

# Resonance and Tuning Methods

**Part 16:** Have you ever wondered how a piece of radio gear is able to tune in a particular frequency?

By Doug DeMaw,\* W1FB



A recent letter, postmarked Pittsburgh, Pennsylvania, said, in part: "Your First Steps in Radio is super, and to some degree I understand the series. If only I could understand bias with respect to cathode ..."

This letter brings to mind an important point: The beginner series can't be explicit in all areas. No matter where we go to learn new subject matter, we should always consider additional reference material. All the installments in this series can be greatly enhanced if you are willing to dig deeper into the subjects covered. Don't be reluctant to do so!

## This Month: Tuned Circuits

Radios contain many tuned circuits (made up of coils, also called inductors, and capacitors) that are set for a particular frequency. These take many forms. Furthermore, a given radio receiver or transmitter will have circuits that are tuned to many frequencies. Seldom are all of the tuned circuits adjusted for operation on the same frequency.

An understanding of tuned radio-frequency circuits is helpful in your quest for electronics knowledge. When you graduate to the level of home-equipment design and repair, it is essential that you know how these circuits operate. Another term you will encounter is "resonator." This is simply a coil and capacitor combination that forms a tuned circuit for a selected frequency. The inductors in these circuits are also known as "tank coils," especially in transmitters. You will hear amateurs men-

tion the "final amplifier tank," for example. This refers to the coil and capacitor used in the output tuned circuit of the amplifier.

Still another popular expression for a coil-capacitor combination is "network." For example, the matching network between a transmitter driver stage and the power amplifier may contain coils and capacitors that are used to change one impedance to another, such as a 50-ohm driver output to a 10-ohm power-amplifier input line. As we learned earlier in the series, maximum power transfer will take place only if unlike impedances are matched.

Like resistance, impedance is expressed in ohms. An impedance usually consists of resistance and reactance. The symbol for impedance is the letter Z. If an impedance happens to contain only resistance, it is defined as "resistive impedance."

Since we have mentioned reactance, it

would be wise to discuss it here. Reactance is also expressed in ohms. There are two kinds — capacitive and inductive. The impedance of a capacitor or an inductor changes as the frequency of operation changes. The part of the impedance that is frequency dependent is called "capacitive reactance" in capacitors and "inductive reactance" in inductors.

Capacitive reactance is expressed as  $X_C$  and inductive reactance is expressed as  $X_L$ . When a coil and capacitor are said to be tuned to resonance, the inductive and capacitive reactances are equal but opposite in action. When this condition is met, the reactances cancel one another. The tuned circuit then looks like a pure resistance at the frequency of resonance, a desirable condition. A more detailed explanation of reactance and impedance can be found in *Understanding Amateur Radio*

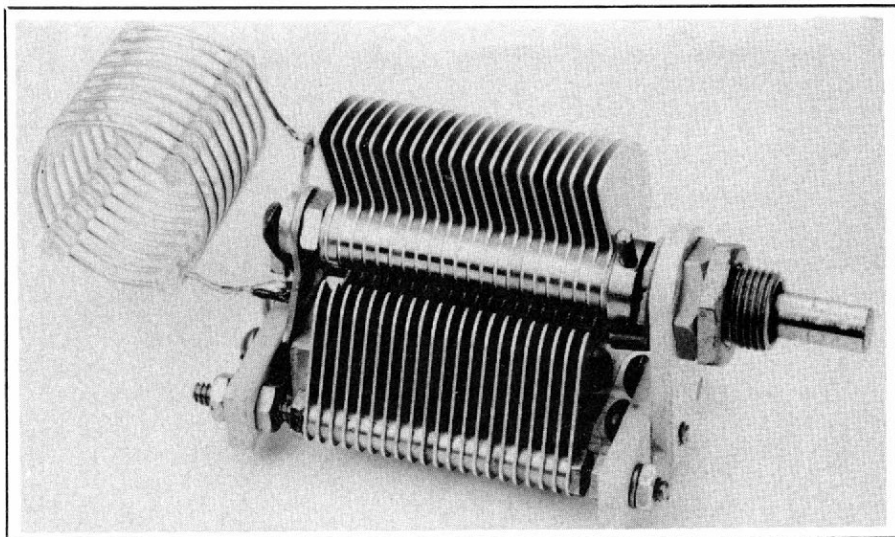


Fig. 1 — A tunable coil-capacitor combination. This is a parallel-resonant circuit. As the capacitor is adjusted through its range, various frequencies of resonance are established. The coil inductance and capacitance range are chosen to cover a specific range of frequencies.

\*Several League publications are designed for this purpose. The first is *Tune in the World With Ham Radio* (\$8.50), which contains a clear, basic explanation of radio theory. If you'd like more detail, *Understanding Amateur Radio* (\$5) is a good source. The best all-around reference for Amateur Radio operators, of course, is the *ARRL Handbook* (\$15).

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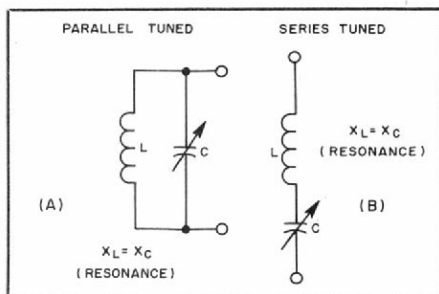


Fig. 2 — Illustration A is the electrical equivalent of the tunable coil capacitor in Fig. 1. It is a parallel-resonant circuit. A series-resonant circuit is shown at B.

or the *ARRL Handbook*.

### Conventional Tuned Circuits

Let's look at some older types of tuned circuits to see how they are hooked up. Fig. 1 shows an air-wound coil and a mechanical tuning capacitor. The inductance value of the coil is not changed in this arrangement. Rather, the capacitor is adjusted to change the resonant frequency of the coil-capacitor combination. At each setting of the capacitor, we will have resonance (canceled reactance) at a different frequency within the adjustment range of the capacitor. Because of this ability to change the resonant frequency, the variable capacitor is called a "tuning capacitor" or a "resonating capacitor."

The electrical equivalent of the parts in Fig. 1 is offered in Fig. 2. The arrow through the capacitor indicates it is adjustable. The illustration at A represents what is known as a parallel-resonant circuit, since the coil and capacitor are in parallel. At B of Fig. 2, the same parts are arranged in a series-resonant circuit. In both instances, the reactances must cancel one another for the circuit to resonate.

Tuning capacitors take a host of forms. Some are adjusted by means of screwdrivers or tuning tools. These are generally called trimmers or padders. They are set for resonance just once, then left in that position. Trimmer capacitors may be made with metal plates; insulation between the plates can be made of ceramic, plastic, mica or glass. One type has a movable conductive plunger that is adjusted inside a glass cylinder that has a conductive outer coating at one end. These are called "piston trimmers."

Fig. 3 shows various trimmer and padder capacitors that might be used in a tuned circuit. Some are more desirable than others, since they are mechanically superior to the less-expensive types. This helps to ensure that they remain set to a specific capacitance in the presence of vibration or temperature changes. The insulation used between the movable plates of a trimmer capacitor also affects the performance. The better the dielectric quality of the material, the better the capacitor for RF tuned circuits. Some trimmer capacitors resemble the larger variable capacitors, except that they are

miniature versions of the larger units. Air is the insulating material between the plates.

### Other Tuning Methods

A coil-capacitor combination can be used to cover a range of frequencies by using a fixed-value capacitor and a variable coil (Fig. 4). You will see many such circuits in pocket-size AM and FM broadcast receivers. These are little metal cans with tuning slugs that are accessible through holes in the cans. The resonant frequency is changed by adjusting the coil slug. The slugs are made from powdered iron or ferrite, which increases the coil inductance as it is moved farther into the coil. Brass slugs can be used in place of the powdered-iron ones, but the farther they are inserted into the coil the smaller the inductance becomes — the op-

posite effect from powdered iron or ferrite. Fig. 5 contains the electrical details of a number of adjustable inductors. You can see that various mechanical schemes make it possible to change the effective inductance of a coil.

### Modern Tuned Circuits

Circuits used in modern radio gear are tuned electronically rather than mechanically. A semiconductor, such as a diode or transistor, serves as the tuning capacitor. Most modern TV receivers are tuned in this manner (varactor tuning).

An example of a typical electronically tuned circuit is given in Fig. 6. D1 is a special diode manufactured for use in tuning an inductor to resonance or for changing the oscillation frequency of a quartz crystal. Il-

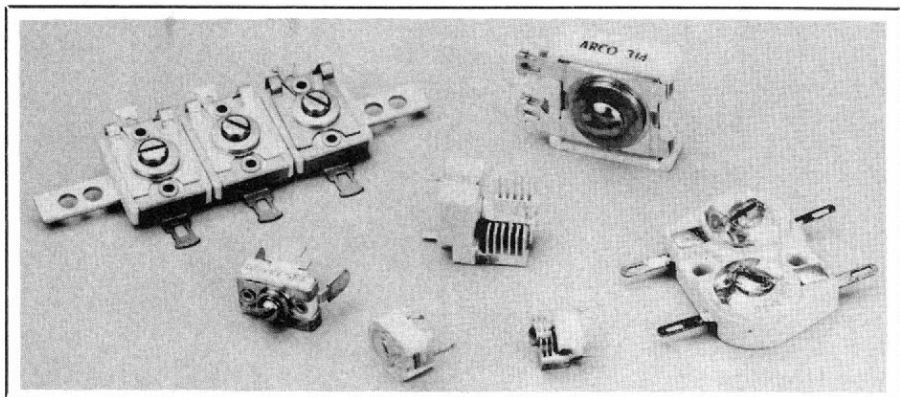


Fig. 3 — A collection of trimmer and padder capacitors. These units have variable capacitance, but are not suitable for use as a main-tuning control because they have no shafts on which to mount a knob or dial mechanism.

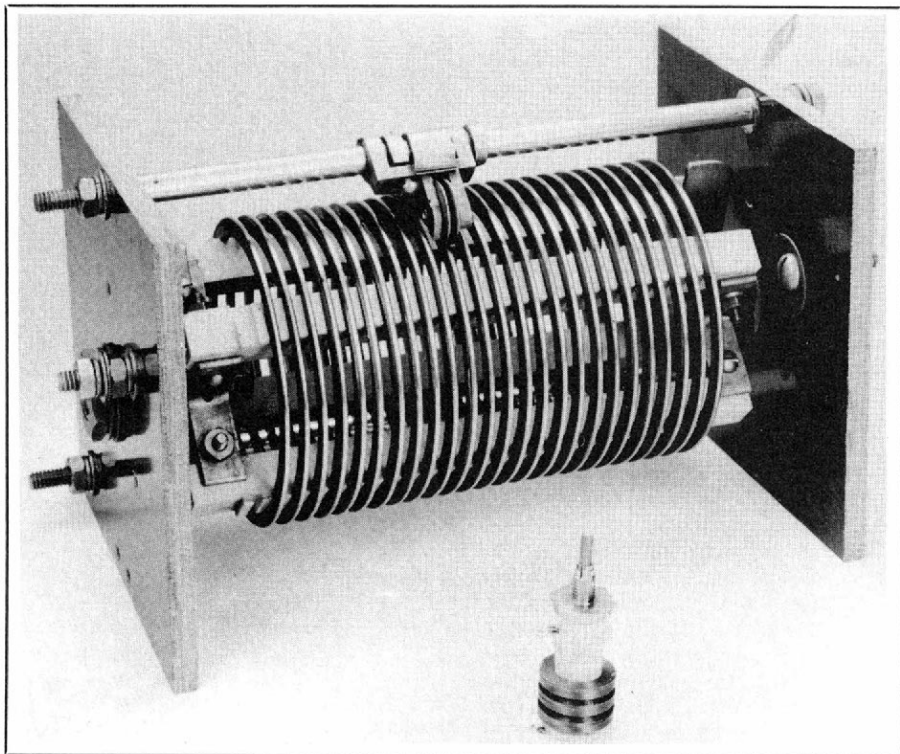


Fig. 4 — A slug-tuned coil (foreground) and a roller inductor coil. These inductors are variable, which permits the use of a fixed-value capacitor to form a tunable resonant circuit.

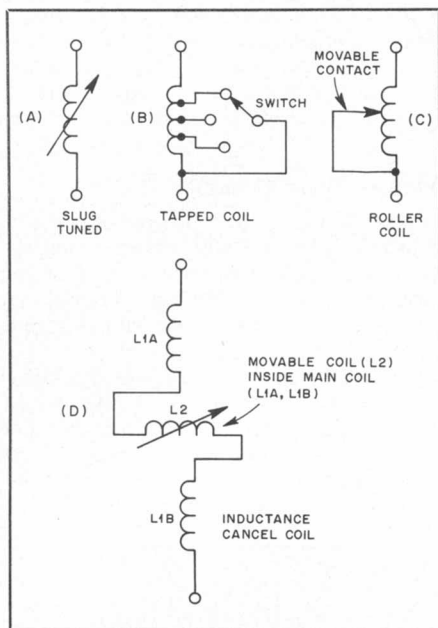


Fig. 5 — Electrical symbols for a slug-tuned coil (A), a tapped coil (B), a roller inductor (C) and a bucking or canceling coil (D). L2 of D rotates inside L1 to aid or oppose the total inductance, thereby changing the effective inductance. This old-style coil is seldom used.

Illustration A is for a VXO (variable-frequency crystal oscillator), while drawing B demonstrates schematically the arrangement for a resonant coil-capacitor circuit that uses a tuning diode. In both circuits, the internal junction capacitance of the diode is varied by changing the dc voltage applied to the diode. This is done at R1, which can be mounted on the equipment panel for accessibility. For the most part, the outward appearance of a tuning diode is no different from that of a rectifier diode or glass Zener diode.

Is there a shortcoming to the use of tuning diodes? Yes. They are not as frequency-stable as are mechanical variable capacitors: The diode junctions are affected by changes in temperature; therefore, they will change capacitance gradually after the operating voltage is applied. This causes frequency drift. Also, the ambient-temperature changes within a piece of equipment will cause the diode capacitance to vary slightly — a further cause of drift. Of course, mechanical capacitors are also affected to some extent by temperature changes, but not so dramatically as are tuning diodes. For many circuits, however, it is entirely practical to use tuning diodes.

Another important difference between mechanical and electronic tuning capacitors is the minimum-to-maximum capacitance range. Take, for example, a 100-pF (maximum capacitance) air-variable capacitor. When the plates are fully meshed it will provide 100 pF. With the plates completely unmeshed the capacitance might be only 10 pF. A tuning diode, on the other hand, may have a maximum capacitance of, say, 100 pF, but the minimum capacitance

may be 35 pF. This means that the tuning range with a given coil will be smaller than that with a mechanical tuning capacitor.

Once we recognize and accept the peculiarities of tuning diodes, we can proceed to use them in our amateur circuits. They are far less expensive to use than air-variable capacitors and they permit miniaturization that would otherwise be impossible. A tuning diode can cost as little as 35 cents, whereas a mechanical equivalent capacitor could cost \$20!

### Tuned Circuits Versus Power

We have thus far overlooked the matter of RF and dc power that must be accommodated by a tuned circuit. In transistor or IC circuits, we need not be too concerned about the operating voltages of the variable capacitors we use. It is unusual to have more than 28-V dc in a semiconductor circuit, so small capacitors can be used without fear of arcing or overheating. This is not true in circuits that use vacuum tubes — particularly at high RF and dc voltage levels. The greater the voltage, the wider the plate spac-

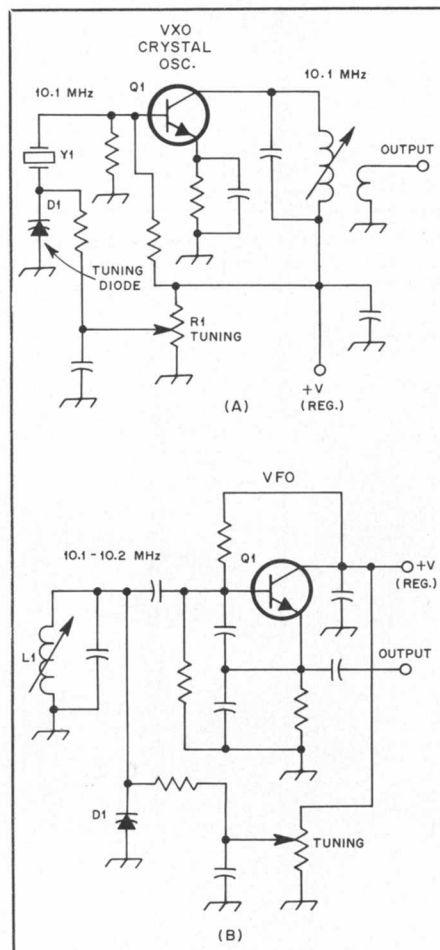


Fig. 6 — A crystal (Y1) can be shifted in frequency by using a tuning diode (D1) in series with it. As the dc voltage applied to D1 is varied by means of R1, the diode capacitance changes, and this changes the oscillation frequency of Y1 slightly, as indicated at A. A VFO can be tuned (B) by using a tuning diode in place of a mechanical tuning capacitor.

### Glossary

dielectric — an insulating material or medium that, ideally, has zero conductivity. A vacuum is a perfect dielectric. Solid materials, such as glass or ceramic, are suitable insulating materials, but not as good as air or a vacuum.

drift — a condition under which an electrical property changes as a function of temperature — internal or external to the components. Frequency drift is associated with oscillator circuits that change frequency as a function of time and heating.

network — a group of conductive components connected to form a specific circuit function. A group of coils and capacitors can, for instance, comprise a network.

resonator — a device intended to introduce resonance into a circuit. A coil-capacitor combination tuned to a specific frequency is a resonator. A quartz crystal is also a resonator.

tuning diode — a special type of semiconductor diode that exhibits a significant change in junction capacitance as the dc potential across the junction is varied. A varactor is a type of tuning diode.

ing of the variable capacitor must be to prevent voltage from arcing across the capacitor plates. In circuits where high RF power is developed, it is wise not to allow dc voltage to be applied to the tuning capacitor, even though some amateurs have done this in homemade gear. Fig. 7 shows both methods, but the illustration at B is recommended for safety reasons as well as voltage-breakdown considerations.

The power-handling capability of a coil is dependent on the wire size. The greater the dc current or RF current that flows through a coil, the larger the conductor must be. The smaller wire has a higher dc resistance in ohms. The ac (or RF) resistance is higher also. Ohm's Law tells us that the greater the resistance and current in a conductor, the higher the loss, or voltage drop. Power is dissipated in the wire, and dissipation causes heat. A coil with too small a wire size can burn up easily. The coil resistance should always be as low as possible. The insulating material on which the coil is wound should also be able to sustain the developed or operating voltage without burning or arcing. If the wire in a coil becomes more than slightly warm after a few moments of circuit operation, chances are that the wire diameter is too small. Heating losses impair the efficiency of a circuit.

### A Laboratory Experiment

Perhaps you have a desire to warm up a soldering iron and try your hand at building an electronically tuned circuit. This would be a fine way to observe what happens when the voltage on a tuning diode is varied. You will need a shortwave radio or ham receiver for this lab experiment. You will be building a 40-meter oscillator, and you will want to listen to the signal in a receiver.



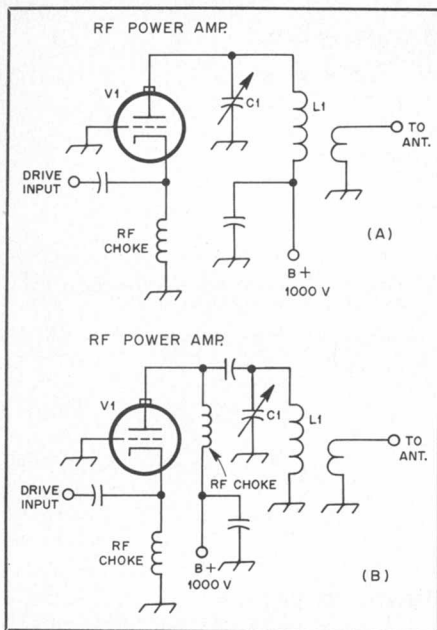


Fig. 7 — High voltage should be kept off the tuning capacitor (see text). Illustration A shows series feed of the B+ voltage (poor practice), whereas shunt or parallel feed is depicted at B (desirable).

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Fig. 8 is the schematic diagram of our voltage-controlled VFO (variable-frequency oscillator). An MPF102 or 2N4416 FET functions as the oscillator transistor. Any high-frequency N-channel junction FET can be used for Q1. The coil is wound on an Amidon T68-6 (yellow) toroid core. But, if you have access to other powdered-iron toroids that are 0.68-in OD, with a permeability factor of 8, you may use them (see the Amidon ads in *QST*). Any 3.8- $\mu$ H coil that can be tapped about  $\frac{1}{4}$  the way from the ground end can be used, also.

The two 100-pF fixed-value capacitors can be silver-mica, polystyrene, or NP0 disc-ceramic. If you don't care about frequency stability (drift), you may use ordinary disc-ceramic capacitors. The trimmer capacitor need not be elaborate for this test. One of the Radio Shack plastic 10-pF trimmers will suffice. The tuning control, R1, is not critical. I suggest that you use a 100-k $\Omega$  control with a shaft, but a PC-

board-mount potentiometer can be used. The value of the control can be anything from 20 k $\Omega$  to 100 k $\Omega$  for this circuit. The smaller the value of R2, the greater the tuning range. But don't make it less than 22 k $\Omega$  under any circumstances. My tuning range was 25 kHz when I used 100 k $\Omega$  at R2, but it increased to 55 kHz when R2 was changed to 33 k $\Omega$ .

Rather than buy tuning diodes, I chose to use four 2N3904 transistors. They are inexpensive (as little as 10 cents each). You may use only two transistors if you wish, which will compress the tuning range about 10 kHz. The transistors are hooked up so the emitter-base junctions act as tuning diodes. The collectors are not attached to the circuit. You may snip the collector leads or bend them out of the way.

The circuit of Fig. 8 can be tacked together on perforated board. If you want to make a circuit-board type of foundation, glue strips or squares of thin hobby copper to a scrap of Formica®. Or, use a block of wood on which you have mounted multilug terminal strips. Use your imagination: This is the nature of experimentation!

### Circuit Testing

Once you're certain all the parts have been wired correctly into your circuit (check two or three times), you are ready to connect the battery and see what happens. Tune your receiver to 40 meters (7.0-7.1 MHz) and connect a short length of wire to the antenna post. Allow this wire to lie near the oscillator (a few inches from L1 of Fig. 7). This will permit ample signal pickup for the receiver.

Set R1 at midrange, then adjust the trimmer (C1) until you hear the signal in your receiver. Next, tune the oscillator by adjusting R1 through its range. As you retune your receiver, you will note that the oscillator frequency has changed in accordance with the setting of R1.

When you first turn on the oscillator, the frequency will drift quickly. It should settle down in 2 or 3 minutes. This is caused by the heating of the Q2 and Q3 junctions when voltage is applied. Also, the junction inside Q1 will change capacitance slightly until it warms up. This condition is known as "short-term drift." If an oscillator continues to drift for long periods (an hour or more), the condition is referred to as "long-term drift."

Later you may want to replace Q2 and Q3 with a 25- or 50-pF air-variable capacitor and repeat the tests. You will find that the drift will practically disappear. With either type of tuning capacitor, you should remember that L1 and the tuning capacitor form a tuned circuit or resonator.

If you can't locate some 2N3904s, use any equivalent NPN transistor. Whatever you select, be sure it has a top-frequency rating ( $f_T$ ) of at least 50 MHz. A 2N2222 type of transistor can be used at Q2 and Q3, also. The amount of capacitance change versus voltage will vary somewhat with the transistors used.

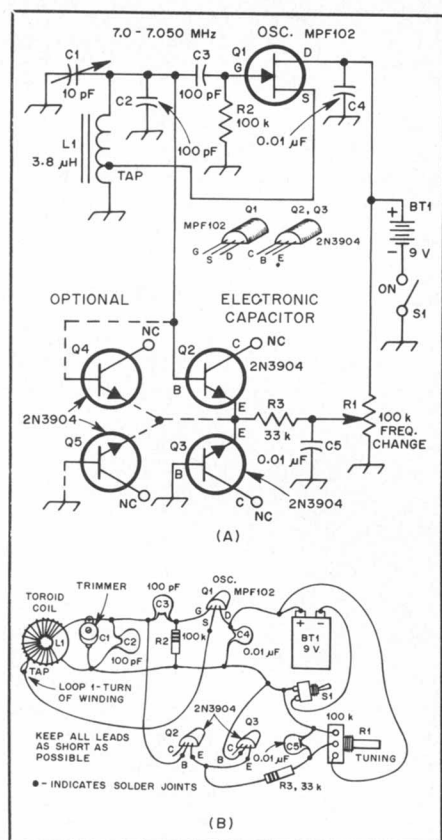


Fig. 8 — The diagram at A is for an oscillator that is tuned by means of diodes (Q2 and Q3), as detailed in the text. The frequency range via R1 is approximately 40 kHz at 40 meters when two transistors are used as diodes. Adding two more diodes (Q4 and Q5 in dashed lines) will increase the tuning range to roughly 50 kHz. Resistors are  $\frac{1}{4}$ - or  $\frac{1}{2}$ -W carbon composition. Fixed-value capacitors are disc-ceramic. A pictorial diagram of the hookup is provided at B.

BT1 — 9-V transistor-radio battery. Radio Shack 23-464 with snap-on connector (Radio Shack 270-325 or equiv.).

C1 — 10-pF maximum capacitance trimmer (Radio Shack 272-1338 or equiv.). Not a critical value for this experiment.

C2, C3 — 100-pF NP0 capacitor (Radio Shack 272-152 or equiv.).

C4, C5 — 0.01- $\mu$ F capacitor (Radio Shack 272-131 or equiv.).

Circuit Foundation — Suggest Radio Shack general-purpose type, 276-148.

L1 — 28 turns of no. 24 or 26 enameled wire on an Amidon Assoc. T68-6 (yellow) powdered-iron toroidal core. Amidon Assoc., 12033 Otsego St., North Hollywood, CA 91607 (catalog available). Tap L1 at six turns above grounded end by forming a one-turn loop (twist), then scraping enamel from the loop wire.

Q1 — Junction FET, type MPF102 (Radio Shack 276-2062).

Q2, Q3 — 2N3904 NPN or MPS3904 (Radio Shack 276-2016).

R1 — 100-k $\Omega$  audio-taper control with shaft (Radio Shack 271-092). A PC-board-mount thumbwheel control may be used.

R2, R3 — Radio Shack 271-045 and 271-040, respectively.

S1 — SPST slide switch or similar (Radio Shack 275-406).

Good luck, and please do some additional reading on this important subject.