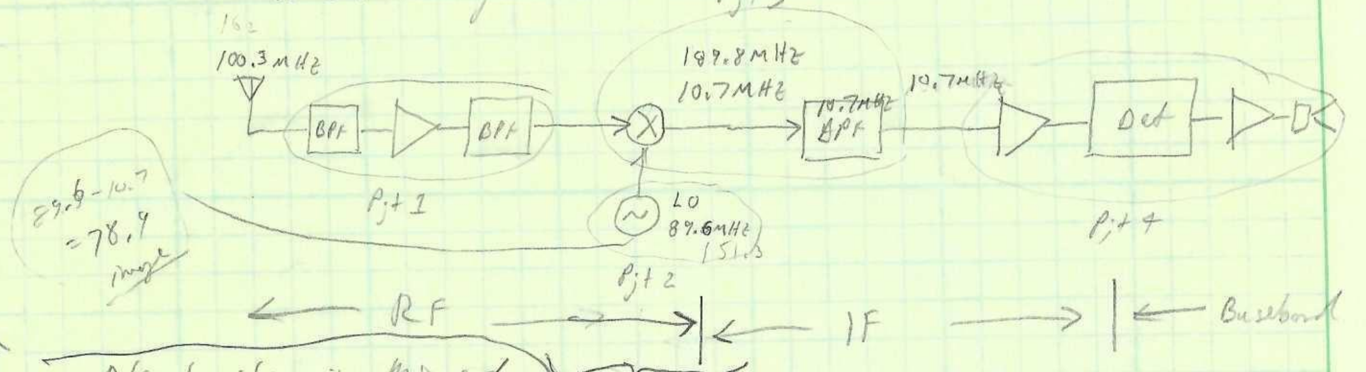
10/22

Mixer Designs

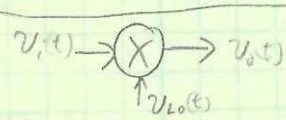
Recall Recvr Block Diagram



Show Cellphone Schematic (mixer + filter)

Next step is mixer / Downconvert "Down conversion"

☆ Consider "Ideal" mixer



$$v_o(t) = A_v \, v_{RF}(t) \; v_{LO}(t)$$

Simplified Analysis

Let $v_{RF}(t) = V_1 \cos(\omega_{RF} t)$ $v_{LO}(t) = V_2 \cos(\omega_{LO} t)$

(V_1 ↑ Input amplitude; V_2 ↑ LO amplitude)

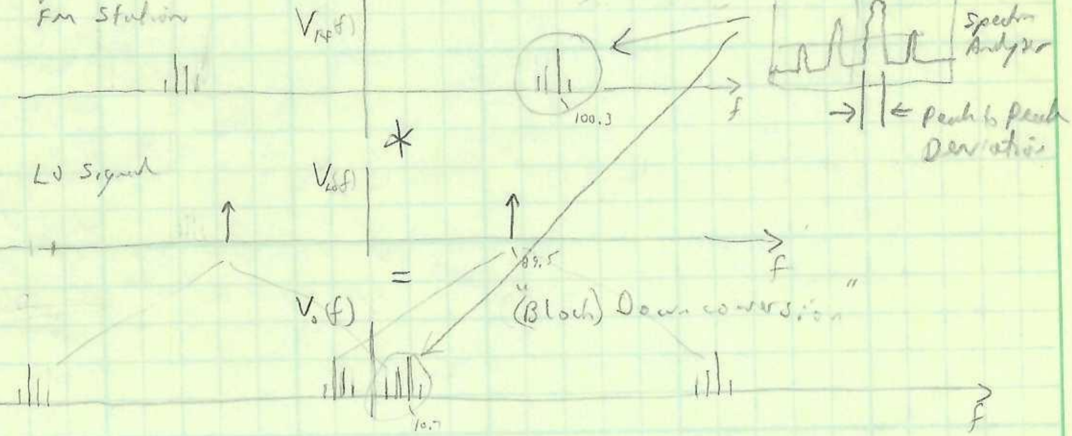
Recall $\cos(\alpha)\cos(\beta) = \frac{1}{2}\cos(\alpha+\beta) + \frac{1}{2}\cos(\alpha-\beta)$

Then

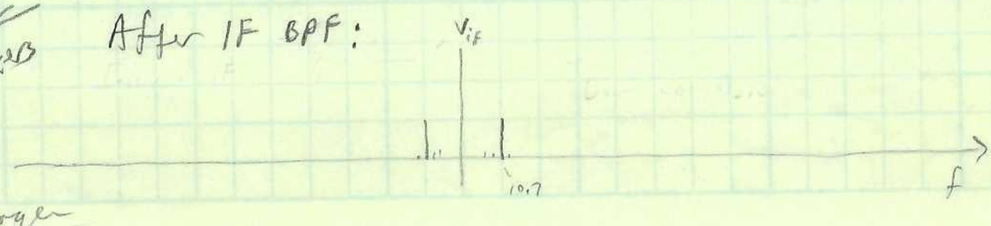
$$v_o(t) = \frac{A_v}{2} V_1 V_2 \cos((\omega_{RF} + \omega_{LO})t) + \frac{1}{2} V_1 V_2 \cos((\omega_{RF} - \omega_{LO})t)$$

Undesired output — Filter to remove   Desired "product" at 10.7 MHz

In Frequency Domain: $v_o(t) = v_{RF}(t)\, v_{LO}(t) \Longleftrightarrow V_o(f) = V_{RF}(f) * V_{LO}(f)$



After IF BPF:



Practical Implementation

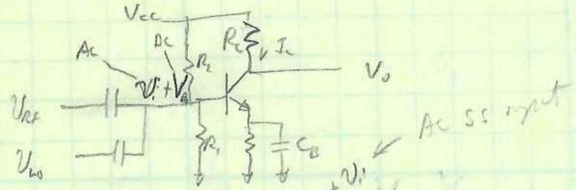
- Diode & Transistor mixers
- Switching mixers
  - Diode Ring
  - IC Gilbert cell

Images

Practical Implementation

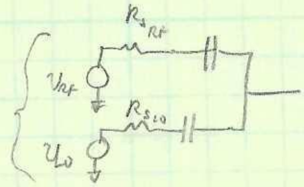
{ Diode & Transistor mixers
{ Diode Ring mixers
{ IC mixers – Gilbert Cell

Older BJT mixer (simple, cheap, and high frequency)



$V_B \approx R_1/(R_1+R_2)\, V_{CC} + V_i$

$v_i = k_1 V_{RF} + k_2 V_{LO}$ (assume:



$I_C \approx I_E = I_0\, e^{\frac{V_{BE} + v_i(t)}{nV_T}} = I_{CQ}\, e^{v_i/nV_T}$

$V_o = V_{CC} - R_C I_C$ ("a scaled - offset version of I_C")

Look at I_C:

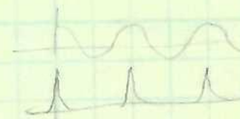
$$I_C = I_{CQ}\, e^{\frac{k_1 V_{RF} + k_2 V_{LO}}{nV_T}}$$

$$= I_{CQ}\left(e^{\frac{k_1 V_{RF}}{nV_T}}\right)\left(e^{\frac{k_2 V_{LO}}{nV_T}}\right) \qquad \text{Recall } e^x = 1 + x + \frac{x^2}{2} + \dots$$

$k_1 V_{RF} \ll nV_T$, $V_{LO} = \cos(\omega_{LO} t)$

$$= I_{CQ}\left(1 + \frac{k_1}{nV_T} V_{RF} + \dots\right)\left(e^{\frac{k_2 \cos(\omega_{LO} t)}{nV_T}}\right)$$

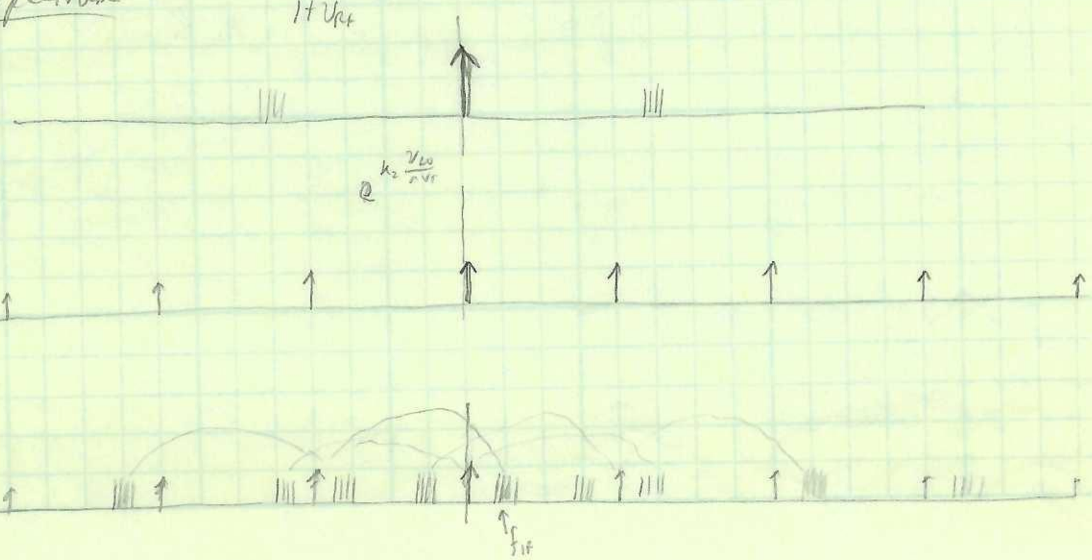
McClorin Expansion; ← periodic



$$\cong I_{CQ}\left(1 + \frac{k_1}{nV_T} V_{RF}\right)\left(\sum_{n=0}^{\infty} c_n \cos(n\omega_{LO}(t) + \theta_n)\right)$$

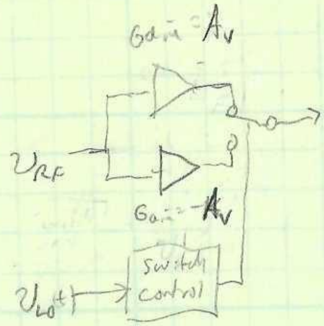
$$= \left(\frac{I_{CQ} k_1}{nV_T} V_{RF}\right)\left(c_1 \cos(\omega_{LO} t + \theta_1)\right) + \text{extra terms}$$

Spectrum



Switching Mixers

Concept

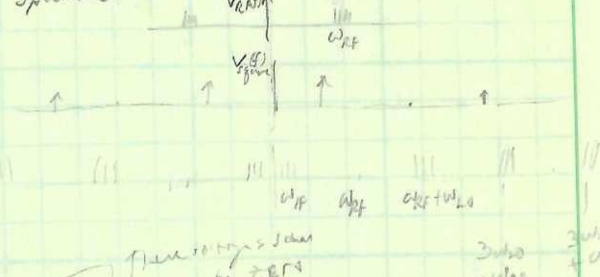


Signum ...

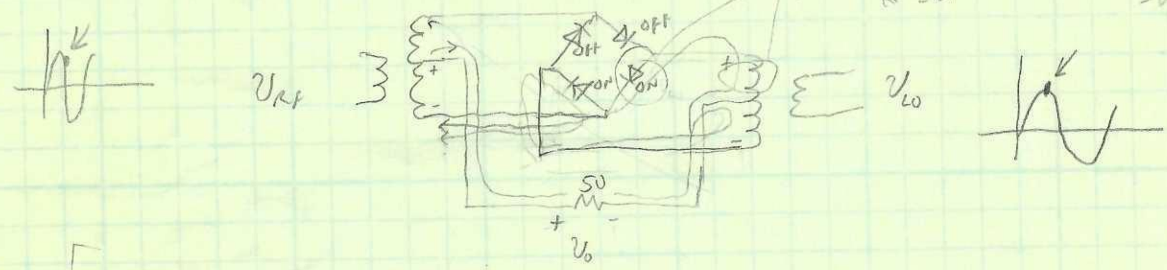
$$V_{IF}(t) = V_{RF}(t)\ \mathrm{Sgn}[V_{LO}(t)] \cdot A_V$$

$$= V_{RF}(t) \cdot \text{(square wave)}$$

Spectrum:



Diode Ring Mixer



Diode Behavior

Diode off — "open circuit" ("large" reactance) — 1pF

Diode on — "small" resistance

$r_d = \frac{nV_T}{I_D}$ ← From

$$I_D = I_0 e^{\frac{V_D}{nV_T}}$$

$$\frac{dI_D}{dV} = \frac{1}{nV_T} I_0 e^{\frac{V_D}{nV_T}} = \frac{I_D}{nV_T}$$

$$\Rightarrow \frac{dV}{dI_D} = R = \frac{nV_T}{I_D}$$

Called Double Balanced because...

RF isolated from LO — "No" LO signal goes out RF port

IF isolated from LO & RF — "No" LO or RF signal goes to IF ideally

☆ Show Example from MCL

Typical Impedance

Diode off:

$1\,pF$ @ $160\,MHz \approx -j\,1K\Omega$

Diode on:

r_d @ $1\,mA \approx 26\,\Omega$

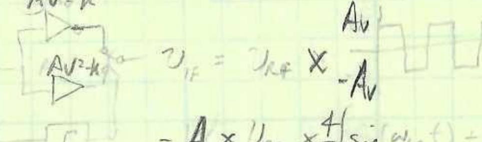
1E12 / 6(150E6) ≈ 1kΩ

.026 / 1

① Recall Ideal mixer / Downconvert

$f_{RF}+f_{LO}$ $f_{RF}-f_{LO}$

② Switching mixer

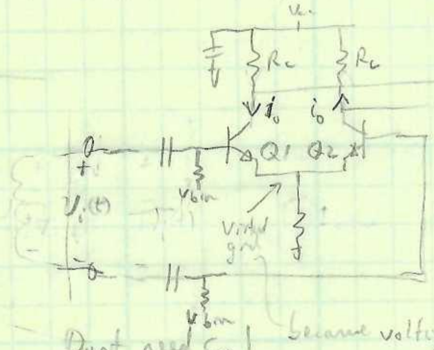


$$v_{IF} = v_{RF} \times A_v \text{ (square wave } \pm A_v)$$

$$= A_v \times v_{RF} \times \frac{4}{\pi}\left[\sin(\omega_{LO} t) + \frac{1}{3}\sin(3\omega_{LO} t) + \ldots\right]$$

IC Switching mixers Implementation

Begin with a Differential Amplifier



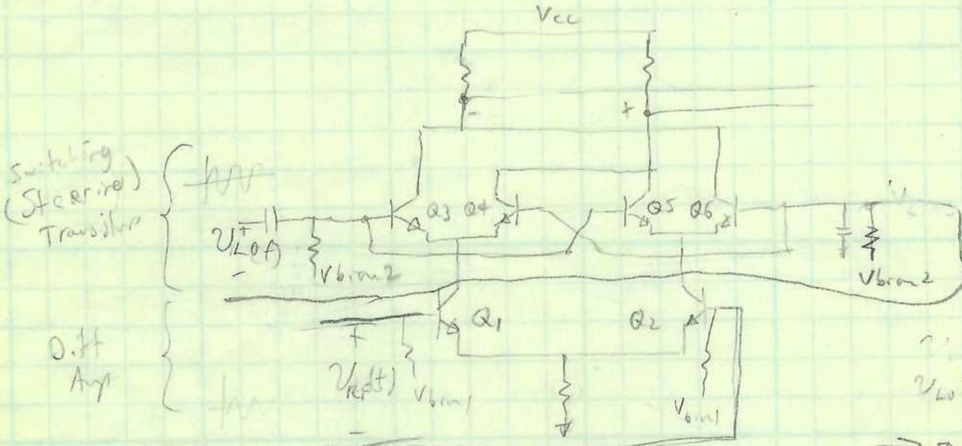
$$v_o(t) = g_m R_C v_i(t)$$

Don't need C_E! because voltage stays constant due to balance

→ Show cascode version:

Add cascode/switching/ transistors

Mixer:



$v_{LO} > 0V \Rightarrow Q_3, Q_5$ ON, Q_4, Q_6 OFF

$\Rightarrow$ Inverting Amp (cascode)

$v_{LO} < 0V \Rightarrow Q_3, Q_5$ OFF, Q_4, Q_6 ON

$\Rightarrow$ Non-inverting amp

Result: Switching mixer with gain

Called "Gilbert Cell mixer" after Barry Gilbert

Abstract View: