IQ, IMAGE REJECT, AND SINGLE SIDEBAND MIXERS DEMYSTIFIED

Doug Jorgesen | May 28, 2020
WHAT IS AN IQ MIXER?

Two mixers that add in quadrature

Balanced Mixers
MIXERS PROVIDE PORT ISOLATIONS AND PERFORM THE FREQUENCY CONVERSIONS

LO Quadrature Splitter
Create two identical high power tones 90° out of phase with each other

In-phase Splitter/Combiner
Splits the high frequency signal for downconversions or combines it for upconversions

Quadrature LO Tones

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Signal Cancellation
Eliminate unwanted signals without filtering.

Standard Mixing
Image must be filtered

Single Sideband/Image Reject Mixing
Images are suppressed

IQ Mixing
Data transmitted in both sidebands
**Incoherent Single Sideband Transmission**

Quadrature demodulation leads to signal cancellation.

\[
\begin{align*}
\cos(f_{LO} + f_{IF}) & \quad \sin f_{LO} \\
\sin(2f_{LO} + f_{IF}) - \sin(f_{IF}) & \quad \cos f_{LO}
\end{align*}
\]

**Coherent Double Sideband Transmission**

\[
\begin{align*}
\cos(f_{LO} - f_{IF}) + \cos(f_{LO} + f_{IF}) & \quad \sin(2f_{LO} - f_{RF}) + \\
\cos(f_{IF}) + \cos(2f_{LO} - f_{IF}) + \cos(2f_{LO} + f_{IF}) & \quad \sin(2f_{LO} + f_{RF})
\end{align*}
\]
**IQ MIXER MAGIC**

\[
\cos(f_{LO} - f_{IF}) + \cos(f_{LO} + f_{IF})
\]

Phase adds for the upper sideband and subtracts for the lower sideband (180° out of phase)

\[
\sin(f_{LO} - f_{IF}) - \sin(f_{LO} + f_{IF})
\]

*How to think about IQ mixers*
Addition of IF hybrid combiner/splitter creates signal cancellation within one structure
Upper or lower sideband/image selection depends on IF phase

**Single Sideband (SSB) Refers to Upconversion**
Useful for low IF upconversion

**Image Reject Mixing (IR) Refers to Downconversion**
Typically used to improve noise figure

*It can be shown...*
IQ, Image Reject, & Single Sideband Mixer Primer
How to think about IQ mixers
IQ MIXER COMPONENTS

Mixer Core
Determines isolations and linearity
Must be matched
MMIC Bare Die/Modules
MMIC Surface Mounts

Power Splitter/Combiner
Can be reactive or resistive, but Wilkinson is best
Phase/amp balance is critical
Wilkinson 1:2

Quadrature Splitter
Single Tone only
Phase Balance Critical
Amp Balance *less important*
90° Bare Die/Modules

SMT coming soon
Power Divider with Delay Line
Easy to implement
Tunable
Single Frequency

Top 7 Ways to Create a Quadrature (90°) Phase Shift

Branchline Coupler
Easy to implement
Low Loss
Planar
Isolated
Narrowband
Large

Polyphase Filter Quadrature Splitter
Cheap
Small
Integrates with CMOS
Loss
Differential input
Low power
Poor Isolation

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**Lange Coupler**
- Wideband
- Quasi-planar
- Sometimes integrated
- Low Power
- Crossovers

**T Flip Flop (digital)**
- Broadband
- Excellent Balance
- High power handling
- Large
- Difficult to design
- Difficult to make planar
- 90° Bare Die/Modules

**3 dB Quadrature Coupler**

Top 7 Ways to Create a Quadrature (90°) Phase Shift

- DC- daylight
- ‘Perfect’ balance
- Limiting
- Requires 2xF<sub>LO</sub>
- Low Power
Create Arbitrary Tones

- Modulate phase and amplitude
- Single Frequency tones

Detect Arbitrary Tones

- Unambiguous phase detection
- Detect phase and amplitude

Quantum Computing Sources

- Allows creation of arbitrary pulses at high frequency
- Phase control required for Qubit manipulation
- This is hard

IQ mixers provide for phase control; standard mixers do not.

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Modifying current/voltage allows manipulation of a single tone through entire state space.

LO Quadrature hybrid loss/balance comes into play.

Harmonics might be weird.

All About Mixers as Phase Modulators.
Phase (vector) Detectors

- Double balanced mixers are frequently used as phase detectors because they have zero IF (i.e. phase).
- DBM cannot discriminate between phase and amplitude variation.
- IQ mixers provide phase and amplitude information with no ambiguity.
Pulse generation for quantum computing

Barends, R., et al. “Supplementary Information for “Superconducting quantum circuits at the surface code threshold for fault tolerance”.”

Plot of non-linear potential $U(\delta)$ for the Josephson phase qubit. The qubit states $|0>$ and $|1>$ are the two lowest eigenstates in the well. The junction bias $I_{dc}$ is typically chosen to give 3-7 states in the well. Microwave current $I_{\mu w}$ produces transitions between the qubit states.


- IQ mixers can be driven with DACs to generate arbitrary pulses
- Quantum computing typically doesn’t require high dynamic range, therefore may benefit from lower LO power

MMIQ-0416LSM

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IQ Mixer Calibration Technique

1. Null LO-RF feedthrough
2. Adjust phase/amplitude balance on IF port to achieve maximum suppression (digital or analog)
3. Repeat for all LO frequencies and temperatures

LO feedthrough determined by mixer cores
Sideband/image suppression determined by balance
Both can be tuned, but practically limited to 10-20 dB improvement
Phase tuning can be done on LO or IF side (no difference)
IQ Usability: Linearity

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Input IP3 and P1dB</th>
<th>Output IP3 and P1dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>IQ mixer upconversion</td>
<td>None</td>
<td>-3 dB</td>
</tr>
<tr>
<td>IQ downconversion</td>
<td>+3 dB</td>
<td>None</td>
</tr>
<tr>
<td>Image Reject Downconversion</td>
<td>+3 dB</td>
<td>+3 dB</td>
</tr>
<tr>
<td>Single Sideband Upconversion</td>
<td>+3 dB</td>
<td>+3 dB</td>
</tr>
</tbody>
</table>

Signal IP3, P1dB, spectral regrowth, ACPR, etc

Power division improves by using signal division

Multitone Spurs

Some spurs cancel for IR/SSB mixers (not IQ), but very hard to predict

More for SSB upconversion than IR downconversion
MARKI MISSION STATEMENT

Empower our customers to **design faster, simplify production, eliminate complexity**, and **shatter performance barriers**