Integrated Circuits and Systems
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TSEK02 – Radio Electronics

Tutorial 1

Digital Modulation and Transmitter Architectures

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Part A - Digital Modulation

1.1 A standard wired telephone circuit has a usable frequency range extending from 600 Hz to 3000 Hz with a signal-to-noise ratio of about 30 dB. According to the channel capacity expression, what is the maximum data rate that can be achieved with this system?

Answer: 24 kbps

1.2 Evaluate the Shannon channel capacity theorem for an IS-54 cellular phone system. The channel bandwidth is 30 kHz. Assume a receive signal power of -60 dBm and $n_0/2$= 1e-18 W/Hz.

Answer: 420 kbps.

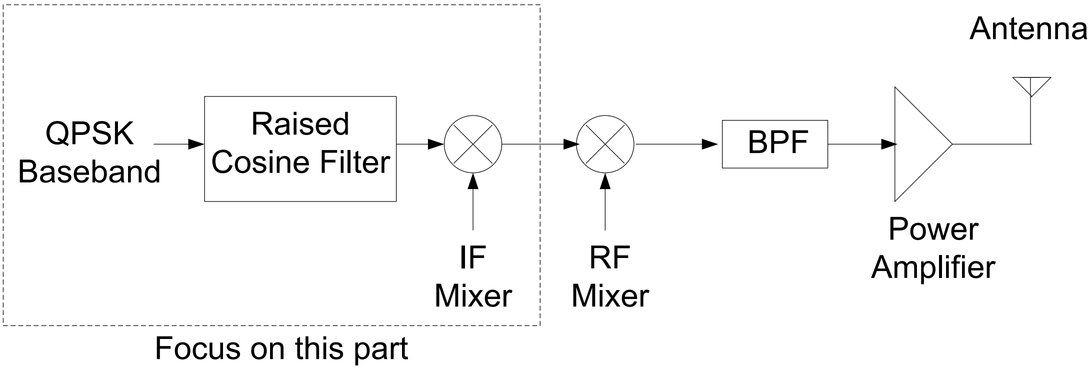
1.3 Compare QPSK, 16QAM and 64QAM modulation schemes in terms of their

a. constellation diagrams
b. I and Q time domain waveforms. For e.g. different configurations of QPSK and 16-QAM are possible, discuss how certain configuration may be advantageous over others.
c. bandwidth efficiency
d. peak power to have the same error probability

Answer: (c) QPSK 2 bits/Hz, 16-QAM 4 bits/Hz, 64-QAM 6 bits/Hz (d) 16-QAM has 9.5 dB higher peak power over QPSK, 64-QAM has 16.9 dB higher peak power than QPSK.

Part B - Transmitter Architectures

1.4 The heterodyne transmitter architecture shown below is used for transmission of a 10 Mbps QPSK modulated signal with raised cosine pulse shape filtering having $\alpha=0.3$. What is the minimum possible choice of the intermediate frequency, IF?

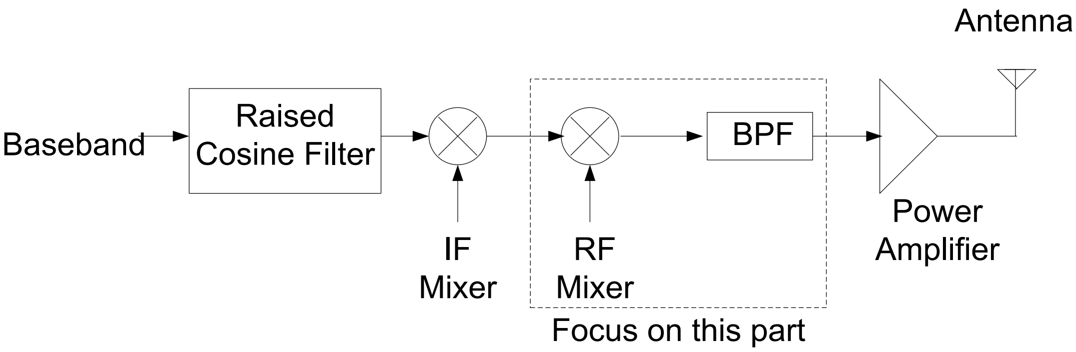


Answer: IF ≥ 6.5 MHz.

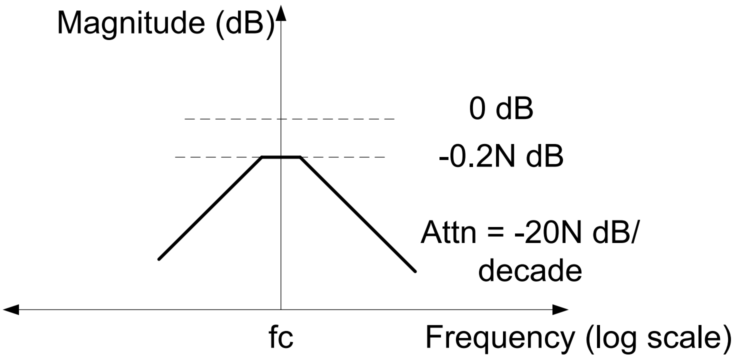
1.5 The heterodyne transmitter in the figure below uses a band pass filter at the output of the second up-conversion mixer to remove the undesired sideband. The band pass characteristics of the filter are also shown in the figure. If the carrier frequency is 500 MHz and the IF frequency is 150 MHz,

a. calculate the filter order required to achieve a sideband rejection of 30 dB,
b. calculate the power loss due to this filter.
c. If the maximum available filter order in the lab is 5, how would you redesign the frequency plan of this transmitter?

In all your calculations assume a narrow band baseband signal so that this can be neglected in your calculations.



TX of problem 1.5



BPF Characteristics of Problem 1.5

Answer: a) Filter order = 7, b) 1.4 dB power loss c) Increase IF to 249 MHz.

1.6 A two-step conversion transmitter is designed similar to problems 1.4 and 1.5. This transmitter should operate in the frequency range of 2.15 - 2.45 GHz with multiple channels of 30 MHz bandwidth. What should be the minimum value of IF required in order for this system to operate properly?

Answer: IF≥ 150 MHz.

Part C - Transmitter linearity

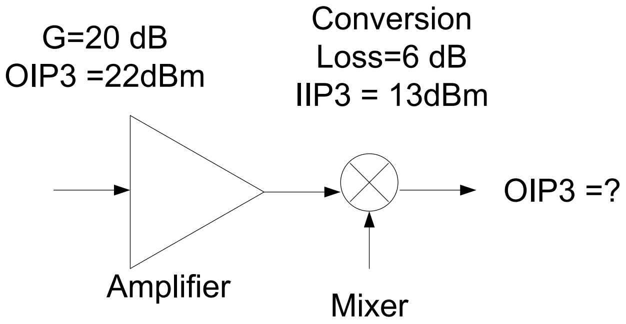
1.7 A transmitter requires the IM3 products to be -65dB below the main tones when the total output power is 20 dBm. Calculate the output IP3 of this transmitter.

Answer: 49.5 dBm

1.8 The output IP3 of the final amplifier in a transmitter is 33 dBm. To reduce the distortion of the transmitted waveforms, this amplifier should operate at a 6 dB back-off mode. What is the peak output signal power that can be transmitted with this transmitter?

Answer: 17.4 dBm

1.9 Calculate the OIP3 of the cascaded stages shown below. How would the performance be affected if the order of stages is reversed?



Answer: a) 6.48 dBm b) 20.8 dBm when the locations are exchanged.

Additional recommended problems to be solved on your own

Important Note: Use the soft cover book version only. The hardcover version has different problems.

1.10 Problem 4.16 in the course book.

1.11 Problem 2.1 in the course book.

1.12 Problem 2.5 in the course book.

1.13 Problem 3.6 in the course book.

Important Note: Always watch out for the scale. Check whether you are in dB scale or the linear scale. This is a very common mistake.

List of Important Formulae

1. Shannon's Channel Capacity Theorem

   $$C = B\times \log_2(1+SNR) = B\times \log_2\left(1+\frac{S}{n_0\times B}\right)\left[{}^{b}/{}_{s}\right]$$

   n_0 is the noise power spectral density in W/Hz, S is the signal power in W, B is the bandwidth, SNR is **NOT** in dB scale. Also note the $\log_2$ which is not the common $\log_{10}$.

2. Bandwidth of a signal shaped by a raised cosine pulse filter is $\frac{1+\alpha}{T_b}$
   α is the roll-off factor, T_b is the original pulse period.

3. Boltzmann's Constant, $k = 1.38 \times 10^{-23}$ J/K.

4. Use a room temperature of 27 °C = 300 K whenever temperature is not specified.

5. Thermal noise power spectral density, PSD=kT. At T=300 K, PSD is -174 dBm/Hz. The PSD is independent of the resistor value. This is true only when the source resistor and the load resistances are matched.

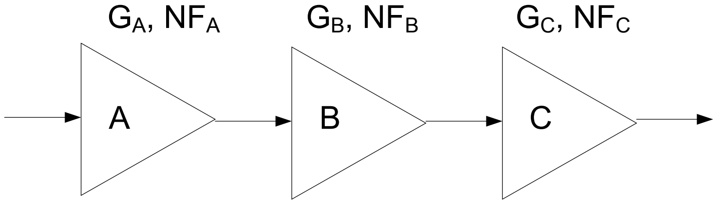
6. Thermal noise power in a bandwidth B: $P_{RS} = kTB$.
   In dB scale at 300 K, the total thermal noise power $P_{RS|dB} = 10\log(kTB) = 10\log(kT)+10\log B$
   => $P_{RS|dB} = -174$ dBm/Hz + $10\log B$

7. Noise Factor [not in dB] $NF = \dfrac{SNR_{in}}{SNR_{out}}$

   Noise Figure [dB] $NF_{dB} = 10\log\left(\dfrac{SNR_{in}}{SNR_{out}}\right) = SNR_{in|dB} - SNR_{out|dB}$

8. Noise figure of a passive lossy component is equal to its loss: NF=L.

9. Effective noise figure of cascaded stages.



$$NF_{total} = NF_A + \frac{NF_B - 1}{G_A} + \frac{NF_C - 1}{G_A G_B}.$$

This is called Friis' equation. This equation is **not in dB**.

10. $IP3 = P_{1db} + 9.6$.
    in dBm and valid for both input and output referred quantities

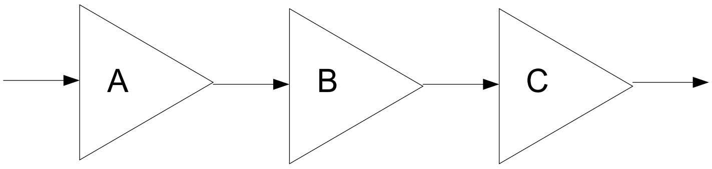
11. Output IP3 of a component can also be calculated from the two-tone test:

$$OIP3\ [dBm] = P_1[dBm] + \frac{\Delta P[dBc]}{2}$$

where P_1 is the power of each of the main tones, ΔP is the power difference between the two tones and the distortion tones.

12. $IP3 = P + \Delta P/2$.
in dBm and valid for both input and output referred quantities.
P is the input/output power in each of the main tones, ΔP is the power difference between the main tones and the distortion tones

13. IP3 of cascaded stages:



Effective IIP3 (in W, **not in dBm/dB**)

$$\frac{1}{IIP3_{total}} = \frac{1}{IIP3_A} + \frac{G_A}{IIP3_B} + \frac{G_A G_B}{IIP3_C}$$, where G is the gain.

If referred to the output, OIP3 becomes

$$\frac{1}{OIP3_{total}} = \frac{1}{G_B G_C \bullet OIP3_A} + \frac{1}{G_C \bullet OIP3_B} + \frac{1}{OIP3_C}$$

14. At 300 K, the power required at the receiver input in dBm for a given output SNR in a bandwidth B is given by $P_{in|dBm} = -174\ dBm/Hz + 10\log(B) + NF_{dB} + SNR_{out|dB.}$.

15. Dynamic Range Linear (referenced to input) **in dB:** $DR_L = P_{1dB}$(referenced to input) - $P_{sen.}$

16. Spurious Free Dynamic Range, SFDR (referenced to input) **in dB:**

$$SFDR = \frac{2\left(P_{IIP3} + 174\ dBm/Hz - NF - 10\log B\right)}{3} - SNR_{\min}$$

This formula assumes that the input noise is thermal at 300 K.

17. After propagation through an ideal channel of R meters, the received power level is given by

$$P_{receive} = P_{transmit} \times G_t \times G_r \times \frac{\lambda^2}{(4\pi R)^2}$$

G_R and G_T are receive and transmit antenna gains and λ is the wavelength given by $\lambda = \frac{c}{f}$, where $c=3*10^8$ m/s.