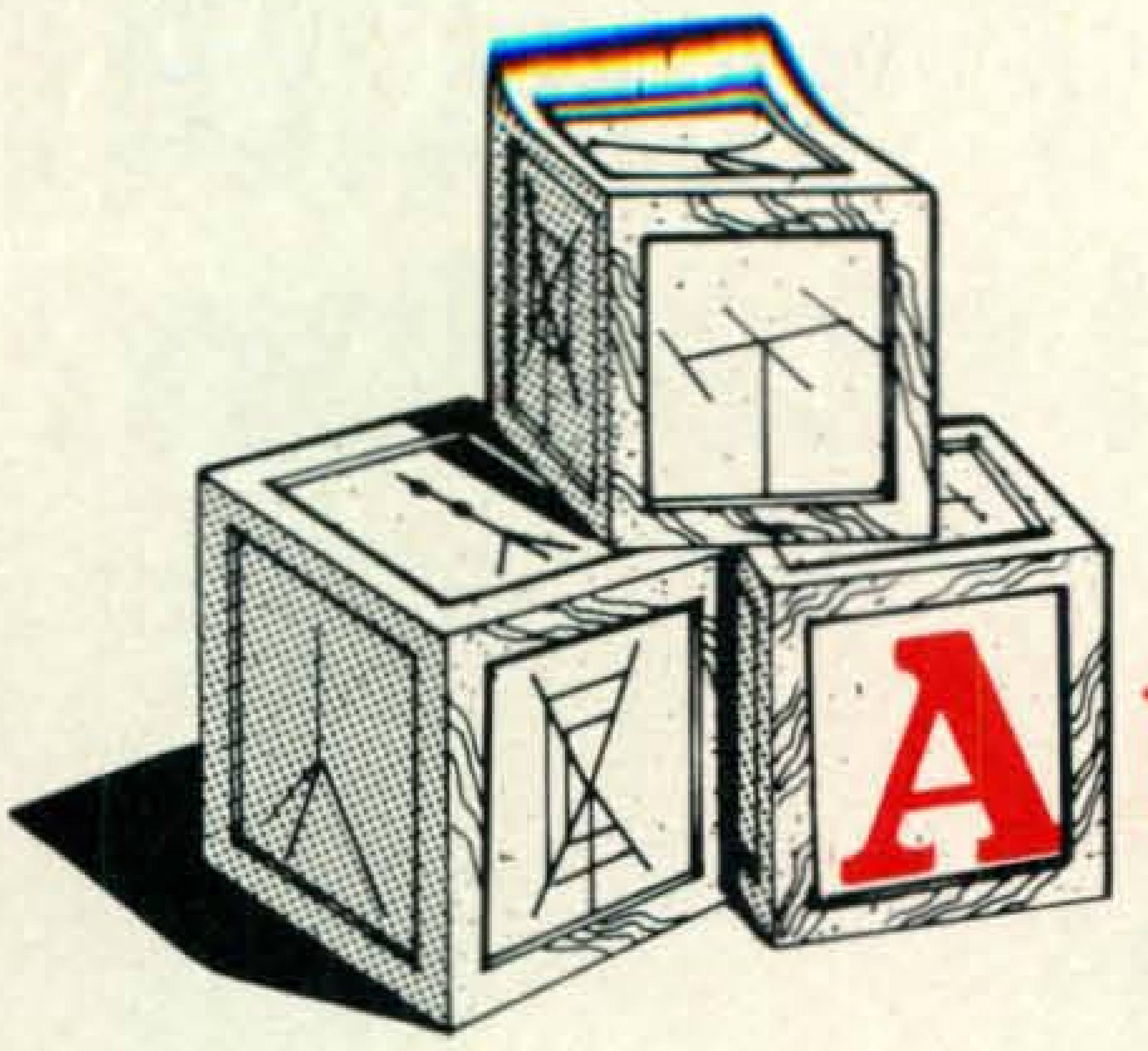

Antenna basics

BY J. L. SMITH,* W5LLE

Of the various equipments necessary for an amateur radio station, perhaps the antenna is the most mysterious. Like most other mysteries, this one has come about through a lack of knowledge and understanding of the operating principles of the antenna. We understand best those things that we can evaluate by measurements. Unfortunately, detailed antenna measurements cannot be made using only the v.s.w.r. indicators that make up the antenna instrumentation available to most of us. By necessity then, the antenna is usually cut to length by formula and pruned a bit to reduce the v.s.w.r. The user is then left to wonder about the results and he is often subjected to a host of problems, many of which are self-created by simple "not knowing."

This article collects some of the basic information about the horizontal dipole antenna and applies it to the non-ideal situations that exist for most of us. Hopefully, it will explain relevant and interesting statements like:

(1) Pruning an antenna is necessary, not because the formula for the length is inexact, but because of the effects on the antenna of its surroundings.

(2) Pruning a transmission line may improve the way a transmitter loads, not because the v.s.w.r. is reduced, but because the line impedance is transformed to a more compatible value.

(3) No matter how much an antenna length is pruned, the transmission line v.s.w.r. may never equal 1:1, not because the antenna does not reach the correct length, but because the radiation resistance of the antenna never equals the characteristic impedance of the transmission line.

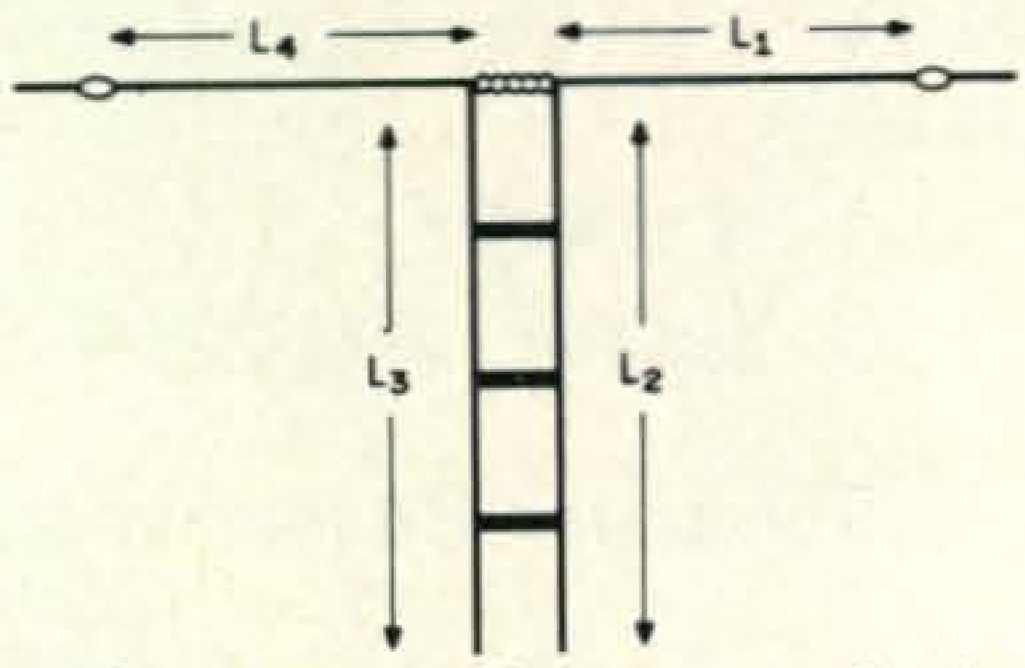

Fig. 1—Dipole antenna with open wire feed section.

An understanding of the few basics outlined in this article may save the heartbreaks that usually accompany the back-breaking task of trying to achieve the impossible.

The Antenna Proper

Those who have the real estate to place an antenna in the ideal location and at the ideal height represent a very select minority. Most of us must string our antenna between existing supports that predetermine the antenna height, direction and length. From the telephone pole in the backyard to the house gable, or from the chimney to the far eaves are much more likely supports for the majority of us. The object then is to learn how we can make the best of these supports and effectively use what we have available to us.

If the antenna is intended for use on a particular band, try to make it as near the resonant length as possible. If it is not possible to make the antenna long enough to be resonant at the desired freuency, a few extra feet can be picked up at the center with an open wire line, as shown in fig. 1. The total electrical length is the sum of L_1 through L_4, however, the lengths L_2 and L_3 do not radiate because the antenna currents are flowing in opposite directions through L_2 and L_3. These two lengths are so close together that the radiation of one cancels the other. Only L_1 and L_4 con-

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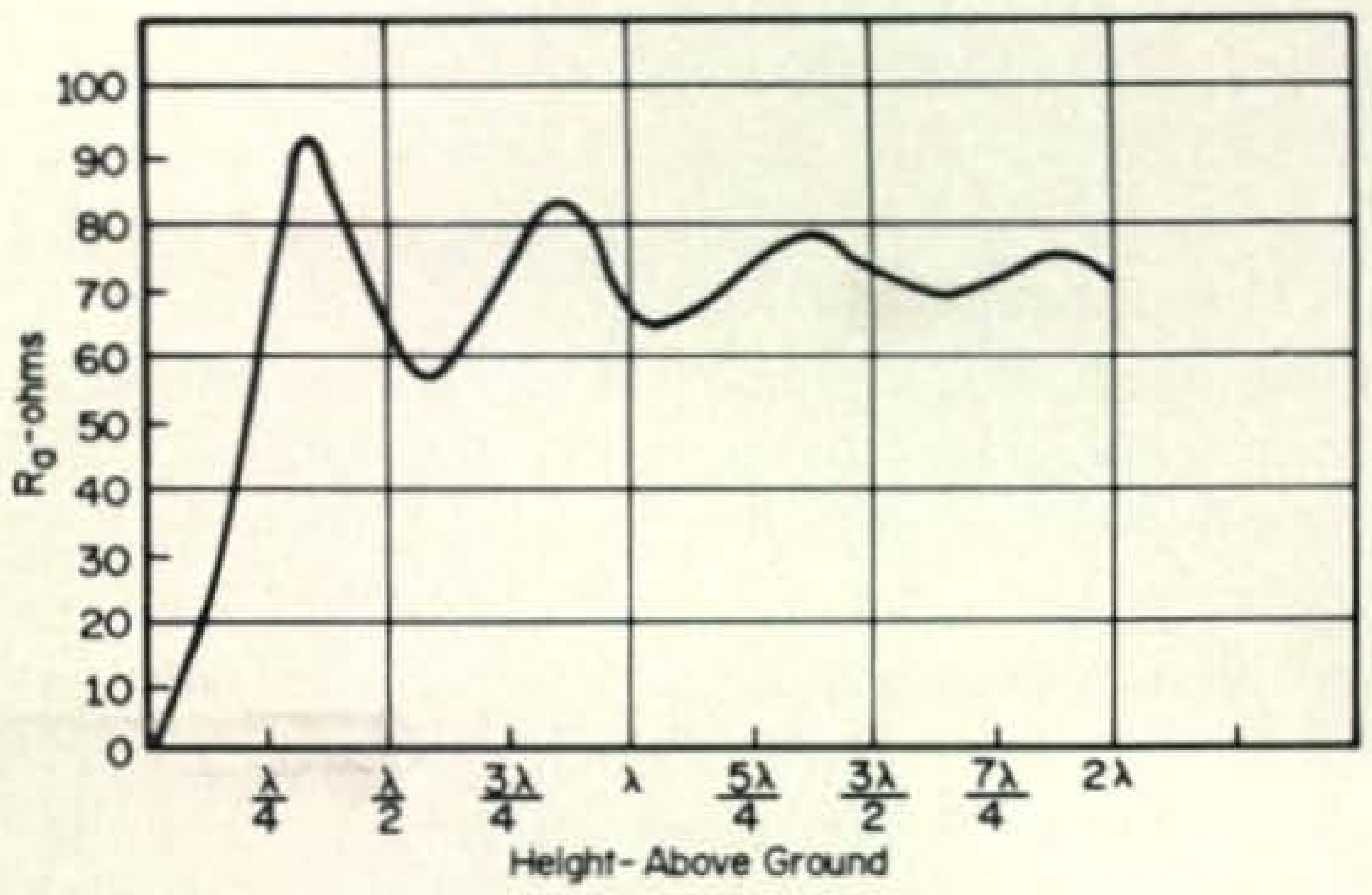

Fig. 2—Plot of theoretical radiation resistance versus antenna height in wavelengths for a resonant dipole.

stitute the radiator, but all four lengths affect the antenna tuning.

If it is not possible to achieve enough length even with the open wire lines, then empirically add a little inductance in series with the antenna until resonance is reached.

If a coaxial feed line is planned, then it is recommended that a balun be used to transform the unbalanced coaxial line to the balanced dipole or open wire feed line section. The balun is good for several reasons. It makes it easier to add the inductance mentioned earlier since the inductance can be added in only the hot leg on the unbalanced side. (Otherwise, the inductance should be inserted such that half of the total is placed in each side of the open wire feeder and this is somewhat difficult to adjust empirically.) The balun also reduces the pickup and radiation from the transmission line with the result that the receiver picks up less noise and there is less r.f. floating around the shack.

An antenna may be considered to be a series *LCR* resonant circuit where *R* is the radiation resistance. Above the resonant frequency the antenna looks like an inductive reactance in series with *R* and below the resonant frequency, the antenna looks like a capacitive reactance in series with *R*. At resonance, of course, the antenna looks resistive and this is usually the condition of lowest v.s.w.r. and the greatest power transfer.

The usual method of evaluating an antenna is to measure the v.s.w.r. at several frequencies in the band where resonance is sought. If the minimum v.s.w.r. occurs at a frequency lower than desired, the antenna length should be shortened and the v.s.w.r. vs. frequency data taken again. If the minimum v.s.w.r. occurs at a frequency higher than desired, the antenna should be lengthened before retaking the data. This more or less "cut and try" method is continued until the minimum v.s.w.r. is obtained at the desired frequency.

Effect of Antenna Height

The mere fact that the antenna length has been adjusted such that the antenna drive point is purely resistive does not insure that the v.s.w.r. will be 1:1. Figure 2 is the familiar plot of antenna resistance vs. antenna height for a resonant horizontal dipole antenna. Notice that the impedance varies greatly, especially at the lower heights. Unfortunately, most of us must use the lower heights when we try to use a set of existing supports and, therefore, seldom do we achieve a perfect match to the transmission line.

The variation of radiation resistance with antenna height is caused by the current flow that is induced in the antenna by the wave reflected from the ground. For a given voltage impressed across the antenna, the normal *E/R* current flow is augmented by the induced current and this gives a net effect of a resistance change. Different antenna heights affect the magnitude and phase of this induced current and thus affect the antenna reactance and radiation resistance. Because the radiation resistance terminates the transmission line, a v.s.w.r. other than 1:1 will result unless the radiation resistance and characteristic impedance of the line are equal. Since most of us use standard transmission lines, then the minimum v.s.w.r. on these lines is determined by the radiation resistance of the antenna. Figure 3 is a plot of v.s.w.r. vs. the height of a resonant dipole for 50 and 75-ohm transmission lines. The v.s.w.r. shown in figure 3 is the absolute minimum that will be observed when the antenna is resonant. At a given frequency, for example, as a slightly long antenna is pruned through resonance, a

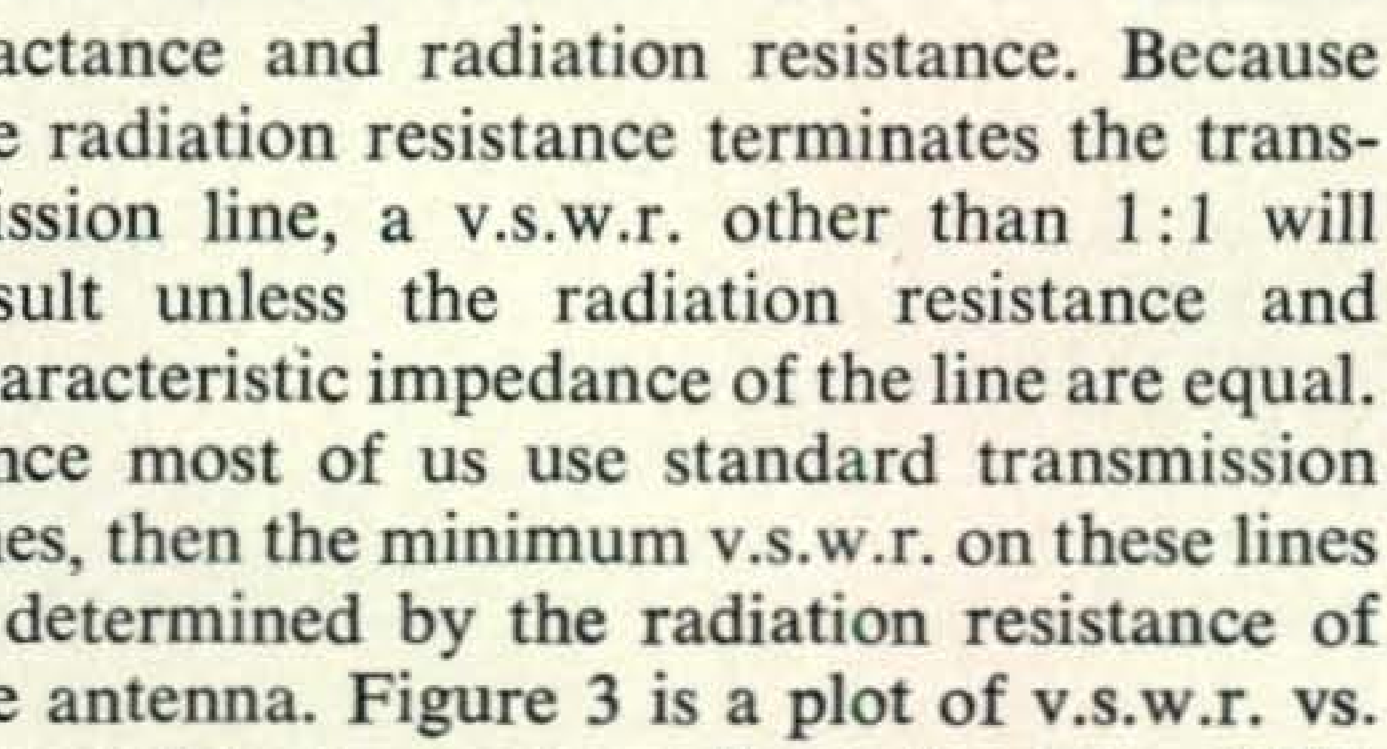

Fig. 3—V.s.w.r. vs. antenna height for a horizontal resonant dipole.

minimum v.s.w.r. will be observed and this minimum will not be less than that determined by the relation of the radiation resistance to the characteristic impedance of the transmission line. Figure 3A is a plot of antenna height vs. minimum v.s.w.r. for a resonant horizontal dipole used with a 50-ohm line. Figure 3B is a similar plot for a 75-ohm transmission line.

The fact that the v.s.w.r. does not go to 1:1 does not constitute a major disaster. However, the v.s.w.r. does effect transmitter loading and power transfer, so it is usually made as low as practical considerations permit.

In addition to the radiation resistance, the height of the antenna affects the radiation angle and the angle of the main radiation lobe affects the local and DX performance of the antenna system. While it is not intended that this article concern itself greatly with the pros and cons of the angle of radiation, fig. 4 is presented to show how the height of a horizontal antenna influences this angle. The portion of the radiated signal that gets reflected from the ground appears to originate from an "image antenna" that is apparently located below the surface of the ground similar to a mirror image.

The real and image antennas function similar to the elements of an antenna array in which the image antenna is fed with a phase difference of 180°.

Notice that at low antenna heights, *i.e.*, 1/8 wavelength, the vertical radiation pattern is practically circular. This means that the strongest signal is being radiated straight up where it does the least good. As the antenna height is increased, however, the circular pattern begins to flatten on top as shown at the quarter wavelength height. Additional increase in antenna height causes a depression to develop at the zenith in the vertical radiation pattern and this depression grows until at an antenna height of a half wavelength, minimum signal is radiated upward. If the antenna height is beyond a half wavelength, then a third lobe begins to develop vertically as shown in the 5/8 wavelength pattern. This third lobe grows with antenna height (See 3/4λ), develops a depression (see 7/8λ), and eventually splits into two lobes with minimum radiation to the zenith when the antenna height is a full wavelength.

This process of developing the vertical lobe, its splitting, etc. continues as the antenna height continues to increase. At multiples of a half wavelength, there will be minimum signal radiated to the zenith, but the number of lobes will increase such that there are two lobes for each half wavelength of height. Consequently, the more practical antenna height appears to be a half wavelength for at this height, the signal radiation is concentrated in only two vertical lobes and fortunately they have a desirable vertical radiation angle. Also, at this height, the radiation to the zenith is at a minimum.

VSWR and the Transmission Line

A radio wave on a transmission line continually travels forward and away from the source until it reaches an impedence discontinuity on the transmission line. At the discontinuity, some or all of the wave is reflected back toward the source. A discontinuity is anything that has an impedance that differs from the characteristic impedance of the transmission line. If a transmission line is terminated in an impedance equal to its characteristic impedance, then all the energy of the radio wave is absorbed by the termination and none is reflected. The result is as though the transmission line were infinitely long because a wave started at the source never returns. A short circuit or an open circuit on the transmission line are the extremes in discontinuities and all the energy of an incident radio wave is reflected from either of these terminations.

The radio wave reflected from a discontinuity travels back toward the source and during its journey the reflected wave meets the forward traveling wave at various phase angles relative to each other. At some points along the transmission line, the forward and reflected waves add in phase and the voltage or currents reinforce each other. At other points along the transmission line, they add in opposition and the voltages or currents reduce each other. It is conceivable, then, if

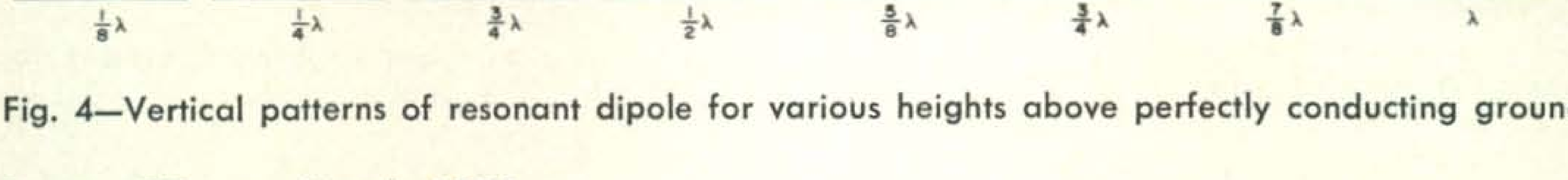

Fig. 4—Vertical patterns of resonant dipole for various heights above perfectly conducting ground.

100% of the wave were reflected, there would be locations on the transmission line where the voltages were as much as twice the normal voltage and other points where the voltages were zero. If less than 100% of the wave were reflected, then the maximums and minimums would be intermediate between double and zero.

The Voltage Standing Wave Ratio (v.s.w.r.) describes the degree of match between the characteristic impedance of a transmission line and its termination by relating the forward traveling voltage and the reflected voltage.

An important concept to note is that the v.s.w.r. is the same no matter where along the line it is measured. The voltage, however, may vary as described above.

The impedance seen looking into a transmission line at a given point is the ratio of the voltage present at the given point and the current at that particular point. Assuming a lossless line, power cannot be created or destroyed by the transmission line, so the product of E and I must be constant at any point along the line. If the voltage varies due to the standing wave, then the current must also vary in the opposite direction to keep the EI product constant. The impedance of the line, or the ratio of E/I, will therefore vary considerably with a given v.s.w.r. depending where along the line it is viewed. For example, a 50-ohm line terminated with 25 ohms resistive will have a 2:1 v.s.w.r. caused by this discontinuity no matter where along the line it is measured. The impedance, however, will be 100-ohms resistive if it is measured a quarter wavelength from the termination and it will be some difference and complex impedance if it is measured at intermediate distances. The complex impedances result because the phase of the reflected wave causes a phase difference between the voltage and current except at points which are multiples of a quarter wave along the line. If the impedance were measured at a distance a half wave from the discontinuity, it would measure 25 ohms resistive and the impedance would repeat during the next half wave.

This impedance transformation effect of transmission lines is the reason that transmitters are able to load into some lengths of transmission line better than others. If the transmission line has a v.s.w.r. resulting from a resistive termination, such as a resonant antenna), the impedance seen at various points along the line varies from the terminating resistance as one limit to as much as or as little as the terminating resistance multiplied or divided by the v.s.w.r. squared. This means that a 50-ohm line with a 5:1 v.s.w.r. may require loading into impedances as low as 10 ohms or as high as 250 ohms, or complex impedances in-between, depending upon the length of the transmission line. The impedance presented by a certain length of transmission line may not be compatible with the loading scheme of a particular transmitter so pruning the transmission line until a more palatable impedance is seen allows the transmitter to load—the v.s.w.r. is not changed by pruning the line, however.

A transmission line which is a half-wavelength long appears as a transformer with a 1:1 impedance transformation ratio. For this reason, it is usually better to make the transmission line length a half wave or a multiple thereof and therefore avoid the $(\text{v.s.w.r.})^2$ transformation ratio that may cause difficulty in loading the transmitter.

Antenna Tuners

An antenna tuner is capable of accepting a complex impedance from the antenna or transmission line and transforming that impedance into a resistance that matches the transmission line or transmitter. Figure 5 illustrates the fact that the v.s.w.r. is reduced by an antenna tuner between the source and the tuner but the v.s.w.r. is unchanged between the tuner and the load. This means that any detrimental effects caused by the v.s.w.r. will continue to exist in that portion of transmission line beyond the tuner. If the tuner is located in the shack, then the entire transmission line is exposed to the high v.s.w.r. If the antenna tuner is located at the antenna, then none of the transmission line is exposed to the high v.s.w.r.

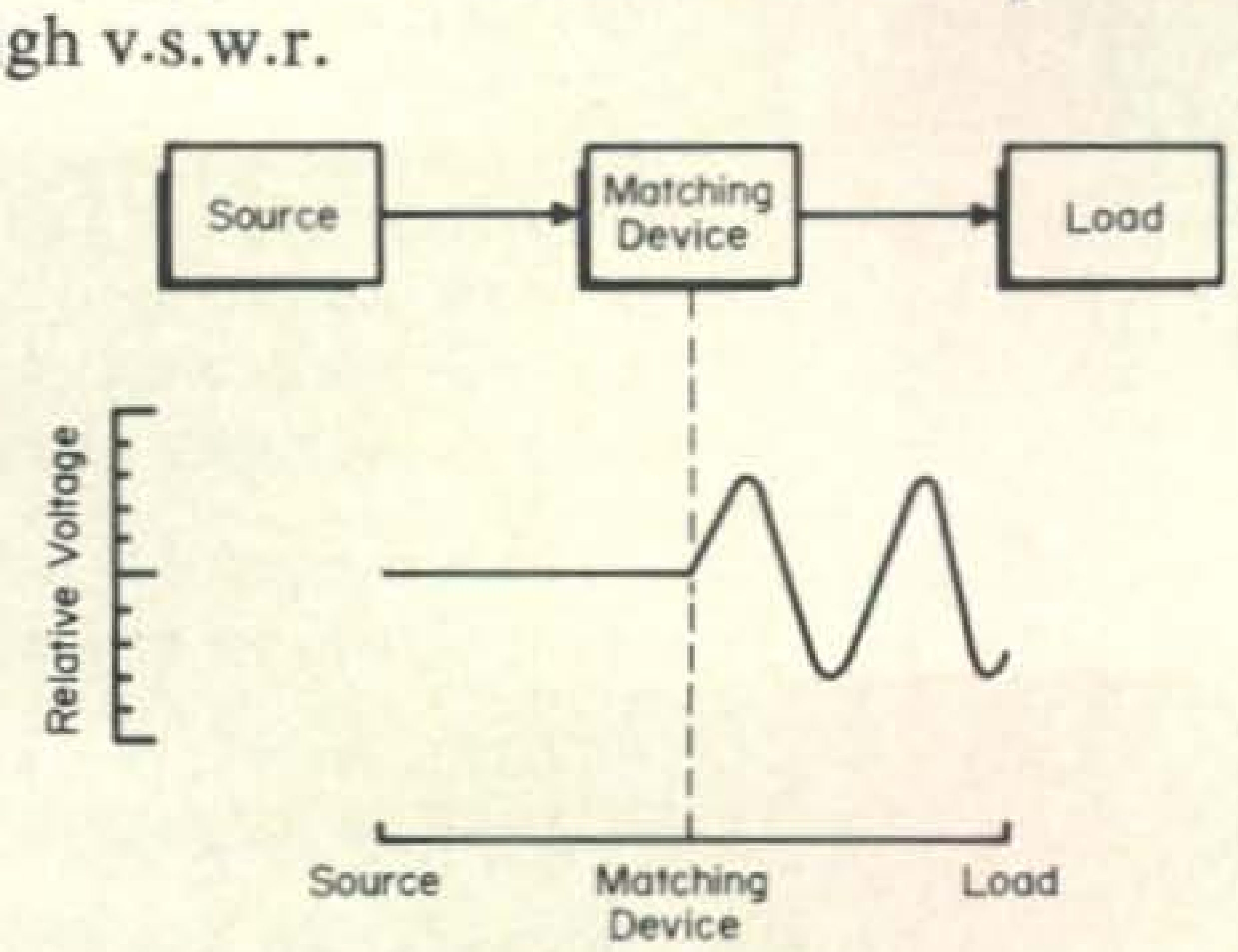

Fig. 5—Effect of impedance matching on v.s.w.r.

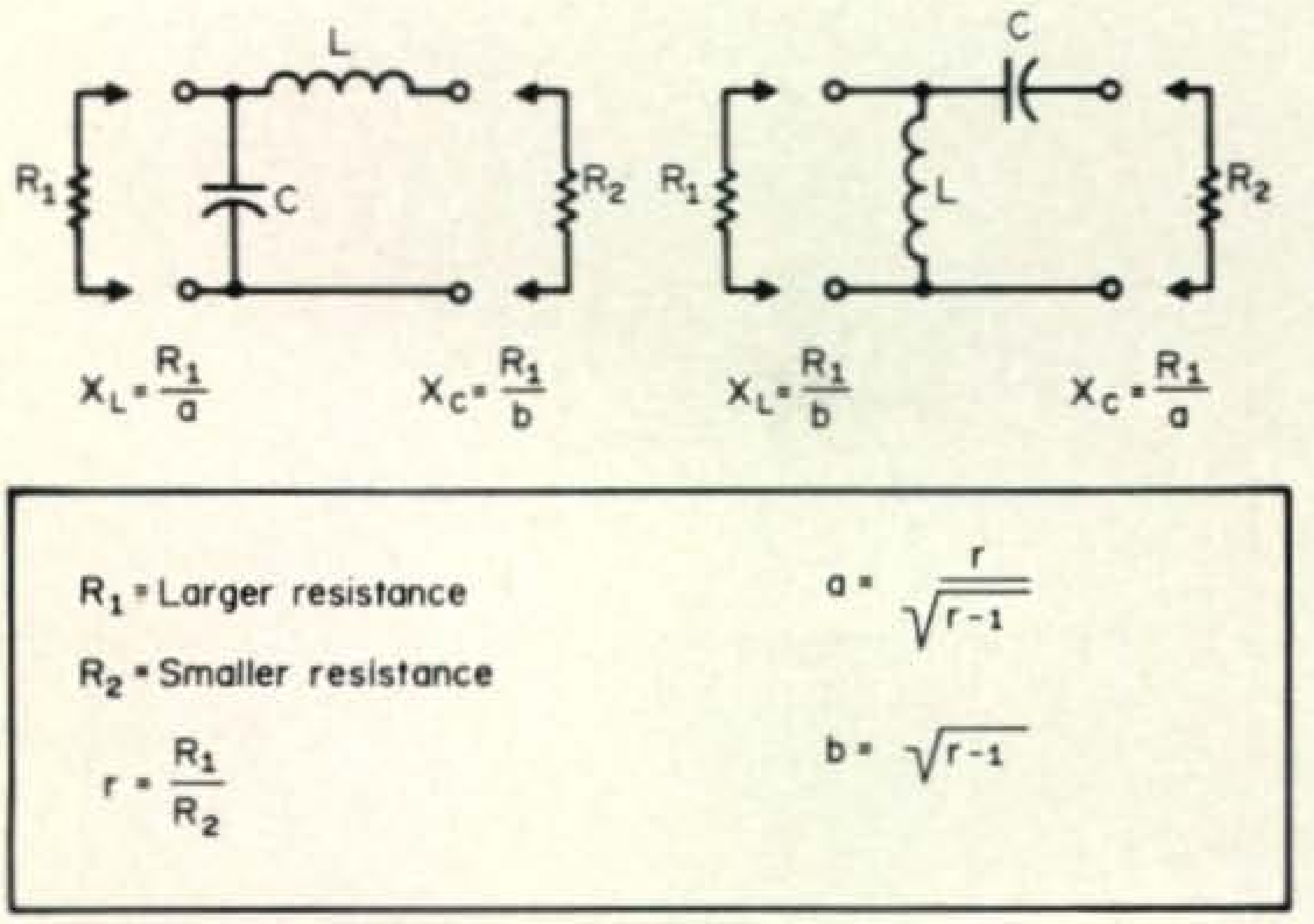

Fig. 6—L-Section impedance matching networks.

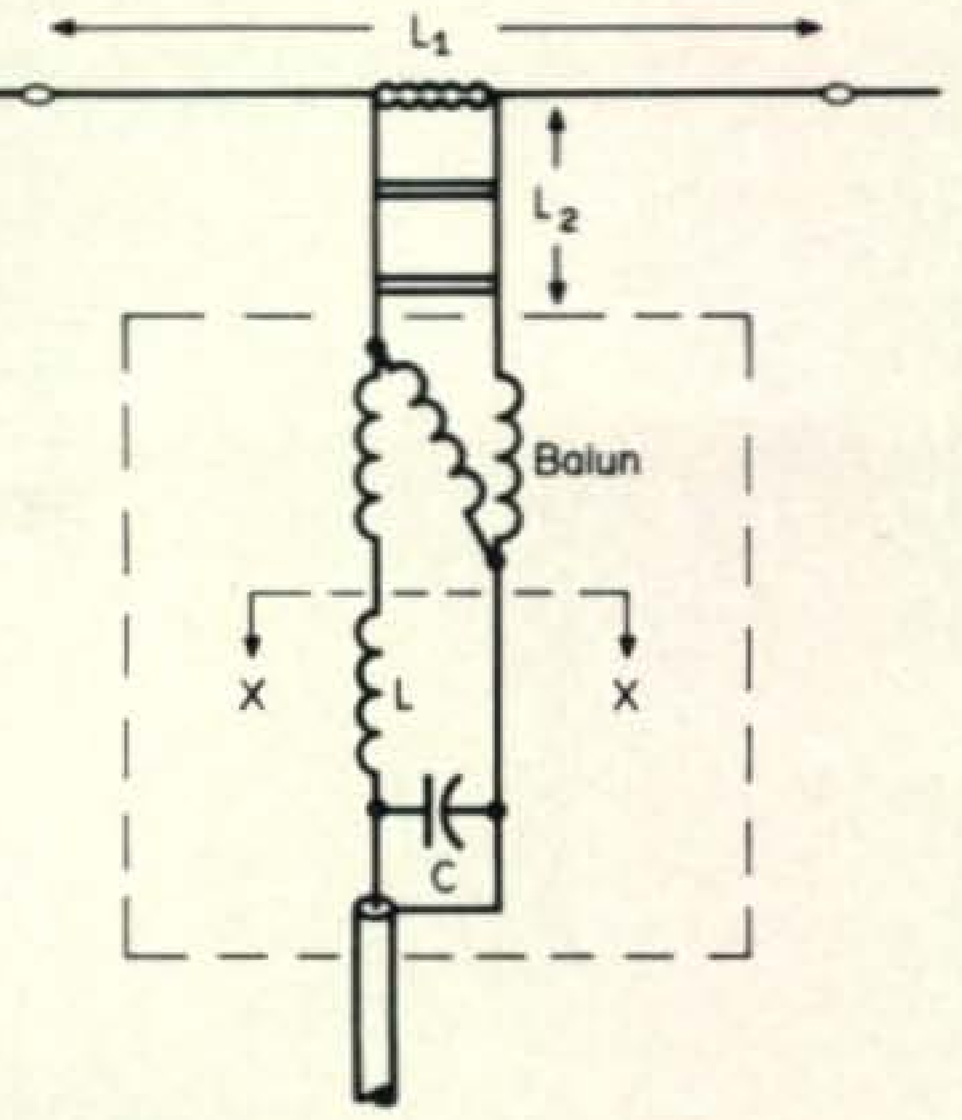

Fig. 7—Schematic of 40 meter antenna.

A high v.s.w.r. affects power loss more in solid dielectric lines than it does in air dielectric lines because the solid dielectric dissipates power in the form of heat. As a matter of fact, very little power is lost in an air dielectric line due to high v.s.w.r. because only the extra Ohmic loss due to the higher v.s.w.r. current is present. In view of this, if for some reason the antenna tuner cannot be located at the antenna end of the transmission line, then open wire transmission line should be used between the tuner and the antenna. Solid dielectric coax line may be used between the tuner and the transmitter.

When an open wire line is used, the antenna tuner will be simplified if a balun is used between the tuner and open wire line. The tuner simplifies to a simple "L" section between the balun and coax line if the mismatch is non-reactive or perhaps to a "T" if the load is reactive.

Designing Simple Matching Networks

Two resistances can be matched with the "L" sections shown in fig. 6. The values for X_L and X_C are determined from the relations listed in the figure.

If the antenna contains a reactive part, *i.e.*, it is $R + jX$, then the reactive part may be eliminated by placing a reactance of opposite sign in series with the antenna.

Unfortunately, most amateurs have no bridge to measure the impedance of the antenna. An alternate is to prune the antenna for minimum v.s.w.r. and assume that it is then non-reactive. The v.s.w.r. remaining will be the result of a difference between the transmission line characteristic impedance and the radiation resistance of the antenna. If the antenna height is low, *i.e.*, less than a half wave above ground, then the radiation resistance will be less than the common 72 ohms for a dipole. In that case, a fair estimate of the radiation resistance of a low dipole that has been pruned to minimum v.s.w.r. is:

$$R_a = \frac{R_o}{\text{VSWR}}$$

With this estimate of the antenna resistance, a matching section may be calculated from fig. 6.

Applying the Basics

Figure 7 is a schematic of an antenna system for the 40 meter band that has employed the basics outlined earlier. The radiator length, L_1, has been augmented by a short section of open wire transmission line, L_2. The electrical length of the antenna is $L_1 + 2L_2$. The balun is used to transform the balanced open wire feeder to an unbalanced arrangement compatible with the coaxial transmission line. The v.s.w.r. looking at the output of the balun (section x-x) is shown in fig. 8A. The matching section, L and C, transform the resistance of section x-x to the characteristic impedance of the transmission line. The resulting v.s.w.r. is shown in fig. 8B.

In Conclusion

Perhaps the greatest factor that promotes a more content attitude toward the ham an-

[*Continued on page 83*]

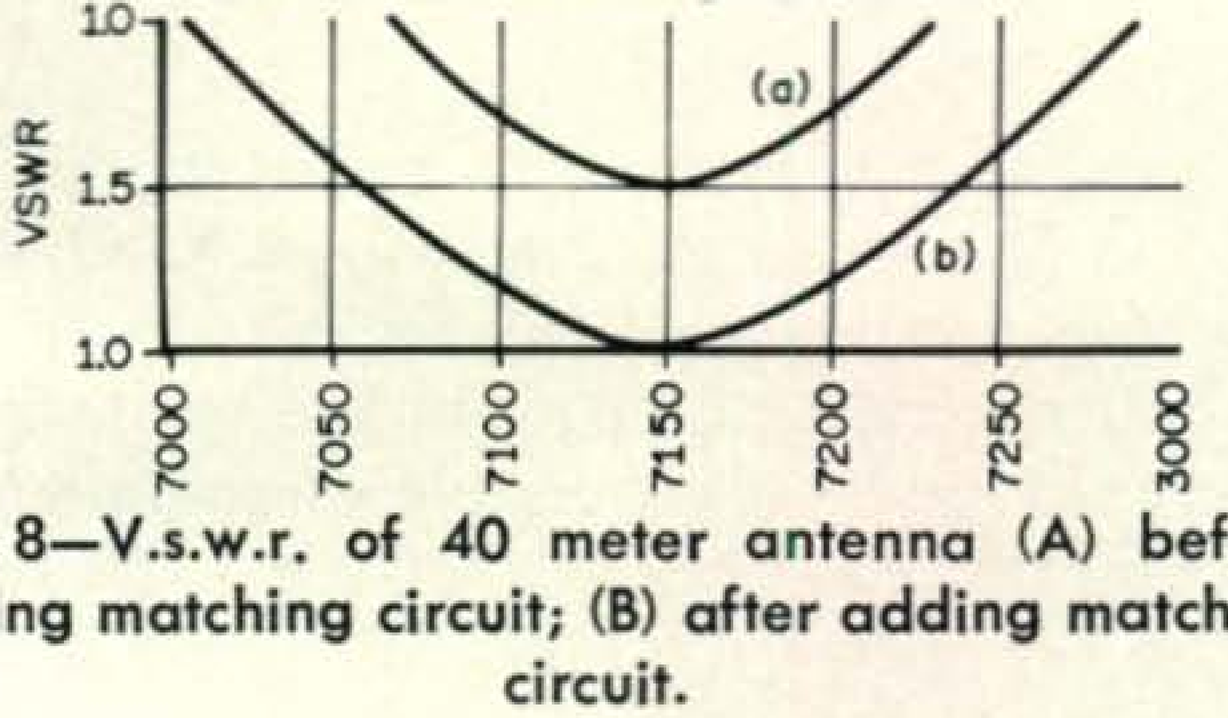

Fig. 8—V.s.w.r. of 40 meter antenna (A) before adding matching circuit; (B) after adding matching circuit.

I really envy these people. They have a beautiful house on the top of a hill, a few hundred feet above the sea level, overlooking San Juan. Two huge towers, a 4 el. triband Quad, a 5 el. full sized beam for 20m., a dipole for 80m., and they were just installing a 3 el. beam for 40m.

They have two separate stations; his and hers. The gear is mostly Collins and the attractive callsigns starting with KP4, are just adding to the ingredients of a successful station.

How could I not envy them? I have to share my rig, my antenna even my microphone with my wife Eva, WA2BAV, and then listen to the reports she gets, always 2 S units higher than mine! ■

Antenna Basics *[from page 21]*

tenna is a better understanding of the basic principles of operation. If we know why antennas behave as they do, then we are less likely to expect the impossible. Hopefully, this article has made some small contribution to a better understanding of antennas and feed lines. Perhaps we will hear less frequently the erroneous story of how some OM "pruned his transmission line until he got a 1:1 v.s.w.r." ■

C.W. Speed *[from page 45]*

the kind of copying I have in mind is tape c.w., or the kind sent by an electronic keyer. Shun copying lids and Lake Erie swingers; replace them, for the time being, with the best c.w. you can find on the band, including W1AW's practice sessions. If you can afford it, buy or rent a tape machine.

Try to copy at a speed just slightly higher than your solid speed. Once a copying speed becomes too comfortable, your learning curve takes a rest, too. In short, it's like any other skill: if you want to improve your copying speed, keep trying to better your own best time. And keep this in mind, too—McElroy, at one time, must have thought that even 20 w.p.m. was pretty racy stuff. ■

2M. Mobile *[from page 48]*

Conclusion

Although the design concepts described above can be put to work in many different ways, the author's practical set-up may be of interest. The whole receiver uses vacuum tubes which are powered by the transistorized auto radio supply, beefed-up. Its buttons are pre-set to five monitor frequencies—the closest to actual crystal switching you can get. The transmitter, up to the 24 mc stage, is solid state, and fits into the dashboard betwen the auto radio and the converter. The 24 mHz is fed to dynamotor-powered vacuum tube multipliers and final located behind the driver's seat. A rooftop antenna for reception is separate from the rear-mounted transmitting antenna. I installed a second battery in the trunk which saves the starting battery for that function, as well as providing a pure source of d.c. for the solid state first part of the transmitter. This puts the uncritical receiver and dynamotor power supplies together with the noisy charging and ignition circuits on the rear battery. A flexible knife-switch patch panel, which allows any other power routing combinations, completes the mobile installation. ■

DX *[from page 67]*

23 rue de Fressies, Aubencheul Au Bac, 56 265 Aubigny-an Bac, France.

A2CAB—Via W2RHK
AP2AD—Via POB 94, Lyallpus, West Pakistan
DL4VA—Via Vandegrift, Matcom-DSO, APO N.Y. 09052
DU7MC—Via POB 273, Bacolod City, Philippines
F9UG—Via DL4VA
F0ACO—Via K11XG
FM0IX—Via W7VRO
FY7AE—Via WA4WTG
FY7AF—Via K3RLY
FY0NA—Via F0NA
HB9XID—Via DL4VA
HB0XHS—Via DK3SF
HB0XID—Via DL4VA
HB0XVN—Via DK3ST
HS3AFB—Via WA2WMT
JD1ABO—Via JA1BA
K4CSY/KC4—Via W4 Bureau
KC6RS—Via W6MMG
KF4SJ—Via KP4AST
KY4CD—Via W4DQD
KY6PMR (c.w.)—Via WA6GFE
KY6PMR (s.s.b.)—Via WA6WWC
PJ6JT—Via W1BIH
TE0A—Via T12J
TU4AA—Via VE7BWG
TY0ABD—Via DJ6QT
VK9JV—Via JA2KLT
VP1EK—Via DL1JW
VP2AAC—Via WB4GGA
VP2DAE—Via K3RLY
VP2ES—Via W2BBK
VR1AB—Via K3RLY
VR1W—Via W6CUF
VR3C—Via K3RLY
VR2FO—Via W4FXA
WA4WME/LX—Via DL4VA
WA6GLD/6Y5—Via W6ANN