using the p-i-n diode

The p-i-n (or PIN) diode is a semiconductor diode that contains a region of almost intrinsic (i-type) semiconductor between the p-type and n-type regions. The depletion layer associated with the p-n junction is entirely contained within the i-type region in the p-i-n structure. At low signal frequencies the diode behaves similarly to a normal p-n junction, but at high frequencies it exhibits a variable resistance. The p-i-n diode is used extensively as a modulator and switch in microwave systems.

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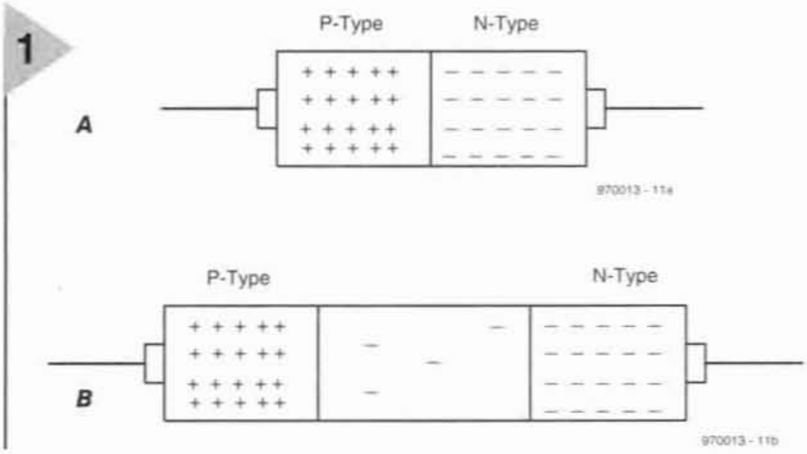


Figure 1. (A) PN junction diode; B) P-I-N diode.

Let us consider some of the applications of the p-i-n diode. Most modern radio transceivers (i.e. "transmitter–receivers") use "relayless" switching to go back and forth between the *receive* and *transmit* states. Relayless switching is usually done with p-i-n diodes. Receiver i.f. filters and front-end bandpass filters are selected with a front panel switch that handle only direct current. How? Again, p-i-n diodes. These interesting little components allow us to do switching at r.f., i.f. and audio frequencies without routeing the signals themselves all over the cabinet. In this article we will see how these circuits work.

The p-i-n diode is different from the standard p-n junction diode (see Fig. 1A). It has an insulating ('intrinsic', hence the 'i' in 'p-i-n) region between the p- and n-type material (Fig. 1B). It is therefore a multiregion semiconductor device despite having only two electrodes. The i-region is not really a true semiconductor insulator, but rather is a very lightly doped n-type region. It is called an 'intrinsic' region because it has very few charge carriers to support the flow of an electrical current.

When a forward bias potential is applied to the p-i-n diode, charge carriers are injected into the i-region from both n- and p-regions. But the lightly-doped design of the intrinsic region is such that the n- and p-type charge carriers don't immediately recombine (as in p-n junction diodes). There is always a delay period for recombination. Because of this delay phenomenon, there is always a small but finite number of carriers in the i-region that are uncombined. As a result, the resistivity of the i-region is very low.

One application that results from the delay of signals passing across the intrinsic region is that the p-i-n diode can be used as an r.f. phase shifter. In some microwave antennas phase shifting is accomplished by the use of one or more p-i-n diodes in series with the signal line. Although there are other forms of r.f. phase shifter usable at those frequencies, the p-i-n diode remains popular.

Several styles of package are used for p-i-n diodes at small signal power levels. Most of these will be familiar to most readers, but some are probably recognized only by people with some experience in u.h.f. and up switching circuits. The NTE-553 and ECG-553 p-i-n diodes will dissipate 200 mW, and use the standard cylindrical package style. The NTE-555 and ECG-555 devices, on the other hand, use the u.h.f. flat package style and can dissipate 400 mW. I used these diodes for the experiments performed to write this article because they are service shop replacement lines, and both ECG and NTE are widely distributed in local parts stores. An alternative that might be harder to come by is the MPN3404, which uses a TO-92 plastic package.

Radio frequency signals can pass through the p-i-n device, and in fact

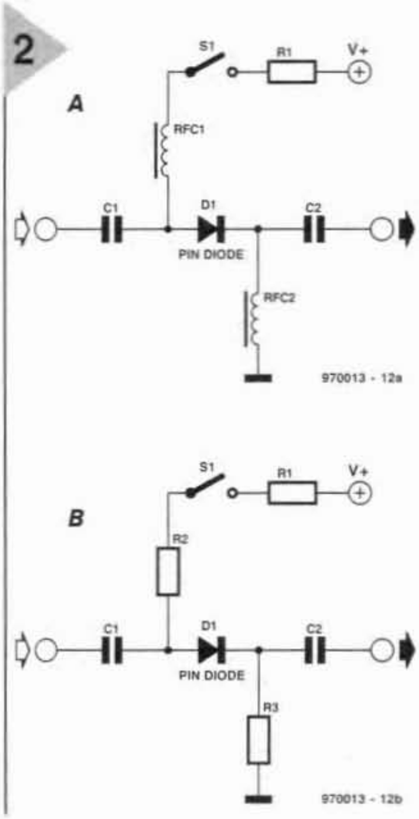


Figure 2. Series p-i-n diode switch circuits: (A) RF choke loaded; (B) resistor loaded.

see it in some circumstances as merely a parallel plate capacitor. We can use p-i-n diodes as electronic switches for r.f. signals, and as an r.f. delay line or phase-shifter, or as an amplitude modulator.

P-I-N DIODE SWITCH CIRCUITS

P-I-N diodes can be used as switches in either series or parallel modes. **Figure 2** shows two similar switch circuits. In the circuit of Figure. 2A the diode (D_1) is placed in series with the signal line. When the diode is turned on, the signal path has a low resistance, and when the diode is turned off it has a very high resistance (thus providing the switching action). When switch S_1 is open, the diode is unbiased so the circuit is open by virtue of the very high series resistance. But when S_1 is closed, the diode is forward biased and the signal path is now a low resistance. The ratio of off/on resistances provides a measure of the isolation provided by the circuit. A pair of radio frequency chokes (RFC_1 and RFC_2) are used to provide a high impedance to r.f. signals, while offering low d.c. resistance.

Figure 2B is similar to Figure 2A except that the r.f. chokes are deleted, and a resistor is added. **Figure 3** shows a test that I performed on the circuit of Figure 2B using a 455 kHz i.f. signal (the 'scope was set to show only a few cycles of the 455 kHz). The upper trace in Figure. 3A shows the input signal and the lower trace the output signal. The amplitude of the nearly unattenuated output signal is 1,200 mV peak-to-peak. The trace in Figure. 3B shows the same signals when the switch open (i.e. +12 V d.c. disconnected), but with the oscilloscope set to the same level. Increasing the sensitivity of the 'scope showed a level of 12 mV getting through. This means that this simplest circuit provides a 100:1 on/off ratio, which is 40 dB of isolation. [Note: for this experiment the ECG-555 and NTE-555 hot carrier p-i-n diodes were used].

Figure 4 shows the circuit for a shunt p-i-n diode switch. In this case, the diode is placed across the signal line, rather than in series with it. When the diode is turned off, the resistance across the signal path is high, so operation of the circuit is unimpeded. But when the diode is turned on (S_1 closed) a near-short-circuit is placed across the line. This type of circuit is turned off when the diode is forward biased. This action is in contrast to the series switch in which a forward biased diode is used to turn the circuit on.

A combination series-shunt circuit is shown in **Figure 5**. In this circuit, D_1 and D_2 are placed in series with the signal line, while D_3 is in parallel with the line. D_1 and D_2 will turn on with a positive potential applied, while D_3 turns on when a negative potential is applied. When switch S_1 is in the lower position, a positive potential is applied to the junction of the three diodes. As a result, D_1 and D_2 are forward biased and thus take on a low resistance. At the same time, D_3 is hard reverse biased, so has a very high resistance. Signal is passed from input to output essentially unimpeded (most p-i-n diodes have a very low series resistance).

But when S_1 is in the upper position, the opposite situation obtains. In this case, the applied potential is negative so D_1-D_2 are reverse biased (and take on a high series resistance), while D_3 is forward biased (and takes on a low series resistance). This circuit action creates a tremendous attenuation of the signal between input and output.

OTHER P-I-N DIODE APPLICATIONS

When used as a switch, p-i-n diodes can be used to switch devices such as attenuators, filters and amplifiers in and out of the circuit. It has become standard practice in modern radio equipment to switch d.c. voltages to bias p-i-n diodes rather than

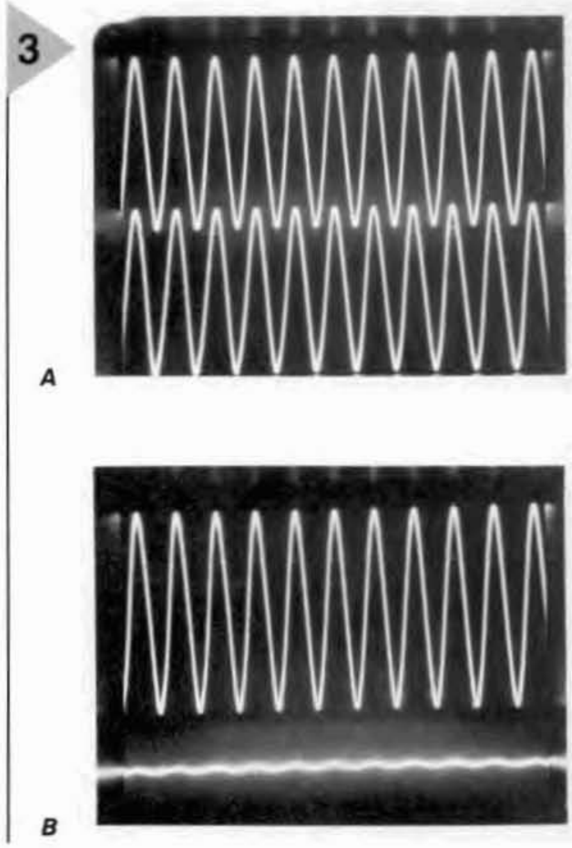


Figure 3. Switched and unswitched input/output waveforms.

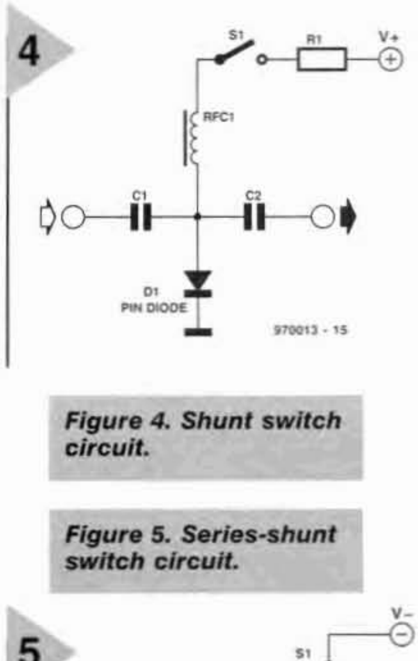
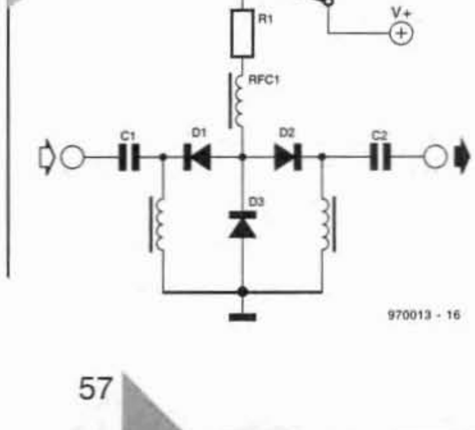


Figure 4. Shunt switch circuit.

Figure 5. Series-shunt switch circuit.



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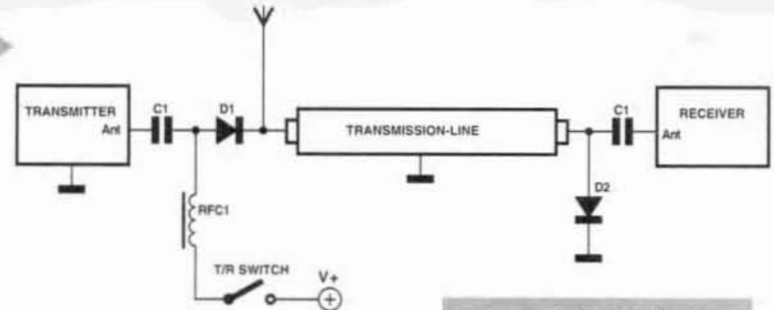

Figure 6. P-I-N diode T/R switching.

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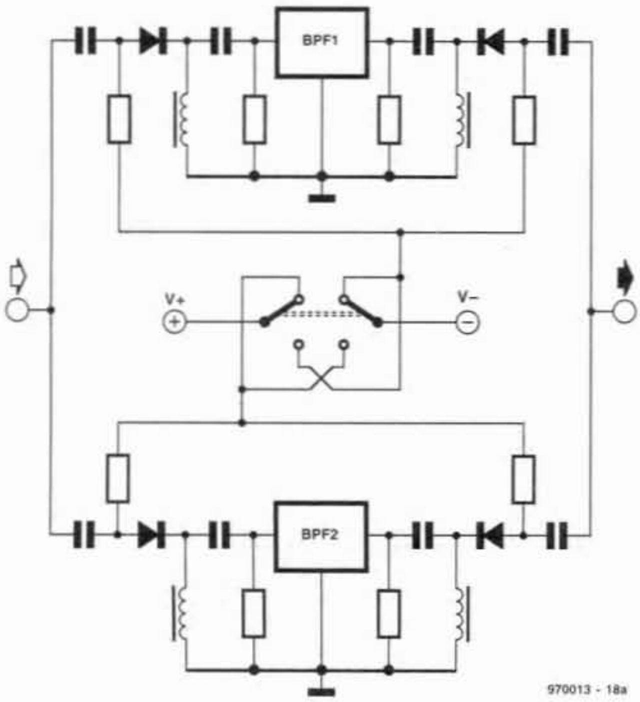

Figure 7. IF bandpass filter switching.

directly switch r.f./i.f. signals. In some cases, the p-i-n diode can be used to simply short out the transmission path to bypass the device.

The p-i-n diode will also work as an amplitude modulator. In this application, a p-i-n diode is connected across a transmission line, or inserted into one end of a piece of microwave waveguide. The audio modulating voltage is applied through an r.f. choke to the p-i-n diode. When a c.w. signal is applied to the transmission line, the varying resistance of the p-i-n diode causes the signal to be amplitude modulated.

Another application is shown in **Figure 6**. Here we have a pair of p-i-n diodes used as a transmit-receive (TR) switch in a radio transmitter; models from low-h.f. to microwave use this technique. Where you see a so-called 'relayless TR switch', it is almost certain that a p-i-n diode network such as Figure 6 is in use. When switch S_1 is open, diodes D_1 and D_2 are unbiased, so present a high impedance to the signal. Diode D_1 is in series with the transmitter signal, so blocks it from reaching the antenna; diode D_2, on the other hand, is across the receiver input so does not attenuate the receiver input signal at all. But when switch S_1 is closed, the opposite situation occurs: both D_1 and D_2 are now forward biased. Diode D_1 is now a low resistance in series with the transmitter output signal, so the transmitter is effectively connected to the antenna. Diode D_2 is also a low resistance, and is across the receiver input so causes it to short out.

Figure 7 shows how multiple i.f. bandpass filters are selected with only d.c. being routed around the cabinet between circuitry and front panel. When the switch is in the position shown, V+ is fed to filter no. 2 diodes and V– to those of BPF1; so filter no. 2 is activated and BPF1 is blocked. When the switch is in the opposite position, the alternate filter is turned on. This same arrangement can be used in the front-end of the receiver, or the local oscillator, to select *LC* components for different bands.

Another filter selection method is shown in **Figure 8.** This circuit is a partial representation of the front-end circuitry for the Heathkit SW-7800 general coverage shortwave receiver.

The circuit of Figure 8 is shown using a switch (S_1) to apply or remove the +12 V d.c. bias potential on the diodes, but in the actual receiver this potential is digitally controlled. The digital logic elements sense which of thirty bands are being used, and selects the input r.f. filter accordingly.

P-I-N DIODE ATTENUATORS

Another application for p-i-n diodes is as a voltage-variable attenuator in r.f. circuits. Because of its variable resistance characteristic, the p-i-n diode can be used in a variety of attenuator circuits. One of the simplest is the shunt attenuator of **Figure 9**. The p-i-n diode acts like an electronically variable resistor. The resistance across the diode's terminals is a function of the applied bias voltage. This voltage, hence the degree of attenuation of the r.f. signal, is proportional to the setting of potentiometer R_1. The series resistor (R_2) is used to limit the current when the diode is forward biased. This step is necessary because the diode becomes a very low resistance when a certain rather low potential is exceeded. This circuit is used as an r.f. gain control on some modern receivers. [970013]

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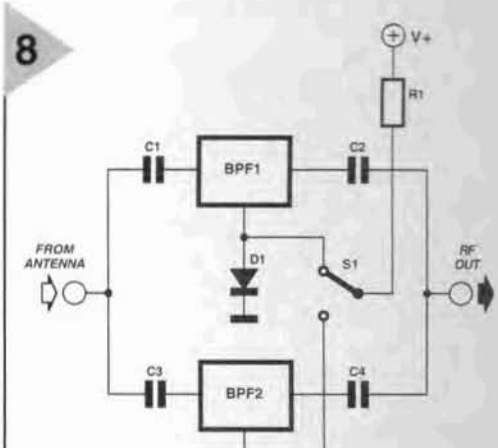

Figure 8. Front-end filter switching.

Figure 9. Simple variable r.f. attenuator circuit.

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