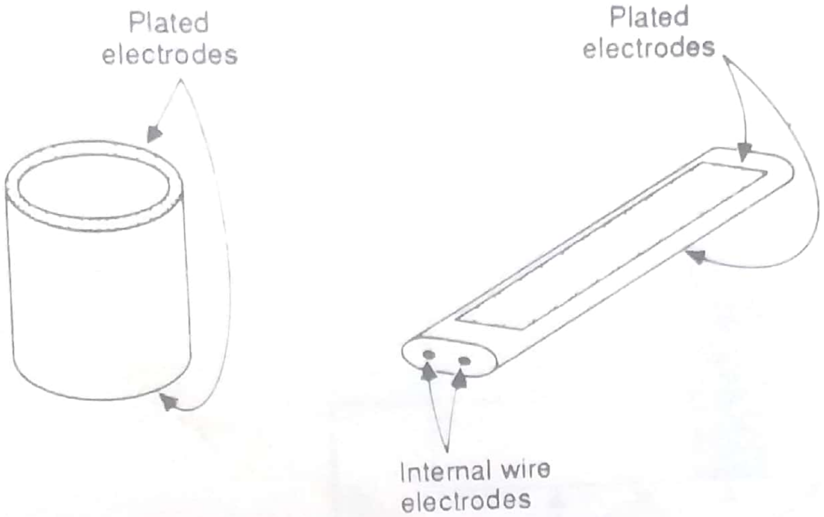


(a) Cylindrical transducer (b) Bimorph

Figure 20-7 Ceramic piezoelectric transducers are produced in a variety of shapes for applications in which quartz crystals are not suitable.

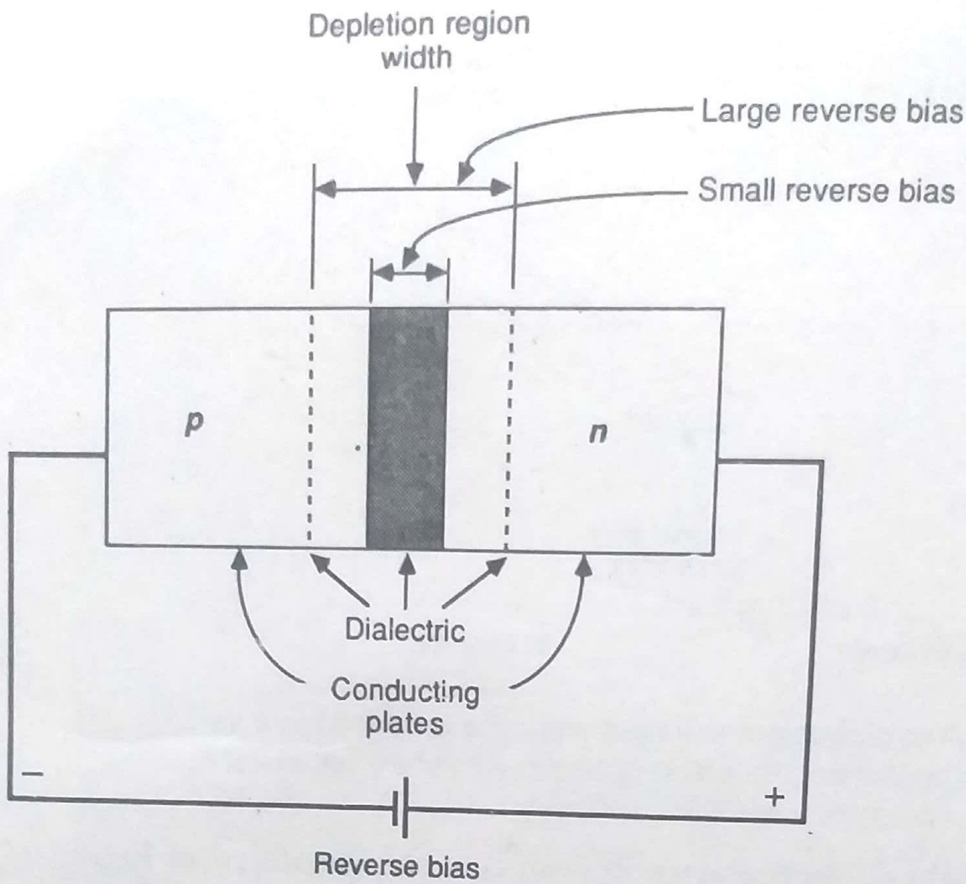
Two types of synthetic piezoelectric transducers are illustrated in Fig. 20-7. Figure 20-7(a) shows a cylindrical-shaped ceramic device with electrical contacts plated on each end. This kind of transducer is frequently used for measuring pressure changes in a liquid, or for listening to underwater sounds. The pressure variations produce electrical signals at the device terminals.

Figure 20-7(b) shows a ceramic device known as a *bimorph*. When supported at one end, electrical signals are generated at the internal and external electrodes by vibrations picked up at the other end. This device is basic to a record-player cartridge. The minute vibrations generated as the stylus moves in the record track are converted into electrical signals and then amplified and fed to speakers.

Varactrons, minicaps, voltacaps, capistors.

20-3 Voltage-Variable Capacitor Diodes

Voltage-variable capacitor diodes (VVCs) are also known as *varicaps*, *varactors*, and *epicaps*, as well as by several trade names. Basically, a VVC device is simply a reverse biased diode, and its capacitance is that of the junction depletion region. Recall that the width of the depletion region at a *pn*-junction depends upon the reverse bias voltage [Fig. 20-8(a)]. A large reverse bias produces a wide depletion region, and with a small reverse bias the depletion region tends to be very narrow. Since the depletion region acts as a dielectric between two conducting plates, the device has the characteristics of a capacitor. As with all capacitors, the depletion layer capacitance C_{pn} is proportional to the junction area and inversely proportional to the width of the depletion region. Since the depletion region width is proportional to the reverse bias voltage, C_{pn} is inversely proportional to the reverse-bias voltage.



(a) Principle of voltage variable capacitor diode

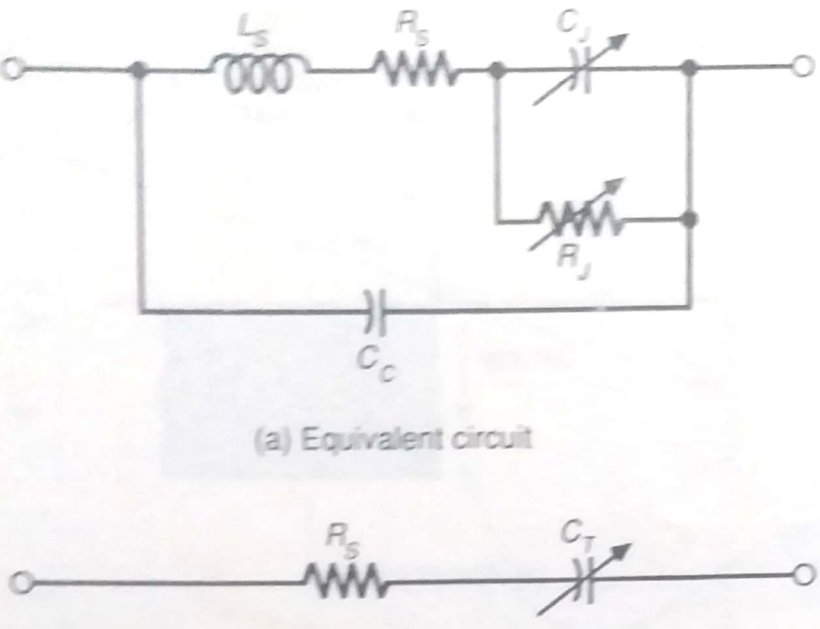
(b) Circuit symbol

Figure 20-8 The voltage-variable capacitor (VVC) diode uses the capacitance of a *pn*-junction. Increasing the reverse voltage widens the depletion region and reduces the capacitance.

This is not a direct proportionality: rather, $C_{pn} \propto 1/V^n$, where V is the reverse bias voltage and n depends upon doping density. The circuit symbol for a VVC diode is shown in Fig. 20-8(b).

Figure 20-9(a) shows the equivalent circuit for a VVC diode. C_J is the *junction capacitance* shunted by R_J (the junction reverse leakage resistance). R_s represents the resistance of the semiconductor material, L_s is the package inductance, and C_c is the capacitance of the package. L_s is normally very small and R_J is very large, so for most purposes the equivalent circuit can be simplified to that of Fig. 20-9(b). In this case the diode capacitance is $C_T = C_J + C_C$. *Q factors* for the device can be as high as 600 at a frequency of 50 MHz. However, since Q varies with bias voltage and frequency, it can be used only as a figure of merit for comparing the performance of different VVCs.

A wide selection of nominal device capacitances is available, ranging from 6 pF to 550 pF. The *capacitance tuning ratio* TR is the ratio of C_T at a



(a) Equivalent circuit

(b) Simplified equivalent circuit

Figure 20-9 The complete equivalent circuit of a VVC diode has many components. The simplified equivalent circuit is made up of the semiconductor resistance R_s and the total (junction + terminal) capacitance C_T

small reverse voltage to C_T at a large reverse voltage. Depending upon the *doping profile* of the device, TR may be as small as 2 or as large as 15. Figure 20-10 shows the doping profiles for an *abrupt junction* diode and for a *hyperabrupt junction* device. For the abrupt junction doping profile, the semiconductor material is uniformly doped and changes abruptly from *p*-type to *n*-type at the junction. In the case of the hyperabrupt junction, the doping density is increased close to the junction. This increased density makes the depletion region narrower and consequently produces a larger value of junction capacitance. It also causes the depletion region width to be more sensitive to bias voltage variations, and thus it produces the largest values of TR. Figure 20-11 shows typical graphs of diode capacitance plotted against reverse bias for abrupt and hyperabrupt junction devices.

The major application of VVC diodes is as tuning capacitors to adjust the frequency of resonance circuits. An example of this is the circuit shown in Fig. 20-12, which is an amplifier with a tuned circuit load. The amplifier produces an output at the resonance frequency of the tuned circuit. Since the VVC diode provides the capacitance of the cirucit, and since C_T can be altered by adjusting the diode bias, the resonance frequency of the circuit can be varied. C_c is a coupling capacitor with a value much larger than that of the VVC diode.

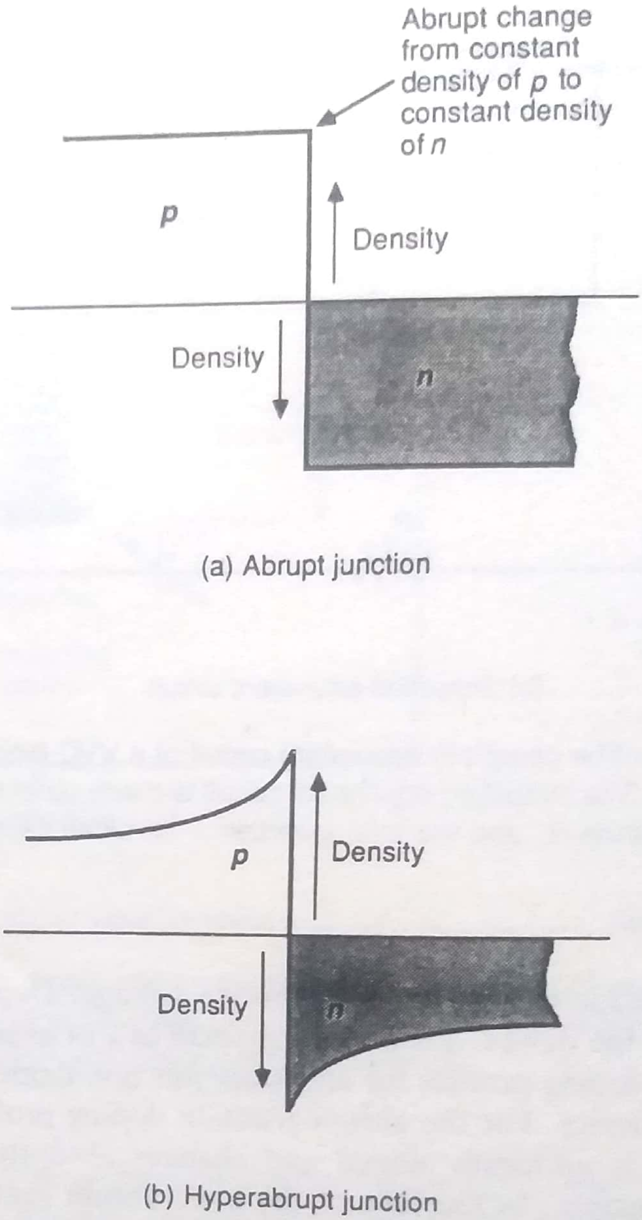


Figure 20-10 Doping profile in abrupt junction and hyperabrupt junction VVC diodes. Doping density is constant in the abrupt junction device. In the hyperabrupt junction diode, the doping density is greatest at the junction.

Example 20-1 Calculate the capacitance tuning ratio TR at 1 V and 10 V for the abrupt junction and hyperabrupt junction devices with the characteristics in Fig. 20-11.

Solution

From the abrupt junction device characteristics in Fig. 20-11,

$$\text{At } 1\text{ V}, \quad C \approx 150 \text{ pF}$$
$$\text{At } 10\text{ V}, \quad C \approx 60 \text{ pF}$$

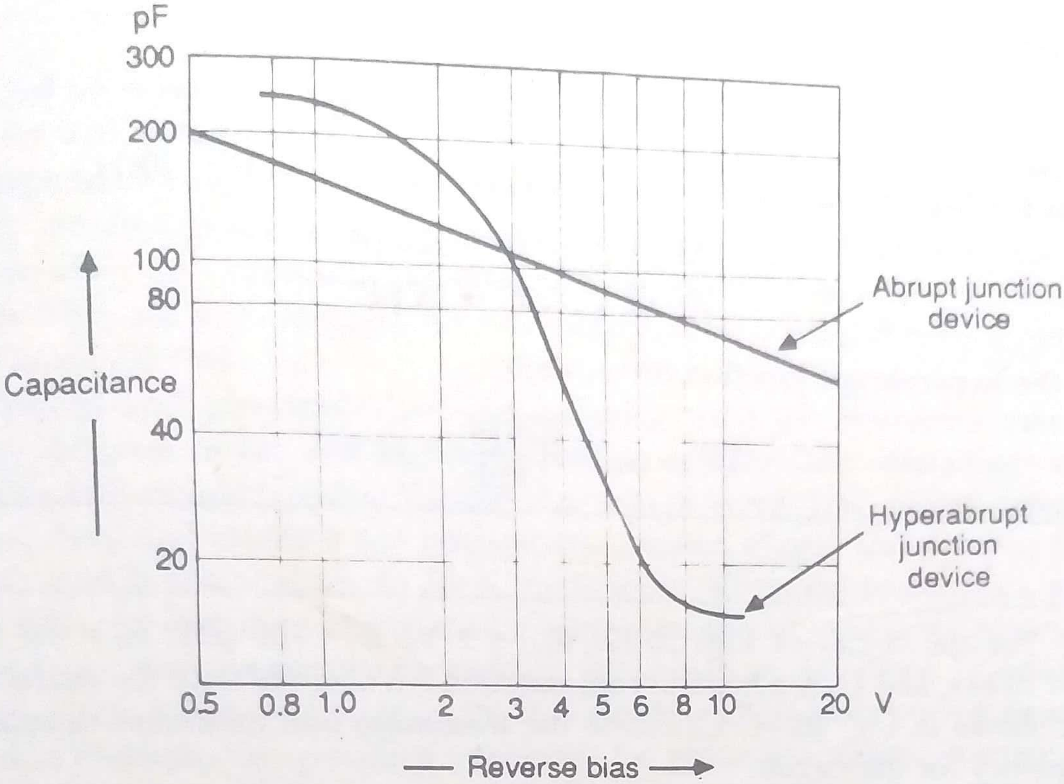


Figure 20-11 Capacitance/voltage characteristics for abrupt junction and hyperabrupt junction VVC diodes. The capacitance of the hyperabrupt junction device shows the greatest change for a given change in bias voltage.

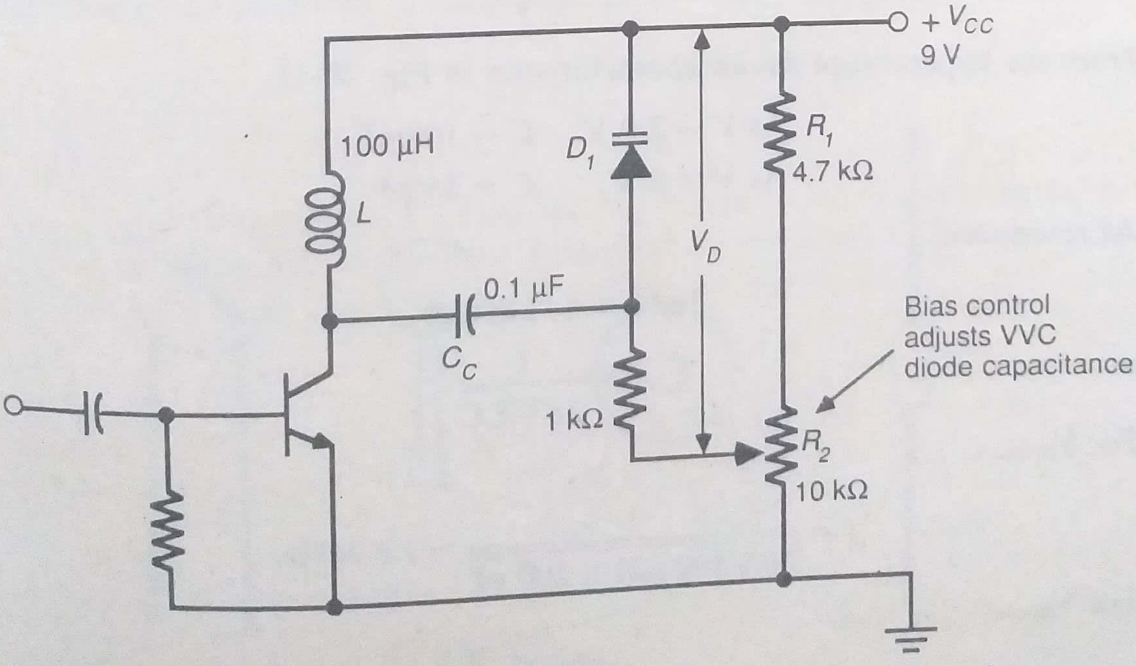


Figure 20-12 The resonance frequency of an amplifier with an LC load can be adjusted by varying the bias voltage on a VVC diode.

For the abrupt junction device, then,

$$TR_{(1V-10V)} = \frac{150\,\text{pF}}{60\,\text{pF}} = 2.5$$

From the hyperabrupt junction device characteristics in Fig. 20-11,

At 1V, $C \approx 220$ pF

At 10 V, $C \approx 15$ pF

For the hyperabrupt junction drive, then,

$$TR_{(1V-10V)} = \frac{220\,\text{pF}}{15\,\text{pF}} = 14.7$$

Example 20-2

For the circuit of Fig. 20-12, $V_{CC} = 9$ V, $L = 100$ μH, $R_1 = 4.7$ kΩ, $R_2 = 10$ kΩ, and D_1 is a hyperabrupt junction VVC diode with the characteristic shown in Fig. 20-11. Calculate the maximum and minimum resonance frequency for the circuit.

Solution

$$V_{D(\min)} = \frac{R_1}{R_1 + R_2} \times V_{CC} = \frac{4.7\,\text{k}\Omega}{4.7\,\text{k}\Omega + 10\,\text{k}\Omega} \times 9\,\text{V} = 2.9\,\text{V}$$

and

$$V_{D(\max)} = V_{CC}$$
$$= 9\,\text{V}$$

From the hyperabrupt device characteristics in Fig. 20-11,

At $V = 2.9$ V, $C \approx 100$ pF

At $V = 9$ V, $C \approx 15$ pF

At resonance,

$$2\pi f L = 1/2\pi f C_1$$

or,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

For $V_{D(\min)}$,

$$f = \frac{1}{2\pi\sqrt{100\,\mu\text{H} \times 100\,\text{pF}}} \approx 1.6\,\text{MHz}$$

For $V_{D(\max)}$,

$$f = \frac{1}{2\pi\sqrt{100\,\mu\text{H} \times 15\,\text{pF}}} \approx 4.1\,\text{MHz}$$

The resonance frequency range is 1.6 MHz to 4.1 MHz.
