INEL 4301 – COMMUNICATION THEORY
ENGINEERING DESIGN PROJECT
Due – 11:50 PM, Fri., Nov. 19, 2021

Prof. Domingo Antonio Rodríguez – Fri., Oct. 01, 2021

Analog and Digital Deep Underwater Acoustic Communications Using Double Sideband Suppressed Carrier Communication Systems

The objective of this **design project** is to use a double sideband suppressed carrier (**DSB-SC**) communications system for the transmission & reception of **dtmf signals** using analog **(Part 1)** and digital **(Part 2)** communications in an **underwater medium**. In this engineering project, a **uniformly time-sampled** signal is considered to be an analog signal if $20 \log_{10} R_a < -90 \text{ dB}$, where R_a is defined as its **amplitude resolution**.

Part 1.- ANALOG COMMUNICATIONS:
The **maximum frequency content** of an analog continuous-time **dtmf** signal is assumed to be $F_V = 2000Hz$ and the "**one-sided**" **channel bandwidth** is said to be e $B = 12000Hz$. A receiver must be designed to recover the signal $x_r(t) \approx s(t)$ (see ***Fig. 3***).

The channel itself is modeled as a composition of two basic systems, an **ideal**, **linear phase**, **low-pass filter** T_C, with ***cut-off frequency*** $\boldsymbol{f = F_L}$, and a signal **summing system**, T_N, where the channel **underwater noise signal**, $n(t)$, is added to the output of the linear phase filter T_C. This DSB-SC communications channel is given the name $T_{CN} = T_{AM}$ (see ***Fig. 2***).

The overall sampling frequency of the DSB-SC communications system must be set to a value greater than **twice the maximum frequency** (**Nyquist-Shannon sampling theorem**) content of the output of the demodulator at the receiver side. That is, $F_S > 2(2f_c + F_V)$, where f_c is the carrier frequency of the modulator (demodulator) and must be $6000 < f_c < 10000$.
The input signal $x_m(t) = s(t) + g(t)$ to the modulator is the sum of a "**wanted**" **dtmf** signal $s(t)$ and an "**unwanted**" **interference signal** $g(t)$. After the demodulator, an ideal, linear phase, low-pass filter, T_L is used, with cut-off frequency $F_M = 2000Hz$, to recover the "**wanted**" **dtmf** $s(t)$ (see ***Fig. 1***).

Part 1.- PROJECT TASKS:

1. **Design** an ideal, linear phase, **band-pass filter** to eliminate the input interference signal $g(t)$. Important **figures of merit** to rate this task will be center frequency, filter's order, and filter's bandwidth.

2. **Design** an ideal, linear phase, **low-pass filter** to model the channel filter T_C. Important **figures of merit** to rate this task will be filter's bandwidth and filter's order.

3. **Modify** the power of the noise signal $n(t)$ and describe the computed channel's output **signal/noise ratio** (SNR) characteristics. For this task, assume the SNR at the channel's input is equal to $80\,dB$. Important **figures of merit** to rate this task will be the lowest SNR obtained at the channel's output, allowing **intelligibility** of the wanted output signal, as well as the average and variance values of the **AWGN**.

4. **Design** an ideal, linear phase, **band-pass filter** T_R to reduce the **receiver's noise** and improve the **signal/noise ratio** at the input of the demodulator's subsystem when compared to the **signal/noise ratio** at the output of the channel; that is, by comparing the **spectral densities** between the channel output signal $y_{co}(t)$ and the demodulator input signal $y_{di}(t)$. Important **figures of merit** to rate this task will be center frequency, filter's order, filter's bandwidth, as well as the highest SRN obtained at the filter's output.

5. **Design** a linear phase, **low-pass filter**, with cut-off frequency $F_V = 2000Hz$ for the receiver's filter T_L. The most important figure of merit for this task will be the lowest time-delay, $D_r = \left(\frac{M_L-1}{2}\right)T_s$, obtained for this filter, where M_L is the order of the filter and $T_s = \frac{1}{F_s}$ is the overall **sampling time** of the system.

6. **Design** an ideal, linear phase, **band-pass filter** (**upper sideband**) to eliminate the input interference signal $g(t)$. Proceed to leave all the designed subsystems without modifications, except for the **band pass filter** at the **transmitter** which will be modified and substituted by this new **upper sideband** band pass filter. Important **figures of merit** to rate this task will be the filter's order.

Part 2.- DIGITAL COMMUNICATIONS:

In this part of the design project, an analog modulating signal is **quantized** in order to produce a digital signal which serves as input to the modulator of the designed system in **Part 1**.

Part 2.- PROJECT TASKS:

2.1 **Proceed** to quantize the modulating signal $x_m(t)$ used in **Part 1** of the project. **Record** the output signal $x_{mq}(t)$ of the quantizer. A figure of merit for this task will be the lowest number of quantization levels used. Record **intelligible** $x_r(t)$.

2.2 **Proceed** to quantize the desired or wanted signal $s(t)$ and the interference or unwanted signal $g(t)$, separately. Use this added quantized signal $\overline{\overline{x_{mq}}}(t)$ as a new modulating signal for the system, repeating **Task 2.1**, above.

Hand in a formal design report in **.pdf** format and name the script for **Part 1** "**s086gpzz115**" and the script for **Part 1**, **Task 6**, "**s086gpzz166.**" Name the script for **Part 2.1** "**s086gpzz201**". Name script for **Part 2.2** "**s086gpzz202.**" These script files must plot, in the time domain, segments of the input signals and output signals of every subsystem of the designed DSB-SC system. It must also plot the entire frequency axis of the magnitude of the spectrum of every input signal and output signal of every subsystem of the designed DSB-SC system. Please, follow these **report format guidelines**.

Hand in the following **.WAV** files:

S086GPZZ_EDP_INP1s (input **Part 1**: $s(t)$ = "dtmfzz.wav")
S086GPZZ_EDP_INP1g (input **Part 1**: $g(t)$ = "uwtdzz.wav")
S086GPZZ_EDP_INP1n (input **Part 1**: $n(t)$ = "noiszz.wav")
S086GPZZ_EDP_INP1x (input **Part 1**: $x_m(t) = s(t) + g(t)$ = "dtmfzz.wav"+uwtdzz.wav)
S086GPZZ_EDP_INP2s (input **Part 2**: $\boldsymbol{Q}\{s(t)\}$ = "qdtmfzz.wav")
S086GPZZ_EDP_INP2g (input **Part 2**: $\boldsymbol{Q}\{g(t)\}$ = "quwtdzz.wav")
S086GPZZ_EDP_INP2qa (input **Part 2**, **Task 1**: $x_{mq}(t) = \boldsymbol{Q}\{s(t) + g(t)\} = \boldsymbol{Q}\{x_m(t)\}$)
S086GPZZ_EDP_INP2aq (input **Part 2**, **Task 2**: $\overline{\overline{x_{mq}}}(t) = \boldsymbol{Q}\{s(t)\} + \boldsymbol{Q}\{g(t)\}$)

S086GPZZ_EDP_OUP115 (output **Part 1**, **Tasks 1-5**: $x_r(t) \approx$ "dtmfzz.wav")
S086GPZZ_EDP_OUP166 (output **Part 1**, **Task 6**: $x_r(t) \approx$ "dtmfzz.wav")
S086GPZZ_EDP_OUP201 (output **Part 2**, **Task 1**: $x_r(t) \approx \boldsymbol{Q}\{s(t) + g(t)\}$)
S086GPZZ_EDP_OUP202 (output **Part 2**, **Task 2**: $x_r(t) \approx \boldsymbol{Q}\{s(t)\} + \boldsymbol{Q}\{g(t)\}$)

Remarks:

1.- Here, $\boldsymbol{Q}$ is a Uniform Quantizer System.
2.- You must design your own $s(t)$ signal to test your system.
3.- You must design your own $g(t)$ signal to test your system.
4.- You must design your own $n(t)$ signal to test your system.
5.- For **Part 1**, **Task 6** you need to submit the requested m-script file. This script file is going to be the same as the script for **Part 1**, **Tasks 1** to **5**. The only difference will be the designed upper single sideband, band-pass filter.

Name of **.zip** folder and the name of the **e-mail subject**:

Inel4301_MCWDP_SXXX_GPZZ

REMEMBER TO INCLUDE TAT INFORMATION