Using Anaren's BD0205F5050A00 Balun with Analog Devices, Inc. AD9445 and AD9446 High Speed Data Converters

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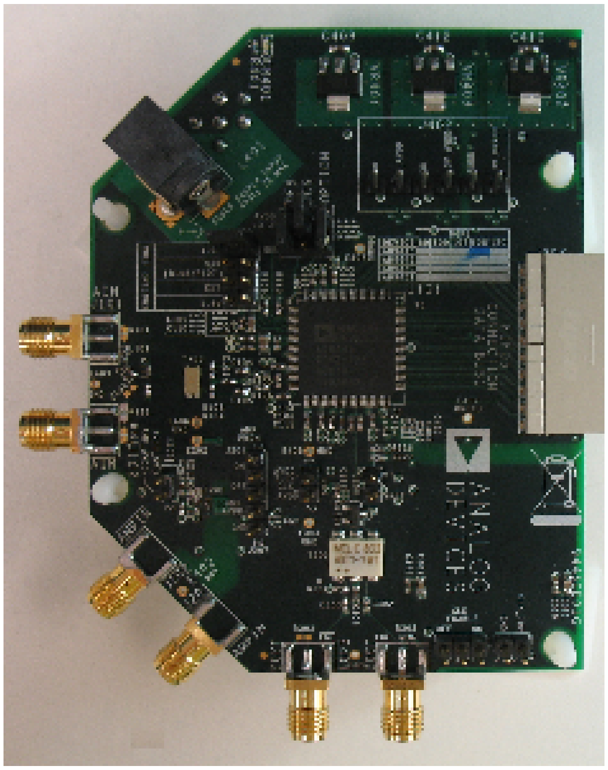


Introduction

This application note helps explain the use of Anaren's multilayer BD0205F5050A00 balun, in conjunction with either the Analog Devices AD9445 or AD9446 14bit / 16bit high speed data converters, This implementation will contribute to both a higher Signal to Noise ratio and an improvement in SFDR. Anaren's baluns offer superior part to part consistency through their proven fabrication technology based on multilayer organic substrates. This differentiation allows faultless operation and performance repeatability not available in a wire-wound equivalent. A reduced overall component count also comes through a single Anaren balun replacing multiple wire-wounds parts while maintain performance.

The AD9446 product operates up to 100 MSPS, providing superior SNR for instrumentation, medical imaging, and radar receivers employing baseband (<100 MHz) IF frequencies. While the AD9445 product operates at up to an 125 MSPS conversion rate and is optimized for multi-carrier, multimode receivers, such as those found in cellular infrastructure equipment and very high end instrumentation.

Anaren's multi-layer components are part of a wider family of baluns, couplers and power dividers covering frequencies from 50MHz to 9GHz and based on a multilayer organic material set offering CTE's comparable with PWB materials smaller footprints and higher performances than both ceramic LTCC and ferrite based wire-wound parts.

Role of Baluns in ADC Design

Baluns (or transformers) are passive devices that a) provide an impedance transformation and b) convert a single ended signal into a differential one. Baluns are used in analog to digital conversion circuits to couple signals appropriately to the converter's analog inputs. In this discussion, the terms balun and transformer will be used interchangeably.

Single ended signals travel on an individual trace with a certain characteristic impedance, usually 50Ω. However, a two conductor system can carry "differential signals". In this configuration, the currents and voltages on the differential lines are 180° out of phase and are of equal magnitude.

Conversely, common mode signals have voltages and currents on the differential lines which are in phase. The balun may be thought of a common mode filter which rejects common mode signals on the differential lines but allows differential signals to pass.

As stated in the Analog Devices Datasheet for the AD9445 [2], since the analog inputs to the ADC are differential, significant performance improvements result from the differential analog stages having a high rejection of even-order harmonics. Performance improvements also occur because the common mode rejection function of the balun will effectively reject ground and power noise in addition to common mode signals such as local oscillator feed through.

At higher frequencies, the electrical performance of a balun is more conveniently characterized by microwave performance parameters such as return loss, insertion loss, phase and amplitude balance, and common mode rejection ratio. Insertion loss is a description of signal attenuation through the balun and as such can be used to define the bandwidth of the component. Unbalanced return loss defines how much RF power is reflected from signals incident on the unbalanced, single ended port. Conversely, balanced return loss defines how much RF power is reflected from balanced, differential port. Return loss describes how well the port impedances of the balun is matched to other components.

Finally, amplitude and phase balance are indicators of how well the balun transforms a signal from single ended to differential. As mentioned above ideally, the signals on the two differential lines should be equal and opposite. To this end, a simple ratio of the amplitudes of the signals will provide a measure of the amplitude balance with 1 or (0 dB if a logarithmic scale is being used) being the ideal value. Similarly, ideally the phase difference between the differential pairs should be 180°.

Effect of Balun Amplitude & Phase Balance on ADC Performance

The performance of ADCs is heavily influenced by amplitude and phase imbalances arising from the balun especially in high frequency applications. Specifically, non-linearities in the ADC will cause even harmonics to be generated if the balun has amplitude or phase imbalance. The presence of harmonics will adversely affect ADC performance parameters such as SFDR, SNR, THD, and SINAD (See Section "ADC Performance Parameter Definitions" for definitions of these parameters).

Reeder and Ramachandran [1] investigate the effect of non-ideal amplitude and phase balance on ADC performance by modeling the ADC as a symmetrical 3'rd order transfer function and the differential output signals as sinusoids. Following the nomenclature of [1], the ADC transfer function and differential sinusoids are defined as:

$$h(t) = a_0 + a_1 x(t) + a_2 x^2(t) + a_3 x^3(t)$$

$$x_1(t) = k_1 \sin(\omega t)$$

$$x_2(t) = k_2 \sin(\omega t - 180^\circ + \phi)$$

The following conclusions are made in their paper:

1. In the ideal case (i.e. perfect phase and amplitude balance) , even harmonics cancel out, while the odd ones do not, i.e. $k_1 = k_2$ & $\varphi = 0°$

2. In the case of a magnitude imbalance and no phase imbalance, the 2’nd harmonic is proportional to k_1^2 and k_2^2, specifically

$$2f_0 \propto k_1^2 - k_2^2$$

where k_1 and k_2 are the amplitudes of the differential pair signal.

3. In the case of phase imbalance and no magnitude imbalance, the 2’nd harmonic is in proportion to k_1^2, i.e.

$$2f_0 \propto k_1^2$$

where f_0 is the fundamental frequency.

Note from the above that since $k_1^2 > k_1^2 - k_2^2$, a phase imbalance condition will yield a larger 2’nd harmonic than an amplitude imbalance condition. Emphasis then should be placed on minimizing phase balance errors.

The generation of harmonics will have a direct effect on SFDR since SFDR is defined as the ratio of the RMS value of the signal to the RMS value of the peak spurious spectral component. This is illustrated below in Figure 1:

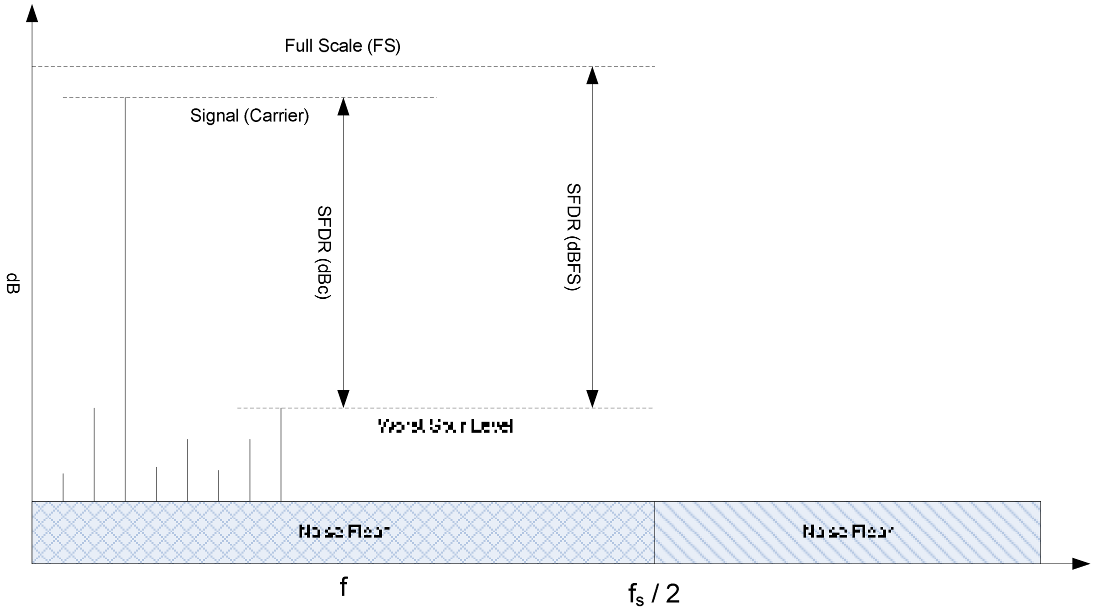


Figure 1 Definition of SFDR

Signal to Noise Ratio (SNR) is also dependant on the levels of spurious harmonics. SNR is defined as “*the ratio RMS signal amplitude to the RMS value of the sum of all spectral components except the first 6 harmonics and DC*”.

It is clear that a significant performance enhancement of ADCs can be obtained through the choice of a balun or transformer with the best possible amplitude and phase characteristics.

The next section compares the SFDR, SNR and Full Power Bandwidth / Input Drive of Anaren balun BD0205F5050A00 to Mini-Circuits ADT-1-1 and MA-Com ETC1-1-13 wire wound baluns.

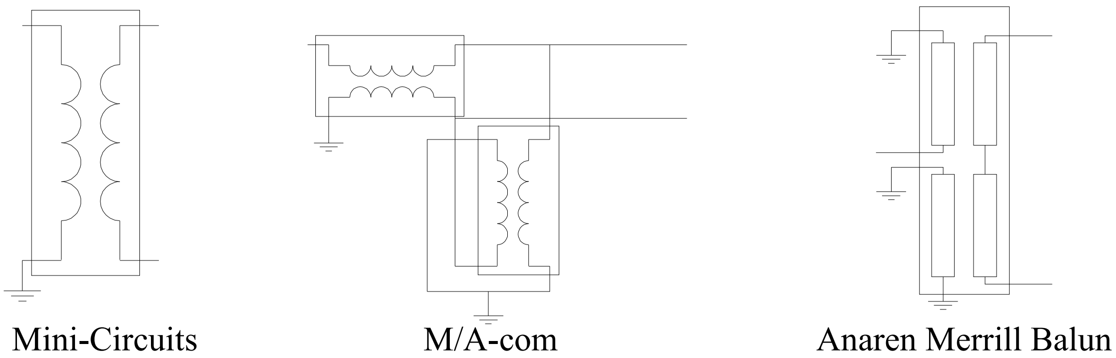
Wire Wound Balun vs. Anaren Balun Performance Comparison

Until recently, wire wound transformers have been typically the solution of choice in ADC converter front end circuit design to convert single ended signals to differential. The transformation ratios are typically 1:1 although 1:4 transformations are also used. Wire wound baluns deliver good performance at lower frequencies (i.e. < 200 MHz) where they exhibit good balanced phase, amplitude performance, good insertion and return loss.

However, wire wound baluns suffer from some drawbacks, the most serious of which is the deterioration of performance at higher frequencies. Wire wound baluns are essentially lumped element components which work well at lower frequencies, but whose performance deteriorates as the effects of parasitics become more pronounced at higher frequencies and ferrite losses increase. By definition, lumped element components are not suited for use as the wavelength of operation becomes comparable to the physical dimensions of the component.

Anaren baluns are coupled, microwave stripline structures and as such are inherently suited for operation at higher frequencies (i.e. > 200 MHz). These baluns are coupled stripline designs which use softboard (PTFE / Teflon) type material as the dielectric medium. The dielectric is typically low loss thus ensuring that insertion loss is kept to a minimum at higher frequencies. In addition, the use of proprietary design techniques allows significant amount of circuitry to be packed into a package, thus minimizing package size.

Figure 2 below compares the internal circuitry of the Mini-Circuits and M/A-com baluns with the Anaren balun. Note that the M/A-com balun is comprised of 2 transformers in order to improve the performance of a single balun.



Mini-Circuits M/A-com Anaren Merrill Balun

Figure 2 Balun Schematic Comparison

Unlike wire wound baluns, no ferrites are used in Anaren baluns. This is a significant advantage given recent trends in moving away from the use of ferrites on present day circuit boards.

In addition to the above, Anaren balun offers a smaller footprint than wirewounds demonstrated by Anaren BD0205F5050A00 balun which comes in a 1608 size. Table 1 compares the dimensions of the Anaren balun with those of the wire wound baluns. Table 2 shows the percentage reductions in area required by using Anaren baluns

Table 1 Size Comparison Between Wire Wound Baluns and Anaren Balun

	Length	Width	Height	PCB Area
BD0205F5050A00	0.157”	0.079”	0.029”	0.0124 sq. in.
MA/Com ETC1-1-13 Double Balun	2 X 0.150” = 0.300”	2 X 0.150” = 0.300”	0.105”	0.0900 sq. in
Mini-Circuits ADT-1-1	0.310”	0.220”	0.112”	0.0682 sq. in

Table 2 Space Savings Achieved by using Anaren Balun

	MA/Com ETC1-1-13	Mini-Circuits ADT-1-1
BD0205F5050A00	Anaren 85% smaller	Anaren 82% smaller

Finally, RF performance parameters were measured using an Analog Device AD9445 evaluation board populated with Anaren BD0205F5050A00 balun. Testing was performed using the test setup and methods described in the Section “Test Setup & Methodology”. Comparisons with the MA-Com and the Mini-circuits baluns are made.

Results for the important performance parameters of SFDR, SFR, and Gain Flatness are presented.

SFDR Comparison

The BD0205F5050A00 balun with is compared to the Mini-circuits (orange) and MA/Com dual balun configuration (light blue) in Figure 3. The Anaren balun offers a significant improvement in SFDR over the Mini-Circuits balun. SFDR improvement over the wire wounds goes from about 10 dB improvement at 200 MHz to about 20 dB at 500 MHz in the case of the Mini-circuits balun.

The MA/Com dual configuration has roughly the same performance over the band at the higher frequencies although the Anaren balun have superior performance at the low end. However, 2 baluns are required to achieve this performance as opposed to a single Anaren balun.

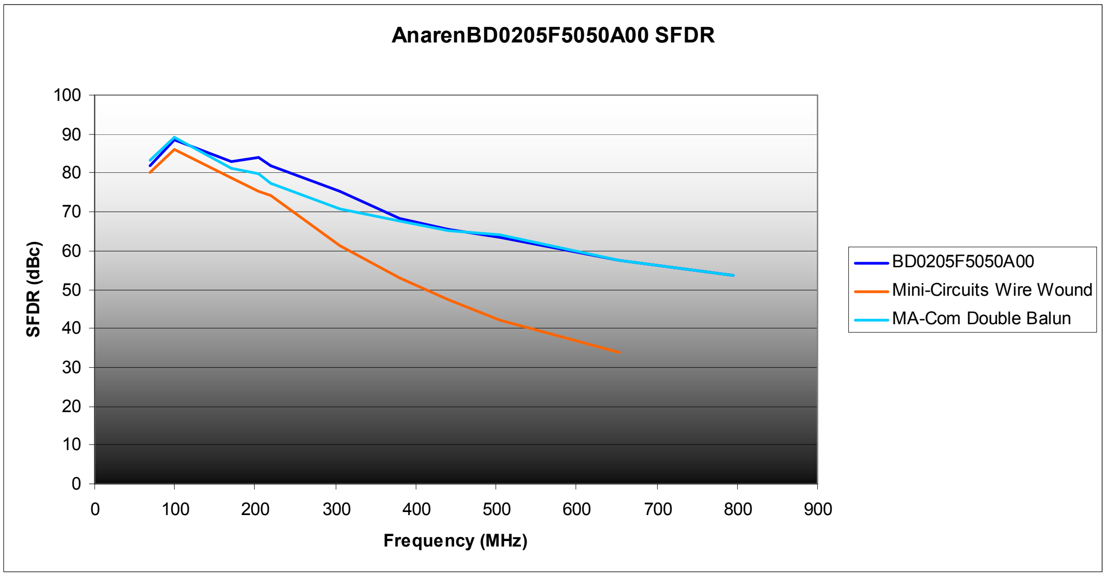


Figure 3 BD0205F5050A00 vs. Mini-Circuits Wire Wound & MA-Com dual balun configuration

Gain Flatness

This test measures the loss through the matching network and the data converter for a particular balun or transformer. The measurement band is from 10 MHz to 1005 MHz.

The test is performed by setting the power level of the signal generator so that the peak signal value obtained anywhere in the band from 10 MHz to 1005 MHz at that setting is -1 dB full scale, i.e. all other values in the band will be below -1 dB. A frequency of 1005MHz is used because it is well beyond the converter's BW. A 100MHz reference setting was chosen at -1 dB full scale, i.e. all other values in the band will be referenced to that frequency (usually they will be equal or lower).

With the signal generator set at that value, a frequency sweep is performed over the 10 MHz to 1005 MHz bandwidth with signal level being recorded. Note that as expected the -1 dBFS point is at the lowest frequency while for the Anaren baluns, the -1dBFS point is at about 200 MHz.

Figure 4 shows BD0205F5050A00 plotted against the results for the Mini-Circuits balun. It is seen that response for the Anaren part is significantly wider band than the wirewound balun and comparable to the MA/Com dual balun. As expected the wire wound balun drops off at the higher frequency whereas the Anaren part exhibit much less of a loss making the converter easier to drive to fullscale at high IF frequencies.

Similarly, Figure 5 shows the absolute full power bandwidth, i.e. unnormalized to -1 dBFS.

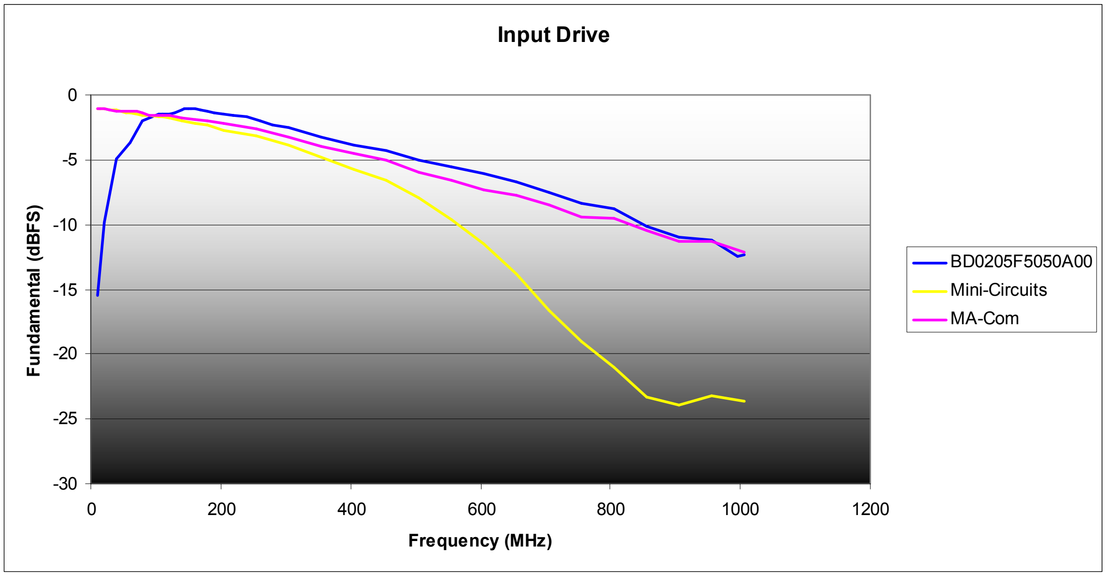


Figure 4 Gain Flatness - BD0205F5050A00 vs Mini-Circuits & MA/Com dual balun wire wound baluns

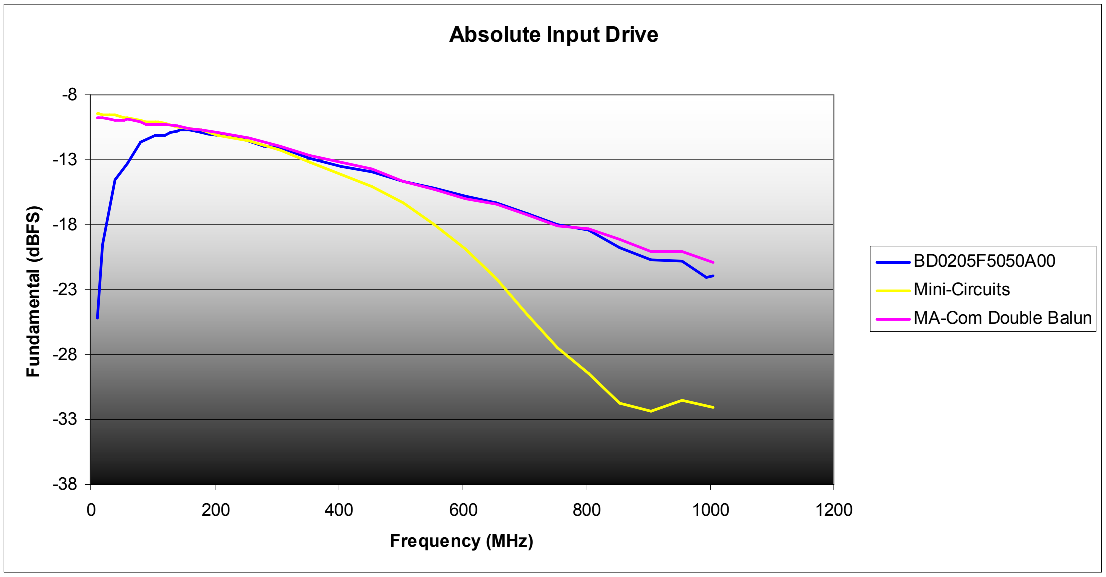


Figure 5 Absolute Full Power bandwidth for BD0205F5050A00 vs Mini-Circuits Wire Wound & MA-Com dual balun wire wound baluns

Signal to Noise Ratio

The SNR measurements are comparable for the different solutions using either the Anaren or wire wound transformers. These are summarized in Figure 6.

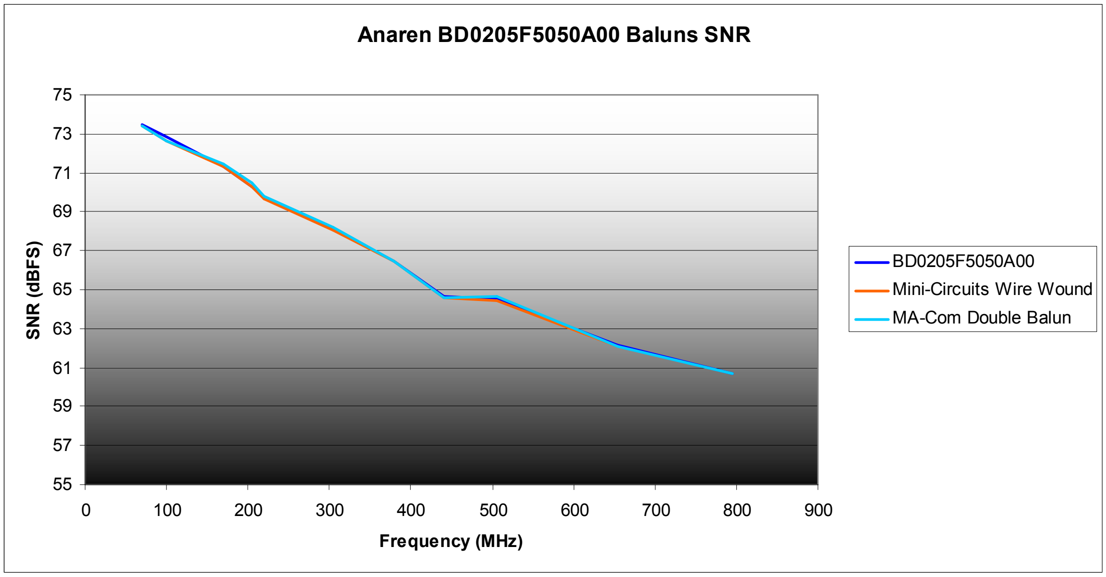
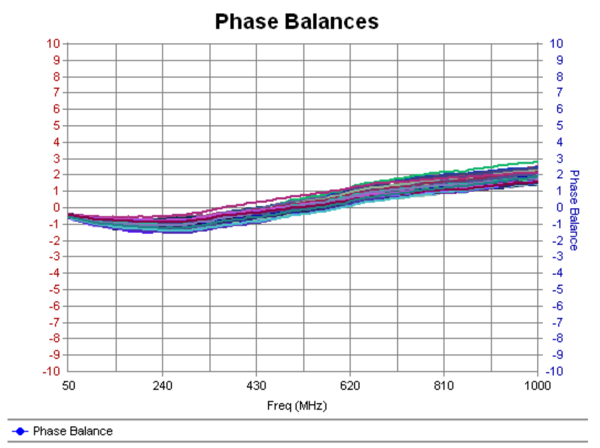


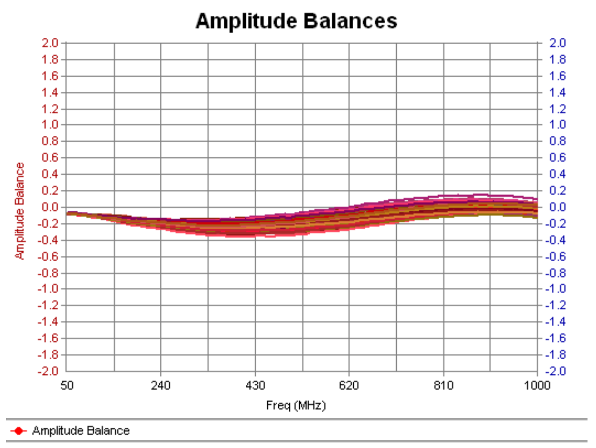
Figure 6 SNR for BD0205F5050A00 vs. Mini-Circuit & MA-Com wire wound

Repeatability Advantages of Anaren ADC Baluns

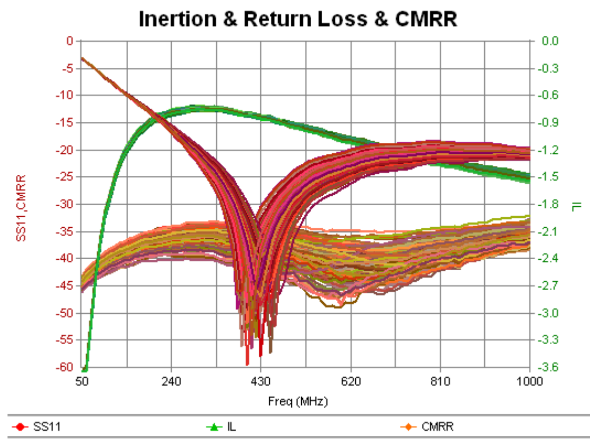
Another significant advantage offered by Anaren ADC balun is repeatability. The baluns are manufactured using a well defined and repeatable process which ensures that part to part variation is kept to a minimum. As an example of this, Figure 7 below shows a plot of the RF data for 180 parts of BD0205F5050A00.



Phase Balance 50 MHz – 1000 MHz 180 parts



Phase Balance 50 MHz – 1000 MHz 180 parts



Insertion, Return Loss & CMRR 50 MHz – 1000 MHz 180 parts

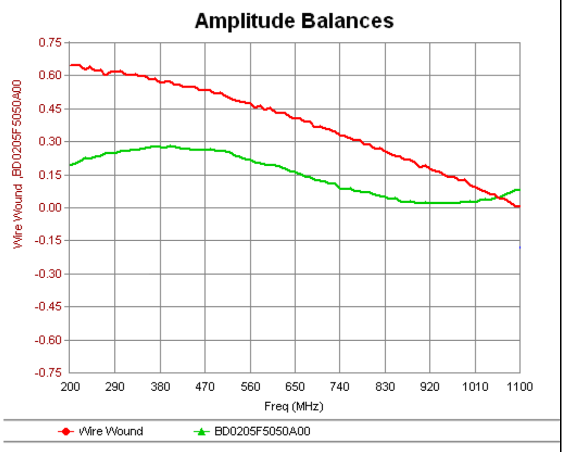
Figure 7 Plot of 180 BD0205F5050A00 showing repeatability of insertion loss, return loss and amplitude and phase balances.

It can be seen from the above plot that variation of insertion loss over the 180 parts is about ±0.05 dB, while amplitude balance is constant to within ±0.1 dB. Phase is constant to within ±1°.

S-parameter Comparison Between Wire Wound and Anaren Baluns

In this section, a direct S-parameter comparison is made between a MA-Com ETC1-1-13 and Anaren's softboard, multi-layer BD0205F5050A00 balun

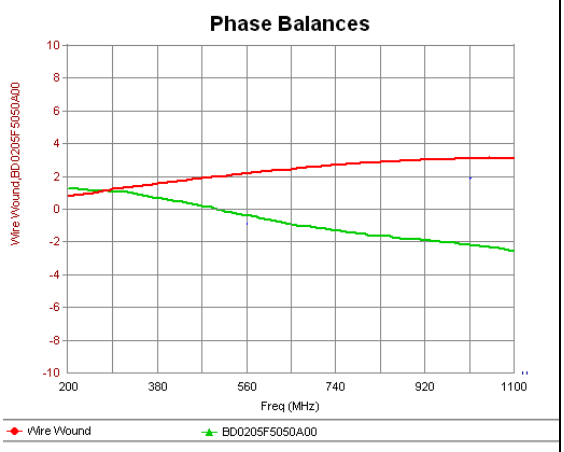
Figure 8 compares the RF performance of the wire wound balun with Anaren balun from 200 MHz to 1100 MHz. It is clear that the Anaren balun has superior amplitude and phase balance and hence CMRR over almost the entire band.



Amplitude Balance

Red = Wire Wound

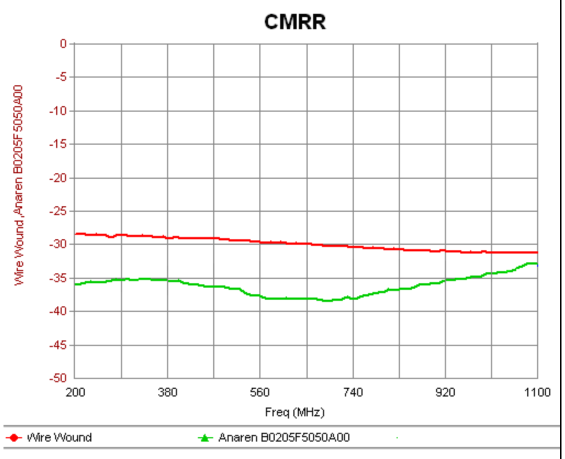
Green = BD0205F5050A00



Phase Balance

Red = Wire Wound

Green = BD0205F5050A00



CMRR

Red = Wire Wound

Green = BD0205F5050A00

Insertion Loss

Red = Wire Wound

Green = BD0205F5050A00

Figure 8 Comparison of Wire Wound Baluns & Anaren Balun

Test Setup & Testing Methodology

The AD9445 Evaluation Board A was measured for gain flatness, SNR and SFDR using the methods outlined in, AN-835 - Understanding High Speed ADC Testing and Evaluation, [3]. The data is taken directly using the Visual Analog Software package.

Complete information regarding the Visual Analog Software can be found on the Analog Devices website at **www.analog.com/visualanalog**

The following test equipment is used for measuring the data converters:

- 2 Rohde & Schwarz SMA 100 A signal Generators (Analog Input and Clock)
- Lumped element anti-aliasing filters
- Evaluation Board Rev A (equipped with dual footprint for measuring both Mini-circuits and M/A-com transformers, Anaren baluns use piggy back adapter board to meet footprint)
- Analog Devices HSC_ADC_EVALB_DCZ data capture board
- DC Power supplies

A typical test setup is shown below (diagram adapted from [3]):

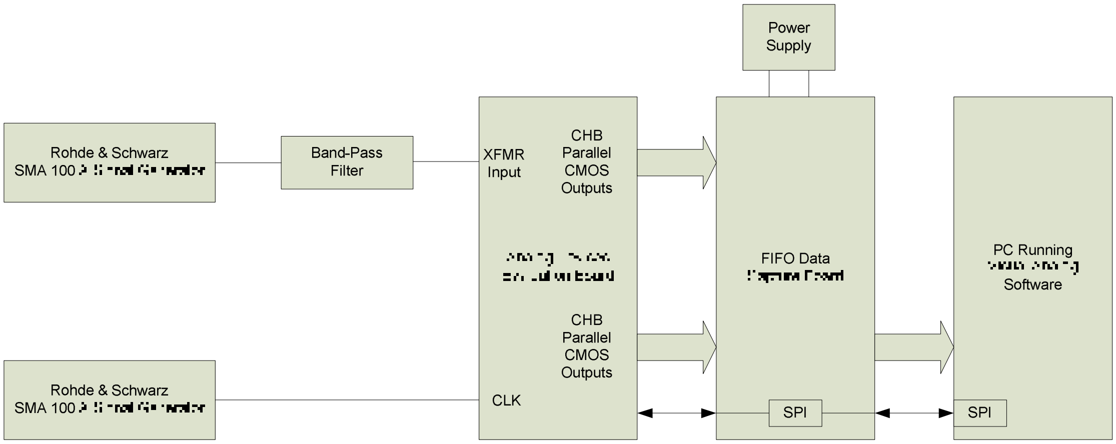


Figure 9 Typical Characterization Test Setup

ADC Performance Parameter Definitions

In this section, some of the more common performance parameters pertaining to ADCs are described. These are taken from Brannon and Reeder[3]:

2'nd & 3'rd Order Harmonic Distortion

The ratio of the rms signal amplitude to the rms value of the second or third harmonic component, reported in dBc.

Total Harmonic Distortion (THD)

The ratio of the rms signal amplitude to the rms sum of all harmonics (neglecting noise components). In most cases, only the first five harmonics are included in the measurement because the rest have negligible contribution to the result. The THD can be derived from the FFT of the ADC's output spectrum. For harmonics that are above the Nyquist frequency, the aliased component is used.

Spurious Free Dynamic Range (SFDR)

The ratio of the rms signal amplitude to the rms value of the peak spurious spectral component. The peak spurious component may or may not be a harmonic. May be reported in dBc (i.e., degrades as the signal level is lowered) or DBFS (related back to converter full-scale).

Signal-to-Noise-and-Distortion Ratio (SINAD)

The ratio of the rms signal amplitude (set 1 dB below full-scale to prevent overdrive) to the rms value of the sum of all other spectral components, including harmonics but excluding dc.

Signal to Noise Ratio (SNR)

The ratio of the RMS input signal to the RMS value of the sum of all other spectral components below the Nyquist frequency, excluding the first 6 harmonics and DC.

Summary – Advantages of Anaren vs. WireWound

- Superior amplitude and phase balance at higher frequencies leading to improvements in SFDR over wirewound baluns
- High part to part repeatability of RF performance
- Smaller footprint than wirewound baluns
- Better gain flatness at high frequencies (> 100 MHz)

References

[1] Reeder, R., Ramachandran, R, “Wideband A/D Converter Front-End Design Considerations”, Analog Dialogue, 40-07, July 2006.

[2] Analog Devices Datasheet, 14-bit, 105/125 MSPS, IF Sampling ADC AD9445, Rev 0, Analog Devices Ltd., 2005.

[3] Brannon, B, Reeder, R, Analog Devices Application Note, “AN-835 - Understanding High Speed ADC Testing and Evaluation”, Analog Devices Ltd., www.analog.com

[4] Analog Devices Application Note, “AN-905 VisualAnalog Converter Evaluation Tool Version 1.0 User Manual”, Analog Devices Ltd., www.analog.com

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