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Multiband Tuning Circuits

Some Considerations in the Design of Single-Ended Networks

BY R. W. JOHNSON,* W6MUR

• In recent months, we have been hearing more and more about multiband tuning circuits — circuits that cover 3.5 Mc. to 30 Mc., for instance, without switching or changing coils. This article covers the design of the single-ended type, and considers some possible variations from the popular version of the circuit.

A MULTIBAND tuning circuit was introduced by King [1] of the National Company in 1948. The circuit has been used in a recent transmitter by Chambers,[2] and is commercially available as the National Company Type MB-150 and MB-40L. There appears to have been only scant design data [3] presented on this circuit, to permit the average amateur to design his own circuit. There also has been overlooked a possible modification of the circuit using but one tapped coil instead of the two coils usually used. In this article, both of these subjects will be discussed.

Circuit Description

The basic circuit of King is shown in Fig. 1, in single-ended form. Equal capacitors are used

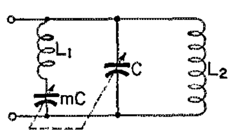

Fig. 1 — Basic circuit of a single-ended multiband tuner.

in the National circuits, but we will not restrict this discussion to equal capacitors. The capacitors are ganged together, and the coils (in the simplest case) have no mutual inductance between them. This circuit, properly designed, is capable of tuning ratios equal to the capacity ratio (C_{max}/C_{min}) instead of the square root of this capacity ratio as in ordinary circuits. Thus a continuous 8:1 or 9:1 frequency range is possible with this circuit, without coil switching.

Calibration

There are simultaneously always two parallel-resonant frequencies for the circuit of Fig. 1, as well as one series-resonant frequency. The two parallel-resonant frequencies may or may not be harmonically related, depending on design. The series-resonant frequency always lies between the parallel-resonant frequencies, and can even be used to advantage in suppression of certain harmonics.

If f_o is defined as the resonant frequency of L_2C taken alone, then the parallel-resonant frequencies of the total circuit are

$$f_{r_1} = K_1 f_o \qquad (1)$$

and

$$f_{r_2} = K_2 f_o \qquad (2)$$

where K_1 and K_2 are constant for all settings of C, and depend on L_1, L_2 and m of Fig. 1. If, as C is tuned through its range, f_o changes from f_{o_1} (the lowest frequency) to f_{o_2} (the highest frequency), frequencies f_{r_1} and f_{r_2} change from $K_1 f_{o_1}$ to $K_1 f_{o_2}$, and from $K_2 f_{o_1}$ to $K_2 f_{o_2}$, respectively. This situation is depicted in Fig. 2 on a frequency scale (not tuning scale). The two bands occupy the same positions on the capacitor tuning dial even though they are separated in frequency.

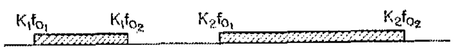

Fig. 2 — Frequency-scale representation of tuning range.

Since K_1 and K_2 depend only on L_1, L_2 and m of Fig. 1, they can be chosen arbitrarily, within limits. K_1 is a number less than unity, and K_2 is a number greater than unity, for realizable cases. The ratio K_2/K_1 can be almost anything desired, which means that the two bands of Fig. 2 can (a) overlap, (b) be adjacent, or (c) be separated, on the frequency scale. The maximum possible *continuous* (all frequencies covered) tuning range occurs in case (b), or when $K_1 f_{o_2} = K_2 f_{o_1}$, or $K_2/K_1 = f_{o_2}/f_{o_1}$. The tuning ratio for this case is $K_2 f_{o_2}/K_1 f_{o_1} = (f_{o_2}/f_{o_1})^2 = C_{max}/C_{min}$.

Selection of parameters is thus determined by the desired tuning ratios, or in other words, by K_2 and K_1. The design must be such that K_2/K_1 is about midway between integers, if harmonic response is to be minimized. We therefore need the relation between the Ks and the circuit parameters.

Relation for K

Input admittance of the circuit of Fig. 1 can be written in the usual fashion and set equal to zero. A fourth-degree quadratic frequency equation results, giving the parallel-resonant fre-

* % The Ralph Parsons Company, Pasadena 8, Calif.

[1] King, "No Turrets — Just Tune!" *QST*, March, 1948.

[2] Chambers, "Three-Control Six-Band 813 Transmitter," *QST*, Jan., 1954.

[3] DiMarco, "Circuitos de Resonancia Multiple y Su Apicacion en los transmisiores para Aficionades," *Revista Telgrafica Electronica* (Argentina), March, 1954.

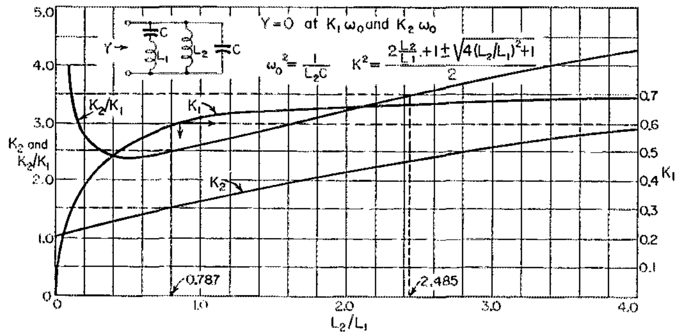

Fig. 3 — Curves of K_2, K_1, and the ratio K_2/K_1 *vs.* L_2/L_1, for equal capacitors ($m = 1$).

quencies (and hence K) when solved. The relation for K is

$$\left.\begin{aligned} K_1^2 &= \frac{S - \sqrt{S^2 - 4\dfrac{L_2}{mL_1}}}{2} = (f_{r_1}/f_o)^2 \\ K_2^2 &= \frac{S + \sqrt{S^2 - 4\dfrac{L_2}{mL_1}}}{2} = (f_{r_2}/f_o)^2, \end{aligned}\right\} \quad (3)$$

where $S = \frac{L_2}{L_1}\frac{1+m}{m} + 1$, and $f_o = \frac{1}{2\pi\sqrt{L_2C}}$

Since L_2/L_1 is usually desired when given m and K, *Eq.* (3) can be rearranged to give this result. Thus,

$$L_2/L_1 = mK^2\,\frac{K^2 - 1}{(1+m)K^2 - 1} \quad (4)$$

which is valid for either K_1 or K_2. For the usual case of equal capacitors, $m = 1$ and *Eqs.* (3) and (4) become

$$K^2 = \frac{2L_2/L_1 + 1 \pm \sqrt{4(L_2/L_1)^2 + 1}}{2} \quad (3a)$$

and

$$L_2/L_1 = K^2\left(\frac{K^2 - 1}{2K^2 - 1}\right) \quad (4a)$$

In *Eq.* (3a), the plus signs is used in solving for K_2 and the minus sign for K_1.

Curves of K_2, K_1 and the ratio K_2/K_1 *vs.* L_2/L_1 are shown in Figs. 3 and 4. Fig. 3 is for equal capacitors ($m = 1$), and Fig. 4 is for $m = 0.5$. Preferred operating points, to avoid harmonic responses, are shown on the curves.

If unequal but ganged capacitors are used, then $m \neq 1$. As can be seen from Fig. 4, the preferred operating point, $K_2/K_1 = 2.5$, falls at $L_2/L_1 = 1.06$ when $m = 0.5$. Thus, if it is more convenient to use identical coils for L_1 and L_2, m can be chosen accordingly. The value $m = 0.789$ gives $L_1 = L_2$ and $K_2/K_1 = 2.5$.

Example

As a design example, suppose we desire to tune all amateur bands in the range 3.5–21.5 Mc. Assume that equal ganged capacitors are used, and that the available capacitor ratio is at least 6.25:1 (corresponding to, say, 150 $\mu\mu$f. maximum and 24 $\mu\mu$f. minimum). If we want continuous frequency scale coverage, we would choose $K_2/K_1 = (6.25)^{1/2} = 2.5$. This value is a preferred operating point in Fig. 3, at which $L_2/L_1 = 0.8$, $K_2 = 1.5$ and $K_1 = 0.6$. The lowest desired frequency, 3.5 Mc., is $K_1 f_{o_1}$, so that f_{o_1} (the resonant frequency of L_2C_{max} is 3.5/0.6 = 5.83 Mc. For a given capacitor, coil L_2 is determined from this frequency of 5.83 Mc. Coil $L_1 = L_2/0.8 = 1.25L_2$. At minimum capacity, the resonant frequency of L_2, C_{min} is $5.83 \times 2.5 = 14.6$ Mc. Thus, the two bands A and B of Fig. 2 extend from $0.6 \times 5.83 = 3.5$ Mc. to $0.6 \times 14.6 = 8.75$ Mc., and from $1.5 \times 5.83 = 8.75$ Mc. to $1.5 \times 14.6 = 21.9$ Mc. These two bands are of course coincident across the dial, and are covered simultaneously in 180° of capacitor rotation.

Coupled Impedance

Output coupling can be to coil L_2 only. In this case, parallel-resonant impedance is about K^2 times what it would be for a normal L_2C circuit. This means that in the lowest band, where K_1 (< 1) is used, capacitor C can be smaller than that which would otherwise be

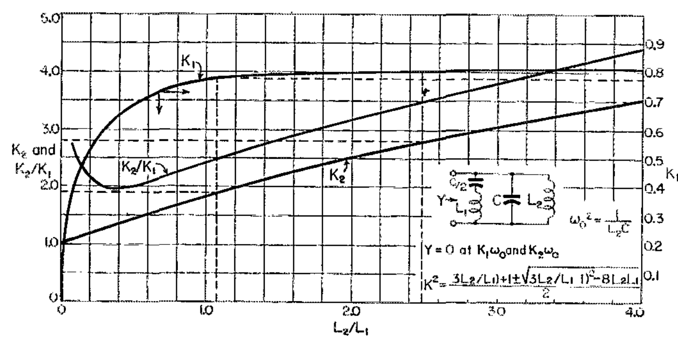

Fig. 4 — Curves of K_2, K_1, and the ratio K_2/K_1 *vs.* L_2L_1 for $m = 0.5$.

necessary; and in the higher band, where K_2 (> 1) is used, C can be larger than would otherwise be necessary. L/C ratio and ease of coupling thus tend to remain more constant with this circuit than with an ordinary resonant circuit. This was pointed out by King.[1]

Coupled Coils

The general case, where mutual inductance exists between L_2 and L_1, has been worked out, but the results will not be presented here, except for one special case that is extremely useful. This case is that of a center-tapped coil, connected as shown in Fig. 5 with a split-stator capacitor C.

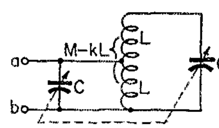

Fig. 5 — Multiband-tuner circuit using a center-tapped coil.

Connection to the tank circuit is made at terminals a and b in Fig. 5. The impedance between a and b is parallel-resonant at $K_1 f_o$ and $K_2 f_o$ as before, where K is now given by the relations

$$K_1^2 = \frac{3 + 2k - \sqrt{(3 + 2k)^2 - 4(1 - k^2)}}{2(1 - k^2)}, \quad (5)$$

$$\text{and } K_2^2 = \frac{3 + 2k + \sqrt{(3 + 2k)^2 - 4(1 - k^2)}}{2(1 - k^2)},$$

where k is the coupling coefficient between the two halves of the coil. (k is negative for this case, but this has already been considerated in *Eq.* (5), to avoid errors in using the relations.) Frequency f_o for use with *Eq.* (5) is given by

$$f_o = \frac{1}{2\pi\sqrt{LC}},$$

and is the resonant frequency of half the total coil taken alone with C. A curve of *Eq.* (5), showing K_1, K_2 and K_2/K_1 *vs.* coupling coefficient k is shown in Fig. 6. Preferred operating points, to avoid harmonic response, are also indicated in Fig. 6.

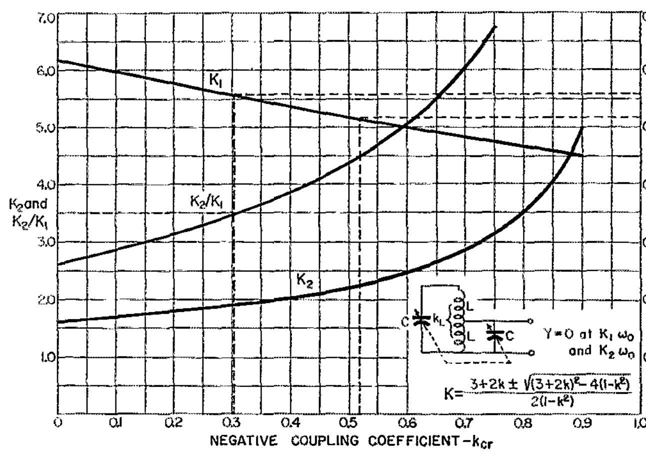

Fig. 6 — Curve of *Eq.* (4), showing K_1, K_2, and K_2/K_1 *vs.* coupling coefficient k.

Estimation of Coupling Coefficient

To use the curves of Fig. 6 or the relations of *Eq.* (5), a relation between coupling coefficient and coil dimensions is needed. Fortunately, this relation is not complex for a center-tapped coil. As shown in Fig. 7, a center-tapped coil can be replaced by a T equivalent. Looking into terminals *a-b* or *b-c* we see merely L, but looking into terminals *a-c* we see $2L(1 + k)$. One can apply the Wheeler formula[4] for the inductance of a single-layer solenoid that is not too short (length at least equal to 0.8 times diameter) to solve for coupling coefficient k. This is done by first calculating the inductance between *a-b* (or *b-c*) for a coil of half the total length and half the total turns, and then the inductance between *a-c* for a coil of the total length and total turns. These two relations when solved simultaneously give coupling coefficient as

$$k = \frac{9}{9 + 20(l/d)} \quad (6)$$

where k is of the correct sign for substitution into *Eq.* (5). (l/d) is the ratio of length to diameter of the coil, in the same units of measurement. *Eq.* (6) holds only for values of (l/d) of about 0.8 or greater. A curve of k *vs.* (l/d) is shown in Fig. 8. The portion much below $(l/d) = 0.8$ has been obtained by another more exact inductance formula, but with the same approach.

Example

Suppose we wish to cover the range 3.5–30 Mc., such as to tune all amateur bands. For a given capacitor and capacitor tuning ratio, what must be the size and proportions of a single, center-tapped inductance?

We first observe that the total tuning ratio is

[4] Terman, *Radio Engineer's Handbook*, 1st ed., 1943, McGraw-Hill, p. 55.

30/3.5 = 8.58. If we were to insist on continuous frequency scale coverage of the entire range, ratio K_2/K_1 must be $(8.58)^{1/2} = 2.93$. This is dangerously close to 3, so that third harmonic response would be appreciable if this ratio were used. We therefore choose the nearest value of K_2/K_1 that is a preferred operating point, or $K_2/K_1 = 3.5$, realizing that in so doing we must allow a gap to exist in the frequency coverage, if we must still tune 3.5–30 Mc. (Continuous coverage with $K_2/K_1 = 3.5$ requires a capacity tuning ratio of $(3.5)^2 = 12.25$, which is impracticably high.)

From Fig. 6 at $K_2/K_1 = 3.5$, we find $K_2 = 1.92$, $K_1 = 0.55$ and $k = 0.3$. From Fig. 7 at $k = 0.3$ we find l/d of the coil to be 1.05. Arbitrarily setting the lower band limit at 3.4 Mc. to insure coverage at 3.5 Mc., resonant frequency f_{o_1} is $3.4/K_1 = 3.4/0.55 = 6.19$ Mc. With a capacitor tuning ratio of 9:1, $f_{o_2} = 3 \times 6.19 = 18.55$ Mc. Thus the two bands are

$6.19 \times 0.55 = 3.4$ Mc. to $1855 \times 0.55 = 10.2$ Mc., and

$6.19 \times 1.92 = 11.9$ Mc. to $18.55 \times 1.92 = 35.6$ Mc.

No coverage is obtained between 10.2 Mc. and 11.9 Mc., but this is unimportant for amateur applications.

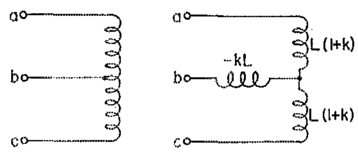

Fig. 7 — T equivalent of a center-tapped coil.

The design is therefore complete. One selects a coil such that *one half of the coil* has a length-to-diameter ratio of 0.525, and for a given maximum value of capacitor C, finds the number of turns this half-coil must have to resonate at 6.19 Mc. The final coil has just twice the number of turns and twice the length of the half-coil. The capacitor must be at least 9 times the minimum value expected, which minimum includes strays and tube capacitances. Thus a capacitor of maximum value about 200 $\mu\mu$f. per section is necessary if a 9:1 capacity tuning ratio is required.

The circuit can be tested by first tuning only half of the coil by C, with the remainder of the circuit disconnected. A grid-dip meter can be used to indicate resonance in the usual way. Connecting the remainder of the circuit as in Fig. 5, a grid-dip meter coupled to the coil will show the desired resonance points. Depending on coupling to the grid-dip meter, *three* dips may be noted as the grid-dip meter is tuned, for any setting of C. These will be at a low, medium and high frequency. The one at medium frequency may be disregarded: it is the series-resonant frequency of the circuit. Only the lowest and highest dip need be considered, and these should be close to the calculated values.

Experimental Verification

A Barker & Williamson Type 3015 coil (1-inch diameter, 16 turns per inch) was used in a test circuit. The coil used had 34 turns total, and was center-tapped and connected with ganged 150-$\mu\mu$f. capacitors in the circuit of Fig. 5. Resonant frequencies were measured with a grid-dip meter, using the calibration of the meter (which is not highly accurate). The following results were obtained:

	Measured	*Calculated*
Band A	3.45 — 11.4 Mc.	3.41 — 11.15 Mc.
Band B	10.4 — 35.9 Mc.	10.4 — 34.0 Mc.

Summary

This article has given essential design relations for the two-coil and center-tapped single-coil cases of wide-range tuning circuits. Application of these circuits, especially the latter (Fig. 5), to transmitters can result in much more compact equipment than has been possible with band-switching circuits, with resultant saving in cost, complexity and efficiency.

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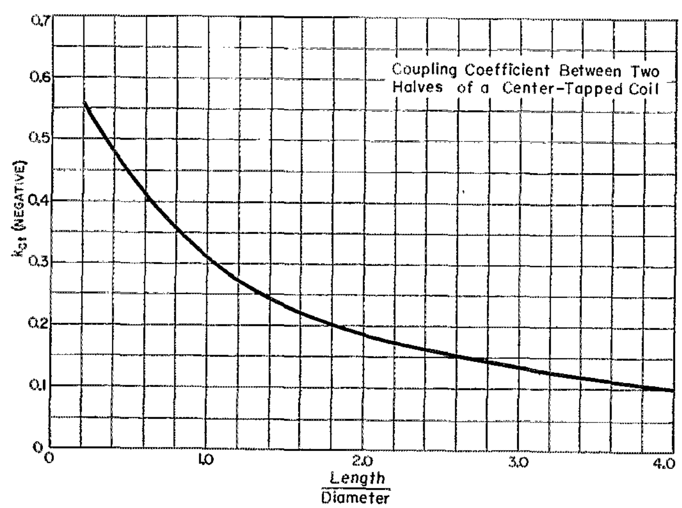

Fig. 8 — Curve of *k* vs. *l/d* for center-tapped coil.

Multiband Tuning Circuits

(*Continued from page 28*)

It is also felt that these circuits can be applied to receivers, when it is *desired* to have simultaneous coverage of two bands. Using a harmonic relation (such as 2.0) for ratio K_2/K_1, one can have r.f. circuits (and hence a receiver) with eventually simultaneous coverage of two bands. Such a receiver has some obvious applications for contest work where one may operate on two bands at once or in close sequence. Tuning rates are in the ratio K_2/K_1 (in this case 2, 3 or 4), so identification of signals as to band is possible.

This article has not been intended to cover other important factors, such as resonant impedance under various coupling situations, bandwidth, loaded Q, etc. Further experimental work will undoubtedly bring forth improvements and further modifications of the circuit, as well as actual data on factors omitted from this article.

Never-Never Land

(*Continued from page 30*)

ably to the mechanical strength of the chassis.

It is easy to get into trouble in the circuit layout if you have one tube performing too many jobs, or if you use regeneration or other shortcuts in the hope of getting good performance with too few tubes. The best way is to use plenty of stages at low gain and separate tubes for each job. The usual precautions about short grid and plate leads have to be taken also, and the old rule about keeping an i.f. amplifier strip (for any one frequency) in a straight line is a good one. If you put the power supply, last audio stage and speaker in a separate cabinet, you will keep your receiver cabinet cool and away from the mechanical vibrations of the speaker.

Dials

Don't overlook the importance of a good dial mechanism. You can build your own by using one of the popular planetary-drive units and making a dial bezel of thin metal or plastic. A dial scale can be made of cardboard, with dial lights added for a de luxe job. This type of dial allows a half-circle scale length.

If you have some gears from surplus equipment, you can make a dial that will go around about 330 degrees while the condenser rotates 180 degrees. Naturally, such a dial will give nearly twice the scale length of the half circle. An example is shown in Figs. 3 and 6.

Remember to keep the dial simple. A direct-reading single dial is easier to read than a two-dial system or one that requires interpolation. There are many types — slide rule, drum, semicircle and others — but the one that gives the most dial length in a given space is the circular dial. Above all, the most important thing is to have a dial with plenty of bandspread and no backlash.

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