From: Qui Luu
Subject: Voltage Gain vs. Power Gain for Demodulators
Date: July 10, 2012

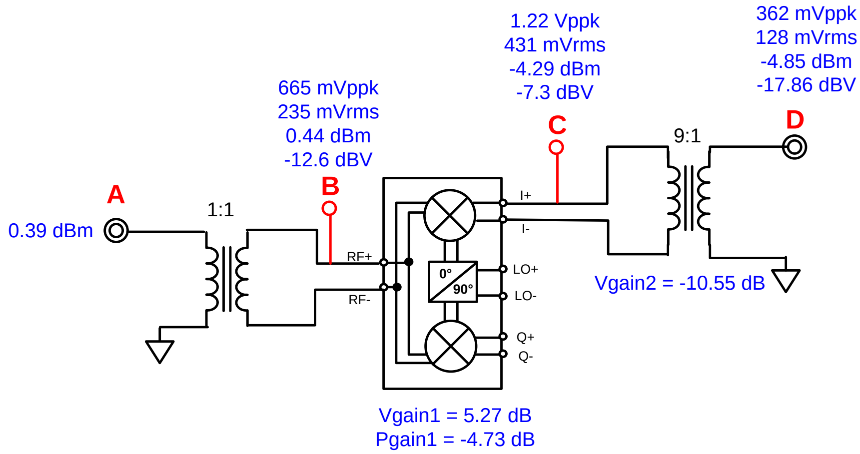


Figure 1

*Note: Measurement taken on the ADL5380 at 900 MHz.

Measurement Setup

POINT A:

A power meter was used to measure the RF signal power and the measurement was done at the end of the cable to include any cable loss. It is assumed that the power measured is the actual power going into the DUT since the traces from the SMA connector to the DUT are short with minimal loss.

POINT B:

Using a differential probe the RF inputs were measured directly at the pins of the DUT. This was a differential measurement across RF+ and RF-. Using an oscilloscope to measure peak to peak voltage, the measurement yielded a 665 mVppk signal. From this peak to peak measurement the RMS, dBm, and dBV values were calculated. The input impedance of the RF port is 50 ohms differential.

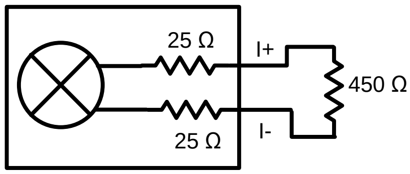
RMS Voltage	Power (dBm)	Voltage (dBV)
$V_{RMS} = \frac{V_{ppk}}{2\sqrt{2}}$	$dBm = 10\log(\frac{V_{RMS}^{2}}{R} \times 1000)$	$dBV = 20\log\frac{V_{RMS}}{1V}$
$V_{RMS} = \frac{665mV_{ppk}}{2\sqrt{2}}$	$dBm = 10\log(\frac{235mV_{RMS}^{2}}{50} \times 1000)$	$dBV = 20\log\frac{235mV_{RMS}}{1V}$
$V_{RMS} = 235mV_{RMS}$	$dBm = 0.44dBm$	$dBV = -12.6dBV$

Comparing the power measurement at point A and point B, it can be seen that the measured RF power at the end of the cable using a power meter is a very good approximation to the actual input power going into the DUT. The power meter measurement gave 0.39 dBm while the measurement at the input pins of the DUT gave 0.44 dBm.

POINT C:

Using a differential probe the baseband outputs were measured directly at the pins of the DUT. This was a differential measurement across I+ and I-. Using an oscilloscope to measure peak to peak voltage, the measurement yielded a 1.22 Vppk signal. From this peak to peak measurement the RMS, dBm, and dBV values were calculated.

The output impedance of the I± port is 500 ohms differential. This output impedance came about by the 9:1 transformer reflecting a 450 ohm impedance to the output of the demodulator assuming a 50 ohm load impedance from the spectrum analyzer. Additionally, internally within the ADL5380 and ADL5382 the baseband outputs have a 50 ohms differential impedance, 25 ohms on each leg



This measurement was only done on the I channel however the same approach can be taken for the Q channel.

RMS Voltage	Power (dBm)	Voltage (dBV)
$V_{RMS} = \frac{V_{ppk}}{2\sqrt{2}}$	$dBm = 10\log(\frac{V_{RMS}^2}{R} \times 1000)$	$dBV = 20\log\frac{V_{RMS}}{1V}$
$V_{RMS} = \frac{1.22V_{ppk}}{2\sqrt{2}}$	$dBm = 10\log(\frac{431mV_{RMS}^2}{500} \times 1000)$	$dBV = 20\log\frac{431mV_{RMS}}{1V}$
$V_{RMS} = 431mV_{RMS}$	$dBm = -4.29dBm$	$dBV = -7.3dBV$

POINT D:

Using a differential probe the single ended output of point D was measured referenced to GND. The peak to peak voltage was measured to be 362mVppk. From this peak to peak measurement the RMS, dBm, and dBV values were calculated. The impedance at point D is assumed to be 50 ohms due to the load impedance of the spectrum analyzer.

RMS Voltage	Power (dBm)	Voltage (dBV)
$V_{RMS} = \frac{V_{ppk}}{2\sqrt{2}}$	$dBm = 10\log(\frac{V_{RMS}^2}{R} \times 1000)$	$dBV = 20\log\frac{V_{RMS}}{1V}$
$V_{RMS} = \frac{362mV_{ppk}}{2\sqrt{2}}$	$dBm = 10\log(\frac{128mV_{RMS}^2}{50} \times 1000)$	$dBV = 20\log\frac{128mV_{RMS}}{1V}$
$V_{RMS} = 128mV_{RMS}$	$dBm = -4.85dBm$	$dBV = -17.86dBV$

VOLTAGE GAIN:

The conversion gain as reported on the ADL5380/82 datasheet is a voltage gain and not a power gain. In this example the voltage gain was measured and calculated as follows:

$$Gain = 20\log\frac{V_{out}}{V_{in}}$$

$$Gain1 = 20\log\frac{1.22V_{ppk}}{665mV_{ppk}} = 5.27dB$$

Similarly the 9:1 impedance transformer has a voltage conversion gain/loss associated to it. The voltage difference between the primary and secondary windings of the transformer is √N, where N is the turns ratio. In this example, N = 9, In other words, the voltage on the side of the transformer closest to the demodulator is 3 times larger than the side of the transformer with the SMA connector. Similarly the gain/loss is measured and calculated as follows:

$$Gain = 20\log\frac{V_{out}}{V_{in}}$$

$$Gain2 = 20\log\frac{362mV_{ppk}}{1.22V_{ppk}} = -10.55dB$$

Voltage and Power Analysis

When working with units of power it is very important to pay attention to the associated impedances. The equation for power is repeated here once again and it can be seen that there is a "R" term in the equation while the voltage equation is immune to the termination resistance.

Power (dBm)

$$dBm = 10\log(\frac{V_{RMS}{}^2}{R}\times 1000)$$

Voltage (dBV)

$$dBV = 20\log\frac{V_{RMS}}{1V}$$

With this said to convert from a voltage gain to a power gain a correction factor has to be included to compensate for the impedance mismatch. This can be further explained by looking at the derivation for power gain.

$$P_{gain} = 10\log\frac{P_{out}}{P_{in}} = 10\log\left(\frac{\frac{V_{out}{}^2}{R_{out}}}{\frac{V_{in}{}^2}{R_{in}}}\right)$$

$$P_{gain} = 10\log\left(\frac{V_{out}{}^2}{V_{in}{}^2}\times\frac{R_{in}}{R_{out}}\right) = 10\log\left(\frac{V_{out}{}^2}{V_{in}{}^2}\right) + 10\log\left(\frac{R_{in}}{R_{out}}\right)$$

$$P_{gain} = 20\log\left(\frac{V_{out}}{V_{in}}\right) + 10\log\left(\frac{R_{in}}{R_{out}}\right) = V_{gain} + 10\log\left(\frac{R_{in}}{R_{out}}\right)$$

The voltage conversion gain of the demodulator was measured to be +5.27 dB. From the power gain equation above, the corresponding power gain is -4.73 dB. The RF input of the demodulator has a 50 ohms input impedance, R_{in}, while the output, R_{out}, was terminated with 500 ohms as explained above at point C.

$$P_{gain} = V_{gain} + 10\log\left(\frac{R_{in}}{R_{out}}\right) = 5.27dB + 10\log\left(\frac{50\Omega}{500\Omega}\right) = -4.73dB$$

If the same analysis was done for the 9:1 transformer, it can be seen that power is preserved across the transformer. We know that

$$V_{in} = \sqrt{N} \times V_{out} = 3 \times V_{out}$$

$$R_{in} = N \times R_{out} = 9 \times R_{out}$$

$$P_{gain} = 10\log\left(\frac{V_{out}^{2}}{V_{in}^{2}} \times \frac{R_{in}}{R_{out}}\right) = 10\log\left(\frac{V_{out}^{2}}{\cancel{9}V_{out}^{2}} \times \frac{\cancel{9}R_{out}}{R_{out}}\right) = 0dB$$

Putting all the pieces together, let's see how well the calculated results match up with the measured data as shown in Figure 1.

Demod Pwr Gain   Transformer Pwr Gain

$$Power(dBm) = 0.44dBm - 4.73dB + 0dB = -4.29dBm$$

$$Voltage(dBV) = -12.6dBV + 5.27dB - 10.55dB = -17.88dBV$$

Demod Voltage Gain   Transformer Voltage Gain

The table below summarizes the measured and calculated results. As can be seen from the data, the measured and calculated results are within 0.5 dB from each other.

	Power (dBm)	Voltage (dBV)
Measured	-4.85	-17.86
Calculated	-4.29	-17.88

As a last and final sanity check, the output voltage in dBV can be converted to dBm and visa versa.

$$dBm = 10\log\left(\frac{\frac{V_{RMS}^{2}}{R}}{1mW}\right) = 10\log\frac{V_{RMS}^{2}}{R} + 10\log(1000) = 10\log V_{RMS}^{2} - 10\log(R) + 30$$

dBV

In this example, R is assumed to be 50 ohms since the single-ended side of the transformer is connected to the 50 ohm source impedance of the spectrum analyzer.

$$dBm = 10\log V_{RMS}^{2} - 10\log(R) + 30 = -17.86 - 17 + 30 = -4.86dBm$$