Correlating high-speed ADC performance to multicarrier 3G requirements

Data-converter contribution to 3G receiver system performance is not well understood. This article provides guidelines for ADC selection based on performance requirements.

By Brad Brannon

The sensitivity analysis of multicarrier 3G receivers depends on various aspects of the system design goals. While linear devices have well known system contributions, data converters contribution to system performance is less well understood. This article will provide guidelines for analog-to-digital converter (ADC) selection based on receiver performance requirements. In addition, the full scale of the ADC will be closely examined to determine what full scale is and how it relates to code division multiple access (CDMA) signals.

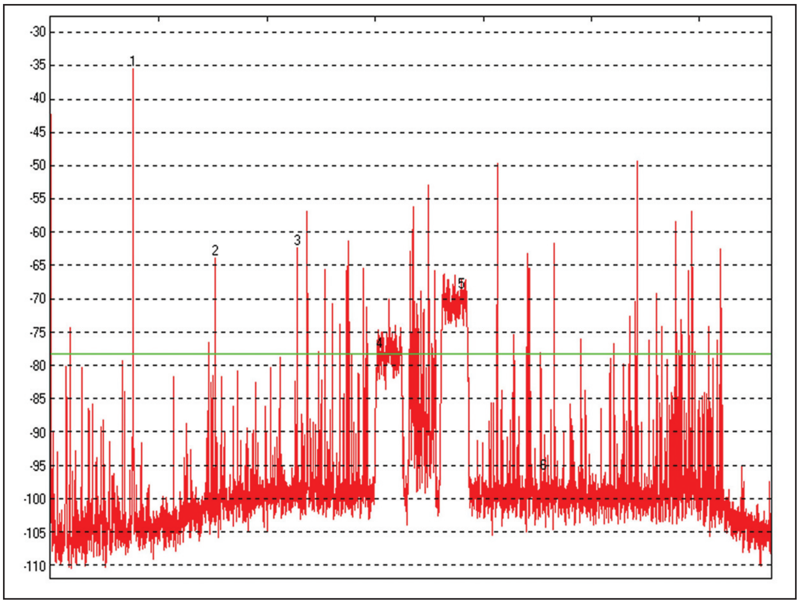

Figure 1. Typical RF spectrum of a multicarrier receiver

Introduction

Although 3G services seem to be slow to deploy, a lot of hard work is going on behind the scenes at both the original equipment manufacturers (OEMs) and the service providers to ensure the seamless integration of data with voice when the market is ready. IS-95 providers are quietly converting their systems to CDMA2000 networks, which will continue to support current voice customers and be ready for data services. Likewise, global system for mobile communications (GSM) providers are updating their systems to be ready for wideband code division multiple access (WCDMA) deployment.

Regardless of which side of the standards fence a design sits on, the receiver design faces some serious challenges. On the CDMA2000 side, it is clear that multiple carriers will be required to support even a modest volume of data when mixed with normal voice traffic volumes. Over the last few years, several different OEMs have shown transceiver platforms capable of supporting multiple CDMA2000 carriers. Although multicarrier receivers offer distinct advantages, they place significant challenges on the receivers' designs.

On the WCDMA side, deployment in North America poses a different set of challenges. Most notable is that of spectrum allocation. The planners for WCDMA designated relatively unused spectrum outside of North America for deployment. Unfortunately, in the U.S., this space is largely occupied. Although some efforts are under way to reallocate that spectrum, there is significant momentum to deploy WCDMA in spectrum already licensed in the 1900 MHz band along side other existing services, including CDMA2000, IS136 and GSM services.

This poses an interesting challenge. The specification for WCDMA was not originally written with adjacent narrowband signals in mind. Therefore, work is currently under way to determine the requirements for deploying WCDMA in the 1900 MHz band. One general conclusion is that even if multicarrier WCDMA receivers are not deployed, because of the wideband input filter characteristics and the proximity to large narrowband signals such as GSM, WCDMA receivers will likely have to tolerate many of the blockers just as if it were a multicarrier receiver.

Multicarrier architecture

Regardless of the standard, these potentially large blockers must be tolerated in a manner that does not disrupt the performance of the receiver. As shown in the RF cellular spectrum seen in figure 1, numerous narrow band signals completely surround the two CDMA2000 carriers located midband. The goal of the receiver design is to tolerate

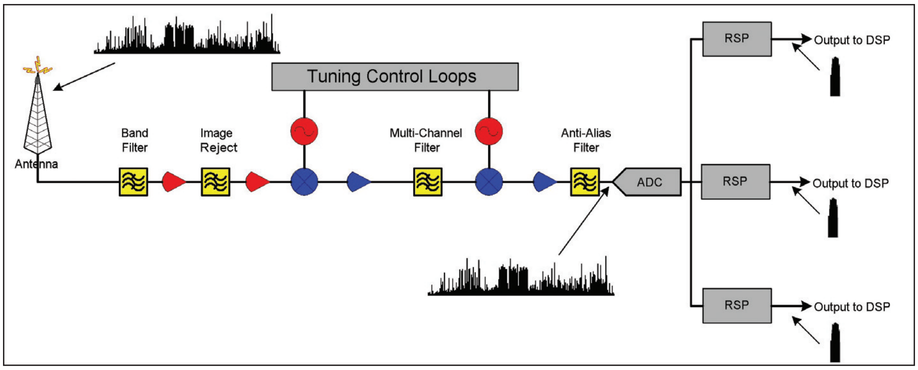

Figure 2. Typical architecture of a multicarrier receiver

all of the narrowband signals while maintaining the required sensitivity. Traditional receiver architectures would simply provide as much RF and IF channel filtering as possible to remove the undesired carriers early in the signal chain. This is not possible with multicarrier receivers, nor is it possible in a wideband, single carrier receiver to entirely filter nearby blockers due to the relatively poor transition bands of the channel filters required to achieve of flat passband performance.

Because of the large in-band signals in addition to the desired wideband signal, the analog and mixed signal paths of the receiver must tolerate these strong signals. This puts additional burdens on the analog signal path, which could be mitigated with the use of narrowband channel filters. However, in the absence of these filters, the signal path must deal with the strong signals appropriately.

In the typical block diagram for a multicarrier receiver, as shown in figure 2, the spectral content is shown for various points in the system. At the antenna, the full RF spectrum is presented to the antenna. Since the antenna has some selectivity to the desired band, much of the interfering signals are attenuated. However, strong signals such as local broadcast and neighboring cellular services may make it into the receiver front end and eventually be filtered by the band and image filters.

However, since multicarrier receivers require wideband performance, the entire band passes the IF stages and is presented to the ADC for digitization. As shown, the spectrum presented to the ADC is nearly identical to that at the antenna. The primary difference is that all signals outside the band of interest must be completely removed to prevent aliasing in the sampling process of the ADC. Channel selection in multicarrier receivers does not take place until the digital domain in the receive signal processors (RSP) as shown in the spectral plots on their output.

Because the ADC must process all of the active signals, a unique set of requirements are placed on the data converter. Quite often, the ADC becomes the bottleneck in a multicarrier receiver. However, a good understanding of the actual performance requirements can facilitate the proper selection of an ADC without risk of over- or under-selection of that critical device.

Performance requirements

Before working through the converter requirements for a 3G system, a little background on how a direct sequence spread spectrum (CDMA) receiver works is required. The information to be transmitted is combined with a pseudorandom number (PN) spreading sequence that has a much wider bandwidth using a function similar to a mixer. This has the effect of spreading the desired information over the wider bandwidth of the spreading signal. On the receive end, the same PN sequence is correlated with the incoming signal. The correlation process has the main effect of “gathering” the energy of the desired transmission into the original information bandwidth, allowing it to be detected and further processed. At the same time, any energy, including interferers that do not correlate to the PN sequence, become spread over the wider bandwidth of the PN sequence. Since the information bandwidth is now much narrower than the interfering energy, a low pass filter can be used to remove all of the interfering energy except the small amount that appears in the information bandwidth. This energy typically appears as Gaussian noise. This process is shown in figure 3.

Figures 3(d) and 3(e) show two components to the noise. The flat noise (blue) represents broadband thermal noise present in the receiver. The source of this is available atmospheric noise plus the active noise of the receiver and transmitter. In addition to this is the band limited noise (purple) generated by spreading the interferer while the main signal is being despread. Since the receiver does not care about the source of the noise, the effective noise is the rms sum of these two. This information can be used to determine the performance requirements for a 3G receiver, or any other receiver used for spread spectrum reception. Unlike GSM and other narrowband standards, spurious effects usually are not directly specified when it comes to “co-channel” interference, but they may be determined by carefully studying the operations in conjunction with the given standard specifications. From this it is possible to determine the required performance from an ADC and the rest of the signal chain.

There are two figures of merit that are important in selecting an ADC. These are signal-to-noise ratio (SNR) and spurious-free dynamic range (SFDR). However, relating wideband receiver performance to these converter specifications can be confusing. Since the radio standards are generally neutral in terms of architectural choices, it is up to the designers’ understanding and interpretation of those standards to determine required component performance for the selected architecture. Since the general goal of any receiver is to have the highest sensitivity possible, and to maintain that in the presence of other interfering signals, these are the key specs to look towards when determining the required converter performance.

ADC SNR

Sensitivity indirectly determines the SNR required from a data converter. When looking at sensitivity requirements, there are several external factors that must be determined. Referring back to figure 3(d), there are several sources for noise. The dominant term should be the thermal noise, which is the combined available noise from the antenna plus the noise figure of the receiver. The receiver noise fig-

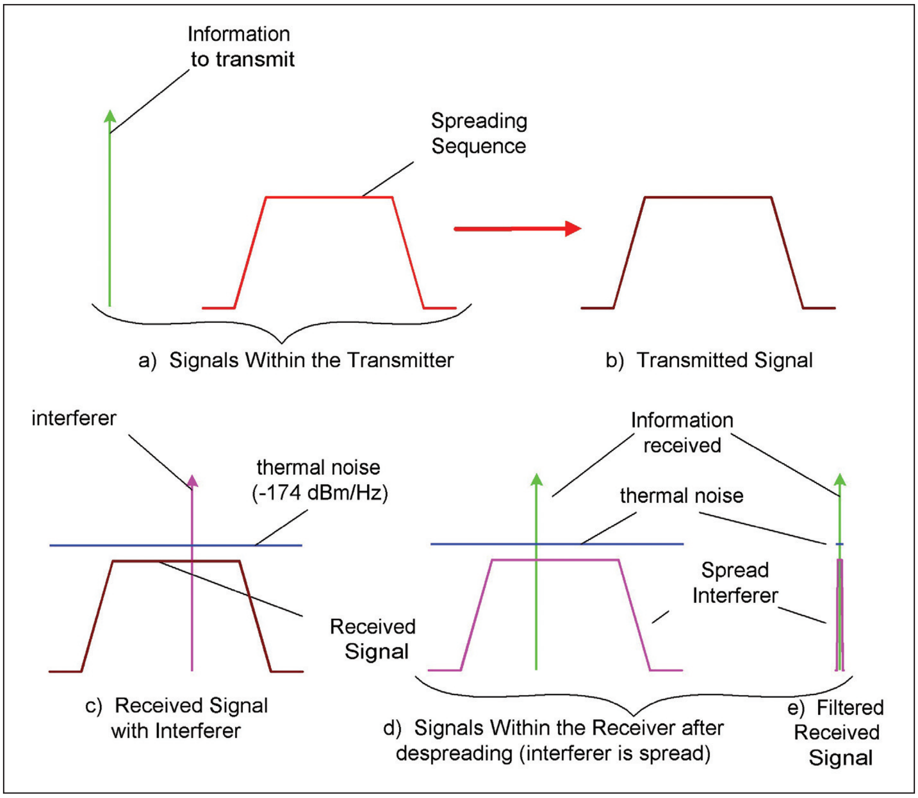

Figure 3. Signals at locations within a CDMA system

ure is the sum of the noise of all of the components in the signal chain — of which the ADC is one. Ideally, the ADC noise floor should be 10 dB below the thermal noise of the front end so that it doesn't significantly contribute to the sensitivity of the receiver. This is desirable because the noise from an ADC is not white and can cause undesirable receiver anomalies if allowed to dominate. In reality, anything 5 dB or greater is good. Assuming that the receiver noise figure is 5 dB, not including the ADC, the input referred noise spectral density would be about -169 dBm/Hz. If the input referred ADC noise is 5 dB below this, it should be about -174 dBm/Hz. Once the conversion gain is known for the receiver, the actual ADC noise can be found.

Conversion gain can be determined by looking at all of the in-band blocking and two-tone requirements. Usually this is specified as single tone desensitization and gives an indication of how much the sensitivity of the receiver is reduced in the presence of another strong signal. Depending on the standard, this signal may be a narrowband signal or it may be another wideband signal. This specification also often gives an indication of the largest in-band signal that must be tolerated if not otherwise explicitly stated. For example, IS-95 calls for in-band blocking with a signal +87 dBc compared to the reference input level of -117 dBm/1.25 MHz. This blocking signal will be -30 dBm in level at the antenna and will approximately represent the largest input to the receiver. Normally, headroom is provided to allow for larger input powers. This can come from a variety of sources. First, this blocker may have an envelope that contains a significant instantaneous peak power. Second, there could be several large signals that cause an increase in the composite power through the signal chain. In either case, this must be accounted for when setting the conversion gain.

Since the blocker should have a minimal envelope, a 5 dB margin is allowed at the top to prevent clipping associated with this peaking. Finally, once the full scale input to the ADC is known, the conversion gain can be calculated. Typically an ADC may have a full scale of +5 dBm. Allowing for headroom on the largest input signal of 5 dB, the largest anticipated signal will be -25 dBm. The conversion gain is the difference between the ADC full scale and the largest anticipated signal, giving 30 dB in this example.

With 30 dB of conversion gain and a noise figure of 5 dB, the front-end noise presented to the ADC is -139 dBm/Hz. In order to minimize converter effects on the receiver, the ADC noise must be 5 dB below this or -144 dBm/Hz. Total noise within the ADC may be determined by integrating over the Nyquist bandwidth. If the ADC is sampling at 61.44 Msps, the total ADC noise must be less than -69.1 dBm. At 92.16 Msps, the noise should be less than -67.4 dBm. If the ADC full scale is +5 dBm, the required SNR is 74.1 dBFS and 72.4 dBFS for these two sample rates, respectively. As with any design, these numbers can vary depending on the amount of margin assigned to a particular signal chain, but this provides a good starting point.

$$SNR_{ADC} = Fullscale_{ADC} - \left(\left(10 * \log\left(\frac{k * T * BW_{Nyquist}}{0.001}\right)\right) + NF + Gain - Margin\right) \text{dBFS}$$

where fullscale = ADC fullscale rms input power in dBm
k = 1.38 x 10^{-23} J/K
T = *temperature* K
BW is ADC Nyquist bandwidth Hz
NF = receiver noise figure (dB)
Gain = receiver conversion gain (dB)
Margin = required implementation margin (dB)

ADC SFDR

There are two general specifications that may indicate the required SFDR. The first is single tone desensitization — as already discussed — which gives an indication of how much the sensitivity of the receiver is reduced in the presence of another strong signal. In a single-carrier receiver, desensitization occurs when the automatic gain control (AGC) reduces the gain in response to a nearby large signal. Since multicarrier receivers typically have only a limited AGC function, desensitization occurs from the spurious energy generated by these blockers. This spurious energy is typically a harmonic of the blocker that may fall in-band with the signal of interest and adds to the thermal noise of the channel after de-spreading.

The second specification is intermodulation distortion requirements between two nearby carriers. The two input signals may be continuous wave (CW) signals, wideband modulated signals or one of each. This test is usually defined such that one of the intermodulation products, either 2f1-f2 or 2f2-f1, falls in the channel of interest and, therefore, becomes a co-channel interference allowing direct determination of the spurious performance requirements. Since these interferers look like noise after spreading, they can be added to the thermal noise already within the channel.

For the typical intermodulation test, the desired signal level is allowed to increase by 3 dB above the reference sensitivity level. This indicates that the total noise power is also allowed to increase by 3 dB to retain the same overall signal SNR. Given that the front-end thermal noise presented to the ADC input is already known to be -139 dBm/Hz, this allows the energy from the spurious to have the same power level, and increase the overall noise by 3 dB. Any narrowband spurious product that falls in-band with the signal of interest will be spread in the correlation process and appear and band limited noise. If this energy is integrated, the total energy can be determined. Since the spectral density of the additional noise is known to be -139 dBm/Hz, integration of this over the spreading bandwidth will result in the total energy of the CW signal interferer that will not cause disruption and, thus, the power of the ADC spurious for either single or multi-tone stimulus.

For an IS-95 bandwidth of 1.25 MHz, this is a total spurious power of -78 dBm referenced to the ADC input. If the ADC full scale is +5 dBm, this is a SFDR of 83 dBFS, regardless of its source. Knowing this general SFDR requirement, other specific measurements such as IMD can easily be determined. Since IMD for an ADC is usually given in terms of dBc, knowing what level each tone is presented to the ADC, comparing this to the absolute level of the spurious requirement can determine this. Since conversion gain in this example is 30 dB, if each tone signal is -45 dBm at the antenna port, it would be -15 dBm at the ADC input. Since the SFDR must be -78 dBm, IMD will be 63 dBc.

$$SFDR_{ADC} = Fullscale_{ADC} - \left(10\log\left(\frac{k*T*BW_{chip}}{0.001} \right) + NF + GAIN \right)$$

where fullscale = ADC fullscale rms input power in dBm
k = 1.38 x 10^{-23} J/K
T = *temperature* K
BW is spreading bandwidth Hz
NF = receiver noise figure (dB)
Gain = receiver conversion gain (dB)

Conclusion

Selecting the appropriate ADC for a multicarrier, spread spectrum receiver can be a daunting task. While many complicated tradeoffs can be made in noise allocation to meet the overall sensitivity, the starting points provided here can be quite useful in selecting the appropriate data converter. While the overall task can challenging, a good understanding of the specification plus an understanding of how spurious energy is spread in a direct sequence spread spectrum system can make the task relatively straight forward.

Additional reading

For additional reading on data converter in wireless applications go to www.converter-radio.com.

About the Author

Brad Brannon has worked at Analog Devices Inc. (www.analog.com) for 19 years in a number of roles including test engineer, designer, applications engineer and system engineer. During that time he has focused on a variety of data converter topics relating to their design, use and application. Currently Brannon is a systems engineer working in the high-speed converter product line, and can be reached at brad.brannon@analog.com.