Laboratory Lesson 2

Digital Communications (EITG05)

Lund University
Department of Electrical and Information Technology

Signal alternatives, bit rate, and bandwidth

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Contents

1 INTRODUCTION

The purpose of the laboratory lessons is to give an increased understanding of commonly used digital communication methods. In this second session, we focus on the ML receiver and its bit error probability.

Note: if you have not managed to complete all steps of the previous session, you can finish them before proceeding with Part C.

2 HOME PROBLEM

(To be solved at home ***before*** this laboratory lesson.)

1. In a binary communication system with equiprobable signal alternatives the received signal is $r(t) = z_\ell(t) + N(t)$ if message m_ℓ is sent in $0 \leq t \leq T_b$, $\ell = 0, 1$. The noise $N(t)$ is AWGN with $R_N(f) = N_0/2$, and $z_\ell(t) = \alpha s_\ell(t)$, where $\{s_0(t),\ s_1(t)\}$ are the signal alternatives used by the transmitter. The parameter α represents the influence of the communication channel. The average signal power in $z(t)$ is denoted P_z, and the receiver is ML. If the bit rate is 38.4 kbps, and if BPSK is used then it is known that the bit error probability equals 10^{-5}.

   i) Calculate the bit error probability if the bit rate is increased to 384 kbps, while keeping P_z unchanged. Conclusion?

   ii) What is the relationship between the average transmitted energy per information bit denoted $\bar{E}_{b,sent}$, and the average received energy per information bit denoted $\mathcal{E}_b$?
   Is it $\bar{E}_{b,sent}$ or $\mathcal{E}_b$ that determines the bit error probability?

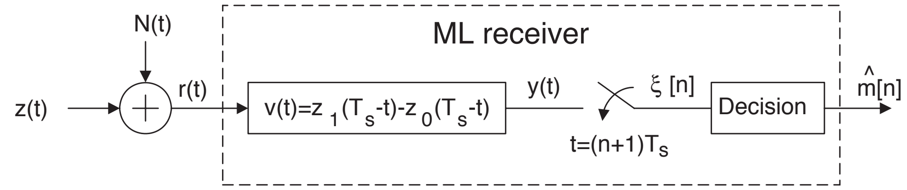
   iii) Is it true that a 20 dB loss in signal energy is obtained if $\alpha = 1/10$?

3 LABORATORY EXERCISE C: The bit error probability

Part C1: Binary RZ (Return-to-Zero) PAM

Execute the file **brus1.m**

Three figures are shown on the screen. Each figure shows ***the information carrying signal $z(t)$*** ($z_1(t), z_0(t), z_0(t), z_1(t), \ldots$), ***the additive noise $N(t)$***, ***the received noisy signal $r(t)$***, and ***the output signal $y(t)$*** from the receiver filter $v(t)$, see below.



The ML receiver above is identical with Figure 4.10 on page 247 in the compendium. ***The average received signal energy per information bit $\mathcal{E}_b$*** is the same in the three figures, but ***the noise parameter N_0*** is different.

Figure 1 $\longleftrightarrow$ $\mathcal{E}_b/N_0 = 1$ (i.e. 0 dB)
Figure 2 $\longleftrightarrow$ $\mathcal{E}_b/N_0 = 5$ (i.e. $\approx$ 7 dB)
Figure 3 $\longleftrightarrow$ $\mathcal{E}_b/N_0 = 10$ (i.e. 10 dB)

Is it possible in Figure 3 to observe the signal $z(t)$ in the noisy signal $r(t)$? ......
....

Is it possible to modify the receiver above such that the bit error probability is reduced? ....
....

Note that the dashed (red) $y(t)$-curve is the ideal *noise-free* version of $y(t)$, i.e. the output obtained if there were no additive noise in the received signal. A rectangular input signal gives a triangular output signal. Note also that $y(t)$ is quite "similar" to the red curve!
Consequently, the filter $v(t)$ reduces the effect of the noise significantly!!

How is the value $y(5T_s/2)$ used by the receiver above? ....
....

Is a decision error (i.e. bit error) made at $t = 7T_b$ for the specific realization of $y(t)$ in Figure 3?

. . . .

How many decision errors are made for the specific realization of $y(t)$ in Figure 3?

. . . .

Calculate the bit error probability for the receiver in Figure 3 (use a known formula).

$P_b =$ . . . .

Calculate the bit error probability for the receiver in Figure 1 (use a known formula).

$P_b =$ . . . .

Part C2: Binary NRZ PAM

Execute the file **brus2.m**

Three figures are shown on the screen. The difference compared to Part C1 is that now we use NRZ signal alternatives (**N**on-**R**eturn-to-**Z**ero).

Calculate the bit error probability for the receiver in Figure 3 (use a known formula).

$P_b =$ . . . .

Why are these signal alternatives better than those in Part C1.

. . . .

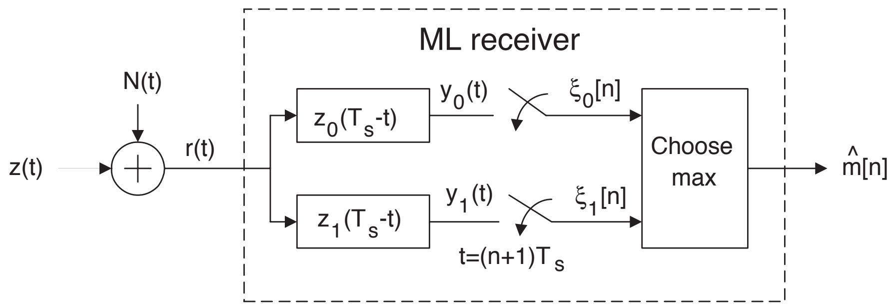
. . . .

Part C3: Binary orthogonal FSK

Execute the file **brus3.m**

Three figures are shown on the screen, as before corresponding to $\mathcal{E}_b/N_0 = 1$, $\mathcal{E}_b/N_0 = 5$ and $\mathcal{E}_b/N_0 = 10$ respectively.

The signal alternatives are here binary orthogonal FSK with $f_1 = 2f_0$, and the receiver below is used (compare with Figure 4.9 on page 245 in the compendium).



Study the ***noise-less versions*** of $y_0(t)$ and $y_1(t)$ in Figure 3, especially at *the sampling times*, and explain why $\{y_0(6T_b) > 0,\ y_1(6T_b) = 0\}$.

. . . .

. . . .

Is a decision error made at $t = 8T_s$ for the specific realization of $y(t)$ in Figure 1?

. . . .

Calculate the bit error probability for the receiver in Figure 1 (use a known formula).

$P_b =$ . . . .

Calculate the bit error probability for the receiver in Figure 3 (use a known formula).

$P_b =$ . . . .

Compare the energy efficiency for binary orthogonal FSK with the methods studied in Part C1 and in Part C2. Is it true that binary orthogonal FSK is 2 dB better?

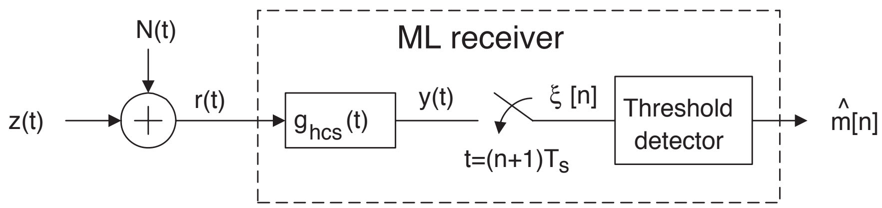
. . . .

. . . .

Part C4: 4-ary PAM

Execute the file **brus4.m**

Three figures are shown on the screen, as before corresponding to $\mathcal{E}_b/N_0 = 1$, $\mathcal{E}_b/N_0 = 5$ and $\mathcal{E}_b/N_0 = 10$ respectively.
The signal alternatives used here are 4-ary PAM with a hcs pulse shape and with $T = T_s$. The ML receiver may in this case be implemented as below (compare with Problem 4.24, and also with comments 2–3 in Example 4.4 on pages 242–243 in the compendium).



The symbol error probability is in this case $P_s = \frac{3}{2}\, Q(\sqrt{0.8\mathcal{E}_b/N_0})$ (see Table 5.1 on page 361 in the compendium).

Determine the decision thresholds from Figure 3.

$B_0 =$ . . . . , $B_1 =$ . . . . , $B_2 =$ . . . . ,

Is a decision error made at $t = 6T_s$ for the specific realization of $y(t)$ in Figure 1?

. . . .

Estimate the bit error probability for the situation represented by Figure 3.

.... $\leq P_b \leq$ ....

What is the advantage, and disadvantage, of using 4-ary PAM instead of binary PAM? ....
....

Note! The laboratory assistent must check your answers before ending this Laboratory lesson.

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