

CARR'S CORNER

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Joseph J. Carr K4IPV
P.O. Box 1099
Falls Church VA 22041

Selecting Variable Capacitors, Part II

Last month we introduced the topic of variable capacitors by showing two different types: straight line frequency and straight line capacitance. We examined their different styles of construction. We also looked at two-section capacitors and how they are used to tune doubly-tuned RF circuits and the RF/LO circuits of superheterodyne radio receivers. In this month's column we will take a look

at transmitting variables, special variables, and some interesting related topics.

Differential and Split-Stator Capacitors

Two special forms of air variable capacitor are the split-stator and the differential. The symbols for these devices are shown in Figure 1. The split-stator (Figure 1A) uses a common set of rotor plates, but two sets of stator plates. In other words, it is similar to a two-section variable, but with a common set of rotor plates rather than two sets. The capacitances of each section of the split-stator

capacitor track each other. Any given change of shaft position causes the same capacitance on both C1A and C1B of Figure 1A. The differential capacitor (Figure 1B) also has a split-stator plate set, but they are configured with respect to the rotor such that the "shading" increases on one as it decreases on the other. Thus, C1A is at maximum capacitance when C1B is at minimum, and vice versa. A 2X-100 pF differential capacitor is shown in Photo A. The rotor is set to mid-range so that you can see clearly the opposed stator plates. As the rotor moves in one direction or the other, it will shade more of one set and less of the other.

Figure 2 shows how split-stator and differential capacitors are used in practical circuits. The circuit of Figure 2A is an antenna tuner for parallel feeder transmission line. The 50 ohm coaxial cable from the transmitter is connected to L2, which is a link coupling to the main inductor L1. This inductor has two taps, one for each wire of the parallel transmission line. In order to tune the inductor, a split-stator capacitor, with the rotor grounded, is connected across the length of L1.

The circuit in Figure 2B is an RF bridge that can be used to measure antenna impedance, or at least the resistive component of antenna impedance. The bridge is balanced when the ratio of the two halves are equal, or when:

$$\frac{X_{C1A}}{X_{C1B}} = R1/Z$$

(where Z is the unknown impedance). Resistor R1 is generally set to the system impedance, typically 50 ohms or 75 ohms. In most amateur radio applications it is permissible to use a 68 ohm resistor for R1 in order to accommodate both 50 ohm and 75 ohm systems with only a small error in each. Resistor R1 must be a non-inductive type, such as carbon composition or metal film. Excitation is provided by a signal generator applied to J1.

Large Variables and Transmitting Variables

Photo B shows a large air variable capacitor that was salvaged from an old radio receiver. It is designed to provide 10 to 365 pF of capacitance in each section. In superheterodyne radio receivers, this capacitor would be connected such that one section tunes the RF amplifier input, the second section tunes the RF amplifier output (or, if no RF amplifier is used, the sections would tune a doubly-tuned LC resonant tank circuit), and the third section (with padder capacitor) would tune the local oscillator. If you go back far enough, when "tuned radio frequency" (TRF) receivers were the order of the day, all three sections were used to tune the RF amplifiers (and there was no LO in those receivers).

Other applications for capacitors such as the one pictured in Photo B are found where all three sections are connected in parallel. For example, the loading control of pi-network output tank circuits (used in vacuum tube final RF amplifiers in transmitters), often require 800-1200 pF of capacitance. The RF voltages are quite low



Photo A. Differential capacitor from author's junk box (some "junk"—the bloody thing's expensive!).

because the output impedance (50 ohms) is low, so it is not necessary to use wide "high voltage" spacing for the loading control (in most cases . . . always calculate for any given power level and allow a margin). Another 3X parallel situation is found in LF and VLF receiving antenna loops where high capacitance is needed. Also, some transmitting loops, as well as many receiving loops, use a single turn input/output loop (depending on point of view, RX or TX) to couple a multi-turn loop antenna to the rig. The multi-turn loop can be resonated with a relatively small capacitance, but the single-turn coupling loop typically wants to see a very high capacitance.

Photo C shows a "transmitting variable" that can be used in high power (2 kW) RF power amplifiers and antenna tuning units. What makes this a "transmitting" variable is the wide spacing between the plates. Wider spacing means that the breakdown voltage of the air insulator between the plates is increased. But wider spacing also reduces capacitance, so the plates tend to be larger and more numerous than in smaller capacitors of the same value.

Perhaps the ultimate in transmitting variables is the vacuum capacitor shown

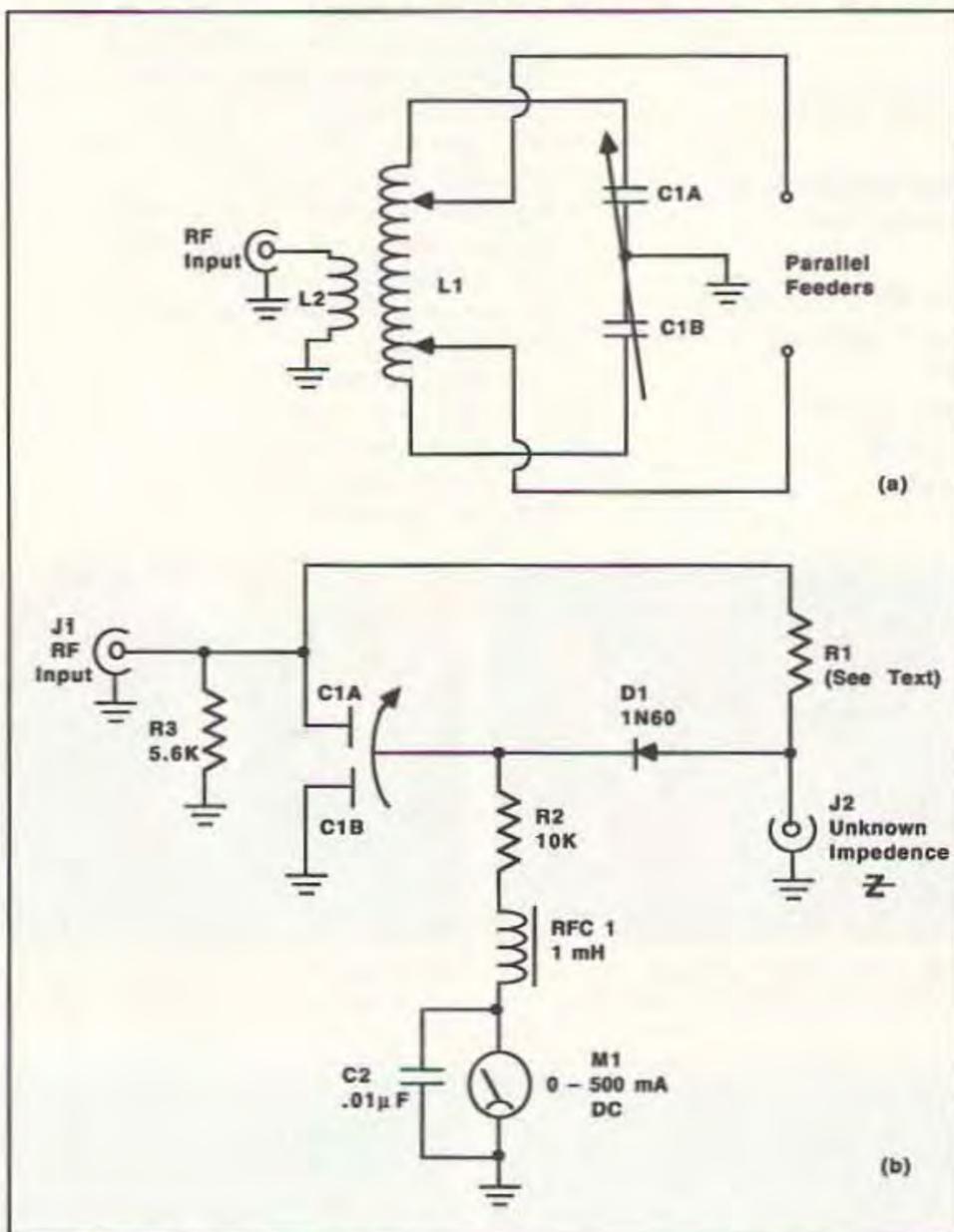


Figure 2. A) ATU circuit using split-stator capacitor; B) Antenna RF bridge using differential capacitor.

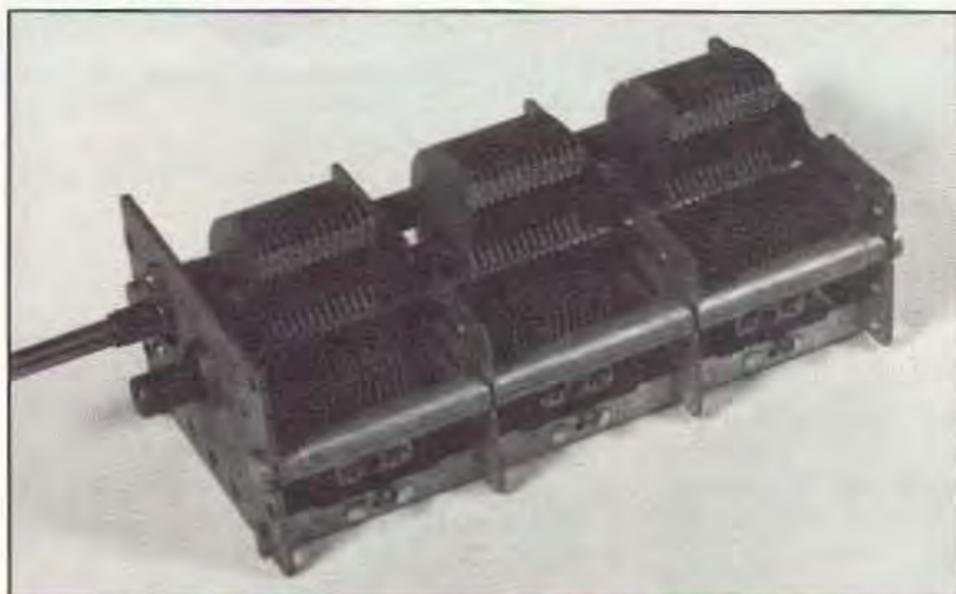


Photo B. Three-section 3X-365 pF variable capacitor.

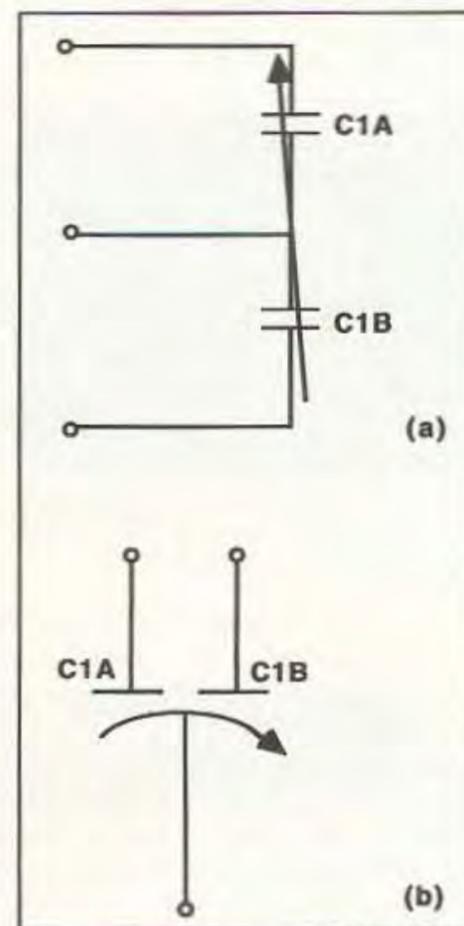


Figure 1. A) Split-stator capacitor symbol; B) Differential capacitor symbol.

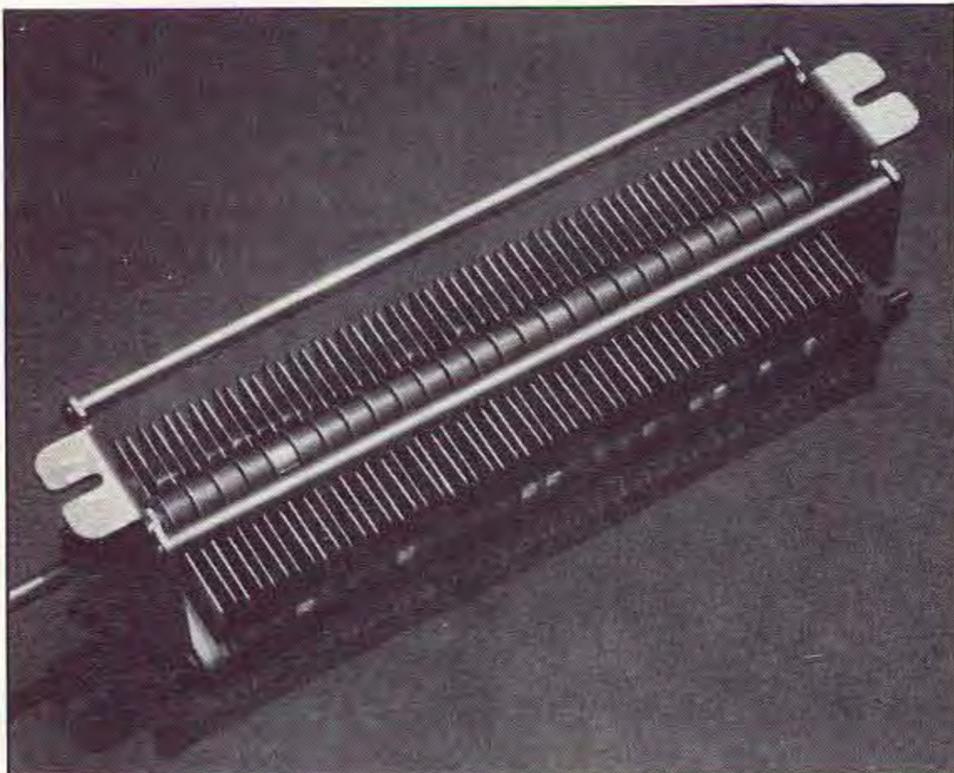


Photo C. Transmitting air variable capacitor.

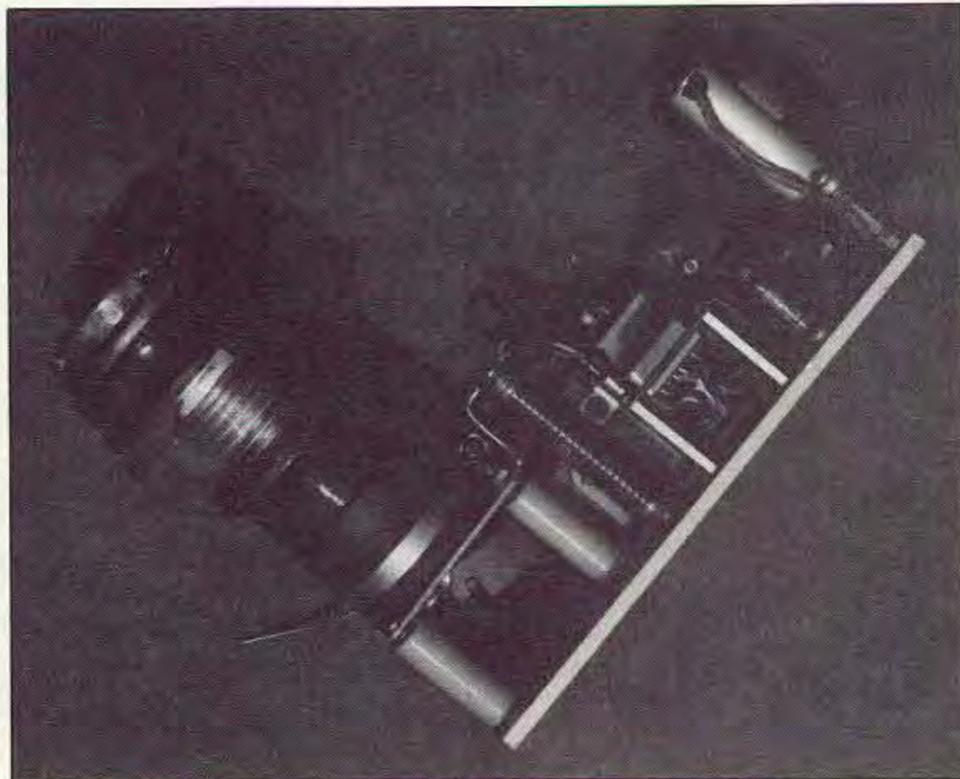


Photo D. Vacuum variable (10-1000 pF) capacitor.

in Photo D. Although vacuum variables tend to be quite high-priced, I bought this 10-1,000 pF unit from Fair Radio Sales (see Table 1) for less than \$40 a couple of years ago. This particular capacitor is fitted with a small DC motor and a reversing relay. The capacitor is tuned by operating the motor, although it appears that removing the motor apparatus would make it possible to directly tune the capacitor.

Calculating the Tank Circuit Component Values

When we design an RF LC tank circuit it is usually for a specified band of frequencies. For example: 3,500 to 4,000 kHz for the 75/80 meter band (we actually want to tune a small overlap, so 3,490 to 4,010 kHz is what we'll use). We need to know what values of inductor and trimmer capacitor to use with specified main tuning capacitors. We first select a trial variable capacitor for the main tuning job. Look in a catalog for the minimum and maximum capacitances. For this example, I selected a Hammarlund MC-100-M from Ocean State Electronics (see Table 1) with a capacitance range of 7.7 to 100 pF. Refer to Figure 3 as you use this procedure:

1. Determine minimum and maximum capacitance of C1 (7.7 - 100 pF).
2. Calculate ΔC : $C1_{\max} - C1_{\min} = 100 \text{ pF} - 7.7 \text{ pF} = 92.3 \text{ pF}$.
3. Determine the required frequency ratio (F.R.):

$$F.R. = \frac{F_{\max}}{F_{\min}} = \frac{4010 \text{ kHz}}{3490 \text{ kHz}} = 1.15$$

4. Calculate the required capacitance ratio (C.R.) by squaring the frequency ratio:

$$C.R. = (F.R.)^2 = (1.15)^2 = 1.32$$

5. Calculate the minimum total capacitance from:

$$C_{\min.} = \frac{\Delta C}{C.R. - 1} = \frac{92.3 \text{ pF}}{1.32 - 1} = 288.4 \text{ pF}$$

6. Calculate the maximum total capacitance:

$$C_{\max} = C_{\min} + \Delta C = 288.4 \text{ pF} + 92.3 \text{ pF} = 380.7 \text{ pF}$$

7. Calculate the inductance by selecting either maximum or minimum capacitance, and the lowest or highest frequency (as indicated by the capacitance value selected). I selected the maximum capacitance (380.7 pF) and minimum frequency (3,490 kHz) combination:

$$L = \frac{10^6}{4\pi^2 F_{\min}^2 C_{\max}} \mu\text{H} = \frac{10^6}{(4\pi^2)(3,490,000\text{Hz})^2 (3.807 \times 10^{-10}\text{F})} = 5.46 \mu\text{H}$$

You can check the calculation with the normal resonance formula (below) to see if the correct frequencies are obtained at the minimum and maximum total capacitance (which correspond to the minimum and maximum values of C1 plus other capacitances in the circuit). The calculations should be accurate to within rounding errors (my calculator showed 3489+

and 4009+ kHz). The resonance equation is:

$$F = \frac{1}{2\pi \sqrt{LC}}$$

Where: F is in hertz, L is in henrys, and C is in farads.

In actual practice you will use a trimmer capacitor (C2 in Figure 3), and possibly a fixed capacitance (C3), to make up the difference between the required capacitance and the values obtained from C1. For example, we need a minimum capacitance of 288.4 pF, but C1 has a minimum of 7.7 pF. Thus, we need a total of 288.4-7.7, or 280.7 pF. The

trimmer should have enough range to account for any tolerance errors in calculation and the values of the parts. I selected a trimmer with a range of 8 to 100 pF, with the idea of setting it approximately in the middle of the range (or about 46 pF \pm a little bit). Thus far, of our required 280.7 pF, we've accounted for 7.7 + 46 pF, or 53.7 pF. We need to find an additional 227 pF. By using a 220 pF fixed capacitor at C3, we leave 7 pF for strays. In some RF circuits this is a reasonable value for strays, and the range of C2 (the "a little bit" part) can make up for errors. In some Colpitts and Clapp oscillators, however, there is a tremendous capacitance contributed by the capacitive voltage divider feedback network, so these calculations are wrong for that case.

Sources of supply for variable capacitors include hamfests (but look out for the "sharks" who have inflated ideas of their capacitor's worth—"a crudded up transmitting variable is not worth anywhere near the high price commanded by a shiny new one . . . at least to me"). Table 1 lists some of the places where I've bought variable capacitors in the recent past. The listing for Maplins in England can be used for Americans . . . they accept Visa and Mastercard. The bank card companies will convert the price from £ to \$. Be a little careful reading the Maplin catalog, by the way . . . cost more than \$ (\$1.52/£ as of this writing), so the actual price is higher than it appears in the listing.

Table 1. Variable Capacitor Suppliers

Barker & Williamson
10 Canal Street
Bristol PA 19007
(215) 788-5581 (voice)
(215) 788-9577 (fax)
Transmitting variables.

Fair Radio Sales
1016 E. Eureka
Box 1105
Lima OH 45802
(419) 227-6573 (voice)
(419) 227-1313 (fax)
Transmitting and receiving variables (mostly surplus).

Ocean State Electronics
P.O. Box 1458
6 Industrial Drive
Westerly RI 02891
(401) 596-3080 (voice)
(401) 596-3590 (fax)
1-800-866-6626 (voice/orders only)
Transmitting and receiving variables (a lot of "new/old" material, i.e. capacitors that are unused, but of older construction).

Oren Elliott Products, Inc.
128 W. Vine St.
P.O. Box 638
Edgerton, OH 43517
(419) 298-2306 (voice)
(419) 298-3545 (fax)

Manufacturer, wholesales, and retailer of all sizes of transmitting and receiving variable capacitors, variable inductors, and vernier drives. Price list of standard products is available.

Maplin Electronics
P.O. Box 3
Rayleigh, Sussex, SS6 8LR
ENGLAND
+44 (0) 81 523-5977 (voice)
+44 (0) 81 523-4879 (fax)

Receiving variables, both UK and USA standard values.

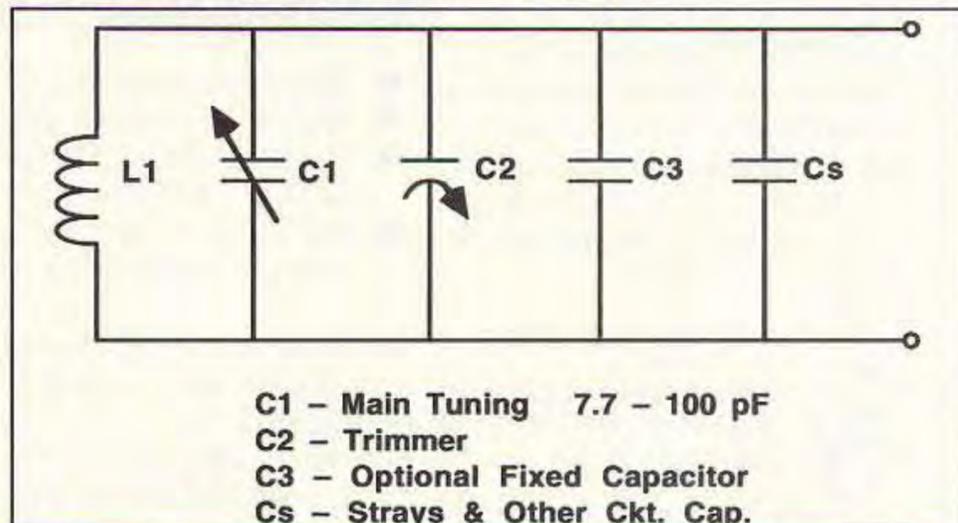


Figure 3. L-C resonant tank circuit for example calculations.