Computational homework

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Simulink-based implementation of an $\boldsymbol{M}$-QAM modem

Digital communication systems

Telecommunication Engineering

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Problem 1 Develop a Matlab function that calculates a bit sequence in Gray encoding. It must input the number of bits (an integer value) and output the bit sequence. For example, for a sequence of 3 bits, your function must return

```
    >> get_gray_codes(3)

ans =

     0     1     1     0     0     1     1     0
     0     0     1     1     1     1     0     0
     0     0     0     0     1     1     1     1
```

where each column corresponds to a sequence (from the left to the right) of 3 bits in Gray encoding. The first row is the least significant bit (LSB) and the last row is the most significant bit (MSB).

Tips:

1. Before generating the Gray encoding, first generate the bit sequence without any encoding, i.e.,

```
>> original

original =

     0     1     0     1     0     1     0     1
     0     0     1     1     0     0     1     1
     0     0     0     0     1     1     1     1
```

2. Transforming the uncoded bit sequence into Gray encoding is easier if you use a recursive function. See here.

Note: For the following problems, use the Simulink template provided by the professor.

1 Baseband modulator

Problem 2 Generate a bit stream with the following parameters:

- Bit rate: $R_b = 10\,\text{Mbit/s}$.
- Equiprobable bits.

Problem 3 Use a block called "Matlab function" to create a function that maps a stream of $N_b = \log_2(M)$ bits to a complex symbol from a constellation of $M = 256$ symbols. The real and imaginary part of each constellation point, must be spaced as Proakis suggests, i.e., $\left\{\pm 1, \pm 3, \ldots, \pm\sqrt{M}\right\}$. Moreover, the mapping of the real/imaginary part to the complex symbol must be in the Gray encoding sequence (see [3] for more info).

(a) What is the new operating rate of the system?

(b) Use a block called "Gain" to apply a gain of $\sqrt{E_g}$ to the complex symbol outputs, where $E_g = 9$.

(c) By using a block called "Constellation Diagram", show that each point in the constellation is now in the form $\sqrt{E_g}A_m$, where $A_m = A_{mi} + jA_{mq}$ is the constellation for the mth symbol and that $A_{mi}, A_{mq} \in \left\{\pm 1, \pm 3, \ldots, \pm\sqrt{M}\right\}$. Note that the kth transmitted symbol can be represented by the vector

$$\mathbf{s}_m[k] = \begin{bmatrix} A_{mi} & A_{mq} \end{bmatrix}^\top \in \mathbb{R}^2 \tag{1}$$

Tips:

1. Use the "Buffer" block to vectorize the bit stream to N_b symbols and use it as input of the "Matlab function".
2. You can pass a matrix of the sequence of bits with Gray encoding to the "Matlab function" block. You can use your function developed in Problem to generate this matrix.

Problem 4 Pass your symbol stream through the "Raised Cosine Filter block" with the following parameters

- Roll-off factor: 0.2.
- Filter span (in symbols): 4.
- Number of samples per symbol: $N = 100$ samples.

The filter gain must be adjusted so that the energy of the discrete-time impulse response is 1.

Tips:

1. You can obtain the impulse response of the Raised Cosine Filter and compute numerically its energy (it is an finite impulse response (FIR) filter as the impulse response is truncated).
2. Use the "square" and the "mean" block to check if the input and output energy remain unchanged after the filtering.

(a) What is the new operating rate of the system? Why has the operating rate changed to this value?

(b) Check if the raised cosine filter obeys the Nyquist criterion for non-intersymbol interference (ISI). Use the "scope" block to prove your answer graphically.

2 Upconverter

Problem 5 Use a block called "sine wave" (from the DSP system toolbox) with the following parameters

- Amplitude: $\sqrt{2}$;
- Frequency: $f_c = 100\,\text{MHz}$;
- Sample mode: Discrete;

- Output complexity: Complex;

The sampling rate must be consistent with the sampling rate of your system. Let us denote the baseband (BB) pulse shaping (i.e., the raised cosine filter) of your system as $g(t) \in \mathbb{R}$, whose energy is denoted as E_g. Then the pre-envelope (or analytic signal) of the mth symbol is

$$s_{m+}(t) = s_{ml}(t)\, e^{j2\pi f_c t} \in \mathbb{C}, \tag{2}$$

where $s_{ml}(t) = A_m g(t) \in \mathbb{C}$ is the complex envelope (or lowpass equivalent) of the real-valued transmitted signal for the mth symbol,

$$s_m(t) = \sqrt{2}\,\mathrm{Re}\left\{ s_{ml}(t)\, e^{j2\pi f_c t} \right\}. \tag{3}$$

The pre-envelope has important properties concerning the spectrum of the transmitted signal. The output of the block named "sine wave" should exactly be the pre-envelope discussed in the literature. By using the "Spectrum Analyzer" block, make a mathematical analysis of this signal, and compare its theoretical spectrum with the spectrum obtained in Simulink. Good references can be found in [1–3]

References

[1] Umberto Mengali. *Synchronization Techniques for Digital Receivers.* Springer Science & Business Media, 1997.

[2] Heinrich Meyr, Marc Moeneclaey, and Stefan A. Fechtel. *Digital Communication Receivers: Synchronization, Channel Estimation, and Signal Processing.* Vol. 444. Wiley Online Library, 1998.

[3] John Proakis and Masoud Salehi. *Digital Communications.* 5th ed. edição. Boston: Mc Graw Hill, Jan. 1, 2007. ISBN: 978-0-07-295716-7.