EECE 690/890
Digital Radio Hardware Design
HW #2
Due Tuesday, 9/8/98

** indicates a problem which is not required for undergraduate (690) students

1. The cordless phone we are developing will operate in the 902 - 928 MHz ISM (Industrial, Scientific, and Medical) frequency band. Using the median of these frequencies, find:

   a) The radio wave's wavelength in meters and in inches.

   b) The length of antenna we will need if we use a 1/4 wavelength monopole design.

2. The FCC (Federal Communications Commission) places a limit on transmitted power in this band of 1 mW. We will put out slightly less power - about -3 dBm. For this transmitted power level, find:

   a) The corresponding power in mW.

   b) The RMS voltage at the antenna, assuming R_{ANT} = 50 Ohms.

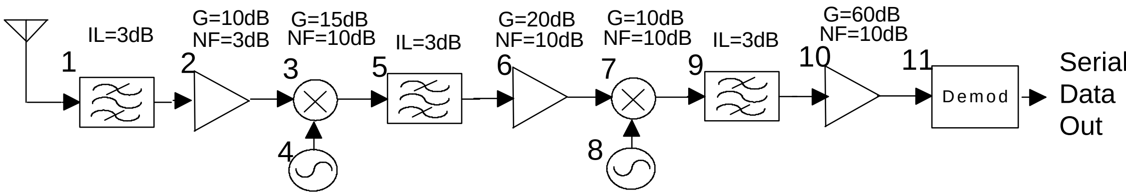
3. The smallest signal we will be able to receive (and hence, the maximum range of our phone) will be limited by noise in the environment, excess noise generated in the receiver (i.e. its "Noise Figure"), the bandwidth of the signal, and the minimum signal-to-noise ratio (S/N or C/N) needed for demodulation. We will use Frequency Shift Keying (FSK) modulation for which C/N must be at least 15 dB. Our bandwidth will be on the order of 200 kHz, and our receiver's noise figure will be around 10 dB. Using these values, find:

   a) The receiver sensitivity (minimum signal level it can receive)

** b) The maximum range of the phone. Assume Gt=2 dB, free-space propagation (for which power density falls off as $1/R^2$), and that the receive antenna effective area is approximately $(\lambda/4)^2$.

** c) Repeat part b using a more realistic "propagation constant" of 4 (i.e. power falls off as $1/R^4$).

4. Our phone will use a "dual-conversion" receiver design similar to that used in modern cell phones:



Note that this design "downconverts" the received signal twice, first to a relatively high intermediate frequency (IF), and then to a lower IF. This is typically done in high frequency radios to make filtering easier. Note also that in this particular dual-conversion design, there is no "image filter". Our first mixer incorporates a modern "image-reject" design that eliminates the need for this filter.

For this receiver:

a) Name each numbered block in the diagram and write a sentence identifying its purpose.

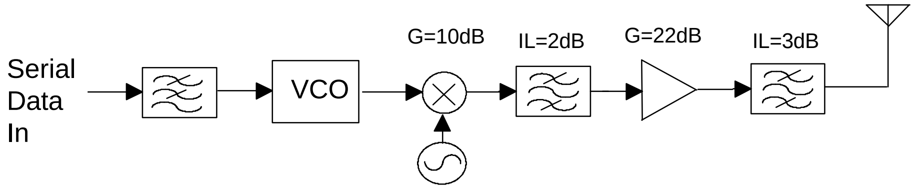
b) Assuming the signal to be received is at 903 MHz, and the first IF is at 45 MHz, find the frequency needed for the oscillator of block 4. There are two possible solutions here.

** c) Find the overall receiver noise figure.

** d) Find the largest signal that can be received before at least one circuit block enters compression. (Assume that the output compression point for all blocks is 0 dBm, and only consider blocks up to the first IF filter).

** e) Recall that our receiver will be connected to the same antenna used for transmitting using a "duplex filter". Assume the receiver is tuned to 903 MHz and the transmitter is at 927 MHz. The receive portion of the duplexer must pass 903 MHz while attenuating 927 MHz enough to prevent receiver compression and desensitization. Using your result from part (d), find the amount (in dB) that the duplexer must attenuate the -3 dBm transmitted signal.

5. Our transmitter will use the architecture shown below:



The lowpass filter at the left will smooth the serial data waveform to limit the bandwidth of the transmitted signal - preventing the transmitter from interferring with other phones on other channels. The VCO (voltage-controlled-oscillator) is our modulator. A logic one will cause the oscillator frequency to go up by about 100 kHz, while a logic zero will cause it to go down by the same amount, producing an FSK signal. The nominal frequency of this oscillator will be in the range of 10 to 50 MHz (to be determined by the RF design team). This signal will then be "upconverted" by the mixer to the transmit frequency (e.g. 927 MHz) where it is amplified to about 0 dBm. The actual transmitted signal power will be about -3dBm as previously mentioned, due to a total of about 3 dB of loss in the duplex filter and PC-board traces leading to the antenna. Given this design and the gains and losses in the figure:

a) Find the required output power of the VCO in dBm. (Remember that gains in dB add, and that the output power in dBm is the input power in dBm plus the overall gain.)

b) Find the LO frequency needed to transmit at 927 MHz, assuming the VCO frequency is 10.7 MHz.

c) What is the purpose of the bandpass filter following the mixer?

6. An important marketing issue in cordless and cellular phones is the so-called talk and standby times. These are a function of battery capacity (in mA-hours) and the current drawn by the phone's electronics. For example, a 600 mA-h battery could allow a phone that draws 60 mA to operate for 10 hours (60 mA times 10 hours = 600 mA-h).

When a user is talking on the phone, both the transmitter and receiver are active and the phone draws the most power (current). Hence, it's "talk-time" is significantly less than "stand-by time" where the phone is either in receive mode (monitoring for in-coming calls), or is "asleep".

A sleep mode is incorporated into almost all modern wireless products to extend standby time. In sleep mode, most of the electronics (except for low-power oscillators and control circuits) are turned off to conserve power. The control circuit periodically wakes up the phone (activates the receiver) in order to check for incoming calls. If nothing is found, the phone returns to sleep. By keeping the active time shorter than the sleep time, battery life can be significantly extended.

a) Assume a 600 mA-h battery is used in our phone and when the user is talking the current drawn by various portions of the electronics are: RX-30 mA, TX-30 mA, digital/baseband-10mA. Find the total talk-time for the phone.

b) Assuming no sleep mode is used, find the standby time. (Assume the TX is off, but the other circuits are active.)

c) Assuming the phone alternates between sleeping for 500 ms and receiving for 20 ms, find the extended stand-by time. (Assume 1mA is consumed in sleep mode.)