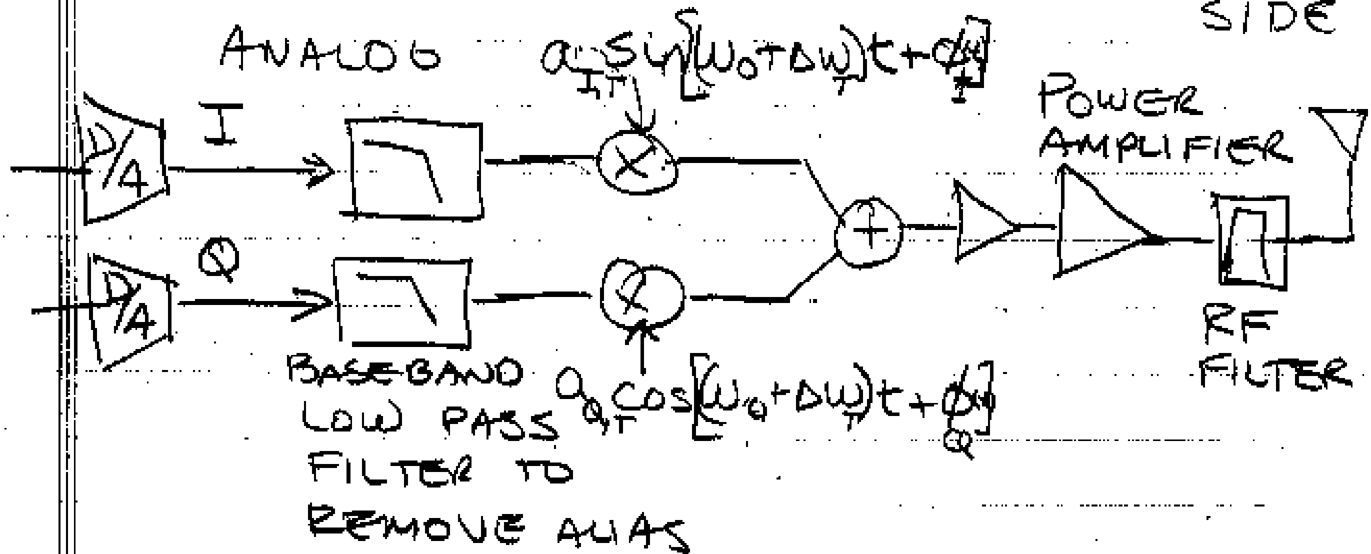
ANALOG IMPAIRMENTS (CONT) (11)

NOW BACK TO THE ANALOG / CHANNEL BLOCK - TRANSMIT SIDE



TX IMPAIRMENTS:

* a) I Q MISMATCH

a) DIFFERENT GAINS IN EACH PATH

$a_I \neq a_Q$

b) PHASE SHIFT NOT EXACTLY 90°

$\bar{\phi}_I \neq \bar{\phi}_Q$ (AVERAGE VALUES)

* b) PHASE NOISE

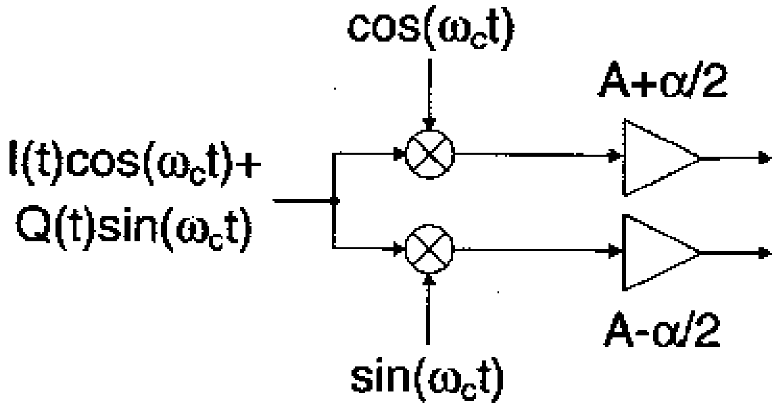
TIME VARIATION IN PHASE

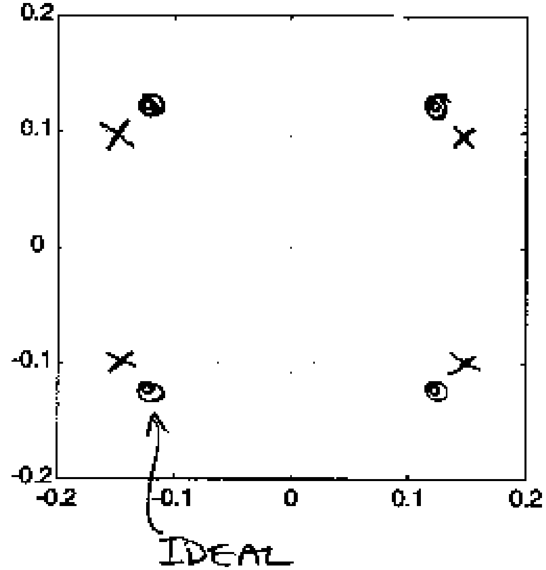
$\phi_I(t), \phi_Q(t)$

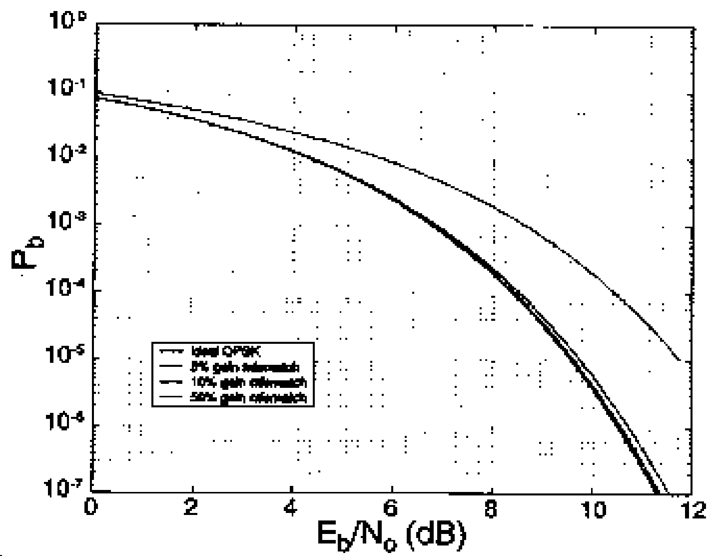
* c) NON-LINEARITIES IN POWER AMPLIFIER

d) BASEBAND & RF FILTER RESPONSES

I/Q Gain Mismatch

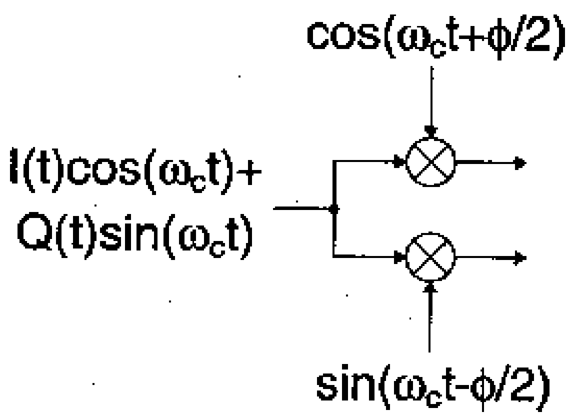


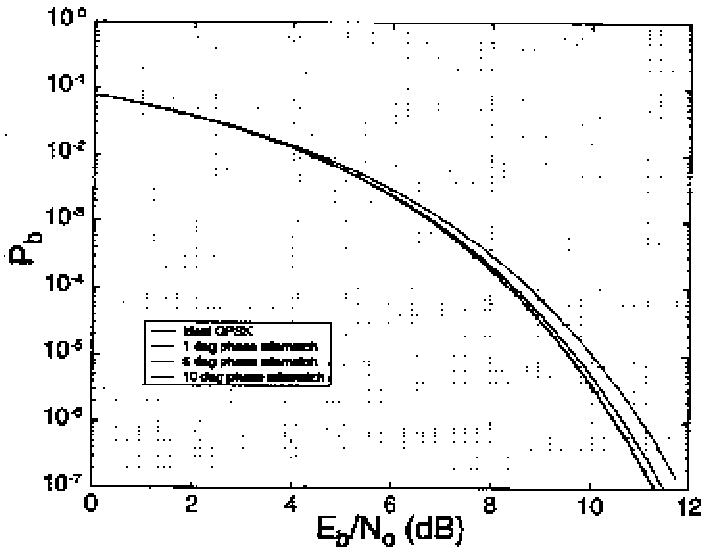


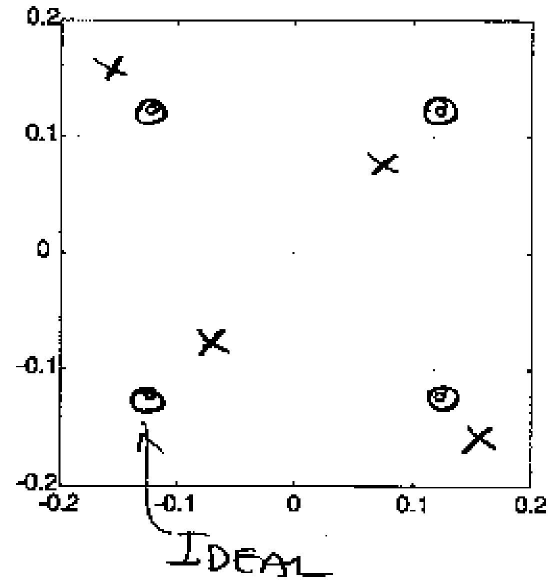


- **Gain mismatch results in BER degradation**

I/Q Phase Mismatch

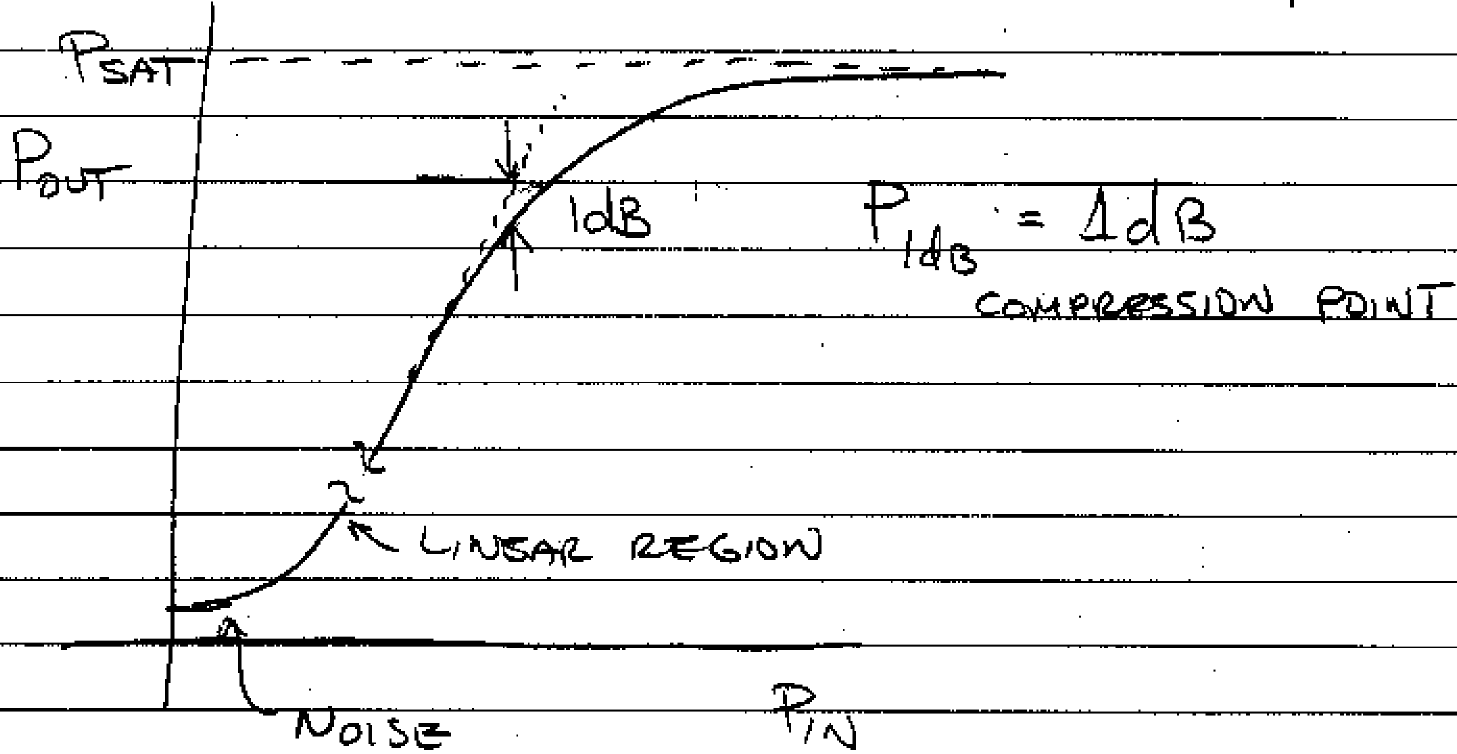






- **Phase mismatch results in BER degradation**

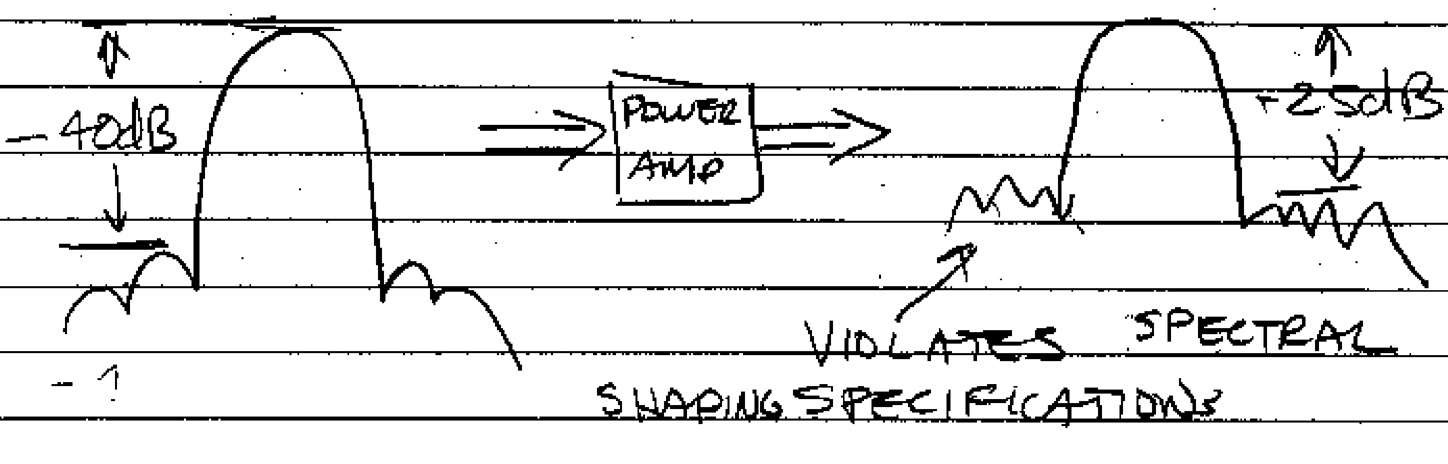
POWER AMPLIFIER NON-LINEARITY



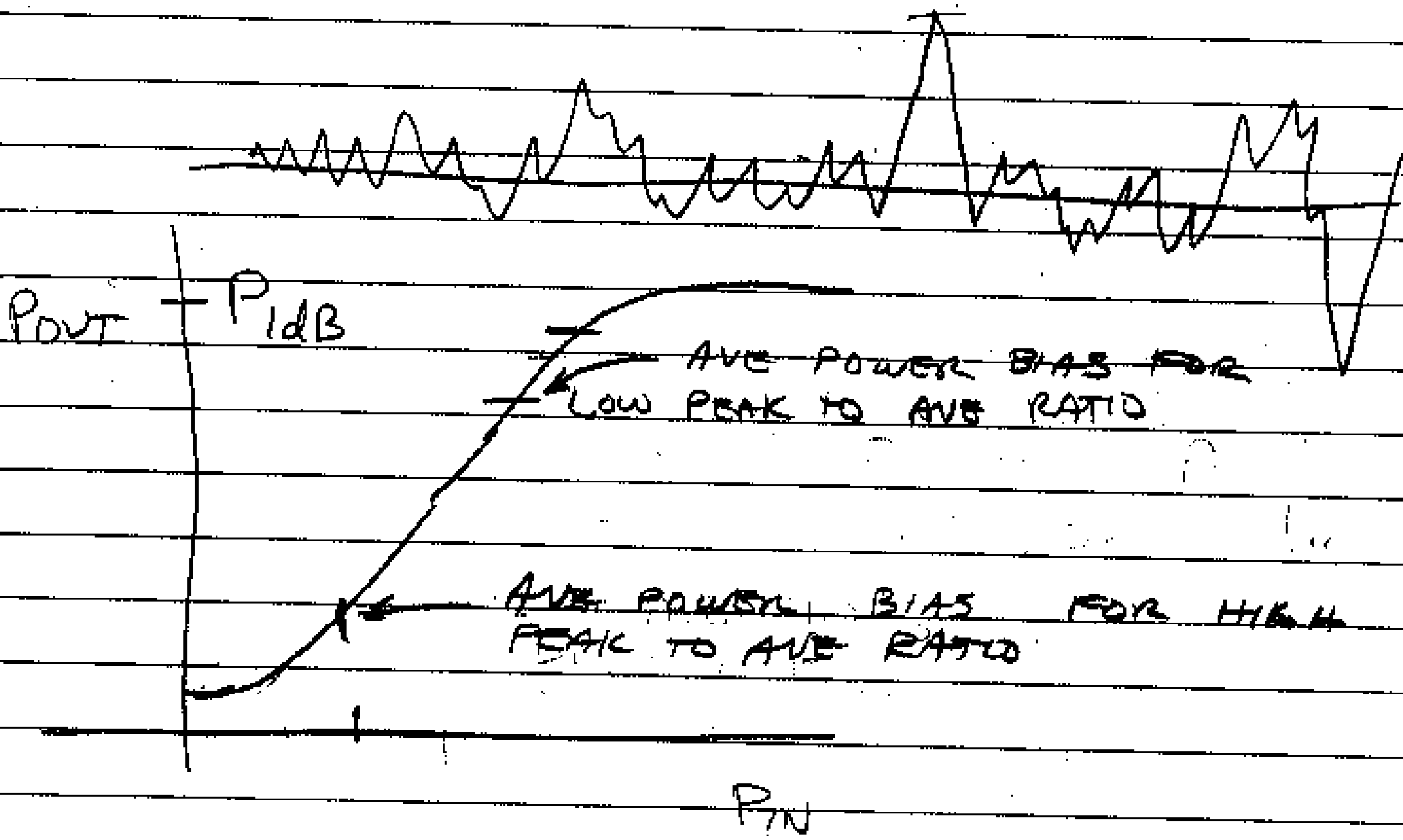
P_{SAT} DEFINES MAXIMUM POSSIBLE POWER OUT OF POWER AMP.

P_{1dB} DEFINES EDGE OF LINEAR REGION

SPECTRAL REGROWTH FROM DISTORTION



PARTICULARLY BAD FOR WAVEFORMS WITH HIGH PEAK-TO-AVERAGE RATIOS



EFFICIENCY = η = $\frac{P_{OUT}}{P_{DC}}$ ← RF POWER, ← POWER FROM SUPPLIES

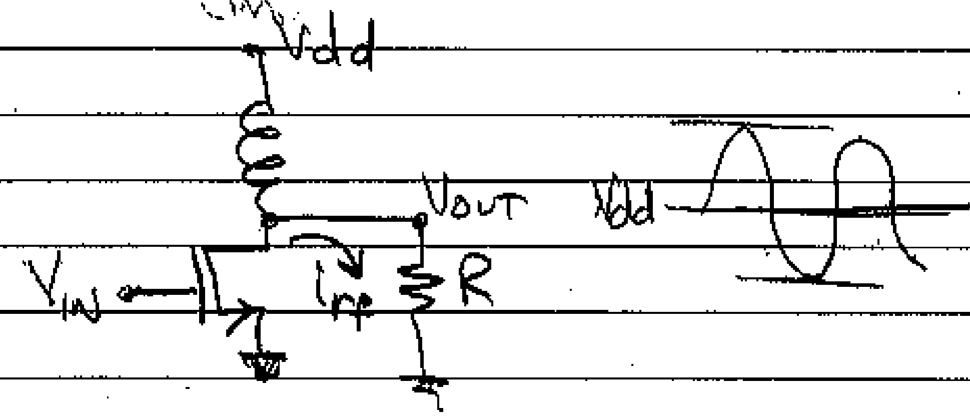
$$P_{OUT} = \frac{i_{rf}^2 R}{2}$$

$$P_{DC} = i_{rf} V_{dd}$$

$$\eta = \frac{\frac{i_{rf}^2 R}{2}}{i_{rf} V_{dd}} = \frac{i_{rf} R}{2 V_{dd}}$$

ABSOLUTE MAX EFFICIENCY IS 50% WHEN $i_{rf} R = V_{dd}$ (NOT ACHIEVABLE)

TYPICAL POWER AMP

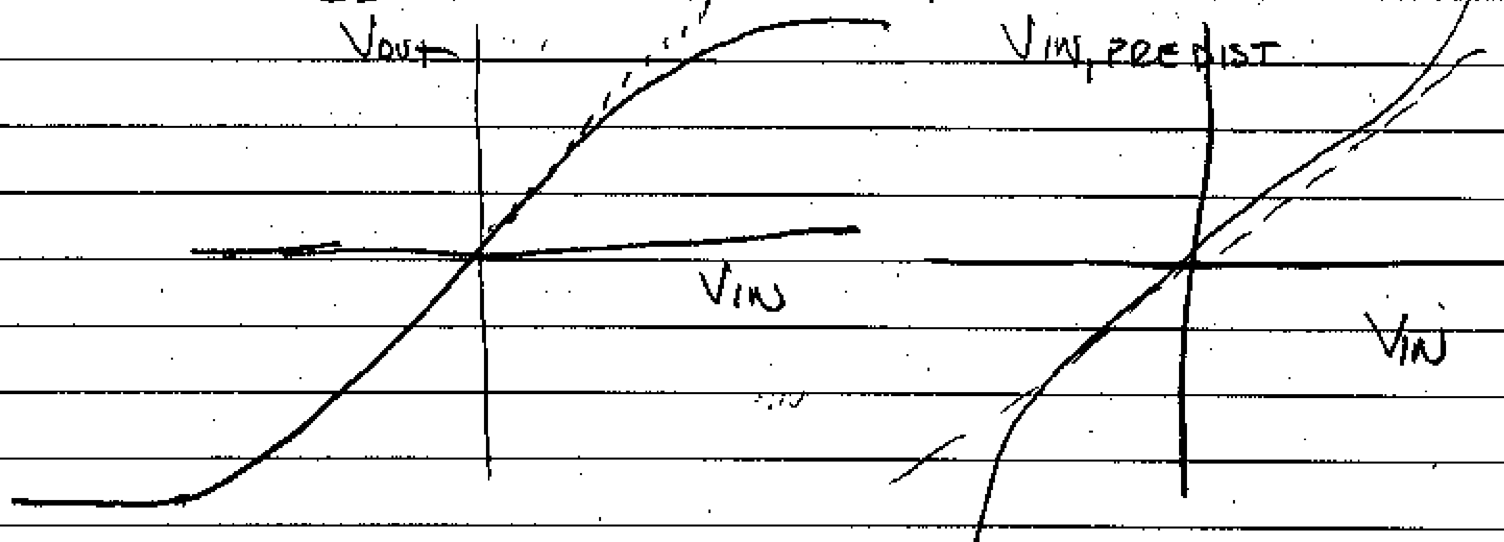


IF AVERAGE $i_{rf} R = .1 V_{dd}$ TO KEEP IN LINEAR REGION (DURING PEAKS), THEN THE EFFICENCY IS

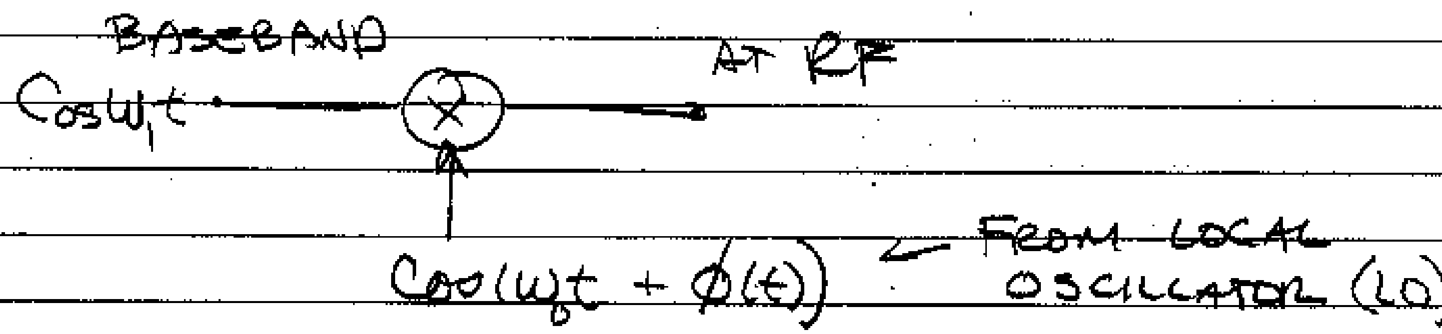
$$\eta = \frac{.1 V_{dd}}{2 V_{dd}} = 5\%$$

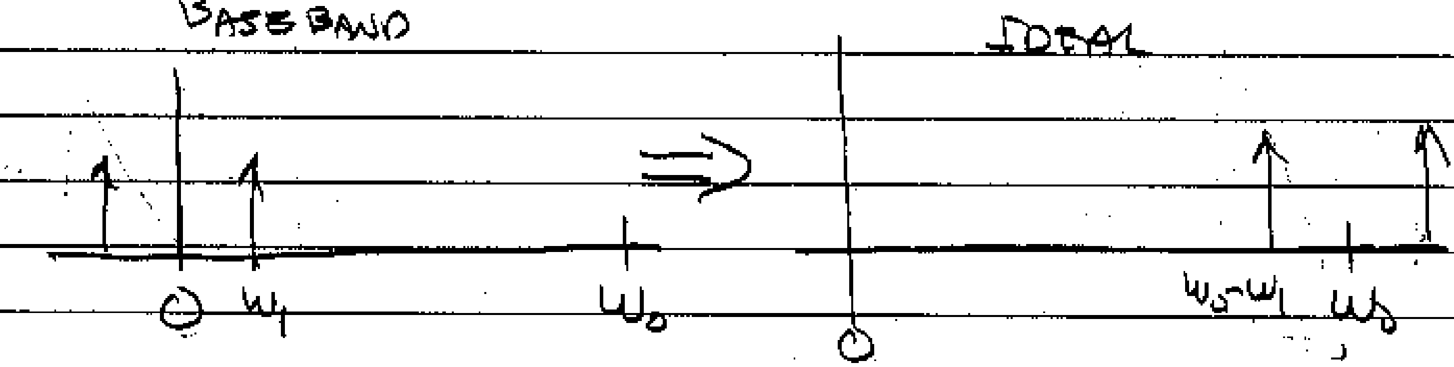
THIS IS TYPICAL FOR HIGHLY LINEAR TRANSMITTERS.

NEED TO PREDISTORT

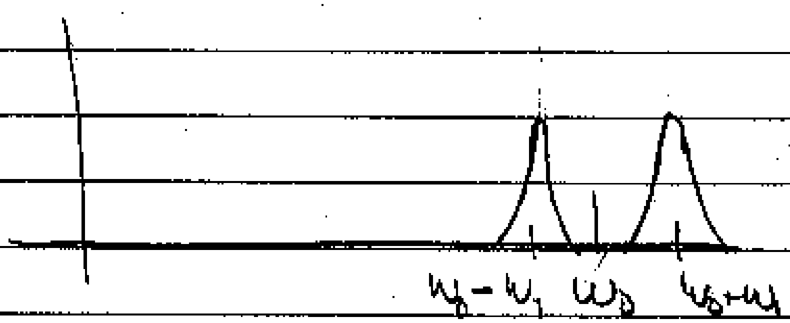


PHASE NOISE



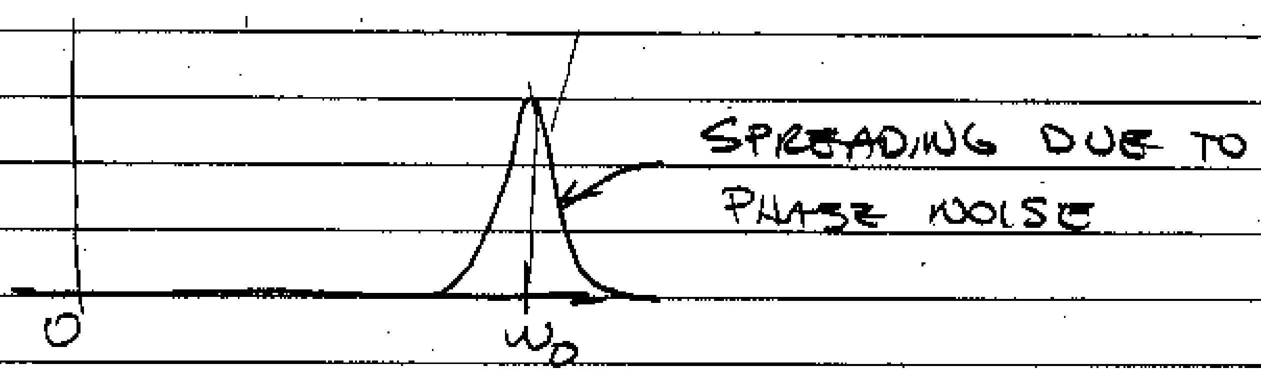


ACTUALLY WE GET

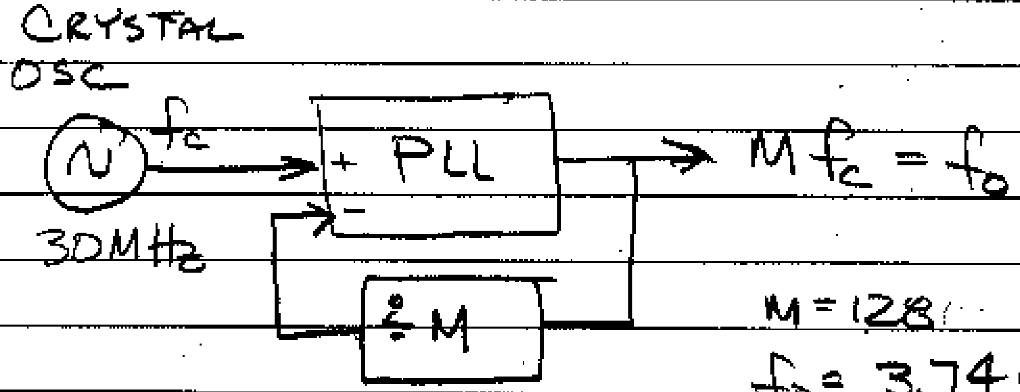


WHAT WENT WRONG?

THE LO ACTUALLY LOOKS LIKE



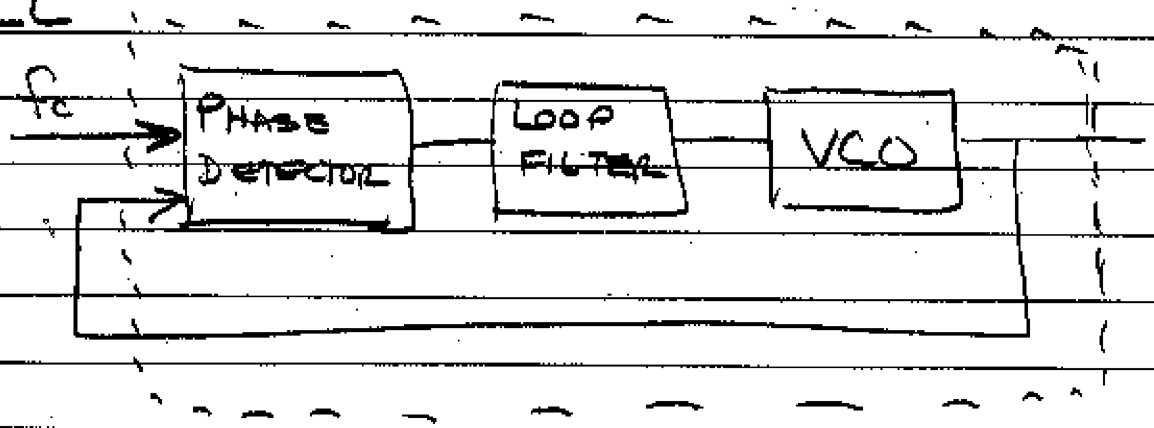
HOW DO WE GENERATE THE CARRIER FREQUENCY ...



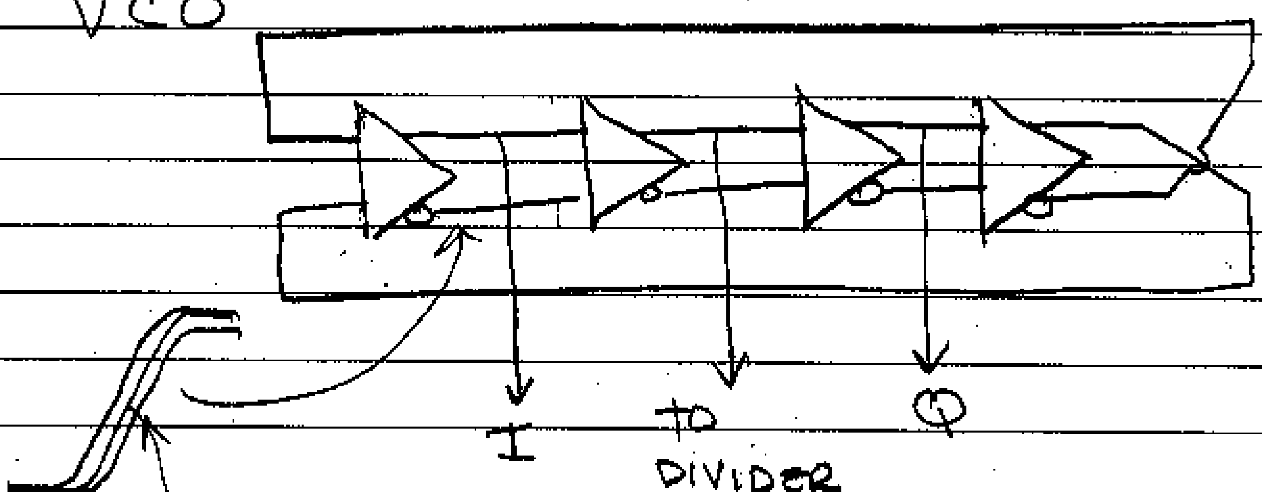
$M = 128$

$f_o = 3.74\,GHz$

PLL

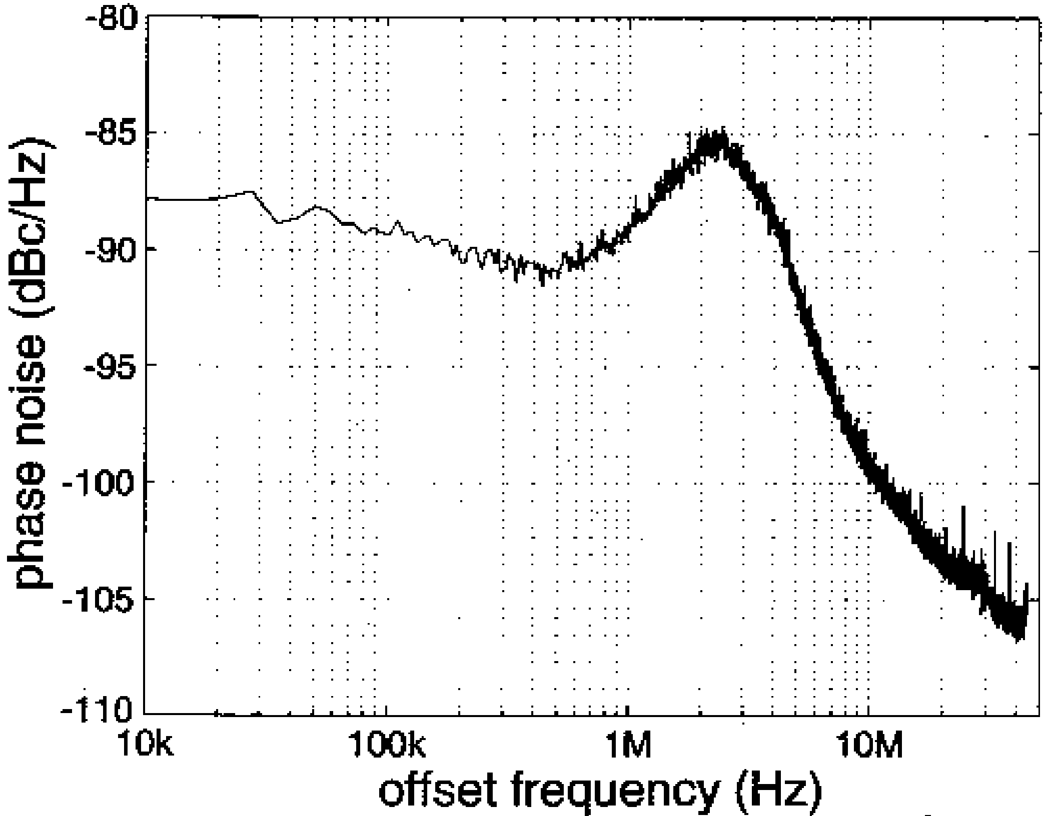


VCO



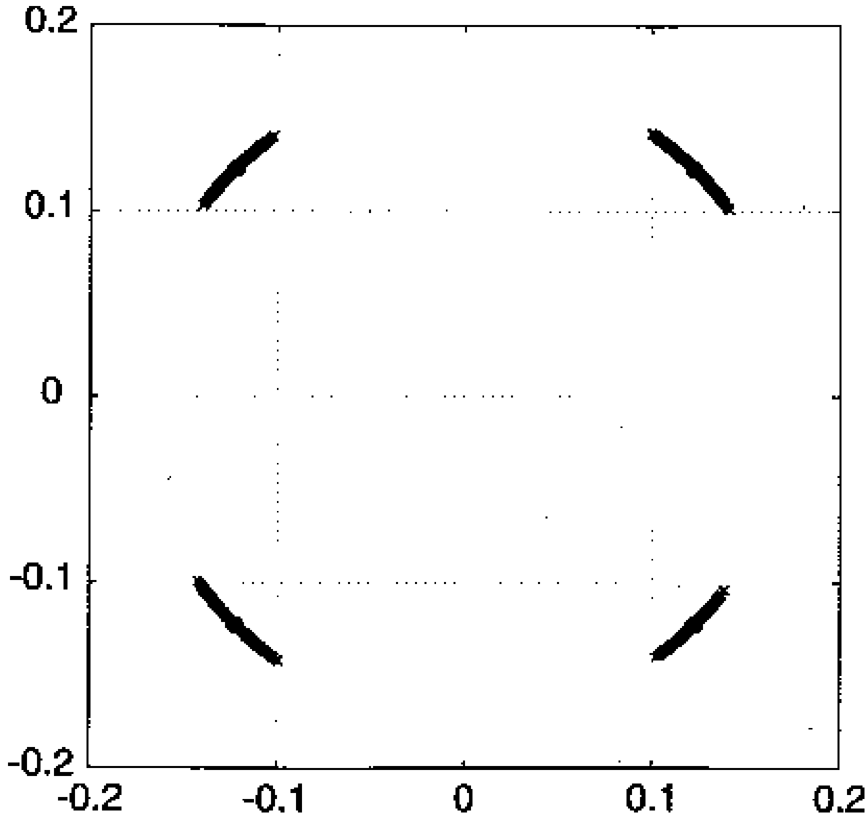
JITTER IN THESE TRANSITIONS CAUSES PHASE NOISE

Frequency Synthesizer Phase Noise



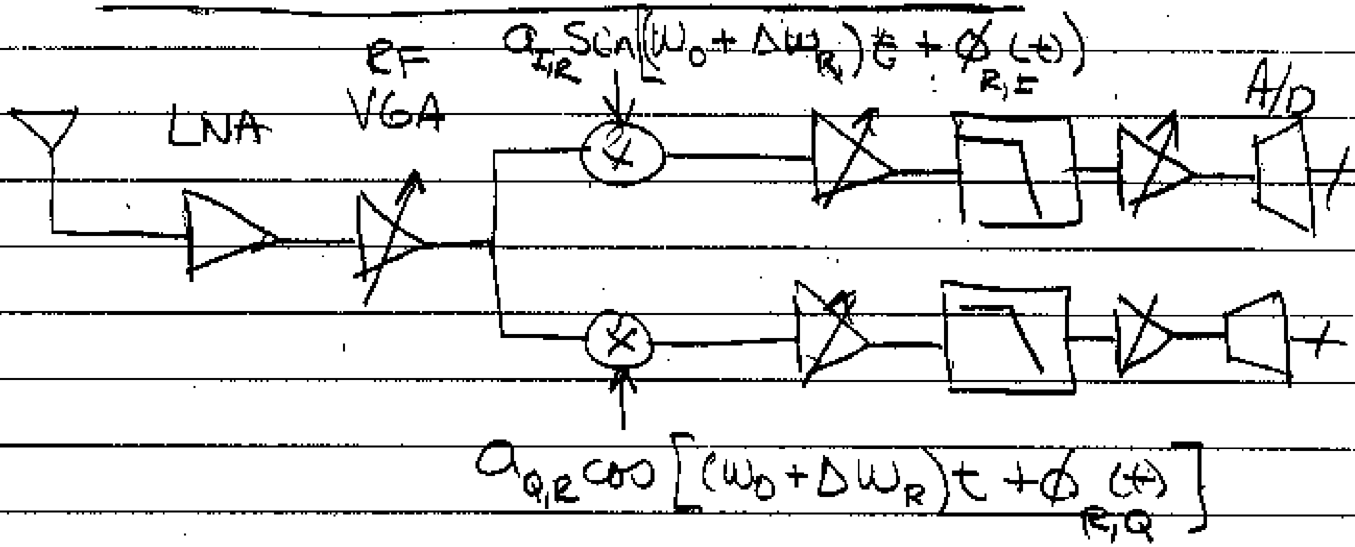
- -85 dBc/Hz @ 2.5 MHz
  (VERY HIGH

RMS Phase Noise



- **Close-in phase noise causes constellaton rotation**

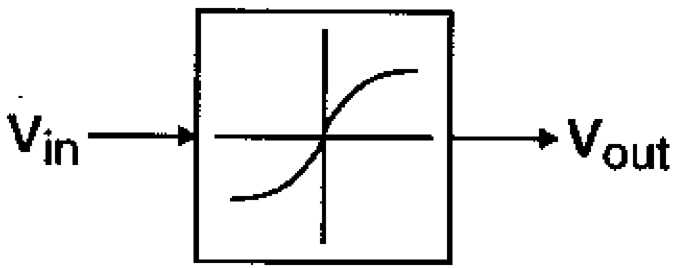
RECEIVE SIDE IMPAIRMENTS



IMPAIRMENTS

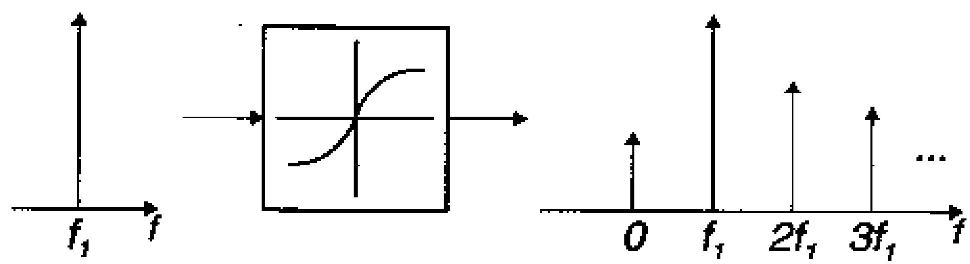
a) IQ MISMATCH - GAIN & PHASE (SAME AS TX)
b) PHASE NOISE (SAME AS TX)
* c) RF AMPLIFIER NON-LINEARITIES
  i) HARMONICS
  ii) DISTORTION
d) GAIN VARIATION IN VGA'S (VARIABLE GAIN AMPLIFIER)
  - ABSOLUTE GAIN NOT CONTROLLED - AGC
* e) THERMAL NOISE, 1/f NOISE
f) MIXER NONLINEARITIES, CONVERSION LOSS
g) DC OFFSET

c) RF Amplifier Distortion

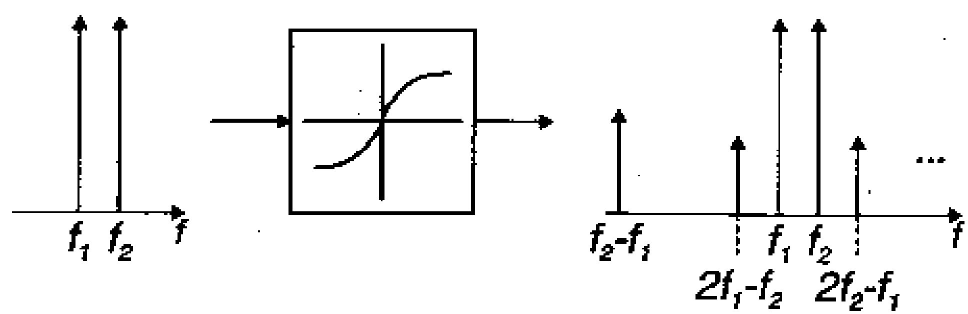


$$v_{out} = a_1 v_{in} + a_2 v_{in}^2 + a_3 v_{in}^3 + K$$

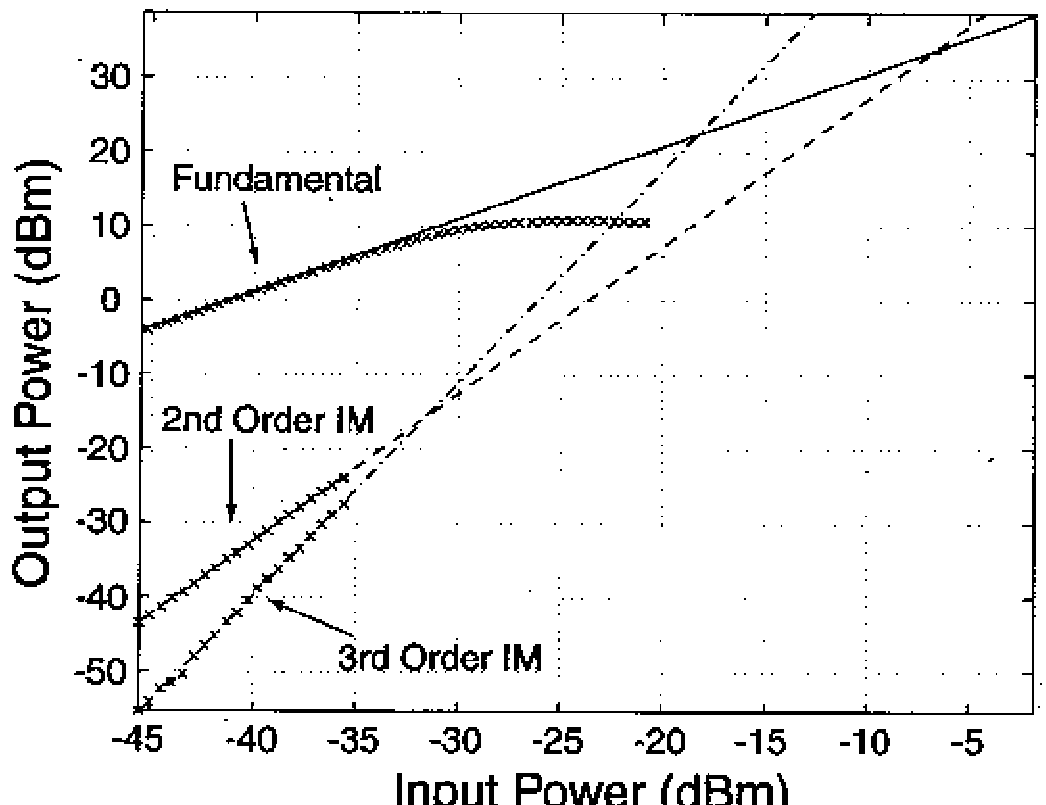
- **Harmonic distortion**



- **Intermodulation distortion**



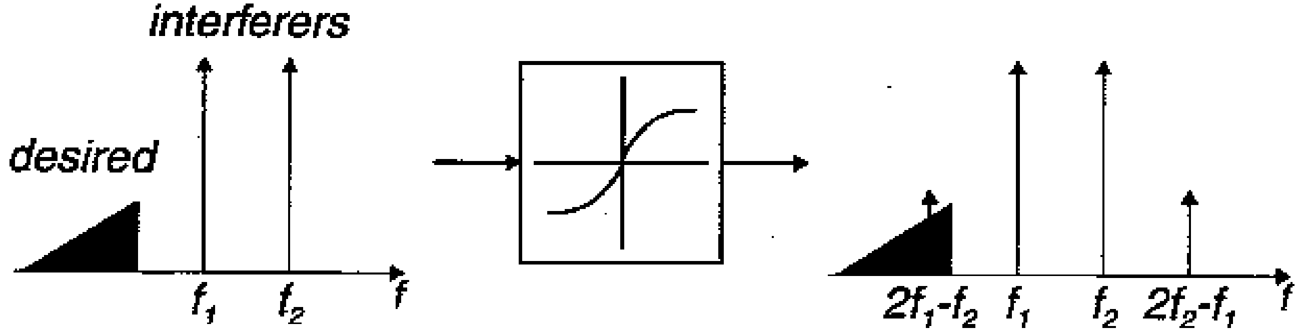
RF Receiver Distortion

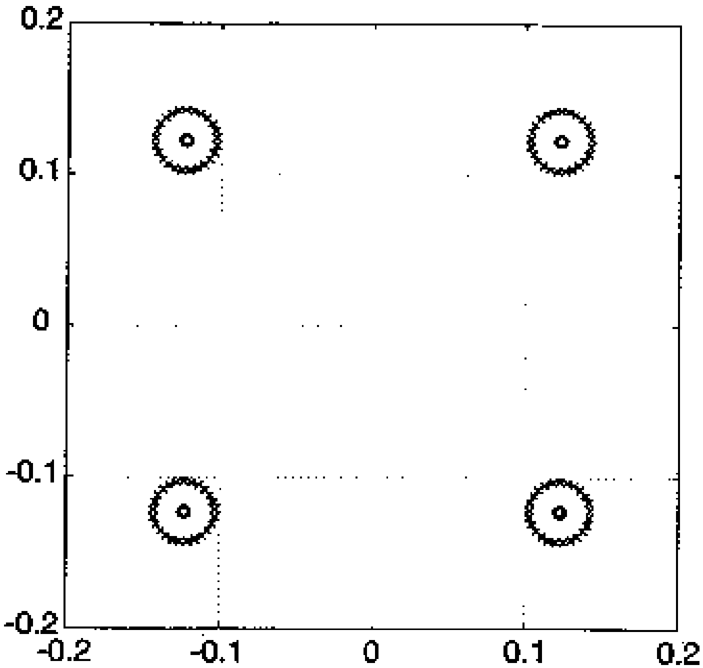


- P_{-1dB} = -31.1 dBm
- IIP2 = -6.7 dBm
  27 MHz, 37 MHz
- IIP3 = -18.3 dBm
  35 MHz, 60 MHz

IIP2 ≡ 2[ND] ORDER INTERMODULATION INTERCEPT POINT

Example: Third-Order Intermodulation



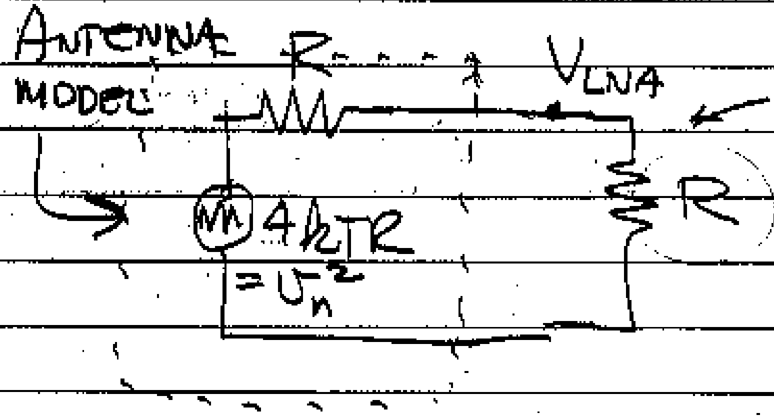


- **Intermodulation distortion corrupts desired signal**

a) Thermal Noise

Noise in a resistor

$\overline{v^2}(f) = 4kTR \; \left(V^2/Hz\right)$



Ques: How much power is input into LNA?

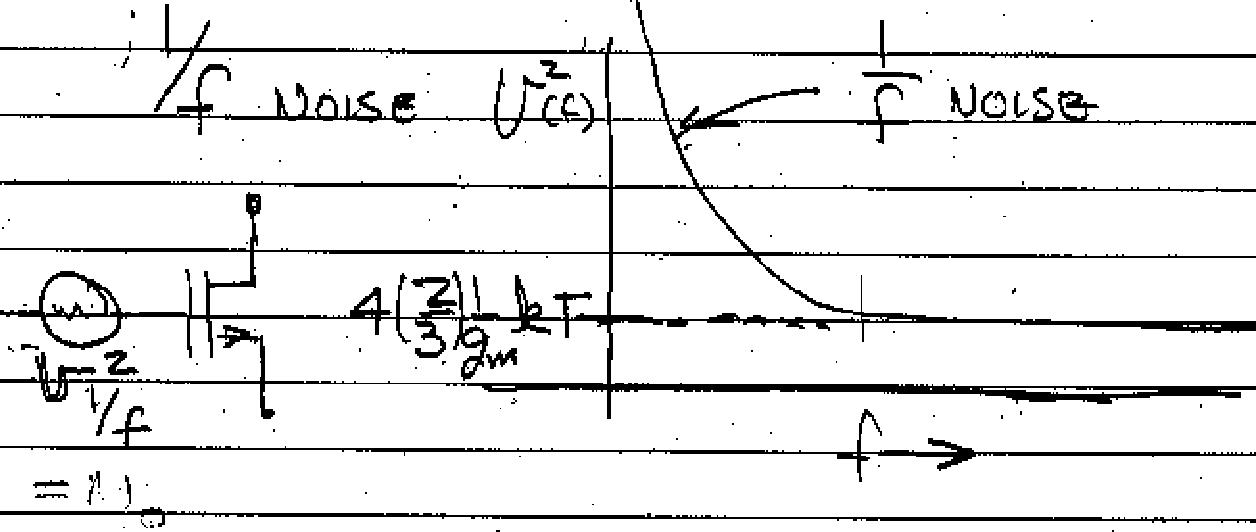
$$\overline{V_{LNA}^2} = 4kTR\left(\frac{R}{R+R}\right)^2 = kTR$$

$$\text{Power} = \frac{\overline{V_{LNA}^2}}{R} = \underline{\underline{kT}}$$

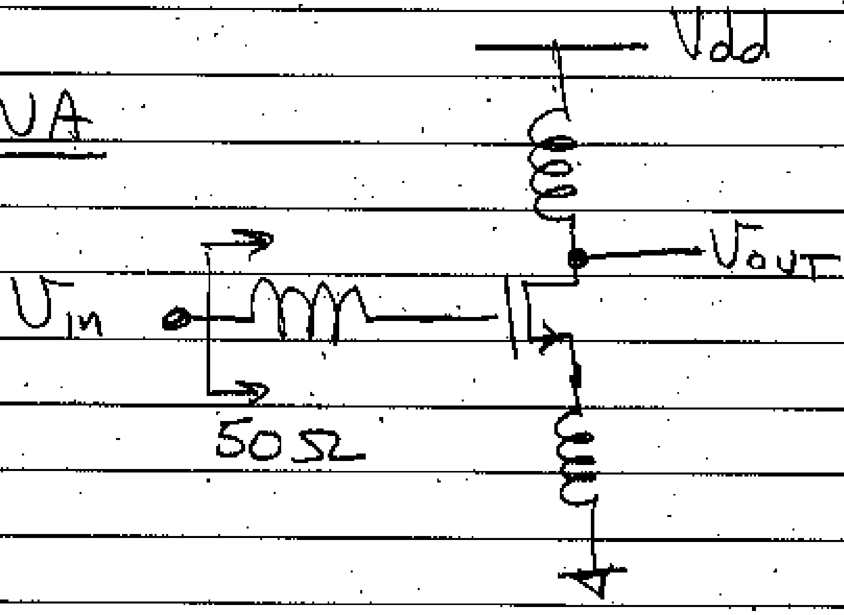
$$= -174 \text{ dBm}$$

dBm is dB below 1 mW.

THERMAL NOISE (CONT)



LNA



NOISE FIGURE

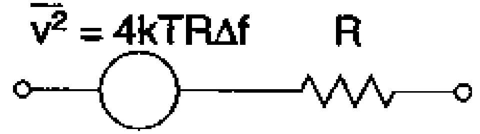
$$(N_F)_{dB} = \frac{(SNR)_{IN}}{(SNR)_{OUT}} = \frac{N_{OUT}}{G^2 N_0} = 1 + \frac{N_{LNA}}{G^2 N_0}$$

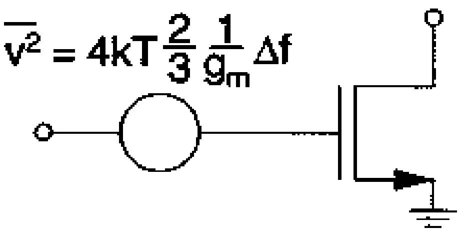
$N_0 = 4kTR$ $\qquad$ $N_{OUT} = N_{LNA} + G^2 N_0$

NOISE FIGURE DESCRIBES HOW MUCH THE SIGNAL TO NOISE RATIO DEGRADES

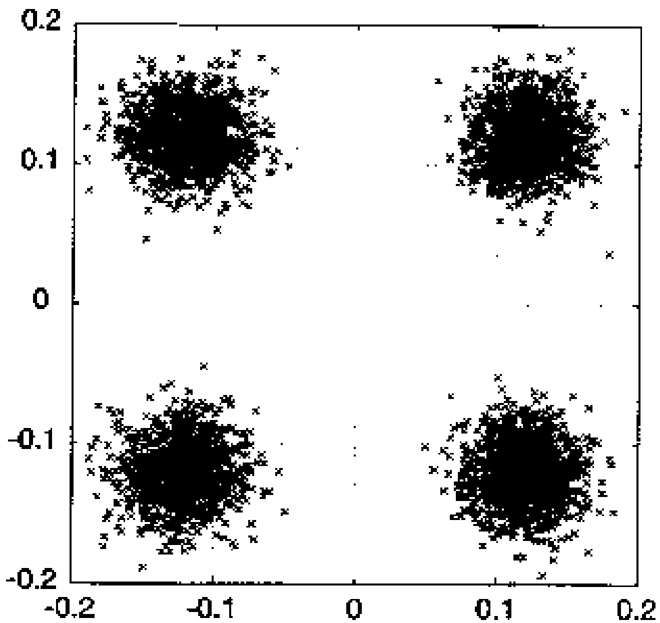
Thermal Noise

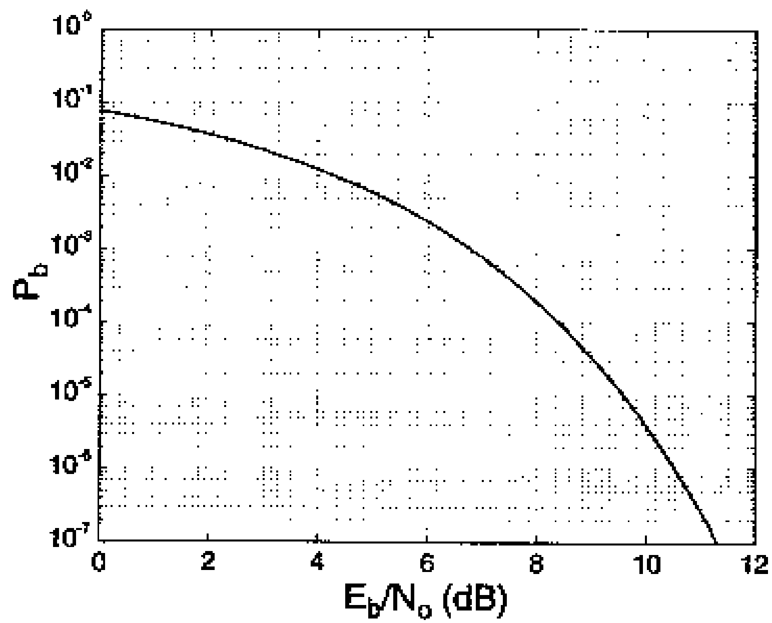
- **Random thermal motion of electrons**





- **For QPSK modulation:**





LINK BUDGET (802.11)

1. TRANSMIT POWER	20dBm	
2. TRANSMITT CIRCUIT LOSS	18dBm	(-2)
3. ANTENNA GAIN	21dBm	(+3)
4. PATH LOSS (1 METER)	-19dBm	(-40)
5. PATH LOSS - 100 METERS r^3 $\left(\frac{1}{10^2}\right)^3$	-79dBm	(-60)
6. RECEIVE ANTENNA GAIN	-76dBm	(+3)

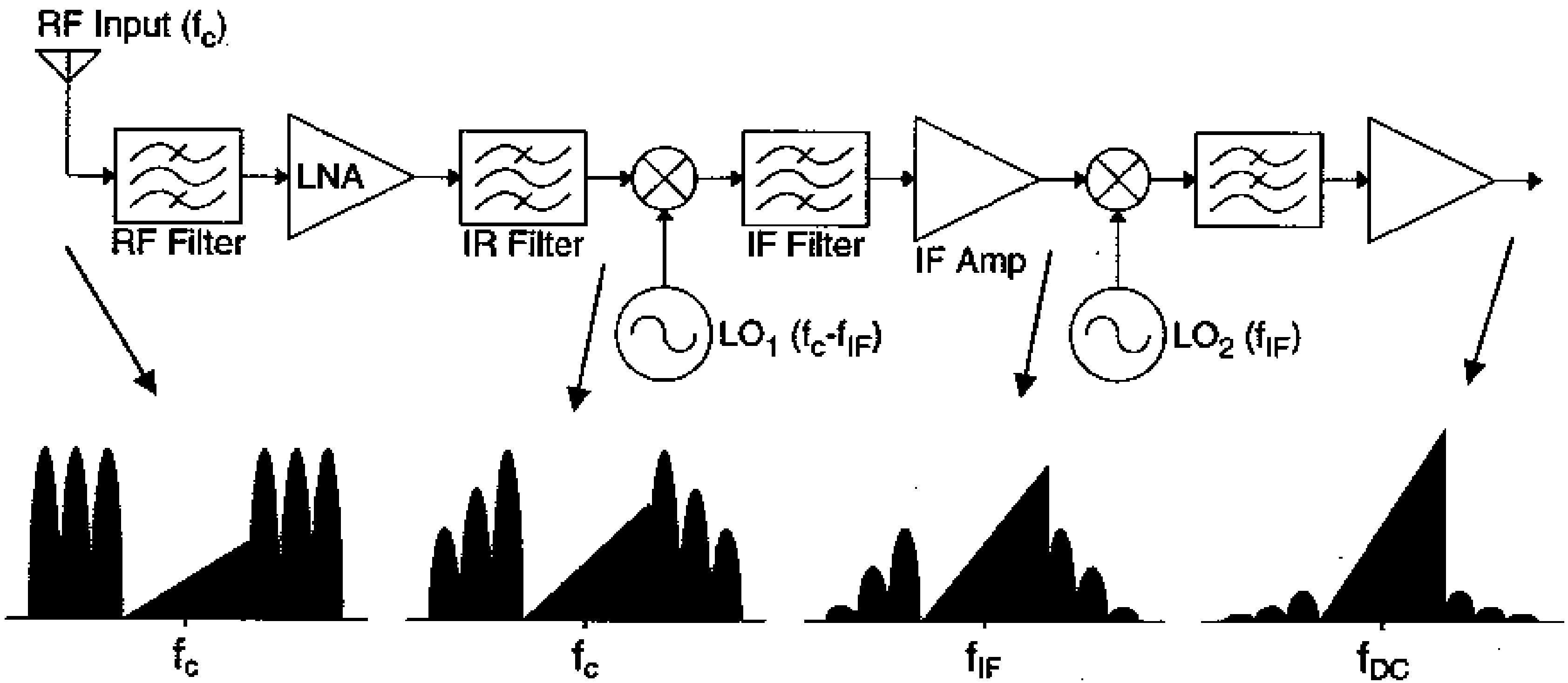
RECEIVED SIGNAL -76dBm

NOISE ON 50Ω =	-174dBm/Hz	
NOISE IN 20MHz BW =	-101dBm	(+73)
NOISE FIGURE OF RECEIVER =	-94dBm	(+7)
IMPLEMENTATION LOSS	-92dBm	(+2)
REQUIRED E_b/N_0 (10^{-5} BER)	-85dBm	(+7)

LINK MARGIN +9dB

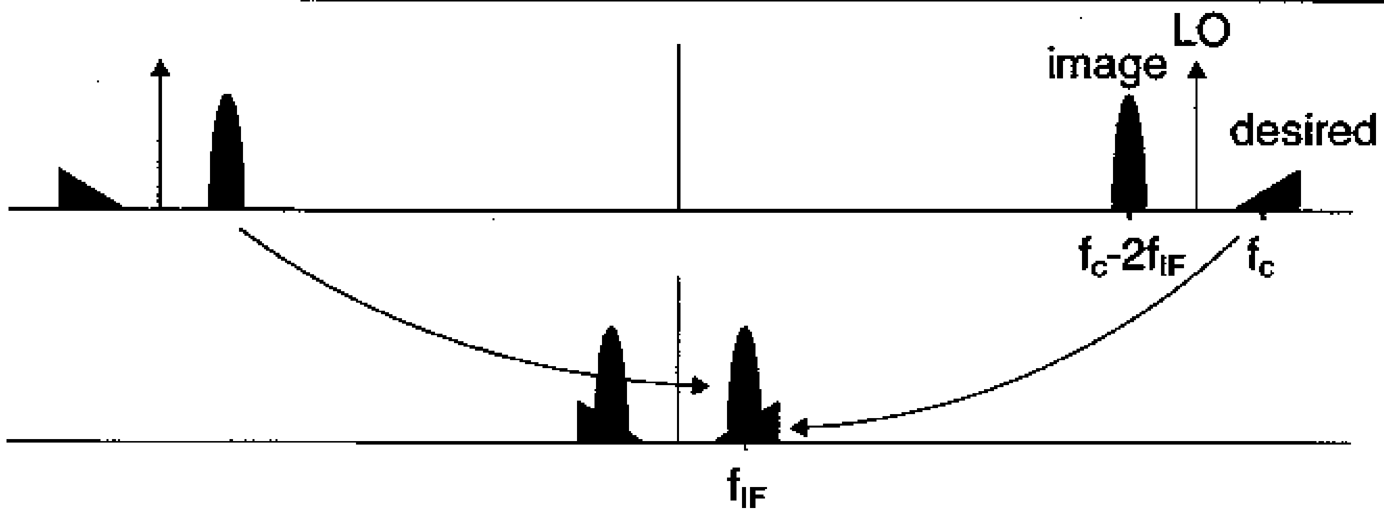
Receiver Architectures

Heterodyne Architecture



- **Most commonly used architecture in practice**
- **How is f_{IF} chosen?**

The Image Problem



- **Image signal can be much stronger than the desired signal and must be attenuated before downconversion**
- **Trade-offs:**

  High IF relaxes RF filtering requirements

  Low IF relaxes IF amplification and filtering requirements

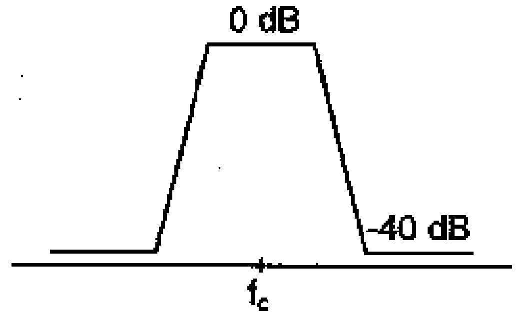


Image-Reject Mixing

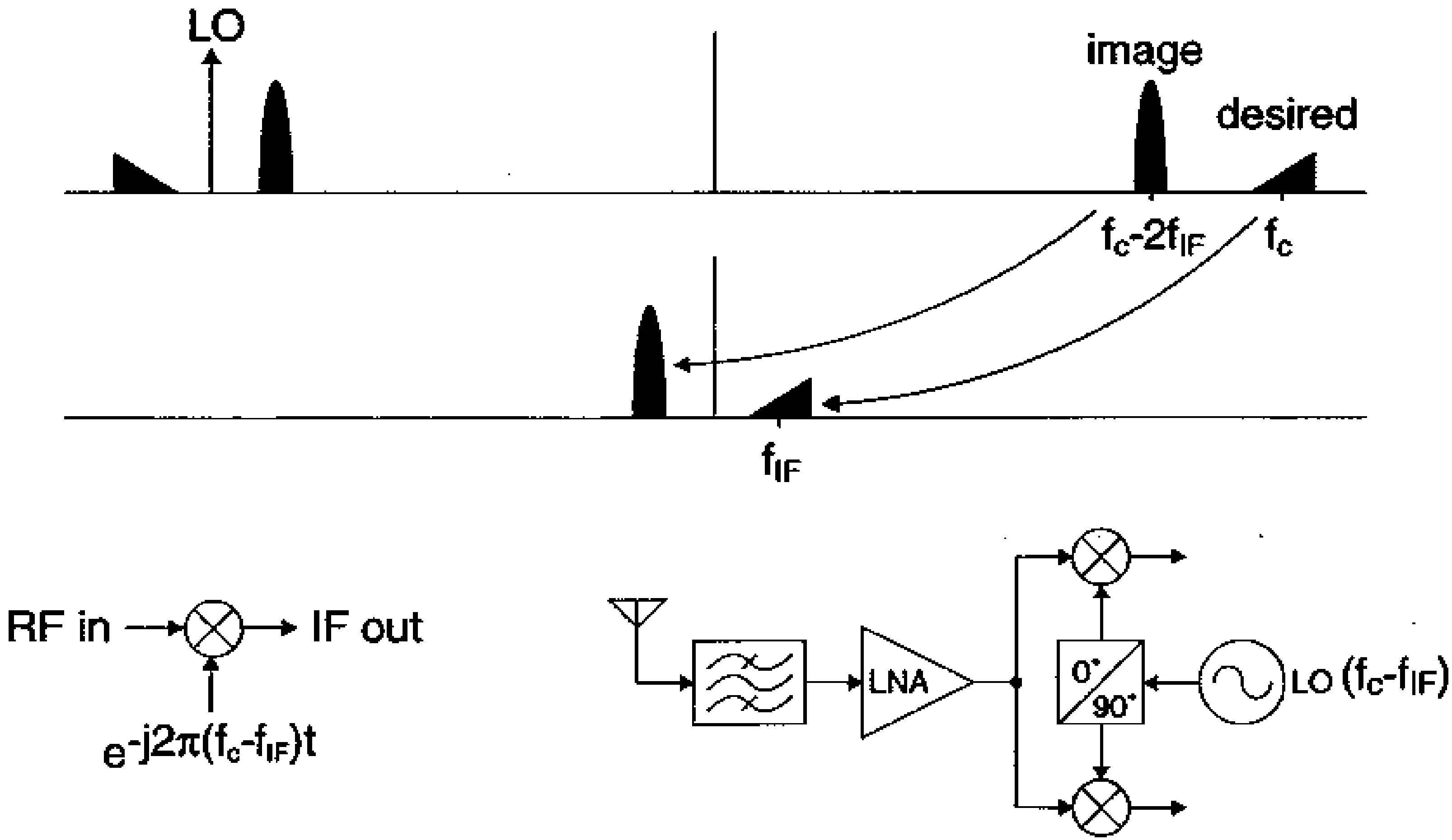
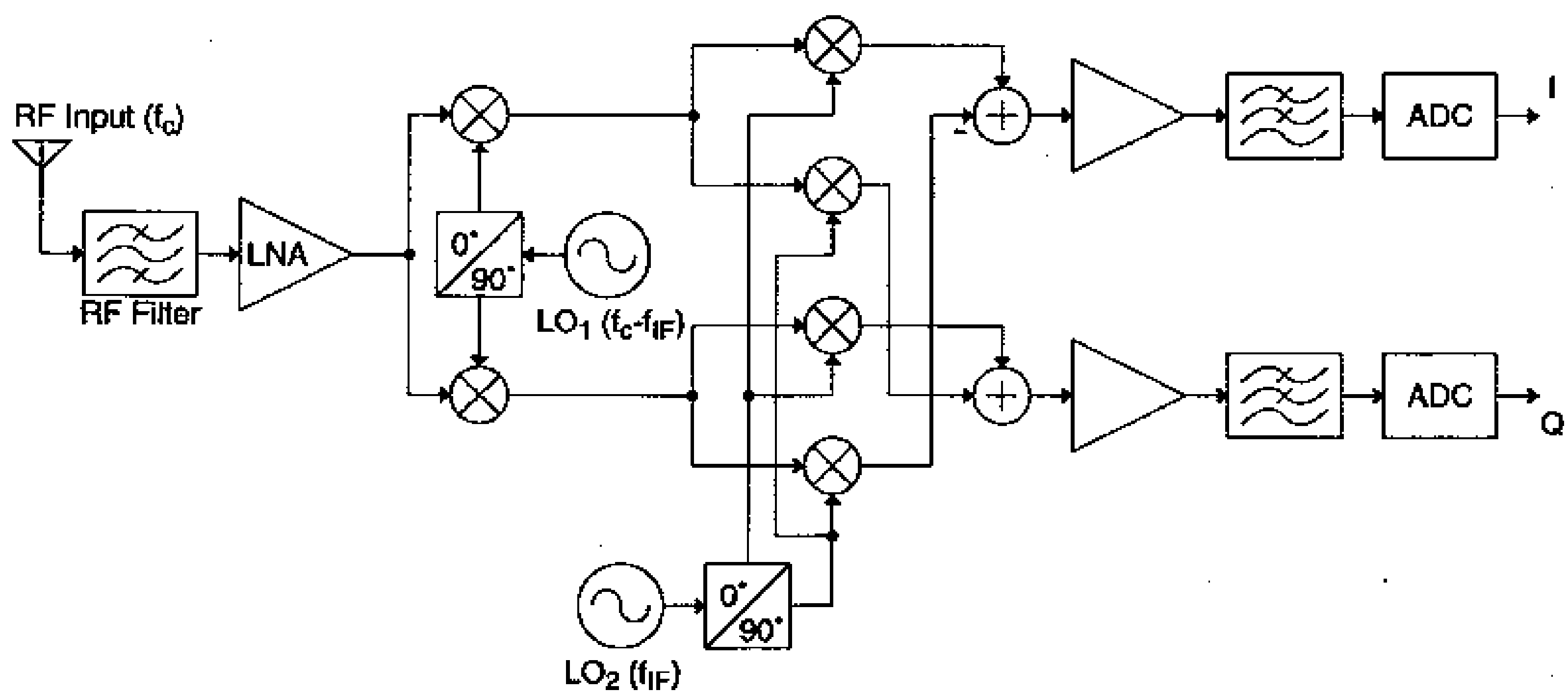


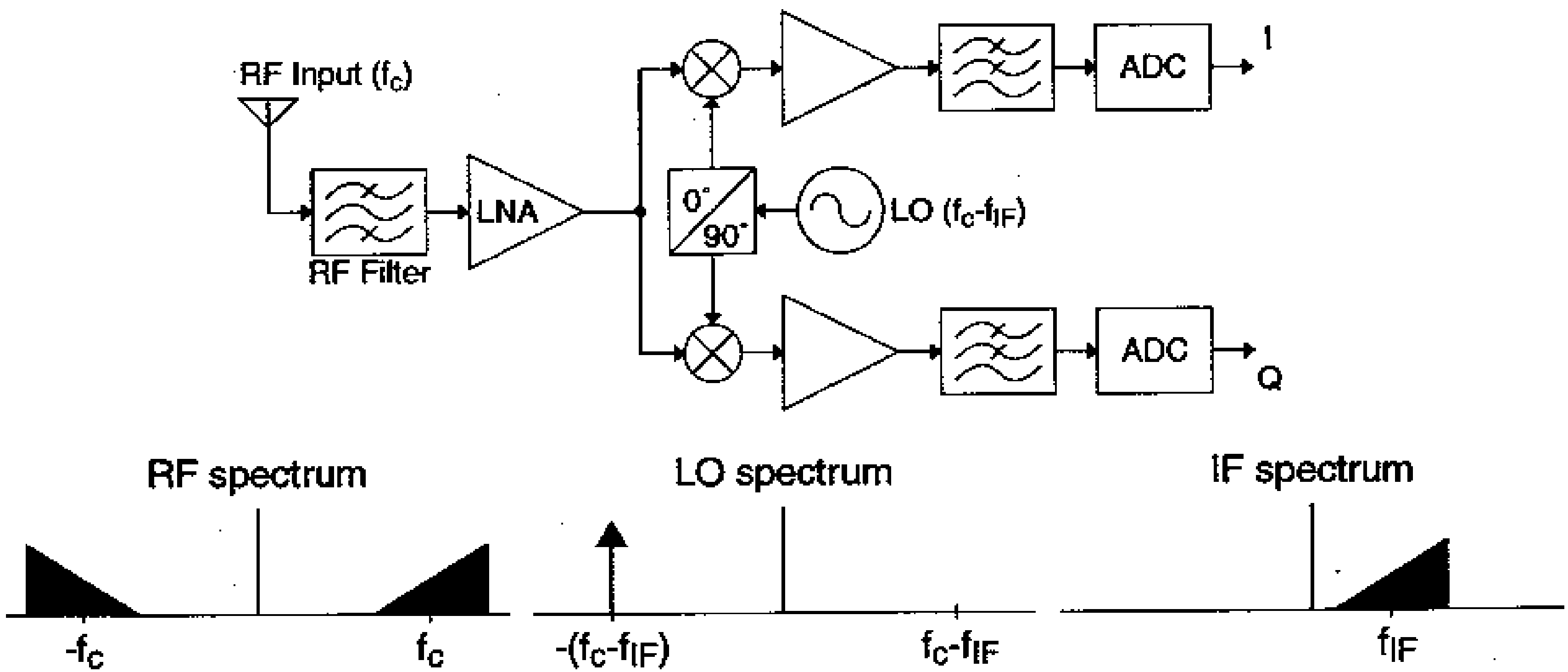
Image-Reject (Weaver) Architecture



- **Image rejection limited by gain and phase mismatch**

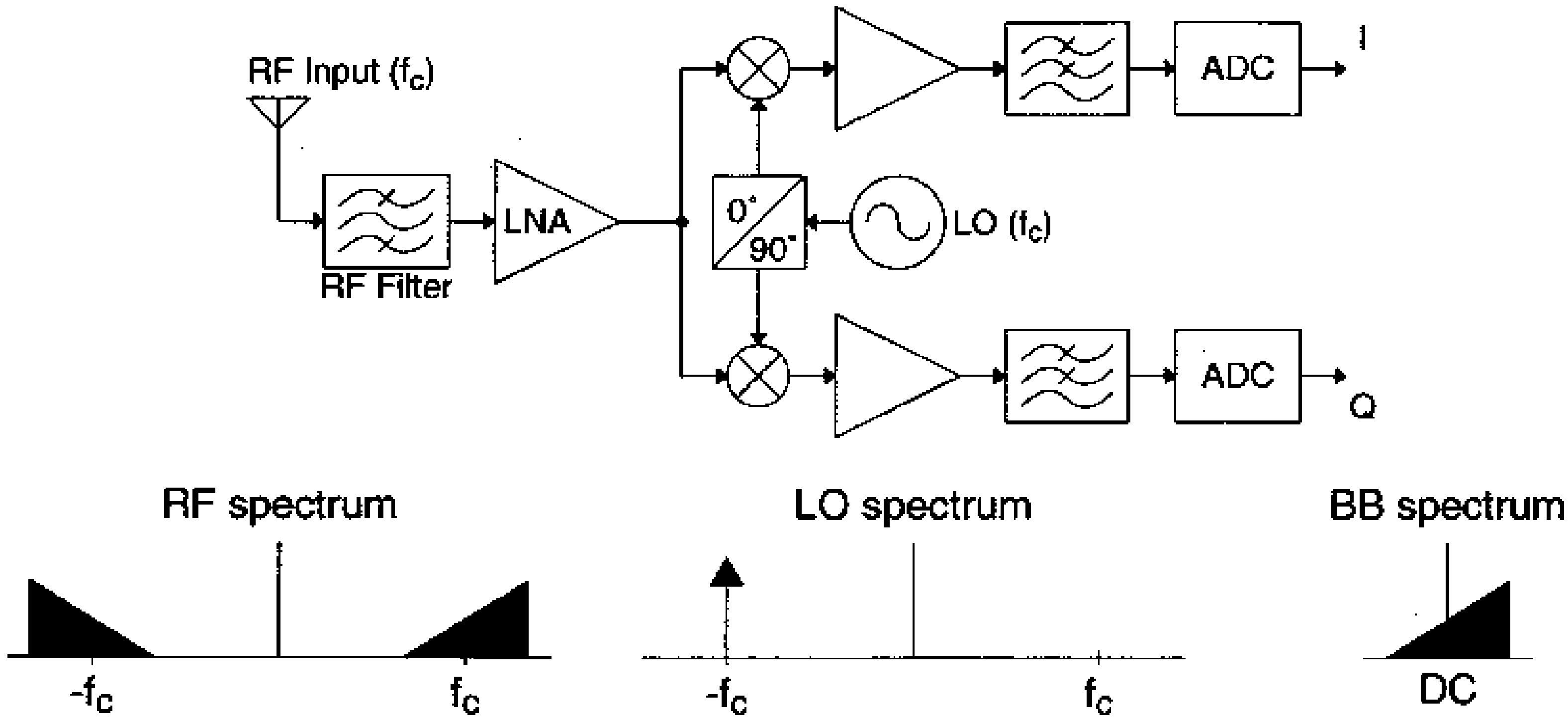
  30 – 45 dB image rejection typical

Low-IF Architecture



- **Final downconversion from f_{IF} performed digitally**
- **Requires relaxed image-rejection requirements at small frequency offsets from the carrier**

Direct-Conversion Architecture

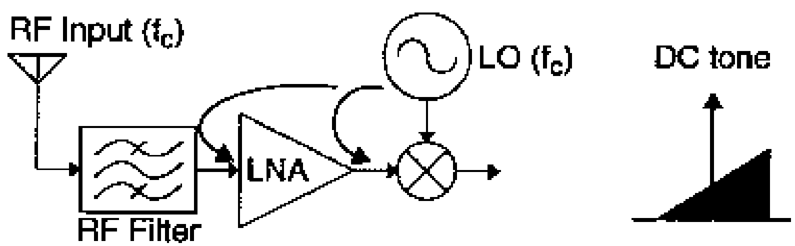


- **No image-reject problem**

  Eliminates intermediate-frequency stage(s)

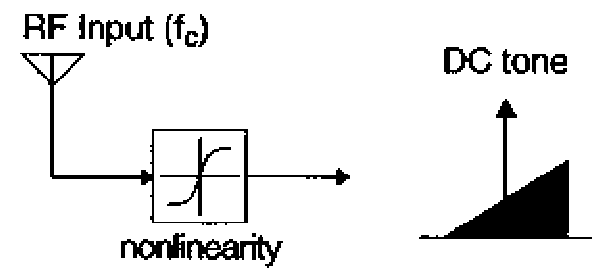
Direct-Conversion: Practical Considerations

LO Self-Mixing



$$\cos^2(2\pi f_c t) = \frac{1}{2}\{1 + \cos[2\pi(2f_c)t]\}$$

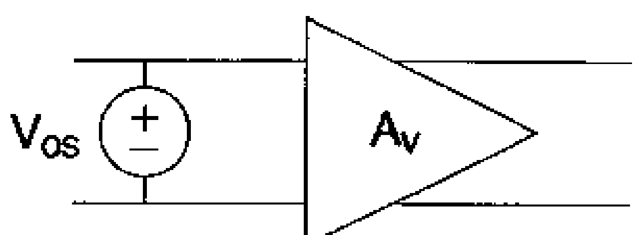
Even-Order Distortion



$$s_o = a_1 s_i + a_2 s_i^2 + a_3 s_i^3 + \ldots; \quad s_i = \cos(2\pi f_c t)$$

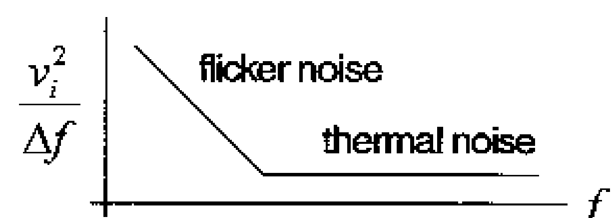
2nd order: $\frac{a_2}{2}\{1 + \cos[2\pi(2f_c)t]\}$

Baseband Circuit Offset



caused by device mismatch

Flicker Noise



$$\frac{v_i^2}{\Delta f} = \frac{K_f}{WLC_{ox} f} + 4kT\frac{2}{3}\frac{1}{g_m}$$