Radio Astronomy Supplies

APPLICATION NOTE 6
SQUARE LAW DETECTORS

Square Law Diode Detectors in 50 ohm Systems

By

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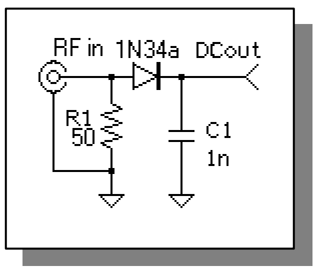
NOTE: This piece was taken from the web. It represents an accurate description of this circuit. We thank the author for his work and sharing the knowledge.

A diode peak-detector gives a relatively accurate method of determining RF power delivered to a load, for powers above about 100mW. Measured DC voltage is simply equal to the peak voltage of the RF waveform: power in watts may be determined by calculating $V_{peak}^2/100$.(for 50-ohm systems).



For smaller signals, the diode forward voltage (0.6v for silicon, 0.3v for germanium or schottky) causes error: output DC voltage is lower than peak RF voltage. And any diode no longer has a well-defined delineation between conduction and non-conduction for small signals: its rectifying properties become inefficient. Signal levels between a few volts down to a few tens of millivolts require some significant non-linear corrections to be factored in. Detectors such as thermocouples or thermistors (bolometers) can do a better job in this region. We tend to dismiss diodes as error-prone for small signal measurements.

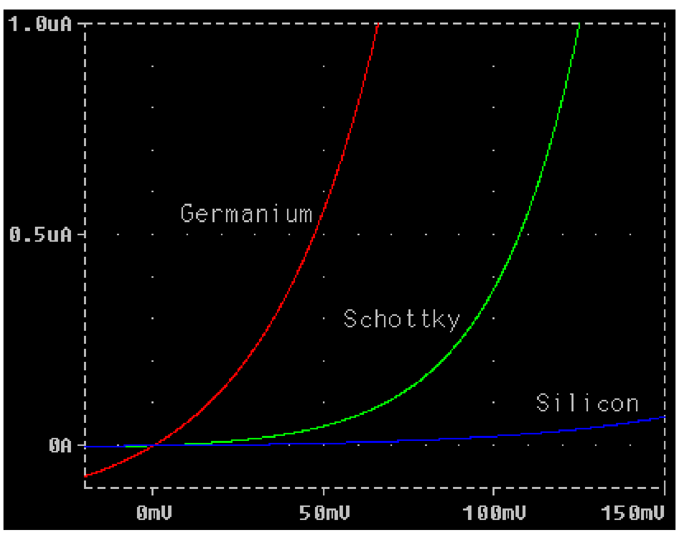
But for really small signals (below about -20dBm) diodes once again can give predictable and useful amplitude measurements. It is useful to divide diode peak-detector operation into three regions: linear (above 20dBm), transition (-20dBm to 20dBm) and square-law (below -20dBm).

What is square law? It simply means that the DC component of diode output is proportional to the square of the AC input voltage. So if you reduce RF input voltage by half, you'll get one quarter as much DC output. Or if you apply ten times as much RF input, you get 100 times as much DC output as you did before. An increase of 3dB results in twice as much output voltage. Square law means that output DC voltage is proportional to RF power delivered to the 50 ohm input terminating resistor. So you could have a linear scale of power (in milliwatts or microwatts or nanowatts) on the scale of the output meter.

There is a downside: square law greatly limits input dynamic range. At -60dBm (223.6uV rms in a 50-ohm system) an efficient detector diode might yield only one microvolt of DC output: not easy to measure.

Note that output is *proportional* to input^2. This proportionality constant depends strongly on how "curved" is the diode's I vs. V curve. Schottky and germanium beat out silicon in this case. Temperature affects the I vs. V curve too, along with the proportionality constant. Much of the utility of our square-law detector will be in *relative* measurements: if *absolute* amplitude isn't required, we can ignore the proportionality constant, and forego absolute amplitude calibration. The detector is still very useful. If you want to measure absolute RF input power, you'd have to know the diode's temperature, and do some non-linear corrections of the DC output. This would most likely involve a microcomputer.

What diode to use? All diodes will follow the square-law rule for small signals. We should choose one that is fast, so 1N4000-series power diodes are out. Any diode with a lot of capacitance is out. Diodes with a sharp I vs. V curve will give more output, so silicon diodes are less desirable. Schottky diodes are great, but they require DC biasing to get into the really curved part of the I vs.V curve. With zero bias, a germanium diode has very decent qualities (apart from nasty temperature effects). When Hewlett Packard makes square-law diodes using exotic semiconductors like gallium arsenide with molecular-beam-epitaxy machines, the result looks remarkably similar to a simple point-contact germanium diode like a 1N34A. Only repeatability and stability are much better - they need to measure absolute voltage.



At zero-bias the dynamic resistance of a 1N34A is about 50Kohms (at room temperature). This is the slope of the V vs. I curve at zero volts. For small signals encountered in square-law, the diode primarily looks like a (50K) resistor which is a bit non-linear, even though all the output depends on the non-linear bit. This means that the diode, and all the circuitry that follows, will load down the 50-ohm input resistance very little. Indeed, we can use two diodes, one for positive swings and the other for negative swings, to double the detected output voltage, and still not affect the 50-ohm termination.

How to measure such small DC output voltage? Square-law detection is only valid for input signals below about -20dBm. At -20dBm, input voltage across the 50-ohm resistor will only be 63.24 millivolts, peak-to-peak. DC detector output voltage will be even less, and smaller input signals yield ever-smaller output (square-law at work). So the range of detectable input signals depends greatly on how carefully we amplify these small DC voltages. We particularly want to avoid DC offsets: these result in an output where none should exist. For example, in a test setup, a sensitive DC meter capable of displaying in 0.1uV increments showed a DC offset of about -23uV from each diode detector. The source was likely a thermocouple within the RF generator.

In any case, a "zero" control will be required. With no input signal, the zero control will be adjusted to give a zero output voltage. This zeroing process compensates for any offsets, be they from op-amps, or thermocouples. Since most offsets are temperature sensitive, a change in temperature will likely require re-zeroing. Many modern DC meters will indicate full-scale voltage of about 200mV. With such a meter, we still need to amplify the detector's DC output by a factor of 100 to 10000 times.

What's the RF bandwidth of a diode detector? Hewlett Packard's diode detectors go up to 18GHz. Our simple germanium diodes are not as good, but the upper bandwidth limit (-3dB point) is still a respectable 500MHz. A biased schottky diode such as 1N5711 should do better.