

APPLICATION NOTE

HANDLING SENSOR BRIDGE OFFSET

ABSTRACT

Anisotropic Magneto-Resistive (AMR) sensors are typically implemented in a popular four-element form known as a wheatstone bridge. These bridge sensors offer many desirable characteristics, but one undesirable characteristic is an output voltage without any detected sensor stimulus; known as an “offset” voltage. This offset voltage may cause reduced performance of the sensor system if not compensated for. This application note shall detail the property of bridge offset, the impact on sensor circuits, and run through several candidate methods to compensate for the offset.

AMR SENSOR BRIDGES

Because AMR sensors are designed in wheatstone bridge configurations, the manufacturing objective is to create four electrically identical magneto-resistive elements with diagonal pairs of elements physically identical to react similarly to nearby magnetic fields.

The principal of wheatstone bridges is to create two voltage divider elements (half-bridges), each with normally equal electrical impedances at a “null point”, or when a sensor has no stimulus. With each half-bridge at its null point, the expected voltage across each divider should be half the total bridge supply voltage (Vb). Thus the wheatstone bridge output nodes (Vo+, Vo-) should be identical. Figure 1 shows schematically a typical AMR wheatstone bridge circuit.

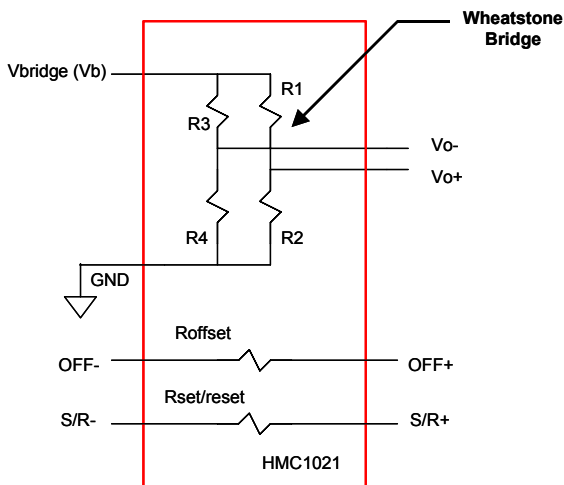


Figure 1
Bridge Circuit

WHAT IS BRIDGE OFFSET?

Bridge offset voltage is result of the difference in volts of the output nodes, Vo+ and Vo-. A voltage output is expected on a wheatstone bridge across the output nodes, but an offset voltage is undesired output that does not change value or polarity if the sensor stimulus varies. Figure 2 shows a typical bridge offset voltage imposed on a HMC1001 sensitivity graph.

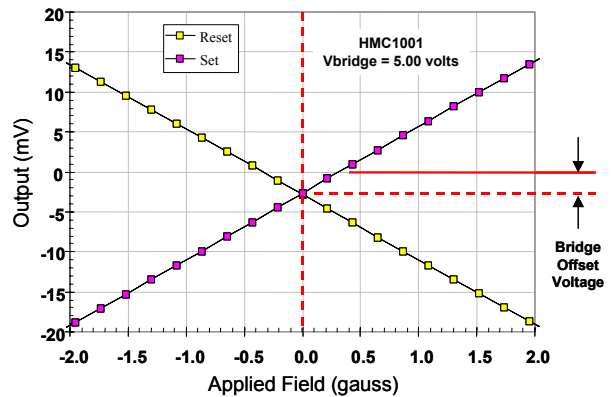


Figure 1
Offset/Sensitivity Graph

In the case of AMR sensors, the bridge offset voltage is primarily caused by in-exact resistive values of each sensor element. While Honeywell’s manufacturing processes using semiconductor fabrication equipment result in precision matched AMR elements, the tolerances on depositing permalloy (NiFe) films to lithographically controlled areas leads to some resistive value mis-matching. Even with several hundred to thousands of ohms of element resistance, an error of a fraction of an ohm can create a sizable bridge offset voltage.

Using Figure 1 as an example with a HMC1021, bridge element resistances R1, R2, R3, and R4 are nominally 1100 ohms each. Thus the positive bridge output node voltage (Vo+) will be:

$$Vo+ = Vb [R2 / (R1 + R2)]$$

And the negative bridge output node voltage (Vo-) will be:

$$Vo- = Vb [R4 / (R3 + R4)]$$

So the resulting bridge offset voltage will be:

$$V_{off} = (V_{o+} - V_{o-})$$

$$V_{off} = V_b \{ [R_2 / (R_1 + R_2)] - [R_4 / (R_3 + R_4)] \}$$

If for example R1 and R4 are 1101 ohms with R2 and R3 remaining at 1100 ohms, with Vb = 5 volts, then Voff equals -0.00227 volts or -2.27 millivolts. No big deal you say? Well if your HMC1021 has to measure an earth's field vector component of 100 milligauss (a realistic quantity), the sensor bridge output due to the field with a Vb of 5 volts is 0.50 millivolts; a pretty small voltage compared to the offset voltage. So the sensor bridge's output voltage sensitivity has to be compared to the bridge offset voltage for the degree desired to undesired output signals.

The good news is that these bridge offset voltages stay the same over the whole useful life of the sensor. So compensating for each sensor bridge's offset voltage is a one time routine that can be accomplished at product manufacturing. The other good news is that this offset voltage is proportional to the bridge voltage and thus scales up or down along with the bridge's sensitivity specification. So bridge offset voltages can be either specified with a known bridge voltage, or be given as a normalized value such as +1.25mV/V or +1.25 millivolts of bridge offset voltage per volt of bridge supply.

IMPACT ON SENSOR DESIGNS

Bridge offset voltages have impact on AMR sensor system designs beyond just shifting the operating point of the output voltages. The bridge offset voltage specification has a tolerance on it, indicating that from sensor to sensor the offset voltage measured is a variable and not a wafer or production lot stable phenomenon. So when designing successive voltage amplification stages after the sensor bridge, this offset voltage tolerance must be added to the expected output voltage range of a magnetically stimulated AMR bridge.

As an example, take a HMC1022 product for a two-axis compassing solution for an automotive application with a regulated 5 volt supply on the sensor bridges. Normally the HMC1022's 2.5 volt output terminals on the half bridges will have bridge offset voltage from -10mV to +11.25mV as measured from Vo+ to Vo-. This normalizes to -2mV/V to +2.25mV/V. For a compassing application, earth's field measures about 625 milli-gauss maximally on any one sensor bridge. So with the HMC1022's sensitivity specification of 0.8 to 1.25mV/V/gauss, the maximum possible earth's field stimulus could be +/-3.9mV on any one bridge.

The problem arises when the +/-3.9mV is added to the possible -10mV to +11.25mV bridge offset

voltage. The sum becomes -13.9mV to +15.15mV with the magnetic portion of the output signal only about 25 percent of the total variation. So to next amplify this bridge output voltage to the 0.5 to 4.5 volt input range of an Analog-to-Digital Converter (ADC), the maximum 15.15mV must be gained towards a 2 volt peak signal swing, or a gain stage of 2/0.01515, or 132. Figures 3 and 4 show these offset tolerance bands and the interaction with earth's magnetic field sensitivity.

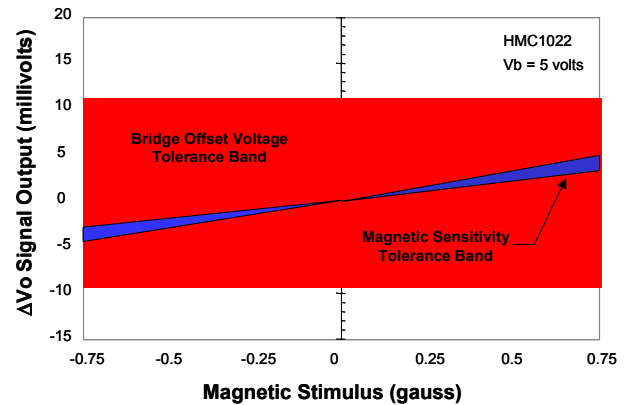


Figure 3
Offset & Sensitivity

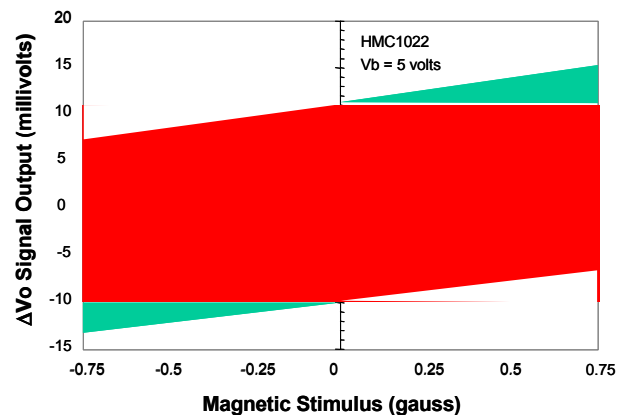


Figure 4
Combined Output Tolerance

Where it hurts you is in compassing resolution, because that 0.5 to 4.5 volt ADC range is wasted on only 1.03 volts of compass signal swing. If the ADC is a ten-bit version then the possible 1024 counts are spread over the whole 0.5 to 4.5 volt input range and only about a quarter of the counts (~256) will help in the compass heading computation. Under optimum conditions, about 0.5° resolution results, and around 1° resolution in most of North America.

If the same 10-bit ADC had all bridge offset voltage corrected before the converter, then all 1024 counts could be used in compass heading computation for a possible 0.1° resolution, or 0.2° resolution in most of North America.

Another impact of bridge offset voltage on system designs is thermal drift of any offset present will exacerbate the worst case computation of gain for ADC input range. It is possible that up to $\pm 5\%$ temperature compensation range would be added, thus further decreasing possible resolution.

BRIDGE OFFSET REDUCTION METHODS

Several candidate methods of bridge offset reduction are known to wheatstone bridge designers for AMR sensors. These are listed as 1) Shunt Resistance Method, 2) Amplifier Bias Nulling, 3) Switching Feedback, 4) Offset Strap Current, and 5) Digital Subtraction.

SHUNT RESISTANCE METHOD

The shunt resistance method is simply adding parallel resistances across one or more legs of the sensor wheatstone bridge to re-balance the bridge with an offset voltage. To do this accurately, all magnetic signal stimulus should be removed. This can be done in either a helmholtz coil set or in a well shielded enclosure to remove the effects of earth’s field on the sensor.

To minimize the quantity of trimming shunts used on the bridge, the largest resistive leg of the wheatstone bridge needs to be identified. In a production line setting, the large leg identification can be done with Automated Test Equipment (ATE), and then prompt an assembler to place a computed value of shunt resistance across the large leg spare component pads. Figure 5 shows a typical implementation of this shunt resistance method.

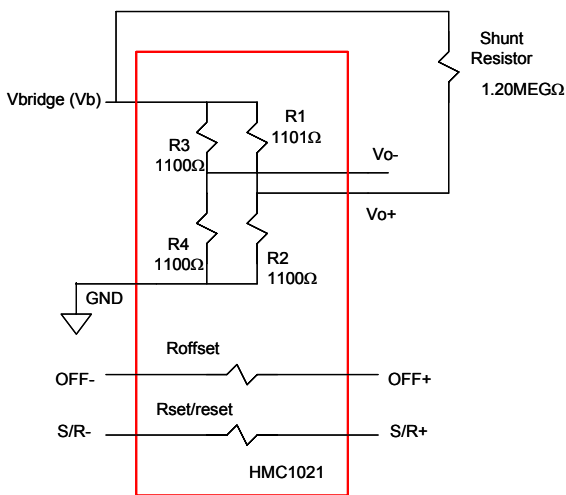


Figure 5
Shunt Resistance Method

As you can see, the downside of this method is that you will need four resistor shunt locations and a large variety of possible shunt resistor values.

AMPLIFIER BIAS NULLING METHOD

This next method does not directly affect the bridge performance, but creates an opposite polarity voltage at the instrumentation amplifier stage to cancel the bridge offset voltage. For example, if the bridge has a ten milli-volt offset voltage, a bias voltage of half-supply ($1/2 V_b$) minus ten milli-volts is also applied to create an opposite direct current force to cancel (null) out the offset. With zero magnetic field applied, the instrumentation amplifier will remain at half-supply, and only gain up any magnetic field induced voltage difference from the AMR bridge. Figure 6 shows an example instrumentation amplifier circuit with a potentiometer providing a nulling bias voltage.

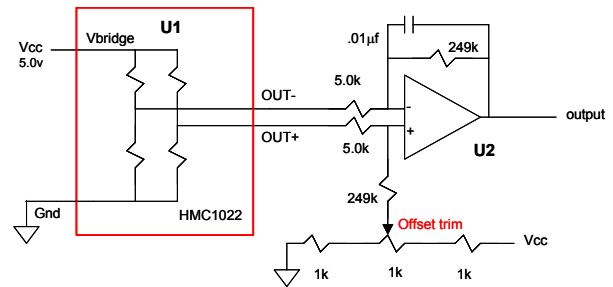


Figure 6
Bias Nulling Method

SWITCHING FEEDBACK METHOD

The switching feedback method uses the property that toggling the sensor element between “set” and “reset” conditions via the set/reset strap element; allows the field induced sensor output to reverse polarity, but the bridge offset voltage remains a constant bias on the output. Figure 7 shows the toggling routine graphed with typical output levels.

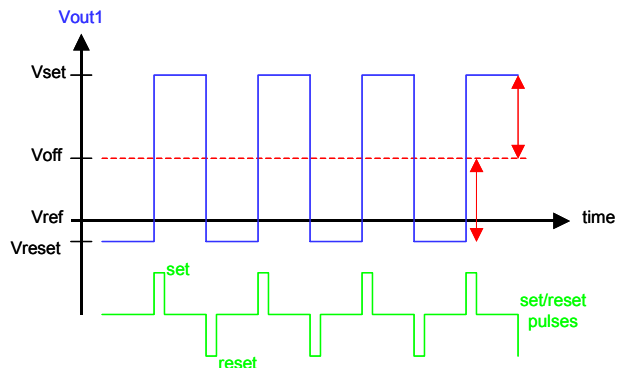


Figure 7
Switching Bridge Output

By toggling the set/reset strap to create the square wave bridge output voltage, a slow responding circuit is used that does not react to the toggling, but averages the peaks and creates an inverse signal that nulls bridge offset voltage. Figure 8 shows a typical schematic of a switching feedback circuit.

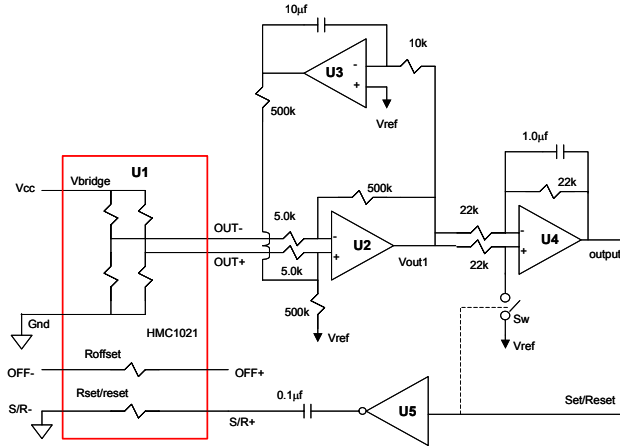


Figure 8
Switching Feedback Method

From Figure 8, the first amplifier stage performs the normal instrumentation amplifier function with its output described as Vout1. The second amplifier stage (U3) actually performs as an integrator that “feeds back” the output signal less most of the the toggling waveform performing the null voltage (DC restore) compensation to remove the bridge offset voltage. The third amplifier stage (U4) performs a “de-toggle” function to remove the polarity reversal from Vout1, leaving just the amplified magnetic field output (Applied) as the result.

This method “modulates” the sensed output signal and then “demodulates” the signal and removes the bridge offset. By choosing a quick enough integrator response time and a set/reset toggle time around a hundred times or more faster than the integrator time, the above circuit will produce a smoothed output. Careful choices in resistor and capacitor values will be required.

OFFSET STRAP CURRENT METHOD

Honeywell’s patented offset strap on its AMR sensor permits an additional method of compensating for bridge offset voltages. This strap consists of a spiral of metalization placed near the bridge to couple a magnetic field induced by current flowing through the strap. Not only does this strap make a nice current sensor, but the magnetic field produced can sum with an external sensed field to cancel the offset voltage.

Offset strap resistances and offset coefficients (mA/gauss) vary widely depending on the AMR design, but generally require milliamperes of current through low strap resistances to perform an offset nulling function. For low currents, an operational amplifier with a modest series resistance will perform adequately. For heavier strap currents beyond 10 milliamperes or more, the circuit in Figure 9 shows a buffered amplifier for increased current outputs.

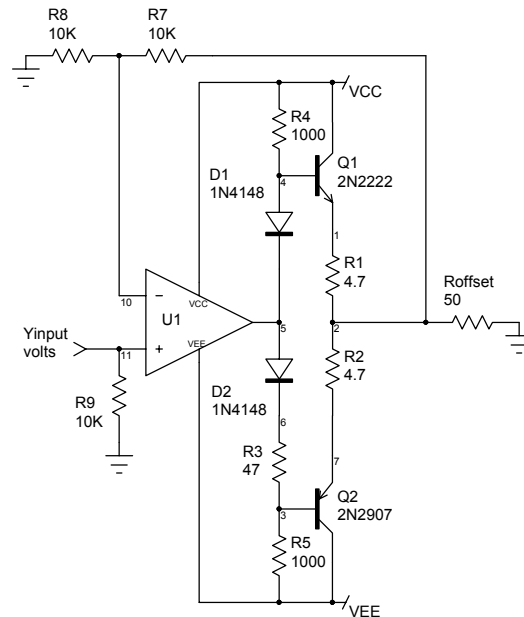


Figure 9
High Current Amplifier Circuit

DIGITAL SUBTRACTION METHOD

This method is the most popular as it requires no change in hardware. But as mentioned early in this application note, ADC resolution is sacrificed to accommodate the dynamic range of sensor bridge offsets. As a way of demonstrating this mathematical method, the following example is described.

A HMC1052 dual sensor bridge device is used as a compass in a consumer electronics (0 to +70°C) application. The HMC datasheet gives bridge offset voltage values of ±1.25mV/V and a sensitivity of 1.0±0.2mV/V/gauss. Factoring the tempco’s for each value yields negligible change for bridge offset and a nominal ±0.135mV/V/gauss addition. So the worst-case situation would be maximum sensitivity (1.335mV/V/gauss) and the widest range of bridge offsets. Additional variables are a nominal 3.0 volt DC supply and a 625 milligauss maximum earth’s field intensity on any one sensor bridge.

The resulting bridge offset voltage could then be:

$$V_{off} = (3.0V) * (\pm 1.25mV/V)$$

$$V_{off} = \pm 3.75mV$$

And then the maximum magnetic field swing would be:

$$V_{field} = (3.0V) * (\pm 1.335mV/V/gauss) * (0.625 gauss)$$

$$V_{field} = \pm 2.5mV$$

So the total swing of the bridge outputs could be:

$$V_o = V_{off} + V_{field} = (\pm 3.75mV) + (\pm 2.5mV)$$

$$V_o = \pm 6.25mV$$

Now we can proceed with the basic circuit design using a dual operational amplifier feeding a microcontroller for the digital conversion and offset subtraction. Figure 10 shows a typical implementation.

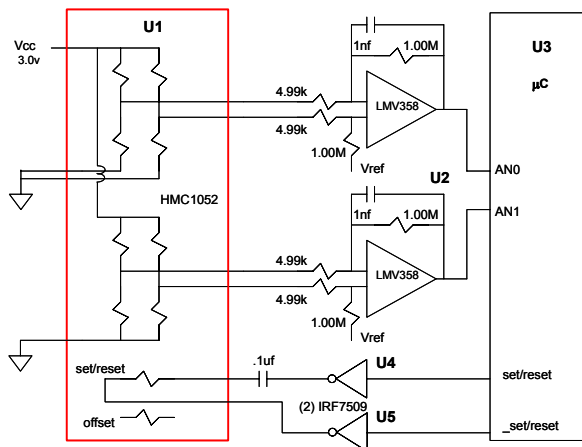


Figure 10
HMC1052 Compass Circuit

The onboard Analog-to Digital converters on the microcontroller are assumed to be running off the same 3.0 volt DC supply as the op-amps and sensor bridges. To be a bit conservative, we will further assume the converter's range will be 200 millivolts from each side of the power supply. In this example, 0.2 to 2.8 volts or $\pm 1.3V$ from a 1.5 volt mid-point, or reference voltage (V_{ref}) for maximum dynamic input range. This allows the op-amps that are configured as instrumentation amplifiers to fix their gain to amplify the $\pm 6.25mV$ signal up to the $\pm 1.3V$ ADC range. Thus the amplifier gain stages are:

$$Gain = (\pm 1.3V) / (\pm 0.00625V) = 208$$

In the above schematic, the 208 calculated gain is rounded down to 200. The 200 gain allows for the

choice of 4.99k-ohm and 1 Meg-ohm metal film gain setting resistors. The choice of 4.99k-ohm comes from nominal bridge resistance of 1000 ohms and that this amplifier input impedance should be a "bridging" type in which the impedance should be 4 to 10 ten times or more of the source (bridge) impedance. The 1 Meg-ohm resistors are then $1/200^{th}$ the size of the 4.99k-ohm input resistors.

With the possible $\pm 1.3V$ range of the ADCs used to handle the earth's field input signal and the bridge offset after amplification, then the digital manipulation begins. Another assumption will be that the microcontroller contains a multiplexed input 10-bit ADC for 1024 digital levels over its $\pm 1.3V$ (2.6V) range.

Each of the 1024 ADC levels or "counts" now becomes numerical representation of an input voltage. So the 512^{th} count becomes 1.5 volts or the zero input reference voltage and each count away from the 512^{th} count is about 2.5 milli-volts swing from the reference.

To put some "real world" voltages and counts in this example, lets assume HMC1052 sensor bridge A has -127 milli-gauss applied to it and has +3.00 milli-volts of bridge offset with a 3.0 volt system supply voltage. For this situation, the -127 milli-gauss produces -0.381 milli-volts which is added to the +3.00 milli-volts for a net 2.619 milli-volts. This voltage is then gained by 200 via the amplifiers and referenced to the 1.5 volt reference to create:

$$V_{adc} = (1.5V) + (2.619mV) * (200) = 2.024 volts$$

When converted to its digital representation, V_{adc} becomes about 206 counts above the 512 count reference, or 718 counts. So how do you come up with the subtraction of the bridge offset? There are at least two ways.

The first one would be to determine the natural bridge offset at the factory with no magnetic field applied, by testing in a shielded fixture or helmholtz coil fixture to counter the earth's field. Thus the +3.00 millivolts would still be present on bridge A and after 200 gaining, would be 600 milli-volts above the 1.5 volt reference, or 2.10 volts. This would equate to 236 counts above the 512 count reference, or 748 counts. Then the factory would preset a minus 236 count correction factor to every field reading performed on bridge A. The same procedure would apply to bridge B.

A second method would be similar to the switching feedback method described earlier in this application note. The difference would be no additional circuits would be required and the set/reset switching could be done on a one-shot basis, or with a much slower

flipping rate. In the above example, if the reset/set strap received an opposite polarity current from its previous state, the -127 milli-gauss field input would suddenly look like a $+127$ milli-gauss input with a resulting $+0.381$ milli-volt output. The 3.00 milli-volt bridge A offset voltage would remain the same, but the output at the sensor bridge nodes would be the sum of the voltages, or $+3.381$ milli-volts.

After the gain stage the output would be 676 millivolts over the 1.5 volt reference, or 2.18 volts. This would equate to 266 counts over the 512 count reference, or 778 counts.

Thus with one set/reset polarity you have 206 counts over the reference, and the opposite polarity results in 266 counts over the reference. If you added the two count tallies together, you find that the bridge offset portions of the counts would double, but the field portions of the counts would cancel out. Thus taking 206 plus 266 yields 472 , and then halving the sum provides the 236 count correction factor.

The advantage of the set/reset toggling method is that it can be done without special fixturing and in any orientation relative to earth's field. Many compass manufacturers will recompute these correction factors each time they toggle through a periodic set/reset routine, even though the result will be the same throughout the life of the product. This has the advantage of nulling out every last bit of offset for large operational temperature swings.

Note that the ± 127 milli-gauss swing exhibited the 206 to 266 swing, or only 60 counts difference. So be aware that low fields on small bit ADCs (8 or 10 -bit) will not provide very high resolution compass solutions. In this example the ± 625 milli-gauss maximum earth's field range would provide ± 1.875 milli-volts of bridge signal gained to ± 0.375 volts or ± 148 counts of the total 1024 count range. This would result in about a 0.4° best case resolution for this design.

SUMMARY

Handling magnetic sensor bridge offset voltages is a necessary problem to be overcome. The methods described herein show that various means can be used to accomplish the task of offset cancellation or correction. The choice of methods is determined by your specification priorities and cost of production. If high resolution performance is above all the other requirements, then the analog component methods will preserve the highest resolution. If low cost, modest performance comes first, then the digital subtraction method should be a preference.