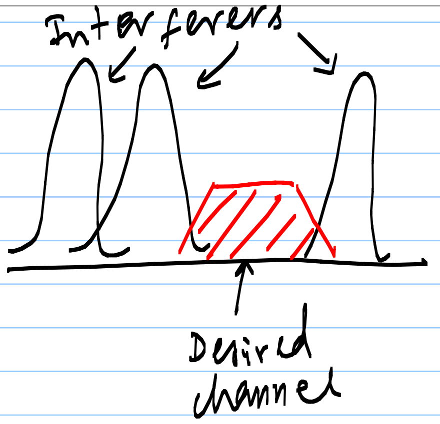
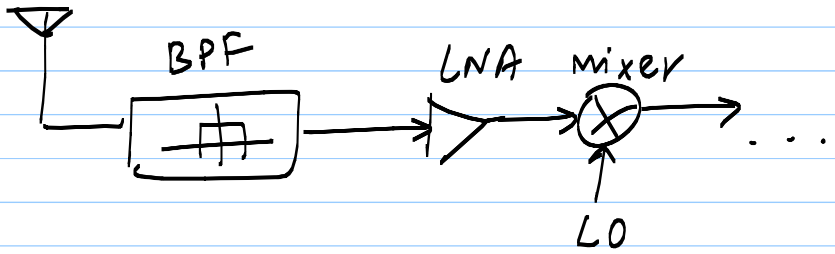
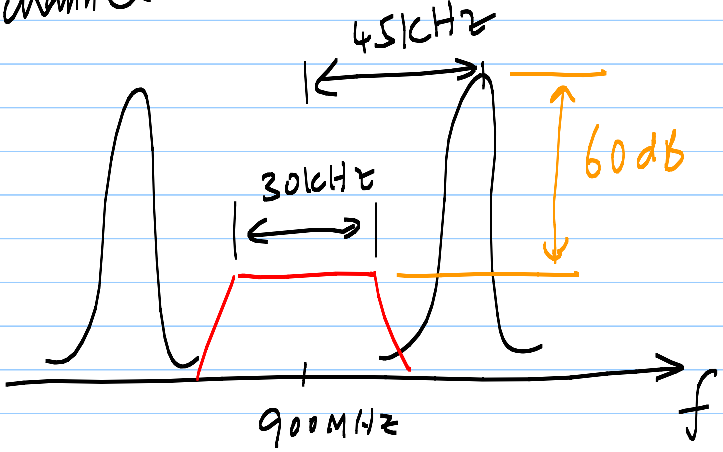
Lecture #10: Introduction to Rx & Tx

Note Title 6/21/2011







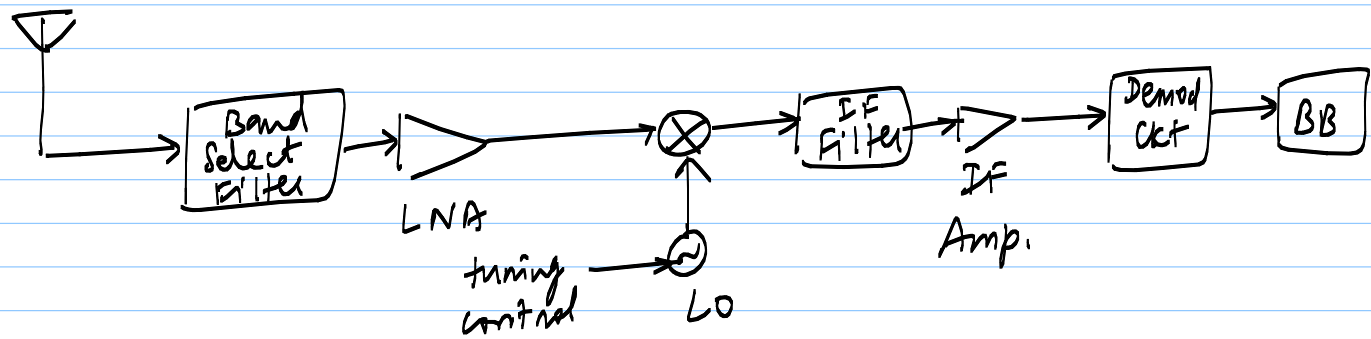
Overall RF system may require selectivity with equivalent $Q \sim 10^7$!!

Important to distinguish Band & Channel:

Band ≡ entire spectrum occupied by all users of a particular standard
e.g. 935 – 960 MHz in GSM

Channel ≡ signal BW of one user
e.g. 200kHz in GSM

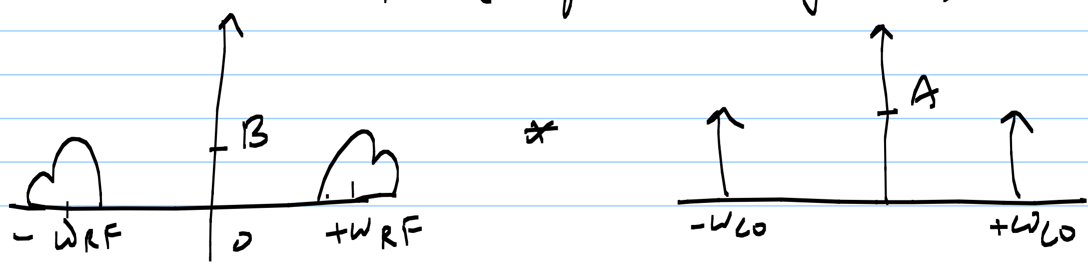
Single conversion Super Heterodyne Receiver

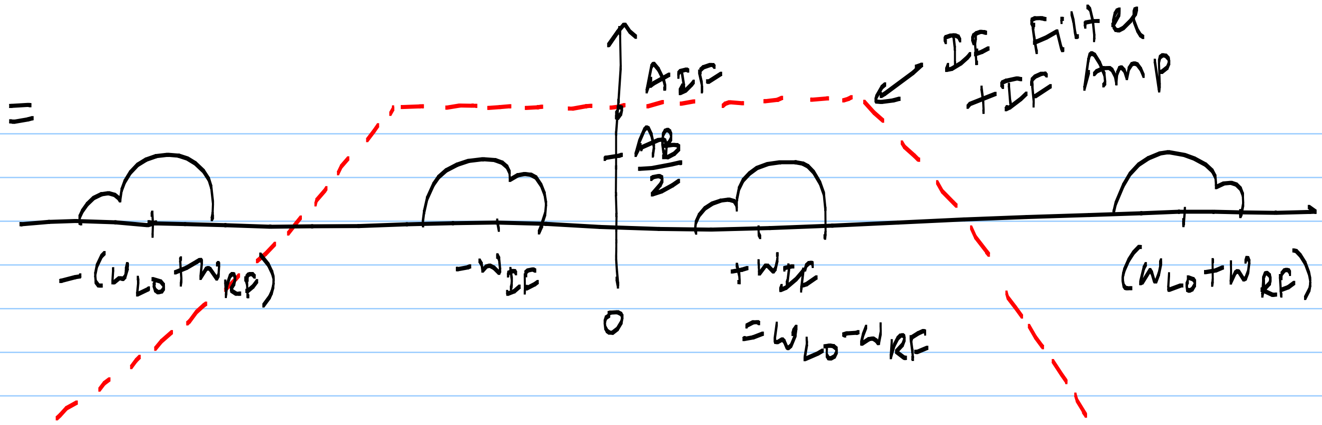


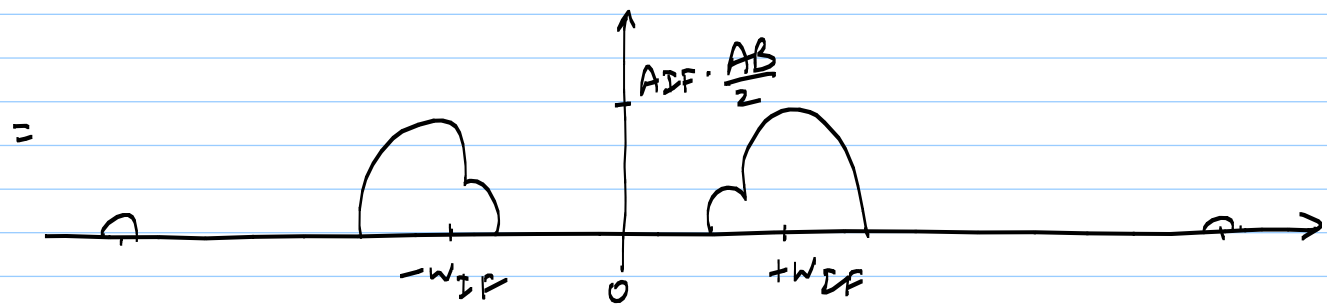
Mixer Operation:

$$(A\cos\omega_{RF}t)\cdot(B\cos\omega_{LO}t) = \frac{AB}{2}\left[\cos(\omega_{LO}-\omega_{RF})t + \cos(\omega_{LO}+\omega_{RF})t\right]$$

assume $\omega_{LO} > \omega_{RF}$ (high side injection)



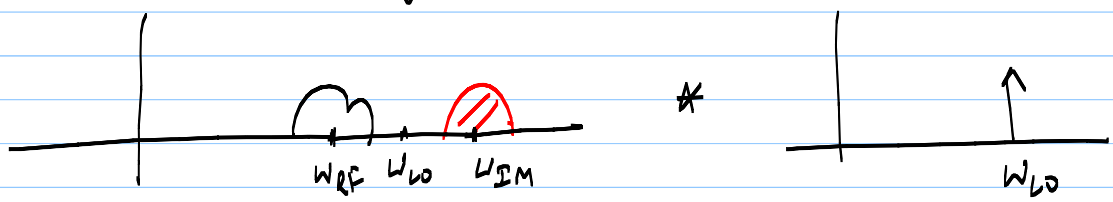




* For easy IF design (ie. high gain, high Q filtering etc.), we want small ω_{IF}

The image problem:

consider a signal at $\omega_{IM} = \omega_{LO} + \omega_{IF}$



=

$$(C\cos\omega_{IM}t)\cdot(B\cos\omega_{LO}t) = \frac{BC}{2}\Big[\cos(\omega_{IM}-\omega_{LO})t + \cos(\omega_{IM}+\omega_{LO})t\Big]$$

{Mathematically $\because \cos(\theta) = \cos(-\theta)$}

Image frequency is located at:

$$\omega_{LO}-\omega_{RF} = \omega_{IM}-\omega_{LO} \Rightarrow \boxed{\omega_{IM} = 2\omega_{LO}-\omega_{RF}}$$

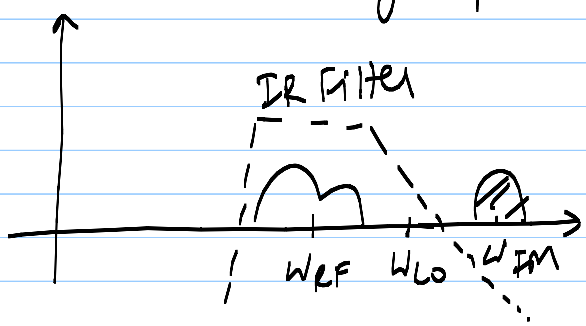
another way of looking at it:

$$\omega_{IF} = \omega_{LO}-\omega_{RF}$$

$$\boxed{\omega_{IM} = \omega_{LO}+\omega_{IF}}$$

also $\omega_{IM} - \omega_{RF} = 2\omega_{IF}$

One Solution to image problem: use an image-reject filter



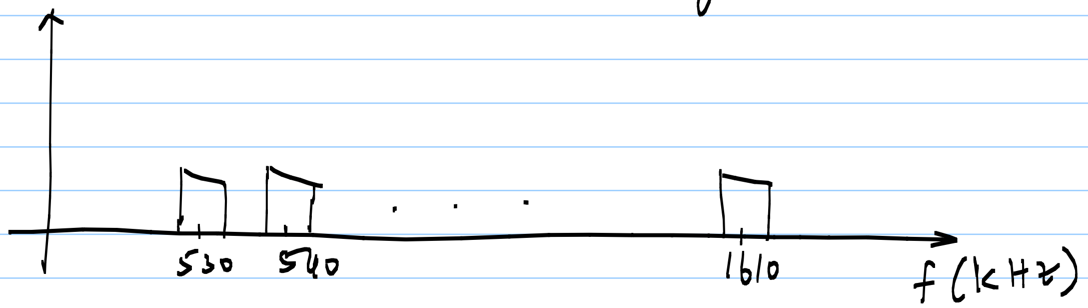
For easy IR filter design, we want large ω_{IF}

$\Rightarrow$ Motivates Double-conversion receivers and IR architectures

Proper frequency planning is an important step in the design of a transceiver to overcome these issues.

AM Radio example:

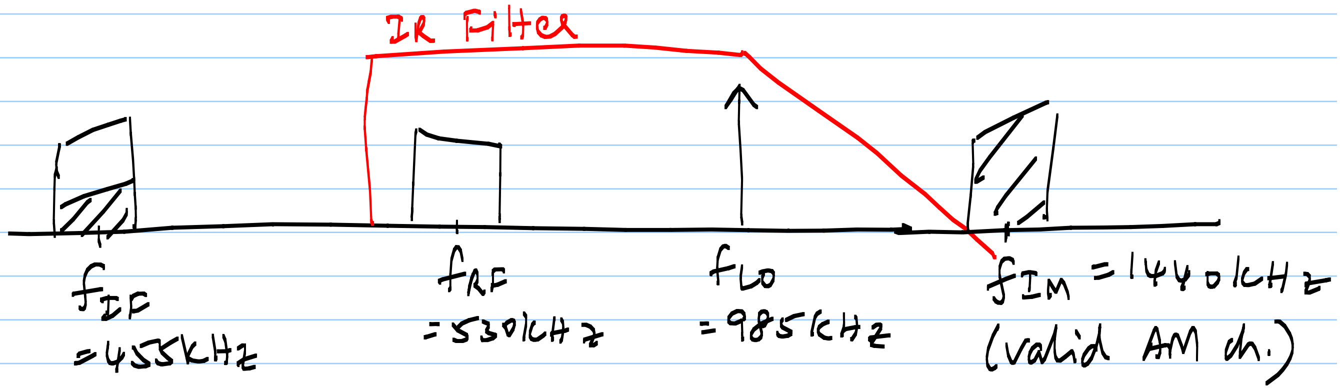
AM band – 530 kHz to 1610 kHz
– 109 channels
– channel spacing = 10 kHz



* What IF to choose?

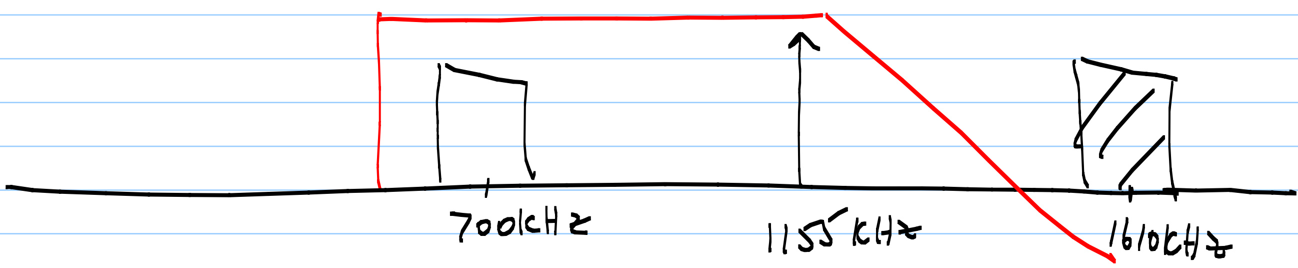
1) Suppose we choose $f_{IF} = 455$ kHz (actual IF in AM)

Assume we tune to channel 1 ; $f_{RF} = 530$ kHz



* IR filter tracks LO

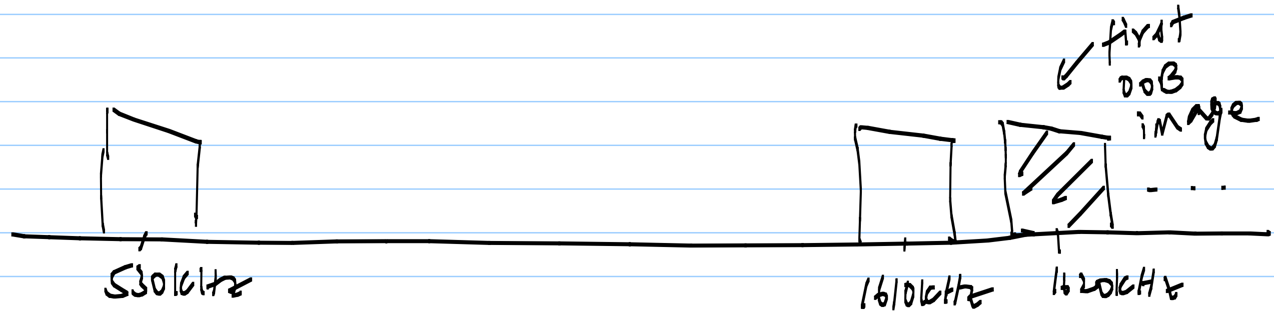
tune to channel $f_{RF} = 700$ kHz ⇒ $f_{IM} = 1610$ kHz



* Images are Out-of-band for channels $\geq 710\,kHz$

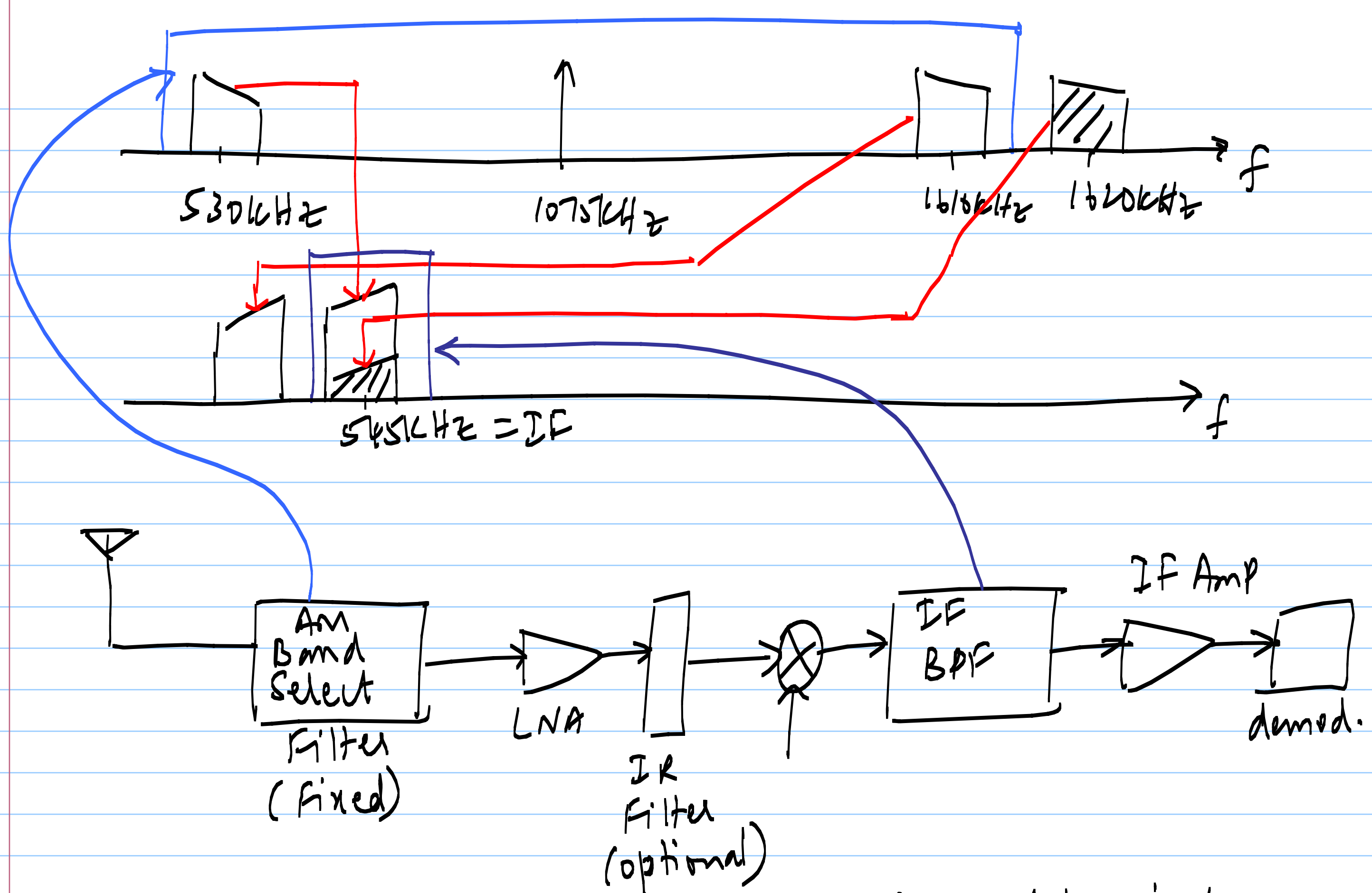
→ we can propose a better solution: choose f_{IF} so that all images are OOB

⇒ can use a fixed IR filter



choose $f_{IF} > \dfrac{1610 - 530}{2} = 540\,kHz$

e.g. $f_{IF} = 545\,kHz$



* We will come back to Tx & Rx Arch. later in the course ...

Low-side vs. high-side injection:

AM: $f_{ch.} = 530\,kHz - 1610\,kHz$

$IF = 455\,kHz$

High-side injection:

$f_{LO} - f_{RF} = f_{IF}$

$\Rightarrow f_{LO} = 985\,kHz$ to $2065\,kHz$

$\Rightarrow 1525\,kHz \pm 540\,kHz$

tuning range $= \pm 35.4\%$ ← much better (in this case)

Low-side injection:

$f_{RF} - f_{LO} = f_{IF}$

$f_{LO} = 75\,kHz$ to $1155\,kHz$

$= 615\,kHz \pm 540\,kHz$

tuning range $= \pm 87.8\%$

How do you represent such RF signals?

Bandpass signal representation:

1) Polar: $x(t) = a(t) \cdot \cos(2\pi f_c t + \phi(t))$

$a(t)$: AM component

$\phi(t)$: PM component

* used in "polar modulators" using PLLs
* signals are usually narrowband (e.g. GSM)

2) Cartesian : $x(t) = x_I(t)\cos(2\pi f_c t) - x_Q(t)\sin(2\pi f_c t)$

$$a(t) = \sqrt{x_I^2(t) + x_Q^2(t)} \quad \text{and} \quad \phi(t) = \tan^{-1}\frac{x_Q(t)}{x_I(t)}$$

* used in "image reject" receivers

3) Complex : $\tilde{x}(t)$ = complex envelope (i.e. low pass complex signal)

$$\tilde{x}(t) = x_I(t) + j\,x_Q(t)$$

Eulers identity : $e^{j2\pi f_c t} = \cos 2\pi f_c t + j\sin 2\pi f_c t$

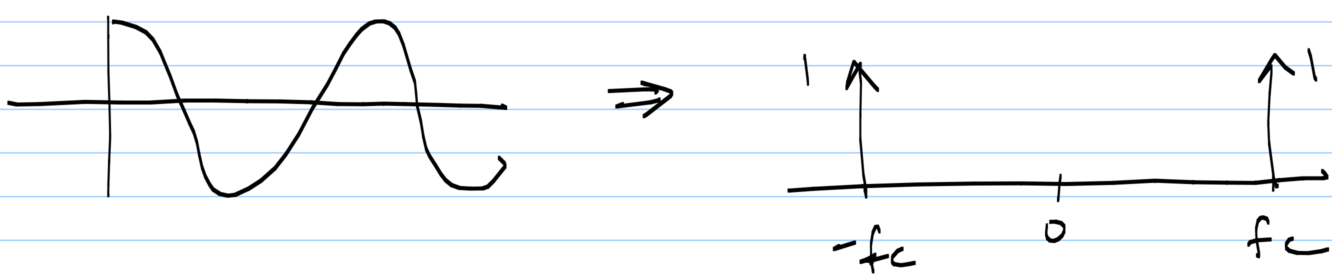
$$x(t) = \mathrm{Re}\left[\tilde{x}(t)\cdot e^{j2\pi f_c t}\right]$$

$$= x_I(t)\cos 2\pi f_c t - x_Q(t)\sin 2\pi f_c t$$

* similar to phasor representation
* Used in tranceivers having a mix of low-pass and bandpass signals

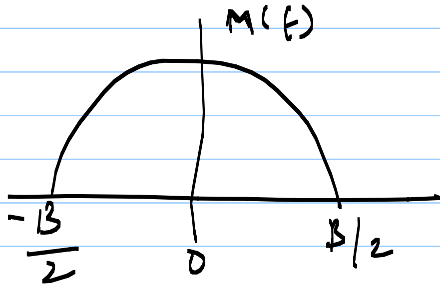
General Tx

Recall : $c(t) = \cos(2\pi f_c t) \underset{FT}{\Longrightarrow} C(f) = \dfrac{\delta(f-f_c) + \delta(f+f_c)}{2}$



Desired signal $m(t)$ = low pass signal of narrow BW $B \ll f_c$

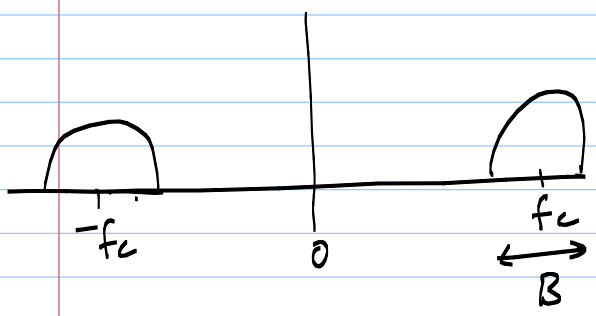
$M(f) \longrightarrow$



DSB-SC = double sideband - suppressed carrier

modulated signal

$$x(t) = m(t) \cdot c(t)$$
$$= m(t) \cos 2\pi f_c t$$
$$X(f) = M(f) * C(f)$$
$$= \frac{M(f-f_c) + M(f+f_c)}{2}$$



* each "sideband" has ½ the original power
* <u>Basic</u> <u>Mixer</u> <u>Operation</u>

Multiply in time domain = frequency shift in freq. domain

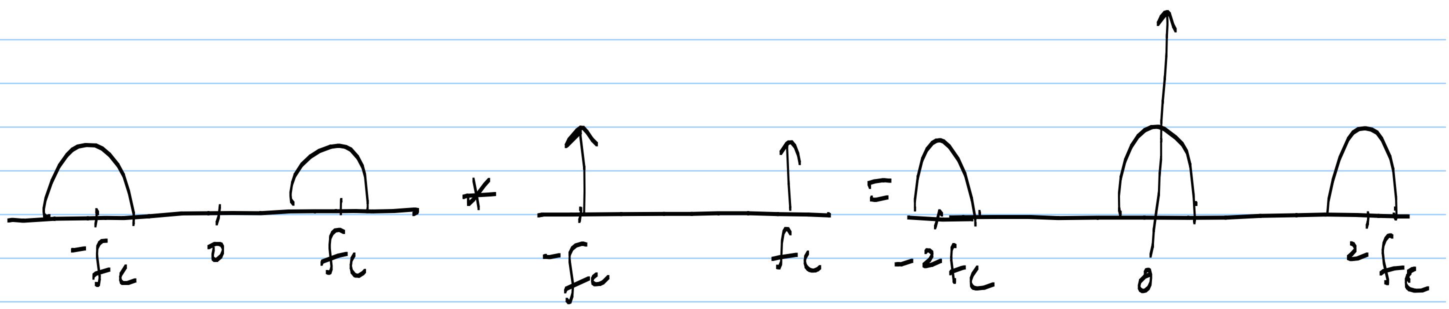
<u>General Rx</u>

received signal $r(t) = m(t) \cos 2\pi f_c t$

multiply $r(t)$ with a locally generated cosine of same frequency

$$r'(t) = r(t) \cdot \cos 2\pi f_c t$$
$$= m(t) \cdot \cos^2 2\pi f_c t$$
$$= m(t) \frac{(1 + \cos 2\pi f_c t)}{2}$$

"Direct-conversion" or "Homodyne" receiver



For a cartesian signal,

$$r(t) = x_I(t)\cos 2\pi f_c t - x_Q(t)\sin 2\pi f_c t$$

$$r(t)\cdot\cos 2\pi f_c t = x_I(t)\cos^2 2\pi f_c t - x_Q \sin 2\pi f_c t \cos 2\pi f_c t$$

$$= \frac{1}{2}x_I(t) + \frac{1}{2}x_I(t)\cos(2\cdot 2\pi f_c t)$$

$$+ \frac{1}{2}x_Q(t)\sin(2\cdot 2\pi f_c t)$$

$$r(t)\sin 2\pi f_c t = -\frac{1}{2}x_Q(t) + \frac{1}{2}x_I(t)\sin(2\cdot 2\pi f_c t)$$

$$+ \frac{1}{2}x_Q(t)\cos(2\cdot 2\pi f_c t)$$

Note: the 2^{nd} harmonic components need to be filtered out using an LPF