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CREATING A BIPOLAR INPUT RANGE FOR THE DDC112

By Jim Todsen

Many current-output sensors produce unipolar currents. Photodiodes are one such sensor and for them, the DDC112's unipolar input range is a perfect match. Other sensors, however, produce bipolar currents—currents that flow both into and out of the sensor. In order to use the DDC112 with these sensors, the input range of the DDC112 must somehow be made bipolar. Fortunately, this is easily done. The following sections of this application note review the DDC112's input range, describe how to make it bipolar, show how to experiment with bipolar ranges using the DDC112 Evaluation Fixture and finally how to derive the noise contribution that comes with making the range bipolar.

First, a quick review of the DDC112's input range. Figure 1 shows the DDC112's output code versus signal level. Referred to as "unipolar with offset" in the DDC112's data sheet, this range reads "4096" with a zero input and clips at all zeros with a negative input signal equal in magnitude to approximately 0.4% of the positive full-scale range. Having this small offset, or "safety margin", helps prevent negative input offsets and/or leakage currents from clipping the DDC112's output. Suitable for use with unipolar sensors, this range probably won't work for sensors more bipolar in nature. For these, the negative and positive signal ranges of the DDC112 need to be made closer in size by introducing a larger offset.

CREATING A BIPOLAR RANGE

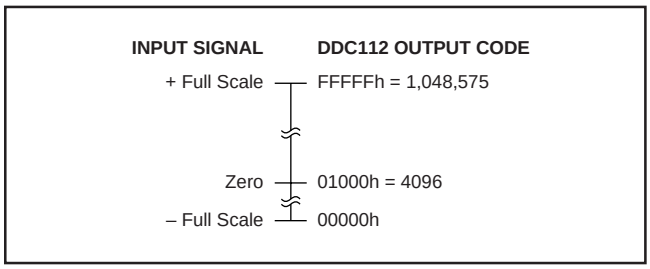

FIGURE 1. DDC112 Output Code vs Input Signal.

As the DDC112's input naturally sums currents together, adding an offset current at the input is easy to do. Figure 2 shows the circuit. For simplicity, only one of the DDC112's two inputs is shown. All that is needed is a resistor and a voltage source. The offset current is V/R and adds directly to the signal current. With the added offset, the DDC112 doesn't clip on the low side until the *sum* of the input and offset currents reaches –0.4% of positive full scale. (The

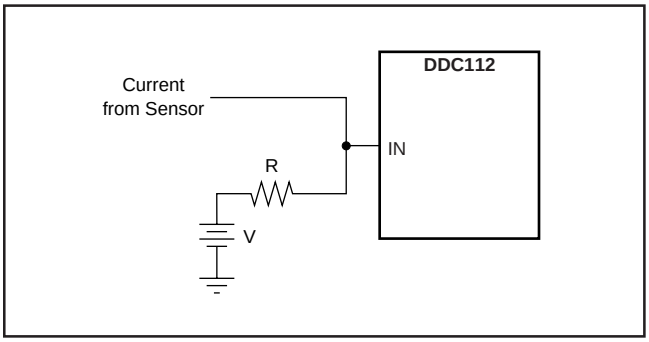

FIGURE 2. Conceptual Circuit to Add Offset.

DDC112's input range is actually in units of *charge*, but it is sometimes more convenient to talk about the equivalent *current* input range.) In general, the current offset can be any value and should be chosen using the expected maximum positive and negative input signals. Of course, as the value of the offset changes, the output code for a zero-input signal will also change. Table I shows various combinations of Range (set by DDC112 pins GAIN0, GAIN1, and GAIN2), T_{INT}, and the resistor (R) used to apply the offset versus the resulting positive full scale, negative full scale and DDC112 output code with zero input signal. The resistor is assumed to be connected to a voltage source equal to 4.1V.

RANGE (pC)	T_{INT} (μs)	R (MΩ)	+FULL SCALE (pC)	–FULL SCALE (pC)	ZERO INPUT SIGNAL DDC112 OUTPUT CODE
50	500	100	29.5	–20.7	434,012
50	500	50	9	–41.2	863,927
150	500	100	129.5	–21.1	147,403
150	500	50	109	–41.6	290,707
150	500	20	47.5	–103.1	720,622
150	2000	100	68	–82.6	577,317
250	500	100	229.5	–21.5	90,079
250	500	50	209	–42	176,062
250	500	20	147.5	–103.5	434,012
250	2000	100	168	–83	348,029
250	2000	50	86	–165	691,961
350	500	100	329.5	–21.9	65,513
350	500	50	309	–42.4	126,929
350	500	20	347.5	–103.9	311,179
350	2000	100	268	–83.4	249,762
350	2000	50	186	–165.4	495,428

TABLE 1. Various Configurations and the Associated Full Scale Ranges and Zero Input Signal DDC112 Output Codes.

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For example, consider a DDC112 configured with a Range and T_{INT} equal to 250pC and 500µs respectively. A 20MΩ offset resistor connected to 4.1V results in a positive full scale of 147.5pC, a negative full-scale of –103.5pC. When the input signal is zero, the DDC112 output code reads 90,079. Figure 3 shows the DDC112's output code versus signal level for this example. In general, the output code with a zero input signal is

$$\text{Output Code}_{\text{ZEROINPUT}} = 4096 + \left(2^{20} - 1\right)\frac{\left(\frac{V}{R}T_{INT}\right)}{Q_{FS}} \quad (1)$$

where Q_{FS} is the selected Range.

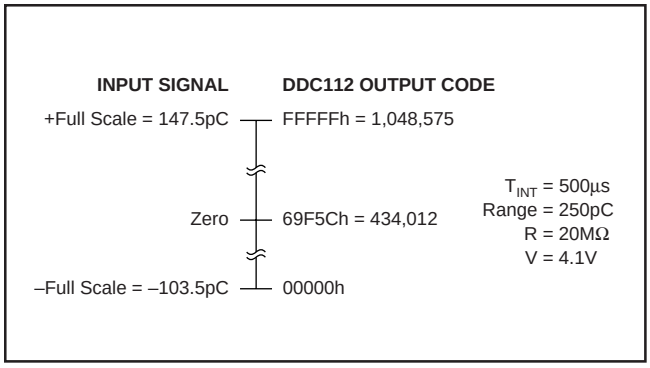

FIGURE 3. DDC112 Output Code vs Input Signal with Offset Applied.

There are a few things to mention about the circuit in Figure 2. First, use a large resistor, preferably greater than 10MΩ. A large resistor better approximates an ideal current source and actually helps reduce the thermal noise seen at the DDC112's output (discussed in more detail in the last section). The voltage coefficient of the resistor doesn't matter, but the temperature coefficient may, if the offset drift over temperature is a concern. In most cases, Caddock's MK632 series of high valued resistors are a good choice. Second, a convenient voltage for the resistor is the V_{REF} signal used by the DDC112, see Figure 4.

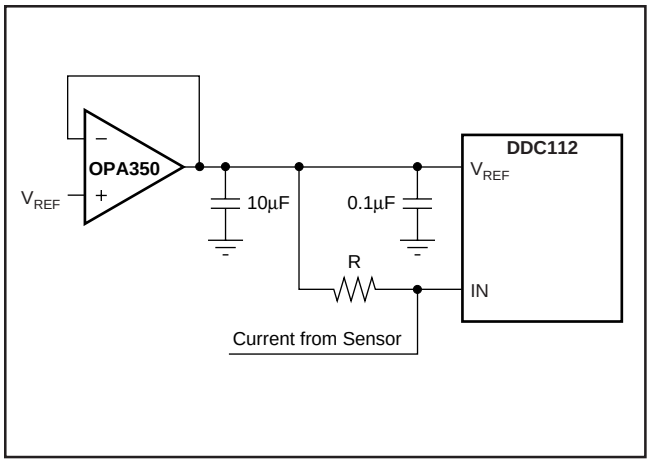

FIGURE 4. Typical Circuit Implementation to Add Offset.

Remember, however, that during the A/D conversions, V_{REF} is sampled by the DDC112, which tends to produce glitches on this node. For a single DDC112 system, using Figure 4's op amp buffer and large bypass capacitors reduces the glitches sufficiently so that V_{REF} can also directly drive the resistor. But, for multiple DDC112 systems, the glitches will be larger and may interfere with generating the offset currents. In that case, use a separate buffer to drive the resistors as shown in Figure 5. If V_{REF} (typically 4.1V) is too large of a voltage, use a resistor voltage divider as shown in Figure 6. Keep the sum of the resistor values large enough as not to load the op amp; $(R_1 + R_2) > 100k\Omega$ should be fine. Additionally, use a capacitor in parallel with R_2 to help lowpass filter the noise on that node. And finally, it is a good idea to place the resistor as close to the DDC112's input as possible and to surround it with ground shielding. The input is very susceptible to pickup. Keeping it short and shielded can dramatically reduce coupling from 60Hz and other sources.

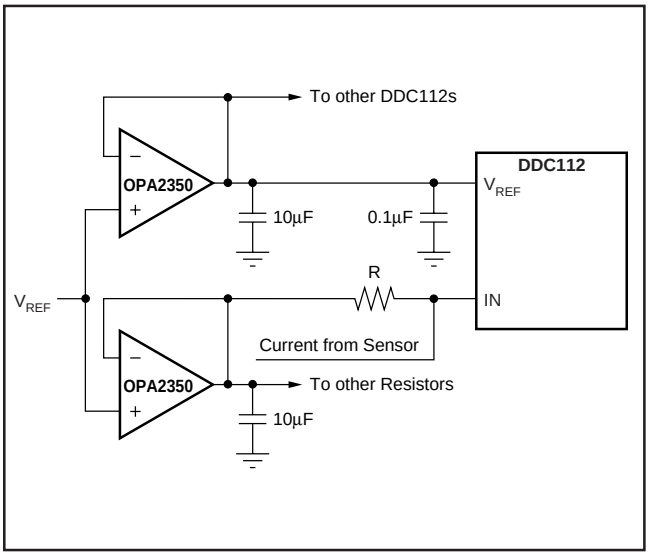

FIGURE 5. Typical Circuit Implementation to Add Offset When Using Multiple DDC112s.

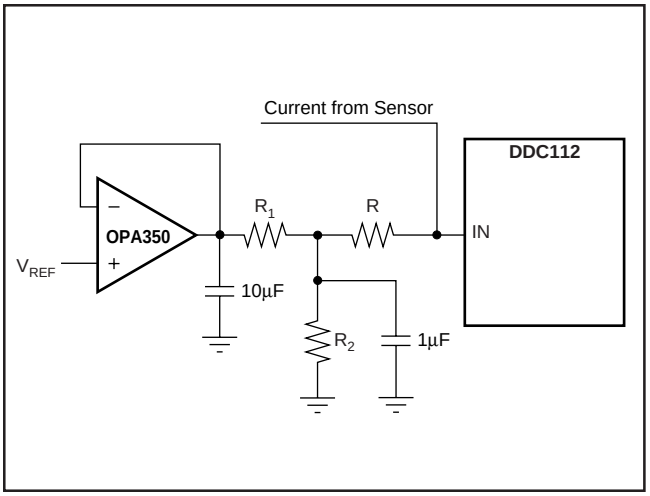

FIGURE 6. Resistor Divider to Reduce Voltage Applied to Offset Resistor.

EVALUATION FIXTURE

The DDC112 Evaluation Fixture quickly configures to incorporate the circuit in Figure 4. Simply set jumpers J1A and J1B and connect V_{REF} to the resistor using a short coaxial cable on the DUT board as illustrated in Figure 7. Afterwards, apply the input signals using the other BNCs. The breadboard area can be used to experiment with the circuit shown in Figure 6. Run the software as normal to collect and display the data. The evaluation software uses a normalized scale when displaying data. Figure 8 shows the software's normalized reading versus DDC112 output code and input signal. Using a normalized range makes it easy to read

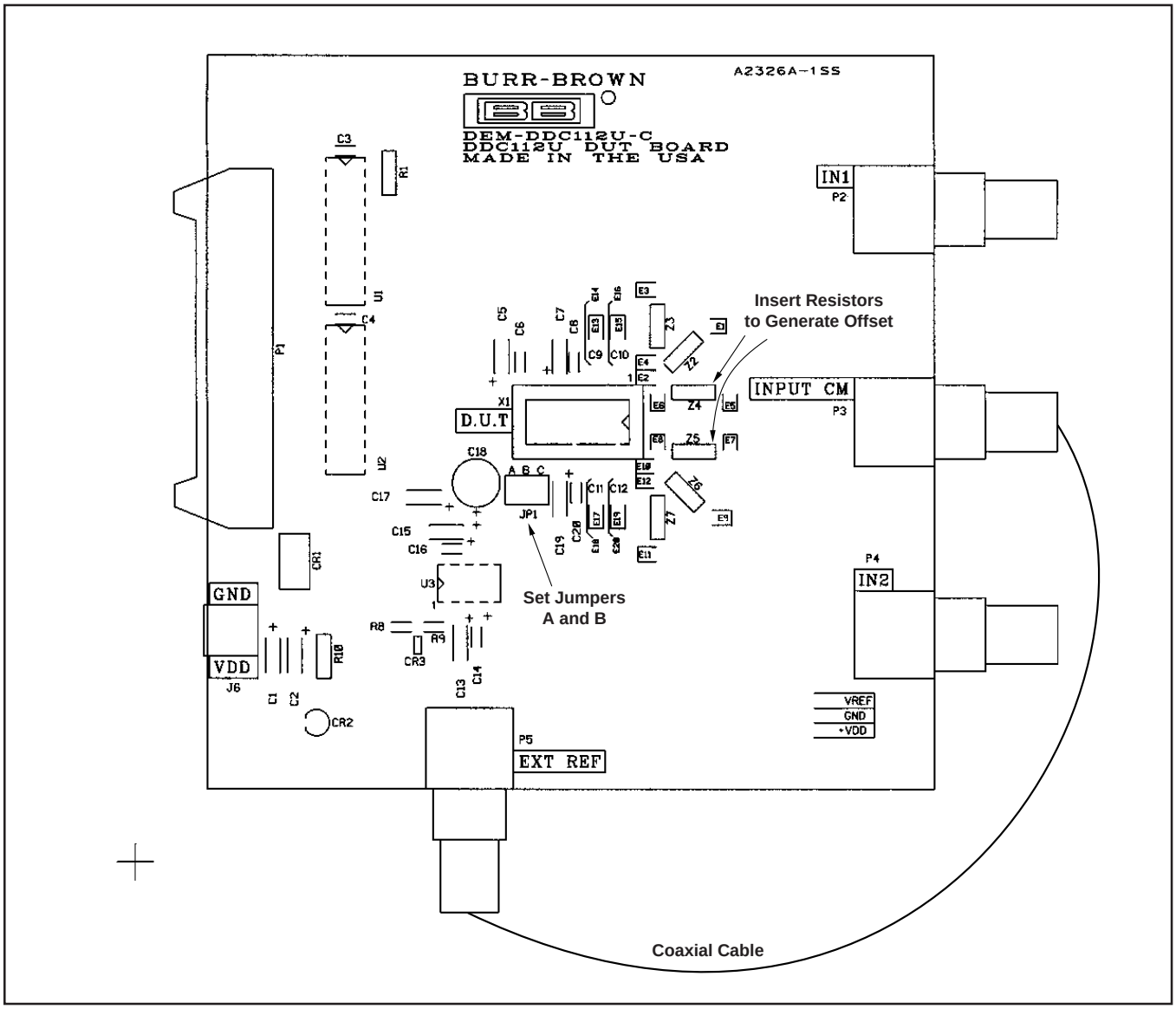

FIGURE 7. Using the Evaluation Fixture to Create a Bipolar Input Range.

INPUT SIGNAL	DDC112 OUTPUT CODE	EVALUATION FIXTURE SOFTWARE READING
+Full Scale = 157pC	FFFFFh = 1,048,575	1.0
Zero	69F5Ch = 434,012	0.412
–Full Scale = –104pC	00000h	–0.0039216

T_{INT} = 500µs
Range = 250pC
R = 20MΩ
V = 4.1V

FIGURE 8. DDC112 Output Code and Evaluation Fixture Software Reading vs Input Signal with Offset Applied.

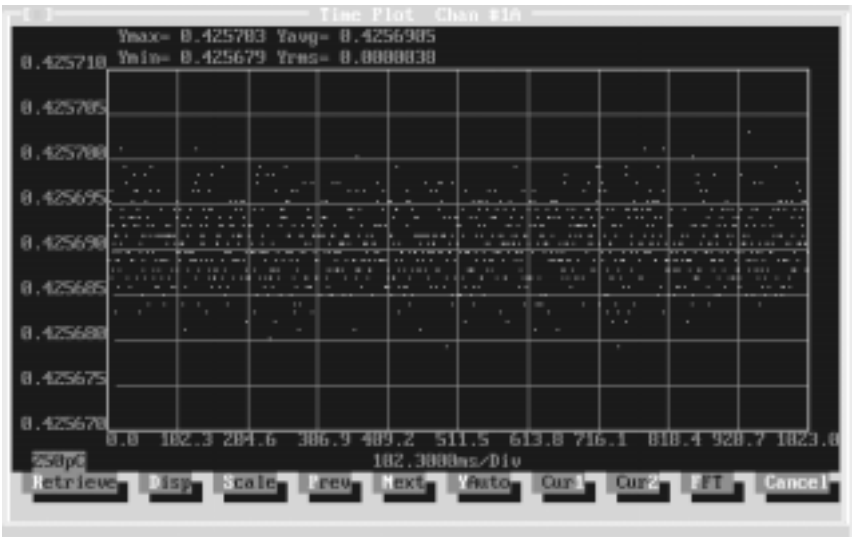

FIGURE 9. Time Plot While Using the Evaluation Fixture as Configured in Figure 7 With No Input Signal.

"ppm" numbers directly from the plots. Figure 9 illustrates a typical time plot using the DUT board setup of Figure 7: T_{INT} equals 500µs, the DDC112's Range is set at 250pC and a 20MΩ resistor generates the offset current. The input signal is zero. Reading the data from the upper right-hand corner of the time plot, the average value (Yavg) is 0.4256905, roughly a DDC112 output code of 450,464. The tolerances in Q_{FS}, R, and V cause the difference between Figure 9's Yavg and the predicted value of 0.412 shown in Figure 8. The rms noise (Yrms) is 0.0000038 out of full scale of 1.0 or 3.8 ppm of full scale.

THERMAL NOISE OF THE RESISTOR

At first glance, the very large resistor placed in series with the input of the DDC112 to generate an offset current might seem to also generate a lot of thermal noise. Surprisingly, in this configuration the additional noise at the DDC112's output from the resistor is usually low, and in fact, decreases as the values of the resistor increases. To understand why this is, consider the two identical noise models of a resistor shown in Figure 10. The one on the left is probably more familiar and shows the resistor modeled as a voltage source in series with a noiseless resistor. Considering only thermal noise, the spectral density of the voltage noise is proportional to the value of resistance. The one on the right is the Thevinen equivalent: a current source in parallel with a noiseless resistor. Notice that the spectral density of the current noise is inversely proportional to the value of resistance. That is, the bigger the resistance, the smaller the current noise. The DDC112 measures current and therefore, the noise contribution of the resistor is best modeled using the current source equivalent circuit. As seen in Figure 10, the current noise is proportional to the inverse of the resistor's value. Notice that the thermal noise power of the resistor is independent of its value. This comes from the physical nature of thermal noise in a resistor and is explained in detail in Reference 1.

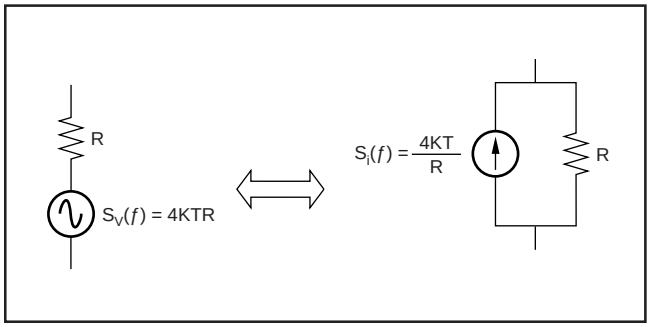

FIGURE 10. Equivalent Models for Thermal Noise of a Resistor.

As just described qualitatively, the resistor's noise contribution seen at the DDC112's output decreases as its value increases. Now, to get some quantitative results to calculate the actual amount of additional noise produced by the resistor, equations are needed. In general, for a linear system, the mean-squared output noise as a function of the system's transfer function and input noise is given by

$$\overline{v}^2 = \int_0^\infty S(f)\left|H(f)\right|^2 df \qquad (2)$$

where $S(f)$ is the spectral noise density of the input noise and $H(f)$ is the transfer function of the linear system. Sometimes, the integral in Equation 2 is shown ranging from $-\infty$ to $+\infty$ but here, only positive frequencies are considered. The transfer function can be found by taking the Fourier transform of the impulse response of the system. For the DDC112, it is the front-end integrators that set its overall transfer function—the DDC112's voltage-input A/D converter always samples the held value of the integrators and doesn't affect the overall frequency response. The integrator's impulse response is simply a pulse of width T_{INT}. Working

through the math shows that the resulting transfer function is

$$H(f) = \frac{T_{INT}}{C_{INT}} \frac{\sin(\pi T_{INT} f)}{\pi T_{INT} f} \quad (3)$$

The normalized AC portion of Equation 3 is shown in Figure 11. The units of the transfer function are V/A since the DDC112 integrates a current to produce a voltage.

Substituting Equation 3 and $S(f) = S_i(f) = 4KT/R$ (spectral

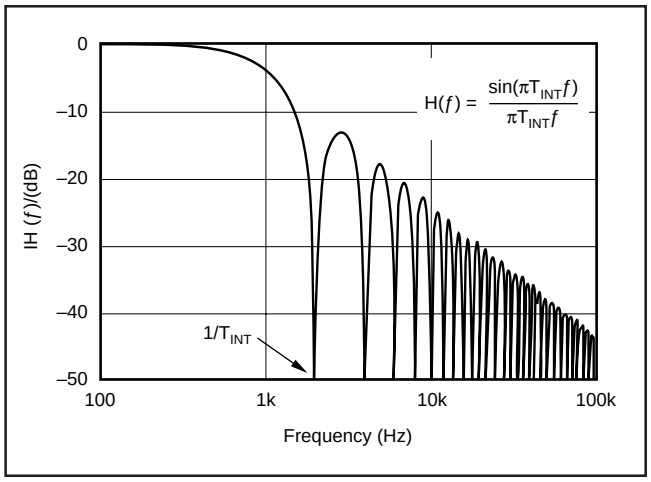

FIGURE 11. Normalized Frequency Response of the DDC112's Front End Integrators for T_{INT} = 500µs.

density of the resistor's current noise) into Equation 2 results in

$$\bar{v}^2 = \frac{4KT}{R} \frac{T_{INT}^2}{C_{INT}^2} \int_0^\infty \left| \frac{\sin(\pi T_{INT} f)}{\pi T_{INT} f} \right|^2 df \quad (4)$$

The integral in Equation 4 can be shown to equal $1/(2T_{INT})$ so that after taking the square root, Equation 4 reduces to

$$\bar{v} = \frac{1}{C_{INT}} \sqrt{\frac{2KT}{R} T_{INT}} \quad (5)$$

giving the root-mean-square (rms) value of the noise. To express the noise in "ppm of full scale", divide Equation 5 by the integrator's full-scale voltage, $V_{FS} = V_{REF} = Q_{FS}/C_{INT}$, and multiply by 10^6. The result, the rms thermal noise of the resistor seen at the DDC112's output in units of ppm of full-scale, is

$$\text{Noise}_{RESISTOR} = 10^6 \frac{\bar{v}}{V_{FS}} = 10^6 \frac{\sqrt{\frac{2KT}{R} T_{INT}}}{Q_{FS}} \quad (6)$$

Combining the resistor noise with the "internal" noise of the DDC112 gives the total noise seen at the output. The internal noise is the noise produced by the DDC112 without the resistor. It is proportional to the sensor capacitance and inversely proportional to the DDC112's full-scale range. The DDC112 data sheet provides typical "rms ppm of full scale" values in the Typical Performance Curves section. Since the two noise sources are independent, they add as "powers" and the total noise equals

$$\text{Noise}_{TOTAL} = \sqrt{\text{Noise}_{RESISTOR}^2 + \text{Noise}_{DDC112}^2} \quad (7)$$

Figure 12 shows the results of actual noise measurements vs the calculated noise of Equation 7. The Evaluation Fixture was configured as shown in Figure 7 to measure the noise with different values of T_{INT}, Q_{FS}, and R as shown.

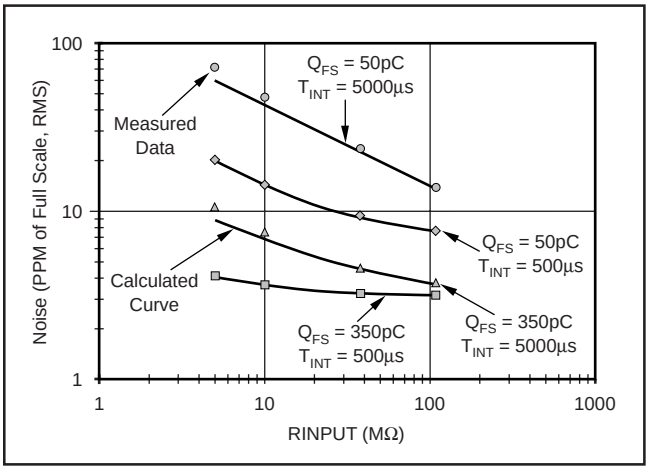

FIGURE 12. Measured and Calculated Noise vs R for Different Values of T_{INT} and Q_{FS}.

References

1. Van der Ziel, Aldert; *Noise in Solid State Devices and Circuits*; John Wiley & Sons; 1986

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