The L Network as An Impedance Transformer

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THE USE OF COMBINATIONS of L and C for impedance matching is well known, and many excellent articles have been written on this subject. For the greater part, these articles have treated the subject on a mathematical basis with little regard for the manipulations necessary to put information in a practical form.

It is the purpose of this article to present the amateur with a simple, yet versatile, matching network stripped of all mathematics, and to give data that will enable him to match feed lines to 2, 3 and 4-element beams. Many clever and interesting methods have been presented for solving this problem, but as far as we can determine the "L" network has been largely overlooked in amateur literature. The proposed circuit takes advantage of the characteristics of a simple tank circuit.

Fig. 1a shows a parallel tuned circuit. If it is tuned to resonance, the impedance that appears at terminals *D* and *E* is a pure resistance at the resonant frequency whose value depends on the "Q" of the circuit and the reactance of the condenser or inductance at the resonant frequency. Since the losses in the condenser are negligible for the frequencies we are going to discuss, this is tantamount to saying that it is a function of the Q of the inductance. If for a certain value of L and C the Q is high (a-c coil resistance low), the terminal impedance will be high. If the Q is low (a-c coil resistance high), the terminal impedance will be low.

Normally the a-c resistance of a well designed inductance is quite low, but suppose that we open the circuit as shown in *Fig. 1b* and intentionally introduce resistance at *HJ*. As more and more resistance is introduced, the impedance at terminals *F* and *G* becomes less and less, and if a source of fixed r-f voltage is applied to these terminals, more and more power will be drawn from the source. An excellent example of this that every amateur has experienced is the action of an unloaded Class C amplifier. If the unloaded tank circuit Q is not too high, the plate current dip at resonance will not be very great, showing that power is being drawn from the amplifier and being absorbed by the tank circuit. By using heavier wire in the coil and securely soldering connections to reduce the a-c resistance in series with the tank circuit, a lower dip usually can be achieved, which indicates a higher impedance circuit with less power being furnished by the amplifier. This further illustrates a very important point— *a relatively small amount of resistance in series with a parallel tuned circuit will produce a radical change in the impedance at its terminals.* From the foregoing it can be perceived that a tank circuit has a very valuable property: *Power can be absorbed by a low resistance in series with the circuit, and can be delivered to the circuit at a high impedance across its terminals.* Of course, in actual practice, a resistance would not be used at the output terminals *H* and *J* in *Fig. 1b*. Instead, the radiation resistance of an antenna would be connected at this point.

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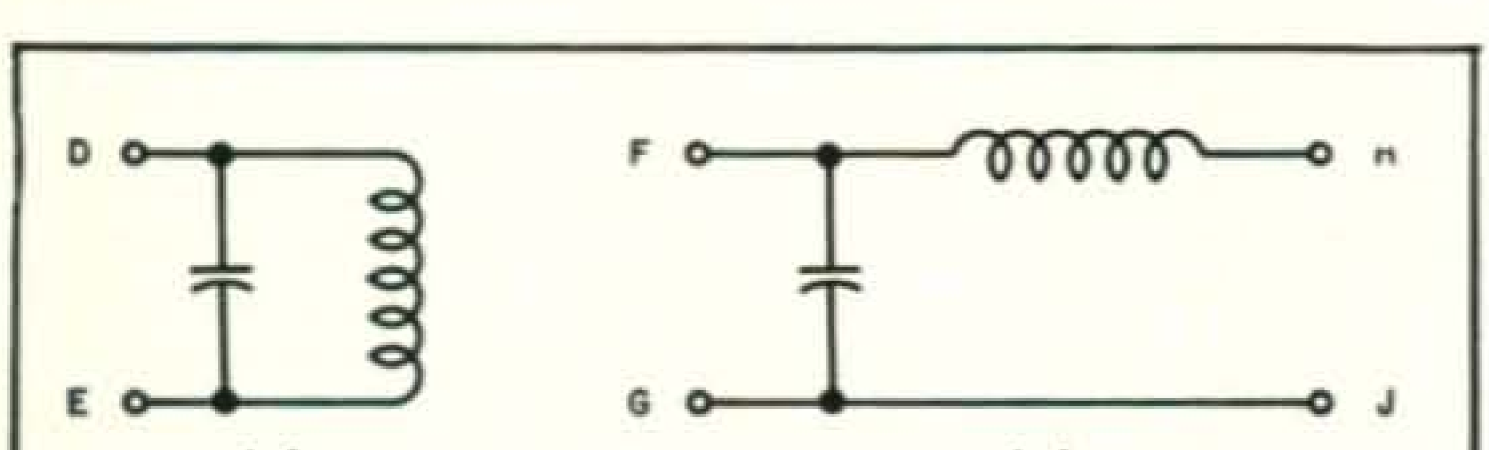


Fig. 1. The development of a parallel-tuned circuit into the basic L network, as explained in the text.

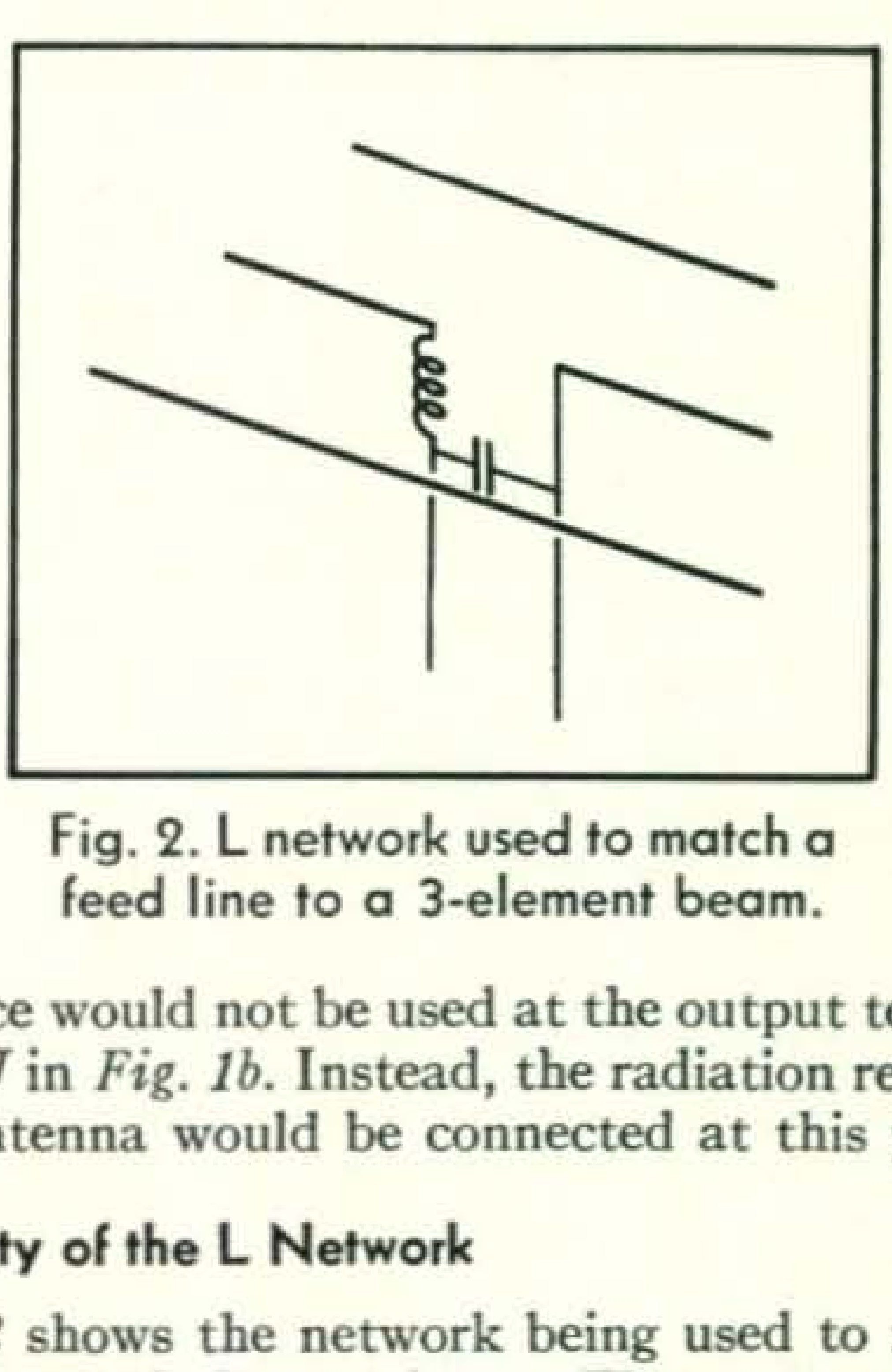


Fig. 2. L network used to match a feed line to a 3-element beam.

Versatility of the L Network

Fig. 2 shows the network being used to match a feed line to a 3-element beam. The constants are so chosen that the input terminals of the network present an impedance that matches the line when the low radiation resistance of a beam antenna is connected to the output. The calculations are a bit tedious, hence tables have been prepared giving the coil turns and diameter, and the capacity necessary to match the commonly used feed lines to close-spaced arrays. It will be noted that the values of inductive and capacitive reactance, as well as the inductance in microhenries, are given for those who wish to check the operation of the equations which are printed in the appendix.

For purposes of calculation, it was assumed the feeding impedance of 2, 3 and 4-element close-spaced beams is fifteen, eight, and five ohms, respectively. If the beam spacing, tubing diameter and tuning are such that the antenna does not meet these specifications, pruning of the inductance and retuning the condenser may be necessary to produce a "flat" feed-line. This ability to alter the constants slightly to achieve an exact match should make the "L" network particularly attractive to the amateur.

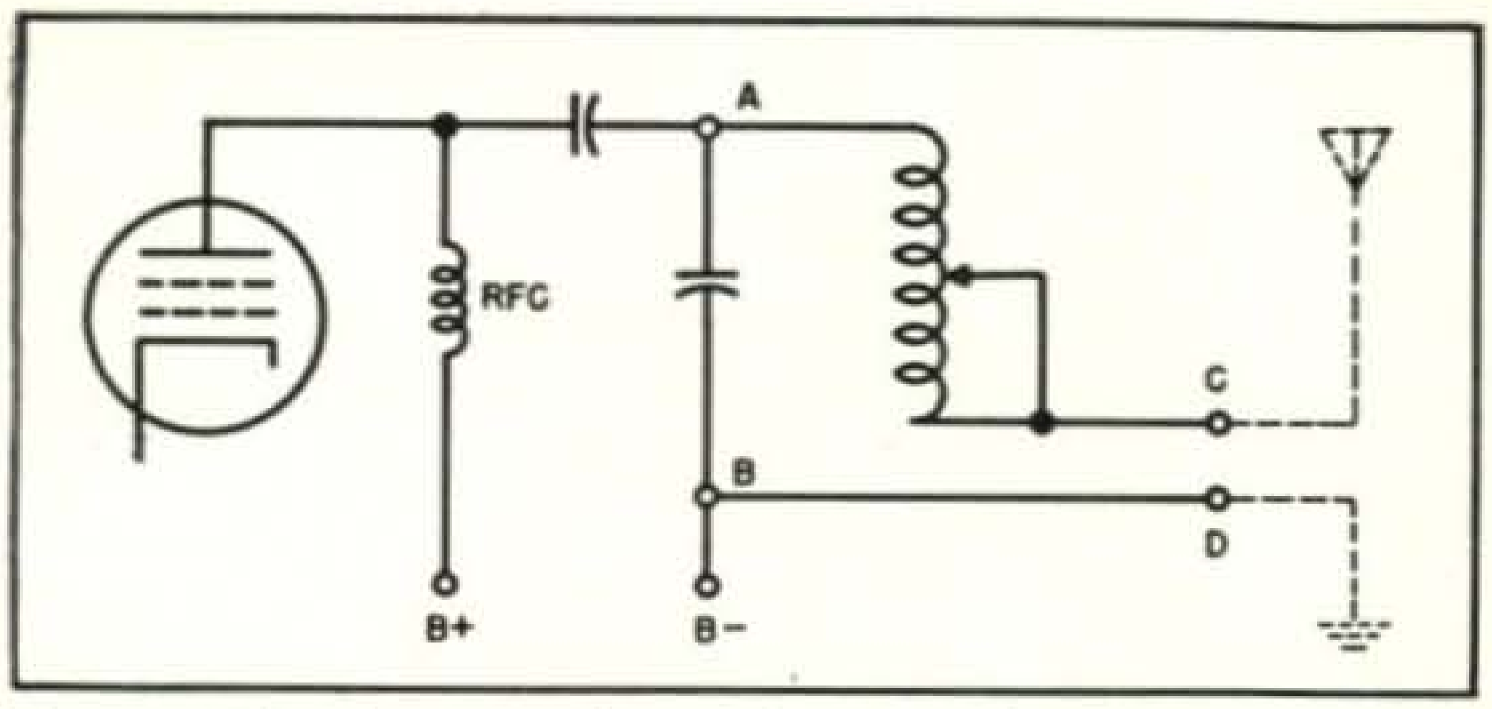


Fig. 3. The L network used to match antenna wire to a Class C amplifier. The values as discussed in the text are fully developed in Table 3.

The network should be located as close to the center of the radiator as is mechanically possible, and should be in some sort of water-proof enclosure. This need not be very large, since the components are not bulky. The peak voltage that will occur across the condenser when 500 watts of unmodulated r-f is fed to the network is shown in *Table 1.* From this it can be seen that relatively close plate spacing can be used.

Practical Illustrations

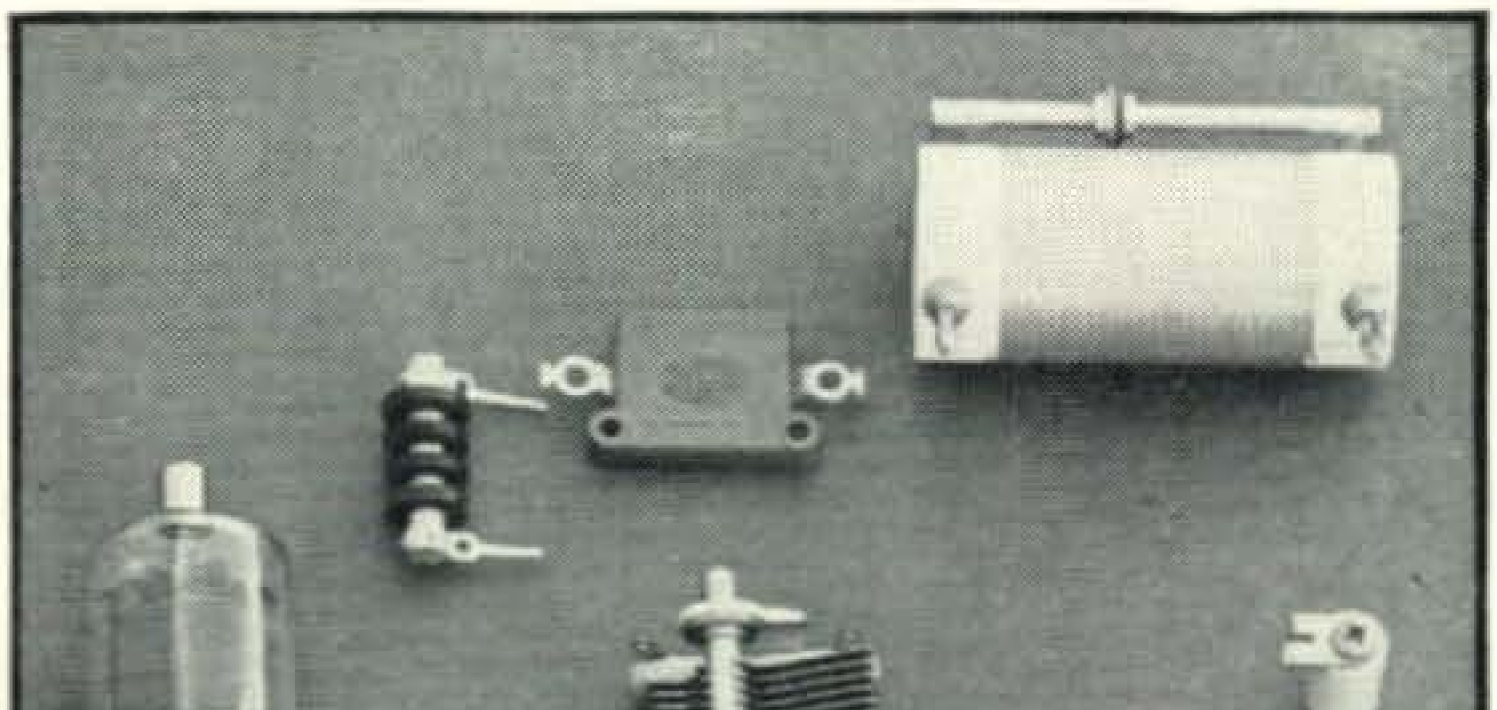
As an example, suppose that a 3-element close spaced beam is to be fed with 600-ohm open-wire line on 29 mc. The theoretical impedance of the beam is about 8 ohms. In the bottom half of the 29-mc table find in the column marked "MATCH" the line "600 to 8." The third column gives the capacity as 79 μμf; the last three columns give the coil data. A self-supporting coil of heavy wire should be wound on a one-inch diameter having six turns and so spaced that the length is 1¼ inches. If the exact operating frequency is other than 29 mc, the same trial values of capacity and inductance should be used, since an adjustment will be made after the beam is tuned.

When tuning the beam elements, check the network condenser for correct capacity by noting the response in the field-strength meter, or by using a loop-light loosely coupled to the network inductance. This should be repeated after each adjustment of the radiator.

After all elements have been tuned and locked, check the feed lines for standing waves. If the line is "flat," you have had an unprecedented bit of luck. Let us suppose a thermocouple galvanometer is to be used to check for standing waves. If the current decreases as the network is approached, the impedance presented to the line by the network is too high. Under these circumstances the inductance in the matching network should be reduced and the capacity increased. This could be inferred from looking at the table, which shows that 110 μμf are needed to match 8 to 300 ohms, and only 29 μμf to match 8 to 600 ohms. It will also be noticed that the capacity and inductance of the network almost form a resonant circuit at the operating frequency, particularly if the transformation ratio is high. If XC equaled XL, the circuit would be resonant; but in each case, the values are slightly different. The capacity is always somewhat less than that required to tune the inductance to resonance at the operating frequency. Before the network is installed at the antenna, it should be connected as a parallel tuned circuit and *loosely* coupled to the transmitter tank circuit to determine the setting of the condenser for which it resonates. When properly operating at the antenna, a slightly lesser value of capacity should be necessary, and this value should closely match that given in the table.[1]

Fig. 3 shows another application of the matching

[1] It should be clearly understood that Tables 1 and 2 are based on R (the impedance of the driven element at the feed point) being purely resistive. To insure that this is the case, the feed line should be connected to the driven element at the normal feed point with the L-C matching network completely removed. For the case of close-spaced arrays with half-wave elements the resistive term of the impedance of the driven element at the feed point will be less than the characteristic impedance of the feed line. Hence when the impedance of the driven element is purely resistive, a current maximum will occur at the feed point. Couple the feeders to the final tank circuit, and excite the array. Lengthen or shorten the driven element until the current maximum is at the feed point. If the current maximum is on the antenna side of the feed point, the driven element is too long. If current maximum is on feeder side of feed point, the driven element is too short. The adjustment of the length of the driven element to present a resistive impedance at the feed point must be performed after the parasitic elements have been adjusted to their final length, since the parasitic elements reflect a reactance into the driven element that varies as a function of the length of the parasitic element.



The components of the basic L network, as compared to a 2E25, enable the construction of a compact and highly versatile tuning unit.

Table 1—14,250 kc

Match	XC (Ohms)	Cap. ($\mu\mu f$)	Peak Voltage	XL (Ohms)	Inductance (μh)	Diam. (Inches)	Length (Inches)	Turns
600 to 15	96.2	116	770	93.6	1.045	1⅝	1½	6
600 to 8	69.8	160	770	68.8	.768	1⅜	1½	6
600 to 5	55.0	203	770	54.5	.608	1½	1½	5
300 to 15	68.8	162.5	540	65.4	.73	1¼	1½	6
300 to 8	49.7	224	540	48.3	.539	1	1¼	6
300 to 5	39.1	286	540	38.4	.428	1	1	5
72 to 15	37.0	302	270	29.2	.326	1	1¼	5
72 to 8	25.5	438	270	22.6	.252	1	1	4
72 to 5	19.7	567	270	18.3	.204	⅞	1	4
50 to 15	32.8	341	220	22.9	.256	1	1	4
50 to 8	21.9	510	220	18.3	.204	⅞	1	4
50 to 5	16.7	669	220	15.0	.168	¾	1	4

Table 2—29,000 kc

Match	XC (Ohms)	Cap. ($\mu\mu f$)	Peak Voltage	XL (Ohms)	Inductance (μh)	Diam. (Inches)	Length (Inches)	Turns
600 to 15	96.2	57	770	93.6	.514	1	1¼	6
600 to 8	69.8	79	770	68.8	.378	1	1¼	5
600 to 5	55.0	100	770	54.5	.299	⅞	1	5
300 to 15	68.8	80	540	65.4	.359	1	1¼	5
300 to 8	49.7	110	540	48.3	.266	1	1	4
300 to 5	39.1	140	540	38.4	.211	⅞	1	4
72 to 15	37.0	148	270	29.2	.160	¾	1	4
72 to 8	25.5	215	270	22.6	.124	¾	¾	3
72 to 5	19.7	279	270	18.3	.100	⅝	⅝	3
50 to 15	32.8	167	220	22.9	.126	¾	¾	3
50 to 8	21.9	250	220	18.3	.100	⅝	⅝	3
50 to 5	16.7	328	220	15.0	.082	⅝	¾	3

Table 3

Plate Load	Ant. Imp.	Freq.	XL	Diam.	Inductance Length	Turns	Turns/Inch	XC	Cap. ($\mu\mu f$)
3000	36	3750 kc	327	2½	3½	21	6	330	129
5000	36	3750 kc	423	2½	4	24	6	425	100
10,000	36	3750 kc	599	2½	5½	33	6	601	70
3000	36	7150 kc	327	2½	2⅛	13	6	330	68
5000	36	7150 kc	423	2½	2½	15	6	425	52
10,000	36	7150 kc	599	2½	3½	21	6	601	37

system. If a quarter-wave antenna is connected to *C* and a ground to *D*, the proper impedance to load a Class C amplifier will be presented at terminals *A* and *B*, provided the correct values of capacity and inductance are chosen. *Table 3* shows the amount of capacity and inductance necessary to match 36 ohms to 3,000, 5,000, and 10,000-ohm plate loads on 80 and 40 meters. A rough estimate of the impedance required by a Class C amplifier can be made by dividing plate voltage by the desired "loaded" plate current. This is sufficiently accurate since some measure of adjustment must be provided in any case.

The ideal arrangement would be to have both L and C continuously variable. The inductance could be a "roller" coil such as is manufactured by Silver, Johnson, Barker & Williamson and others. Many of these have appeared on the surplus market. Lacking one of these, a simple tapped coil could be used. The tank condenser would be selected in the same manner as for any other Class C amplifier, taking into account the plate voltage that is to be used. The desirability of a continuously variable inductance will become obvious from the tuning procedure.

The following procedure should be followed in loading the Class C amplifier. First, short terminals *C* and *D*, apply power and dip the tank circuit. Since there are an infinite number of combinations of L and C that will hit resonance, a combination should be selected which uses the minimum capacity available in the tank condenser. The short should then be removed and the antenna and ground should be connected to *C* and *D*. Assuming that the antenna does not present a pure resistance, the tank circuit should be re-dipped *using the variable inductance.* The new value of plate current will be higher, indicating that power is being delivered to the antenna. To increase the load, slowly increase the amount of capacity in the circuit, each time re-dipping with the variable inductance. This seemingly wrong tuning method is based on the nature of the network. The impedance across the input terminals of the

(*Continued on page 82*)

YL of the Month

Speaking of "firsts," firsts are nothing new to Theresa McLaughlin, W3VYU, of Greensburg, Pa. Terry was always "the first girl I ever knew who was so technically minded" to most of her friends, and is now the first girl to graduate from Carnegie Tech's electrical engineering school.

Only 20 years old and with an E.E. degree, Terry is working at Curtiss-Wright in Columbus, Ohio. She hopes through her work to help make flying the safest mode of transportation.

Terry has been intensely interested in the radio field since she was 14, when she saw a Pete Smith movie short about hams. That same year, while attending high school, she studied for and passed her exam. Before long she was ORS, EC, and had been nominated for the Hiram Percy Maxim Award as the young amateur to accomplish the most that year.

During the war Terry was able to combine in CAP work her two main interests of electronics and flying, serving as communications officer in charge of an all-girl flight group. About this time she also had received her private pilot's license, her first and second-class radiotelephone commercial licenses, and was working in her "spare" time as an engineer at WHJB in Greensburg.

Terry never lacks for things to do. "Besides my present opportunity to work with my first love, radio control and robots, as engineer at Curtiss-Wright," she says, "I'm working for a commercial pilot's license with a couple of ratings on the side. Have a little 25-watt transmitter here as well as my trusty Sky Champion, and will be having skeds back home. There's also a chance here to get a master's degree . . . "

Terry has made many friends on the air and says: "I was always bumping into pals on the bands when I least expected to—just happened to park on their frequency and hear them calling me. Strangest one in that category was the nignt I was in W8IYI's shack (now W3LEJ) and heard someone sending a test from my station! Thought at first it was spooks; it is peculiar to hear one's own call being sent when there one sits somewhere else. It turned out to be one of the boys who had stopped to check my rig which had developed a little quirk, and since I wasn't there he had been admitted to the shack anyway and decided to give it a test.

"I also met on the air some blind friends to whom I now write regularly in Braille. Radio also gave me an interest in cryptography, after a course in the AARS."

Terry seems to be not only the "firstest" but also the "mostest" in the way of interests. So outstanding have been her accomplishments, in fact, that she has been selected for a feature write-up in a fall issue of *Parade*. We suggest you watch for it.

THE L NETWORK

(from page 40)

network is inversely proportional to the capacity, whereas the inductance is used to bring the circuit into resonance. Hence, if the tank condenser is used for dipping the circuit, the loading on the Class C amplifier is being varied simultaneously. In case a tapped inductor is used instead of a "roller" coil, it will be necessary to cross-juggle capacity and inductance until the proper degree of loading is achieved, observing as closely as possible the circuit principles as outlined above. *(Continued on 84)*

So far, we have considered the case of a quarter-wave antenna with a theoretical impedance of 36 ohms. If this were the only possible application, the circuit would not offer much attraction. Let us investigate its use in a portable rig which is to operate on 80 and 40 meters and is to use a wire strung to a convenient tree.

Let us stipulate that the antenna used will be less than a quarter wave long for the highest frequency that is to be used. There is a two-fold reason for this: One, inductance in series with the antenna will resonate it; two, the impedance will be less than 36 ohms. (This is essential since the network is only suitable for low impedances.)

In *Fig. 3*, *L* represents the inductance necessary to resonate the antenna and the inductance of the matching network. It is obvious at a glance that they can be combined, and the actual circuit will be the same as *Fig. 2*. The only difference is that the total amount of inductance will be greater than that given in *Table 3*, and hence the capacity required will be somewhat less. Since both the capacity and inductance are variable, an impedance match can be achieved over a wide band of frequencies with a wide variation in antenna resistance and reactance.

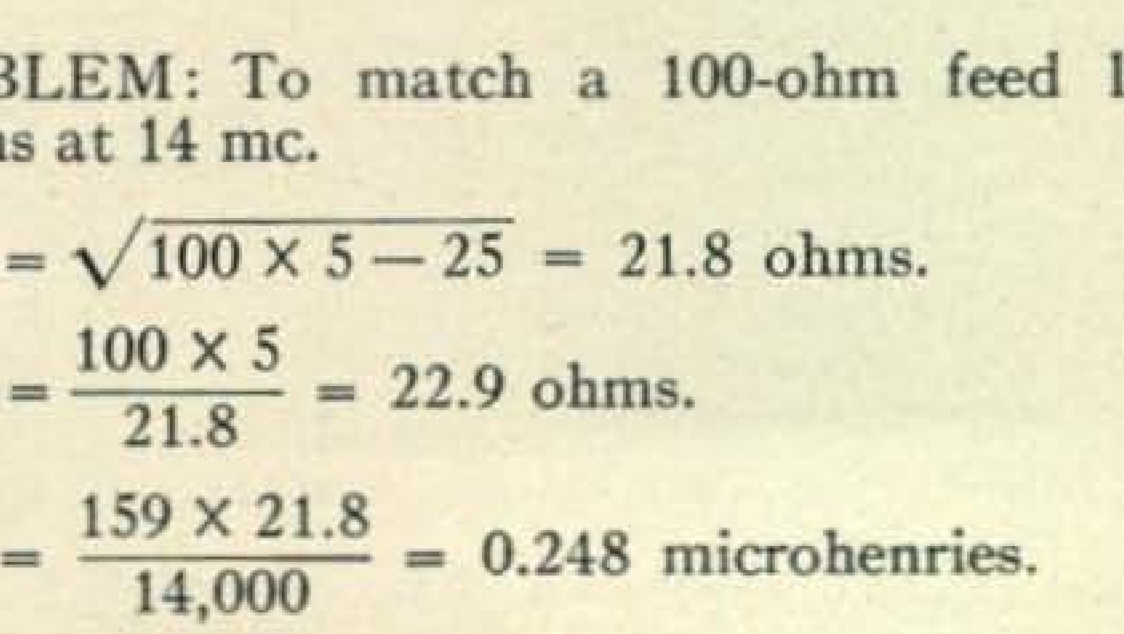
Appendix

$$X_L = \sqrt{ZR - R^2} \text{ ohms.}$$

$$X_C = \frac{ZR}{\sqrt{ZR - R^2}} \text{ ohms.}$$

$$L = \frac{159\ X_L}{f} \text{ microhenries (f in kilocycles).}$$

$$C = \frac{159{,}000}{f \times X_C} \text{ micromicrofarads (f in megacycles).}$$



PROBLEM: To match a 100-ohm feed line to 5 ohms at 14 mc.

$$X_L = \sqrt{100 \times 5 - 25} = 21.8 \text{ ohms.}$$

$$X_C = \frac{100 \times 5}{21.8} = 22.9 \text{ ohms.}$$

$$L = \frac{159 \times 21.8}{14{,}000} = 0.248 \text{ microhenries.}$$

$$C = \frac{159{,}000}{14 \times 22.9} = 496 \text{ micromicrofarads.}$$

The arrangement illustrated in the appendix where *C* is across the load and *L* in series with the load will only match a transmission line to a load whose impedance is less than the surge impedance of the line. In the case where the impedance of the load is greater than the surge impedance of the line, *C* goes across the load, rather than across the transmission line, that is, at *R*.