Let's look at electronic tuning diodes, some unusual newsletters, parametric amplification, association book resources, and preventing modem dropouts.

DON LANCASTER

We might start off with the reminder that we do have our technical helpline available for your use per the box below. That's where you can go for tech help, referral to highly qualified consultants, for book and software purchases, and for general off-the-wall networking.

Your best calling times are weekdays 8–5, *Mountain Standard time.* Before you call, please re-read the *entire* column and especially the *Names and Numbers* and *Resource* boxes. Hardware Hackers calling without a pencil or pen handy will get chopped up and fed to the cows.

You could also reach me via my personal BBS, otherwise known as *GEnie* PSRT. Call (800) 638-9636 for voice connect info.

But, please do note that I am an independent developer and author sitting here on my sand dune in the middle of the Upper Sonoran desert. I have very little input to any **Radio-Electronics** editorial policy and know next to nothing about projects by other authors. To leave comments for the editors, you may want to use the RE-BBS at (516) 293-2283.

Yeah, I sometimes do welcome any visitors that call in advance. But do note that Gurus are supposed to be hard to reach, because (A) it adds to the mystique, and (B) the Guru's and Swami's Union Local #415 rules demand it. At any rate, there is a seven-hour drive involved in reaching the nearest airport from here. I won't even mention the deadly Gila Monsters or hostile Indians.

Every once in a while I'll get a call that sounds reasonable at the time, but after thinking things over... For instance, one Hardware Hacker wanted to crystal control that low-cost BA1404 FM stereo broadcaster we've looked at in past issues. He wanted to do this so that several actors in a play could be on the same frequency.

Uh, whoops. You can't get there from here. Sure, you can crystal control your BA1404. And you certainly can put as many of them as you want on the same frequency. But one of the key properties of FM reception is that you will receive only your *strongest* station, with virtually zero pickup of any of those others. That normally desirable action is known as the *FM capture effect* and is caused by the hard limiting present in virtually all FM receivers. As little as a fraction of a decibel can cause any one signal to utterly and totally dominate. Sorry about that. We return you to our column already in progress...

Electronic tuning

The traditional method of tuning a resonant circuit to your desired frequency is to use some adjustable or variable capacitor. While obvious and cheap, those capacitors are often large and sometimes expensive, could be sensitive to fields and vibration, and usually require human intervention for their use. These days, it is much better to go to one or more *electronic tuning* methods.

The simplest method of electronic tuning is to never do it. As much as possible, you purposely design out any need for a variable capacitor or a direct replacement. For instance, you use digitally synthesized frequencies instead of a local oscillator or BFO. You use switched-capacitor filters or active filters that are tunable by an input frequency or voltage. Or you use ceramic or SAW filters that are so precise and so repeatable that no adjustment is needed. You also tend to use a few higher-quality filters, rather than lots of individually tuned and cascaded LC circuits.

But after all of that, there remain times and places where you'll still need a few electronically variable capacitors. Selecting a station on a radio or TV are obvious examples.

One very popular, well performing, and ultra-low-cost electronic tuning method is called a *varactor diode*, sometimes known by the trademarked name *Varicap*. Varactor diodes are diodes that have been optimized to look and behave like a high-quality electrically variable capacitor.

Most any diode conducts current in the forward direction and blocks it in the reverse direction. Specifically, when you reverse bias a diode, you create a *depletion region* containing neither electrons nor holes. As you increase your reverse bias, the depletion region gets thicker, and vice versa. Thus, *any* diode will behave as an electrically variable capacitance as you vary its reverse bias voltage.

For most diodes, this unavoidable depletion region capacitance is a flaw that restricts your maximum speed of operation. But in a varactor diode, the depletion-region capacitance is purposely made rather large, quite high quality, and very controllable.

Figure 1 shows you a typical circuit. From the electrical control side, you simply reverse bias your diode by way of a large series resistance or some other method that has a very high RF impedance. When you change the value of the voltage, you electrically change the capacitance of the varactor's depletion region, and thus tune your circuit. Typically, you change your tuning voltage over a 3- to 30-volt reverse-bias range.

On the resonant circuit side, you do have to provide a DC return path to ground for the tuning voltage bias. You also have to provide a series blocking capacitor to keep any other

NEED HELP?

Phone or write your **Hardware Hacker** questions directly to:
Don Lancaster
Synergetics
Box 809
Thatcher, AZ 85552
(602) 428-4073

DC path from shorting out your diode. Normally the series capacitor is very much larger than the varactor's capacitance, so it does not significantly alter any of your resonance calculations.

Sadly, the varactor's capacitance changes nonlinearly with the reverse voltage. Depending on the varactor, you might have 60 pF at 1 volt reverse bias, 45 pF at 2 volts, and 18 pF at 20 volts. Thus, your first couple of volts of reverse bias will by far give you the most variation. The plot of capacitance versus reverse voltage is roughly linear when plotted on semi-log paper.

Varactor capacitances can go from a fraction of a picofarad with exotic microwave devices on up to several hundred or more picofarads for use in audio filters or AM tuning. You can sometimes use giant silicon power diodes for lower frequency varactor experiments. But the Q will often be low when you try that, and the tuning range will be limited.

The *capacitance range* of a varactor is usually defined as the ratio between your 3- and 30-volt bias settings. An ordinary varactor will often have a capacitance range of

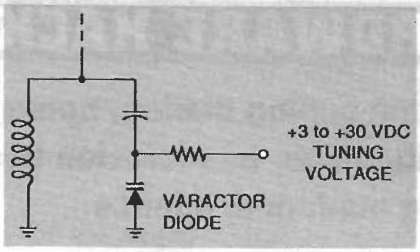

FIG. 1—ELECTRONIC TUNING using a varactor diode. The diode depletion-layer capacitance varies with the applied reverse bias. The large series capacitor serves as a DC block to prevent shorting out the tuning voltage.

3:1.

But note that a frequency change varies with the *square root* of your capacitance change in any resonant circuit. So, this type of 3:1 varactor can shift a resonant frequency only by 1.73 or so.

One way to increase the range of a Varactor is to cheat and use a lower bias voltage. Your capacitance will increase dramatically for very low values of reverse bias. But at that point the diode will start to conduct and very much reduce the available Q or selectivity for your tuned circuit. Linearity will also be awful.

For wider tuning ranges, special varactors are obtainable which have different doping profiles. Varactors with a medium tuning range have an *abrupt* doping profile, while those with very high tuning ranges use a *hyperabrupt* profile.

The tradeoffs for a wider tuning range are more nonlinearity, somewhat higher cost, lower circuit Q, and harder tuning. It will also become vastly more sensitive to noise and the precision of your tuning voltage.

The AM broadcast frequencies of 550 to 1650 kilohertz have a 3:1 range. Thus, you should use a hyperabrupt varactor having at least a 9:1 and preferably a 10:1 tuning range here. The hyperabrupt *Motorola MVAM108* is one good choice here, having an extreme 15:1 range.

Those television frequencies are spread out over a very wide range. To prevent having to tune them all at once, three varactor tuners are separately used in several individually selected circuits. One for the lower VHF channels 2–6, a second for the high VHF channels 7–13, and a third for the remaining UHF channels. And sometimes a fourth for special cable channels. Note that there is a rather large frequency gap between channel 6 and channel 7 that holds both the FM broadcast band and emergency services.

Should you instead want to restrict the tuning range of a varactor, you can either put a fixed capacitor in parallel with it or else use a narrower voltage control range. The fixed parallel capacitor is often the better choice.

Varactors work best with tuned signals in the microvolt range. Should your signals being tuned get above several millivolts, the signals themselves can add to or subtract from the tuning voltage. Thus, your positive signal excursions will increase the resonant frequency and vice versa—which can introduce moderate to severe second-harmonic distortion.

You might resolve that possible distortion problem by using a pair of varactor diodes as shown in Fig. 2. The two varactors are in parallel as far as the DC tuning voltage goes, but are in series with any signals being tuned. Thus, on a positive peak, the capacitance of one Varicap will increase as the other decreases, and largely cancel each other out.

Dual varactors in a single package are rather popular. The *Motorola MV104* is one example. Note that two capacitors in series give you *one half* the total capacitance. Be sure to allow for that in your designs.

It is extremely important to have a *very* stable reference for your tuning voltage, since any drift at all could detune your circuit. If possible, you will also want to use some sort of feedback to keep your tuning locked on channel. Various types of automatic frequency control (AFC) can sometimes do that for you.

Sadly, varactors drift over temperature. Their values will increase with increasing temperature. One typical value is in the 200-parts-per-million range. On the other hand, a regular diode that is *forward* biased will have

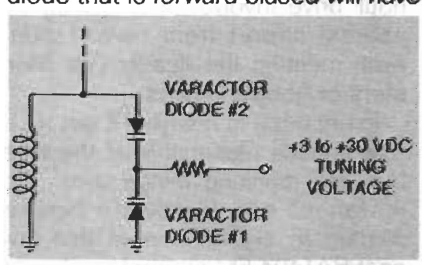

FIG. 2—A PAIR OF BACK-TO-BACK varactor diodes can be used to prevent larger signals from detuning themselves. A positive signal swing raises the capacity of one varactor and lowers that of the other. The changes largely cancel out.

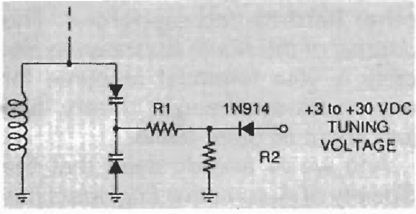

FIG. 3—A TEMPERATURE compensated varactor tuner. The forward drop temperature drift of the ordinary diode can be used to offset the capacitance drift of the reverse-biased tuning varactors. Resistor R1 has to be large enough to not load the tank circuit. Resistor R2 adjusts the temperature coefficient.

a current-dependent drift with a negative temperature coefficient.

Figure 3 shows how to add an ordinary diode in series with your tuning voltage to temperature-compensate a varactor diode. The load resistor of the diode is adjusted to give a minimum overall drift. Sometimes a parallel capacitor can also be added to the circuit having a chosen temperature coefficient.

A precise temperature compensation over a wide range could get tricky. At the least, everything has to be tightly heatsinked together. More details appear in the *Motorola* ap note *AN551*.

As we've just seen, *Motorola* is one leading supplier of a wide variety of low-cost and easy-to-get varactor diodes. Some cost under a dollar. See their *RF Device Data II* handbook for data sheets and ap notes.

Parametric amplifiers

Surprisingly, varactor diodes were not initially designed for electronic tuning. Instead, they were created for a unique beastie once known as a *parametric amplifier*. Back in the days of tube-style UHF TV tuners with 35 decibel noise figures, the idea of an ultra-low-noise, high-gain, high-frequency amplifier that used nothing but a diode sounded like a great idea.

Today, low-noise and high-gain microwave transistors are a buck each from such outfits as *Mini-Circuits Lab* and *Avantek*. Paramps are largely limited to esoteric ultra-microwave lab uses and for optical and infrared experiments. Although I do strongly suspect you'll soon see a stunning resurgence of paramps in a brand-new application area.

Figure 4 shows you how the parametric amplifier works. This is exactly the same idea as pumping a swing on the playground. The local oscillator called the *pump frequency* causes the capacitance of a varactor to change in a time-varying manner. The "parameter" we are varying is the diode capacitance. A low-level input signal known as the *input frequency* is also routed to the same time-varying capacitor. A filter extracts an output signal that is called the *idler frequency*.

The net result can be a very strong and low-noise amplification and a possible frequency conversion for your input signals. Since a purely reactive capacitor is in use, there are theoretically none of those noise problems associated with resistance or traditional tube or semiconductor amplifier circuits. I once used a plain old three-cent 1N914 computer diode

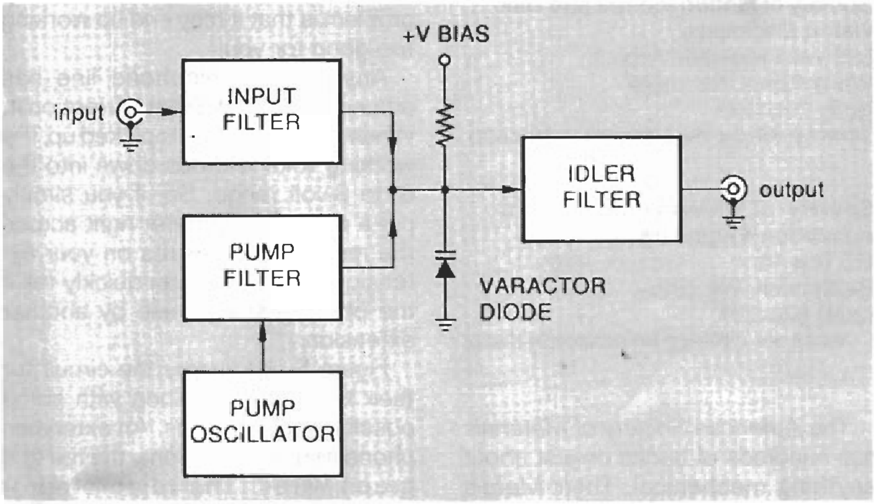

FIG. 4—A VARACTOR DIODE PARAMETRIC AMPLIFIER in which a diode provides low-noise amplification. The pump frequency causes the varactor capacitance to vary in such a time-dependent "parametric" way that its interaction with the input frequency produces an amplified output at the idler frequency.

to produce 20 decibels of gain and a 2-decibel noise figure at 600 MHz. The diode was DC back-biased to −3 volts or so and a suitable pump frequency was capacitively superimposed. Long ago and far away.

Paramps can be designed as upconverters with gain, as downconverters with loss, or as negative-resistance devices with potentially high gain but possible instabilities.

The key math behind paramps is known as the *Manley-Rowe* relations. One horse's mouth classic on the subject is Blackwell and Kotzebue's *Semiconductor Diode Parametric Amplifiers*, published by Prentice Hall, way back in 1961. Included is a good summary of Manley-Rowe and an extensive bibliography. For more modern info on paramps, check out the *Dialog Information Service*.