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A Tunable RF Preamplifier Using a Variable Capacitance Diode

Variable capacitance diodes can replace expensive mechanically adjustable capacitors in an RF project.

Substituting a variable capacitance diode for an expensive mechanically adjustable capacitor can be done in many RF projects. But there are a few tricks that need to be learned. Take a look at how it's done with this versatile RF preamplifier that you can build yourself.

Working with home brew ham receivers, inexpensive commercial short-wave sets and software defined receiver (SDR) based "dongle" radios can be fun and challenging. In some cases, however, the benefits of good front-end RF selectivity may have been overlooked. For these cases adding a RF filter between the antenna and receiver as shown in Figure 1 can help. Filtering signals from the antenna provides rejection of strong out of band signals, which otherwise might overload the input. The filter can also prove to be highly beneficial in situations where there is a lot of noise or interference.

If your application requires just a single frequency or narrow band of frequencies then a fixed input filter can be used. But if your application requires a number of bands, as in short wave listening, you will need an input filter that is tunable to the desired band of interest.

Presented here is an easy to build tunable preamplifier that should find use in many interference situations. It has good performance and can be built for a fraction of the cost of a commercial unit. An interesting aspect of this project is that it uses a variable capacitance diode (VCD), sometimes referred to as a varicap or varactor in the literature.

The design offered here covers the frequency range of 6 MHz to 23 MHz. But we'll show you how to change some component values to cover the frequency band of your own interest. To ease construction, through-hole components are used exclusively — no surface mount parts. It runs on a 12 V dc supply and requires less than 100 mA. And, it doesn't require any fancy equipment except for your antenna and receiver to verify its operation.

So, if you want to get started experimenting with a tunable RF preamp, tame your interference problems and at the same time learn a bit about the application of a varicap diode, read on. Home brewing your own tunable preamp might be the way to go.

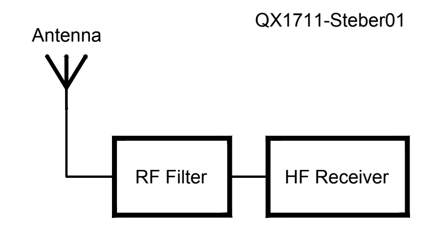

Figure 1 — An RF filter between the antenna and a low cost radio or experimental HF SDR "dongle" receiver can significantly reduce noise and interference problems

RF Tuner Background

This project began when I found that the low cost short-wave radio I used for receiving WSPR and JT9 signals on various bands was suffering from severe interference because of its wide input RF stage. My dongle-based SDR receiver was also suffering the same fate, being overloaded from strong nearby stations. WSPR and JT9 signals by definition are low power signals and this interference was making it more difficult to copy them with my computer software. The interference from the computer wasn't helping either. Adding this filter made it a lot easier to reduce this noise — but it does require turning a knob to peak the filter on the desired frequency.

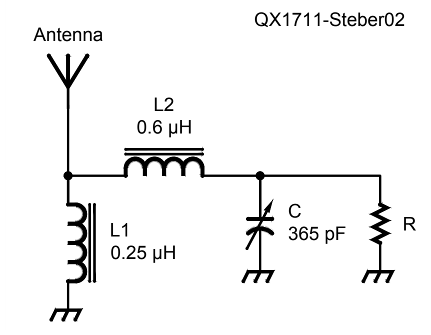

Figure 2 — Classic tunable RF band-pass filter with variable capacitor *C*. Resistor *R* represents input to next stage, usually a FET amplifier.

Figure 2 shows a classic tunable circuit that is often used to provide RF selectivity. It is not the same as an antenna tuner, which is used to match the impedance of your antenna/feedline to your receiver or transmitter. The tuner shown here is basically an adjustable band-pass filter. The inductors *L*1 and *L*2 provide matching to the antenna in the range of 25 to 100 Ω and form a tuned circuit with *C*. Resistor *R* is shown to represent the high impedance input of the next stage. *R* must be very high — in the megohm range — to avoid loading down the tuned *LC* circuit. Normally a FET is used here. The peak in the RF response is moved over the frequency range by adjusting the variable capacitor *C*. Figure 3 shows response curves for various values of *C*. They were taken from a SPICE simulation and were found to closely follow those seen with a spectrum analyzer on the actual circuit.

Finding a mechanically adjustable capacitor to use in the tuner would have been a piece of cake a few years ago. This once common part is now hard to find — even at hamfests! When found, the cost is skyrocketing. I found a few on an auction site but the prices were quite high. This could be a special hardship to those in clubs or outreach programs that wish to build your project using this component.

Fortunately there is another way to do the tuning. Use a varicap! In the next section we'll talk about the varicap and how it can be used in this application.

Using A Varicap

A varicap is essentially a voltage-controlled capacitor. They have been around since the 1960s and are commonly used in voltage-controlled oscillators, parametric amplifiers and frequency multipliers.

Here's how it works. When a diode is operated in a reverse-biased state very little current flows in the device. The effect of applying the reverse bias voltage is to control the thickness of the depletion zone and therefore its p-n junction capacitance. The greater the applied voltage, the greater is the depletion zone and the smaller the capacitance. Most diodes exhibit this characteristic to some extent but varicaps are manufactured to exploit this effect and increase the capacitance over a larger range.

The varicap used in this project (1SV149) has a very large capacitance variation and was designed to replace the tuning capacitor in AM radios. It has high Q (at least 200), a small package, high capacitance ratio, and low voltage operation. It can be found on the internet for under a dollar! The varicap capacitance variation for the 1SV149 with respect to applied dc voltage is shown in Figure 4.

Substituting a varicap for a mechanical capacitor requires a bit of planning. We need to know the capacitance range covered and the tuning voltage required. The tuning curves shown in Figure 3 covered a range of 30 pF to 365 pF. So we would like to find a varicap that covers that range with a reasonable bias voltage range. The 1SV149 varicap covers 25 pF to 500 pF with a voltage range of less than 10 V.

When the 1SV149 varicap is substituted for the mechanical capacitor using an

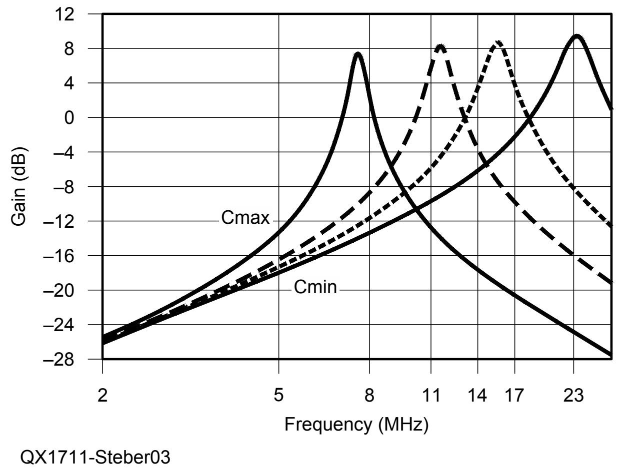

Figure 3 — Four frequency response curves of the tuned preamplifier as capacitor *C* is varied.

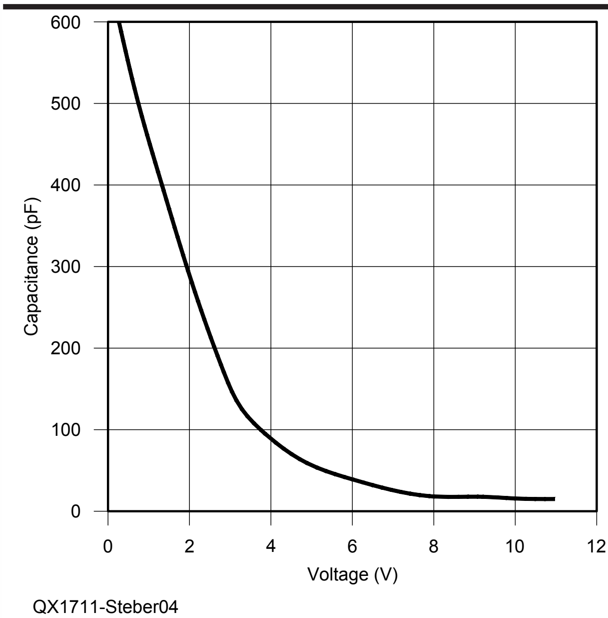

Figure 4 — Varicap capacitance *C* versus applied dc voltage for the 1SV149 diode used in the project. Data was taken from the manufacturer's data sheet.

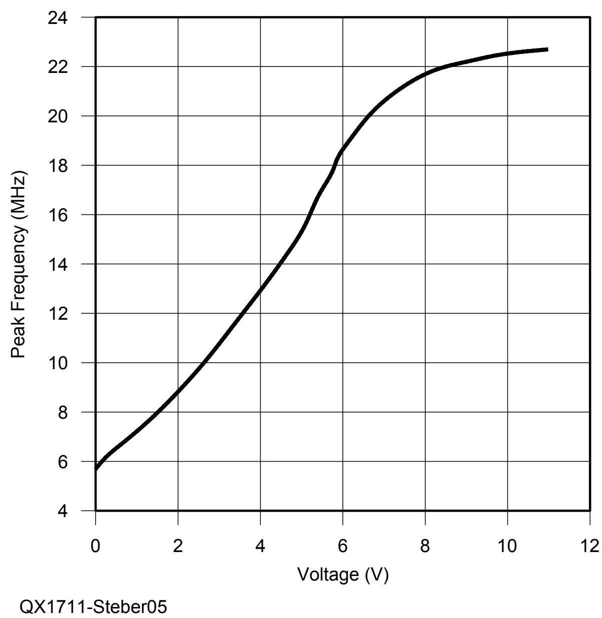

Figure 5 — Variation of peak frequency with varicap voltage. Data is taken for the 1SV149 used in the project. Frequency range is about 6 to 23 MHz.

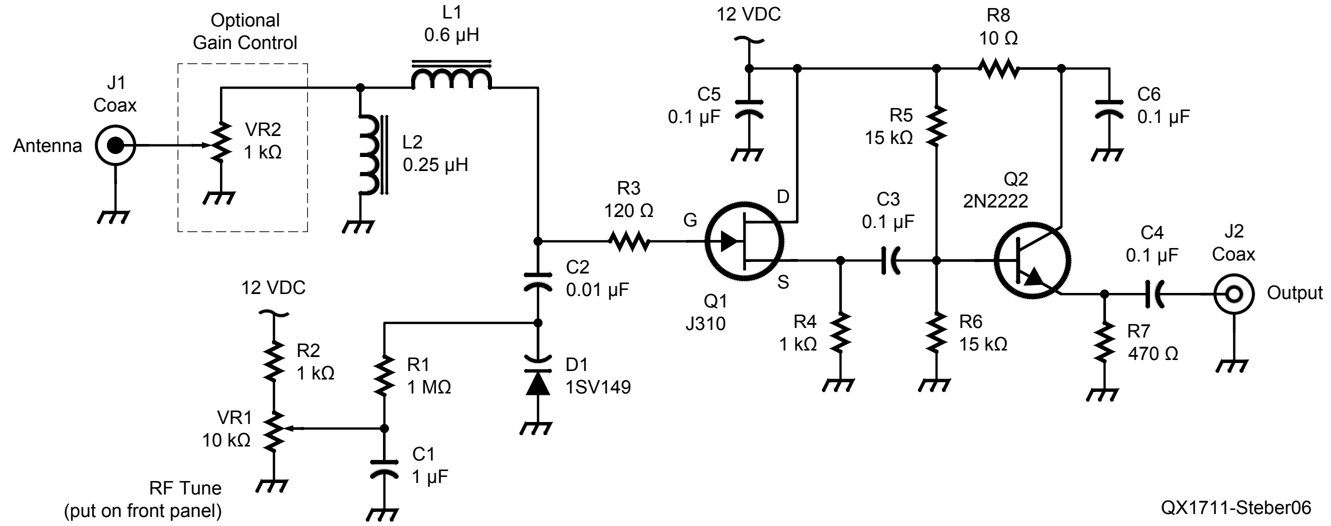

Figure 6 — Schematic diagram of the tunable RF preamplifier. The component values are shown in Table 1.

appropriate circuit, the tuning law shown in Figure 5 is obtained. As is seen, the varicap easily covers the same range as the mechanical capacitor and more — in this case 6 to nearly 23 MHz.

Tunable RF Preamplifier Design Notes

Figure 6 shows the complete schematic of the RF preamp. This circuit was designed using a SPICE simulator, LTspice.[1] After the breadboard circuit was built, it was analyzed using a spectrum analyzer with tracking generator. Very close agreement was found between the Spice simulation and the actual hardware.

This tunable RF preamp can be built for about US $25, depending on your parts inventory. It does not require extraordinary skill with RF circuits. In fact it makes a nice weekend project once the materials are on hand. It is unique in some aspects, such as manual tuning the peak frequency. It will not compete with an expensive transceiver. But it does produce good results in many situations. It made my radios perform significantly better.

Here's how the circuit works. Starting at the antenna there is an optional gain control *VR*2. Its purpose is to reduce the signal level to the preamp if necessary. The preamp does provide RF gain of 6 to 9 dB, which helps with digging out weak signals. But if the signals are too strong, just reduce them with this control.

Next is the tuned circuit consisting of *L*1, *L*2, *C*2 and varicap *D*1. It looks very much like that of Figure 2 and operates the same way. Capacitor *C*2 blocks the dc that is on the varicap *D*1. If *C*2 is made much higher than the capacitance of varicap, the varicap capacitance dominates since they are in series. *R*1 feeds the dc voltage to *D*1 and is very large to avoid loading the *LC* circuit. *VR*1, *R*2 and *C*1 are there to provide a filtered, adjustable dc voltage to control the varicap. *VR*1 should be mounted on the front panel of your unit. Try to obtain a *VR*1 that rotates over a large angle (320 degrees) as this will provide finer control over your tuning.

Table 1.
Components values for the RF tunable preamplifier.

Qty	*label*	*value*	*description*
1	C1	1 µF	electrolytic capacitor
1	C2	0.01 µF	ceramic capacitor
4	C3, C4, C5, C6	0.1 µF	ceramic capacitor
1	L1	0.60 µH	inductor, 11 turns T50-6 core
1	L2	0.25 µH	inductor, 5 turns T50-6 core
1	R1	1 MΩ	1/4 W 5% resistor
2	R2, R4	1 kΩ	1/4 W 5% resistor
1	R3	120 Ω	1/4 W 5% resistor
2	R5, R6	15 kΩ	1/4 W 5% resistor
1	R7	470 Ω	1/4 W 5% resistor
1	R8	10 Ω	1/4 W 5% resistor
1	VR1	10 kΩ	potentiometer
1	VR2	1 kΩ	potentiometer (optional)
1	D1	1SV149	varicap diode
1	Q1	J310	FET
1	Q2	2N2222	bipolar transistor
2	J1, J2	connector	coax connector

*Q*1 (n-channel JFET J310) is used as a high impedance buffer for the *LC* circuit. It has a resistor *R*3 at the gate to reduce possible instability. It must have a bypass capacitor *C*5 close to the drain *D* of the device. The last stage is a standard bipolar transistor *Q*2 that provides a low impedance output. *Q*2 is a 2N2222 type, but if a higher noise figure can be tolerated a 2N3904 may be used. For a lower noise figure try a 2N5109 — but this one may be hard to find. Also be careful of the P2N2222, which has reversed pin order.

BNC connectors were used for *J*1 (antenna) and *J*2 (output) as they matched my equipment. Other connector types may be used. A standard 12 V dc power supply is used. If there is noise from the power supply, add an electrolytic capacitor between the 12 V dc line and ground.

Various techniques may be used to build this preamp. Use your own ingenuity! Some good construction methods may be found in previous *QST* articles or one of the ARRL Handbooks.[2] I constructed a breadboard on a small solderable copper-pad perf-board. A simple PCB inside a metal case would probably be the best approach.

Tunable Preamplifier Modifications

The tuning range measured for this circuit was 6 to 23 MHz. This range can be changed easily. It is mainly dependent on the inductance of $L1$, $L2$ and capacitance of C. It is difficult to predict the range accurately. This is because inductors may be constructed slightly differently, the stray capacitance of the circuit is unknown, and the varicaps have a large range of tolerance.

First, lets take a look at the problem theoretically. The peak frequency f occurs at resonance

$$f = \frac{1}{2\pi\sqrt{(L1 + L2)C}}.$$

The tuning range for ($L1$+$L2$) equal to 0.85 μH and two values of C (30 pF and 500 pF) yields a range of 7.7 MHz to 31.5 MHz. This is quite different from the measured values — most likely because the inductor values are slightly different and there is stray capacitance.

To accurately calibrate the tuner, you must measure the response after building it. A suitable RF generator would prove useful in this case. With that caveat, here are some ranges for my circuit that I obtained experimentally.

Choosing $L1$ = 2 μH and $L2$ = 0.68 μH covers 4.3 MHz to 11.9 MHz. Going even lower choose $L1$=10 μH and $L2$=2 μH which covers 2.1 MHz to 8.0 MHz. You can play with inductor values to get many ranges. You may want to consider putting in a range selector switch to cover the ranges you want.

Generally speaking, $L2$ is chosen to provide 25 to 100 Ω reactance over the frequencies of interest to match the antenna. But that is not a strict rule as the tuner can be used with many different antennas, even long wires.

Final Tuning

The RF tunable preamplifier can prove helpful in a variety of interference situations. Even though its design is simple, the varicap works well and is a good substitute for the mechanical capacitor. One nice benefit of using the varicap is that the variable resistor *VR*1, controlling the dc voltage, has a larger angle of rotation (320 degrees) than the mechanical capacitor (180 degrees) and therefore has finer control. The varicap also has a larger range.

Using the preamp is straightforward. Simply adjust the front panel-tuning resistor *VR*1 until the received signal is the loudest. If you are using decoding software such as JT9 or Fldigi that have a spectrum analyzer display you will see a pronounced increase in the signal as you approach the peak. Remember to tune slowly.

Conclusion

I enjoyed constructing and using this preamp. Hopefully you will find that to be the case as well. While building projects like this is fun, they can also be educational. Consider demonstrating this application of a varicap in a teaching situation such as a presentation at your local ham club or possibly as an outreach tool at your local high school science class.

When you get your RF tuner working, please let me know about it. With the radio interference reduced, you might now be able to copy those weak signals from the far distant regions of the world.

George R. Steber, Ph.D., is Emeritus Professor of Electrical Engineering and Computer Science at the University Of Wisconsin-Milwaukee. He is now semi-retired having served over 35 years. George, WB9LVI, has an Advanced class license, is a life member of ARRL and IEEE and is a Professional Engineer. His last article for QST was "An Easy WSPR 30 Meter Transmitter" in the January 2015 issue. George has worked for NASA and the USAF and keeps busy working and lecturing on various subjects at the University. He is currently involved in cosmic ray research and is designing equipment to study them on a global basis. In his spare time he enjoys WSPR-X mode JT9, racquetball, astronomy, and jazz.

Notes

[1]LTspice, **www.linear.com/designtools/software/**.

[2]*The ARRL Handbook for Radio Communications,* 2017 Edition. Available from your ARRL dealer or the ARRL Bookstore, ARRL item no. 0628. Telephone 860-594-0355, or toll-free in the US 888-277-5289; **www.arrl.org/shop**; **pubsales@arrl.org**.