

Application Notes

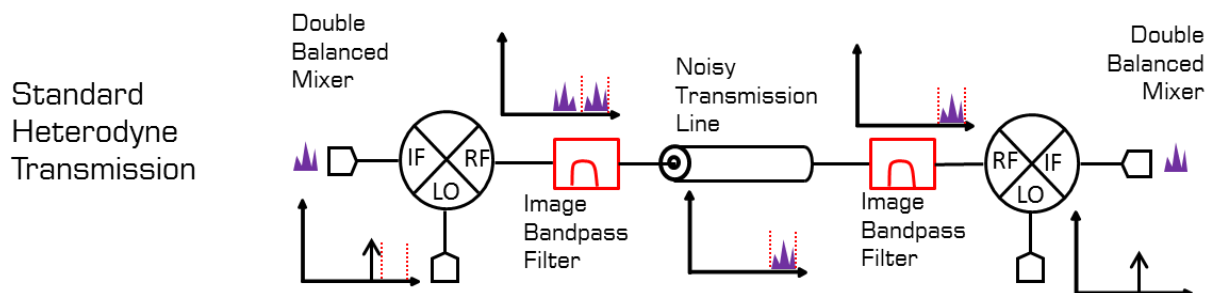
The Why and When of IQ Mixers for Beginners

By Marki Microwave, Posted Mon Jun 15 2015 14:00:00 GMT-0500 (Central Daylight Time)

Sometimes you need a mixer; sometimes you need an IQ mixer. How do you know which one to buy? Before answering this question, I recommend reading the Mixer Basics Primer to get a good understanding of the fundamentals of mixers, the blog post 'IQ, Image Reject, and Single Sideband-Mixers' for an introduction to these mixers, and 'How to think about IQ mixers' if you want a deeper physical understanding of the mechanisms of IQ, image reject (IR), and single sideband (SSB) mixers.

Ed Note: Since this original post much of this content has been updated and combined into our IQ, Image Reject, and Single Sideband Mixer Primer. Check it out!

Now consider the most basic application example, a heterodyne single sideband data transmission and reception:

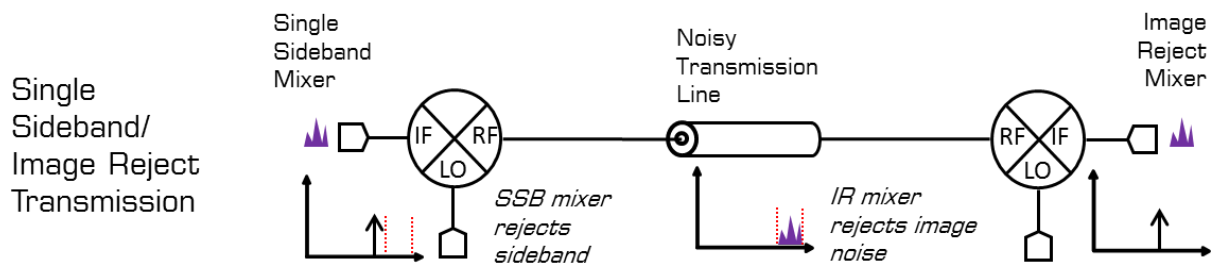


In this example, a signal is upconverted to an RF frequency, along with its identical but reversed image. The image and all other products are filtered out by a bandpass filter to comply with the system channel bandwidth requirements. This single sideband is transmitted over some noisy transmission medium, then at the receiver a similar bandpass filter is used to eliminate noise and adjacent channel transmissions. The mixer then downconverts the RF signal to a lower IF, where it is demodulated. This is a great, time tested system, but it is not very flexible. The filters are generally



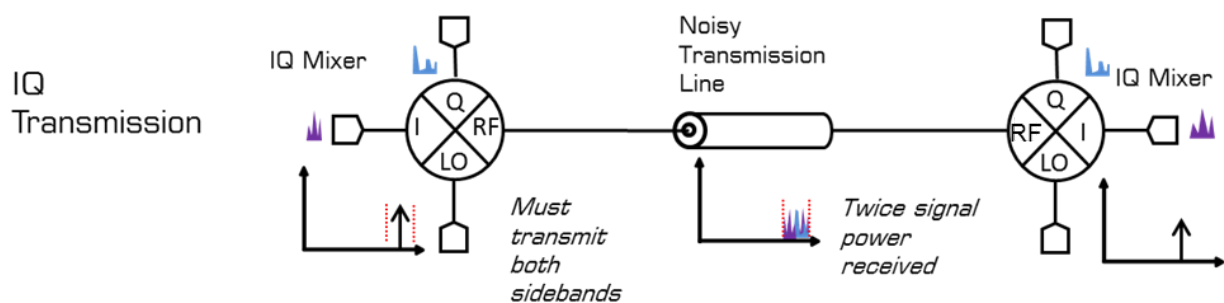
large and most importantly *not tunable*. This means that the RF frequency cannot be changed from its fixed value.

Compare this with a single sideband upconversion of the same signal with an image reject downconversion:



In this case the SSB mixer eliminates the image signal without the bandpass filter, and the IR mixer eliminates the signal in the image channel without a bandpass filter. Eliminating the filter means that the transceiver can be small and frequency agile. Without the bandpass filter the LO can be swept to any frequency that is in band for both mixers without penalty from nearby channels.

An IQ mixer accomplishes a similar goal, but with a different strategy. As specified in previous blog posts, an IQ mixer requires both sidebands to be transmitted to properly demodulate the signals. However, since the quadrature components are used that means that identical data is not being sent in each sideband (they have different phases). Therefore one of the sidebands is not being wasted. To accomplish the same transmission bandwidth without filtering as the SSB/IR transceiver above, you would break the signal into two half-bandwidth signals, and transmit one on the I channel and one on the Q channel. Once again you do not need to filter out the image frequency. As long as your inputs are at baseband, you won't end up using any more bandwidth and you can still fit within your system specified bandwidth limitation:



Once again, the LO is tunable across the IQ mixers band without the need for a tunable filter.

So the benefit of IQ/IR/SSB transmission is that it saves you a filter. This means that it

Can be made small (in the Microlithic/MMIC technology)

Can be tuned across broad bandwidths

Can be operated at arbitrarily low frequencies, unlike filters that need some separation between the sidebands to provide rejection

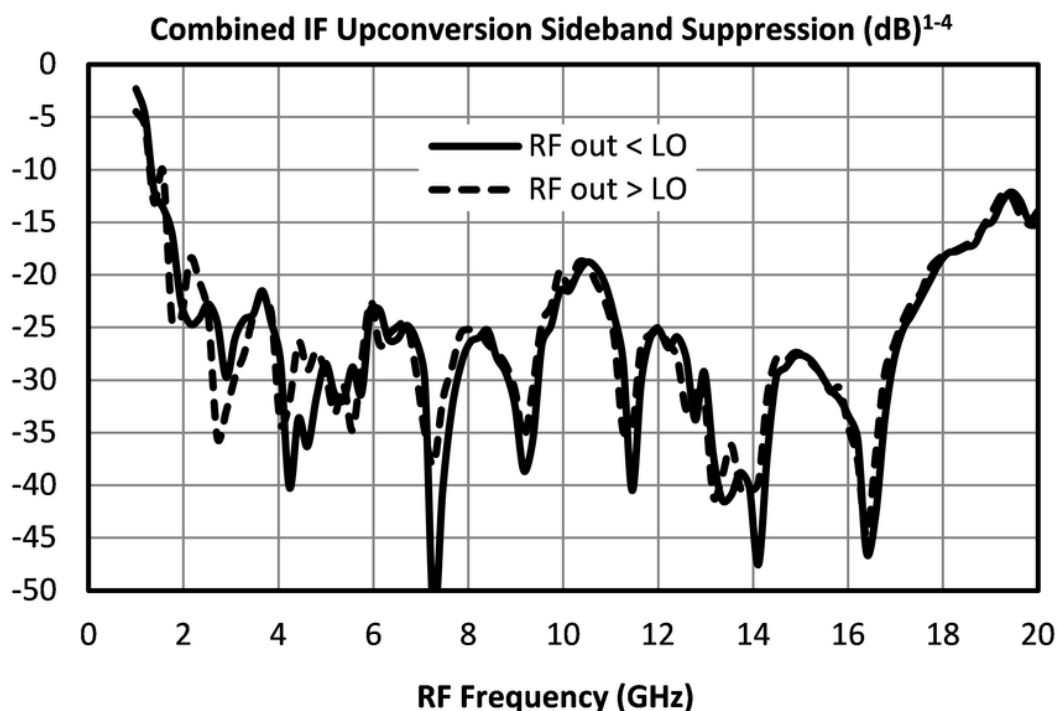
Why not use an IQ/IR/SSB mixer all the time? It turns out that for communications applications, it effectively is the only mixer option. Almost all communications at frequencies less than 6 GHz use some kind of quadrature modulator for both up and downconversion. For electronic warfare, test and measurement, and laboratory applications the landscape is more challenging. Consider the drawbacks of quadrature modulators:

They have less sideband rejection than a filter

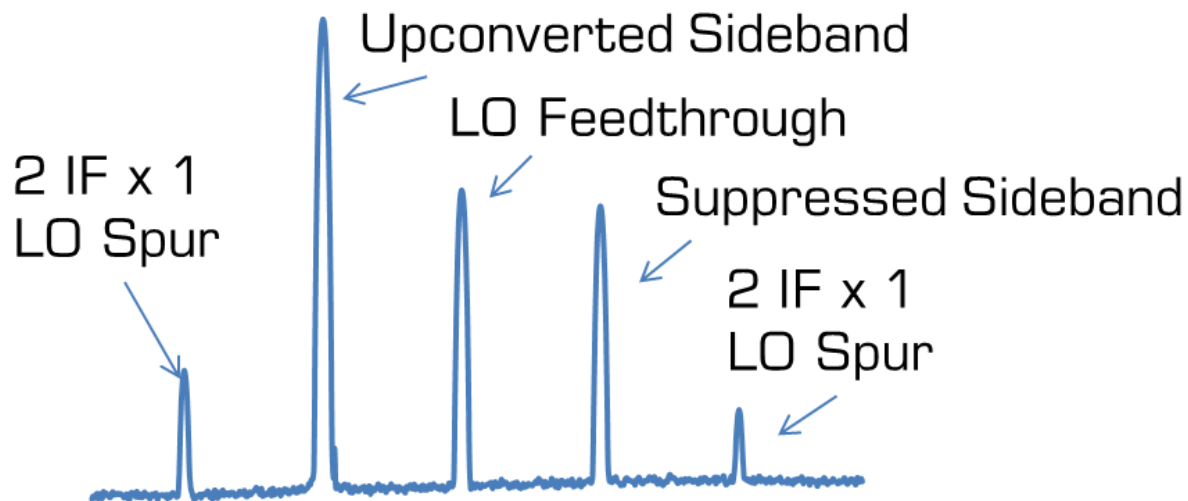
LO-feedthrough and spurious products can be a bigger problem than the image

Quadrature modulation is difficult to achieve over a broad bandwidth

Consider each of these in turn, starting with limited rejection. IQ/IR/SSB mixers are based on vectorial cancellation, and as such are subject to the limits of phase and amplitude balance. In an IQ mixer the 'sideband rejection' refers to how well the I signal will be suppressed in the Q channel and vice versa. This is typically around 20-30 dB for very *good* broadband IQ mixers. It can be higher in lower frequency quadrature modulators used for communications, especially those with a fixed LO frequency. However, a radar system with a -60 dBc spurious spec will not be anywhere close with a broadband IQ mixer. This requires filtering.



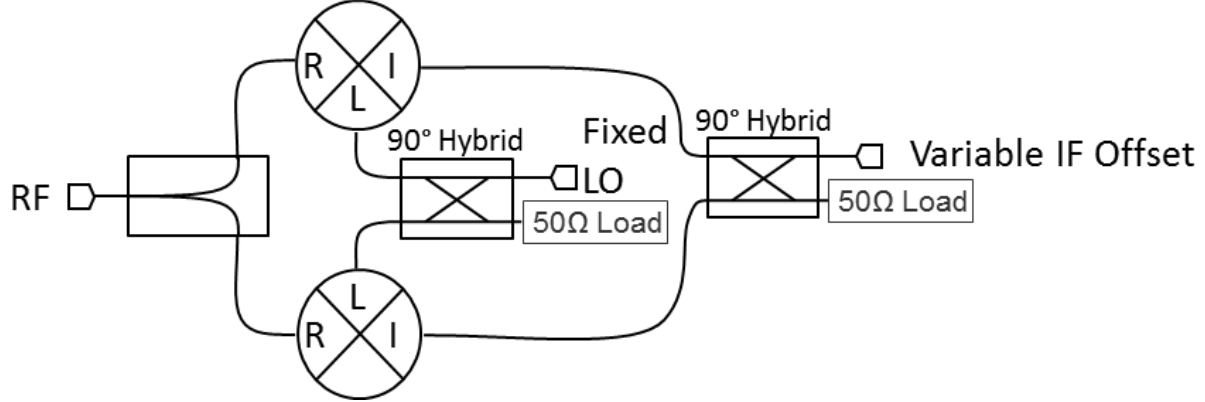
In a related problem, the image signal is generally not the closest spur to the upconverted signal:



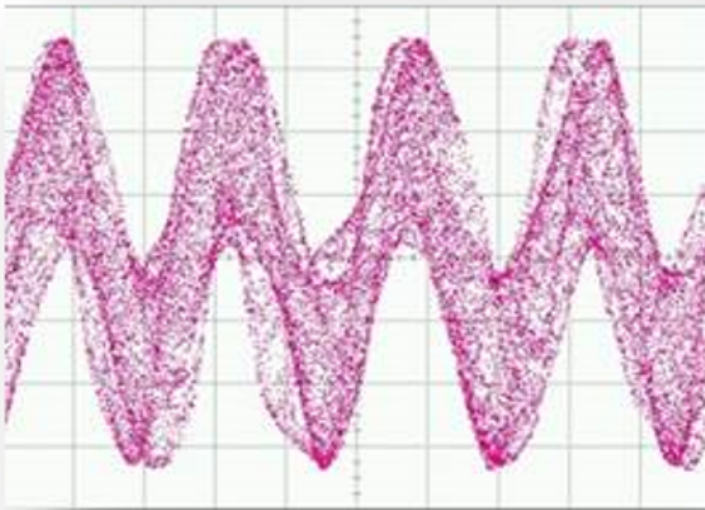
Arithmetically, the LO feedthrough and the $2IF \times LO$ spur will always be closer in frequency to the upconverted signal than its opposite sideband, and these are only suppressed by the balance of the mixer cores inside the IQ mixer. They are not further suppressed by the IQ mixer structure. Typically a system is specified according to its maximum allowable spur level by the spur free dynamic range (SFDR). This is limited by either the LO feedthrough or the sideband suppression, so improving the sideband suppression better than the LO feedthrough is generally not worthwhile.

All of the spurious suppressions in an IQ mixer are based on vectorial cancellation, which means that they are subject to the limits of this technique. It is difficult to maintain good amplitude and phase balance over broad bandwidths, temperature variation, and time. Since an IR/SSB mixer requires a quadrature hybrid on the IF ports, this means that it is limited to the bandwidth over which a quadrature shift can be accomplished with the data, which is typically limited to 2-3:1 bandwidths, and not at DC. These impairments can and are actively tuned out somewhat by using a digital to analog converter on the IF ports to create an SSB mixer or an analog to digital converter on the IF ports to create an IR mixer. This tuning is usually limited to around 10 dB of increased image suppression by the quantization noise of the converter. Modern RF ADCs and DACs typically have registers specifically for holding the correction coefficients for the amplitude and phase, and these can be programmed during a burn-in procedure.

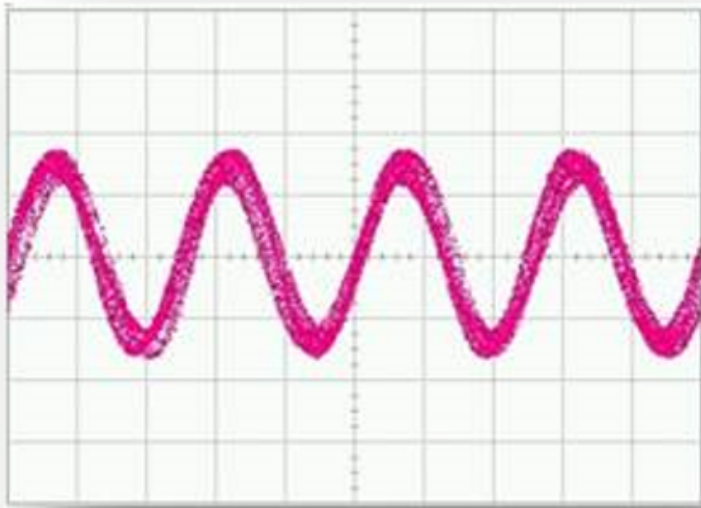
Let's examine a simple application: shifting a fixed LO frequency by a small variable (or fixed) offset.



This is a common application where a high frequency oscillator is fixed, but not at the correct frequency for a given application. Combining the IF and LO in a double balanced mixer will give the desired output, but also an undesired image frequency, resulting in beat tones in the time domain output:



If the IF frequency is low relative to the LO, then the required filter to eliminate the sideband will be impractical. For example even a 10 MHz shift on a 10 GHz LO would be a 0.2% bandwidth filter, much too narrow to make high rejection. If however we use a single sideband mixer, or an IQ mixer with a homebrew 90° phase shift on the IF, then we can get what appears to be a single tone:



Note that there is still residual noise from the image frequency, the LO feedthrough, and the spurious tones. The spurs can be reduced by lowering the input power, and the sideband suppression can be tuned by varying the IF phase if that is available. Ultimately, however, a noise free output cannot be achieved.

This is deterministic, however, which means that someone out there has probably already found a way to program a DAC to eliminate the sideband with forward error correction. If you know of someone who has done this, let me know, I would be interested to see it.

In the meantime, check out some of our super small, high balance, broadband, and world class sideband rejecting MLIQ mixers, and contact us if you have a new application that is not being served.

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