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Short Antennas for the Lower Frequencies

In Two Parts

Part I — Loading and the Use of Traps

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GREATER INTEREST in the use of lower frequencies is likely to result from the advent of the Five-Band DXCC Award and the imminent decline of the sunspot number in the years ahead. Unfortunately, few amateurs have space to put up half-wave antennas for these lower-frequency bands, and practical considerations require them to restrict their antenna lengths to whatever space is available. Then, some form of loading must be included to compensate for the fact that the antenna is not self-resonant. One of the purposes of this article is to review the types of loading that may be used and to discuss how the loading should be adjusted.

The problem is complicated by the fact that modern equipment provides for rapid band switching, and this feature cannot be exploited to the fullest advantage unless antennas are designed for multiband operation. In modern antenna design, this requirement is satisfied by the use of "traps," which consist of parallel-tuned circuits connected in series with the antenna at appropriate places. These are widely used in the three-band commercially-built Yagi antennas used on 14, 21, and 28 MHz. With these, the user has little occasion to delve into the details of the traps. No doubt, many amateurs consider traps as black boxes that work by magic. Actually, traps are easy to understand and to adjust, and can be conveniently incorporated in wire antennas which might be used at lower frequencies.

For simplicity, most of the present discussion is based on vertical (grounded monopole) antennas, since the number of traps and different wire lengths is only one-half that pertaining to a dipole antenna in a corresponding situation. It should be remembered, however, that the properties of a vertical antenna mounted on a perfectly-conducting earth are very closely related to those of a dipole of twice the length in free space. The input resistance and reactance of the vertical are just one-half those of the dipole, and the radiation pattern of the vertical is similar to one-half that of the dipole, but rotated ninety degrees. By use of this correspondence, any statements made here for vertical antennas can be adapted to horizontal dipoles; conversely, some of the reference material used by the author was presented originally in terms of horizontal dipoles.

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With the lower-frequency bands coming into greater prominence, this article is particularly timely. Part I reviews the characteristics of short antennas and discusses means for tuning them to resonance, including the applications of parallel LC *circuits or "traps," on a generalized basis.*

Some Preliminary Remarks on Traps

A vertical antenna with a trap is shown in Fig. 1. In the design procedure commonly employed for two-band operation, the length of the lower section, H_2, is made one-quarter wavelength at the higher frequency of operation, f_2, and the parallel-resonant frequency of the trap LC, if disconnected from the antenna, is made to be at f_2. At this frequency, the trap impedance ideally is infinite – or, in practice, is a very high pure resistance – so that the performance of the lower section is little affected by the presence of the outer section H_1. At the lower frequency, f_1, ideally the trap is so far off resonance as to act as a short circuit, and if this were so the total length, H, could be made one-quarter wavelength at f_1, and the antenna would act as a quarter-wavelength one at both f_1 and f_2. More realistically, the impedance of the trap at f_1 cannot be completely neglected. Since it offers inductive reactance at f_1, it is necessary to compensate by reducing the length of the upper section H_1 such that the total length H is somewhat less than a quarter wavelength at f_1. The reduction in length depends upon the L/C ratio of the trap. In practical cases H may be ten or fifteen percent less than a quarter wavelength at f_1. Also, to be completely realistic, it must be recognized that actually at f_2 a small current does flow in the upper portion H_1 although it may be difficult to detect its effect experimentally.

The common procedure of making the lower section H_2 one-quarter wavelength at the upper frequency is a matter of convenience. This situation is easy to analyze theoretically, and the f_1 and f_2 resonances can be adjusted nearly independently. Fundamentally, other values of H_2 can be used, but the situation where H_2 has other values has not been studied fully. It is conceivable that some other value of H_2 might give better performance, but it is likely that with other values of H_2 the adjustment procedure might be more tedious since any change is likely to affect both reson-

Chapter 1 lists a cross reference of American

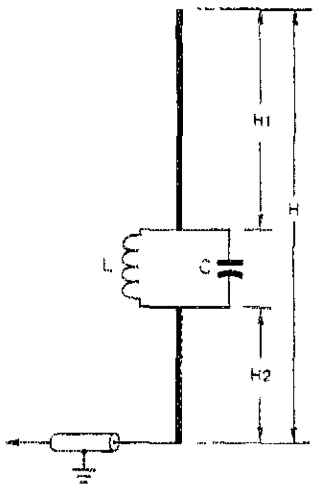

Fig. 1 — Vertical antenna with trap.

ances. In some cases the upper portion, H_1, can be expected to have appreciable current flowing in it at f_2. Later in the article an antenna will be described with which H_2 is only 0.15 wavelength at f_2.

The type of trap which has been referred to in the previous two paragraphs we shall call a "high-frequency trap" since its resonant frequency more or less coincides with the higher frequency of operation. There exists another type of trap,[1] which logically we shall call a "low-frequency trap" since its resonant frequency is made very close to the lower frequency f_1. Crudely, its operation may be described as follows: At the upper frequency f_2, the trap presents a very low impedance, mostly a capacitive reactance, so that if the total length H is made slightly longer than a quarter wavelength at the upper frequency f_2 the antenna behaves very nearly like a quarter-wave antenna at f_2. At f_1 the antenna is very highly reactive, but because of the rapid variation of the reactance of the trap near its resonance there exists an adjustment whereby it can be made to just tune out the reactance of the antenna at f_1 and bring it into resonance at this frequency.

With the low-frequency trap there may also be a wide-variation in the length of the lower section H_2. In fact, in the author's antenna H_2 is made equal to zero. This may or may not be optimum electrically, but mechanically it is very advantageous since heavy trap components may be located directly on the ground.

In this discussion the presence of only one trap has been assumed. In principle any number of traps, including a mixture of high- and low-frequency traps, may be employed.

[1] Since preparing this manuscript the author has become aware of the scheme developed at the E. F. Johnson Company for two-band operation of mobile antennas (See *ARRL Antenna Book*, 4th ed., p. 303). The low-frequency trap might be considered as a special case of the Johnson system in which the length of the antenna is made adjustable while the inductor in series with the capacitor is made zero.

Before these ideas are explained in greater detail it is necessary to review how the input impedance of a vertical antenna varies with length and how the impedance and reactance of a parallel-tuned circuit vary with frequency. Then the two sets of ideas may be merged in a detailed discussion of how a trap works.

Input Impedance of a Monopole Antenna

The radiation resistance and series reactance of a monopole antenna mounted on perfectly-conducting earth are plotted[2] as a function of length in Fig. 2. This figure is given here mainly to show the general trends, rather than to provide precise data. Actually, both quantities depend upon the diameter of the conductor. The data of Fig. 2 pertain to the case where the length-to-diameter ratio is held constant at 320. The effect of varying the diameter is most conspicuous when H is near 1/2 wavelength, when both the resistance and reactance are lowered by increasing the diameter.

It is to be noted that as the length is increased from zero, the resistance increases approximately in proportion to the square of the length, while the reactance starts with a large capacitive value and decreases to zero near a length of 1/4 wavelength. For further increases in length the resistance increases, reaching a maximum of more than 1000

[2] See, for example, S. A. Schelkunoff and H. T. Friis, *Antennas Theory and Practice* John Wiley and Sons, Inc., New York, 1952, Chapter 13.

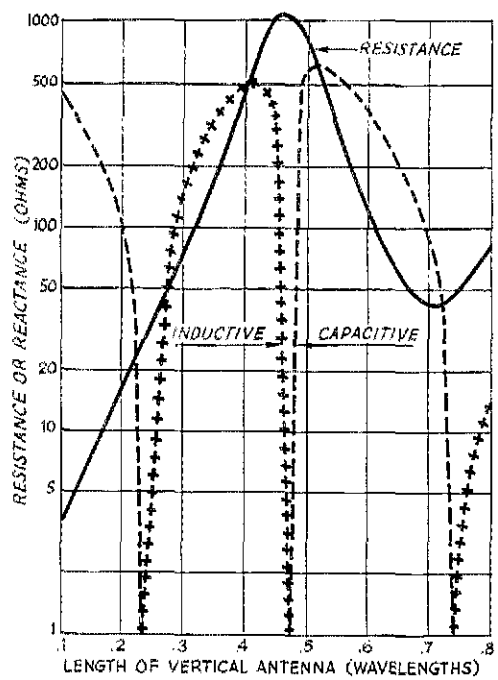

Fig. 2 — Radiation resistance and reactance of a base-fed vertical antenna over perfectly-conducting ground. These curves are for length-to-diameter radio of 320. (The curves have been adapted from Figs. 13.21 and 13.22 of Reference No. 1 for K_a = 800 by dividing the values given there by 2.)

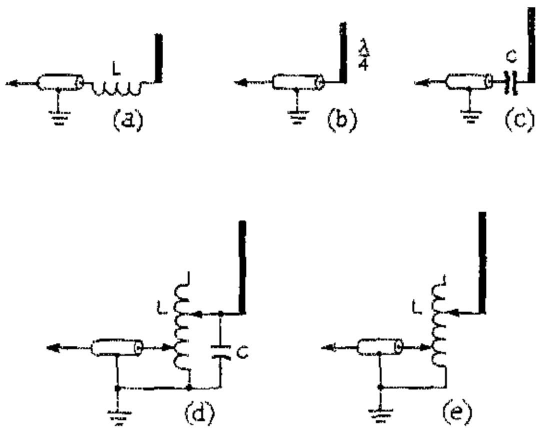

Fig. 3 — Matching networks for single-band operation of base-fed vertical antennas.

ohms near 1/2 wavelength, while the reactance becomes inductive, reaches a maximum close to 1/2 wavelength, and then suddenly goes to zero. For further increases, the resistance goes through minima whenever the length is close to an odd quarter wavelength, maxima when close to an integral number of half wavelengths. Succeeding minima are larger and larger while succeeding maxima are smaller and smaller. With each half wavelength variation in length the reactance curve repeats, approximately. The fact that reactance zeroes do not occur at exactly integral numbers of half wavelengths is due to end effects.

Radiation Patterns

To digress from the main theme for a moment, it is useful to note that if a vertical antenna is mounted on perfectly-conducting earth, the radiation pattern has a single maximum at zero degrees with respect to the horizontal until the length becomes slightly more than 1/2 wavelength. As the length is increased the lobe becomes sharper, corresponding to increased gain in the horizontal direction. When the length becomes more than about 5/8 wavelength, the major lobe starts to rise in angle, and minor lobes start to appear at lower elevations. For the greatest low-angle gain a length of 5/8 wavelength represents the optimum. This length corresponds to a center-fed horizontal antenna 1 1/4 wavelengths long – the so-called "extended double Zepp."

The effect of an imperfectly-conducting earth is to cause the single maximum of short verticals to occur somewhat above zero degrees, and as the length is increased this maximum is pulled down to lower angles until a length of 5/8 wavelength is reached.[3] Again, a length of 5/8 wavelength is optimum for producing low-angle radiation. For further details upon this matter and many others concerning vertical antennas, see the recent series of articles by Lee.[4]

Incidentally, in the author's experience, a 5/8-wavelength vertical is a spectacular improvement over the more familiar quarter-wavelength one.[5] Indeed, at times it seems to almost rival his three-element Yagi – which, however, is not very high above the ground.

Single-Band Operation

Now that we have reviewed the properties of vertical antennas, we are ready to discuss the simplest case, single-band operation. It is assumed that the antenna will be fed at the ground with 50-ohm coaxial cable. In general, it is necessary to tune out the reactance and to transform the resistance of the antenna to 50 ohms. For the moment, we shall suppose that the components necessary to do this are all located at the base. Of course, if the antenna is about 1/4 wavelength long the reactance can be made zero and the resistance will be a fair match to 50 ohms without any network.

In most practical situations, for vertical antennas of less than about 0.3 wavelength and dipole antennas for lengths up to about 0.55 wavelength, it is usually only necessary to tune out the reactance. In usual circumstances, line losses are unimportant[6] with standing-wave ratios up to 3 to 1, although with some modern transmitters it may

[3] Another important effect of increasing the height is that the radiation efficiency — which may be less than 25 percent with short (less than 1/4 wavelength) antennas having mediocre grounding systems — is improved. See *ARRL Antenna Book*, section on grounded antennas, Chapter 2, for details.

[4] Lee, "Vertical Antennas," *CQ*, in 12 parts, June 1968 through May 1969. See expecially Part 1 in June 1968 issue, p. 16, and Part 2 in the July 1968 issue, p. 25.

[5] This can be explained by the marked increase in efficiency at heights of the order of 1/2 wavelength together with the sharper lobe pattern (see Footnote 3).

[6] Beers, "Match or Not To Match," *QST*, September 1958, p. 14.

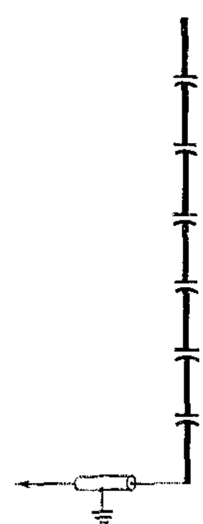

Fig. 4 — Oversize vertical antenna with distributed capacitive loading.

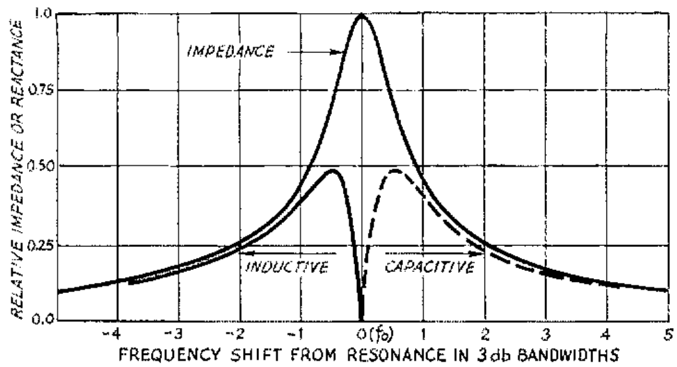

Fig. 5 — Total impedance and reactance of a parallel *LCR* circuit as a function of frequency. The impedance and reactance are given relative to the shunt impedance at resonance. The frequency is measured in terms of 3-dB bandwidths from resonance. In preparing these curves it has been assumed, as an approximation, that the Q of the circuit is large compared to 1 ($Q = 10$).

be necessary to hold the SWR down to 2 to 1 to bring it within range of adjustment of the transmitter's output network. SWRs within these limits usually can be achieved by merely tuning out the reactance. For verticals under 1/4 wavelength, it is only necessary to connect in a single inductance as suggested by Fig. 3A; those between 0.25 and 0.3 wavelength can be resonated by a single capacitor as suggested by Fig. 3C.

For longer lengths it is necessary to step down the antenna resistance. The simplest of many possible methods is shown in Fig. 3D, which is adjusted to give a net capacitive reactance for lengths between 1/4 and 1/2 wavelength. For lengths slightly greater than 1/2 wavelength (including 5/8 wavelength) the capacitor may be omitted as suggested by Fig. 3E, since the reactance of the antenna is capacitive. Networks 3D and 3E may be used with shorter lengths by those who wish to match the resistance as well as the reactance. Also, these networks provide a low impedance for dc and low frequencies, which may aid in lightning protection and in suppressing spurious responses.

Location of the Loading

Fig. 3 has suggested that the loading is to be located at the base. By no means is this the only possible location. One other possibility is to place it in the middle of the antenna — what is commonly called "center loading," but which will be called "body loading" here since with the related dipole antennas the corresponding positions do not fall in the middle but intermediate between the center and the ends.

With antennas shorter than 1/4 wavelength body loading has some advantage since it causes a more favorable current distribution and higher radiation resistance and efficiency. Not all of the theoretical gain in efficiency is realized, since a bigger loading coil is needed, and this has a larger loss resistance. With such antennas, the portion between the loading and the end acts like a capacitance which, of course, is smaller than that of the whole antenna. The portion between the loading coil and the base acts like an inductance. For antennas between 1/4 and 5/8 wavelength it is likely that greater efficiency is obtained with base loading, since the current loop is located higher, where it is further from absorbing material.

Nor is it necessary to locate the loading all in one place. As is well known, resonant antennas with physical lengths less than 1/4 wavelength may be made by winding a helix on an insulating rod, thus distributing the loading over the entire length.

An interesting version of antennas with distributed loading has been described by "Dud" Charman, G6CJ.[7] (His article describes dipole antennas, but for uniformity of style here his results are expressed in terms of the associated vertical monopoles.) The total physical length is considerably more than a quarter wavelength, and the antenna is broken into small sections connected in series with capacitors as indicated in Fig. 4. With proper adjustment, the electrical length is one-quarter wavelength in the sense that there is only one current node (at the upper end) and only one voltage node (at the lower end). The advantages of this over a conventional quarter-wave antenna are greater gain and greater bandwidth. The input impedance is higher than with a conventional antenna. One example he gives is of a 14-MHz antenna 50 feet long (as compared to the conventional 16.5 feet) broken up into sections 5 feet 6 inches long joined by 50-pF capacitors. This is said to have a gain of 2.1 dB over the conventional antenna and a radiation resistance of 100 ohms instead of 35.

Properties of a Parallel-Tuned Circuit

The total impedance and the reactance vs. frequency of a circuit consisting of an inductor and a capacitor in parallel are shown in Fig. 5. These graphs are plotted as "universal" curves that can be used with any such circuit whose reactance and resonant frequency, f_0 and Q are known. The reactance and impedance are given on a relative scale; the shunt impedance is considered unity exactly at resonance, at which point it is purely resistive and equal to the reactance of either the capacitor or the inductor multiplied by the Q. The horizontal scale is in terms of frequency shift from resonance measured in 3-dB bandwidths. The 3-dB bandwidth is found by dividing the resonant frequency f_0 by Q. (In calculating the numbers for Fig. 5 the assumption was made that Q is large compared to unity, an approximation which is

[7] Charman, "Loaded Wire Aerials," *RSGB Bulletin*, July 1961, p. 10.

valid under conditions which are usually encountered.)

There are several important features to be noted in Fig. 5. The maximum inductive and capacitive reactances occur at frequencies that are respectively below and above the resonant frequency f_o by only one-half the 3-dB bandwidth. These are the frequencies at which the total impedance has dropped to 0.7 of the maximum value, and where, of course, the response is 3 dB down from maximum. Within this range of frequency it is possible to obtain, somewhere or other, any value of reactance which is obtainable at all with the particular tuned circuit. Each value of reactance, except the maxima, also is obtainable at a second frequency outside this range. Far from resonance the reactance is small.

The maximum reactance magnitudes are one-half the impedance at resonance which, for a fixed capacitance and f_o is proportional to the Q of the tuned circuit. If the circuit is of very low Q and is to be used as an antenna trap, the reactance may never rise to a sufficiently high value to tune the antenna to resonance at one of its frequencies. On the other hand, if the Q is very high, the bandwidth of both the trap and the antenna as a whole becomes very small. Also, with a high Q the adjustment of the trap is very critical.

It should be said for emphasis, but at the expense of repetition, that the major variation in reactance occurs in a very small frequency range. For example, at 14 MHz with a modest value of 100 for the Q, a complete variation in reactance is obtained within a band of 140 MHz surrounding resonance, and with higher Qs the range of frequency becomes proportionately smaller. However, we are speaking here of the bandwidth of the trap itself and not of the antenna as a whole. The bandwidth of the antenna under favorable circumstances may be considerably wider than that of the isolated trap since the radiation resistance lowers the *overall* Q.

The Principle of Operation of a Trap

Now that we have reviewed the various bits of background material, we shall bring them together in a generalized discussion of the operation of a trap. Using a different design approach from that described earlier, assume that the trap position is arbitrarily chosen, and that the *total* length H is selected to be close to self-resonance on one of the two bands on which the antenna is to be used. On this band the reactance required to produce exact resonance is very small. It is obtainable by having the trap far off resonance for this band, and operation does not depend very critically upon the adjustment of the trap. However, on the second band the antenna is far from self-resonance, and a large magnitude of reactance is required in the trap to bring the antenna into resonance. From what has just been said in the previous paragraphs, it should be evident that this condition is obtained when the resonant frequency of the trap is close to, but not exactly at, the desired frequency of operation.

In the case of a high-frequency trap, the total length H is close to the self-resonant length for the lower frequency f_1. The antenna is much too long to be self-resonant at the higher frequency f_2, and resonance there can be obtained by having the trap produce a significant amount of capacitive reactance. Then from the point of view of Fig. 5 f_2 is just slightly to the right of f_o (f_o slightly less than f_2), while f_1 is far off scale to the left. Strictly speaking, at f_1 the trap produces a small amount of inductive reactance; therefore, to produce exact resonance at f_1 the length H should be slightly shorter than the self-resonant length. The detailed explanation of a low-frequency trap is entirely analagous, except that every statement must be reversed. For example, f_1 is slightly to the left of f_o in Fig. 5, while f_2 is off scale to the right.

As is to be expected, the performance of a trapped antenna on either band is inferior to that obtained when the same antenna is loaded for single-band operation only. Either the efficiency, the bandwidth, or both, is poorer.[8] However, if the self-resonant frequency is not too far from lowest operating frequency, as is usually the case with antennas with high-frequency traps, the deterioration of performance is quite small and can be tolerated as the price of multiband operation.

In other cases, expecially with antennas having low-frequency traps, the deterioration in performance may be significant, and the user must make a decision as to what is the best compromise for his purposes. Largely by changing the L/C ratio of the trap, he can make the performance on one band nearly up to that obtained with monoband loading while having marginal performance, allowing at least local operation, on the other band; or he can make the performance equal on both bands but on each somewhat less than with monoband loading. Fortunately, with vertical antennas with low-frequency traps the principal loading can be located at the base, and often being conveniently accessible, can be made plug-in. Traps with different L/C ratios or monoband loads can be plugged in with changing needs.

The effect of the L/C ratio may be illustrated by reference to the antenna with the high-frequency trap. At one extreme, where the capacitance is left out entirely, resonance can be obtained only by adjusting the inductance for resonance at the lower frequency f_1 (it is assumed that the length H is slightly shorter than the self-resonant length), and the antenna becomes totally ineffective at f_2. At the other extreme, in which the inductor is left out, resonance can be obtained only at f_2 by adjusting the capacitor, and the antenna becomes ineffective at f_1. Thus decreasing the L/C ratio tends to make performance at f_2 improve and that at f_1 decrease.

If practical considerations make it impossible to make the length H reasonably close to self-resonance at one of the frequencies, the adjustment of the trap is likely to become very critical, and in most cases it is necessary to bring the antenna close

(Continued on page 85)

[8] As compared with monoband loading, using a single reactance the reduction in efficiency is almost entirely the result of extra power losses caused by the circulation of current in the traps; the loss can be reduced by using high-Q components, but at the possible expense of reducing the bandwidth of the antenna.

Transcontinental Corps — May reports.

Area	*Functions*	*% Successful*	*Traffic*	*Out-of-Net Traffic*
Eastern	124	97.6	1954	698
Central	93	93.5	1058	499
Pacific	124	95.2	1724	912
Summary	*341*	*95.4*	*4736*	*2109*

The TCC Roster: Eastern Area (W3EML, Dir.) – W1s BIG EJI NJM, K1ESG, WA1JTM, W2s FR GKZ PU QC, K2KIR, WA2s CAL HMO UWA, W3EML, K3s HHK MVO, W4s NLC SQO UQ, K4KNP, W8UM, K8KMQ, WA8YVR. Central Area (WØLCX, Dir.) – W4OGG, K4s AT DPO, W5MI, W9s CXY DND VAY, WA9s RAK VZM, WØs HI INH LCX UCE ZHN, KØAEM, WAØ DOU IAW RVR. Pacific Area (W6VNQ, Dir.) – W5RE, W6s HGF BNX EOT IPW MLF VNQ VZT, K6DYX, WA6s BRG LFA ROF, W7s DZX EM GHT KZ, WA7CLF, KØJSP.

Independent Net Reports.

Net	*Sessions*	*Check-Ins*	*Traffic*
Clearing House	26	398	212
7290 Traffic	53	2491	1972
ECT FN	21	294	85
All Service	5	73	44
North American SSB	26	614	517
Northeast Traffic	31	465	420
Hit & Bounce	31	269	258
EASN	25	127	51

VE/W CONTEST ANNOUNCEMENT

(Continued from page 69)

7) *Reporting*: Follow the sample log shown. Check sheets (or ARRL Op. Aid 6) are required for every entry consisting of 200 or more QSOs. *ANY LOG OMITTING CROSS-CHECK SHEETS OR A SUMMARY SHEET WILL NOT BE CONSIDERED FOR COMPETITIVE QST LISTING OR AWARDS.* Such logs will be counted as check logs and processed accordingly. Entries must be postmarked no later than October 31. All entries become the property of the committee and none can be returned. Participants are encouraged to submit station photos and comments.

Log sheets will be available from the address shown, upon receipt of self addressed legal size envelopes and IRCs, or Canadian stamps.

8) *Awards*: Certificates will be awarded to the highest scoring cw and phone entry in each section. A minimum score of 25 QSOs is required. Certificates for the high scoring multioperator entries will be issued only when there are at least three entries per section. Phone and cw scores will be listed separately. A trophy will be issued to the high scoring Canadian and to the high scoring US entry.

9) *Mailing*: Please make sure that your call and section are on each page, and especially on the top left-hand corner of your envelope. Mail logs to: VE/W Committee (VE2IZ and VE2DCW), 262 Braebrook Avenue, Pointe Claire, Quebec, Canada.

SHORT ANTENNAS

(Continued from 30)

to resonance at this frequency by the use of auxiliary loading in the form of a second inductor or capacitor outside the trap. In such cases, the L/C ratio is very critical. Although there is some interlocking of the adjustments of the trap and the auxiliary loading, to the first approximation one of the resonant frequencies of the antenna is determined by the adjustments of one, while the other frequency is determined by the adjustments of the other.

This discussion has assumed for simplicity a two-band antenna with a single trap. In principle, operation on any number of bands can be obtained by installing the appropriate number of traps. In the first approximation, each trap is designed as though the others were not present although, of course, there is bound to be some influence of one upon another. Correction for this interaction is made by trial and error. QST