TSEK38: Radio Frequency Transceiver Design
Lecture 7: Receiver Synthesis (II)

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Lecture schedule

w4:
- Le1: Introduction (Ch 1)
- Le2: Fundamentals of RF system modeling (Ch 2)
- Le3: Superheterodyne TRX design (Ch 3.1)

w6:
- Le4: Homodyne TRX design (Ch 3.2)
- Le5: Low-IF TRX design (Ch 3.3)
- Le6: Systematic synthesis (calculations) of RX (Ch 4)

w7:
- Le7: Systematic synthesis (continued)
- Le8: Systematic synthesis (calculations) of TX (Ch 5)

w8:
- Le9: Systematic synthesis (continued)

Lab schedule

w6:
- We: Lab1a (after Le6): 15-19 (ASGA)
- Th: Lab1b: 17-21 (SOUT)

w7:
- We: Lab1c (after Le8): 15-19 (SOUT)
- Th: Lab1d: 17-21 (EGYP)

Instructions:
- One long lab (4 x 4 h).
- Lab manual in the Lisam *Course Documents/2019/Lab* folder.
- Supervision (Ted) available at the times above.
- To pass: complete and document the exercises in the lab manual, go through with Ted.

Summary of lecture 6 - I

- Calculations of
  - RX sensitivity and noise figure (4.2.1)
  - Cascaded noise figure (Friis')(4.2.2)
  - RX desensitization from TX leakage (4.2.3)
    - Duplex noise figure + degradation (4.2.3.1)
    - Port isolation
  - Antenna mismatch (4.2.4)

=> NF degradation (added noise)

Reference sensitivity and NF

Min $(S/N)_o$ required for BER for the sensitivity level = $(S/N)_{min}$ = SNR_{min}.
=> Sensitivity = S_{min}[dB] = $10\log(P_{S,min})$ = $-174 + 10\log(B) + NF_{RX} + SNR_{min}$ (4.2.4)

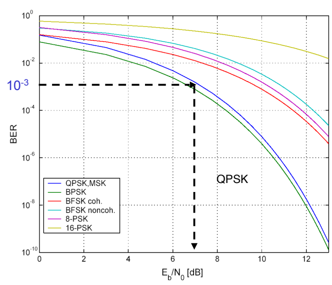
=> NF_{RX} [dB] = $SNR_{in} - SNR_{out} = SNR_{in} - SNR_{min} = S_{min} - (-174 \text{ dBm/Hz} + 10\log(B)) - SNR_{min}$ (4.2.7)

Reference noise or noise floor

Calculation flow:
1. BER requirement.
2. Use graph to convert to E_b/N_0.
3. Calculate SNR_{min}.
4. Calculate S_{min} (sensitivity).
5. Calculate NF.

BER versus SNR in demodulation

2



Dependent on modulation and demodulator implementation.

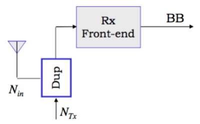
$(S/N) = P_{sig}/N = (E_bR_b)/(N_0B)$
$(S/N) = E_b/N_0 * R_b/B$
$R_b/B \approx 0.5 - 1.5$ (typically)

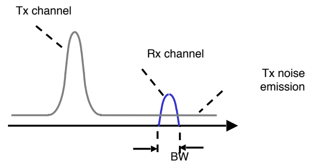
E_b = energy per transmitted byte
N_0 = noise power density
R_b = bit rate
B = channel bandwidth

$SNR_{min} = (E_b/N_0)_{dB} + 10\log(R_b/B)$

For spread-spectrum (e.g. CDMA) $R_b/B \ll 1$ => $SNR_{min} < 0$

4.2.3.1 Duplexer noise figure





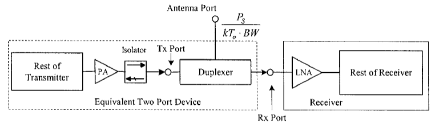


Figure 4.3. Simplified configuration of full-duplex transceiver

Duplexer noise figure

- NF of the duplexer can be largely degraded by TX leakage.

Example: emission noise density in the RX band

$$N_{Tx}\big|_{dB} = -130\text{dBm/Hz}, \quad A = 44\text{dB}$$ attenuation in the duplexer

$$G_{Dup}\big|_{dB} = -2.5\text{dB}$$

$$NF_{Dup} = 10\log\left(10^{\frac{-G_{Dup}|_{dB}}{10}} + 10^{\frac{N_{Tx}|_{dB} - A + 174\text{dBm/Hz}}{10}}\right) = 4.4\text{dB}$$

- If Tx is off, then NF_{Dup} = 2.5 dB

Comparison: NF of TDD and FDD Rx

TDD: $NF_{BPF+Switch} = L_{BPF+Switch} = -G_{BPF+Switch}$
FDD: $NF_{Dup} = L_{Dup} = -G_{Dup}$

$$NF_{Rx} = 8\text{dB}, \quad L_{BPF+Switch}\big|_{dB} = 2.5\text{dB}$$
$$NF_{Rx} = L_{BPF+Switch}\big|_{dB} + NF_{F-E}$$

TDD: NF_{F-E} =5.5 dB

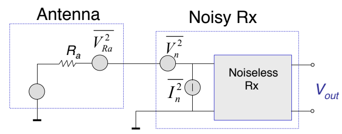
$$NF_{Rx} = 8\text{dB}, \quad L_{Dup}\big|_{dB} = 2.5\text{dB}$$
$$NF_{Dup} = 4\text{dB}$$
$$F_{Rx} = F_{Dup} + \frac{F_{F-E} - 1}{G_{Dup}}$$

FDD: NF_{F-E} =5 dB

Mismatch between antenna and Rx

$$F_{Rx} = \frac{SNR_{in}}{SNR_{out}} = 1 + \frac{\overline{(V_n + R_a I_n)^2}}{\overline{V_{Ra}^2}}$$

$$F_{Rx} = 1 + \frac{\overline{V_n^2} + R_a^2 \overline{I_n^2}}{4kTR_a}$$ when uncorrelated



$$R_{opt}^2 = \overline{V_n^2} / \overline{I_n^2} = R_n / G_n$$
$$F_{Rx,\min} = 1 + 2R_n / R_{opt}$$

$$F_{Rx} = F_{Rx,\min} + R_n R_a (G_a - G_{opt})^2$$
$$= 1 + \sqrt{R_n G_n}\left(\frac{R_a}{R_{opt}} + \frac{R_{opt}}{R_a}\right)$$

$$F_{Rx} = 1 + \frac{F_{Rx,\min} - 1}{2} \times \left(\frac{R_a}{R_{opt}} + \frac{R_{opt}}{R_a}\right)$$

For R_a/R_{opt} = 2 (3)

NF_{min}= 3 dB, NF_{Rx}= 3.5 dB (4.3 dB)
NF_{min}= 6 dB, NF_{Rx}= 6.8 dB (7.8 dB)

Summary of lecture 6 - II

- Calculations of intermodulation characteristics (4.3)
  - Basic about IMD and IPx
    - The RX linearity (cascaded IIP for the whole receiver) is the main cause of intermodulation distortion + LO phase noise + …
  - Allowed maximum degradation (4.3.3.1)
    - Allowed maximum degradation of the RX input desired signal is the maximum noise/interference level which deteriorates the desired signal to SNR_{min}.
  - RX linearity and relation to IMD (4.3.3.2)
    - gives the requirements on IIPx to maintain the allowed degradation
  - Degradation caused by phase noise (4.3.3.3)

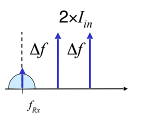
Intermodulation characteristics

IM3 is the main problem, close to the carrier.

$IIP_3 = (3I_{in} - IM_3)/2 = I_{in} + \Delta_3/2$ (4.3.10)

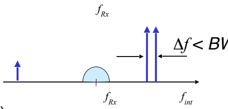
using $\Delta_3 = I_{in} - IM_3$ (see prev. slide)

$IM_3 = 3I_{in} - 2IIP_3$



IP3 test

IM2 is a minor problem, except for the direction conversion receiver.



IP2 test

$IIP_2 = 2I_{in} - IM_2$ [dBm] (4.3.9)

$IM_2 = 2I_{in} - IIP_{2,Rx}$

4.3.2 Cascaded IP…
Can be rather complicated when frequency selectivity and matching are considered.

4.5 Adjacent and alternate channel selectivity

- *Adj and alt channel selectivity* measures a receiver's ability to receive a desired signal in the presence of adjacent/alternate channel signals at a given frequency offset. (modulated)
- *Blocking characteristics* measures the same but in other channels/frequencies than the adjacent/alternate channel. (CW)
- Determined either by:
  - receiver filter
  - phase noise and spurs from LO in the adj/alt channels or around the interferer.
- The interference signal mixes with PN and spurs from LO, generates in-band noise and spurs, which degrades the SNR.

Adjacent and alternate channel selectivity

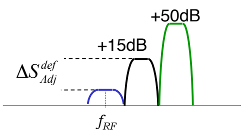
- "Desired signal level" for blocking test is usually defined as 3 dB above the reference sensitivity level $S_{min,ref}$

$$S_{d,i} = S_{\min\_ref} + 3 . \qquad (4.5.1)$$

- But differently defined for adj/alt channel selectivity and also varies between different mobile systems.
- Examples ("mobile station" = mobile terminal, phone etc.)
  - GSM: adj channel sel: 20 dB above ref. sensitivity = -82 dBm.
  - WCDMA, adj channel sel: 14 dB above ref. sensitivity = -92.7 dBm.

Adjacent and alternate channel selectivity and Blocking characteristics (4.5.2)

- The interferer I_{in} mixing with the phase noise and spurs of LO generates in-receiver-channel noise and spurs, which degrade the desired SNR.
- ΔS is defined by the blocking profile and we must verify that the PN + spurious contribution by adj/alt channel does not violate SNRmin.
- Derivation pp. 272-274.



$$\triangle S_{Adj} = I_{Adj} - S_{in}$$
$$\triangle S_{Alt} = I_{Alt} - S_{in}$$

I = interferer, S=signal

Adjacent and alternate channel selectivity

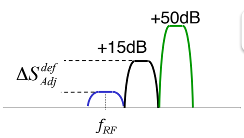
- Adj/alt channel selectivity or the blocking characteristics:

$$\Delta S_{adj/alt/block} = I_{adj/alt/block} - S_{d,i}$$
$$= 10\log\left(\frac{10^{\frac{S_{d,i}-CNR}{10}} - 10^{\frac{-174+10\log BW+NF}{10}}}{10^{\frac{N_{phn,1}+10\log BW}{10}} + 10^{\frac{N_{phn,2}-\Delta R_{IF}+10\log BW}{10}} + 10^{\frac{N_{spu,1}}{10}} + 10^{\frac{N_{spu,2}-\Delta R_{IF}}{10}}}\right) - S_{d,i} \qquad (4.5.8)$$

- Example in book (AMPS): NF = 6.6 dB, SNR_{min} = 2.6 dB, BW= 30 kHz => S_{min} = -120 dBm. Phase-noise profile given. $S_{d,i}$ for AMPS = 3 dB
- => ΔS_{adj} = 41.5 dB, ΔS_{alt} = 68.5 dB.
  Cf. requirements: S_{adj} > 16 dB, S_{alt} > 60 dB.

Adjacent and alternate channel selectivity

Alternative calculations to estimate how large PN + spurious for adj/alt channel can be.



$$(S/N)_{min} = \frac{P_{in}}{N_{PN+Sp} + N_{ref}F_{Rx}}$$

$$\triangle S_{Adj} = I_{Adj} - S_{in}$$
$$\triangle S_{Alt} = I_{Alt} - S_{in}$$

I = interferer, S=signal

$$N_{PN+Sp} = 2\times 10^{\frac{PN+I_{in}+10\log BW}{10}} \Rightarrow N_{PN+Sp}\big|_{dBm} = PN + I_{in} + 10\log BW + 3\,\mathrm{dB}$$

IM and self-mixing can be neglected here

Adjacent and alternate channel selectivity

I_{in} = -38 dBm
S_{in} = -86 dBm
BW = 1.25 MHz
SNR_{min} = 8 dB
NF_{Rx} = 10 dB

$$I_{in} = 10\log\left(10^{\frac{S_{in}-SNR_{\min}}{10}} - 10^{\frac{-174+10\log BW+NF_{Rx}}{10}}\right) - PN - 10\log BW - 3\,\mathrm{dB}$$
$$= -94.6 - PN - 61 - 3 = -155.6 - PN$$

$$I_{Adj} = -155.6 - PN(BW)$$
$$I_{Alt} = -155.6 - PN(2BW)$$

and also (S_{in})

$$I_{Adj} = -86\,\mathrm{dBm} + \Delta S_{Adj}$$
$$I_{Alt} = -86\,\mathrm{dBm} + \Delta S_{Alt}$$

Assume:
PN(5 MHz) ≤ -135 dBc/Hz
(5 MHz = 4BW) (2 octaves)
PN drops 6 dB/oct

⇒

$PN(BW)$ ≤ -135 + 12 = -123 dBc/Hz
$PN(2BW)$ ≤ -135 + 6 = -129 dBc/Hz

⇓

$$\Delta S_{Adj} = 53.4\,\mathrm{dB} \quad \Delta S_{Alt} = 59.4\,\mathrm{dB}$$

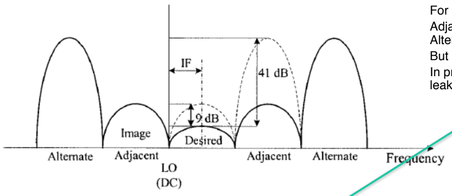
while

$$\Delta S_{Adj}^{def} = 15\,\mathrm{dB} \quad \Delta S_{Alt}^{def} = 50\,\mathrm{dB}$$

There is much reserve on adj/alt channel selectivity

Determination of IR (3.3.3.2)

2



For GSM:
Adjacent channel +9dB
Alternate channel +41dB
But channels overlap so ΔI_{inband} > 9 dB
In practice ΔI_{inband} = 15.5 dB because of leakage of alternate channel image

$IR_{min} = SNR_{min} + \Delta S_d + \Delta I_{inband} - \Delta SNR$ (3.3.24)

IR_{min} = 8 + 20 + 9 - 20 = 17 dB (from adjacent channel)
IR_{min} = 8 + 20 + **15.5** - 20 = 23.5 dB (+ leakage from the alternate channel)
30 dB IR will be sufficient to handle all images
(GSM specs says 24.5 dB is enough)

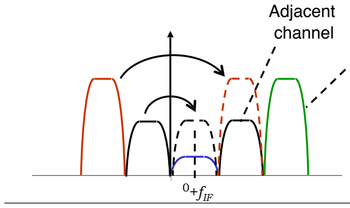
Determination of IR

additional calculations

$$SNR_{min} = S_{in} - 10\log(N_{ref}F_{Rx} + N_{other} + P_{Image\_inband})$$

$$P_{Image\_inband} = \frac{P_{Image}}{R} \Rightarrow P_{Image\_inband}\big|_{dB} = P_{Image}\big|_{dB} - IR$$

$$P_{Image}\big|_{dB} = S_{in} + \Delta I_{inband}$$



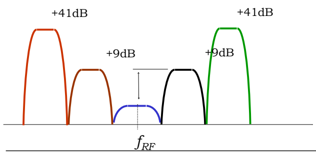
Determination of IR

additional calculations

$$10^{\frac{S_{in}-SNR_{min}}{10}} = N_{ref}F_{Rx} + N_{other} + \frac{P_{Image}}{R}$$

$$IR = S_{in} + \Delta I_{inband} - 10\log\left(10^{\frac{S_{in}-SNR_{min}}{10}} - 10^{\frac{-174+10\log BW+NF_{Rx}}{10}} - 10^{\frac{N_{Other}|_{dB}}{10}}\right)$$

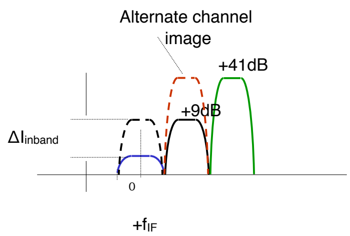
$$IR \cong \Delta I_{inband} + SNR_{min}$$ (when the image dominates)



Blocking profile for GSM:
Adjacent channel +9dB
Alternate channel +41dB

Determination of IR

additional calculations



For GSM:
Adjacent channel +9dB
Alternate channel +41dB
But channels overlap each other so ΔI_{inband} > 9dB and in practice ΔI_{inband} = 15.5dB (because of leakage of alternate channel image)

$$IR_{GSM} \cong 15.5 + 8 = 23.5\,\text{dB}$$

SNRmin

4.5.3 Two-tone blocking (direction conversion receivers)

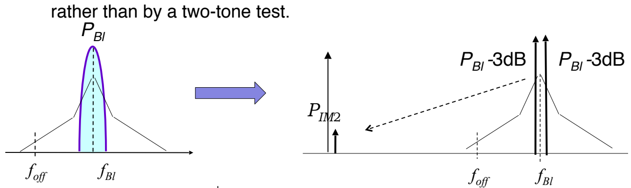
- Two strong interference tones may directly mix and generate in-channel reference due to IM2 in a direct conversion receiver, if the spacing is less than the channel bandwidth:

$$IM_{2,in} = 2I_{block} - IIP_{2,Rx}$$

- Usually IP2 test not defined by standards.
- Instead, blockers are specified, which can be considered as an IP2 test.

Two-tone blocking

- Usually IP2 test not defined by standards or maximum blocker power larger than the power in a two-tone test.
- Instead, blockers are specified, which can be considered as an IP2 test.
- Hence, IP2 and PN would be dictated by the maximum blocker rather than by a two-tone test.



$$P_{IM2}\big|_{dBm} = 2(P_{Bl}-3) - IIP_{2,Rx}$$

(two-tone model)

4.6 Receiver Dynamic Range and AGC

- DR = range at antenna port when BER is acceptable.
- Lower limit = sensitivity, upper limit = allowed maximum input power.

Table 4.2 Maximum input signal and minimum dynamic range

Systems	Maximum Input Power (dBm)	Minimum Dynamic Range (dB)
AMPS	N/A	> 96
CDMA 800	-25	> 79
CDMA 1900	-25	> 79
EDGE	-26	> 72
GPRS	-26	> 73
GSM 900	-15	> 87
GSM 1800	-23	> 79
PHS	-21	> 76
TDMA	-25	> 85
WCDMA	-25	> 81.7

Ref sens = -102 dBm (Table 2.4, p. 104)

Receiver Dynamic Range and AGC

- Automatic Gain Control (AGC) is needed to cover the full DR.
- AGC is usually > DR. E.g. CDMA >79 dB, AGC range may need 100 dB.
- Also handles gain variations because of processing deviations, temperature, supply voltage.
- AGC is mainly in the digital domain, but also in the LNA, IF-VGA, and BB-VGA.

Receiver Dynamic Range and AGC

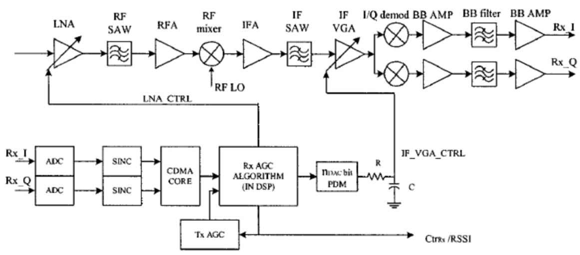
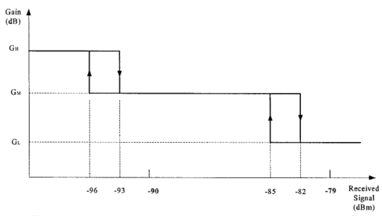


Figure 4.13. CDMA receiver AGC system block diagram

Receiver Dynamic Range and AGC

- RF and IF gain control can be made by stepping the LNA and IF-VGA gain.
- Low number of gain steps, typically three steps for the LNA.
- Hysteresis (typically 3 dB) is used to avoid gain switch back and forth, causing IMD products or other interferences.



from RSSI

Figure 4.14. LNA gain control versus received signal strength

Receiver Dynamic Range and AGC

- The total gain variation of the LNA and IF-VGA must cover the receiver DR, gain variation over temperature, processing, frequency, and some margin.
- ACG control range:
  $GCR_{Rx} > S_{max} - S_{min} - \Delta G_{R,T} + \Delta G_{R,process} + \Delta G_{R,f}$ + margin
- $G_{R,T}$ = gain variation due to temperature
- $G_{R,process}$ = gain variation due to device processing
- $G_{R,f}$ = gain variation due to frequency

RX gain and AGC

3

Gain depends on ADC voltage range V_{range}.
Assume V_{range} = 1.5 V, $S_{in,min}$ = -92 dBm, $S_{in,max}$ = -15 dBm

$$S_{in} = 10\log\left(\frac{V_{in,pp}^2}{8R_0 \times 1mW}\right) = 20\log V_{in,pp} + 4dB$$

$S_{in,max}$ = -15 dBm +6 dB margin for PAR and gain variations = -9 dBm

$20\log V_{in,pp}$ = -13 dBV (max)

$$A_{V,\min} = 20\log V_{range} - 20\log V_{in,pp} \cong 16.5dB$$

While for minimum input signal:

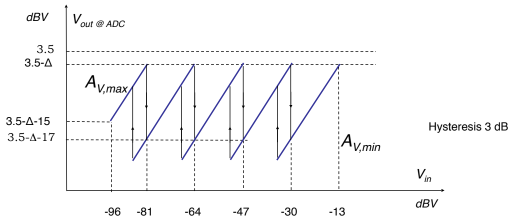
$$A_{V,\max} = 20\log V_{range} - 20\log V_{in,min} - \Delta A$$
$$\cong 3.5 + 96 - \Delta A = 99.5dB - \Delta A$$

$AGC = A_{V,max} - A_{V,min}$
= 83 dB - ΔA

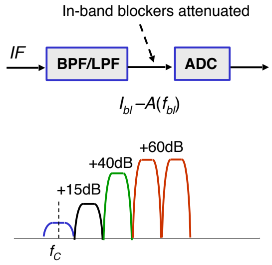
ΔA = gain control of the IF-VGA (continuous)

RX gain and AGC

- Various scenarios possible. Suppose we use AGC = 4 x 17 dB + 15 dB - ΔA (by simple gain stepping)
- ΔA = 15 dB => $A_{V,max} = A_{V,min}$ + AGC = 83+16.5 dB = 96.5 dB



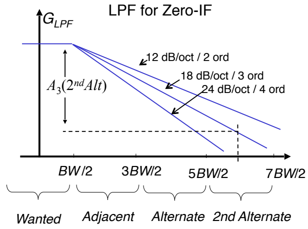
Channel Filter



Blocking profile

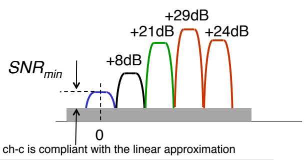
(For $S_{in} = S_{in,min}$+3dB any blocker cannot overload ADC)

Channel selection can be completed in BB but ADC must sustain the blockers



Channel Filter

- Filter attenuation: $A(f_{bl}) \cong n\times 20\log\frac{f_{bl}}{f_T}, \quad (f_{bl} >> f_T)$
- Blocking profile: $(-93dBV + \Delta S_k) - n\times 20\log\frac{k\times BW}{BW/2}$ (*)
  $\cong -93dBV + \Delta S_k - n\times(6+20\log k)$
- Use simple filter (n=2).
- ADC must maintain the max blocker and SNR_{min}.
- Trade-off between filter order and ADC resolution.



(*) The formula works well for larger k values when the filter ch-c is compliant with the linear approximation

4.6.3 DR and ADC

- DR = maximum effective signal-to-(noise+distortion)
- Requirements set by:
  - AGC range and step size
  - min SNR
  - ratio in-channel band noise/interference to quantization noise
  - PAR (peak-to-average ratio)
  - DC offset
  - Fading margins
  - Filtering (e.g. channel filter for close-in interferer)
- Architecture dependent

DR and ADC: examples

- CDMA (DL):
  - PAR = 10
  - Q-noise = 12 dB below in-channel-band noise
  - min CNR = -1 dB (Spread Spectrum can have CNR < 0 dB)
  - fading margin = 3 dB

  => DR = 24 dB
- GSM (superheterodyne)
  - Q-noise = 16 dB below in-channel-band noise
  - DC offset: 4 dB margin
  - min CNR = 8 dB
  - fading margins = 20 dB

  => DR = 48 dB

DR and ADC

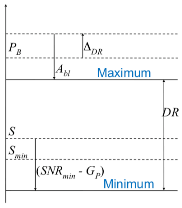
- DR can also be expressed in ENOB (n_b = ADC bits)

$$DR_{ADC} = 20\log(2^{2n_b}\sqrt{1.5}) \cong 6.02n_b + 1.76 \text{ dB.} \qquad (4.6.13)$$

- CDMA: 4 bits,
- GSM: 8 bits,
- TDMA (similar to GSM): 10 bits,
- EDGE: 12-13 bits.

- ADC NF pp. 286-287.

DR of ADC: additional calculations



$$DR = (P_B - A_{bl})_{\max} - (S_{in} + G_P - SNR_{\min}) + \Delta_{DR}$$

Processing gain (if any)

Gain variation and PAR

$$DR = 29dBV - (G_P - 8) + \Delta_{DR}$$
$$= 37dBV + \Delta_{DR} - G_P$$

6.. 10dB

If no spread spectrum

$$SNR_{\min} = (S_{in} + G_{FE}) - 10\log\frac{V_{n+d,FE}^2 + V_{n+d,ADC}^2}{Z_{ADC} \times 1\text{mW}}$$

Including FE noise and distortions

DR of ADC: additional calculations

$$V_{n+d,ADC}^2 = \alpha V_{n+d,FE}^2$$

Keep ADC noise+dist low, α<1

$$SNDR_{ADC} = 10\log\frac{V_{Range}^2/8}{V_{n+d,ADC}^2}$$

ADC under reference conditions

$$ENOB = \frac{SNDR_{ADC} - 1.76}{6.02}$$

Equivalent number of bits

$$DR = 10\log\frac{V_{range}^2/8}{V_{n+d,FE}^2 + V_{n+d,ADC}^2} = 10\log\frac{V_{range}^2/8}{(1+1/\alpha)V_{n+d,ADC}^2}$$
$$= SNDR_{ADC} - 10\log(1+1/\alpha)$$

$$ENOB = \frac{DR + 10\log(1+1/\alpha) - 1.76}{6.02}$$

Equivalent number of bits including contribution of FE

DR of ADC: additional calculations

$$SNR_{\min} = (S_{in} + G_{FE}) - 10\log\frac{V_{n+d,FE}^2}{Z_{ADC} \times 1\text{mW}} - 10\log(1+\alpha)$$

$(37+10)dB$ 9.6dB

$\alpha < 0.122$ $(\alpha < 0.047)$

Impact of ADC on SNR
We assume $\leq 0.5dB$ $(0.2dB)$

$$ENOB = \frac{DR + 10\log(1+1/\alpha) - 1.76}{6.02}$$

Equivalent number of bits including contribution of FE

$ENOB = 9.1$ (9.8)

Since filter simple, ADC should use oversampling (ΣΔ technique).

$$f_s >> BW$$

Otherwise, aliasing would occur !

4.7 System Design, 4.7.1 Basic aspects

- Good electrical performance, lower power consumption, low cost, small size.
- Trade-off between a lot of parameters, e.g. higher linearity will cost more current.
- Highest performance is probably too good!

- Receiver terminal: sensitivity, intermodulation, channel selectivity, blocking, spurious emissions.
- Minimum requirements set by standards, with certain margins, typ. 3 dB at RT and 1.5 dB at max temp. frequency, voltage, for most parameters.
- However: sensitivity 4-5 dB, intermodulation 4 dB.

Basic aspects

- Power consumption will directly affect the operation time of a terminal. The PA is the most power hungry component, in the TX.
- Cost and size => architecture selection:
  - Direct conversion and low-IF less costly and smaller size than superheterodyne.
  - Superheterodyne may have better performance.
  - Fewer parts, higher integration, more standard parts, …
  - ICs costly in low volumes.

Basic aspects

- Start with choosing a receiver architecture.
- Fundamental receiver block diagram is developed.
- Most important components to choose:
  - RF BPF, RF LNA, RF downconverter, UHF LO synthesizer, BB amps, BB LPF, ADC.
  - Additional components for superheterodyne: IF filters, amplifiers, I/Q down-converter, VHF LO.
- All components have characteristics and must be defined to work together to achieve the full receiver specification.

Basic requirements on key devices

4.7.2.1 Filters

- Center frequency
- Bandwidth
- Insertion loss
- Ripple
- Group delay
- Rejection
- Input/output impedance
- Input/output return loss
- Noise figure
- (IIP3 usually very high)

Basic requirements on key devices

4.7.2.2 LNA

- Frequency
- Gain
- Noise figure
- IIP3
- Reverse isolation
- Input/output impedance
- Input/output return loss

Basic requirements on key devices

4.7.2.3 Down-Converter and I/Q Demodulator

- Frequency
- Conversion loss/gain
- Noise Figure
- IIP3
- IIP2 (direct-conversion)
- Isolation between different ports RF/IF/LO
- LO power
- Input/output impedance
- Input/output return loss

+ for I/Q: gain and phase imbalance between output ports

Basic requirements on key devices

4.7.2.4 IF and BB amplifiers

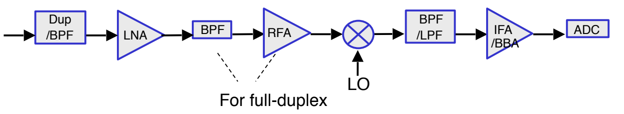
- Similar to LNA, but usually less stringent, especially the BB amps
- IF-VGA: usually continuous adjustable
- BB-VGA: usually step-controlled

4.7.2.5 Synthesized LO

- Frequency
- Output power
- PLL: phase noise, spurious (inband and out-of-band).
- Settling time

4.7.3 Performance evaluation

Line-up analysis



- Some specs already known:
  - Duplexer/switch loss (NF)
  - RF BPF loss (NF)
  - IP2 of downconversion mixer
  - Mixer gain, if passive
  - BW of filters

Distribution of
G, NF, IIP3, (IIP2) ?

Performance evaluation

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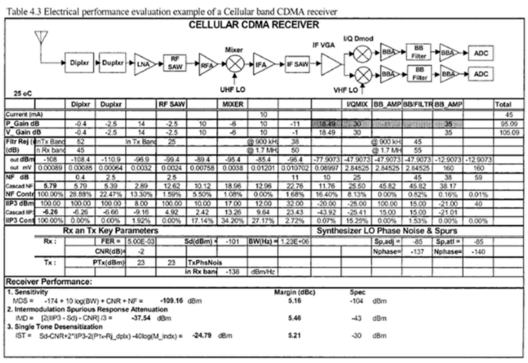


Table 4.3 Electrical performance evaluation example of a Cellular band CDMA receiver

		Diplxr	Duplxr		RF SAW		MIXER				I/QMIX	BB_AMP	BB/FILTR	BB_AMP		Total
Current (mA)								10								45
P_Gain dB		-0.4	-2.5	14	-2.5	10	-6	10	-11	18.49	30			35		95.09
V_Gain dB		-0.4	-2.5	14	-2.5	10	-6	10	-1	18.49	30			35		105.09
Fltr Rej (	InTx Band	52		In Tx Band	25			@ 900 kHz	38			@ 900 kHz	45			
(dB)	n Rx band	45						@ 1.7 MHz	50			@ 1.7 MH	55			
out dBm	-108	-108.4	-110.9	-96.9	-99.4	-89.4	-95.4	-85.4	-96.4	-77.9073	-47.9073	-47.9073	-47.9073	-12.9073	-12.9073	
out mV	0.00089	0.00085	0.00064	0.0032	0.0024	0.00758	0.0038	0.01201	0.010702	0.08997	2.84525	2.84525	2.84525	160	160	
NF dB		0.4	2.5		2.5				11	10	25		45	38	59	
Cascad NF	5.79	5.79	5.39	2.89	12.62	10.12	18.96	12.96	22.76	11.76	25.50	45.82	45.82	38.17		
NF Contr	100.00%	28.88%	22.47%	13.30%	1.59%	5.50%	1.08%	0.00%	1.68%	16.40%	8.13%	0.00%	0.82%	0.16%	0.01%	
IIP3 dBm	100.00	100.00	100.00	8.00	100.00	10.00	17.00	12.00	32.00	-20.00	-25.00	100.00	15.00	-21.00	40	
Cascad IIP3	-6.26	-6.26	-6.66	-9.16	4.92	2.42	13.26	9.64	23.43	-43.92	-25.41	15.00	15.00	-21.01		
IIP3 Cont	100.00%	0.00%	0.00%	1.92%	0.00%	17.14%	34.20%	27.17%	2.72%	0.07%	15.25%	0.00%	1.53%	0.00%	0.00%	

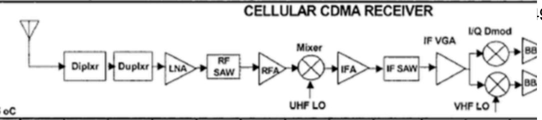
Rx an Tx Key Parameters / Synthesizer LO Phase Noise & Spurs

Rx :		FER =	5.00E-03		Sd(dBm) =	-101	BW(Hz) =	1.23E+06			Sp,adj =	-85	Sp,atl =	-85
		CNR(dB)=	-2								Nphase=	-137	Nphase=	-140
Tx :		PTx(dBm)	23	23	TxPhsNois									
					in Rx band	-138	dBm/Hz							

Receiver Performance:

			Margin (dBc)	Spec	
1. Sensitivity					
MDS = -174 + 10 log(BW) + CNR + NF =	-109.16	dBm	5.16	-104	dBm
2. Intermodulation Spurious Response Attenuation					
IMD = [2(IIP3 - Sd) - CNR] /3 =	-37.54	dBm	5.46	-43	dBm
3. Single Tone Desensitization					
IST = Sd-CNR+2*IIP3-2(PTx-Rj_dplx) -40log(M_indx) =	-24.79	dBm	5.21	-30	dBm

CELLULAR CDMA RECEIVER



25 oC

		Diplxr	Duplxr		RF SAW		MIXER				I/QMIX	BB_A
Current (mA)								10				
P_Gain dB		-0.4	-2.5	14	-2.5	10	-6	10	-11	18.49	30	[illegible]
V_ Gain dB		-0.4	-2.5	14	-2.5	10	-6	10	-1	18.49	30	
Fltr Rej (	InTx Band	52		In Tx Band	25			@ 900 kH	38			@ 900
(dB)	n Rx band	45						@ 1.7 MH	50			@ 1.7
out dBm	-108	-108.4	-110.9	-96.9	-99.4	-89.4	-95.4	-85.4	-96.4	-77.9073	-47.9073	-47.9
out mV	0.00089	0.00085	0.00064	0.0032	0.0024	0.00758	0.0038	0.01201	0.010702	0.08997	2.84525	2.845
NF dB		0.4	2.5		2.5				11	10	25	
Cascad NF	**5.79**	5.79	5.39	2.89	12.62	10.12	18.96	12.96	22.76	11.76	25.50	45.8
NF Contr	100.00%	28.88%	22.47%	13.30%	1.59%	5.50%	1.08%	0.00%	1.68%	16.40%	8.13%	0.00
IIP3 dBm	100.00	100.00	100.00	8.00	100.00	10.00	17.00	12.00	32.00	-20.00	-25.00	100.
Cascad IIP3	**-6.26**	-6.26	-6.66	-9.16	4.92	2.42	13.26	9.64	23.43	-43.92	-25.41	15.0
IIP3 Cont	100.00%	0.00%	0.00%	1.92%	0.00%	17.14%	34.20%	27.17%	2.72%	0.07%	15.25%	0.00

Rx an Tx Key Parameters — Synthesizer LO Pha

Rx :		FER =	5.00E-03		Sd(dBm) =	-101	BW(Hz) =	1.23E+06		Sp,ac
		CNR(dB)=	-2							Nphas
Tx :		PTx(dBm)	23	23	TxPhsNois					
					in Rx band	-138	dBm/Hz			

Receiver Performance:

1. Sensitivity — Margin (dBc) — Spec

MDS = -174 + 10 log(BW) + CNR + NF = **-109.16** dBm — **5.16** — -104 dBm

2. Intermodulation Spurious Response Attenuation

In the project work, more like this…

- From calculations
  - Gain = DR + 10 = 34 dB
  - NF = 11.0 dB
  - IIP3 = -21.4 dB

	Duplexer	LNA	BPF	RFA	Mixer	BBA	LPF	BBA	**Total**
Gain(dB)	-2,5	13,5	-3	10	-6	23	-3	5	**37**
NF(dB)	2,5	5	3	5	6	8	3	6	**8,08**
IIP3(dBm)	100	8	100	3,5	10	10	100	10	**-22,3**

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