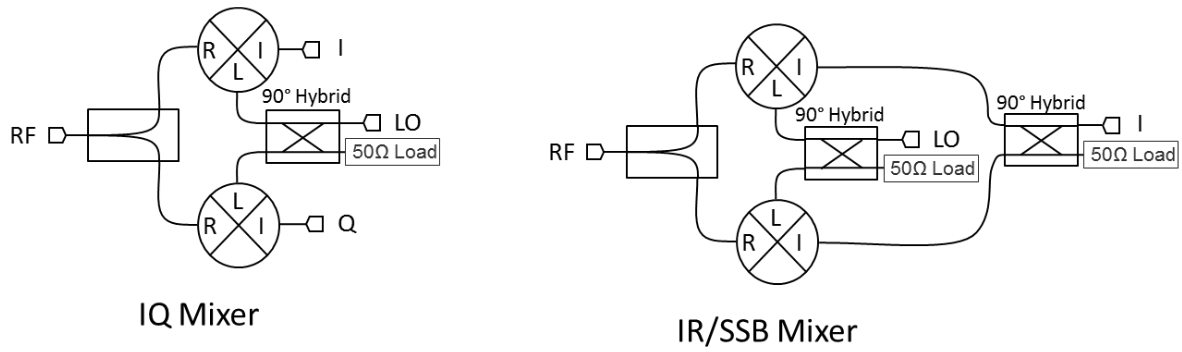
How to think about IQ mixers

There are many ways to think about IQ modulation, and all of them rely on math. This is because 'quadrature' modulation is a mathematical construct, a way of thinking about how time domain signals can be manipulated more than a physical reality. In this blog post I will describe how I think of IQ modulation, which is as the cancellation of a signal through two 90° phase shifts that create a 180° phase shift, which is the negative of the original signal. The negative and positive versions of the signals cancel, resulting in suppression of the other signal. This is identical to the math that governs image cancellation in image reject and single sideband mixers, the only difference is that one of the 90° phase shifts occurs at the transmitter in an IQ scheme, while they are both at the receiver in the image reject/single sideband scheme.



The easiest way to see this is with a combination of a trigonometric derivation and graphics. I will try to make the math as straightforward as possible, since I don't speak math well.

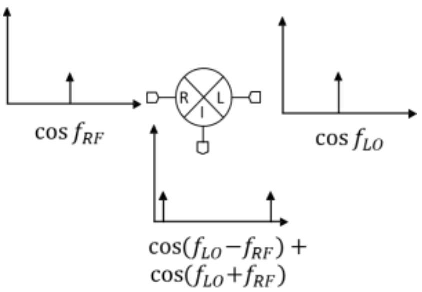
We'll use the following trigonometric identities:

$$\cos A \cos B = \frac{1}{2}(\cos(A+B) + \cos(A-B))$$
$$\cos A \sin B = \frac{1}{2}(\sin(A+B) - \sin(A-B))$$
$$\cos(-A) = \cos A$$
$$\sin(-A) = -\sin A$$

Consider a single sided downconversion imagining the mixer as a perfect frequency multiplier. The output at the RF will be given (ignoring the 2πt terms) by

更多信息，请联系我们：
地址：上海市普陀区中山北路 2911 号中关村科技大厦 1206 室
Tel: 137 6444 1515,　Fax: 021-5291 8556　　www.fulai-elec.com　　Email: sales@fulai-elec.com

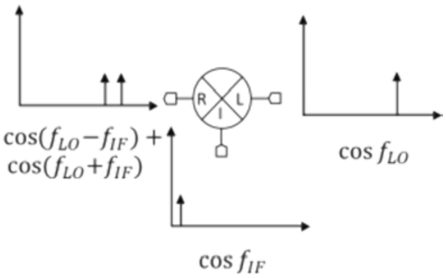
$$\cos f_{LO} \cos f_{RF} = \frac{1}{2}\left(\cos(f_{LO} + f_{RF}) + \cos(f_{LO} - f_{RF})\right)$$



Double Sided Downconversion

The same math works for an upconversion:

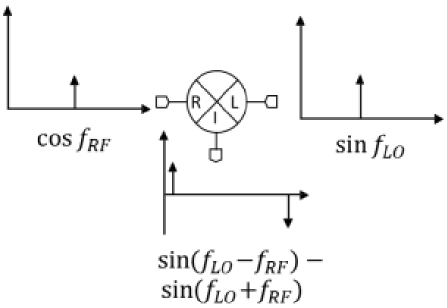
$$\cos f_{LO} \cos f_{IF} = \frac{1}{2}\left(\cos(f_{LO} + f_{IF}) + \cos(f_{LO} - f_{IF})\right)$$



Double Sided Upconversion

It is irrelevant whether we use an in phase (cosine) or out of phase (sine) LO for a double sided downconversion on a single tone, other than a phase shift of the output (90° from the input and 180° between the two products) for a downconversion:

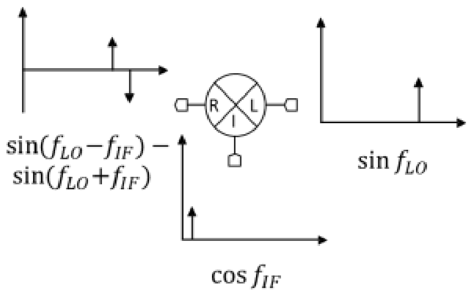
$$\sin f_{LO} \cos f_{RF} = \frac{1}{2}\left(\sin(f_{LO} + f_{RF}) + \sin(f_{LO} - f_{RF})\right)$$



Double Sided Downconversion

Or an upconversion:

$$\sin f_{LO} \cos f_{IF} = \frac{1}{2}\left(\sin(f_{LO} + f_{IF}) + \sin(f_{LO} - f_{IF})\right)$$



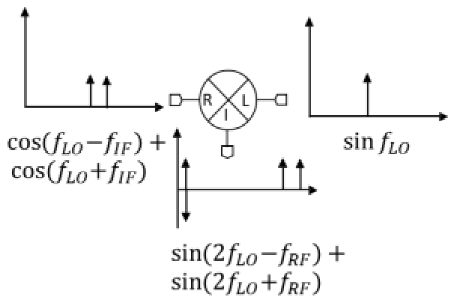
Double Sided Upconversion

Now consider following the double sided upconversion with a double sided downconversion. We'll multiply the original output by an in phase LO

$$\cos f_{LO} \cos(f_{LO} + f_{IF}) + \cos f_{LO} \cos(f_{LO} - f_{IF}) =$$
$$\frac{1}{2}\left(\cos(f_{LO} + f_{IF} + f_{LO}) + \cos(f_{LO} + f_{IF} - f_{LO})\right)$$
$$+ \frac{1}{2}\left(\cos(f_{LO} - f_{IF} + f_{LO}) + \cos(f_{LO} - f_{IF} - f_{LO})\right)$$
$$= \cos(f_{IF}) + \frac{1}{2}\cos(2f_{LO} - f_{IF}) + \frac{1}{2}\cos(2f_{LO} + f_{IF})$$

Where we use the identities given above. Clearly it can be seen that the desired IF frequency is present along with the undesired 2*LO terms. However, if we attempt to perform a downconversion with an out of phase LO, the following results:

$$
\begin{aligned}
&\cos(f_{LO}+f_{IF})\sin f_{LO}+\cos(f_{LO}-f_{IF})\sin f_{LO}= \\
&\frac{1}{2}\left(\sin(f_{LO}+f_{IF}+f_{LO})-\sin(f_{LO}+f_{IF}-f_{LO})\right) \\
&\quad+\frac{1}{2}\left(\sin(f_{LO}-f_{IF}+f_{LO})-\sin(f_{LO}-f_{IF}-f_{LO})\right) \\
&\quad=\frac{1}{2}\left(\sin(2f_{LO}+f_{IF})-\sin(f_{IF})\right)+\frac{1}{2}\left(\sin(2f_{LO}-f_{IF})+\sin(f_{IF})\right) \\
&\quad=\frac{1}{2}\sin(2f_{LO}-f_{IF})+\frac{1}{2}\sin(2f_{LO}+f_{IF})
\end{aligned}
$$



Double Sided Downconversion

As you can see from the math and the diagram, the two sidebands compete at the downconverted sideband, canceling each other out. For this reason a double sided upconversion followed by a double sided downconversion is not recommended. If the phase of the LO is set correctly the signal will be reconstructed with twice the amplitude of a single sided downconversion, but if it isn't phased correctly the two sidebands will cancel each other.

This same phenomenon can easily be shown to occur if a sine wave LO is used as the upconverting LO and a cosine is used as the downconverting LO. This raises an interesting possibility, however. If a phase coherent LO *is* available, then we can upconvert one signal into a sideband and downconvert it with the same phase LO (with some gain). We can also upconvert a *separate* signal using a 90° out of phase LO and transmit across the same medium, downconverting it with the same LO but again 90° out of phase. The sidebands of the signal will cancel each other out for the out of phase signal while adding constructively for the in-phase signal. This is called *quadrature modulation*, and is the basis for such modern signaling techniques as *quadrature amplitude modulation (QAM)*, which is the how all modern wireless communications systems operate.

Here is what the math looks like (it gets a little messy, you can just look at the conclusions):

Combined upconverted signal, with signals added:

$$\begin{aligned}\cos f_{LO}\, a(t) \cos f_{IF} + \sin f_{LO}\, b(t) \cos f_{IF} \\ = \frac{a(t)}{2}\left(\cos\left(f_{LO}+f_{IF}\right)+\cos\left(f_{LO}-f_{IF}\right)\right) \\ + \frac{b(t)}{2}\left(\sin\left(f_{LO}+f_{IF}\right)+\sin\left(f_{LO}-f_{IF}\right)\right)\end{aligned}$$

Now multiply by an in-phase LO:

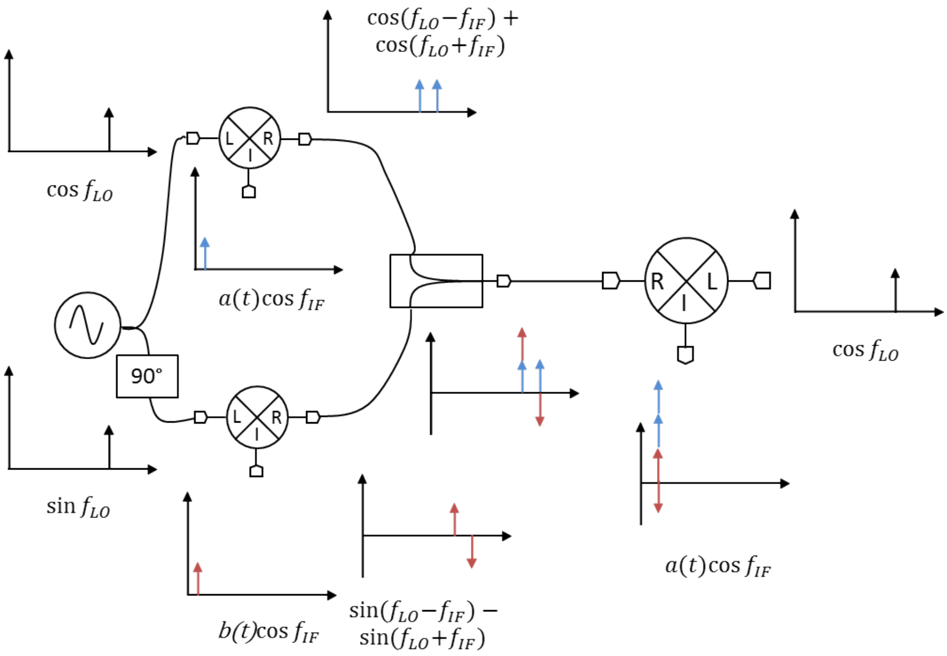
$$\begin{aligned}&\frac{a(t)}{2}\left(\cos\left(f_{LO}\right)\cos\left(f_{LO}+f_{IF}\right)+\cos\left(f_{LO}\right)\cos\left(f_{LO}-f_{IF}\right)\right) \\ &\quad + \frac{b(t)}{2}\left(\cos\left(f_{LO}\right)\sin\left(f_{LO}+f_{IF}\right)+\cos\left(f_{LO}\right)\sin\left(f_{LO}-f_{IF}\right)\right) \\ &= \frac{a(t)}{2}\left(\cos\left(f_{LO}+f_{IF}-f_{LO}\right)+\cos\left(f_{LO}+f_{IF}+f_{LO}\right)+\cos\left(f_{LO}-f_{IF}-f_{LO}\right)\right. \\ &\quad \left.+\cos\left(f_{LO}+f_{LO}-f_{IF}\right)\right) \\ &\quad + \frac{b(t)}{2}\left(\sin\left(f_{LO}+f_{IF}+f_{LO}\right)-\sin\left(f_{LO}-f_{LO}+f_{IF}\right)\right. \\ &\quad \left.+\sin\left(f_{LO}-f_{IF}+f_{LO}\right)-\sin\left(f_{LO-f_{LO}-f_{IF}}\right)\right)\end{aligned}$$

$$\begin{aligned}&= \frac{a(t)}{2}\left(\cos\left(f_{IF}\right)+\cos\left(2f_{LO}+f_{IF}\right)+\cos\left(-f_{IF}\right)+\cos\left(2f_{LO}-f_{IF}\right)\right) \\ &\quad + \frac{b(t)}{2}\left(\sin\left(2f_{LO}+f_{IF}\right)-\sin\left(f_{IF}\right)+\sin\left(2f_{LO}-f_{IF}\right)-\sin\left(-f_{IF}\right)\right) \\ &= \frac{a(t)}{2}\left(2 * \cos\left(f_{IF}\right)+\cos\left(2f_{LO}+f_{IF}\right)+\cos\left(2f_{LO}-f_{IF}\right)\right) \\ &\quad + \frac{b(t)}{2}\left(\sin\left(2f_{LO}+f_{IF}\right)+\sin\left(2f_{LO}-f_{IF}\right)\right)\end{aligned}$$

After low pass filtering we recover:

$$= a(t)\cos\left(f_{IF}\right)$$

The in-phase components add constructively, while the quadrature components add destructively. It can be similarly shown for a quadrature (sine wave) downconverting LO, we will only recover the *b(t)* signal. Graphically this appears like this:



At this point we can see everything that we need to make an IQ modulator: 2 matched mixers, a device to separate the LO into in-phase and quadrature signals (called a quadrature hybrid coupler) and a device to add the two signals together (an in-phase power combiner).

Before we move on from the IQ modulator, consider what would happen if we eliminated one of the sidebands after the upconversion and try to downconvert:

$$\frac{a(t)}{2}\cos(f_{LO})\cos(f_{LO}+f_{IF})+\frac{b(t)}{2}\cos(f_{LO})\sin(f_{LO}+f_{IF})=$$

$$\frac{a(t)}{2}(\cos(f_{LO}+f_{LO}+f_{IF})+\cos(f_{LO}+f_{IF}-f_{LO}))$$

$$+\frac{b(t)}{2}(\sin(f_{LO}+f_{LO}+f_{IF})-\sin(f_{LO}+f_{IF}-f_{LO}))=$$

$$\frac{a(t)}{2}(\cos(2f_{LO}+f_{IF})+\cos(f_{IF}))+\frac{b(t)}{2}(\sin(2f_{LO}+f_{IF})-\sin(f_{IF}))$$

After low pass filtering, this becomes: $\frac{a(t)}{2}\cos(f_{IF})-\frac{b(t)}{2}\sin(f_{IF})$

That is, both versions of the signal are present without cancellation or suppression, and neither can be recovered without the information present in the second sideband. There are many more advanced modulation techniques using DSP that may offer quadrature information transmission in a single sideband, but this cannot be achieved using conventional analog components.

Marki- Image Reject and Single Sideband Mixers 单边带混频器

Model	RF [GHz]	LO [GHz]	IF [MHz]	Conversion Loss [dB]	IR [dB]	Isolations L-R [dB]	Isolations L-I [dB]
IR-4509	4.5 to 9	4.5 to 9	70±20	5.5	23	30	25
IRW-0618	6 to 18	6 to 18	4 to 210	7.5	23	35	25
SSB-0618	6 to 18	6 to 18	4 to 210	7.5	23	35	25

Marki- IQ Mixers

Model	RF [GHz]	LO [GHz]	IF [MHz]	Conversion Loss [dB]	Image Rejection [dB]	Amplitude Deviation [dB]	Phase Deviation [Degrees]	Isolations L-R [dB]	Isolations L-I [dB]
MLIQ-0218	2 to 18	2 to 18	DC to 3500	8.5	29	0.21	5	45	25
MLIQ-0416	4 to 16	4 to 16	DC to 3500	8.5	32	0.13	3.5	45	25
IQ-1545	1.5 to 4.5	1.5 to 4.5	DC to 500	5.5	25	0.3	3	43	30
IQ-0255	2 to 5.5	2 to 5.5	DC to 500	5.5	23	0.3	3	42	30
IQ-0307	3 to 7	3 to 7	DC to 500	5.8	23	0.3	3	30	20
IQ-0318	3 to 18	3 to 18	DC to 500	7	22	0.75	10	40	20
IQ-4509	4.5 to 9	4.5 to 9	DC to 500	5.5	23	0.3	4	30	20
IQ-0618	6 to 18	6 to 18	DC to 500	7.5	23	0.4	3	35	20
IQB-0618	6 to 18	6 to 18	DC to 5000	11.0	23	0.5	5	20	20

Gotmic Mixers

Part number	Type	RF BW [GHz]	IF BW [GHz]	CL [dB]	IRR [dB]	LO-RF isolation [dB]	LO power [dBm]
gMQR0011	IQ demod	70-95	0-10	10	>24	-	5
gMDR0015	IQ mod	71-86	0-10	10	>25	>30	7
gMDR0026	IQ mod	57-66	0-12	9	>25	>30	7
gMBR0011	Balanced mixer	70-100	0-10	10	-	>27	7

更多信息，请联系我们：
地址：上海市普陀区中山北路 2911 号中关村科技大厦 1206 室
Tel: 137 6444 1515, Fax: 021-5291 8556 www.fulai-elec.com Email: sales@fulai-elec.com