

RF Power Detector Operation

On GaN MMIC Power Amplifiers

Introduction

RF power detectors convert the power level of an RF signal into a proportional output DC voltage. This voltage can be used for RF power monitoring and control.

This document provides application information on the operation of the RF detector diode pairs commonly integrated into Qorvo's range of GaN MMIC power amplifiers. It is also applicable to GaAs MMICs with similar detector diode configuration.

Referenced Documents

The reference documents below take precedence over the contents of this application note and should always be consulted for the latest information.

QPA1725 Data Sheet.

TGA4548-SM Data Sheet.

APPLICATION NOTE: RF Power Detector Operation

Background

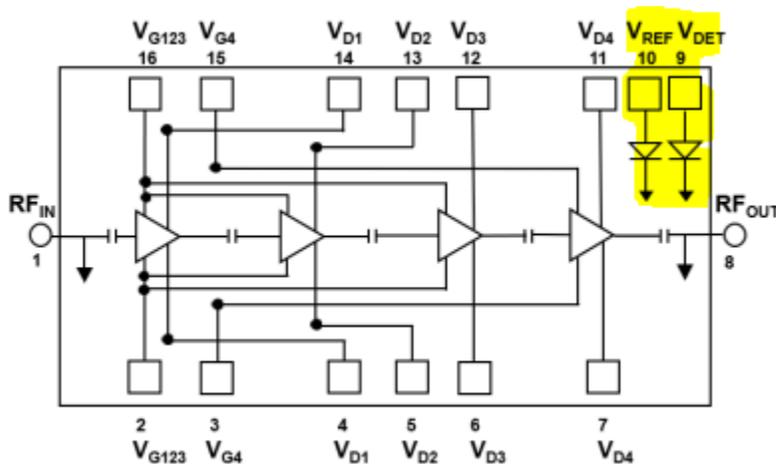
RF power detectors are essential for maintaining the performance, reliability, and safety of RF systems that use power amplifiers (PAs). They can be used to help compensate for changes in amplifier and system gain, which can be due to effects like temperature change and variation between devices.

RF power detectors are used on power amplifier (PA) outputs for several important reasons:

1. **Power Monitoring:** The detector provides real-time monitoring of the output power level, ensuring that the PA is operating within its specified range. This helps in maintaining the desired system performance.
2. **Protection:** By monitoring the output power, RF power detectors can help protect the PA and other components in the system from damage due to overdrive or excessive power levels. If the power exceeds safe limits, corrective actions can be taken, such as reducing the input drive or shutting down the PA.
3. **Feedback Control:** Power detectors are often part of a feedback loop in automatic gain control (AGC) or automatic level control (ALC) systems. They provide the necessary feedback to adjust the PA's input drive level, ensuring consistent output power despite variations in PA gain, input signal strength, temperature or load conditions.
4. **Regulatory Compliance:** Many communication systems must comply with regulatory standards that specify maximum allowable output power levels. Power detectors help ensure compliance by providing accurate power measurements.

Operation

Figure 1.0 below shows the block diagram of a typical GaN MMIC PA, the QPA1725 which was designed primarily for Satellite Communications. The RF detector diode pair is highlighted on pins 9 and 10.



Pin 9 – V_{DET} – Detection diode output voltage. Varies with RF output power.

Pin 10 – V_{REF} – Reference diode output voltage.

Figure 1.0. QPA1725 SatCom MMIC Block Diagram Highlighting Detector Diode Pair

Not shown in Figure 1.0 above is the coupler on the PA output that feeds into the detection diode (V_{DET}) on pin 9. The coupled RF power is rectified by the detection diode and converted to a DC voltage inversely proportional to the output power.

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If just a single diode was used then the DC output voltage would vary with temperature as well as the output power level. Using a pair of diodes makes use of the similar temperature characteristics of the two diodes in order to stabilize the output. The second diode enables temperature compensation. Here is a more detailed explanation:

1. **Diode Pair Configuration:** The detector typically uses two diodes: one for detecting the RF signal and another for temperature compensation. These diodes are matched to ensure they have similar characteristics.
2. **Detection Diode (V_{DET}):** The first diode is used to rectify the RF signal, converting it into a DC voltage. This diode is directly exposed to the RF signal and is responsible for the initial detection process.
3. **Reference Diode (V_{REF}):** The second diode is not exposed to the RF signal but is used to track temperature changes. It is placed in a similar thermal environment to the detection diode to ensure it experiences the same temperature variations.
4. **Differential Configuration:** The output from the detection diode is combined with the output from the reference diode in a differential configuration. This setup allows the temperature-induced voltage changes in both diodes to cancel each other out.
5. **Output Stabilization:** By subtracting the voltage across the detection diode from the voltage across the reference diode, the temperature effects are minimized. This results in a more stable and accurate output voltage (V_{DELTA}) that reflects the true power of the RF signal, independent of temperature fluctuations. This also results in a positive slope of voltage with increasing RF output power, which is generally preferred.

The diodes require an external bias circuit. This is shown in Figure 2.0 below, where each diode is connected to the MMIC drain voltage via a resistor. This sets the bias current flowing through each diode, which is typically in the order of mAs.

In the QPA1725 application circuit the resistors are both 20KOhm. With the typical drain voltage of 20V then the bias current through the resistors is $\sim 0.94\text{mA}$, giving a voltage on pins 9 and 10 of $\sim 1.24\text{V}$ when no RF signal is applied.

Some MMICs have two sets of detector diode pairs, for example the TGA4548-SM. These are on the 'top' and 'bottom' sides of the MMIC. Either pair can be used.

If the detector diodes are not used in the application, then they can be left open circuit (or not connected).

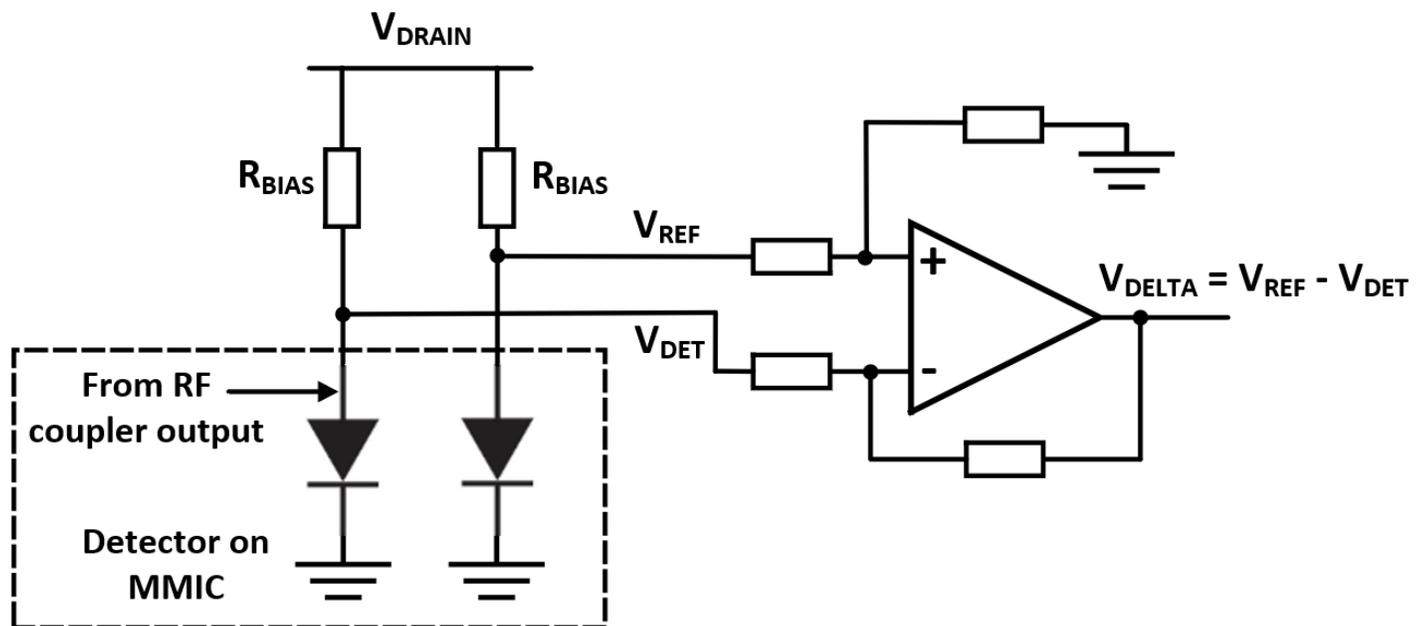


Figure 2.0. Typical Detector Block Diagram Showing External Connections

Application Circuit Recommendations

The application circuit needs to subtract the voltage on the detector diode (V_{DET}) from the voltage on the compensation or reference diode (V_{REF}). This is typically done using a differential op-amp, as shown in Figure 2.0, where the output is V_{DELTA} . Alternatively, a dual or differential analog to digital converter (ADC) could be used to convert the two voltages and subtract them in the digital domain. The detector output voltage for some MMICs can go below 0V, so the op-amp or ADC needs to be able to handle small negative voltages.

QPA1725 Detector Performance

Below are plots of the performance of the diodes in the QPA1725, to help demonstrate the detector operation. The temperature noted in the plots is referenced at T_{BASE} , the MMIC package underside ground pad.

Figure 3.0 below shows how the diode voltage drifts with temperature, in this case the reference diode. Note that the reference diode is also affected slightly by the MMIC output power, this is due to RF leakage across the MMIC die.

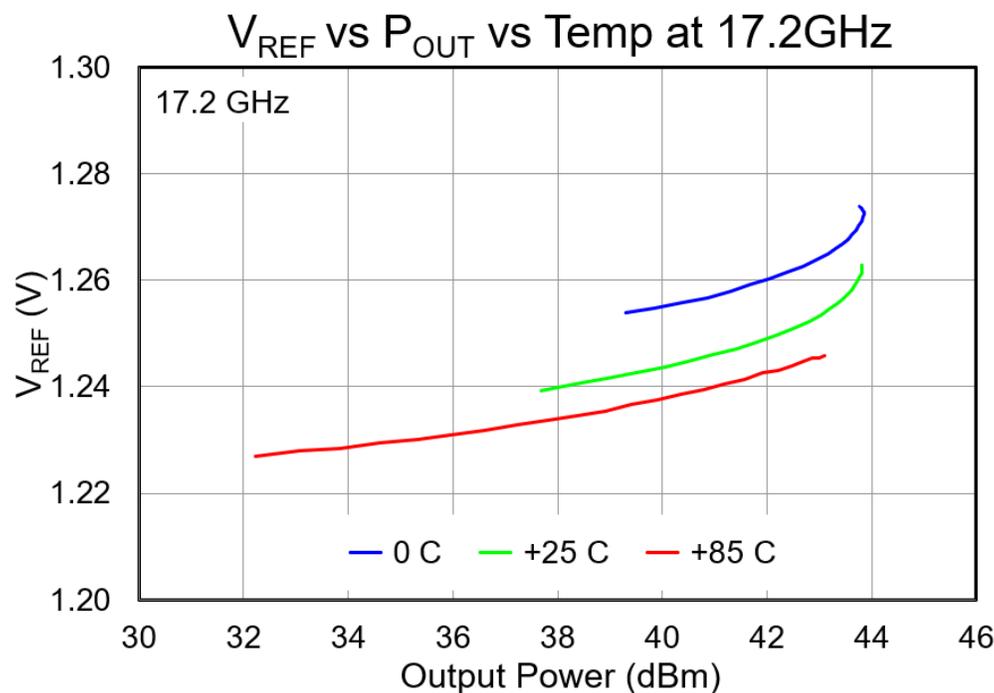


Figure 3.0. Plot of QPA1725 Reference Diode Voltage (V_{REF}) vs Temperature and Output Power

Figure 4.0 below shows that the detection diode voltage decreases with increased RF output power. The response is also affected by the temperature.

Finally Figure 5.0 is the plot of adjusted (single ended) detector output, $V_{DELTA} = V_{REF} - V_{DET}$. This is what you would get for example at the output of a differential op-amp connected to the diodes. This is the compensated output, and it has the advantage of having a positive slope of voltage versus RF output power.

The detector response will also vary slightly with frequency, due to changes in response of the amplifier and coupler.

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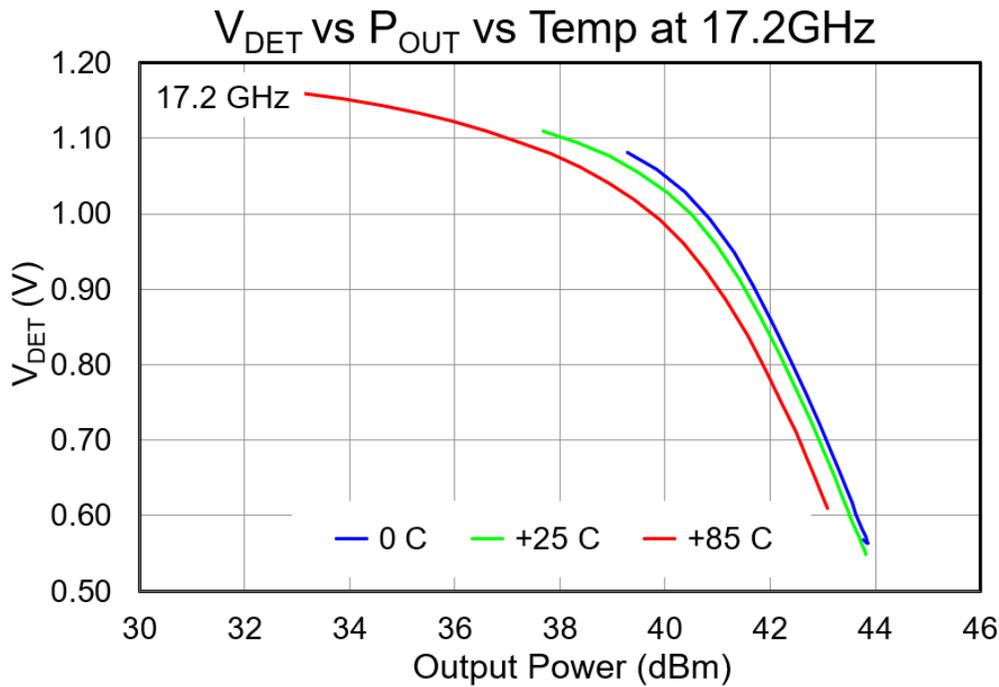


Figure 4.0. Plot of QPA1725 Detector Diode Voltage (V_{DET}) vs Temperature and Output Power

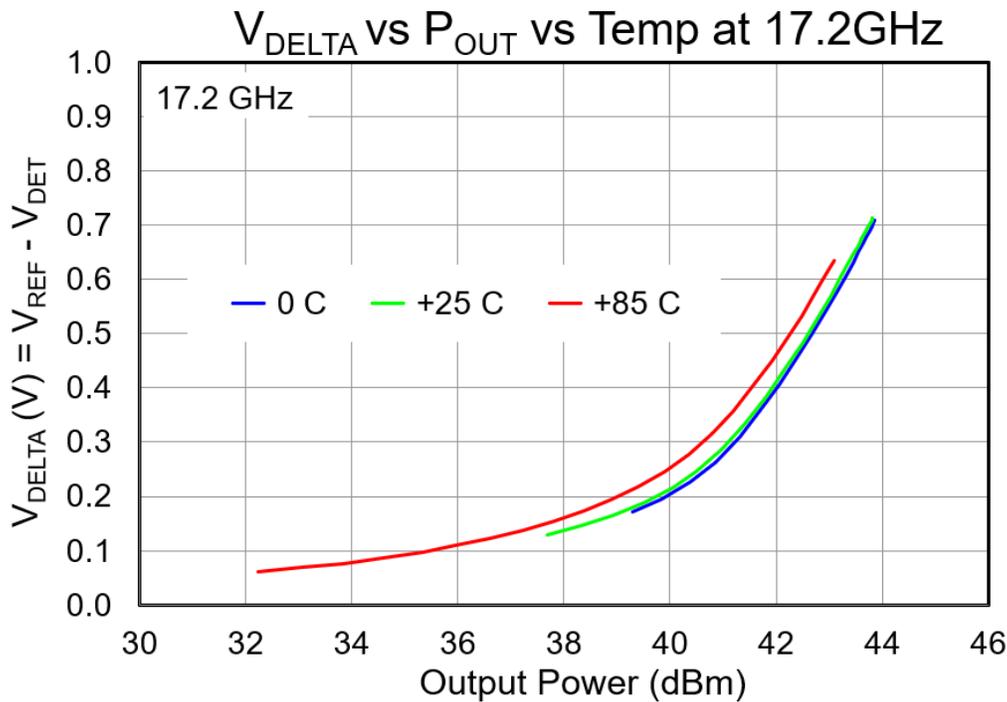


Figure 5.0. Plot of QPA1725 Adjusted Detector Voltage ($V_{DELTA} = V_{REF} - V_{DET}$) vs Temperature and Output Power

TGA4548-SM Detector Performance

The following plots from the TGA4548-SM datasheet also demonstrate detector performance.

Test conditions unless otherwise noted: CW, $V_{D1} = V_{D2} = V_{D3} = 28V$, $I_{D1} + I_{D2} + I_{D3} = 300mA$, adjusting $V_{G1} = V_{G2} = V_{G3}$, $P_N = +22dBm$, $T_{BASE} = +25^\circ C$, $Z_0 = 50\Omega$

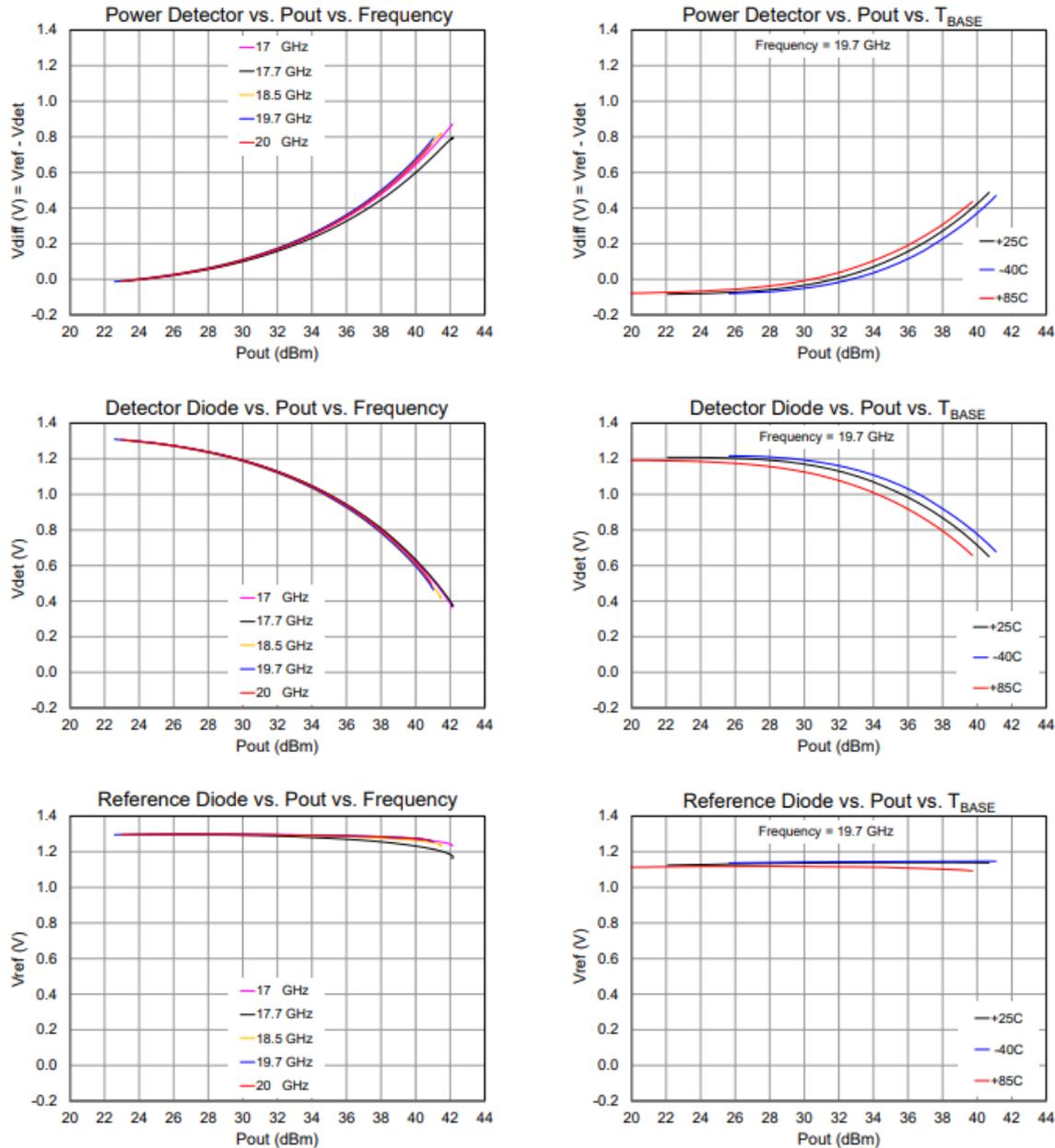


Figure 6.0. TGA4548-SM Detector Plots