform current distribution then the antenna has an intrinsic radiation resistance of about ½ ohm. This low value should not be confused with the much higher resistance presented to the feedline. In order that at least 90% of the energy be radiated this means the antenna wire has to have a circumference of about 4cm or, for a single conductor, a diameter of about 1.3cm (½") at 7MHz. All that is important is the effective 'surface area' of the conductor. The thickness can be quite small since a flat strip of aluminum foil that is four layers thick and 2cm (¾") wide is sufficient. If a small antenna is constructed by joining sections of tubing or wire or whatever together then care must be taken to insure that the joints do not constrict the diameter enough to create points of high resistance and accompanying high heat loses.

The second source of nonradiative energy loss that affects every antenna, regardless of its size or type and in almost all locations, is the heating of the ground near the antenna. This subject is somewhat involved and will be mentioned only briefly here even though ground losses are probably the major limiting factor on the lower ham bands in most amateur radio stations. The less the height of an antenna the greater the ground losses are. Indeed, for antennas close to the ground surface, the ground loss is horrendous and only a small fraction of the rf fed to the antenna is radiated. Ground losses can, however, be greatly reduced and such low antennas can be highly efficient radiators if an adequate ground system is used. While the size of the ground system needed will depend on such factors as the ground conductivity, the height and size of the antenna and the frequency, a minimal system might consist of 100 wires each a quarter wavelength long shallowly buried in a radial pattern. An indication of what can be achieved when ground losses have been reduced to a low level is given in ref. 2.

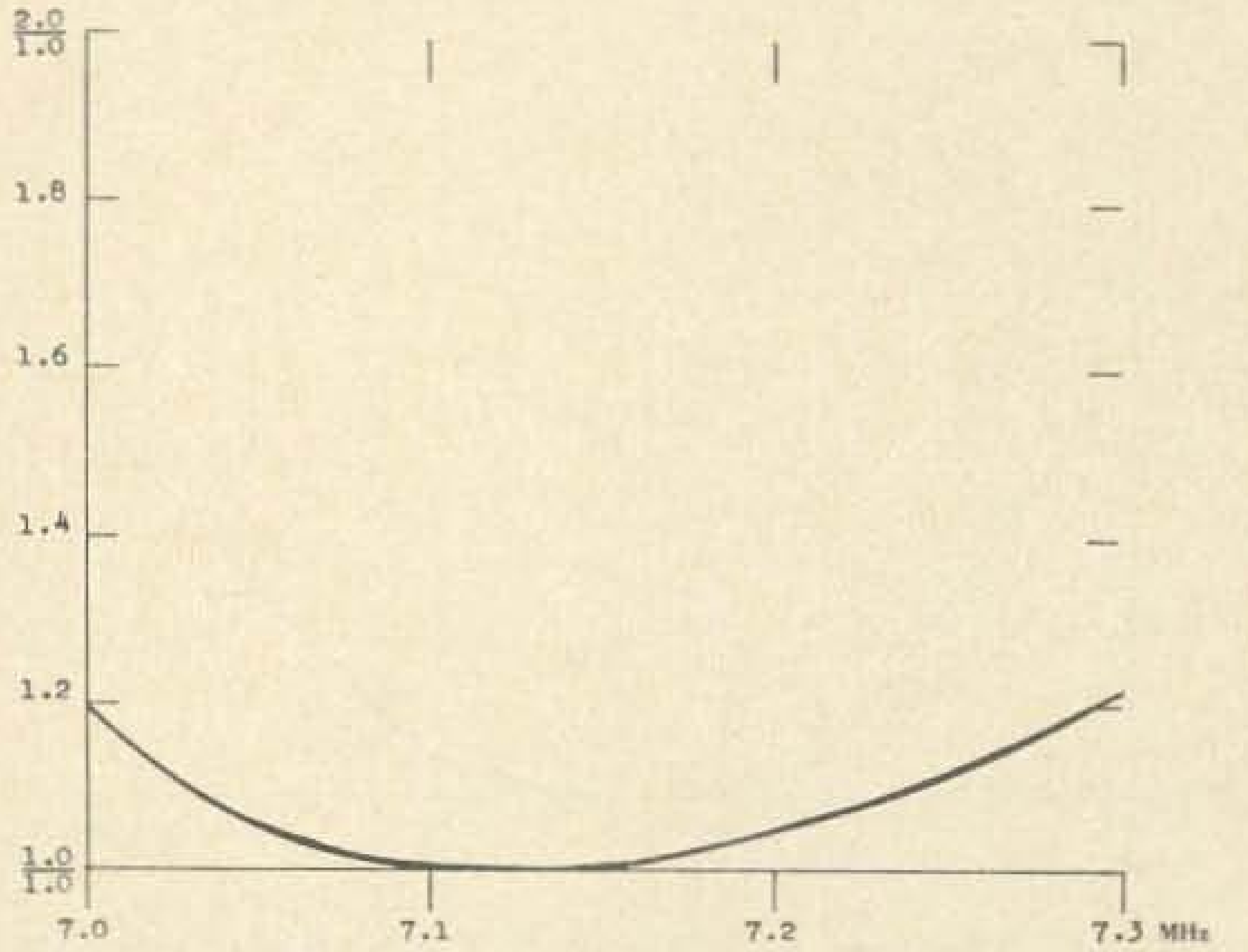


Fig. 5. This is the same plot as Fig. 4. except that the series capacitor was adjusted to give the lowest swr at each frequency.

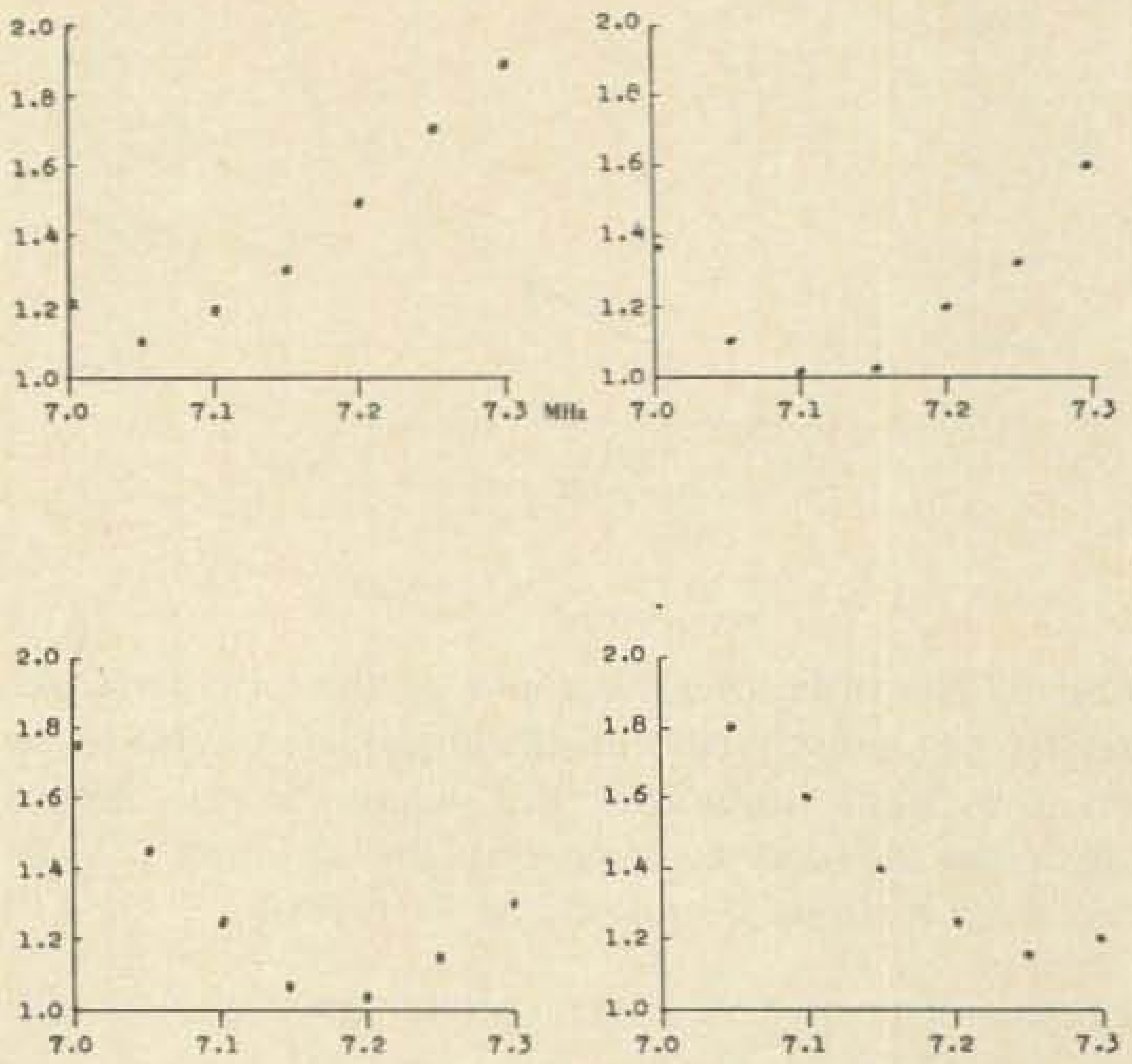


Fig. 6. These plots are the same as Fig. 4. with the exception that each one was made with a different setting of the series capacitor. The antenna length remained fixed.

The aluminum ground plane used here with the 7 MHz loop antenna should be about as efficient as an extensive wire ground system of the same dimensions (6.7 by 4 meters). Assuming a local ground conductivity of 15 millimhos per meter (ref. 3), a rough calculation adapted from ref. 4 indicates that, neglecting wire losses, the efficiency of the antenna system is reduced by ground losses to about 35%. Thus about two thirds of the rf energy fed to the antenna merely heats up the ground near the antenna and is wasted; 35% is radiated to the atmosphere. Wire losses in the loop antenna itself may reduce this to near 30%. To compound the losses a bit further, if the final amplifier in the transceiver used here is assumed to be about two thirds efficient, then a dc input power of 200W to the final amplifier finally results in all of about 40W of rf being radiated to the atmosphere – this is an overall efficiency of about 20%. Without the ground plane the losses would be expected to be much greater than they already are.

Some Results

That the loop antenna works even with a not overly efficient ground plane can briefly be indicated with the operating results obtained on the 40 meter CW band the first couple of nights the antenna was used in San Diego. In addition to a number of closer contacts, QSOs were readily started with east coast, midwest, Canadian and Hawaiian stations. That QSOs resulted from a healthy proportion of the CQs that I responded to was personally satisfying considering that 200W of input to the final was feeding an antenna seven feet high whose base was virtually sitting on the floor of my living room. In addition, the building is located in a shallow canyon which raises the lowest possible radiation angle a number of degrees above true horizontal.

Some Possible Uses of a Short Antenna

As discussed above, the small loop has two disadvantages relative to a conventional full size dipole. First it has to be constructed of a much larger wire size to minimize resistive wire losses. Second it has to be tuned fairly accurately – both the length and the series capacitance have to be within narrow tolerance limits. In addition, the capacitor has to have a hefty voltage rating which for many hams means using a suitable air or vacuum capacitor or a section of coax trimmed to the proper length. In practice, once they have been recognized, the disadvantages can be readily overcome, giving the user a small antenna that can be expected to work much the same as a regular dipole with the same orientation at the same height.

Since the 7 MHz loop is about 7 feet in diameter it is possible to construct it of a self supporting conductor such as copper or aluminum tubing or fairly stiff ¾" diameter coax and to suspend it from a single support. It could, for example, be mounted instead of a center supported horizontal dipole or inverted V. The loop has the advantages that no end supports are needed and that it will usually be possible to orient it as desired instead of orienting it to fit space limitations. The loop also possesses the unique advantage that in such an installation it can be orientated to radiate vertically; it should work much as would a vertical dipole whose center was as high as the center of the loop. In choosing a particular orientation it should be noted that in Fig. 1, with the antenna fed at the bottom, the orientation of the radiated rf will be mostly vertical with a sizeable horizontal component; it looks like a tilted vertical. For true vertical radiation it will be necessary to rotate the loop, capacitor and feedline counterclockwise. A suitable clockwise rotation will make it radiate like a horizontal dipole. It will also radiate horizontally if the plane of the loop is parallel to the ground. In many installations it will be possible to erect two or even three loops so the operator has a choice of polarization.

Table I

Amateur Band	Loop Circumference	Series Capacitance	Conductor Diameter
160 meters	88 feet	200 pf	1.0 inches
80	44	100	.7
40	22	50	.5
20	11	25	.4
15	7.3	12	.4
10	5.5	6	.3

Approximate loop circumferences, tuning capacitances and minimum conductor diameters (if a single round conductor is used) for the lower ham bands.

In addition to being usable where space limitations rule out a full size dipole, the small loop antenna lends itself to emergency and portable operations. If erected close to the ground without an extensive ground system, it can be expected to work as badly as any other antenna at the same height, although there are many situations in which such performance is adequate. The loop is a lot smaller than a full size dipole and it can be oriented to radiate vertically or horizontally. As indicated in Fig. 4, it can be constructed to cover a fairly wide range of frequencies and still maintain an acceptable swr. It might be noted that while the effect depends on the conductivity of the ground, the radiation resistance of an antenna that is not above an extensive ground system will be affected by the height above ground. As a rough figure, the effect can become important below a quarter wavelength and drastic below an eighth wavelength.

Table 1 gives rough length, capacitance and minimum single conductor diameter (for aluminum) for the lower ham bands. With aluminum conductors, either solid or hollow of the diameters given, the wire losses should be less than 10%. Losses in a copper wire of a given size should be about .8 times the aluminum losses. To obtain a suitable conductor it is possible to use two conductors with half the diameter, four conductors with a quarter the diameter, twenty conductors with a twentieth the diameter, etc., provided the wires are well separated from each other and not tightly bundled together. These numbers were obtained by scaling the 7 MHz results. If f is the frequency, the length and the capacitance are proportional to 1/f, while the conductor "surface area per unit length" is proportional to $1 \div f^{1/2}$. The exact length and capacitance values required may well vary with different installations and it is urged that, as with beams, quads, and many other antennas, the length of the loop and the series capacitance be adjusted for an optimum match to the feedline with the antenna at the intended height and orientation.

References

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4. J. R. Wait and W. A. Pope, "Input resistance of 1.f. unipole aerials," *Wireless Engineer,* May, 1955, p. 131.

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