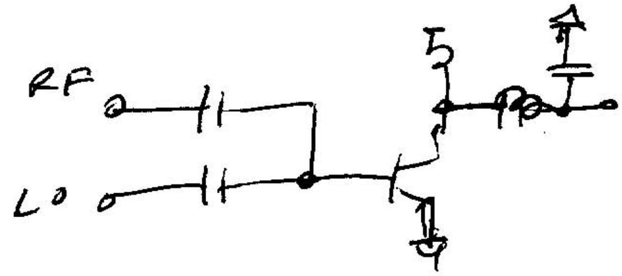
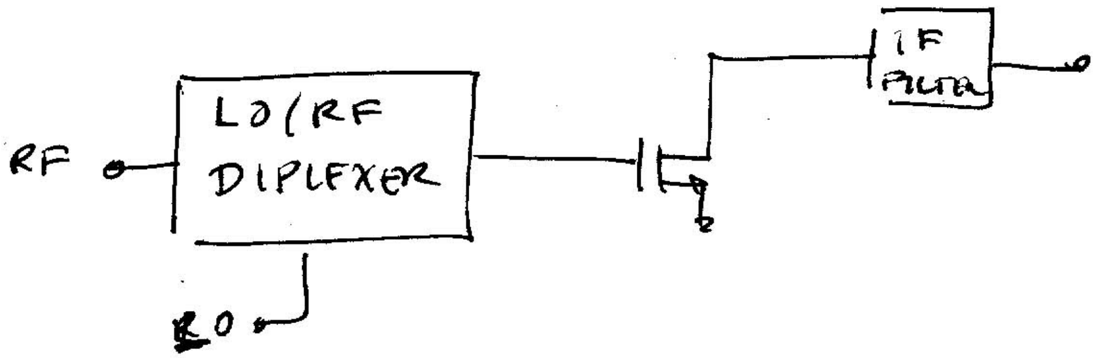
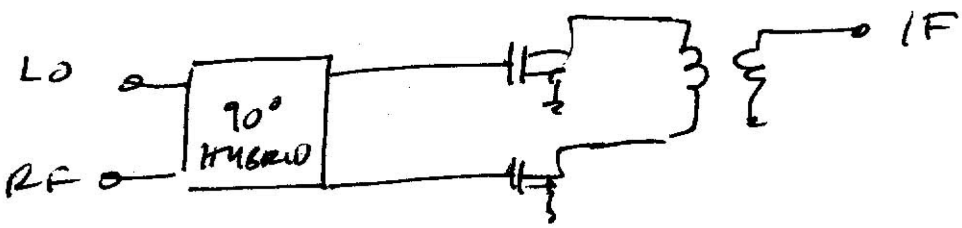


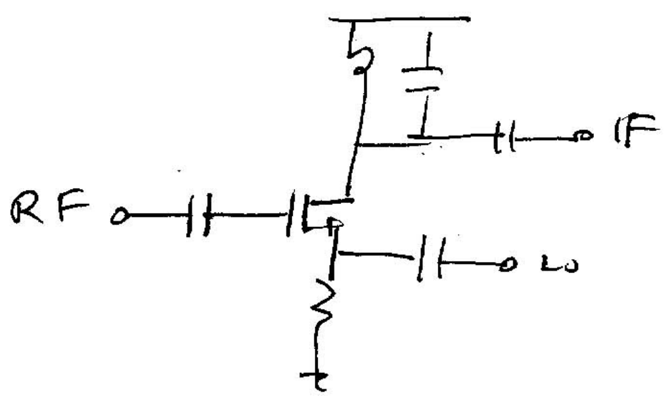
GATE DRIVEN MIXER



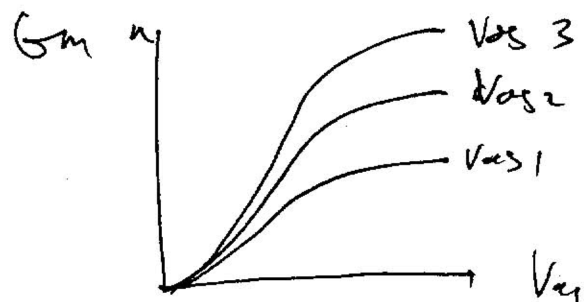


QUADRATURE BALANCED MIXER

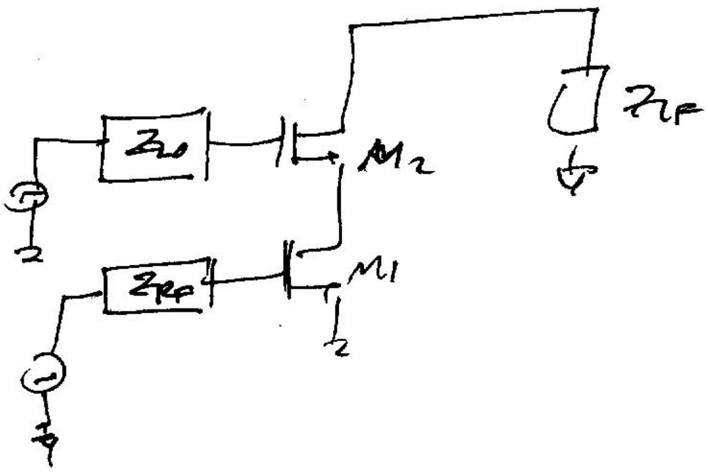
SOURCE DRIVEN MIXER



BETTER LO/RF ISOLATION BUT NOT GREAT



DUAL GATE MIXER

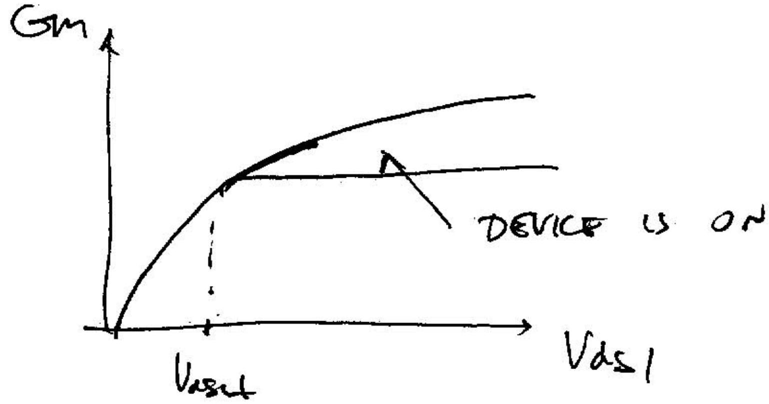


LO MODULATES THE Gm OF M1 BY CHANGING Vds

LO/RF ISOLATION GOOD

DON'T NEED TO COMBINE LO/RF SIGNALS

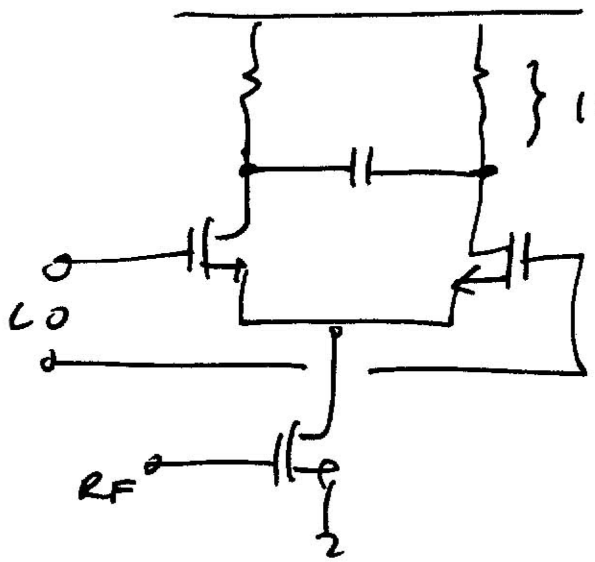
CONVERSION GAIN FROM M1



$$I_{ds} = \begin{cases} \mu C_{ox}\left(\frac{W}{L}\right)\left\{(V_{gs}-V_t)V_{ds} - \frac{V_{ds}^2}{2}\right\}\cancel{(1+\lambda V_{ds})} \\ \mu C_{ox}\left(\frac{W}{L}\right)\frac{1}{2}(V_{gs}-V_t)^2(1+\lambda V_{ds}) \end{cases}$$

$$G_m \cong \begin{cases} \mu C_{ox}\left(\frac{W}{L}\right)\left(\cancel{(V_{gs}-V_t)}\, V_{ds}\right)\cancel{V_{ds}\lambda} \\ \mu C_{ox}\left(\frac{W}{L}\right)(V_{gs}-V_t)(1+\lambda V_{ds}) \end{cases}$$

CURRENT COMMUTATING MIXERS (GAIN)



SWITCHING PAIR

TRANSCONDUCTANCE STAGE

MULTIPLY SIGLAL BY 0 & +1 → HAVE DC CONTENT

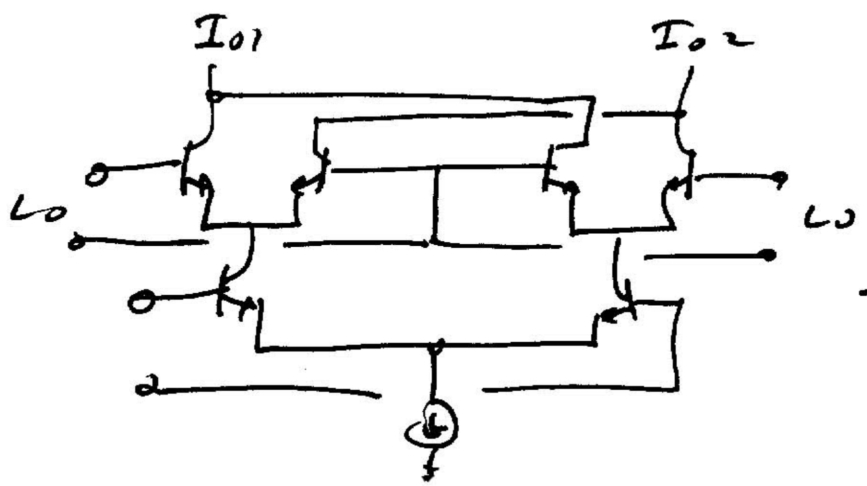
$A_V < \frac{2}{\pi} g_m R_L$ STRONG SWITCHING ASSUMP

LO & RF ISOLATION PRETTY GOOD

BUT LO APPEARS IN O/P

STRONG LO COULD SATURATE IF AMP (EVEN AFTER FILTERING)

DOUBLE BALANCED MIXER

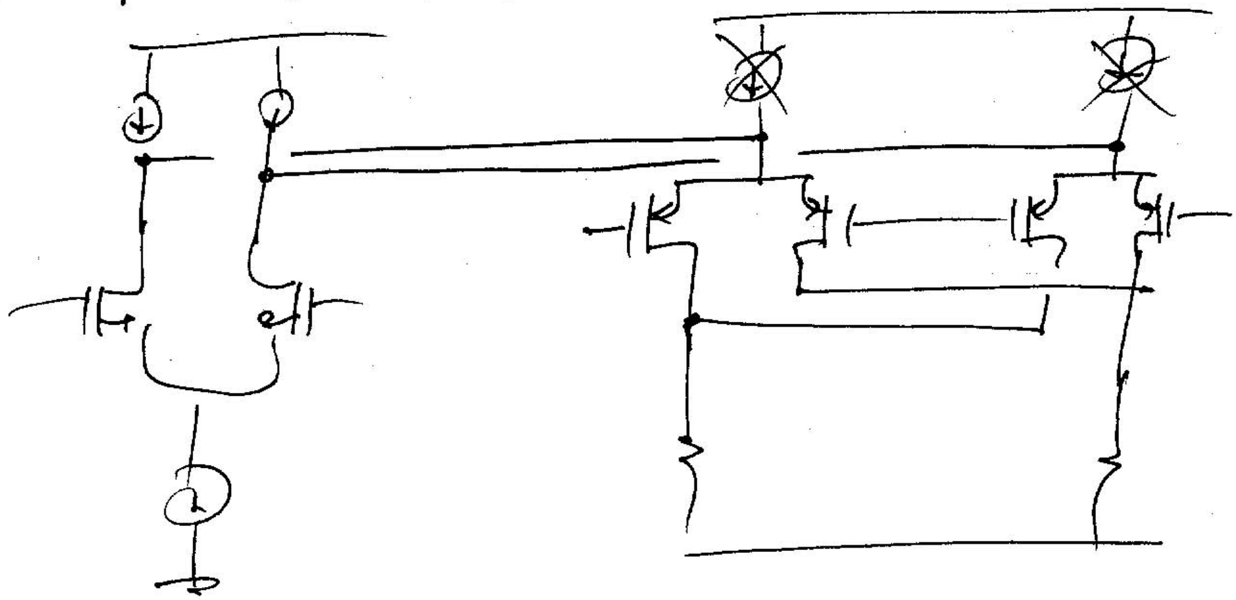


$I_0 = I_{01} - I_{02}$
$= (I_1 + I_3) - (I_2 + I_4)$

→ LO REJECTED UP TO MATCHING

CAN SHOW THAT FLICKER NOISE OF INPUT DEVICES IS UP-CONVERTED BUT FLICKER NOISE OF SWITCHING DEVICES CAN DEGRADE SNR AT IF.

OPTION 1: USE PMOS SWITCHING PAIR



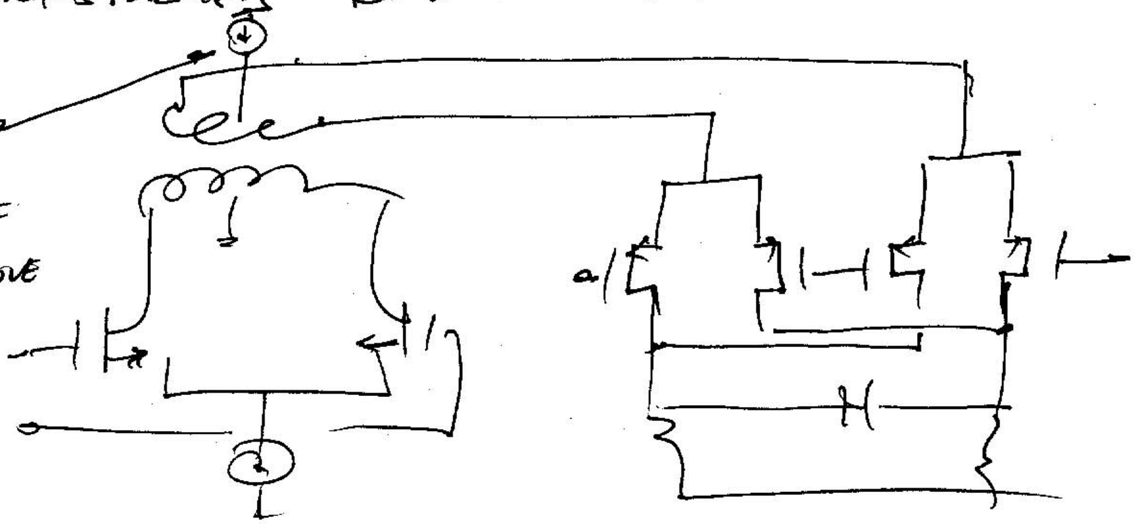
FOLDED DESIGN

NMOS INPUT ⇒ HIGH Gm

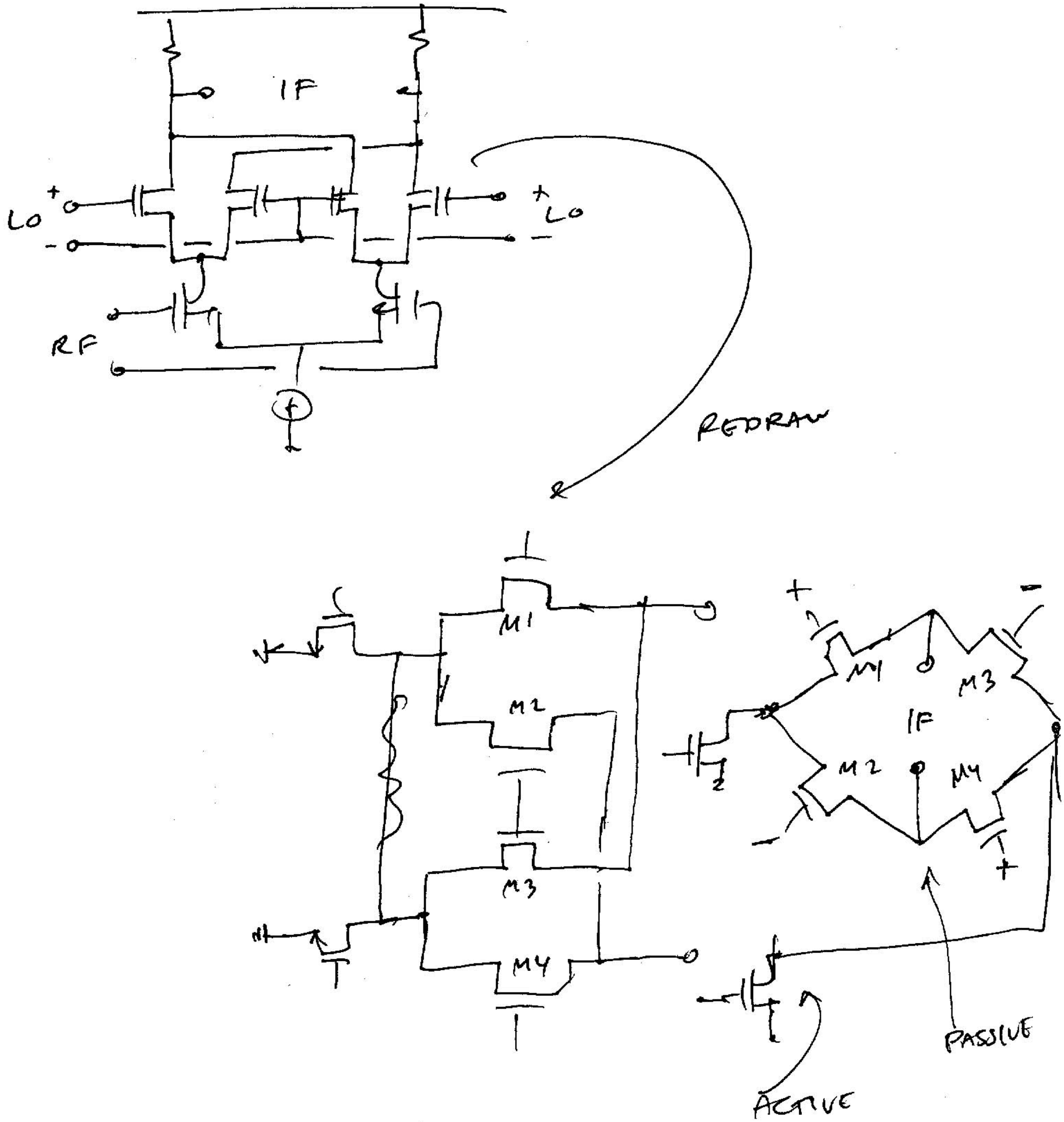
PMOS SWITCH ⇒ LOW FN

OR TRANSFORMER COUPLE: IMPROVED HEADROOM

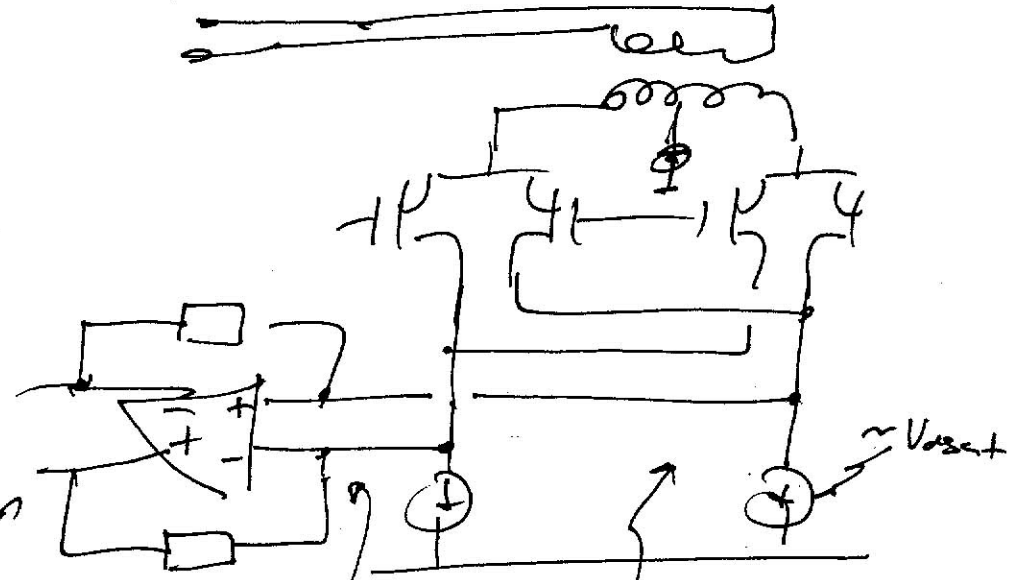
CAN ELIMINATE CURRENT TO IMPROVE PERF!



PASSIVE OR ACTIVE ?



IMPROVED HEADROOM #2: USE CURRENT O/P



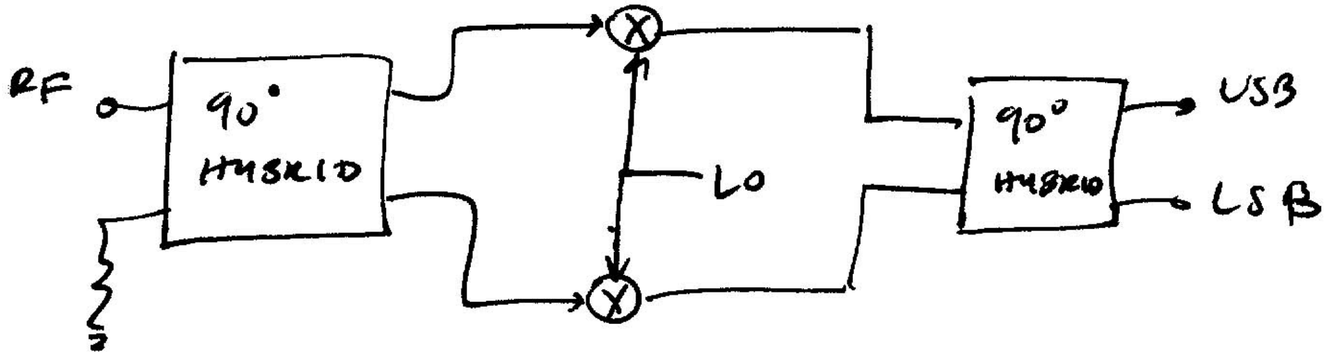
LARGE RAIL-TO-RAIL SWING

VIRTUAL GROUND

NEED COMMON-MODE FB

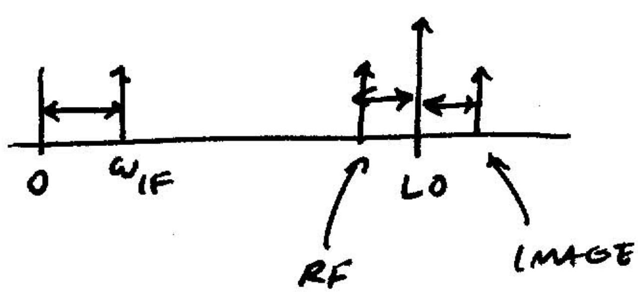
CAN FORM FIRST STAGE OF LPF (IF)

IMAGE REJECT MIXERS

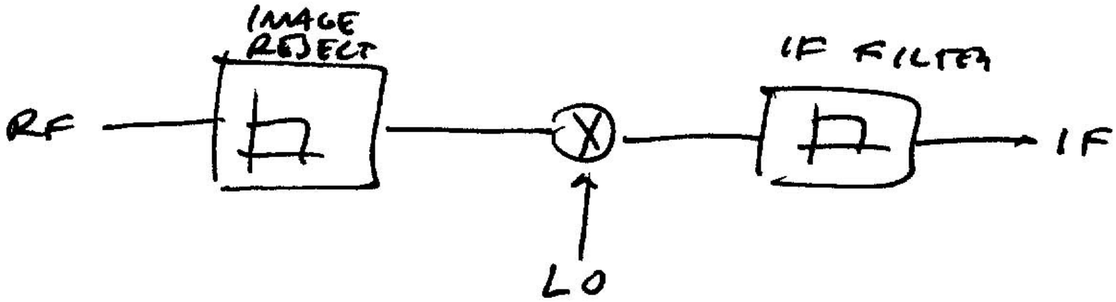


MIXER IS INHERENTLY SENSITIVE TO IMAGE FREQ:

$$\omega_{IF} = |\omega_{LO} \pm \omega_{RF}|$$

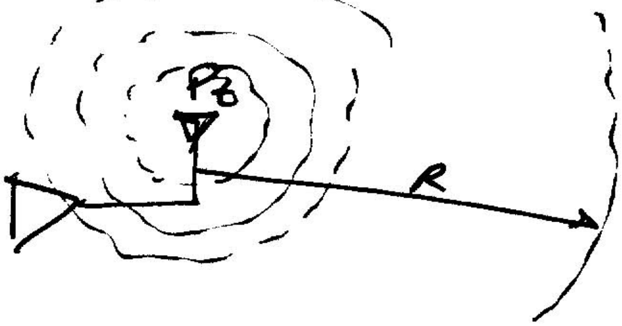


ONE OPTION IS TO FILTER THE IMAGE



BUT THE FREQ MIGHT BE TOO CLOSE

CONSERVATION OF ENERGY ARGUMENT:
IDEAL ISOTROPIC ANT RADIATES POWER RADIALLY WITH UNIFORM DENSITY



AT A DISTANCE R FROM SOURCE THE TOTAL POWER OVER SOLID ANGLE IS THE SAME AS TRANSMITTED ⇒

$$4\pi R_1^2 S_{R_1} = S_{R_2} 4\pi R_2^2$$

→ POWER DENSITY DROPS LIKE $1/R^2$

STATIC FIELDS DROP LIKE $1/R^2$ SO POWER DROPS LIKE $1/R^4$. <u>MUCH</u> FASTER THAN THE RADIATED FIELD.

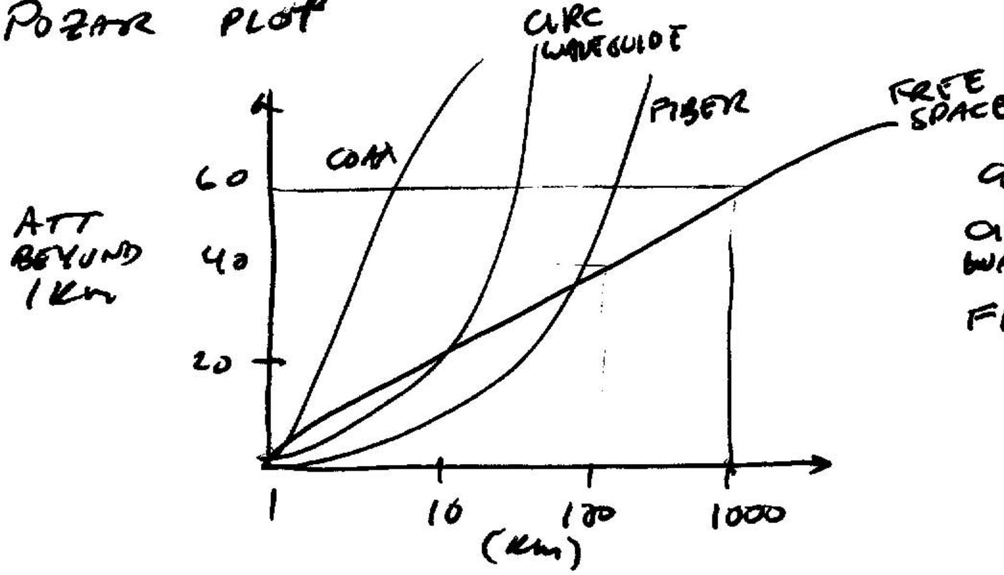
AT A DISTANCE $d \gg \lambda$ THE ~~ACCIDENT~~ ENERGY ~~RADIATION~~ IS DOMINATED BY ELECTRODYNAMIC RADIATION

ON A TRANSMISSION LINE:

$$\frac{P_2}{P_1} = e^{-\alpha(R_2 - R_1)}$$

MUCH FASTER THAN RADIATION!

POZAR PLOT



COAX: 60dB/km

CIRC WAVEGUIDE: 2dB/km

FIBER: 0.5dB/km

FOR 100dB ATTENUATION:

→ COAX HAS FEW KM RANGE

→ WAVEGUIDE HAS ~ 100km

→ FIBER ~100km

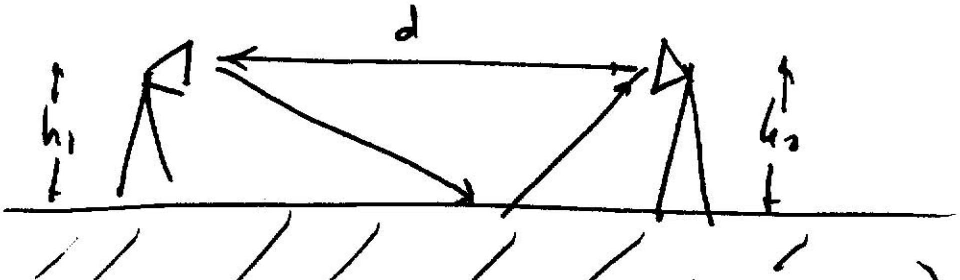
→ FREE SPACE ~ 100,000km!

LINE OF SITE PROPAGATION LIMITED BY CURV. OF EARTH

- REFL (GROUND)
- DIFF (EDGES)
- SCATT (FOLIAGE)
- ATTEN (RAIN)
- DOPPLER (MOVING)

$d \simeq \sqrt{15h}$ (km)

REFLECTIONS FROM EARTH INCREASE PROP LOSS:



PROP FACTOR $F = 2 \sin\left(\frac{k_0 h_1 h_2}{d}\right)$

OUT OF PHASE → $0 \leq F \leq 2$ ← IN PHASE

FOR $d \gg h$ THE FORMULA GIVES THE FOLLOWING SURPRISING RESULT

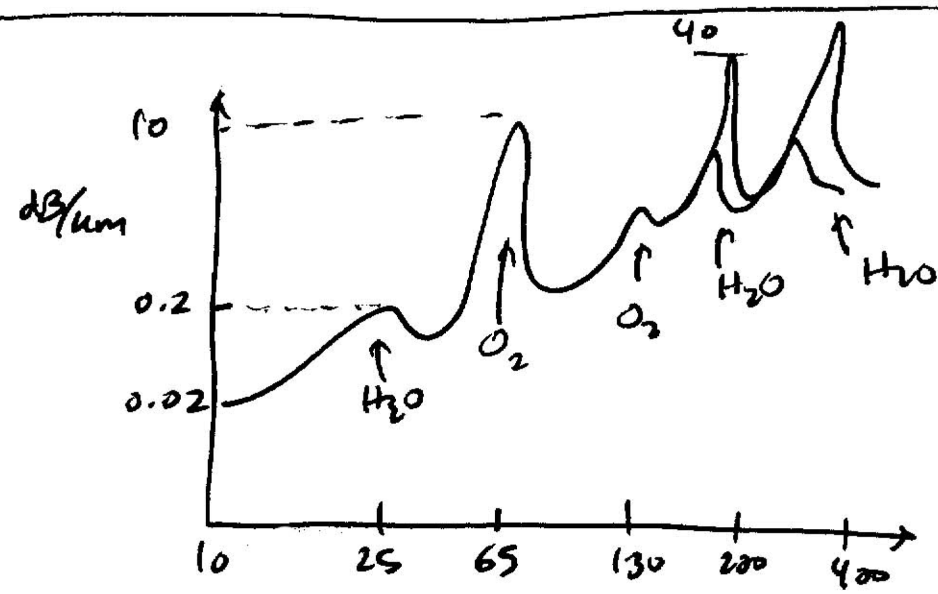
$$\frac{P_r}{P_t} \propto \frac{1}{R^4}$$

RECALL THAT FREE SPACE $\propto 1/R^2$

REALISTIC PROP. FACTOR PATH LOSS

FREE SPACE	2
URBAN	2.7–3.5
SHADOW URBAN	3–5
IN-BUILDING LOS	1.6–1.8
IN-BUILDING SHADOWED	4–6
FACTORY SHADOWED	2–3
RETAIL STORE	2.2
OFFICE – SOFT PARTITION	2-4

OTHER EFFECTS: LOSS TO ATMOSPHERE



BELOW 10GHz NO PROBLEM!

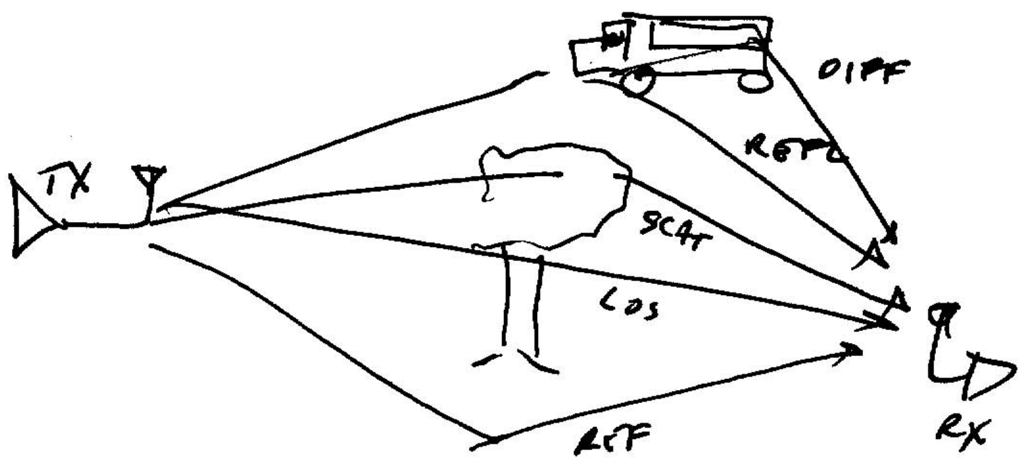
ATTENUATION DUE TO MATERIALS

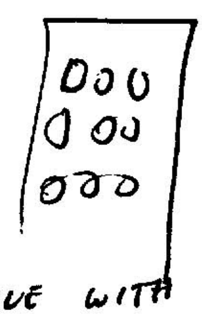
CONCRETE BLOCK WALL	1.3 GHz	13 dB
SHEET ROCK	9.6 GHz	2 dB
PLYWOOD	9.6 GHz	4 dB
CONCRETE WALL	1.3	8–15
CHAIN LINK FENCE	1.3	5–12
LOSS BETWEEN FLOORS	1.3	20–30
CORNER IN CORRIDOR	1.3	10–15

~~FADING~~

MULTI-PATH PROPAGATION

TIME VARYING "CHANNEL"





SINCE SIGNALS ARRIVE WITH APPARENTLY RANDOM PHASE, SIGNAL IS SUBJECT TO FADING

RAYLEIGH FADING

$$v(t) = \sum V_n \cos(\omega t + \phi_n)$$

$$= x(t)\cos\omega t - y(t)\sin\omega t$$

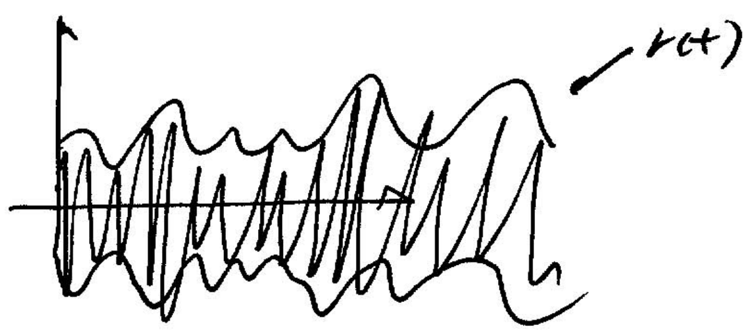
$$x(t) = \sum^{n} V_n \cos\phi_n \qquad y(t) = \sum^{n} V_n \sin\phi_n$$

GAUSSIAN WITH ZERO MEAN

$$V(t) = r(t)\cos(\omega t + \theta(t))$$

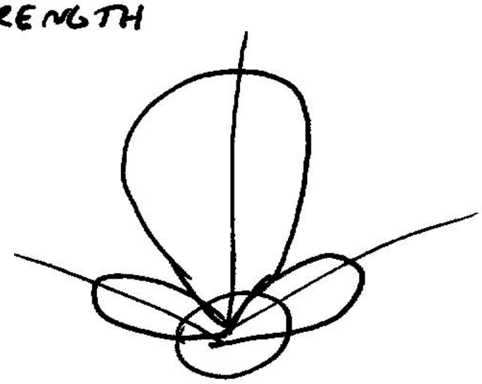
$$f_{r\theta}(r,\theta) = \frac{e^{-r^2/2\sigma^2}}{2\pi\sigma^2} \qquad 0 \le r \le \infty, \quad 0 \le \theta \le 2\pi$$

$$f_r(r) = \frac{r e^{-r^2/2\sigma^2}}{\sigma^2} \qquad 0 \le r < \infty$$



FOR ANTENNAS

RADIATION PATTERN : ~~GAIN~~ NORMALIZE GAIN AS A FUNCTION OF (θ, ϕ) ... OR FAR-ZONE FIELD STRENGTH



DIRECTIVITY :

$$D = \frac{U_{max}}{U_{av}}$$

RAD INTENSITY IN MAIN BEAM

RADIATION EFFICIENCY :

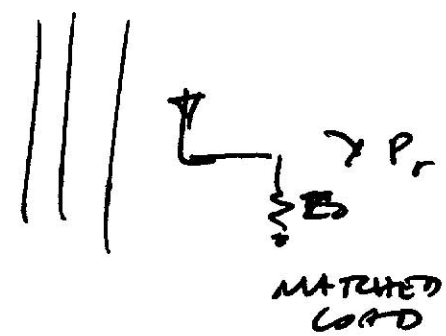
$$\eta = \frac{P_{rad}}{P_{in}} = 1 - \frac{P_{loss}}{P_{in}}$$

OHMIC LOSSES

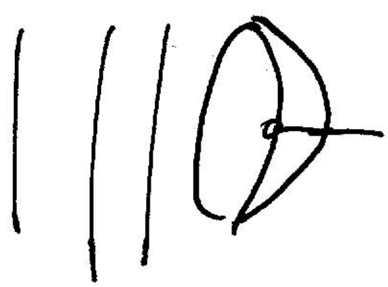
EFFECTIVE AREA :

$$P_r = S \cdot A_{eff}$$

$$A_{eff} = \frac{D\lambda^2}{4\pi}$$



$A_{eff} \cong$ PHYSICAL APERTURE AREA IF ANTENNA IS LARGE ... BUT FOR ELECTRICALLY SMALL ANTENNAS IT'S A MATH. QUANTITY



FRISS EQ:

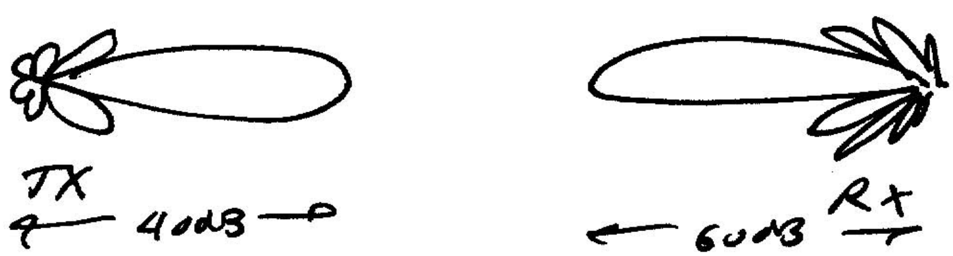
$$S_{avg} = \frac{P_t}{4\pi R^2} \quad W/m^2$$

$$P_r = A_{eff}\, S_{avg} = \frac{G_t P_t A_e}{4\pi R^2} \quad W$$

$$= \frac{G_t G_r \lambda^2}{(4\pi R)^2} P_t$$

VERY PHYSICAL EXPLANATION: $A_{eff} \propto \lambda^2$

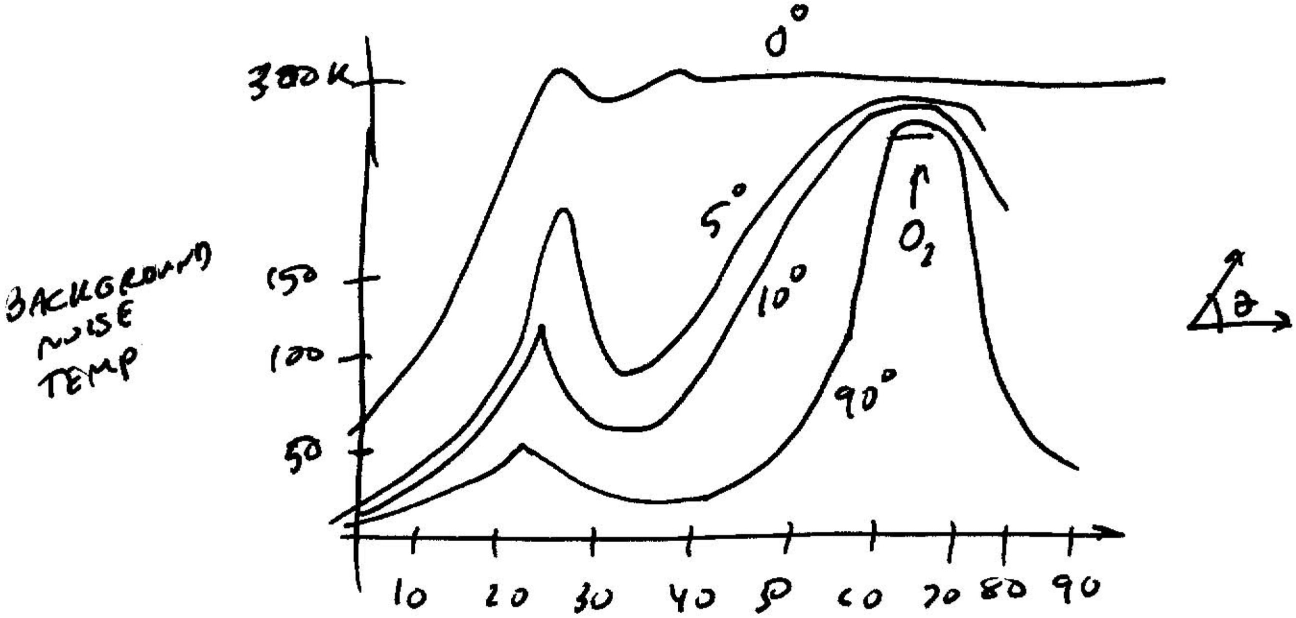
FOR A DISTANCE R, SURFACE AREA IS $\propto R^2$
SO WE INTERCEPT $(\lambda/R)^2$ FRACTION OF
ENERGY X GAIN FACTORS:



DIRECTIVE ANTENNAS DIRECT ENERGY IN DESIRED DIRECTION.

NOISE: ANTENNA NOISE TEMP DEPENDS ON WHAT ITS LOOKING AT! (AND FREQ)

SKY 3-5K (ZENITH)
SKY 50-100K (TOWARDS HORIZON)
GROUND 290-300K



SNR AT RECEIVER INPUT:

$$S_i = \frac{G_r G_t P_t \lambda^2}{(4\pi R)^2}$$

$$N_i = k T_A B$$

$$\left(\frac{S}{N}\right)_i = \underbrace{\left(\frac{G_r}{T_A}\right)}_{\text{GOOD METRIC FOR ANTENNA}} \frac{G_t P_t \lambda^2}{kB(4\pi R)^2}$$

RADIATION RESISTANCE:

$$P_r = \frac{1}{2} I_0^2 R_r$$

SMALL DIPOLE $\quad R_r = 20\pi^2 \left(\frac{L}{\lambda}\right)^2$

$$X = \frac{-60\lambda}{\pi L}\left(\ln\left(\frac{L}{a}\right) - 1\right)$$

$$R_{loss} = \frac{R_s L}{6\pi a}$$

→ WANT BIGGER ANTENNA TO INCREASE
R_r → EASIER TO POWER MATCH
→ MORE EFFICIENT RADIATOR
→ LESS NOISY RX

SAY WE USE A 1cm ANTENNA TO COMM AT
10 MHZ. $a = 0.01\,\text{cm}$
$\sigma = 5.8 \times 10^7$ Cu

$$R_s = \sqrt{\frac{\omega\mu}{2\sigma}} = \sqrt{\frac{\pi\, 4\pi \times 10^{-7}\, 10 \times 10^6}{2 \cdot 5.8 \times 10^7}} = .6\,m\Omega$$

$$R_{loss} = \frac{R_s L}{6\pi a} = 3\,m\Omega$$

$$R_{rad} = 20\pi^2 \left(\frac{L}{\lambda}\right)^2 = 22\,\mu\Omega$$

$$\eta = 0.7\,\%$$

→ MUST USE HIGHER FREQ FOR EFF COMM

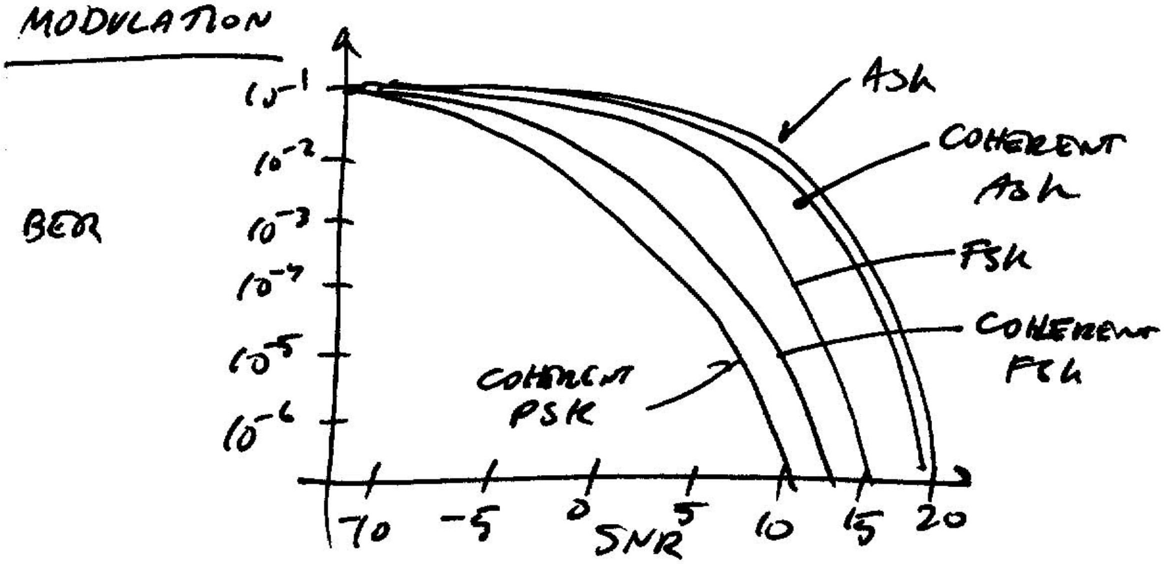
→ IF WE INPUT MATCH ANTENNA / LNA
$R_{in} \cong 0$ CAPACITIVE (OR INDUCTIVE FOR LOOP)

NOISE DOMINATED BY LOSS RESISTOR

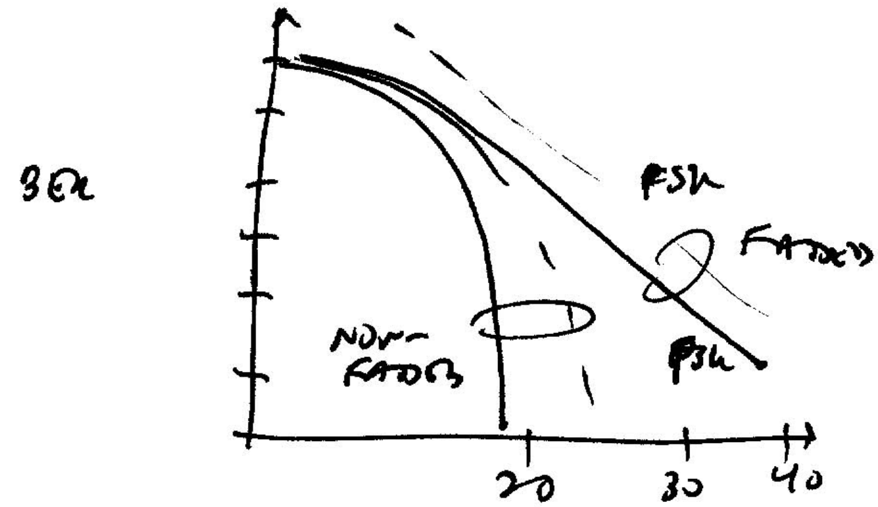
↘ INPUT REFER NOISE OF AMP

$$R_n \sim 1\Omega \gg R_{loss} \gg \cancel{R_{ANT}}\ R_r$$

MODULATION



THIS ASSUMES NO FADING!



THIS LIMITS RANGE OF WIRELESS SYSTEM!

CELL PHONE LINK BUDGET   2GHz, 1km

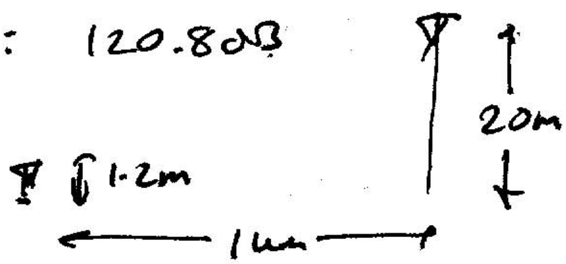
TX POWER = 25 dBm (300mW)

ANT GAIN = 2.4 dB

1km LINK PATH LOSS

$$\mathcal{L} = \frac{\lambda^2}{(4\pi R)^2} = +98.5 \text{ dB}$$

URBAN PATH LOSS: 120.8 dB
(INDOOR)



$$\begin{array}{llllllll} & & 2.5 & & 25 & & & 10\text{ dB} \\ \text{RX SIG} & = & G_{RX} & + & 30\text{ dBm} & - & 121\text{ dB} & + \text{ SHADOW LOSS} \end{array}$$

$= \cancel{-99 \text{ dBm}}$ -103.5

NOISE POWER = − 174 dB/Hz

BW = 200kHz = 53

RX NOISE = −121 + 5dB = − 116 dBm

NF = 5dB

SNR = 12 dB