Lecture 4 / Homework 4 for The Software Defined Radio (SDR) of Purdue VIP

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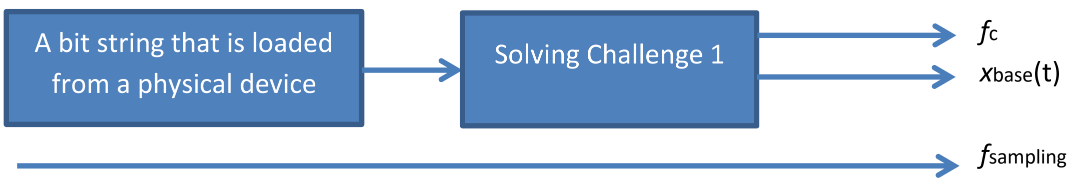
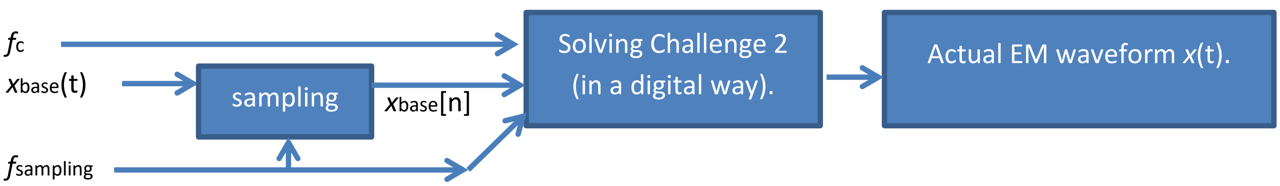
Recap: The main difficulty of learning how to use the USRP is due to the following two challenges, see the diagram as well.

Challenge 1: We need to learn the basic principle of digital communication.
Challenge 2: We need to learn how to implement a communication system in a digital way.



and



Since the USRP only takes f_c, $x_{base}[n]$, and $f_{sampling}$ as input, our goal thus becomes given a bit string b_1, b_2, … b_k, …., how to design the corresponding f_c, $x_{base}[n]$, and $f_{sampling}$ and use them as the input to the USRP. Also notice that the carrier frequency f_c is usually licensed from FCC and thus is hard to control, and the parameter $f_{sampling}$ is limited by the hardware specficiation of the USRP, which is also beyond our control. As a result the main goal of the digital communication system design is

Main goal:

Given a bit string b_1, b_2, … b_k, …., and the pre-specified system parameters takes f_c and $f_{sampling}$, how to design the corresponding $x_{base}[n]$ as the input to the USRP.

In p. 4 of Lecture 3, we have discussed a 3-step process how to generate from a bit string b_1, b_2, … b_k, …., to the corresponding $x_{base}[n]$. The 3-step process described in p. 4 of Lecture 3 is limited to the following parameters (1) sending 3 bits b0, b1, and b2; (2) target bit rate is 2bps; (3) the assumed sampling rate is $f_{sampling}$=20Hz; and (4) the $f_0(t)$ used in the process is described by $f_0(t)$=sinc(t/T), where T=0.5 seconds is the time shifting parameter.

The following is a more general description of how to generate $x_{base}[n]$ in a more general setting. The question we are trying to solve is

Setting:

Recall from p. 3 of Lecture 1 that we can send a group of 2 bits using 4 distinct waveforms. If we would like to send k groups of 2 bits, then we can finish transmissions within k*T seconds. The overall data rate is (2k)/(kT)=2/T bps. For the following, we will demonstrate how to send a group of M bits using 2^M distinct waveforms. If we would like to send k groups of M bits, then we can finish transmissions within k*T seconds. The overall data rate is (kM)/(kT)=M/T bps.

The following 4-step process describes how to (1) convert the kM bits into $x_{base}[n]$ with the group size being M bits and the shift parameter being T; (2) target bit rate is M/T bps; (3) the assumed sampling rate is $f_{sampling}$; and (4) the $f_0(t)$ used in the process is described by a general form $f_0(t)=f_{filter,T}(t)$, where $f_{filter,T}(t)$ is a function depending on the T value of the system.

Task 1:

Compare the scheme described in the later part of this lecture notes with the 3-step process in p. 4 of Lecture 3. Make sure that you understand that the setting in this page is simply a generalization of the setting for p. 4 of Lecture 3.

Task 2:

We know that we have kM bits to be sent out in groups of M bits. How many entries are there in $x_{base}[n]$?

A general 4-step process

Step 0: We choose a so-called "symbol mapper" $f_{Sym}(b_1 b_2 \ldots b_M)$ that takes M bits as input and output a complex number. For example, when M=4, one popular choice is

Equation 1

$f_{Sym}(b_1 b_2 b_3 b_4)$=2(-1)^b_1+(-1)^b_2 + j(2(-1)^b_3+(-1)^b_4)

Task 3:

For the above choice of $f_{Sym}(b_1 b_2 b_3 b_4)$, what is the value of $f_{Sym}(0111)$? Plot $f_{Sym}(0111)$ in a complex plane. (Note that this choice of $f_{Sym}(b_1 b_2 b_3 b_4)$ is usually called 16QAM.)

Step 1: Convert the analog waveform $f_{filter,T}(t)$ through sampling with sampling rate $f_{sampling}$ Hz. Denote the output by $f_{filter,T}[n]$.

Step 2: Since the target throughput is M/T bps and the sampling rate $f_{sampling}$ Hz, we see that a kM-bit string b[1] to b[kM] will eventually be converted to an x_{base}[n] array with kT$f_{sampling}$ entries. We first construct a kT$f_{sampling}$ -entry array $b_{upsampling}$[n] as follows. If n is a multiple of T$f_{sampling}$, then set the value of $b_{upsampling}$[n] to the value of f_{Sym}(b[nM/(T$f_{sampling}$)+1],b[nM/(T$f_{sampling}$)+2], ..., b[nM/(T$f_{sampling}$)+M]). If n is not a multiple of T$f_{sampling}$, then set the value of $b_{upsampling}$[n] to zero.

(This step is sometimes called upsampling.)

Step 3: Compute x_{base}[n] by taking the *convolution sum* of $b_{upsampling}$[n] and $f_{filter,T}[n]$.

Task 4:

Compare the above steps with the 3-step process in p. 4 of Lecture 3. Make sure that you understand that the new 4-step approach in this document is simply a generalization of the steps in p. 4 of Lecture 3. Answer the following question: How to choose the M value, the symbol mapper $f_{Sym}(b_1b_2\ldots b_M)$, the T value, and the k value so that the above 4-step process collapses to the 3-step process in p. 4 of Lecture 3?

Task 5: Discuss with TA for this task.

When using M=4 and the $f_{Sym}(b_1b_2\ldots b_M)$ described in Equation 1 with T=0.5, what is the *continuous time* complex-valued waveform x_{base}(t) when we are sending 8 bits b_1 to b_8 = 01101100? You can assume that the f_0(t)=$f_{filter,T}$(t) we use is simply sinc(t/T). However, make sure you know how to answer this question for arbitrary $f_{filter,T}$(t). If you can only look at the x_{base}(t), are you able to deduce the values of the original b_1 to b_8? Hint: you need to look at the real and the imaginary part of xbase(t) separately.

Task 6:

When M=6, a popular choice of $f_{Sym}(b_1b_2\ldots b_M)$ is

Equation 2

$f_{Sym}(b_1b_2b_3b_4b_5b_6)$=4(-1)^$b_1$+2(-1)^$b_2$+(-1)^$b_3$+ j(4(-1)^b_4+2(-1)^b_5+(-1)^b_6)

For the above choice of $f_{Sym}(b_1b_2b_3b_4b_5b_6)$, what is the value of f_{Sym}(011110)? Plot f_{Sym}(011110) in a complex plane. (Note that this choice of $f_{Sym}(b_1b_2b_3b_4b_5b_6)$ is usually called 64QAM.) Can you derive a rule how we designed this particular $f_{Sym}(b_1b_2b_3b_4b_5b_6)$? What if we are interested in M=8? What will be the corresponding $f_{Sym}(b_1b_2b_3b_4b_5b_6b_7b_8)$?