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TECHNICAL ARTICLE

UNDERSTANDING, OPERATING, AND INTERFACING TO INTEGRATED DIODE-BASED RF DETECTORS

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Abstract

Because of their fundamental rectifying characteristic, diodes have been used to generate dc voltages that are proportional to ac and RF signal levels for as long as there have been diodes. This article will compare the performance of diode-based RF and microwave with integrated circuit alternatives. Topics covered will include transfer function linearity, temperature stability, and ADC interfacing.

Discrete Diode-Based RF Detectors

Figure 1 shows the schematic of a popular diode-based RF detection circuit. This can be thought of as a simple half wave rectifier with output filtering. The positive half cycles of the input signal forward bias the Schottky diode, which in turn charges the capacitor. On the negative half cycle, the diode reverse biases, causing the voltage on the capacitor to be held and yielding a dc output that is proportional to the input signal. To allow this voltage to drop when the input signal decreases or is turned off, a resistor in parallel to the capacitor provides a discharge path.

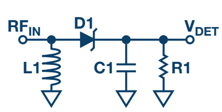

Figure 1. A Schottky diode-based RF detector.

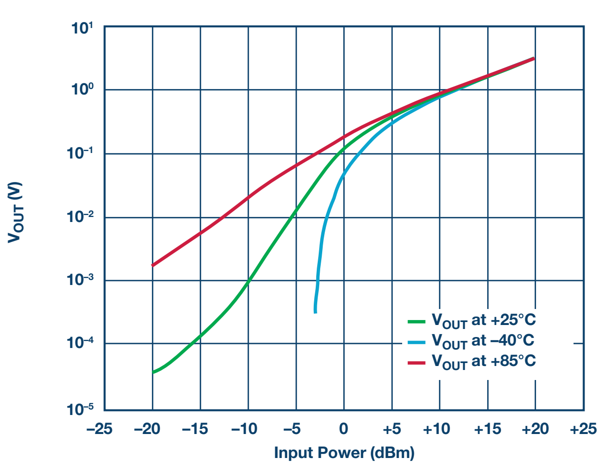

Figure 2. Transfer function of a Schottky diode-based RF detector.

Figure 2 shows the transfer function of this circuit. Input power is scaled in dB and output voltage is on a logarithmic vertical scale. Looking at the 25°C transfer function, there are two distinct operating regions on the curve. The so-called linear region extends from the top end of the input range (approximately 15 dBm) down to around 0 dBm. This term, linear region, derives its name from the fact that the output voltage in this region is roughly proportional to the input voltage.

Below 0 dBm, the so-called square-law region begins. In this region the output voltage is roughly proportional to the square of the input voltage. This results in a higher slope on the plot.

Figure 2 also shows the output voltage vs. input power transfer function of the circuit when the temperature is –40°C and +85°C. This shows significant deviation at power levels below 0 dBm. This renders the device unusable in applications where the temperature varies by any significant amount.

Techniques exist that can be used to somewhat mitigate this temperature drift. They involve introducing a second reference diode either as part of the circuit or as a standalone circuit with its own output. The temperature drift of the reference diode matches that of the primary diode. By a process of subtraction (either in the analog domain or in the digital domain based on the circuit structure), some degree of drift cancellation can be achieved.

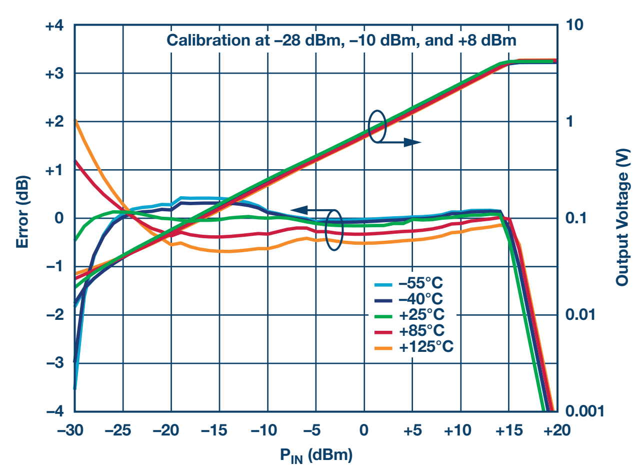

Figure 3. Output voltage vs. input power and linearity error of an integrated Schottky diode detector at 25 GHz.

Figure 3 shows the transfer function at 25 GHz of the ADL6010, an integrated Schottky diode-based detector that has a number of novel features. As part of the signal processing, the input signal passes through a circuit that performs a square-rooting function only on signals below a certain power level. The transition point is deliberately set to be equal to the power level at which the diode transitions from the square law region to the linear region. As a result of this, the square-law effect of the diode is canceled out and there is no sign of the two-region transfer function that is so apparent in Figure 1.

Figure 3 also includes plots showing the transfer function at various temperatures from –55°C to +125°C. The variation in the transfer function vs. temperature is also plotted. Using linear regression of the 25°C transfer function as a reference, the error at each temperature is plotted in dB. As a result of integrated temperature compensation circuitry and the square-law elimination circuit, we see errors due to linearity and temperature drift of approximately ±0.5 dB over the majority of the input range.

ADC Interfacing

While RF and microwave detectors are sometimes used in analog power control loops,[1] it is more common to build a digital power control loop as shown in Figure 4. In these applications, the output of the power detector is digitized by an analog-to-digital converter. In the digital domain, the power level is calculated using the code from the ADC. Once the power level is known, the system will respond by adjusting the transmitted power if necessary.

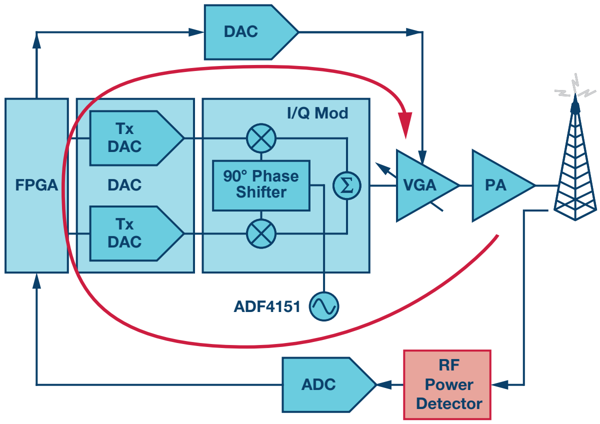

Figure 4. A typical digitally controlled RF power control loop.

While the response time of this loop will depend to a small extent on the response time of the detector, the sampling rate of the ADC and the speed of the power control algorithm will have a far larger impact.

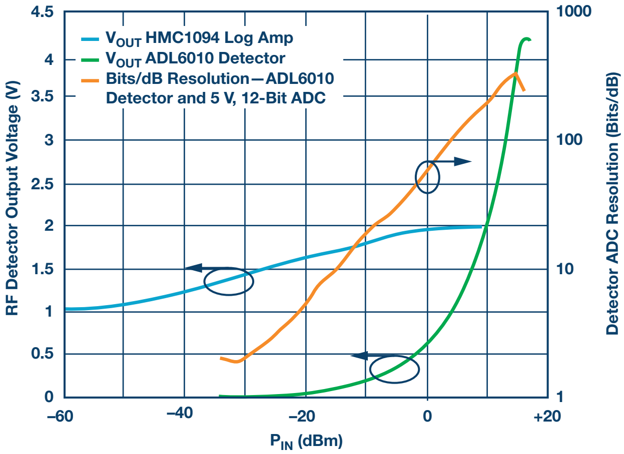

Figure 5. Comparison of linear-in-dB.

The loop's ability to measure and precisely set the RF power level is impacted by a number of factors including the transfer function of the RF detector and the resolution of the ADC. To better understand this, let's take a closer look at the response of the detector. Figure 5 compares the response at 20 GHz of the ADL6010 diode-based detector to that of a microwave log amp, the HMC1094. The log amp has a transfer function that is linear-in-dB, where a 1 dB change in input power always results in the same voltage change at the output (over the linear input range of approximately –50 dBm to 0 dBm). In contrast to this, a diode-based detector such as the ADL6010 has a transfer function that appears exponential when a dB scale is used on the horizontal axis and a linear vertical axis is used for output voltage.

Because analog-to-digital converters have a transfer function that is scaled in bits/voltage, this means that system resolution in terms of dB-per-bit continually decreases with decreasing input power. The plot in Figure 5 also shows the bits-per-dB resolution that could be achieved if the ADL6010 were to drive a 12-bit ADC with a full-scale voltage of 5 V (this plot is scaled on a logarithmic secondary axis for ease of viewing). At the low end of the device's power range, around –25 dBm, the incremental slope would be approximately 2 bits per dB, yielding a resolution of approximately 0.5 dB/bit. This suggests that a 12-bit ADC is adequate to accurately resolve the output of the ADL6010 over its full range.

As the RF input power increases, the incremental slope in bits/dB increases steadily to a maximum of approximately 300 bits/dB at the maximum input power of 15 dBm. This is valuable in an RF power control application where accuracy is most critical when the system is at its maximum power. This is a very typical scenario in applications where RF detectors are used to measure and control the power of a high power amplifier (HPA). In applications where power is often being controlled to prevent the HPA from overheating, high resolution power measurement at max power is of great value.

By contrast, the transfer function of the HMC1094 log amp in Figure 5 also shows that it has a constant slope over its linear operation range. This suggests that a lower resolution ADC (10-bit or possibly even 8-bit) would be adequate to achieve a resolution that is well below 1 dB.

Figure 6 shows an application circuit where the ADL6010 has been interfaced to the AD7091, a 12-bit precision ADC that can sample at up to 1 MSPS. The ADC has an internal 2.5 V reference that sets the full-scale input voltage. Because the ADL6010 detector can reach a maximum voltage of approximately 4.25 V, a simple resistor divider is used to scale this voltage down so that it never exceeds 2.5 V. This scaling can be implemented without the need for an op amp buffer. The achievable resolution in terms of dB-per-bit at the bottom end of the input power range is similar to the example above (that is, approximately 0.5 dB-per-bit).[2]

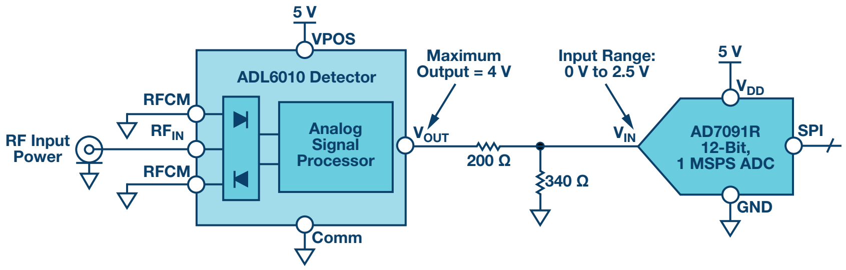

Figure 6. Interfacing an integrated microwave power detector to a precision ADC.

Conclusions

Integrated RF and microwave detectors offer a number of benefits when compared to discrete implementations. Integrated temperature compensation circuitry offers an out-of-the-box output voltage that is stable to within around ±0.5 dB over a wide temperature range. The use of an internal square-rooting function effectively eliminates the square-law characteristic at low input power levels. This results in a single linear transfer function, making device calibration easier. The buffered output of the integrated detector can drive ADCs directly without any concerns that the loading will affect the computational accuracy. Care does need to be taken in choosing and dimensioning the ADC so that adequate bits/dB can be achieved at low input powers.

References

[1]CN-0050 Circuit Note. *Stable, Closed-Loop Automatic Power Control for RF Applications*. Analog Devices, Inc., 2010.

[2]CN-0366 Circuit Note. *A 40 GHz Microwave Power Meter with a Range from –30 dBm to +15 dBm*. Analog Devices, Inc., 2014.

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