

# Physical Layer Design for a Narrow Band Communication System

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**Abstract**—The design and implementation of a simple narrow band communication system is provided in this document. TCM-8PSK is used for modulation, followed by channel estimation and equalization in the presence of Rayleigh fading. Through simulation results, it is shown that the proposed system is robust.

## 1 SPECIFICATIONS

The specifications for the communication system to be designed are listed in Table 1.

Parameter	Value
Hardware	FPGA based baseband
MODEM	8PSK-TCM
Modem Rate	555Kbps
SNR	7.6 db at 1e5
Channel (V/UHF)	30Mhz - 512Mhz
Bandwidth	250khz
Bit Duration	2.7us
Throughput	100kbps ( Throughput at application Layer)
Ramp up time	116 us (Junk symbols will be sent)
Propagation Delay	100 us (Junk symbols will be sent)
Training sequence	421.2us(provided time for training sequence)
Frame Slot	2 ms
Frame SOM	8 bytes
Payload	32 bytes (692 us)

TABLE 1: Specifications

## 2 FRAME DESIGN

The specifications for the communication system 3.1.4. Using the ML criterion, the decision rule for each symbol is given by Fig. 3.1.4.1. For  $s_0$ ,

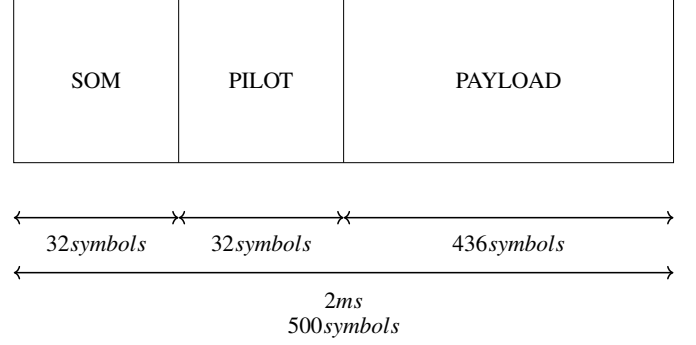


Fig. 2: Physical Layer Frame

## 3 8-PSK

### 3.1 Modulation

3.1.1. See Fig. 3.1.1.1 for the constellation diagram. The transmitted symbol set is given by

$$\mathbf{s}_m = \begin{pmatrix} \cos \frac{2m\pi}{8} \\ \sin \frac{2m\pi}{8} \end{pmatrix}, \quad m \in \{0, 1, \dots, 7\}. \quad (3.1.1.1)$$

The numerical values for  $\mathbf{s}_m$  are listed in Table 3.1.2.1

3.1.2. The gray code shown in Table 3.1.2.1 is used for encoding the 8-PSK symbols.

3.1.3. The received symbol is then obtained as

$$\mathbf{y} = \sqrt{E_s} \mathbf{s} + \mathbf{n} \quad (3.1.3.1)$$

where  $E_s$  is the symbol energy and

$$\mathbf{n} \sim \mathcal{N}\left(\mathbf{0}, \frac{N_0}{2} \mathbf{I}\right) \quad (3.1.3.2)$$

$$\mathbf{s} \in \{\mathbf{s}_m\}_{m=0}^7 \quad (3.1.3.3)$$

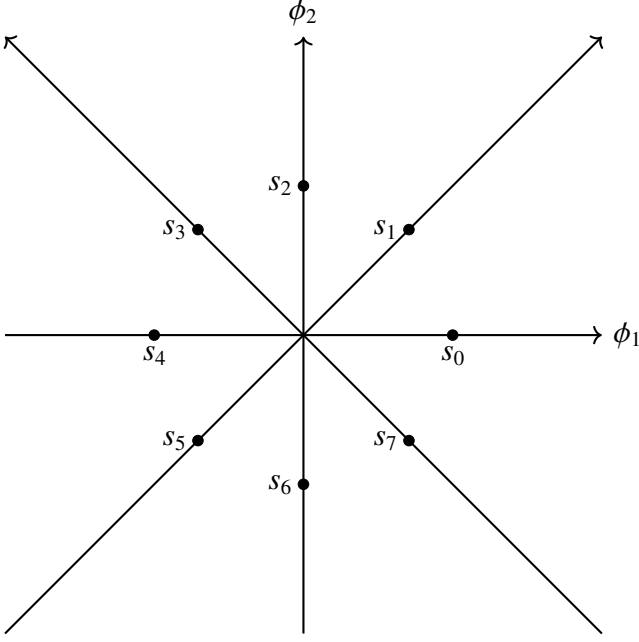


Fig. 3.1.1.1: Constellation diagram

Symbol	Gray Code	Value
$s_0$	000	$\begin{pmatrix} 1 \\ 0 \end{pmatrix}$
$s_1$	001	$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}$
$s_2$	011	$\begin{pmatrix} 0 \\ 1 \end{pmatrix}$
$s_3$	010	$\begin{pmatrix} -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix}$
$s_4$	110	$\begin{pmatrix} -1 \\ 0 \end{pmatrix}$
$s_5$	111	$\begin{pmatrix} -\frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} \end{pmatrix}$
$s_6$	101	$\begin{pmatrix} 0 \\ -1 \end{pmatrix}$
$s_7$	100	$\begin{pmatrix} \frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} \end{pmatrix}$

TABLE 3.1.2.1: Gray coding

this can be expressed as

$$\|\mathbf{y} - \mathbf{s}_0\|^2 \leq \|\mathbf{y} - \mathbf{s}_i\|^2, \quad i = 1, \dots, 7 \quad (3.1.4.1)$$

$$\Rightarrow (\mathbf{s}_0 - \mathbf{s}_i)^T \mathbf{y} \geq 0 \quad (3.1.4.2)$$

$$(3.1.4.3)$$

which can be simplified to obtain the matrix

inequality

$$\begin{pmatrix} (\mathbf{s}_0 - \mathbf{s}_1)^T \\ (\mathbf{s}_0 - \mathbf{s}_2)^T \\ (\mathbf{s}_0 - \mathbf{s}_3)^T \\ (\mathbf{s}_0 - \mathbf{s}_4)^T \\ (\mathbf{s}_0 - \mathbf{s}_5)^T \\ (\mathbf{s}_0 - \mathbf{s}_6)^T \\ (\mathbf{s}_0 - \mathbf{s}_7)^T \end{pmatrix} \mathbf{y} \geq \mathbf{0} \quad (3.1.4.4)$$

resulting in

$$\begin{pmatrix} \sqrt{2} - 1 & 1 \\ \sqrt{2} - 1 & -1 \end{pmatrix} \mathbf{y} \geq \mathbf{0} \quad (3.1.4.5)$$

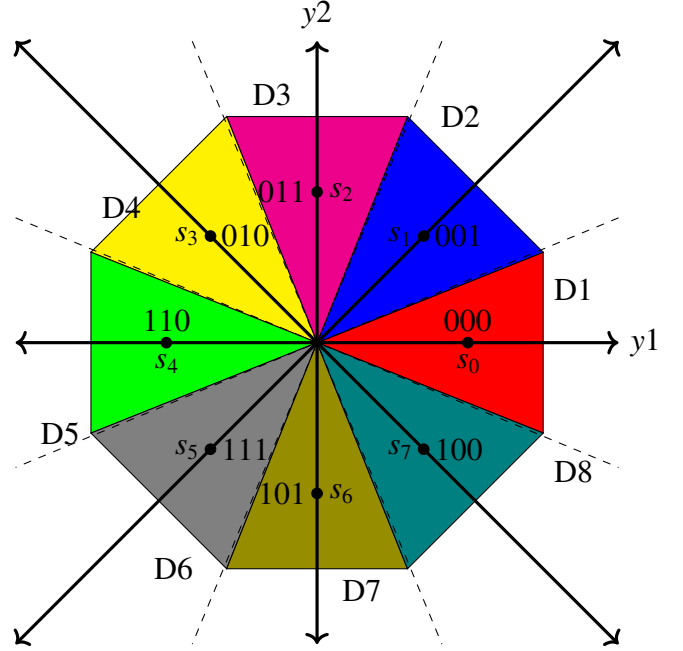


Fig. 3.1.4.1: decision regions

Similarly the decisions for all symbols are available in Table 3.1.4.1

Symbol	Decision region	Inequality
$s_0$	D1	$y_2 + (\sqrt{2} - 1)y_1 > 0, y_2 - (\sqrt{2} - 1)y_1 < 0$
$s_1$	D2	$y_2 - (\sqrt{2} + 1)y_1 < 0, y_2 - (\sqrt{2} - 1)y_1 > 0$
$s_2$	D3	$y_2 - (\sqrt{2} + 1)y_1 > 0, y_2 + (\sqrt{2} + 1)y_1 > 0$
$s_3$	D4	$y_2 + (\sqrt{2} - 1)y_1 > 0, y_2 + (\sqrt{2} + 1)y_1 < 0$
$s_4$	D5	$y_2 + (\sqrt{2} - 1)y_1 < 0, y_2 - (\sqrt{2} - 1)y_1 > 0$
$s_5$	D6	$y_2 - (\sqrt{2} + 1)y_1 > 0, y_2 - (\sqrt{2} - 1)y_1 < 0$
$s_6$	D7	$y_2 - (\sqrt{2} + 1)y_1 < 0, y_2 + (\sqrt{2} + 1)y_1 < 0$
$s_7$	D8	$y_2 + (\sqrt{2} - 1)y_1 < 0, y_2 + (\sqrt{2} + 1)y_1 > 0$

TABLE 3.1.4.1: Decision regions and their inequalities

## 4 QPSK

### 4.1 Modulation

4.1.1. See Fig. 3.1.1.1 for the constellation diagram.  
The transmitted symbol set is given by

$$\mathbf{s}_m = \begin{pmatrix} \cos \frac{2m\pi}{8} \\ \sin \frac{2m\pi}{8} \end{pmatrix}, \quad m \in \{0, 1, \dots, 3\}. \quad (4.1.1.1)$$

The numerical values for  $\mathbf{s}_m$  are listed in Table ??

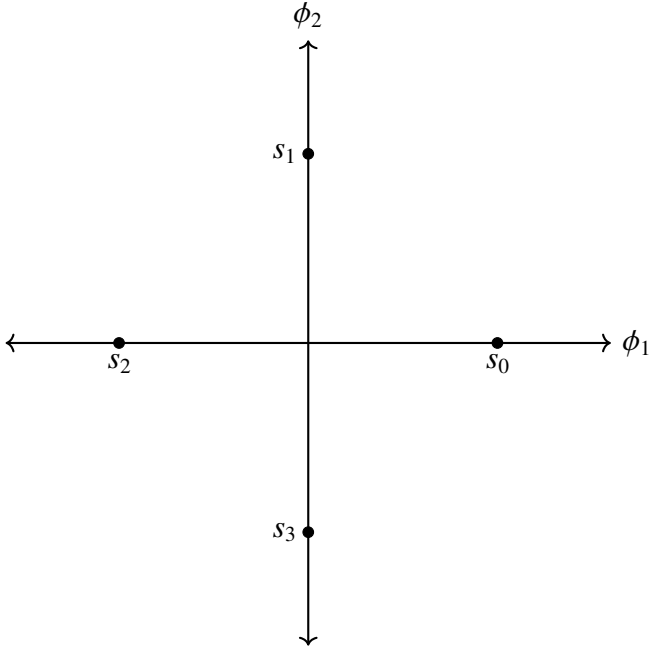


Fig. 4.1.1.1: constellation diagram

4.1.2. See Table ?? for the encoding scheme.

### 4.2 Demodulation

4.2.1. The received symbol is then obtained as

$$\mathbf{y} = \sqrt{E_s} \mathbf{s} + \mathbf{n} \quad (4.2.1.1)$$

where  $E_s$  is the symbol energy and

$$\mathbf{n} \sim \mathcal{N}\left(\mathbf{0}, \frac{N_0}{2} \mathbf{I}\right) \quad (4.2.1.2)$$

$$\mathbf{s} \in \{\mathbf{s}_m\}_{m=0}^3 \quad (4.2.1.3)$$

4.2.2. The decision rule is given by Fig. 3.1.4.1 and can be expressed as

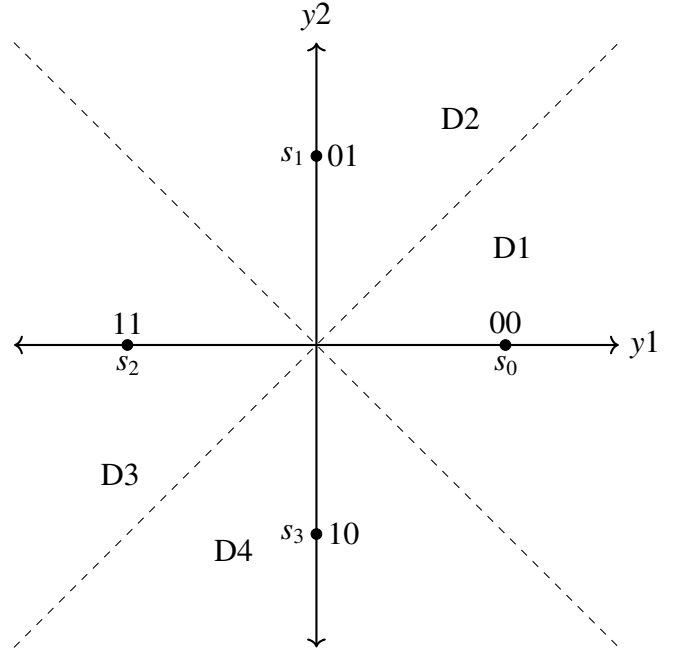


Fig. 4.2.2.1: decision regions

Let  $\mathbf{r}$  be the received bits,  $\mathbf{r} = [r_1, r_2]$ .

$$r_1 = \begin{cases} 0, & \mathbf{y} \in D1 \cup D2 \iff y_1 + y_2 > 0 \\ 1, & \mathbf{y} \in D3 \cup D4 \iff y_1 + y_2 < 0 \end{cases} \quad (4.2.2.1)$$

$$r_2 = \begin{cases} 0, & \mathbf{y} \in D1 \cup D4 \iff y_2 - y_1 < 0 \\ 1, & \mathbf{y} \in D2 \cup D3 \iff y_2 - y_1 > 0 \end{cases} \quad (4.2.2.2)$$

From eq.4.2.2.1 and eq.4.2.2.2

For detecting  $s_0$ ,  $y_1 > -y_2$  and  $y_1 > y_2$ .

For detecting  $s_1$ ,  $y_1 > -y_2$  and  $y_1 < y_2$ .

For detecting  $s_2$ ,  $y_1 < -y_2$  and  $y_1 < y_2$ .

For detecting  $s_3$ ,  $y_1 < -y_2$  and  $y_1 > y_2$ .

4.2.3. The following code has simulation of QPSK.

codes/qpsk.py