RFIC DESIGN ELEN 351
Lecture 7: Mixer Design

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Mixer Specifications

- Conversion Gain / Loss (Gain defined as the ratio of power at the I freq to the power at the R freq)
- Noise Figure
- Match at all ports
- L to R Isolation
- L to I Isolation
- R to I Isolation
- LO Power Requirement
- IIP3
- NxM Spurs
Classes of Mixers

- Single Ended
- Single Balanced
- Double Balanced
- Active Multiplier Type Mixers (both Single and Double Balanced)
Down Converting Mixer: Applications to Receivers
Up Converting Mixer: Applications To Transmitters

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(LO Signal)
Active Device Options

- Schottky Diodes (5 to 9 dB Conversion LOSS)
- MESFET Transistors (5 to 10 dB Conversion GAIN)
- Bipolar Transistors (5 to 10 dB Conversion GAIN)
Basic Non Linear Process Produces Mixer Action

- Active Device Non Linearity is Expressed as a Power Series relating the device’s Voltage and Current: \( I(t) = I_0 + k_1V + k_2V^2 + k_3V^3 + \ldots \)

- If \( V = V_1 + V_2 \) (two input signals), the second order term becomes: \( k_2(V_1^2 + V_1V_2 + V_2^2) \). It is the \( V_1V_2 \) product term that produces mixing action because if \( V_1 \) and \( V_2 \) are sin waves, their produce, \( (v_1\cos W_1t)(v_2\cos W_2t) = (v_1v_2/2)[\cos(W_1-W_2)t + \cos(W_1+W_2)t] \) contain the sum and difference mixing Frequencies.
Single Ended Diode Mixer Topology
Characteristics of a Single Ended Diode Mixer

- Conversion Loss is Typically 5 to 12 dB
- Noise figure equals the Conversion Loss.
- Poor L to R Isolation, R to I and L to I ok.
- IIP3 approximately equals the LO power, and depends on both the Vf and Vbr of the Diode. Increasing either one Increases IIP3.
- Diodes may be combined in Series to increase Vf and Vbr, but the additional series resistance increases Conversion Loss.
- LO power is typically 3 mW per diode, for low Vf
Single Ended Bipolar Transistor Mixer Topology

![Diagram of a Single Ended Bipolar Transistor Mixer Topology]
Characteristics of a Single ended Bipolar Transistor Mixer

- Conversion Gain typically 5 to 10 dB.
- Noise figure is typically 5 to 10 dB.
- Poor L to R.
- Good R to I and L to I isolation (because of output filtering).
- IIP3 is typically equal to (OIP3 – Conversion Gain) where OIP3 is the output 3rd order intercept point for the transistor operated as an amplifier.
- LO power depends on the Transistor’s size.
Single Balance Diode Mixer Topology
Advantages of a Single Balanced Diode Mixer

• Cancellation of the LO Signal at the R/I port Improves L to R and L to I Isolation.
• R to I isolation depends on Filtering and can be very good.
• Doubles the Power handling capability of the Mixer relative to the single ended design, and adds 3 dB to IIP3 for the same diodes.
• Cancellation of LO AM noise.
Double Balanced Diode Mixer Topology

L Virtual Ground

R Virtual Ground

D1
D2
D3
D4
Advantages of a Double Balanced Diode Mixer

- Excellent L to R Isolation.
- Excellent L to I Isolation.
- Excellent R to I Isolation.
- 3 dB higher IIP3 than the Balanced Diode Mixer because the number of Diodes has doubled.
- Cancellation of LO AM Noise.
Single Balance Bipolar Transistor Multiplying Mixer Topology

Q1 collector current controls Transconductance

Vi = Vl x Vr
Advantages of a Single Balanced Bipolar Transistor Multiplier

• High Conversion Gain (5 to 10 dB)
• High L to R Isolation (but not high L to I Isolation).
• Low LO power Requirement (-10 to 0 dBm).
• IIP3 is higher than the LO power level.
• Low DC Power, Small size
Double Balanced (Gilbert Cell) Bipolar Transistor Mixer
Advantages of a Gilbert Cell Transistor Mixer

• All Three ports are differential, which is a natural configuration for creating Quadrature Phase Modulators and Detectors.

• L to R, L to I Isolations are excellent.

• All the Advantages of the Single Balanced Transistor Mixer are available in this case.
A Direct Conversion Receiver using Gilbert Cell Mixers
Home Work #6: Single Balance Multiplying Mixer
### Datasets and Equations

- mixer1
- HB.freq
- HB.I_base1.i
- HB.I_base2.i
- HB.I_cc.i
- HB.SRC1.i
- HB.SRC2.i
- HB.SRC3.i
- HB.Vin
- HB.Vout

### Traces

- mixer1..Mix

#### Buttons

- OK
- Cancel
- Help

#### Actions

- >>Add<<
- >>Add Vs...>>
- <<Delete<<
Single Balanced Multiplying Mixer Layout
Layout Details

800 OHMS
2 PLACES

Q1
Q2
Q3
Mixer Layout Details near the Transistors