Design of a Power Detector for Digital Wireless Amplitude Leveling and Fault Monitoring

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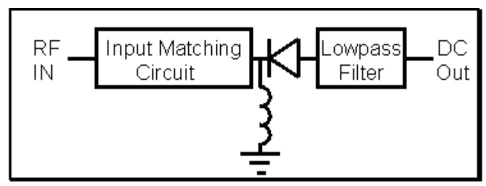
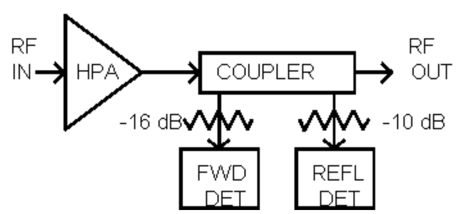
When choosing a component for use as a power detector in a base station application, the diode detector is often thought to be the most practical and economical choice. Although a diode detector (as shown in Figure 1) is uncomplicated, without additional compensation mechanisms the performance of the detector will not meet the demands of a digital system with respect to modulation error and dynamic range. This article addresses some of the drawbacks of the diode detectors and presents an alternative that solves many of the associated problems.



▲ **Figure 1. Diagram of a simple diode detector.**

In a typical base station application, it is desirable to measure the RF power at the output of an amplifier or power combiner to provide feedback for amplitude control or system performance. As an example, the integrity of the amplifier, filters, transmission lines and antennas can be checked by simply measuring forward and reflected power levels, as shown in Figure 2.



▲ **Figure 2. Typical measurement setup.**

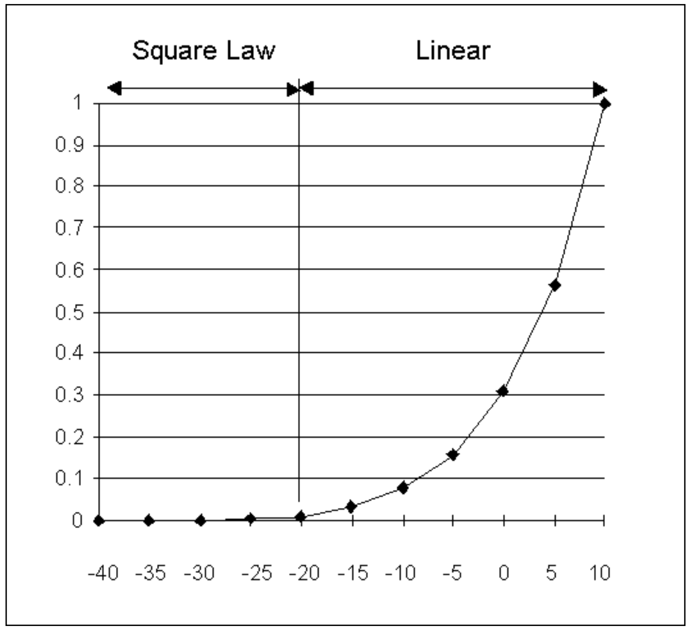
These measurements are compared to expected levels and an error is generated when deviations occur outside of expected performance. For a CDMA system, each of the detectors must perform over a wide dynamic range while maintaining accuracy.

The dynamic range requirement stems from the average envelope power characteristics of the CDMA signal. As the channel usage changes, the envelope power changes by as much as 20 dB. Without adequate dynamic range, system health can only be determined when the system is operating with high traffic density. In order to measure a VSWR ranging from 3.0:1 to 1.4:1 over all power levels, the detector will need at least 10 dB more detection range than the output power range. (This criterion assumes that the forward power detector has at least 6 dB more attenuation than the reverse power detector.)

One final complication to this design task seems to come from the nature of the modulation being presented to the detector. Any nonlinearities in the detector will have a significant impact on the accuracy of the measurement. Figure 3 illustrates the typical output of a diode

Dynamic Range	30 dB
Frequency Range	1930–1990 MHz
Temperature Stability	0 to 60 oC
Modulation Weighting Error	<0.5 dB
Cost	as low as possible

▲ **Table 1. Performance goals for the CDMA detector.**



▲ **Figure 3. Diode response showing detected voltage vs. input power (dBm).**

with a broadband input match. The non-linearity of this diode makes it unusable above –20 dBm for our application. The difference between the detector's performance with a CW signal and its performance with a multi-tone or digitally modulated signal is the weighting error.

At this point, the task becomes one of choosing which type of detector to use, evaluating the circuit development cost, and considering the costs to manufacture and align the chosen design. If one chooses to invest in a design, three types of diodes are worthy of consideration: high-bias Schottky, zero-bias Schottky, and the tunnel diode. Each of these diode types has certain advantages, as shown in Table 2.

All of the diodes share a common disadvantage. For optimum linearity, temperature performance, and best modulation weighting error, these diodes must be operated in their square-law region, as shown in Figure 3. In this region, the diode's response follows a log-log power to voltage transfer characteristic. The voltages present in the square-law region are very small, making them difficult to digitize and process over a wide dynamic range with linear A/D converters.

In addition to the diode approach, several other choices are available off the shelf: logarithmic amplifiers, thermal sensor detectors, and the Praxsym PDM module. Each of these RF power detection devices should be considered carefully for each application. Logarithmic amplifiers can have a large dynamic range, yet suffer from large modulation errors. Band limited in the past, Analog Devices has pushed their logarithmic amplifiers up to 2.5 GHz, although they were band-limited in the past. Thermal based power detectors are true RMS detectors and have good flatness with frequencies beyond 8 GHz but have limited dynamic range. Thermal sensors are sensitive to ambient temperature and require compensation to maintain accuracy. The Praxsym PDM module exhibits the required dynamic range, power flatness, immunity to modulation error, temperature stability, cost, and size requirements put forth in the application described in Table 1.

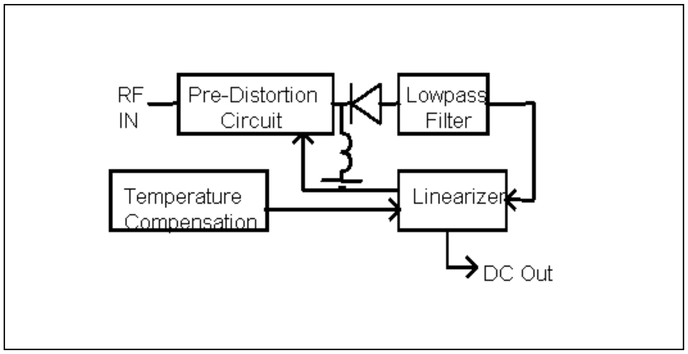
The PDM module's performance advantage comes from the use of a proprietary predistortion network ahead of a zero-bias Schottky detector and an internal temperature compensation network. A block diagram is shown in Figure 4. This network provides partial correction for the deviations in the diode detector.

Generally, to meet the 30 dB dynamic range requirement, a Schottky diode must be matched so that its impedance is equivalent to the sampled port (50 ohms). The diode must be operated in its square-law region to reduce the effects of modulation error. As the matching network is developed for maximum sensitivity, the bandwidth of the diode's response narrows. The theoretical limit of $1/(2RCln(p))$ determines the level to which this matching can be taken. The entire design process is addressed thoroughly in an excellent HP application note [1].

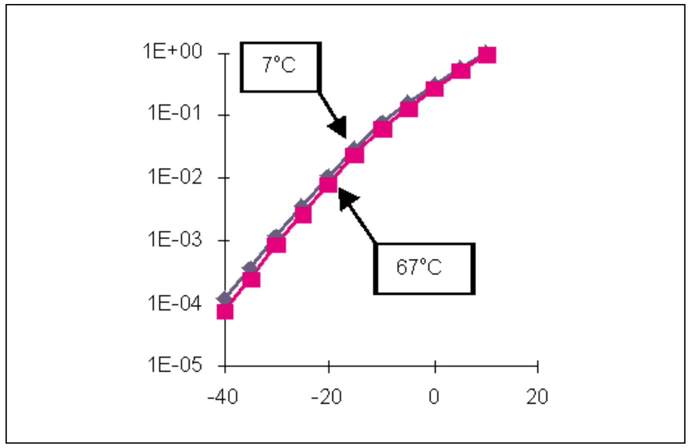
After the diode is matched for dynamic range and bandwidth, the circuit must be compensated to allow for the effects of temperature variations on diode resistance, as well as the commensurate change in the transfer characteristic. One solution to this temperature variation is to use another diode biased with the same amount of current but with no RF applied to provide a correction factor to at least a first-order approximation [2]. This arrangement is shown in Figure 6. The voltage offset and temperature stability requirements prescribe the use of a least one high-quality

Diode Type	Performance	Temp Stability	Relative Cost
High Bias Schottky	Excellent sensitivity, narrow bandwidth	Poor	Moderate
Zero-Bias Schottky	Poor sensitivity	Moderate	Low
Tunnel	Good sensitivity	Excellent	High

▲ **Table 2. Diode performance.**



▲ **Figure 4. PDM block diagram.**



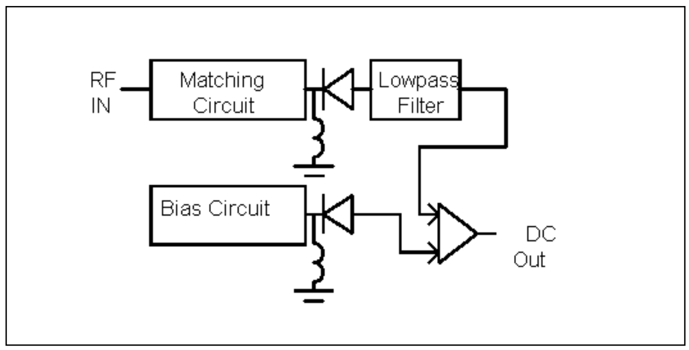
▲ **Figure 5. Diode temperature performance showing detected voltage vs. input power (dBm).**

instrumentation op-amp.

After successfully completing the compensation networks, the circuit meets all the requirements set forth in Table 1. One problem with the design illustrated in Figure 6 is that the detector's response curve in the square-law region is so small, it is difficult to reliably detect the voltage output. To achieve the 30 dB logarithmic change in detected voltage now requires us to sense voltage levels from .1 mV to 50 mV. Even the use of careful low-noise design techniques and expensive low-noise parts may not allow us to obtain reliable readings at –50 dBm input levels.

Since the diode must be operated in its square-law region to ensure repeatable compensations, the maximum power level into the diode must be limited to 10 uW (–20 dBm). Unless adequate shielding of the detector is designed into the amplifier, the transmit signal may begin to affect the operation of the diode. For a 20-watt amplifier, the shielding between the transmit signal (43 dBm) and the detector diode (–20 dBm) must provide at least 63 dB of isolation. The PDM module has relieved this burden through the use of an integral lid, as shown in Figure 7.

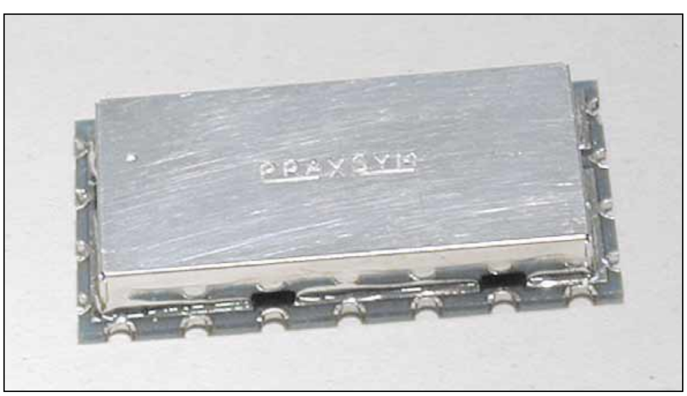
With the use of the feedback mechanisms depicted in Figure 4, the Praxsym PDM module's output is normalized to compensate for a majority of the errors detailed above. Figure 8 demonstrates the detected power output curve from a PDM detector as compared to the standard (uncompensated) diode detector.



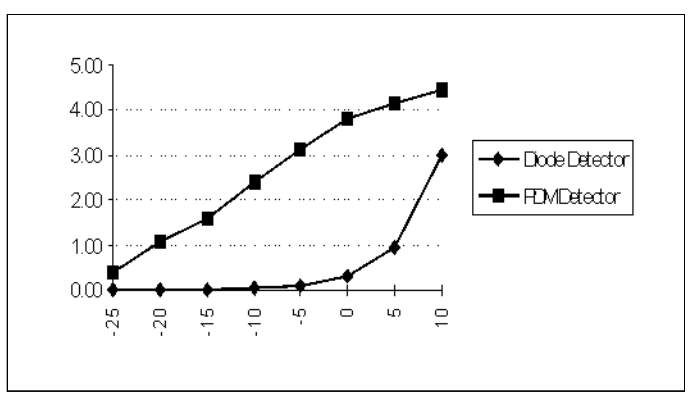
▲ **Figure 6. Dual diode compensation.**

Conclusion

As this article shows, there are many complications to the "simple" diode detector. Without proper consideration, these complications could result in unacceptable performance or costs due to the addition of hardware or software needed to compensate for these errors. OEM



▲ **Figure 7. PDM shielding.**



▲ **Figure 8. PDM vs. diode response showing detected voltage vs. input power (dBm).**

modules now exist that are shielded, matched, and normalized for specific frequency ranges.

In addition to the PDM module, Praxsym has developed power detection solutions based on thermal detectors and logarithmic amplifiers. Some of these RF detectors feature digital outputs, enabling them to communicate directly to an embedded controller. For a complete solution, a unit is available that includes a coupler with forward and reverse power detectors housed in a chassis with connectors. ■

References

1. "Impedance Matching Techniques for Mixers and Detectors," Application Note 963, Hewlett-Packard, 1980.

2. Raymond W. Waugh, "Designing Large-Signal Detectors for Handsets and Base Stations," *Wireless Systems Design*, July 1997.

Also, for a thorough discussion of the various techniques used for power detection, refer to "Fundamentals of RF and Microwave Power Measurements," Application Note 64-1, Hewlett-Packard, July 1977.

Author Information

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New Products

Since the original work on this article was completed, several integrated chip solutions have come onto the marketplace that address many of the multi-tone power detection concerns raised in this article. Although these ICs are appropriate selections for some designs, many of the design considerations raised still apply. These ICs must be shielded, matched and normalized for many applications. No one solution satisfies all possible design criteria, and the designer must carefully consider the cost vs. benefits of these technologies.