Lecture 3 / Homework 3 for The Software Defined Radio (SDR) of Purdue VIP

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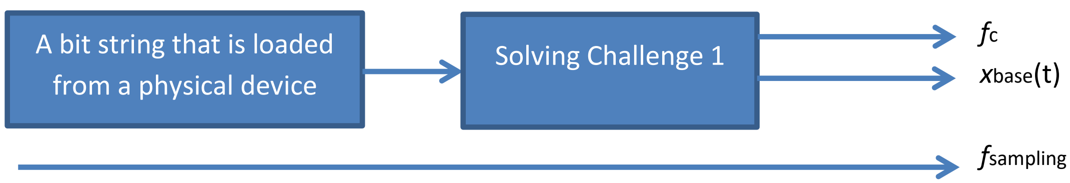
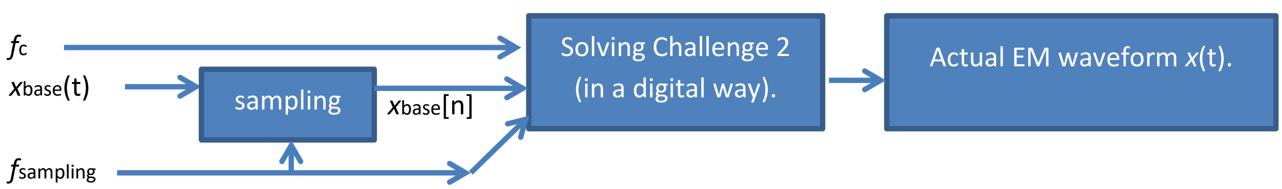
Recap: The main difficulty of learning how to use the USRP is due to the following two challenges.

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.

When we can solve the above two challenges simultaneously, we can successfully use the USRP to perform digital communications. In particular, we are interested in the following combined system



and



where the actual transmitted signal will be

Equation 1

$x(t)= x_{base,Re}(t) \cos(2\pi f_c t) - x_{base,Im}(t)\sin(2 \pi f_c t)$

Recall that the "carrier frequency" f_c and the "base-band signal" $x_{base}(t)$ are designed choices that can be chosen by the system designer. On the other hand the "sampling frequency" $f_{sampling}$ is specified by the hardware (the USRP) and cannot be changed by the USRP system designer.

Simple examples of the above combined system

Example 1: Suppose that we would like to send three bits b_0=1, b_1=1, b_2=0 using the $f_0(t)$ and $f_1(t)$ waveforms described in Lecture 1, Equations 1 and 2. Namely, the time-shift parameter is T=3, or equivalently, the intended transmission rate is 1/3 bps. Also suppose that the sampling frequency of the hardware is 10Hz.

Task 1: How many bits do we send in 9 seconds?

Task 2: What is the $x(t)$ (see Lecture 1) when we send b_0=1 b_1=1 and b_2=0 according to the f_0(t) and f_1(t) specified in Lecture 1, Equations 1 and 2? Plot x(t) by hand.

Task 3: How do you choose the carrier frequency f_c and the base-band signal $x_{base}(t)$ (see Lecture 2) to represent the x(t) specified in the previous task?

Task 4: Suppose we are using the digital communication system for time t=0 to 9 seconds. How many entries are there in $x_{base}[n]$? Write down the first 10 entries of $x_{base}[n]$.

Example 2: Suppose that we would like to send three bits b_0=1, b_1=1, b_2=0 at a rate 2 bps using the $f_0(t)$ and $f_1(t)$ waveforms described in Lecture 1, Equation 3. (NOT Equations 1 nor 2) Also suppose that the sampling frequency of the hardware is 20Hz.

Task 5: (Roughly) how many seconds does it take to finish sending 3 bits?

Task 6: What is the $x(t)$ (see Lecture 1) when we send b_0=1 b_1=1 and b_2=0 according to the f_0(t) and f_1(t) specified in Lecture 1, Equation 3? Plot x(t) by MATLAB.

Task 7: How do you choose the carrier frequency f_c and the base-band signal $x_{base}(t)$ (see Lecture 2) to represent the x(t) specified in the previous task?

Task 8: Suppose we are using the digital communication system for time t=0 to 2 seconds. How many entries are there in $x_{base}[n]$? Write down the first 10 entries of $x_{base}[n]$. You should try to solve Task 8 by yourself first. If you do not know how to solve it, take a look at the following paragraph.

As you can see, Task 8 is not an easy task. One simplest way is to look at the signal plot by MATLAB and find out the "sample points" on the signal. Obviously, this inspection-based method is not very accurate. The following is a step-by-step way of solving Task 8.

Step 1: We write down the mathematical expression of the $x_{base}(t)$ based on Lecture 1, Equation 2 and on Lecture 1, Equation 3 (but with a different time-shift parameter T).

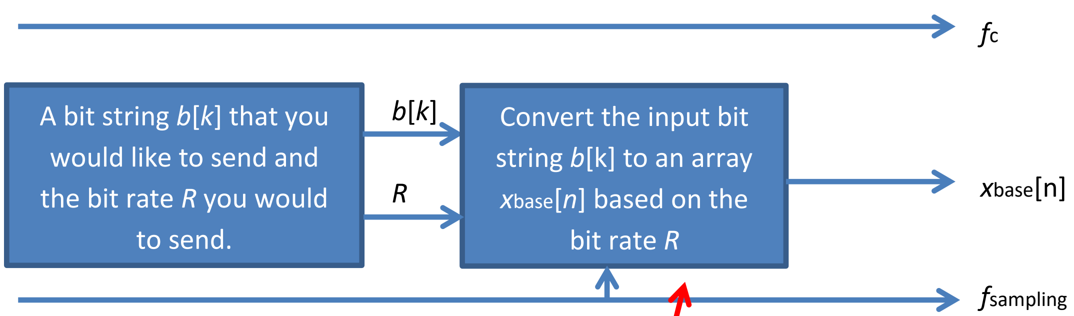
Step 2: We plug in the sampled points t=0, 0.1, 0.2, ….., n ($1/f_{sample}$), and use a calculator to find out exact value of the first 10 entries.

You should be able to use the above two steps to solve Task 8.

Task 9: Repeat Task 8, but this time we are interested in sending 10 bits 0010110111 with rate 2bps and in sampling frequency 20Hz.

A Simplified Interface of USRP

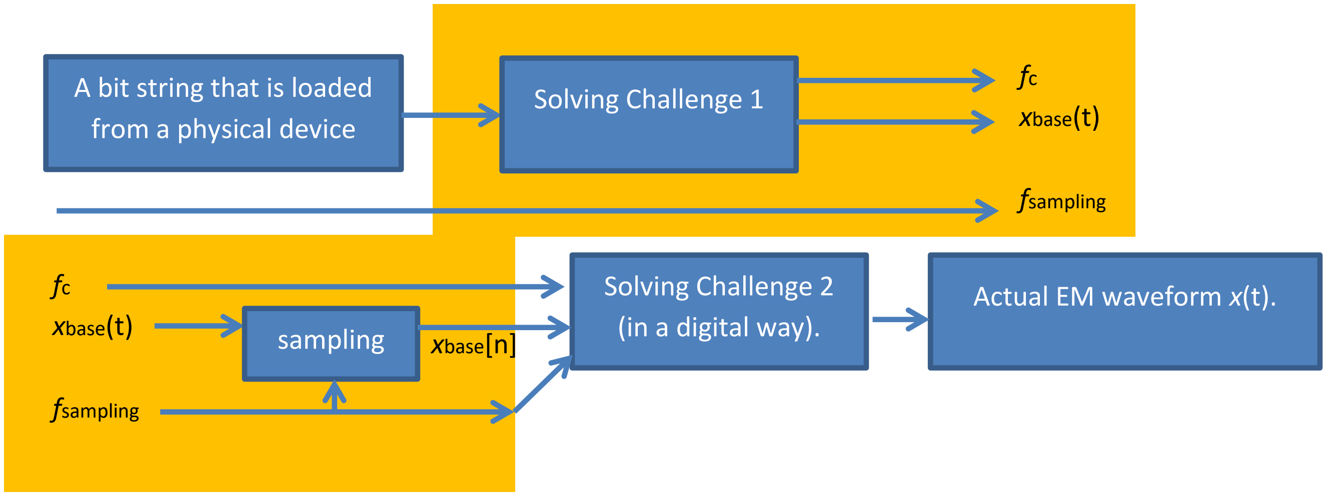
The simplest diagram of using a USRP is as follows.



and

That is, USRP only takes f_c and $x_{base}[n]$ as the input and it does not care about how we generate $x_{base}[n]$. (Recall that $f_{sampling}$ is specified by the hardware and we cannot change this parameter). As a result, it is the user's responsibility to "implement" <u>this block</u>.

If we compare the above diagram of this page to the diagram in the very beginning of this document, it is clear that that the mapping between the digital communication blocks and the USRP interface is following.



That is, the task of "converting the input bit string (array) $b[k]$ to an array $x_{base}[n]$ based on rate R" is described by the shaded area of the above figure. That is why we are interested in solving Task 8 in the first place, which tells us how to convert bit string (3 bits in our example), to an array $x_{base}[n]$ acceptable by USRP as input under the given sampling frequency $f_{sampling}$.

As you can see Tasks 8 and 9 become very tiresome when the length of the bit array b[k] is very long. It turns out that there is another way of solving Task 8.

Step 1: Convert the analog waveform $f_0(t)$ through sampling with sampling rate 20Hz. Denote the output by $f_0[n]$.

Step 2: Since the target throughput is 2bps and the sampling rate is 20Hz, we see that a 3-bit b[k] will be converted to a 30-entry $x_{base}[n]$. We first construct a 30-entry array $b_{upsampling}[n]$ as follows. If n is a multiple of 10, then set the value of $b_{upsampling}[n]$ to the value of $(-1)^{b[n/10]}$. If n is not a multiple of 10, 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 $f_0[n]$.

Task 10: Discuss with TA and with your classmates to see why the above two methods (first method is described in p. 2 and the second method is described in the above paragraph) will yield the same $x_{base}[n]$.

Task 11: In practice the second method is much more systematic and is thus more popular than the first method. Can you see why people prefer the second approach?

The above discussion illustrates how to combine the two challenges together. It also shows how the solution of the two challenges can be used when designing an input array $x_{base}[n]$ that is acceptable by a USRP.

Thus far, we have concluded our discussion of using USRP as a transmitter. Next time, we will discuss how to use USRP as a receiver.