CARR'S CORNER

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Using and Stabilizing Varactor Diodes

Have you tried to buy an air variable capacitor for a receiver project recently? They are very rare these days. I've seen them advertised in British electronics catalogs, and in antique radio supplies catalogs in the USA, but otherwise it's catch as catch can. So, what to do? Well, it seems that commercial radio manufacturers today use voltage variable capacitance diodes, commonly called varactors, for the tuning function. These special semiconductor diodes exhibit a capacitance across the PN junction that is a function of the reverse bias potential (see Figure 1).

The diode representations shown in Figures 1a and 1b are in the form of PN junction diode block diagrams. In the N-type region negative charge carriers (electrons) predominate, while in the P-type region positive charge carriers (holes) predominate. When a reverse bias potential is applied, as in Figure 1a, the charge carriers are pulled away from the junction region to form a depletion zone that is depleted of charge carriers (hence acts like an insulator or "dielectric"). The situation is the same as in a charged capacitor: an insulator separating two electrically conductive regions. Thus, a capacitance is formed across the junction that is a function of the width of the depletion zone. And because the size of the depletion zone is a function of applied voltage (compare Figures 1a and 1b), the capacitance of the junction is also a function of applied voltage. A varactor is a diode in which this function is enhanced and stabilized.

Figures 2a and 2b show two common circuit symbols for a varactor diode. In both cases, the normal diode "arrow" symbol is somehow combined with a pair of parallel lines representing a capacitor. In some cases, I've seen a variant on Figure 2a in which an arrow is drawn through the parallel plates by extending one side of the arrow symbol. I suppose that's used to indicate the property of "variableness."

Several different varactors are listed in Table 1. Several of these are also easily available in the ECG and NTE replacement transistor lines sold by parts houses that normally deal with radio-TV repair shops. Look up the specs for NTE-611 to NTE-618, or ECG-611 to ECG-618 to see if they are appropriate for your application. Alternatively, look up the replacements for those diodes in the table from the ECG or NTE crossover directories.

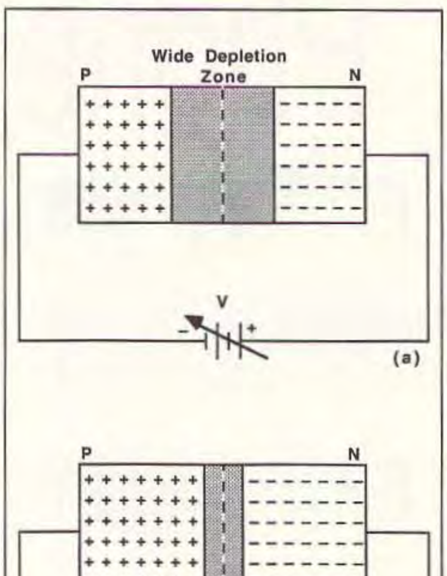

Figure 1. Varactor diode under two different reverse bias conditions.

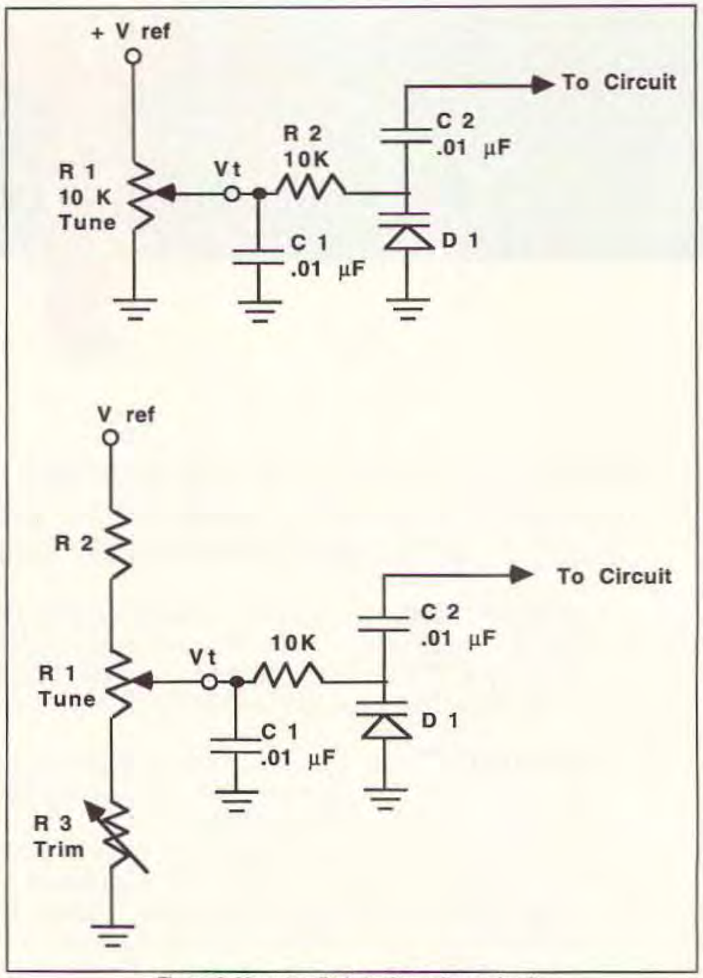

Figure 3. Varactor diode tuning voltage circuits.

Varactor Tuning Circuits

The varactor diode wants to see a voltage that is proportional to the desired capacitance. Several different circuits are used to provide this function, some of which are shown in Figures 3 and 4. In all cases, the tuning voltage must be supplied from a reference voltage source that is very stable. It is normally considered good engineering practice to provide +Vref from a separate voltage regulator that serves only the varactor, even when the maximum value of the voltage is the same as the rest of the circuit (e.g. +12 volts). Therefore, always use a voltage regulator to provide the tuning voltage source potential. Most varactors use a maximum voltage around +30 to +40 volts, while many intended for car radio applications are rated only to +12 or +18 volts (check!).

The simplest and probably most popular circuit is shown in Figure 3a. In this circuit, a potentiometer (R1) is connected across the Vref supply, so the tuning voltage (Vt) is a function of the potentiometer wiper position. In many cases, a 0.001 μF to 0.01 μF capacitor is connected from the wiper of the potentiometer to ground in order to snuff any noise pulses so they don't alter the tuning (they are, as far as the diode is concerned, valid tuning voltage signals!). A series current-limiting resistor (R1), usually of a value between 4.7k ohms and 100k ohms, is used to protect the diode in case the voltage gets to the breakover point, and also to isolate its capacitance from the tuning circuit (otherwise, C1 would always predominate). In many cases, a DC blocking capacitor (C2) is needed to prevent the tuning voltage from affecting following circuits, or other circuit voltages from affecting the varactor diode tuning voltage. From the point in Figure 3a marked "To Circuit," the varactor network acts like a variable capacitor.

A variant circuit is shown in Figure 3b. In this circuit the tuning voltage is only a small portion of the reference voltage. Thus, the tuning voltage is produced by a voltage divider made up of three resistors: R1, R2 and R3. In some cases, one or more of the other resistors will be a trimmer potentiometer to set the "fine" or "vernier" frequency of the overall circuit.

Regardless of which tuning circuit is used, the resistors, including the potentiometer, should be low temperature coefficient types in order to reduce thermal drift. Ordinary carbon composition resistors are probably not suitable for most applications.

If you wish to sweep a band of frequencies, i.e. in a sweep generator or swept receiver (e.g. panadaptor or spectrum analyzer), then replace the +Vref potential with a sawtooth waveform. The sawtooth waveform is a linear ramp that rises to a specified maximum voltage, and then drops back to zero abruptly. Unfortunately, it is rarely the case that the sawtooth voltage range, the desired swept fre-

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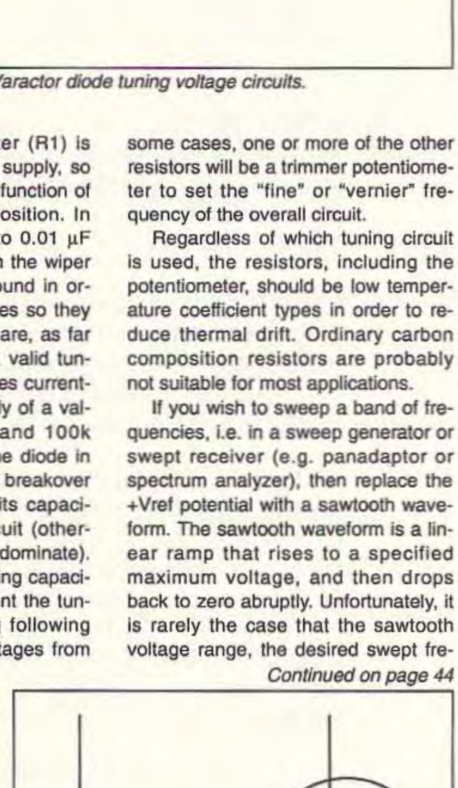

Figure 2. Varactor diode symbols.

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quency range, and the varactor voltage characteristic are in sync with each other. For those situations we need to be able to provide a sawtooth of variable amplitude to set the sweep width and a DC offset tuning voltage to provide the center frequency function. Figure 4 shows how this might be done.

The circuit shown in Figure 4 uses three operational amplifiers to provide the combination tuning voltage. Op amp A1 provides a variable amplitude sweep width control to change the sawtooth amplitude. If feedback resistor R5 is made 10k ohms, then the output sawtooth will have the same amplitude as the input sawtooth. If higher or lower amplitude is needed, then adjust the gain of A1 by selecting a different R5 value: Gain = -R5/R6 = -R5/10k ohms (the "-" indicates that the circuit is an inverter). For tuning voltages to 18 volts, ordinary 741s can be used for A1 through A3.

Digital frequency control can be accomplished by supplying the reference voltage (+Vref) from a digital-to-analog converter (DAC) that has a voltage output. The binary number applied to the DAC binary inputs will set the tuning voltage, which in turn sets the capacitance of the diode. Those who wish to experiment with low cost components will find that the eight-bit National DAC0800 series devices (available in most local parts stores in the Jameco Jim-Pak display) will provide 256 different steps of voltage (hence also of capacitance and frequency). An op amp is recommended to convert the current output of the DAC080x to a voltage (the national Linear Data Book gives example circuits as well as specs for the different devices in the series).

Temperature Compensation

There is one nasty little problem with the varactor tuning circuit—the thermal drift can be horrible! According to one source, the temperature coefficient of capacitance (ppm/xC) varied from about 30 ppm/xC at +Vref = 30 volts to 587 ppm/xC at +Vref = 1 volt. Ouch! There are three approaches to this problem: ignore it; use Figure 5 or Figure 6.

The circuit shown in Figure 5 uses a fixed, regulated voltage for +Vref,

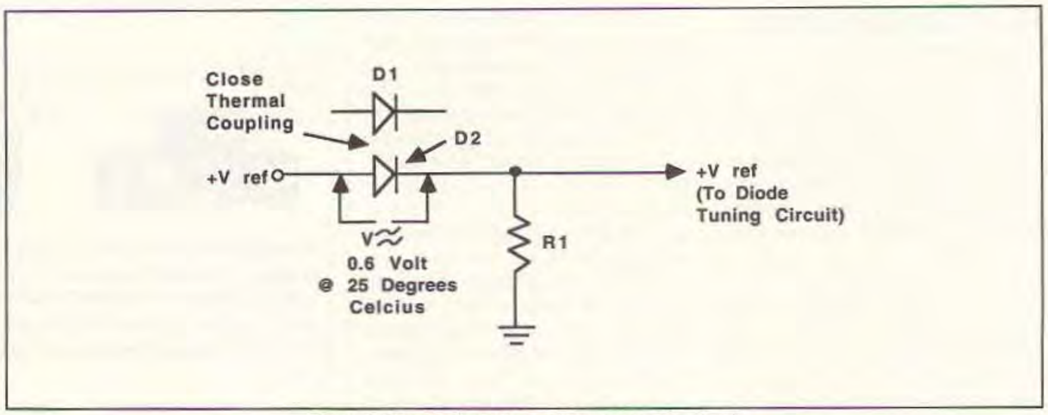

Figure 5. Simple diode thermal compensation circuit.

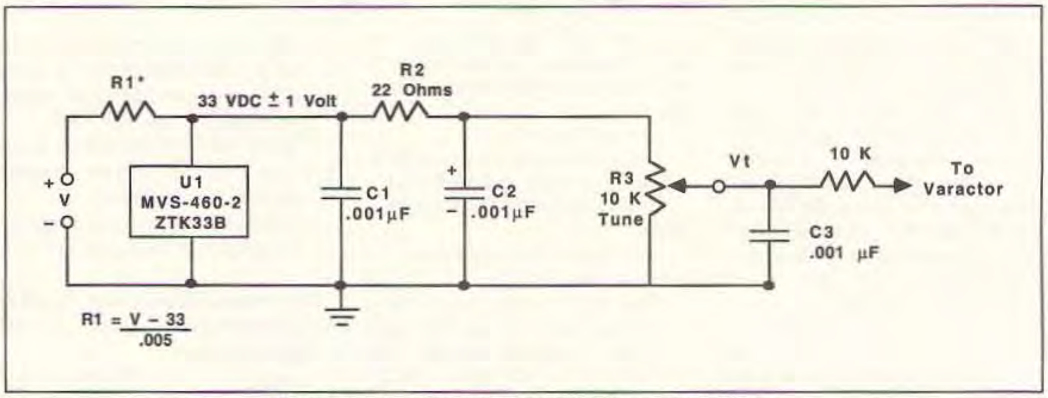

Figure 6. Using a special varactor thermal regulator IC device.

but passes it through an ordinary silicon diode (D2) that is in close thermal proximity to the varactor diode (so they see the same temperature environment). When resistor R1 is set to draw a current through D2 sufficient to get the voltage drop into the 0.6 volt region, then the output voltage +Vref will track the thermal changes to counteract the change of capacitance. In practice, R1 can be the tuning potentiometer when diodes such as 1N4148 or 1N914 are used.

Figure 6 shows a circuit using a special zener diode voltage regulator sold in Europe under both MVS-460-2 and ZTK33B type numbers. It appears to be a +33 volt zener diode that has a -2.3 mV/xC temperature coefficient. It will provide a nominal +33 volt output for all input voltages (V) greater than 34 VDC. Again, the temperature stabilizer (which looks like a diode) is placed in close thermal proximity to the varactor diode being protected. The MVS-460-2 part is in a TO-92-like plastic package, while the ZTK33B is in the normal glass diode package (similar to 1N60 devices).

"Digital frequency control can be accomplished by supplying the reference voltage (+Vref) from a digital-to-analog converter (DAC) that has a voltage output."

Unfortunately, the MVS-460-2 and ZTK33B are hard to find in the USA. I bought some from Maplins Professional Supplies in England (P.O. Box 777, Rayleigh, Essex, SS6 8LU, England) for £0.382 each (as of this writing £1 = $1.57, but the rate changes daily so check before sending money orders denominated in pounds sterling) in lots of 25 or more. Unfortunately, with a minimum practical order of several pounds sterling, plus a shipping charge of £8 for USA and Canada, it is best to order 25 or so. This translates to $27.38 or so, if the price still holds as of publication date. Ordering from the UK is reasonably easy. You can get an international money order denominated in pounds sterling at many banks, but the fee might make you puke (my bank gets $15, which is why I opened a UK checking account). Alternatively, they will accept Visa, MasterCard or American Express cards. The bank card company will make the currency conversion for you, and they use the rate in effect on the day they make the conversion. I've used all three types of cards to make purchases from UK electronic and old book dealers (my other passion), and have experienced no problems. Give them the card number, expiration date and your signature authorizing the charge.

Well, that's that for varactors. If you want to know more theoretical smoke about the subject, then I recommend Motorola Semiconductor's application note AN847 "Tuning Diode Design Techniques" (Motorola Technical Literature Distribution Center, POB 20912, Phoenix, AZ 85036).

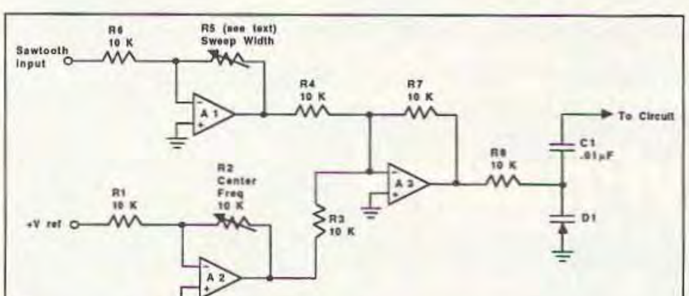

Figure 4. Sawtooth/fixed voltage combiner circuit.

Table 1.

Type No.	Capacitance Range	Tuning Ratio	Frequency Ratio
1N5139	6.8 - 47 pF	2.7 - 3.4	1.6 - 1.8
MV2101	6.8 - 100 pF	1.6 - 3.3	1.6 - 1.8
MMBV105G	120 - 550 pF	10 - 14	3.2 - 3.7
MV209	30 pF	5 - 6.5	2.2 - 2.5