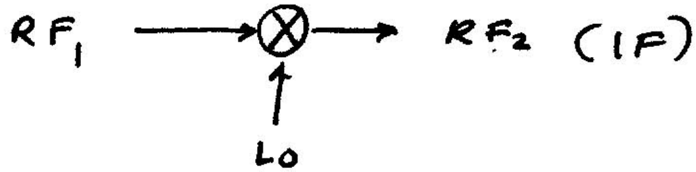
#24

MIXERS (STEPHEN MAAS)

A MIXER IS A FREQUENCY TRANSLATION DEVICE :



$$RF_1 = A_1 \cos(\omega_1 t)$$
$$LO = A_3 \cos(\omega_{LO} t)$$
$$RF_2 = RF_1 \otimes LO$$
$$= A_2 \cos(\omega_2 t)$$

$$\omega_2 = \omega_1 \pm \omega_{LO}$$

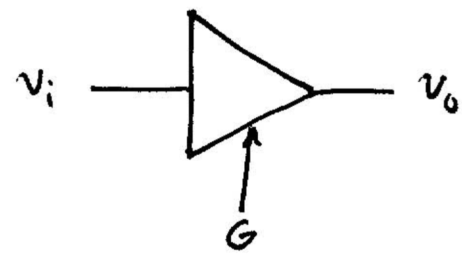
THIS IS NOT A LINEAR TIME-INVARIANT CIRCUIT!

A MULTIPLIER ACTS LIKE AN IDEAL MIXER:

$$V_M = A_1 A_2 \cos \omega_1 t \cdot \cos \omega_2 t \times G$$

$$= \frac{A_1 A_2 \times G}{2} \left\{ \cos(\omega_1 + \omega_2)t + \cos(\omega_1 - \omega_2)t \right\}$$

A TIME-VARYING CIRCUIT ALSO ACTS LIKE A MIXER



$v_0 = G \cdot v_i$ — FOR FIXED "G", CIRCUIT IS LINEAR

LET $G = A_2 \cos \omega_2 t$

$v_i = A_1 \cos \omega_1 t$

$$v_0 = G \cdot v_i = A_1 A_2 \cos\omega_1 t \cos\omega_2 t$$

→ ALSO A MIXER

A LINEAR TIME-VARYING CIRCUIT CAN ACT LIKE A MIXER.

TWO FAMILIES OF MIXERS:

- NON-LINEAR "MULTIPLYING" MIXER
- TIME-VARYING "SWITCHING" MIXERS

NON-LINEAR MIXER: $y = f(x) \simeq a_1 x + a_2 x^2 + \cdots$

$$y_3 = f(x_1 + x_2) \simeq a_1 (x_1 + x_2) + a_2 \underbrace{(x_1 + x_2)^2}_{\text{MIXING}} + \cdots$$

$$\simeq a_1 (x_1 + x_2) + a_2 (x_1^2 + x_2^2 + \underbrace{2 x_1 x_2}) + \cdots$$

ANY DEVICE WITH SQ LAW CAN MIX

PERIODICALLY TIME-VARYING MIXER

$$v_o(t) = p(t)\, v_i(t)$$

$$p(t+T) = p(t)$$

$$= \sum_{n=-\infty}^{\infty} c_n e^{j\omega_0 n t}\, v_i(t)$$

$$c_n = \frac{1}{T}\int_0^T p(t)\, e^{-j\omega_0 n t}\, dt$$

$$v_i(t) = A(t)\cos\omega_1 t = A(t)\left(\frac{e^{j\omega_1 t} + e^{-j\omega_1 t}}{2}\right)$$

$$v_o(t) = A(t)\sum_{-\infty}^{\infty} c_n \frac{e^{j(\omega_0 n t + \omega_1 t)} + e^{+j(\omega_0 n t - \omega_1 t)}}{2}$$

$$\rightarrow \frac{c_1}{2} e^{j\omega_0 t - \omega_1 t} + \frac{c_{-1}}{2} e^{-j(\omega_0 t - \omega_1 t)}$$

$$c_1 = c_{-1}$$

$$= \underbrace{c_1 \cos(\omega_0 t - \omega_1 t)}$$

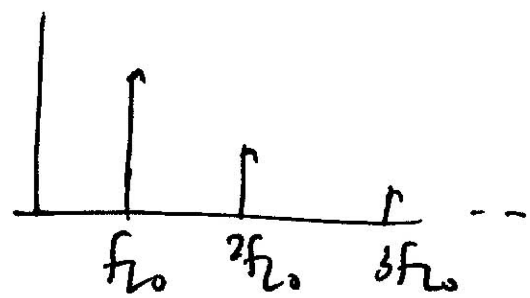
DESIRED SIGNAL ... FILTER OUT UNWANTED SIGNALS

MULTIPLICATION IN TIME IS CONVOLUTION IN FREQ...

$$y(t) = p(t)\, x(t)$$

$$Y(f) = X(f) * P(f)$$

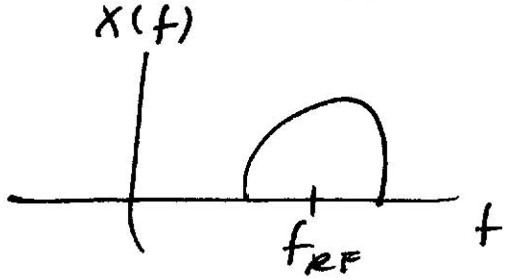
$$P(f) = \sum_{-\infty}^{\infty} c_n\, \delta(f - n f_{LO})$$



$$Y(f) = \int_{-\infty}^{\infty} \sum_{-\infty}^{\infty} c_n\, \delta(\sigma - n f_{LO})\, X(f-\sigma)\, d\sigma$$

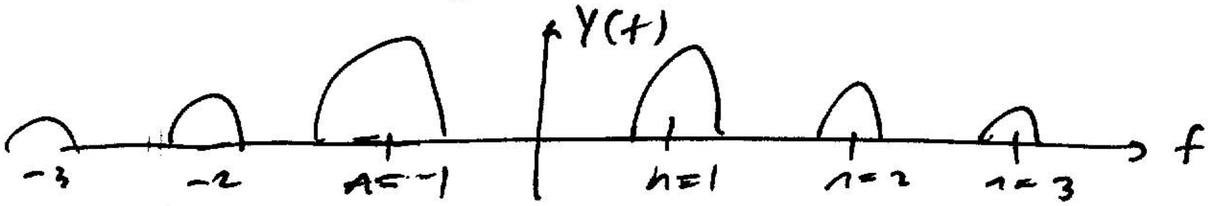
$$= \sum_{-\infty}^{\infty} c_n \left(\int_{-\infty}^{\infty} \delta(\sigma - n f_0)\, X(f-\sigma)\, d\sigma \right)$$

$$= \sum_{-\infty}^{\infty} c_n\, X(f - n f_{LO})$$



TRANSLATE SPECTRUM

$$f = f_{RF} + n f_{LO}$$



MIXER CHARACTERISTICS:

- CONVERSION GAIN (OR LOSS)
- NOISE FIGURE
- BANDWIDTH
- DISTORTION
- SPURIOUS RESPONSE

$$f_{IF} = m f_{RF} + n f_{LO} \qquad (m,n)$$

- FEEDTHROUGH
- DC POWER
- LO/RF/IF ISOLATION (REJECTION)

SPURIOUS SIGNALS:

CONSIDER A DIODE MIXER

$$g(t) = \left.\frac{\partial I}{\partial V}\right|_{V=V_{LO}} = \frac{q I_0}{kT} e^{\frac{q V_{LO}}{kT}}$$

$$\simeq \frac{q}{kT} \; I(V_{LO}(t))$$

$$I(V) = I_0 \left(e^{qV/kT} - 1\right)$$

$$g(t) = \sum_{k=-\infty}^{\infty} G_k \, e^{jk\omega_p t} \qquad \omega_p : \text{LO FREQ}$$

$$i(t) = \sum_{k=-\infty}^{\infty} I_k \, e^{j(k\omega_p + \omega_s)t} = g(t) \, V_s \, e^{j\omega_s t}$$

↑ MIXING PRODUCT

BUT THE VOLTAGE WAVEFORM WILL ALSO HAVE FREQ COMPONENTS AT ALL MIXING PRODUCTS

LET $\omega_0 \equiv |\omega_s - \omega_p|$

$$i(t) = \sum_{k=-\infty}^{\infty} I_k \, e^{j(k\omega_p + \omega_0)t}$$

$$v(t) = \sum_{-\infty}^{\infty} V_k \, e^{j(k\omega_p + \omega_0)t}$$

$$g(t) = \sum_{-\infty}^{\infty} G_k \, e^{jk\omega_p t}$$

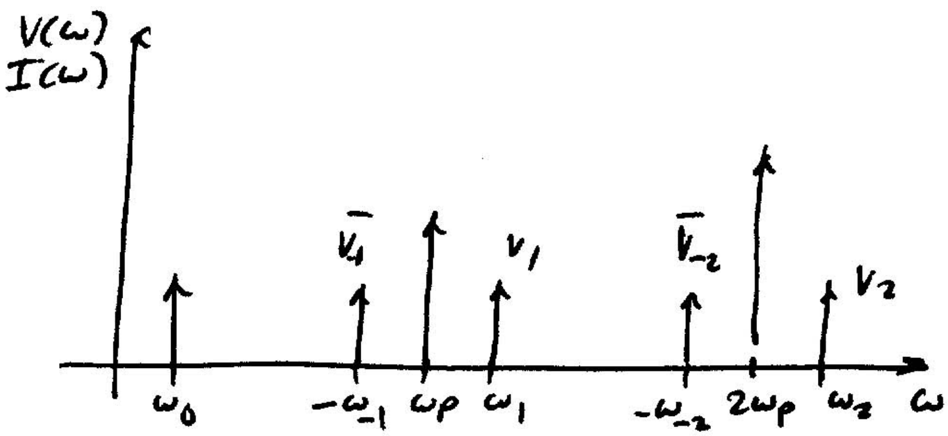
$$i(t) = v(t)\, g(t)$$

$$\sum_{\ell=-\infty}^{\infty} I_\ell \, e^{j(\omega_0 + \ell\omega_p)t} = \sum_m \sum_n G_m V_n \, e^{j(\omega_0 + (n+m)\omega_p)t}$$

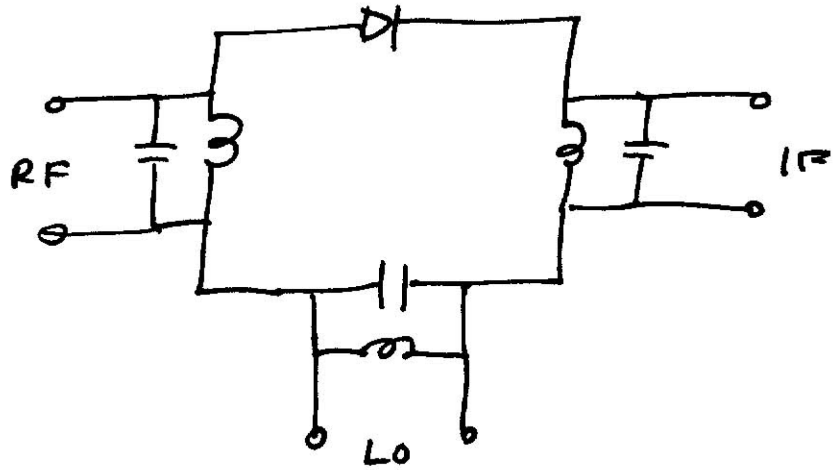
$$\begin{pmatrix} \bar{I}_{-N} \\ \bar{I}_{-N+1} \\ \vdots \\ \bar{I}_{-1} \\ I_0 \\ I_1 \\ \vdots \\ I_N \end{pmatrix} = \begin{pmatrix} G_0 & G_{-1} & G_{-2} & \cdots & G_{-2N} \\ G_1 & G_0 & & & G_{-2N+1} \\ & & \ddots & & \vdots \\ G_{N-1} & & & & \vdots \\ G_N & & \ddots & & \cdot \\ \vdots & & & \ddots & G_{-1} \\ G_{2N} & \cdots & - & - & G_0 \end{pmatrix} \begin{pmatrix} \bar{V}_{-N} \\ \vdots \\ V_0 \\ V_1 \\ \vdots \\ V_N \end{pmatrix}$$

$$\omega_n = n\omega_p + \omega_0$$

$$\omega_{-n} = -\omega_n$$



SINGLE DIODE MIXER



IDEAL "LC" IS A SHORT AT FREQ ~~FAR REMOVED~~ AWAY FROM RESONANCE. B/C OF THIS ALL PORTS ISOLATED:

NO LO FEEDTHRU TO IF
NO IF FEEDTHRU TO IF
NO LO FEEDTHRU TO RF
⋮

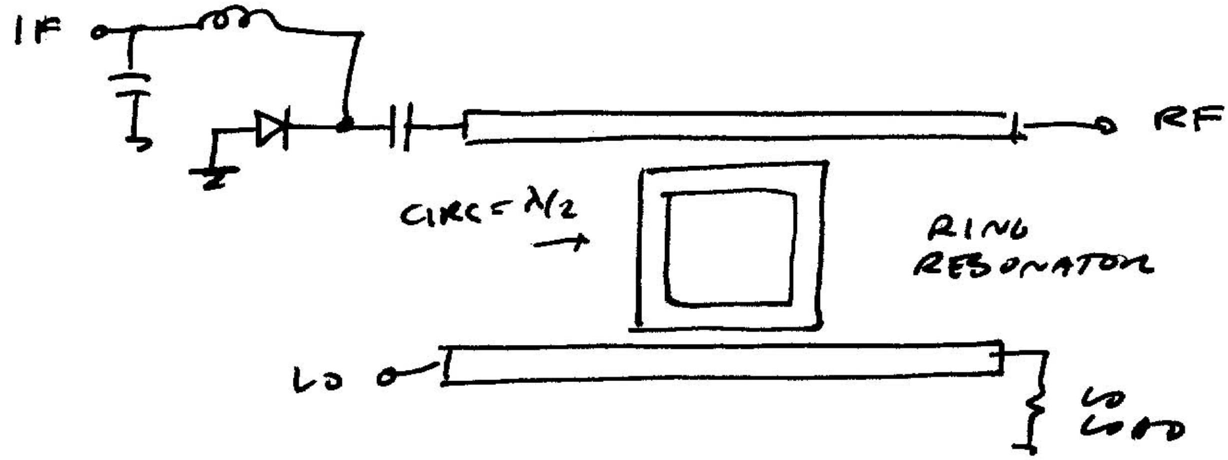
SINCE DIODE IS SHORT CIRCUITED AT ALL FREQ EXCEPT RF, LO, IF

$$\begin{pmatrix} I_{IF} \\ I_{RF} \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} V_{IF} \\ V_{RF} \end{pmatrix}$$

↗ ALL OTHER FREQ PRODUCTS SHORTED

DIODE CAN BE CHOSEN TO PROVIDE MATCH AT ALL PORTS

PRACTICAL IMPLEMENTATION:



RING COUPLES POWER FROM LO TO RF LINE. SINCE DIODE IS MATCHED, RF PORT DOES NOT SEE A REFLECTION. RF IS ISOLATED FROM LO DUE TO NARROW RESONANT FREQ

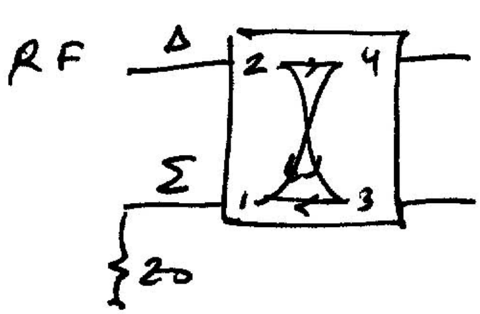
BALANCED DIODE MIXERS

USE BALUN OR HYBRIDS

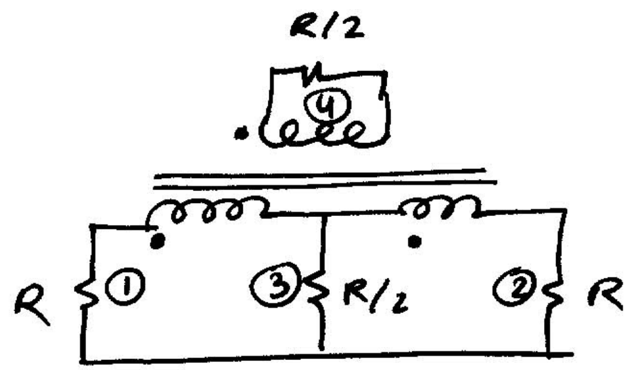
RECALL:

$$S_{90} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & -j & 1 \\ 0 & 0 & 1 & -j \\ -j & 1 & 0 & 0 \\ 1 & -j & 0 & 0 \end{pmatrix}$$

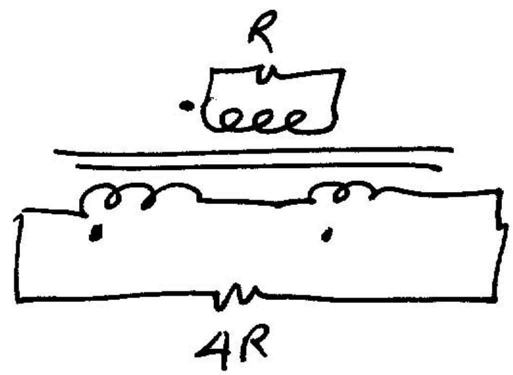
$$S_{180} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$$



TRANSFORMERS AS HYBRIDS / BALUNS

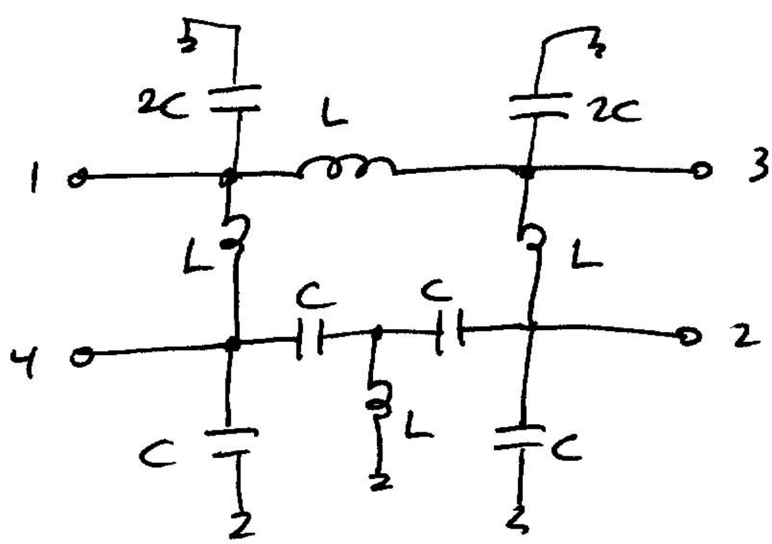


HYBRID



BALUN

LUMPED ELEMENT HYBRID

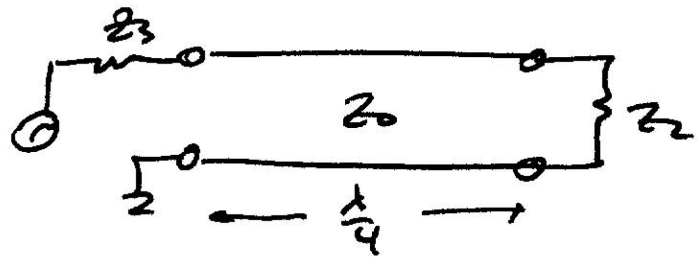


BW ~ 20%

180 HYBRID

$$\omega L = \frac{1}{\omega C} = \sqrt{2}\, Z_0$$

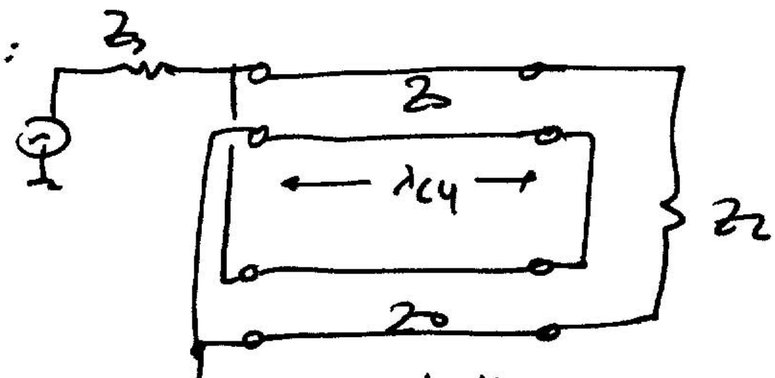
T-LINE BALUNS



$$Z_0 = \sqrt{Z_S Z_L}$$

$Z_{00} = \frac{1}{2} Z_0$ $\qquad$ $Z_{0e} \simeq 10\, Z_{00}$ FOR GOOD PERF

OTHERS:



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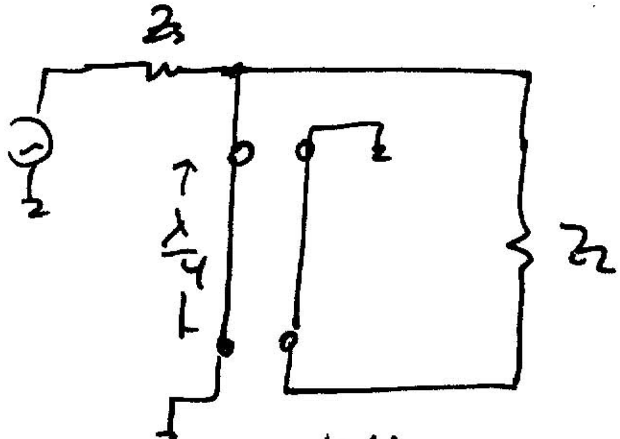

CONVENIENT GROUND RETURN

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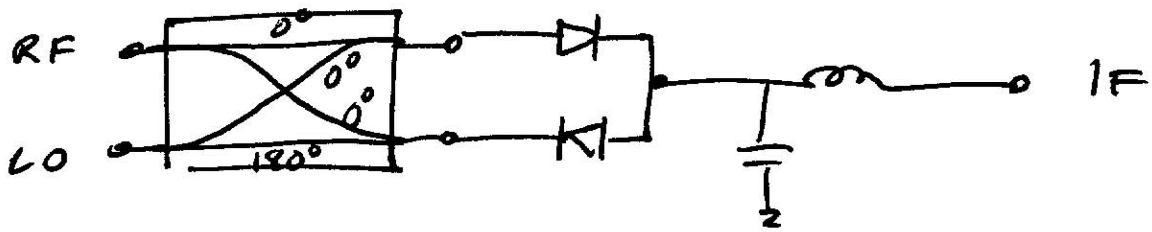
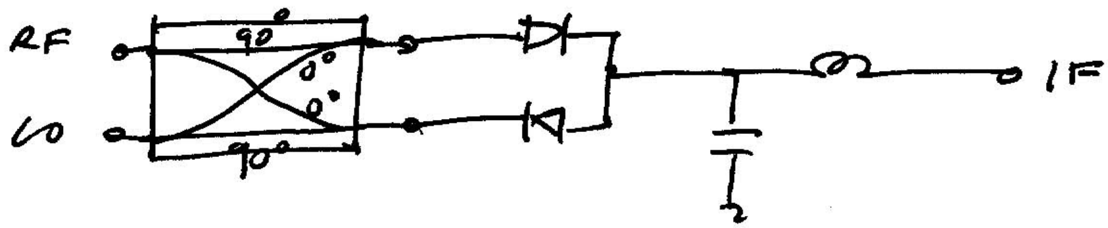
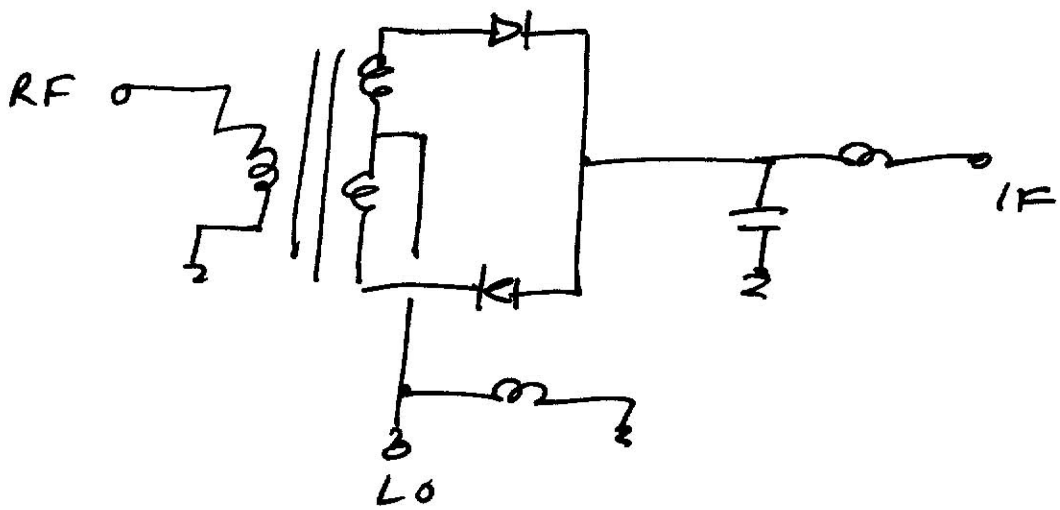
SINGLY BALANCED DIODE MIXERS





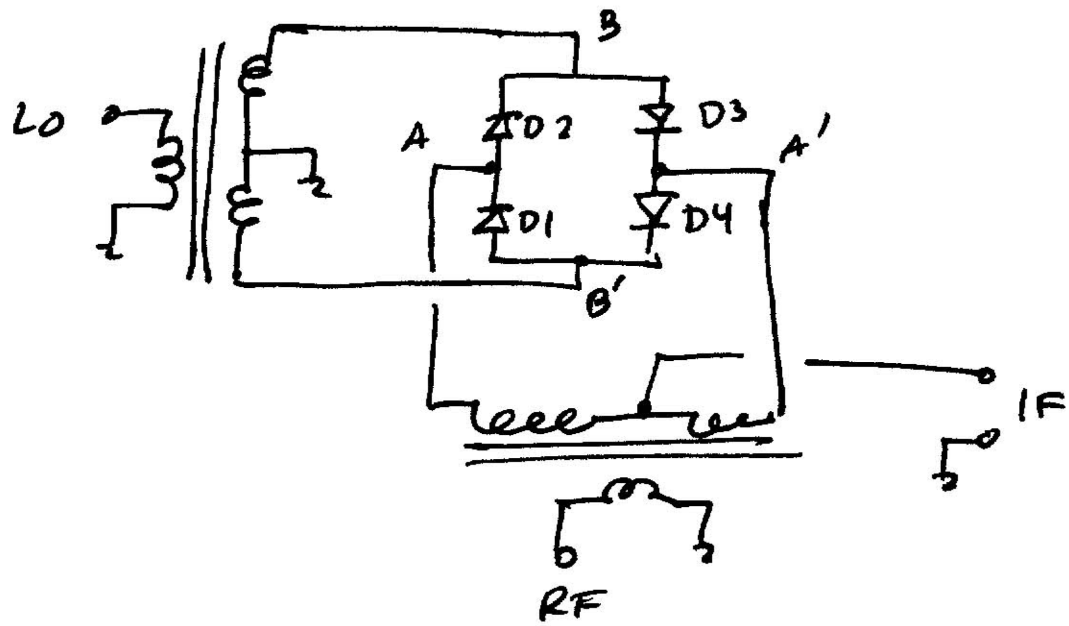
- BETTER RF & LO ISOLATION
- REJECTION OF SPURIOUS SIGNALS
- REJECTION OF AM NOISE FROM LO

TRANSFORMER REALIZATION WITH 180° HYBRID



DOUBLY BALANCED MIXERS

- REJECT ALL EVEN ORDER SPURIOUS RESPONSES
- IF, RF, LO ARE ISOLATED



AA' VIRTUAL GROUNDS FOR LO

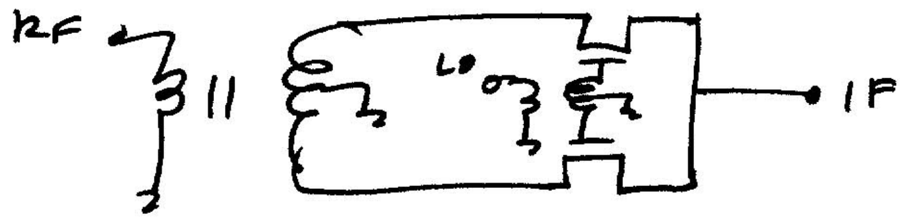
BB' VIRTUAL GROUNDS FOR RF

LO+	B+, B'−	D1 & D2	OFF
		D3 & D4	ON
LO−	B−, B'+	D3 & D4	ON
		D1 & D2	OFF

RF PORT IS COUPLED TO IF PORT WITH CHANGING POLARITY

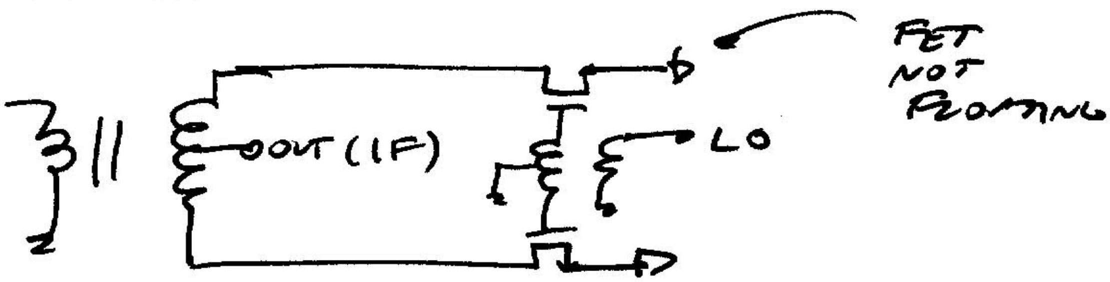
$$V_{IF} = S(t)\ V_{RF}(t)$$

MOS REALIZATION

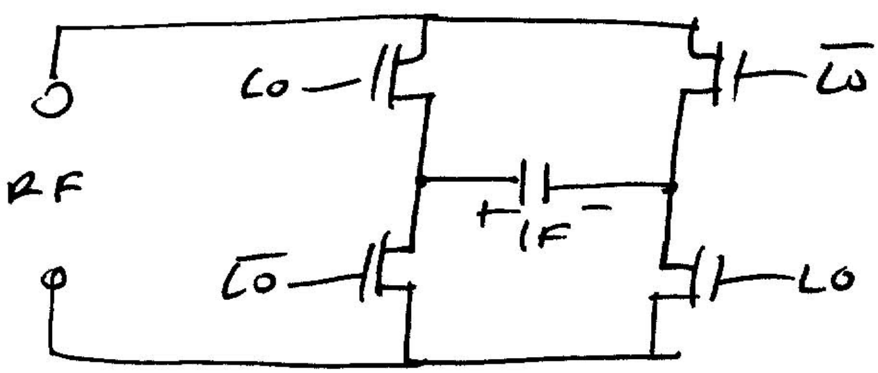


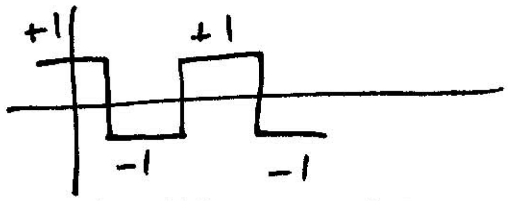
MULTIPLY RF BY ±1

BETTER ...



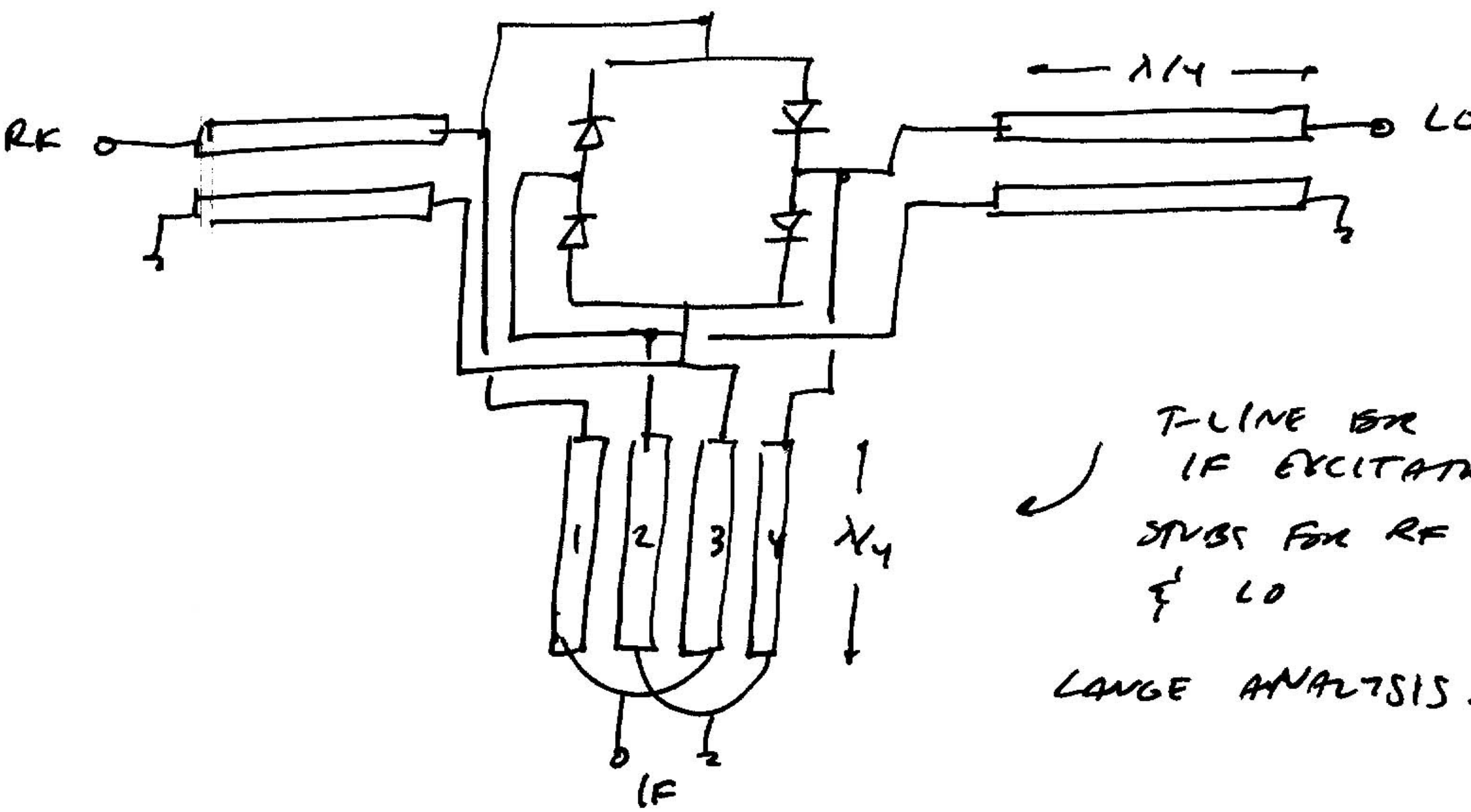
FULLY BALANCED : VERY SIMPLE MIXER





- S(t) HAS NO EVEN HARMONICS
- S(t) HAS NO DC COMPONENT: IF CONTAINS NO RF
- MIXING WITH EVEN COMPONENTS OF RF CANNOT OCCUR
- IF CURRENT EXCITES TRANSFORMERS IN EVEN MODE → NO IF VOLTAGE AT SECONDARIES

MICROWAVE REALIZATION:



T-LINE FOR IF EXCITATION

STUBS FOR RF & LO

LANGE ANALYSIS ...

IF BAND CAN OVERLAP W/ RF/LO BANDS