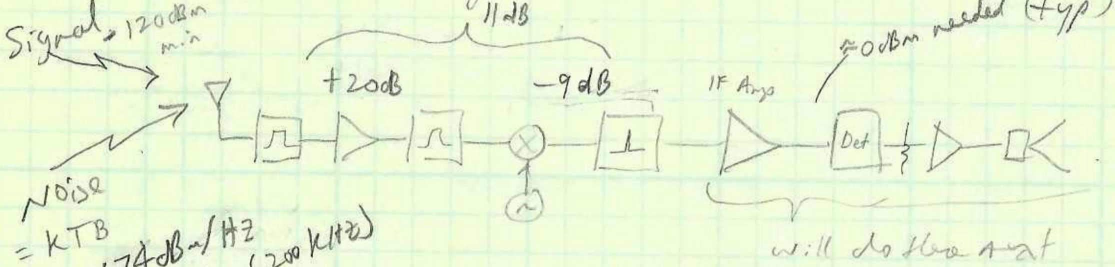
11/5

IF Amps & Detectors (Demods)

Recall RX Block Diagram



Noise
$= KTB$
$\rightarrow -174\,dBm/Hz + 10\log(200\,kHz)$
$= -174 + 53$
$= -121\,dBm$

Amplification Needed (Assume 100mV @ 1KΩ = 10 uW (-20 dBm) needed at detector)

	Pwr at antenna	Pwr @ IF Amp In	IF Gain Needed
Weak Signal	-110 dBm	-99 dBm	79 dB
Strong Signal	-20 dBm	-9 dBm	-11 dB

"Dynamic Range" Needed ≈ 90 dB (less for satellite work) if preselector good

10 Billion to 1 Ratio!

Solutions

1) Use Automatic Gain Control (AGC)

AGC Needed for AM, SSB, some digital modulation

2) Use very high gain & allow to saturate or "limit"

Used on FM, FSK

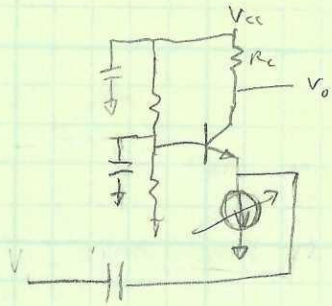
Recall Rx
Signal leading to demodulation
Amp needed for small signal
Amp needed for larger signal

Soln
Linear mod → AGC
FM → Limiting

AGC ckt concept
MC1350 ckt
gain curve
Limiter ckt concept
FM idea in place
Limiter ckt
limiting sensitivity
RSSI

Demodulation
modulation
AM TV
BPSK/QPSK Dig
FM Freq cells
AM detectors
Synch
PLL Synth
BPSK/QPSK demods
FM Demods

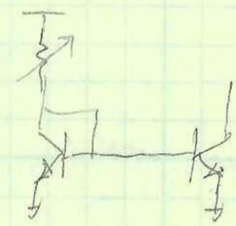
Typical AGC Amplifier (Simplified)



$A_v = g_m R_c$

$g_m = \frac{I_c}{n V_T}$

I_c	A_v	A_v dB
1 mA	100	40
100 μA	10	20
10 μA	1	0
1 μA	0.1	−20



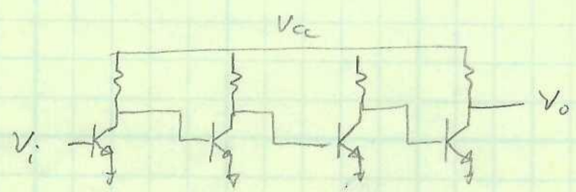
IC Implementation (MC 1350)

Show CKT

Discuss Current Control

Show Gain Curve

Typical Limiter Ckt Simplified



$A_v = 10$ $A_v = 10$ $A_v = 10$ $A_v = 10$

IC Implementation
- Mars Amp
- Show • LM 3089 (Our Chip)

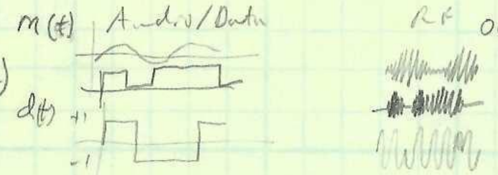
~~Show LM3089~~ Pg 2 w/ 3dB sens of 12μV

11/7
Demodulator Ckts

Recall
~~Classic~~ Basic modulation Types

Math model

1) AM
2) ASK (OOK)
BPSK



$v_{RF}(t) = [1 + m(t)] \cos(\omega_0 t)$
$= d(t) \cos(\omega_0 t)$

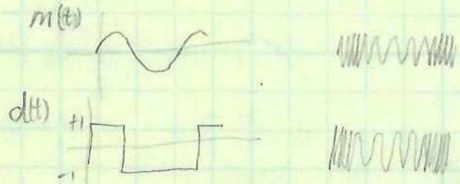
$v(t) = d(t) \cos(\omega_0 t)$

$d(t) \in \{-1, 1\}$ modulator = mixer!

QPSK = 2 BPSK data streams on "quadrature" carriers $v(t) = d_I(t)\cos(\omega_0 t) + d_Q(t)\sin(\omega_0 t)$

Other QAM, GMSK, ... DSSS See ECE661

5) FM
6) FSK



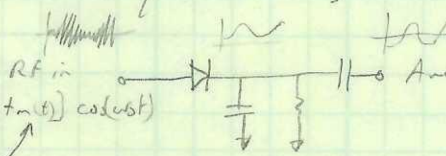
$v(t) \doteq \cos[(\omega_0 + K m(t)) t]$

$v(t) \doteq \cos[(\omega_0 + K d(t)) t]$

Some subtle problems.
Actually need to use:
$\cos[\omega_0 t + K \int v(t) dt]$

AM Detectors (Demodulators)

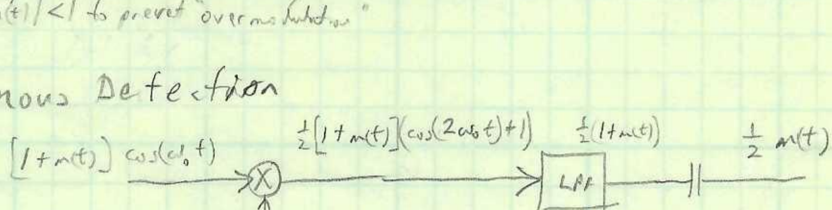
Simple Diode ("square-law") Detector for AM (& OOK/ASK)



Audio waveform
$|m(t)| < 1$ to prevent "overmodulation"

"Can see why need ~ 1V @ demod"

Modern Synchronous Detection



Better sensitivity & noise performance

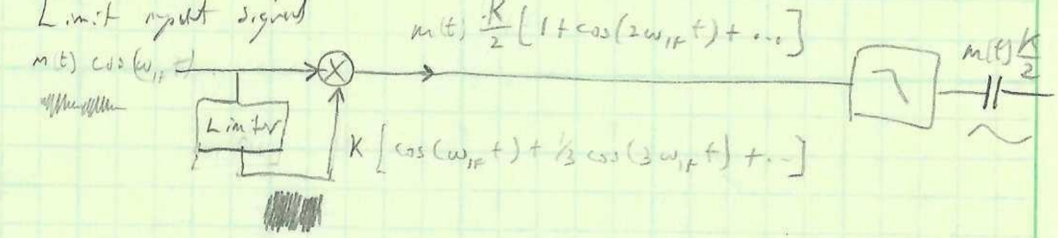
☆ What would happen if mixed w/ $\sin(\omega_0 t)$? ? ☆ Zero output!

Where do we get $\cos(\omega_0 t)$ from?

1) Phase Locked Loop (Later in class)

Skip the math!

2) Limit input signal

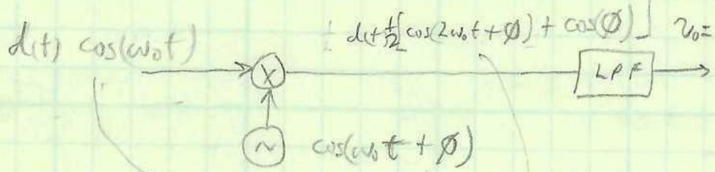


BPSK (~~/ QPSK~~) Demodulators

(Similar, but trickier to get sinusoid to mix with...)

Can use Sync Detector to demodulate BPSK/QPSK also

$\frac{1}{2}[\cos(\alpha+\phi) + \cos(\alpha-\phi)]$

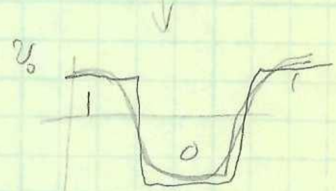


1 if osc in phase

0 if osc ±90° out of phase

−1 if osc 180°

Do viewgraph of this



SMP

Consider QPSK:

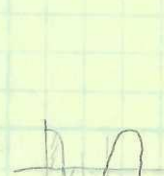
$$v(t) = d_I(t)\cos(\omega_0 t) + d_Q(t)\sin(\omega_0 t)$$

what is output of above detector?

$$v(t)\cos(\omega_0 t)\Big|_{LP} =$$

$$= d_I(t)\cos^2(\omega_0 t) + d_Q(t)\cos(\omega_0 t)\sin(\omega_0 t)\Big|_{LP}$$

$$= \frac{1}{2} d_I(t) + 0$$



$d_Q(t)$ portion is in Quadrature with $d_I(t)$ portion

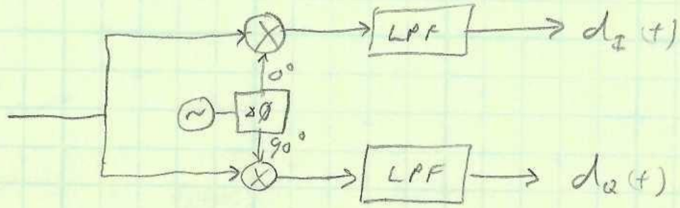
What is output to detector using $\sin(\omega_0 t)$?

$$v_0(t) \sin(\omega_0 t)\Big|_{LP}$$

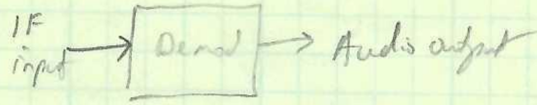
$$= d_I(t) \cos(\omega_0 t) \sin(\omega_0 t) + d_Q(t) \sin^2(\omega_0 t)\Big|_{LP}$$

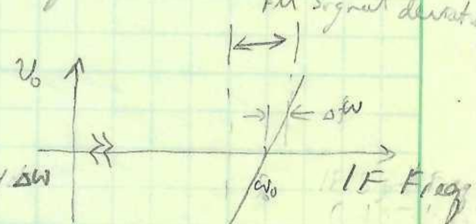
$$\cong 0 + \tfrac{1}{2} d_Q(t)$$

Complete Detector



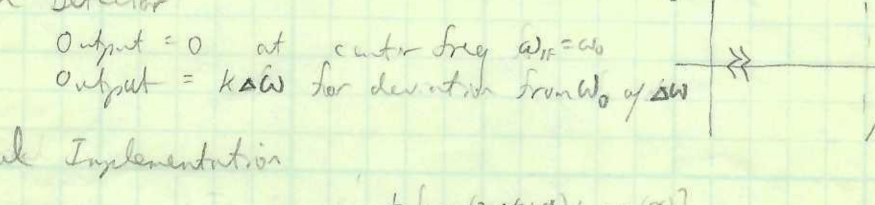
Quadrature FM Detector

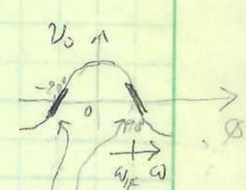




Ideal Detector
Output = 0 at center freq $\omega_{IF} = \omega_0$
Output = $k\Delta\omega$ for deviation from ω_0 of $\Delta\omega$

Typical Implementation





Freq dependent phase shift $\phi(\omega)$, $\pm 90°$ @ center

work in linear range ($-135 < \phi < -45°$)

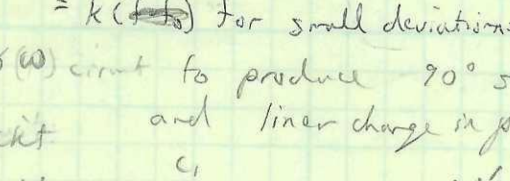
Output = 0 for $\omega \ni \phi(\omega) = -90°$

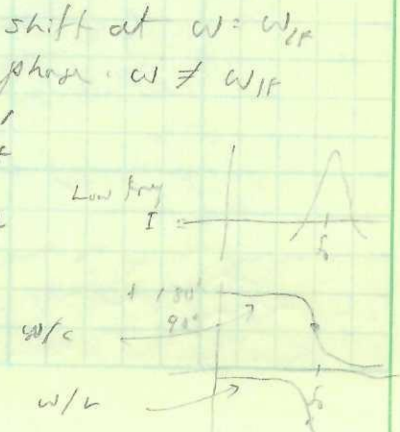
$= k(\omega - \omega_0)$ for small deviations from $-90°$

Design $\phi(\omega)$ circuit to produce $90°$ shift at $\omega = \omega_{IF}$ and linear change in phase $\omega \neq \omega_{IF}$

SKIP to NXT PG

Typical ckt

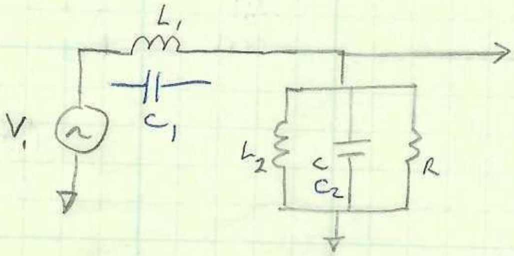




☆ (Show Data Sheet)

cos θ +

$\phi(f)$ analysis ... :



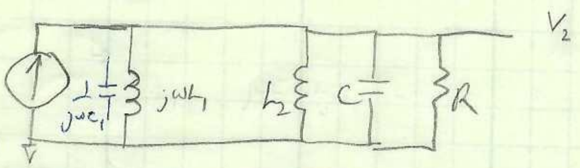
$V_2 = V_1 \angle 90^\circ$ @ f_0

Analysis

1) Convert source, L_1 to Norton equivalent:

$I_1 = \dfrac{V_1}{j\omega L_1}$

or $V_1 j\omega C_1$



2) Combine L_1, L_2 into $L = L_1 \| L_2$

or $C_1 \quad C_2 \qquad C = C_1 + C_2$

3) Solve for V_2 / V_1

$$V_2 = I_1 Z \qquad Z = L \| C \| R$$

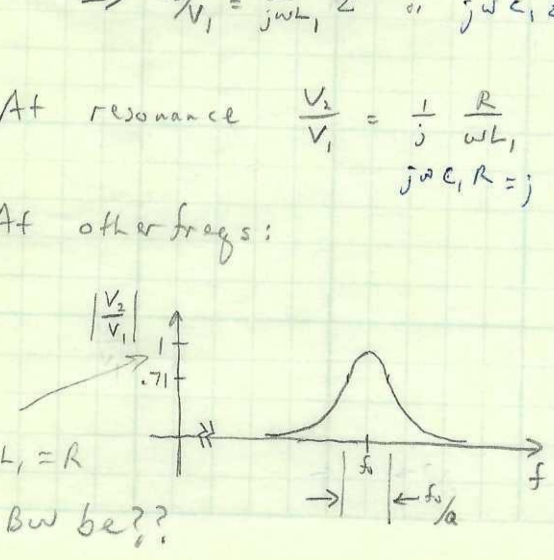
$$= \frac{V_1}{j\omega L_1} Z \text{ or } j\omega C_1 Z V_1$$

$$\Rightarrow V_2/V_1 = \frac{1}{j\omega L_1} Z \text{ or } j\omega C_1 Z$$

At resonance $\dfrac{V_2}{V_1} = \dfrac{1}{j} \dfrac{R}{\omega L_1} = 1 \angle -90^\circ$ if $X_{L_1} = R$

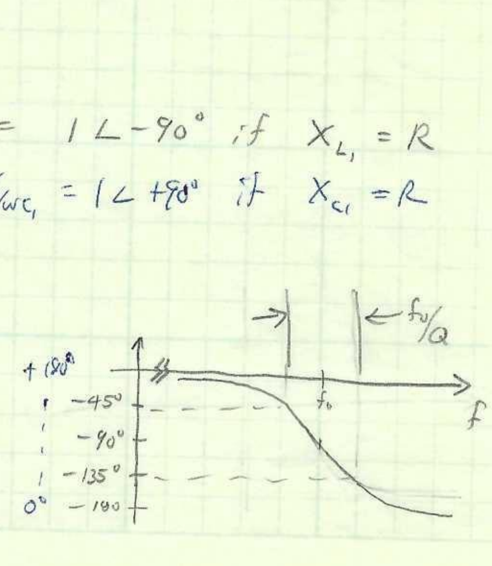
$j\omega C_1 R = j \, R / \tfrac{1}{\omega C_1} = 1 \angle +90^\circ$ if $X_{C_1} = R$

At other freqs:

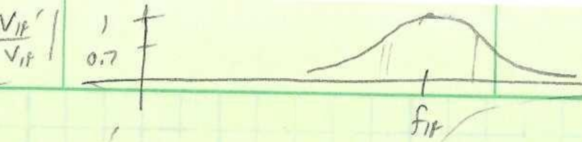


if $\omega L_1 = R$

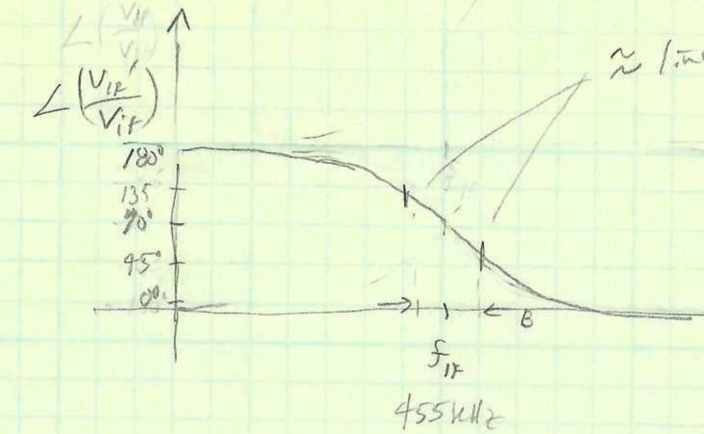
What should BW be??



Mag Response



Ø Response: $\angle\left(\frac{V_{IF}'}{V_{IF}}\right)$



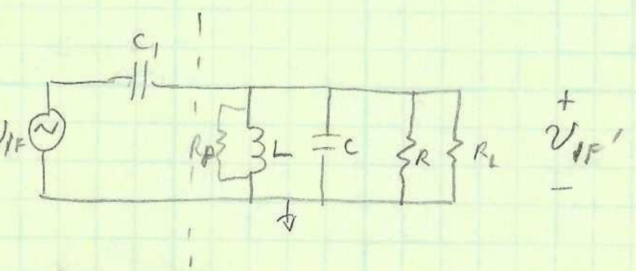
$f_{IF} = \frac{1}{2\pi\sqrt{L(C+C_1)}}$

$B = \frac{f_{IF}}{Q}$

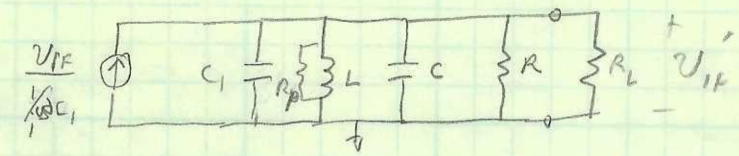
$Q = \left.\frac{R}{X_L}\right|_{f_{IF}}$

$X_{C_1} \simeq R$ (to give gain of $\simeq 1$)

Proof

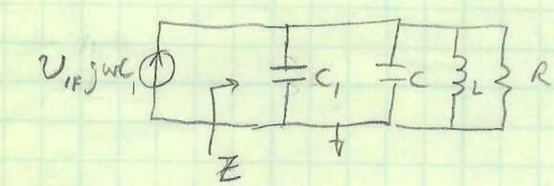


<u>Norton Equiv Src</u>:

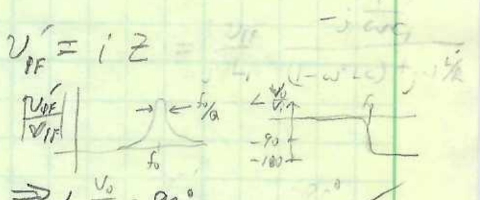


=

$R' = R_p \| R \| R_L$



$V_{IF}' = i\,Z$



At $f = f_0$, $V_{IF}' = i\,R' = V_i\, j\omega C_1 R' \Rightarrow \angle\frac{V_0}{V_i} = 90°$

At $f \ll f_0$, $X_{L'} \ll X_C$ or $R' \Rightarrow Z \approx j\omega L'$ (inductive)

$\Rightarrow V_0 \approx i\, j\omega L' = V_i (j\omega C_1)(j\omega L) \Rightarrow \frac{V_0}{V_i} = -\frac{X_L}{X_{C_1}} \Rightarrow \angle = 180°$

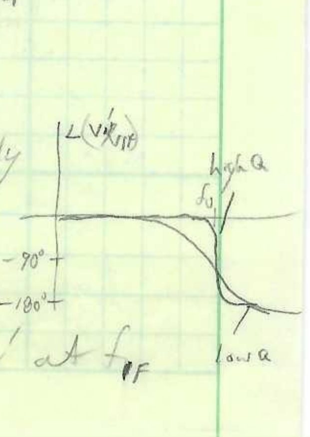
At $f \gg f_0$, $X_C \ll X_{L'}$ or $R' \Rightarrow Z \approx \frac{1}{j\omega C}$ (capacitive)

$\Rightarrow V_0 \approx i\frac{1}{j\omega C} = V_i\, j\omega C_1 \frac{1}{j\omega C} \Rightarrow \frac{V_0}{V_i} = \frac{X_C}{X_{C_1}} \Rightarrow \angle = 0°$

Recall circuit Q is $\frac{R'}{X_{L'}} = \frac{R'}{X_C}$

Large $Q \Rightarrow X_{L'} = X_C \ll R'$

$\Rightarrow$ Transition to looking like just L or C very quickly



NOTE: $\left|V_{IF}'/V_{IF}\right|$ should be ≈ 1 at f_{IF}

$\left.\left|V_{IF}'/V_{IF}\right|\right|_{f_{IF}} = \left|j\omega C R'\right| = \left.\frac{R'}{X_{C_1}}\right|_{f_{IF}} \Rightarrow$ make $X_{C_1} \simeq R'$ at f_{IF}