Get Active!

A nice amp project for building your own active antenna.

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An antenna of any kind, passive or active, is a conductor (radiator) immersed in an electromagnetic (EM) field that converts the intercepted EM radiation to a voltage or current that can be used by the receiver. A passive antenna is just the radiator; an active antenna is a radiator plus transistor(s) and other circuitry that matches the radiator to the load.

Electromagnetic fields are described in terms of volts or amps per meter, so the dimensions of the antenna determine the volts or amps that appear at its terminals. To confound the issue, the antenna's dimensions relative to a wavelength also determine the impedance of the source of voltage or current. The impedance of the antenna is resistive (resonant) only for particular lengths. The longer the antenna, the higher the maximum available power output, but for some dimensions it is very difficult to obtain the power that is available. For example, a full-wave dipole has a high impedance that is difficult to match. In short, bigger is better—but with reservations.

When we are stuck with a small antenna, we can't afford to waste any of those precious few microvolts of signal because of mismatch. We want and need them all. The active antenna described in the following paragraphs losslessly matches a short antenna to the receiver. Its output is only 18 dB less than a full-sized half-wave horizontal or quarter-wave vertical antenna. The theory and design equations are given so that the effects of a particular situation can be understood and to allow the circuit to be adapted to use the components available.

The maximum available power from any source is obtained when the load presents a conjugate match to the source. The maximum voltage from a source is produced across an open circuit even though no power is delivered to an open circuit. A conjugate match occurs when the impedance of the load equals the impedance of the source with phase shifted 180°. That is, the resistive part of the load impedance equals the resistive part of the source's impedance and the reactive part of the load impedance equals the reactive part of the source's impedance—but with opposite sign. With opposite sign reactances, the net reactance is zero and the circuit is resonant. To realize an open circuit requires the reactance to be resonated and the resistance across a parallel resonant circuit to be infinite.

A short antenna, one that is a small fraction of a wavelength, has a resistive part that is small and a reactive part that is high. For example, a short centerfed dipole has a radiation resistance of:

$$R = 20\pi^2(L/\lambda)^2 = 197(L/\lambda)^2$$

where L = the length of a very short centerfed dipole

and λ = the wavelength, in the same units as L.

A six-foot vertical whip over perfect ground is equivalent to a twelve-foot dipole. At 7 MHz, a six-foot whip has a radiation resistance of about 1.4 ohms. At 3.5 MHz, the radiation resistance drops to 0.35 ohms. The reactance of a vertical six-foot whip made of #8 AWG (0.125" diameter) wire with the bottom located a foot or so above ground looks like 15 or 16 pF. The capacitance of a six-foot vertical made with #24 AWG (0.02" diameter) wire looks like 12 or 13 pF. The capacitance is dependent only on the physical dimensions of the antenna, its

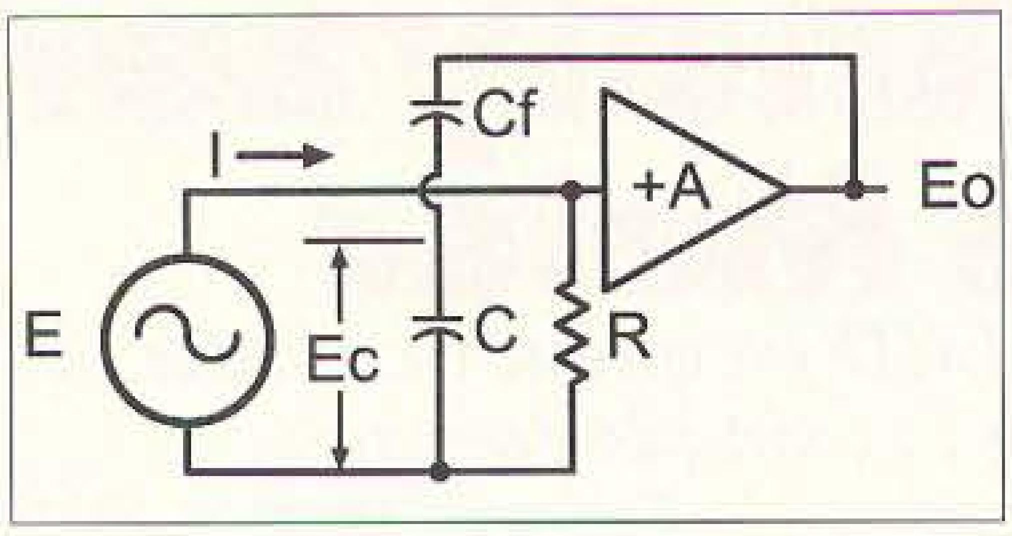

Fig. 1. A negative capacity can be generated.

diameter and length, and its proximity to grounded objects. The capacitance is independent of frequency but the reactance varies inversely with frequency:

$-jXc = 1/(2\pi fC)$

At 7 MHz, 15 pF has a reactance of about -j1500 ohms; at 3.5 MHz, the reactance is about -j3000 ohms. The impedance of the six-foot whip at 7 MHz is 1.4-j1500, 1500∠-89.95° in polar form. A conjugate load at 7 MHz has an impedance of 1500∠+89.95°, which is equivalent to 1.6 MΩ in parallel with +j1500.

Converting from impedance to admittance can be laborious. However, if the ratio of resistance to reactance, or reactance to resistance, is 50 or greater, the smaller term can be neglected: 1.4-j1500 is essentially -j1500 or 1500∠-90° and resonates with +j1500. In theory, an inductor could produce a reactance of +j1500 but a practical one has a significant and unavoidable resistance. An inductor also must be variable to resonate the varying capacitive reactance. +j1500 can be obtained with a negative 15 pF and its reactance varies along with the antenna's reactance.

A negative capacitor is not something to be bought at the local electronic parts store, but it is something that can be generated with a simple circuit that uses commonly available parts. The conceptual circuit shown in **Fig. 1** generates a negative capacitor. The resistor R represents the input conductance of the amplifier and losses in the circuit board; C is the sum of the antenna's capacity, the input capacity of the amplifier, and stray circuit capacity. C_f provides feedback from the amplifier's output to the input. The amplifier has a voltage gain of +A, as the output is in phase with the input.

The generation of a negative capacity can be followed with **Fig. 1**: When the junction of C and C_f is disconnected from the input, the signal current I flows only into R and the voltage E at the input to the amplifier is IR. The output of the amplifier E_o is AE and the voltage E_c appears at the junction of C and C_f. If C_f is chosen so that $E_c = E$, then when the junction of C and C_f is reconnected to the input terminal, no current flows from the signal source into these capacitors and the effect of C is removed. C_f and the amplifier produce a negative capacitor that is equal to C:

$$-C = C_f(A-1)$$
Equation 1

The negative capacity generated is dependent only on A and C_f.

A practical non-inverting amplifier is shown in **Fig. 2**. The gain is determined by the ratio of R_c to R_s and the voltage gain of the source follower VG_{sf}.

$$A = VG_{sf}(1+R_c/R_s)$$
Equation 2

VG_{sf} is the voltage gain from the gate to the source of Q1. A source follower is often assumed to have a gain of unity but, in fact, it is always somewhat less than unity. The gain depends on the value of R_s and the effective transconductance G_m of the amplifier. The effective transconductance is the change in current in R_s for a change in gate voltage. Since the base current of Q2 is the drain current of Q1, and collector current is $I_B h_{fe}$, $G_m = g_{fs} h_{FE}$. Only when $G_m R_s$ is much greater than one does the gain approach unity. The voltage gain of the source follower can be expressed as:

$$VG_{sf} = G_m R_s/(G_m R_s+1)$$
Equation 3

R_s and I_c determine the DC operating point of the amplifier, $V_{gs} = I_c R_s$. The negative feedback provided by R_s stabilizes the operating point of the amplifier and makes the amplifier immune to changes in supply voltage as well as tolerant of the characteristics of the transistors. If a change were to increase I_c, V_{gs} would increase, which would decrease I_D, which would decrease I_c. The negative feedback reduces the output impedance, reduces the input capacitance of the Q1, and increases the output bandwidth.

The relationship of the JFET's parameters are given by Evans in *Designing With Field-effect Transistors:*

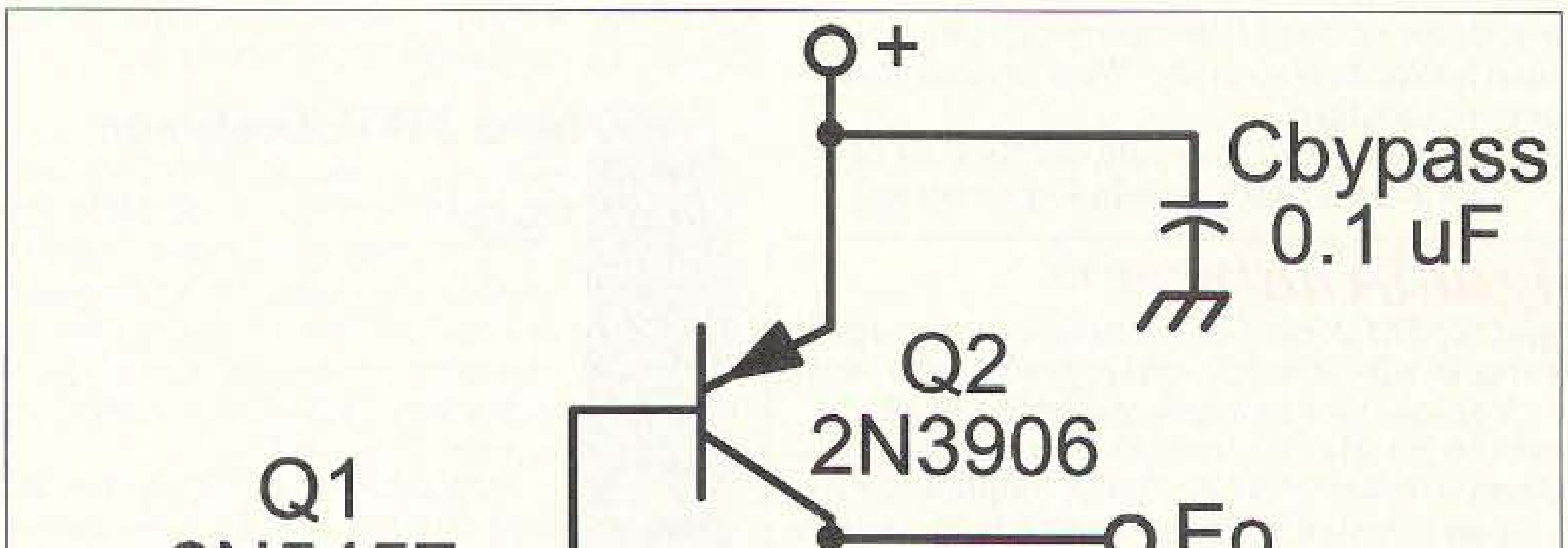

Fig. 2. A practical non-inverting RF amplifier can be very stable.

$$I_D = I_{DSS}(1-V_{gs}/V_{off})^2$$
$$g_{fs} = 2I_D/(V_{gs}-V_{off})$$

The DC operating conditions of the transistors in the amplifier shown in **Figs. 2** and **3** are: I_D = 50 uA at V_{gs} = 2.66, g_{fs} = 2.5 x 10-4, I_c = 10 mA, h_{fe} = 200 at I_c = 10 mA. The effective transconductance is:

$$G_m = 2.5 \times 10^{-4} \times 200 = 0.05\ S.$$

The negative capacity generator shown in **Fig. 3** shows the receiver's input resistance shunting R_s. The resulting RF value of R_s is R_{srf}. When the receiver's antenna input impedance is 50 Ω, R_{srf} is about 42 Ω and VG_{sf} is about 0.68. However, if the receiver's input impedance changes with frequency, then the negative capacitance also changes. When the negative capacity is excessive, the net capacitance at the gate of Q1 is negative and the circuit will oscillate at the frequency at which the vertical radiator is approximately a half-wave long.

In **Fig. 3**, the value of C is assumed to be 30 pF, which is composed of the antenna's 16 pF, the amplifier's 2 pF input capacitance, and 12 pF circuit strays—for a total of 30 pF. The negative feedback provided by R_{srf} reduces the input capacitance of Q1. C_f is arbitrarily chosen to be 15 pF. With **Equation 1** the amplifier gain needed to generate -30 pF when C_f is 15 pF is 3. The uncertainty of the antenna's capacitance, strays, and component tolerances and the receiver's antenna input impedance suggests that the negative capacity be variable. The negative capacity can be varied by changing either C_f or the amplifier's gain. Because variable capacitors are relatively difficult to obtain, C_f is selected to be fixed and the gain is varied by changing R_c. **Equation 2** shows that when R_c is composed of a 250 Ω variable plus 82 Ω fixed, the amplifier gain can be varied from 2 to 6 and the generated negative capacity varied from 15 pF to 75 pF. The power dissipation in R_c is less than a milliwatt, so any variable carbon or cermet pot can be used. A wirewound variable resistor should not be used, because its inductance increases the collector impedance with frequency and causes the negative capacity generated to change with frequency.

While the maximum available power is obtained with a matched load, the maximum voltage is developed across an open circuit. The active antenna's negative capacity generator presents an open circuit to the antenna's terminals. The negative capacity cancels the antenna's capacity—it resonates the antenna's capacitance. The gate of Q1 looks like an extremely large resistor. The DC gate return resistance R_g can be hundreds of megohms because the gate current of the 2N5457 is a fraction of a nanoamp. The leakage across the circuit board or a pencil track on the circuit board can provide the high resistance R_g.

The negative capacity generator can be built on perfboard mounted in something like a minibox. The whip radiator should be connected directly to the gate of Q1. Even a short piece of transmission line between the whip and the negative capacity generator

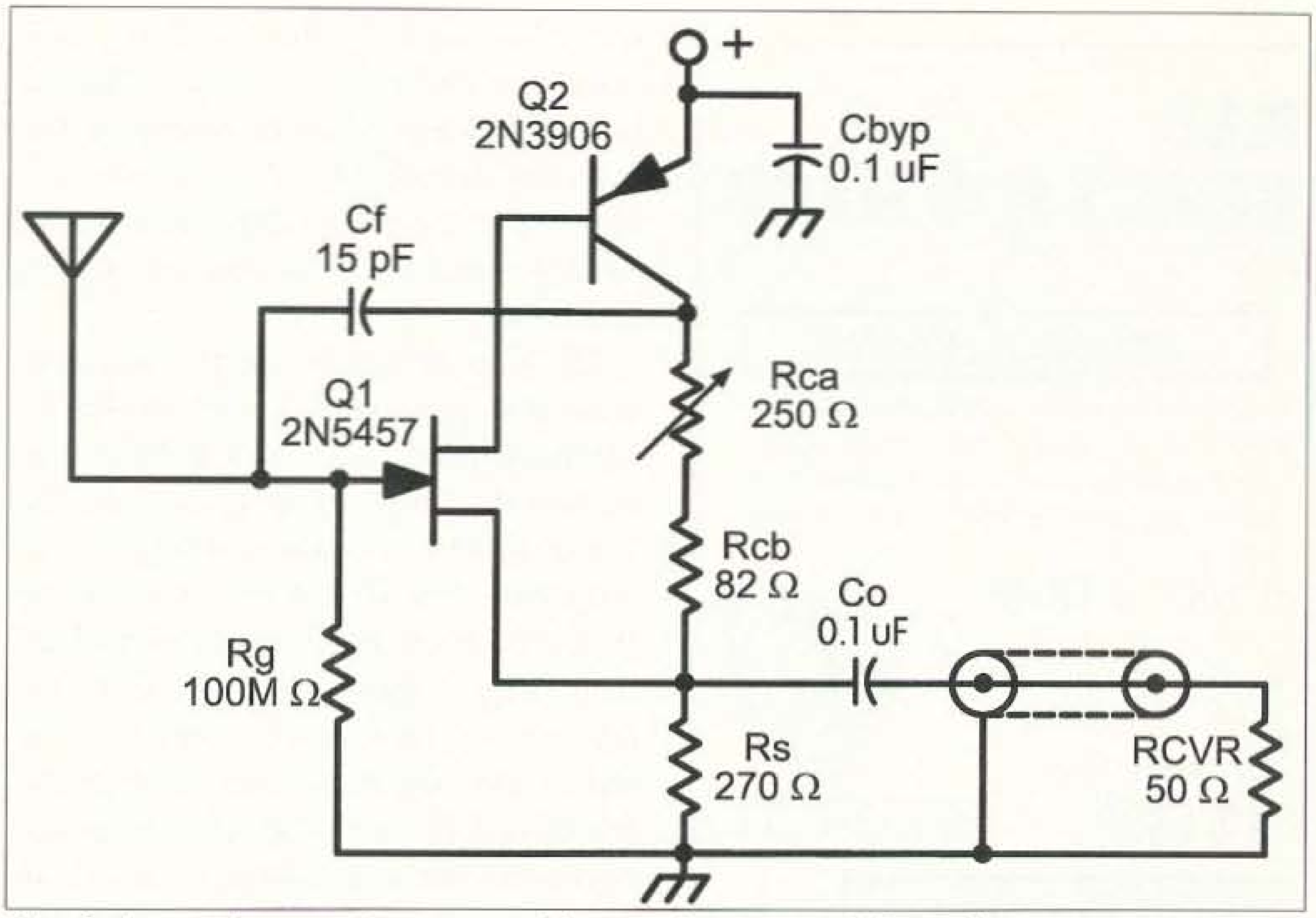

Fig. 3. A negative capacity can provide a conjugate match for a short antenna.

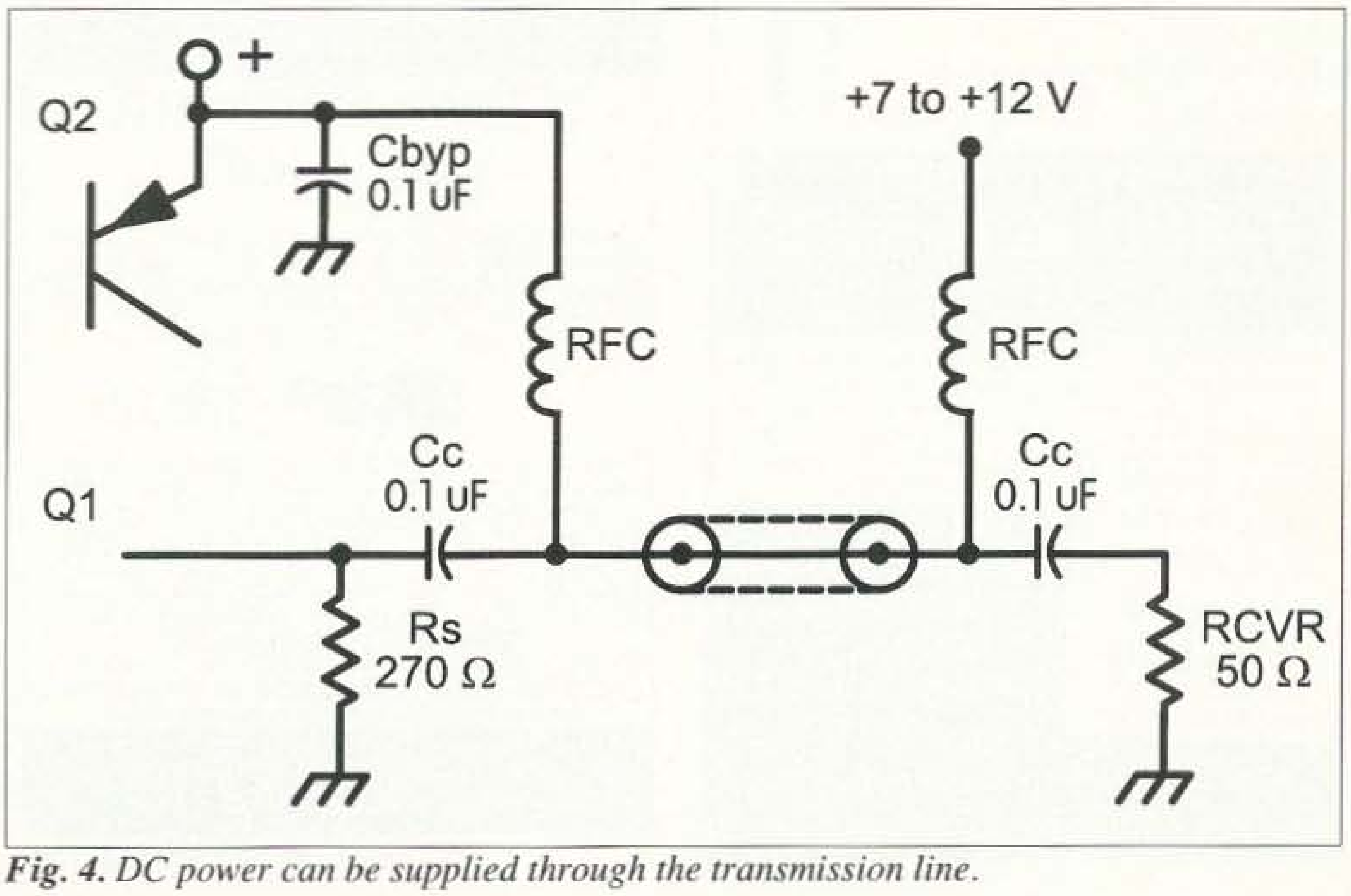

Fig. 4. DC power can be supplied through the transmission line.

just adds capacity that must be canceled and should be avoided. A banana jack makes a good entry connector for the whip. It probably goes without saying, but if the active antenna is to be located outside it should be sealed against the weather.

The power supply for the negative capacitor generator is not critical—anything from 7 V to 24 V will do. The current drawn is about 10 mA, so the life of a battery would not be particularly long. But 10 mA can probably be stolen from the receiver without ill effects. **Fig. 4** shows how DC from the receiver or other remote source can be fed to the active antenna through the transmission line. The separation between the antenna and the receiver can be virtually any distance. The RF chokes in **Fig. 4** can be any inductance that has a reactance of more than 500 Ω at the lowest frequency of interest. The inductance L can be found with the following equation:

$$L = 500/2\pi f = 250/\pi f$$

where L is in henrys
and f is the lowest frequency of operation in Hertz.

If the supply voltage is high enough, the RF chokes can be replaced with resistors. (The voltage drop across the two 470 Ω resistors will be about 9.4 V.) Since the voltage at the emitter of Q2 should be at least 7 V, the supply voltage should be greater than 9.4 V + 7 V = 16.4 V when resistors are used.

The adjustment of R_c is straightforward and only needs to be changed when the antenna is moved or changed: Start with R_c set at minimum, tune the receiver to a convenient frequency someplace in the 80 or 40 meter bands, and adjust R_c for the greatest output. The receiver doesn't need to be tuned to a station, because the man-made noise intercepted by the antenna will surely override the receiver's internal noise. If the receiver has an S-meter or other tuning indicator, this can be used to indicate the maximum signal strength. Of course, it can also be done just by listening.

The receiver's input resistance has been assumed to be 50 Ω, but it may vary with frequency. If this is the case, the negative capacity will change with tuning. When the gain is excessive, the total capacity at the gate of Q1 will be negative and the circuit will oscillate at the frequency where the antenna is a half-wave long. If the receiver's input varies with frequency, adjust R_c for optimum at the frequency that has the highest receiver input resistance. The match will not be perfect at other frequencies but that's the trade-off between peak performance and adjustment-free performance.

The improvement over just a short antenna connected to the receiver is amazing. When the antenna impedance is 1500 ohms, the voltage applied to a 50-ohm receiver suffers a 30:1 loss (29.5 dB). And this loss is to a signal that is already small: A six-foot whip has an open circuit output that is about 1/6 (15.5 dB) the output of a quarter-wave vertical just by virtue of the different lengths. These two losses stack up to a 45 dB penalty imposed by an unmatched six-foot vertical. At lower frequencies, it is even worse. Is it any wonder why short antennas are the very last choice?

With the active antenna described here, a six-foot whip does a reasonable job in the shortwave bands. Not as good a one as a full-sized quarter-wave vertical, but then again, it can fit on the wall and probably cost under $10—and you certainly can't say *that* for a full-sized vertical. 73