owing to amplifier saturation (the UTD-1000 has a 30dB range and operates from 10 to 1000MHz). The active rectifier, by contrast, is highly linear; but it works well only at relatively low frequencies, in common with most op-amp circuits. You can use fast op-amps (Section 13.08) to improve the situation, but you will still be limited to frequencies below 10MHz or so.

Synchronous (homodyne) detection

An interesting method that combines dynamic range, accuracy, and speed is *synchronous detection*, also called "homodyne detection." In this method (Fig. 13.28) the output is rectified by being inverted during alternate half cycles. This obviously requires a clean signal at the same frequency as the signal being detected, either supplied externally or regenerated internally with a phase-locked loop (Section 9.27). Synchronous detection works well up to frequencies of a few megahertz, at least; the big disadvantage is the need for a coherent reference signal. We'll see this same circuit in Section 15.15, in the guise of a *phase detector* (in which form it also made a brief appearance in Section 9.27).

Current-source drive

Another solution to the problem of rectifier diode nonlinearity is to drive the rectifier circuit with a *current*, rather than a voltage; the output is then loaded resistively, to produce a proportional output voltage (Fig. 13.29). Figure 13.30 shows a good implementation with voltage-controlled transistor current source; the performance is shown in Figure 13.31. You can understand this circuit in another way: With no input signal, the amplifier's output is decoupled from the rectifier network, producing very high voltage gain (with its current-sink load); thus, only a very small input signal is needed to turn on the diodes. At that point the voltage gain drops to $G_V = R_L/(R_E + r_e)$ (in this case, $G_V \approx 3$), preventing saturation. With a wideband amplifier and fast diodes, this circuit design will operate to 100MHz or more.

Post-detection diode compensation

From Hewlett-Packard (HP Journal, 10/80) comes the circuit shown in Figure 13.32, which uses matched Schottky diodes in a clever arrangement in which each diode sees the same signal. Since the op-amps operate on the detected (low-frequency) signal, the bandwidth is limited only by the diode circuit. The designers of this circuit deserve a pat on the back (and three "attaboys").

Amplitude-tracking detector

Figure 13.33 shows another clever idea: Eliminate diode nonlinearities and offsets by using a locally generated signal, detected in a symmetrical circuit, to cancel the unknown current. Feedback adjusts

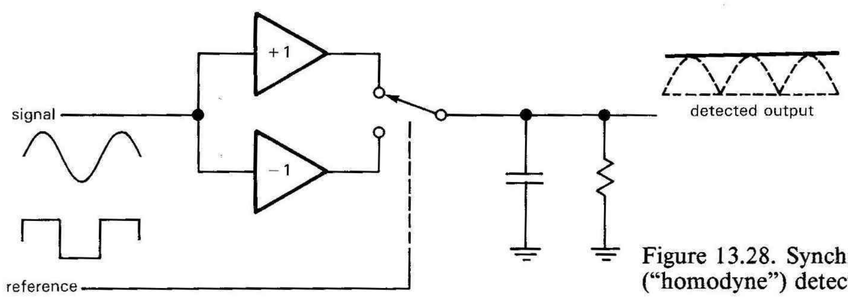

Figure 13.28. Synchronous ("homodyne") detector.

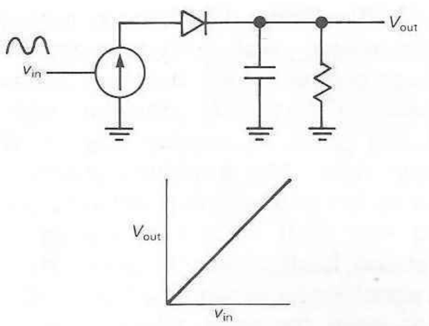

Figure 13.29

the amplitude of the local low-frequency signal until the rectified outputs balance. The frequency of the nulling signal is low enough so that its amplitude can be accurately measured with an op-amp precision rectifier. A good implementation of this circuit will operate linearly down to a few millivolts, and up to a gigahertz.

Power detection

The foregoing methods all measure the *amplitude* of a high-frequency signal. There are many occasions on which you really want to know *power.* Of course, for a sine wave, the two are simply related by $P = V_{\text{rms}}^2/R_{\text{load}}$, so you can simply convert a measured amplitude to a calculated power. For nonsinusoidal waveforms, however, a true power measurement can be made only by averaging the square of the actual voltage waveform. In the language of radiofrequency measurements, you need a "square-law detector."

There are numerous methods available. For signals of low to moderate frequency, you do well with a "function module," for example the AD637 monolithic rms-to-dc converter from Analog Devices. These devices use the exponential diode characteristic within feedback loops to form the square of the input signal, which is then low-pass filtered and fed to an analogous square-root circuit. You get excellent linearity and dynamic range, and good bandwidth, from these circuits. For example, AD637 has 8MHz bandwidth at full level, 0.02% nonlinearity, and 60dB dynamic range; it even has a logarithmic (dB) output.

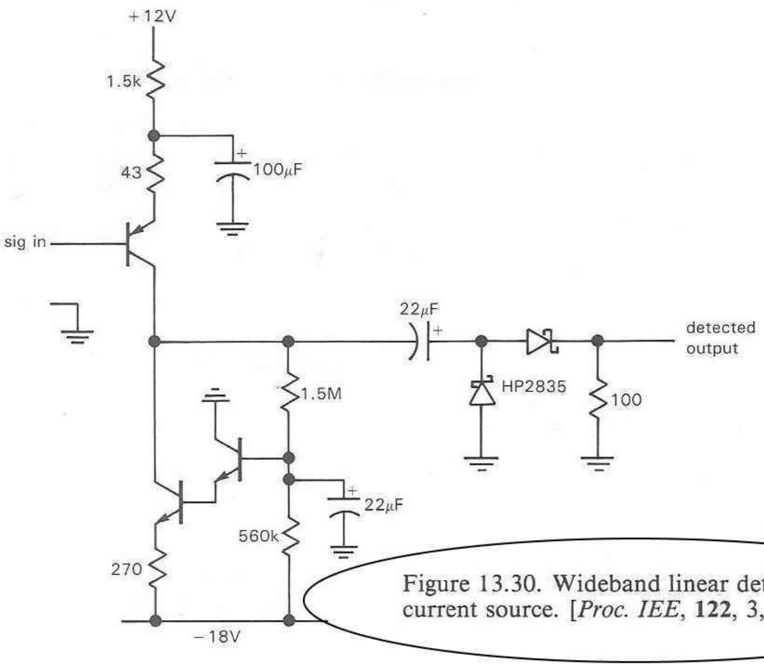

Figure 13.30. Wideband linear detector using current source. [*Proc. IEE*, **122**, 3, 249 (1975).]