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Author: John Marshall, W0ARL

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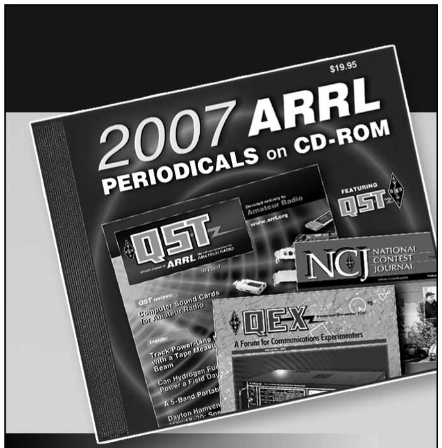

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Two-Band Antenna-Matching Networks

Practical Application of Formulas

PART III

BY JOHN G. MARSHALL,* W0ARL

[This is the third and concluding part of a series of three installments. The first and second parts of this article appeared in the October and November, 1949, issues of QST. — ED.]

To demonstrate the use of these networks and their formulas, examples are given of a simple antenna operating on its fundamental and second-harmonic frequencies, using various types of transmission lines. Driving-point impedances (d.p.i.) of 75 and 1500 ohms are assumed for f_1 and f_2, respectively. These may not be the exact values for individual cases, but they are typical and serve here to demonstrate the use of the formulas. The examples are worked out to normal slide-rule accuracy which should be entirely adequate, since the error in determining the d.p.i. in each case is likely to be much greater.

The relationships existing between Z_0, Z_1 and Z_2 determine which of the networks is needed for any certain example. Table I shows the proper network and formulas to use for any combination of Z_0, Z_1 and Z_2 likely to exist in present-day amateur antennas. These formulas are the same as those discussed earlier.

Example 1

Given: A simple center-fed antenna operating on its fundamental and second-harmonic frequencies, using a 53-ohm line. The d.p.i. is 75 ohms on f_1 and 1500 ohms on f_2. Transmitter power is one kilowatt output.

Solution: Since f_2 is twice f_1, $K = 2$. With $Z_0 = 53$ ohms, $Z_1 = 75$ ohms and $Z_2 = 1500$ ohms, this example falls into the general case where $Z_0 < Z_1$ and Z_2. The table shows that the network of Fig. 5 and its associated formulas are applicable. Substituting numerical values in these formulas, we have the following:

$$X_{P1} = 75\sqrt{\frac{53}{75 - 53}} = 116 \text{ ohms,}$$

and

$$X_{P2} = -1500\sqrt{\frac{53}{1500 - 53}} = -287 \text{ ohms.}$$

Then,

$$X_{LP} = \frac{(116)(2^2 - 1)}{2\left(2 - \frac{116}{-287}\right)} = 72.4 \text{ ohms,}$$

and

$$X_{CP} = \frac{(-287)(2^2 - 1)}{\frac{-287}{116} - 2} = 193 \text{ ohms.}$$

Since

$$X_{B1} = -53\sqrt{\frac{75}{53} - 1} = -34.1 \text{ ohms,}$$

and

$$X_{B2} = 53\sqrt{\frac{1500}{53} - 1} = 277 \text{ ohms,}$$

$$X_{LS} = \frac{[(2)(277)] - [-34.1]}{(2)(2^2 - 1)} = 98 \text{ ohms,}$$

and

$$X_{CS} = \frac{2[277] - [(2)(-34.1)]}{(2)(2^2 - 1)} = 115 \text{ ohms.}$$

$$E_{CP} = \sqrt{(2)(1000)(1500)} = 1732 \text{ volts.}$$

$$E_{CS} = 115\sqrt{\frac{(2)(1000)}{53}} = 706 \text{ volts.}$$

Example 2

Given: Same as *Example 1*, except that the line has a characteristic impedance of 75 ohms.

Solution: With f_2 twice f_1, $K = 2$. With Z_0 and $Z_1 = 75$ ohms and $Z_2 = 1500$ ohms, this example falls into the case of $Z_0 = Z_1 < Z_2$. Table I shows that the network of Fig. 6 and its associated formulas are applicable. Substituting numerical values in these formulas, we have:

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* Box 6023, Kansas City 4, Mo.

TABLE I

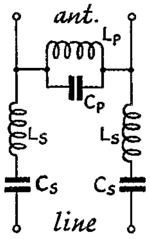
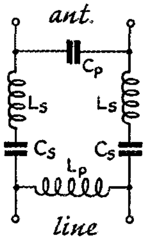
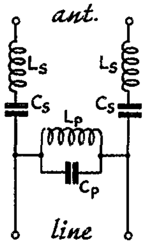
GENERAL CASE	NETWORK SCHEMATIC	CIRCUIT-ELEMENT REACTANCE AT f_1		UNMODULATED PEAK CAPACITOR VOLTAGES	
		PARALLEL	SERIES	ACROSS C_P	ACROSS C_S
$Z_o < Z_1$ *and* Z_2	 FIG. 5	$X_{LP}=\frac{X_{P1}(K^2-1)}{K\left(K-\frac{X_{P1}}{X_{P2}}\right)}\,\Omega \quad X_{CP}=\frac{X_{P2}(K^2-1)}{\frac{X_{P2}}{X_{P1}}-K}\,\Omega$ where $X_{P1}=Z_1\sqrt{\frac{Z_o}{Z_1-Z_o}}$ *and* $X_{P2}=-Z_2\sqrt{\frac{Z_o}{Z_2-Z_o}}$	$X_{LS}=\frac{KX_{B2}-X_{B1}}{2(K^2-1)}\,\Omega \quad X_{CS}=K\frac{X_{B2}-KX_{B1}}{2(K^2-1)}\,\Omega$ where $X_{B1}=-Z_o\sqrt{\frac{Z_1}{Z_o}-1}$ *and* $X_{B2}=Z_o\sqrt{\frac{Z_2}{Z_o}-1}$	$E_{CP}=\sqrt{2W(d.p.i.)}$ Use the larger of Z_1 and Z_2 for d.p.i.	$E_{CS}=X_{CS}\sqrt{\frac{2W}{Z_o}}$
$Z_1 < Z_o < Z_2$ $Z_o = Z_1 < Z_2$ $Z_1 < Z_o = Z_2$	 FIG. 6	$X_{LP}=Z_o\sqrt{\frac{K^2Z_2-\frac{Z_1}{K^2}}{K^2Z_2\left(\frac{Z_o}{Z_1}-1\right)+Z_1\left(1-\frac{Z_o}{Z_2}\right)}}\,\Omega$ and $X_{CP}=K\sqrt{Z_1Z_2\,\frac{K^2Z_2-\frac{Z_1}{K^2}}{K^2Z_1\left(\frac{Z_2}{Z_o}-1\right)+Z_2\left(1-\frac{Z_1}{Z_o}\right)}}\,\Omega$	$X_{LS}=\frac{KX_{B2}-X_{B1}}{2(K^2-1)}\,\Omega \quad X_{CS}=K\frac{X_{B2}-KX_{B1}}{2(K^2-1)}\,\Omega$ where $X_{B1}=\frac{X_{CP}}{1+\left(\frac{X_{CP}}{Z_1}\right)^2}-\frac{X_{LP}}{1+\left(\frac{X_{LP}}{Z_o}\right)^2}$ and $X_{B2}=\frac{KX_{CP}}{K^2+\left(\frac{X_{CP}}{Z_2}\right)^2}-\frac{KX_{LP}}{1+\left(\frac{KX_{LP}}{Z_o}\right)^2}$	$E_{CP}=\sqrt{2WZ_2}$	$E_{CS}=X_{CS}\frac{\sqrt{2WZ_o}}{Z_o\cos\phi}$ where $\tan\phi=\frac{Z_o}{X_{LP}}$
Z_1 *and* $Z_2 < Z_o$	 FIG. 7	$X_{LP}=\frac{X_{P1}(K^2-1)}{K\left(K-\frac{X_{P1}}{X_{P2}}\right)}\,\Omega \quad X_{CP}=\frac{X_{P2}(K^2-1)}{\frac{X_{P2}}{X_{P1}}-K}\,\Omega$ where $X_{P1}=Z_o\sqrt{\frac{Z_1}{Z_o-Z_1}}$ and $X_{P2}=-Z_o\sqrt{\frac{Z_2}{Z_o-Z_2}}$	$X_{LS}=\frac{KX_{B2}-X_{B1}}{2(K^2-1)}\,\Omega \quad X_{CS}=K\frac{X_{B2}-KX_{B1}}{2(K^2-1)}\,\Omega$ where $X_{B1}=-Z_1\sqrt{\frac{Z_o}{Z_1}-1}$ and $X_{B2}=Z_2\sqrt{\frac{Z_o}{Z_2}-1}$	$E_{CP}=\sqrt{2WZ_o}$	$E_{CS}=X_{CS}\sqrt{\frac{2W}{Z_1}}$ or $E_{CS}=X_{CS}\sqrt{\frac{2W}{K^2Z_2}}$ whichever is larger

TABLE II

Circuit-element inductance and capacitance for two-band networks for 3.5 and 7 Mc., 7 and 14 Mc., or 14 and 28 Mc., with an antenna having driving-point impedances of 75 and 1500 ohms at f_1 and f_2 respectively, using a 53-, 75- or 300-ohm transmission line.

Line Zo	*General Case*	*Schematic Diagram*	*Operating Frequencies*											
			3.5 and 7 Mc.				*7 and 14 Mc.*				*14 and 28 Mc.*			
			L_P	L_S	C_P	C_S	L_P	L_S	C_P	C_S	L_P	L_S	C_P	C_S
53Ω (Example 1)	$Z_0 < Z_1 \& Z_2$	Fig. 5	3.29 μh.	4.46 μh.	236 μμfd.	396 μμfd.	1.65 μh.	2.23 μh.	118 μμfd.	198 μμfd.	0.823 μh.	1.11 μh.	53.9 μμfd.	98.9 μμfd.
75Ω (Example 2)	$Z_0 = Z_1 < Z_2$	Fig. 6	31.2 μh.	4.86 μh.	66.2 μμfd.	425 μμfd.	15.6 μh.	2.43 μh.	33.1 μμfd.	212 μμfd.	7.82 μh.	1.22 μh.	16.5 μμfd.	106 μμfd.
300Ω (Example 3)	$Z_1 < Z_0 < Z_2$	Fig. 6	7.87 μh.	5.91 μh.	42.3 μμfd.	236 μμfd.	3.93 μh.	2.96 μh.	21.2 μμfd.	118 μμfd.	1.97 μh.	1.48 μh.	10.6 μμfd.	58.5 μμfd.

$$X_{LP} = 75\sqrt{\frac{\left[(2^2)(1500)\right] - \left[\frac{75}{2^2}\right]}{\left[(2^2)(1500)\left(\frac{75}{75} - 1\right)\right] + \left[75\left(1 - \frac{75}{1500}\right)\right]}} = 687 \text{ ohms.}$$

$$X_{CP} = 2\sqrt{(75)(1500)\frac{\left[(2^2)(1500)\right] - \left[\frac{75}{2^2}\right]}{\left[(2^2)(75)\left(\frac{1500}{75} - 1\right)\right] + \left[1500\left(1 - \frac{75}{75}\right)\right]}} = 687 \text{ ohms.}$$

Since

$$X_{B1} = \frac{687}{1 + \left(\frac{687}{75}\right)^2} - \frac{687}{1 + \left(\frac{687}{75}\right)^2} = 0,$$

and

$$X_{B2} = \frac{(2)(687)}{(2^2) + \left(\frac{687}{1500}\right)^2} - \frac{(2)(687)}{1 + \left[\frac{(2)(687)}{75}\right]^2}$$

$$= 322 \text{ ohms,}$$

$$X_{LS} = \frac{[(2)(322)] - [0]}{(2)(2^2 - 1)} = 107 \text{ ohms}$$

and

$$X_{CS} = 2\frac{[322] - [(2)(0)]}{(2)(2^2 - 1)} = 107 \text{ ohms.}$$

$$E_{CP} = \sqrt{(2)(1000)(1500)} = 1732 \text{ volts.}$$

$$\tan\phi = \frac{75}{687} = 0.109.$$

From trigonometry tables,

$$\phi = 6.25° \text{ and } \cos\phi = 0.9941.$$

Then,

$$E_{CS} = 107\frac{\sqrt{(2)(1000)(75)}}{(75)(0.9941)} = 556 \text{ volts.}$$

Example 3

Given: Same as *Example 1*, except that the line has a characteristic impedance of 300 ohms.

Solution: As in the other two examples, $K = 2$. With $Z_0 = 300$, $Z_1 = 75$ and $Z_2 = 1500$ ohms, this example falls into the general class of $Z_1 < Z_0 < Z_2$. Table I shows that the network of Fig. 6 and its associated formulas are suitable. Assigning numerical values to the formulas:

$$X_{LP}=300\sqrt{\frac{\left[(2^2)(1500)\right]-\left[\frac{75}{2^2}\right]}{\left[(2^2)(1500)\left(\frac{300}{75}-1\right)\right]+\left[75\left(1-\frac{300}{1500}\right)\right]}}=173\text{ ohms.}$$

$$X_{CP}=2\sqrt{(75)(1500)\frac{[(2^2)(1500)]-\left[\frac{75}{2^2}\right]}{\left[(2^2)(75)\left(\frac{1500}{300}-1\right)\right]+\left[(1500)\left(1-\frac{75}{300}\right)\right]}}=1075\text{ ohms.}$$

TABLE III

L μh.	*Coil Form — Number of Turns***								
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*
0.823	5	3	6	10	6	6	3	3	3
1.11	7	3	7	12	8	7	3	3	4
1.22	7	3	8	13	9	7	4	3	4
1.48	8	4	9	14	9	8	4	4	4
1.65	8	5	9	15	10	9	5	4	5
1.97	9	5	10	16	11	9	5	4	5
2.23	9	5	10	17	11	10	6	5	6
2.43	10	5	11	18	12	11	6	5	6
2.96	11	6	12	20	13	12	7	6	7
3.29	12	7	12	20	14	12	8	6	8
3.93	12	8	14	23	15	13	8	7	8
4.46	13	7	15	24	16	14	9	8	9
4.86	14	9	15	25	17	15	9	8	9
5.91	15	10	17	27	19	16	11	10	11
7.82	18	12	19	32	21	19	13	12	14
7.87	18	12	19	32	21	19	13	12	14
15.6	25	21	27	44	30	26	22	18	22
31.2	35	*15	39	64	42	38	41	33	40

A — 1½ inches diameter, 1½ inches long.
B — 2½ inches diameter, 7 turns per inch (National XR10A form).
C — 1¾ inches diameter, 2¾ inches long (National XR13 form).
D — 1 inch diameter, 2¾ inches long (National XR13A form).
E — 1¼ inches diameter, 1¾ inches long (National XR16 form).
F — 1⅞ inches diameter, 3 inches long (Millen 44000 form).
G — 2½ inches diameter, 6 turns per inch (B & W 3905).
H — 2½ inches diameter, 8 turns per inch (B & W 3906).
I — 2 inches diameter, 10 turns per inch (B & W 3907).
* 5 inches diameter, 8 turns per inch (National XR14A form).
** To nearest turn.

Since

$$X_{B1}=\frac{1075}{1+\left(\frac{1075}{75}\right)^2}-\frac{173}{1+\left(\frac{173}{300}\right)}=-125\text{ ohms}$$

and

$$X_{B2}=\frac{(2)(1075)}{2^2+\left(\frac{1075}{1500}\right)^2}-\frac{(2)(173)}{1+\left[\frac{(2)(173)}{300}\right]^2}=328\text{ ohms,}$$

$$X_{LS}=\frac{[(2)(328)]-[-125]}{(2)(2^2-1)}=130\text{ ohms,}$$

and

$$X_{CS}=2\frac{[328]-[(2)(-125)]}{(2)(2^2-1)}=193\text{ ohms.}$$

$$E_{CP}=\sqrt{(2)(1000)(1500)}=1732\text{ volts.}$$

$$\tan\phi=\frac{300}{173}=1.73.$$

From trigonometry tables, $\phi = 60°$ and $\cos\phi = 0.5$.

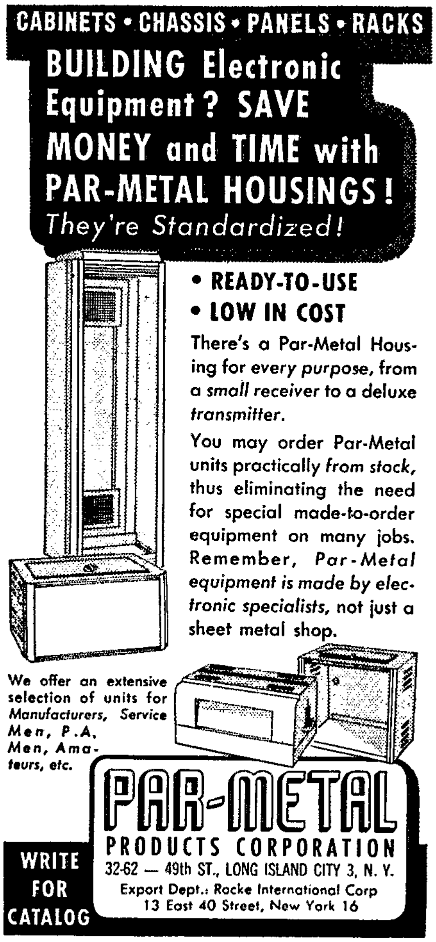
Then,

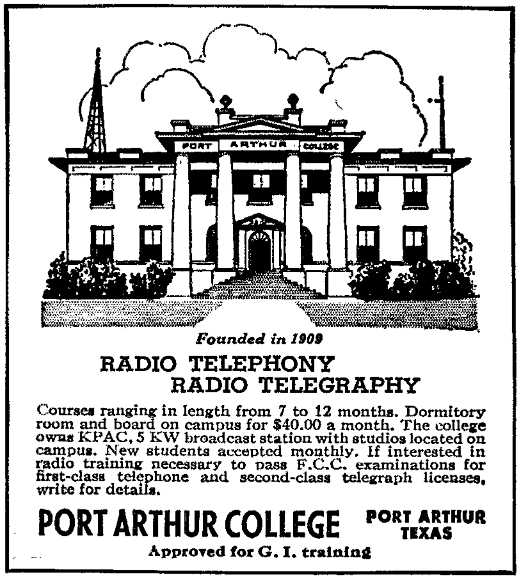
$$E_{CS}=193\frac{\sqrt{(2)(1000)(300)}}{(300)(0.5)}=996\text{ volts.}$$

The reactance values computed in these three examples are valid at the f_1 frequency of any pair of operating frequencies providing that $K = 2$. They could have been worked out for other values of K, of course. However, in such a case, Z_2 might be considerably different from 1500 ohms. Converting the values of reactance shown to inductance and capacitance at 3.5 Mc. permits two-band operation at 3.5 and 7 Mc. Converting them at 7 Mc. provides for operation at 7 and 14 Mc., etc.

Table II shows the values of inductance and capacitance (ordinary slide-rule accuracy) of the network elements in these three examples, for operation at 3.5 and 7 Mc., 7 and 14 Mc., and 14

(*Continued on page 90*)





Hints & Kinks

(*Continued from page 33*)

simply. The filament pins, which extend out of the base of the tube, are just the right size and spacing to fit snugly in a crystal socket designed for the new small crystal holders (½-inch spacing, 0.125-inch diameter pins). For grid and plate "caps" the pins can be removed from an Amphenol type 54 miniature socket and slipped over the pins of the tube. — *Tom McMullen, W1QVF*

Antenna-Matching Networks

(*Continued from page 39*)

and 28 Mc. D.p.i. values of 75 and 1500 ohms are assumed for f_1 and f_2 respectively. These values correspond closely to those of a simple center-fed antenna operating at its fundamental and second-harmonic frequencies. While actual practical values may depart somewhat, the values shown are likely to be close enough for all practical purposes, unless an extremely-low s.w.r. is demanded.

Table III shows several coil dimensions for each of the inductance values given in Table II. These dimensions were chosen to fit various standard coil forms or manufactured strip coils. They are given to the nearest full turn.

How's DX

(*Continued from page 43*)

fire is CN8ET, manned by W3KZQ. Walt used to be prewar KB6RSJ, you know, and is enjoying the pleasures of a U. S.-oriented umpty-hundred-foot Vee array .–.–.– No sooner do we mention W4MR's 7-Mc. ground-plane than he takes it down again due to its adverse effect on the 20-meter beam. Al gives an account of N. C. DX activity in noting that W4GQU quit 20 c.w. for 10 'phone after confirming 101, W4AIT has a new AC4-working 3-element beam, and W4GG keeps his 250-TL almost exclusively on 20 aided and abetted by a couple of stacked collinears .–.–.– VP5BF has swapped his 15-watt 807 Tri-tet oscillator for a 6V6-807 60-watter, according to W4LVV. Ken is contemplating giving the Caicos a good representation on 20, 40 and 80 this season after working all call areas but W7 with the QRP effort .–.–.– Adding a Guantanamo note, KG4AG keeps schedules with his dad, W9ZMK, of Rock Island, Ill. W9AND learns that VP1WS is rather

Aurelio Flores of CX6AD is one of the more active Uruguayan fellows on 14-Mc. c.w. (*Photo courtesy W0UOX*)

(*Continued on page 92*)