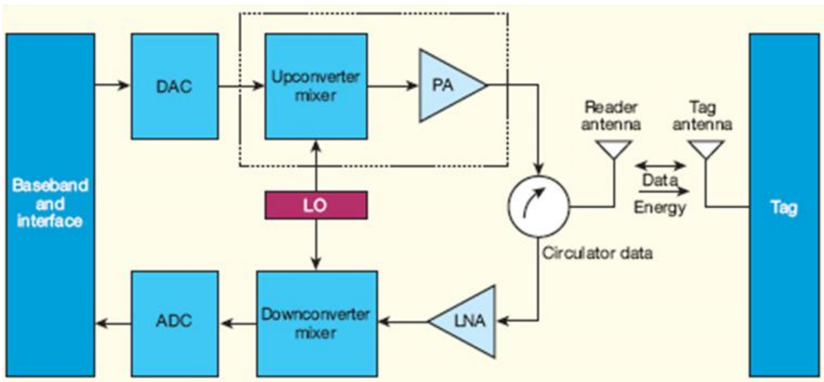
ECE 4880 RF Systems Fall 2016
Homework 5

Due on 9/30/2016 at 5pm in the Phillips Hall dropbox

Reading before homework:

- Lecture summary on Gain Modules and Noises
- Egan's book, Chaps 2 and 3.

1. (**Ideal design of an RFID reader**) A typical RFID reader transceiver block diagram is shown below. The reader listens to the echo modulated by the tag. You can consider that the reader is composed of two radio links: the reader-to-tag downlink and the tag-to-reader uplink. This is a device to be operated around 900MHz with a line-of-sight reading range of 10m. FCC regulation dictates no more than 4W emission in this ISM band.



   (a) First assume that both reader and tag antennas are 0 dBi for the best angle coverage. At the 5m distance, how much power in dBm is impinging on the tag? How much power in dBm is impinging on the reader receiver? What is the link budget (power ratio from TX to RX)? (**5 pts**) If the tag has a RF-to-DC converter of 20% efficiency, how much power in μW can the tag recover for use to execute the air protocol and backscattering modulation? (**5 pts**)

   (b) At the 10m distance, if the circulator provides 60dB rejection and the transmitter can be considered as the main interference for the receiver, what is the signal-to-interference (SIR) ratio in dB? (**5 pts**)

   (c) At the 10m distance, what is the gain in dB needed in the receiving chain so the input to ADC has a minimal voltage amplitude of 10mV? Assume the tag antenna has an impedance of 50Ω. (**5 pts**)

   (d) At the 10cm distance, repeat (a) – (c). Assuming the system is still in the far-field range as 10 cm > $\lambda/2\pi$ (**5 pts**). If this is the minimal distance for the tag to be read, what is the required dynamic range in dB for the reader receiver? (**5 pts**)

   (e) What is the voltage amplitude out of the 50Ω reader transmitting antenna with 36dBm? If the DAC in the transmitter outputs signals with 0.5V voltage amplitude and the PA has a gain of 16 dB, what is the gain needed in the transmitter mixer? (**5 pts**)

   (f) If you are given a reader antenna of 8dBi while the tag antenna still at 0 dBi, assume the range is limited by the power the tag can collect (called tag sensitivity limited or downlink limited), what is the operation range now? At the new maximal range, what is the power in dBm at the reader receiver? (**5 pts**)

   (g) Through some great designs by engineers, the tag sensitivity is improved to –20dBm, with the antenna set in (f), what is the operation range now? At the new maximal range, what is the power in dBm at the receiver? For the same minimal distance at 10cm, what is the present required dynamic range in dB for the reader receiver? (**5 pts**)

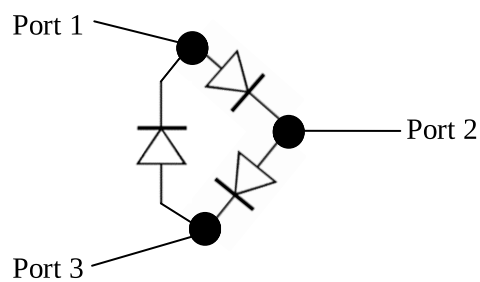
(h) FCC allows operations from 902MHz to 928MHz for this application. If each channel has a 500kHz bandwidth, how many channel can be used? If you are given a 5MHz quartz oscillator for the frequency reference, give an example of the needed *N* and *M* in your rational frequency synthesizer to cover the entire band with a changing LO frequency. (**5 pts**)

(i) The reader uses a "noncoherent amplitude modulation" where the bit rate can just be half of the bandwidth. To leave sufficient channel isolation, you will use a data bandwidth of 200kHz with 150kHz side skirt for better channel isolation. If each data packet has 256 bits, what is the duration of each packet delivered? What is the number of cycles the carrier has gone through for each bit of transmission? (**5 pts**)

(j) With the extended tag sensitivity in (g), if there is a wall with additional 15dB attenuation, , what is the operating range now assuming still the same tag sensitivity limitation at –20dBm? What is the power impinging on the tag and the reader receiver now? (**5 pts**).

(k) The DAC output at the transmitter has many additional frequency components that are up-converted by the mixer. As the PA impedance is around 50 Ω only for the designed bandwidth between 850MHz to 1050MHz, insert a filter after the DAC or after the mixer in the transmitter signal chain to alleviate this problem. Denote the type and give a rough pass/stop band design to the filter. (**5 pts**)

2. (**Circulator considerations**) A student suggests a diode implementation of the circulator for broadband applications as shown above. Choose all correct answers below (can be more than one) (**5 pts**)



(a) The circulator will have a clockwise path only, as the counterclockwise path is always blocked by a reverse leakage diode.

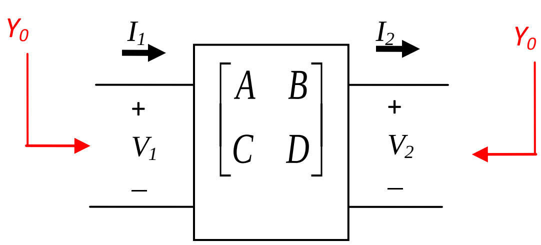
(b) The reverse biased diode from Port 1 to Port 3 may not work well in high frequency due to capacitive coupling.

(c) The circulator will not work well as there is a DC leaky path through Port 1 to Port 3.

(d) Although the circulator will have serious nonlinearity, it will be acceptable in duplex radio transceivers as the signals will always be very small at Port 1 and Port 3.

(e) The impedance at Port 1 and Port 3 will be a strong function of the voltage magnitude, which makes impedance matching difficult.

3. (**ABCD matrix and S parameters**) When we change the view from the traveling waves to static voltages and currents, we have defined the relations of S parameters and the Y matrix as shown below.



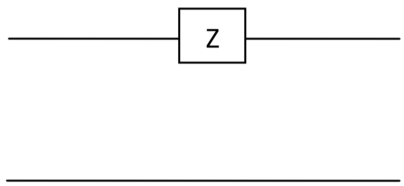
$$I_1 = Y_0(v_{o1} - v_{i1})$$
$$V_1 = v_{o1} + v_{i1}$$
$$I_2 = Y_0(v_{o2} - v_{i2})$$
$$V_2 = v_{o2} + v_{i2}$$

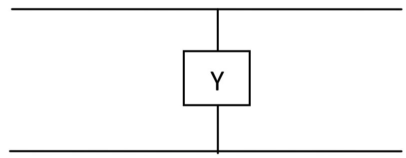
We will still assume that the ports 1 and 2 have admittance of Y_0, and define the ABCD matrix as:

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

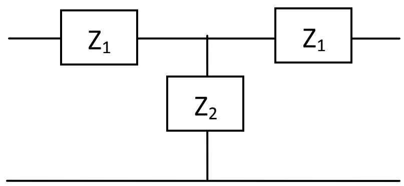
Please be careful that I_2 is defined in the opposite direction with the Y and Z matrix to enable cascading.

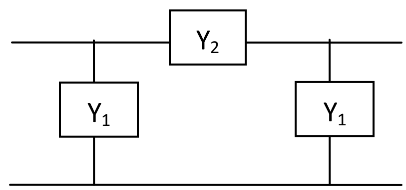
(a) The ABCD matrix is convenient in module cascade just like the T matrix (but T is in the traveling wave view). Write down the ABCD matrix for the two simple cases below. (**5 pts**)





(b) Use the matrix multiplication to find the ABCD matrix for the following two reciprocal T and π networks (**5 pts**)





(c) Express the S matrix with the ABCD parameters. (**5 pts**)

(d) Express the Y matrix with ABCD parameters, and then the ABCD matrix with the Y parameters. (**5 pts**)

(e) The S and T matrices are used for traveling waves, and Y, Z and ABCD (with different definition of I_2 direction) are used for static voltages and currents. They all have their own advantages for the module properties. For a reciprocal network (i.e., the network has symmetry looking from the two ports), we know $Y_{12} = Y_{21}$. What is the requirement on the S and ABCD parameters? Confirm the ABCD parameter property in the T and π networks in (b). (**5 pts**)

(f) For passive lossless network (i.e., no resistive loss or source), we know that all Y parameters are imaginary, i.e., $\mathrm{Re}(Y_{11}) = \mathrm{Re}(Y_{12}) = \mathrm{Re}(Y_{21}) = \mathrm{Re}(Y_{22}) = 0$. Also, all Z parameters are imaginary too. What is the requirement on the ABCD parameters? Confirm the ABCD parameter property in the simple series and parallel element of (a), when $Y = 1/Z = j\omega C$. (**5 pts**)