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 8-PSK

2.1 Modulation

2.1.1. See Fig. **??** for the constellation diagram. The transmitted symbol set is given by

$$\mathbf{s}_m = \begin{pmatrix} \cos\frac{2m\pi}{8} \\ \sin\frac{2m\pi}{8} \end{pmatrix}, \quad m \in \{0, 1, \dots, 7\}. \quad (2.1.1.1)$$

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

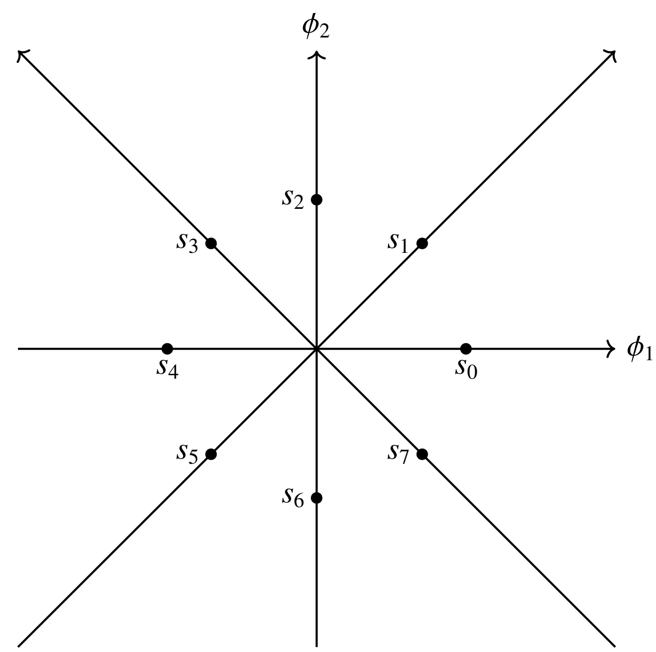

Fig. 2.1.1.1: Constellation diagram

2.1.2. The gray code shown in Table **??** is used for encoding the 8-PSK symbols.

2.1.3. The received symbol is then obtained as

$$\mathbf{y} = \sqrt{E_s}\mathbf{s} + \mathbf{n} \quad (2.1.3.1)$$

where E_s is the symbol energy and

$$\mathbf{n} \sim \mathcal{N}\left(\mathbf{0}, \frac{N_0}{2}\mathbf{I}\right) \tag{2.1.3.2}$$

$$\mathbf{s} \in \{\mathbf{s}_m\}_{m=0}^{7} \tag{2.1.3.3}$$

2.1.4. The decision rule is given by Fig. **??** and can be expressed as

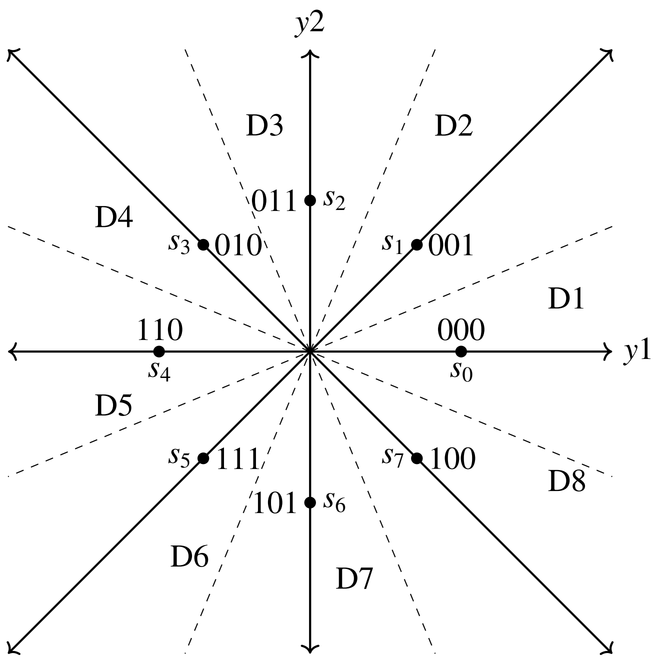

Fig. 2.1.4.1: decision regions

Let $\mathbf{r}$ be the received bits, $\mathbf{r} = [r_1, r_2, r_3]$.

$$r_1 = \begin{cases} 0, & \mathbf{y} \in D1 \cup D2 \cup D3 \cup D4 \Leftrightarrow y_1(\sqrt{2}-1) + y_2 > 0 \\ 1, & \mathbf{y} \in D5 \cup D6 \cup D7 \cup D8 \Leftrightarrow y_1(\sqrt{2}-1) + y_2 < 0 \end{cases} \tag{2.1.4.1}$$

$$r_2 = \begin{cases} 0, & \mathbf{y} \in D2 \cup D1 \cup D8 \cup D7 \Longleftrightarrow y_2 - (\sqrt{2}+1)y_1 < 0 \\ 1, & \mathbf{y} \in D3 \cup D4 \cup D5 \cup D6 \Longleftrightarrow y_2 - (\sqrt{2}+1)y_1 > 0 \end{cases} \tag{2.1.4.2}$$

$$r_3 = \begin{cases} 0, & \mathbf{y} \in D4 \cup D5 \cup D1 \cup D8 \Longleftrightarrow y_2 + (\sqrt{2}+1)y_1 < 0, y_2 - (\sqrt{2}-1)y_1 > 0 \\ 1, & \mathbf{y} \in D2 \cup D3 \cup D6 \cup D7 \Longleftrightarrow y_2 + (\sqrt{2}+1)y_1 > 0, y_2 - (\sqrt{2}-1)y_1 < 0 \end{cases} \tag{2.1.4.3}$$

From eq.2.1.4.1,eq.2.1.4.2 and eq.2.1.4.3
For detecting s_0, $y_2 + (\sqrt{2}-1)y_1 > 0$ and $y_2 - (\sqrt{2}-1)y_1 < 0$.
For detecting s_1, $y_2 - (\sqrt{2}+1)y_1 < 0$ and $y_2 - (\sqrt{2}-1)y_1 > 0$.
For detecting s_2, $y_2 - (\sqrt{2}+1)y_1 > 0$ and $y_2 + (\sqrt{2}+1)y_1 > 0$.
For detecting s_3, $y_2 + (\sqrt{2}-1)y_1 > 0$ and $y_2 + (\sqrt{2}+1)y_1 < 0$.
For detecting s_4, $y_2 + (\sqrt{2}-1)y_1 < 0$ and $y_2 - (\sqrt{2}-1)y_1 > 0$.
For detecting s_5, $y_2 - (\sqrt{2}+1)y_1 > 0$ and $y_2 - (\sqrt{2}-1)y_1 < 0$.
For detecting s_6, $y_2 - (\sqrt{2}+1)y_1 < 0$ and $y_2 + (\sqrt{2}+1)y_1 < 0$.
For detecting s_7, $y_2 + (\sqrt{2}-1)y_1 < 0$ and $y_2 + (\sqrt{2}+1)y_1 > 0$.

2.1.5. The following code has simulation of 8PSK.

```
codes/8psk.py
```

3 QPSK

3.1 Modulation

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

$$\mathbf{s}_m = \begin{pmatrix} \cos\frac{2m\pi}{8} \\ \sin\frac{2m\pi}{8} \end{pmatrix}, \quad m \in \{0, 1, \ldots, 3\}. \tag{3.1.1.1}$$

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

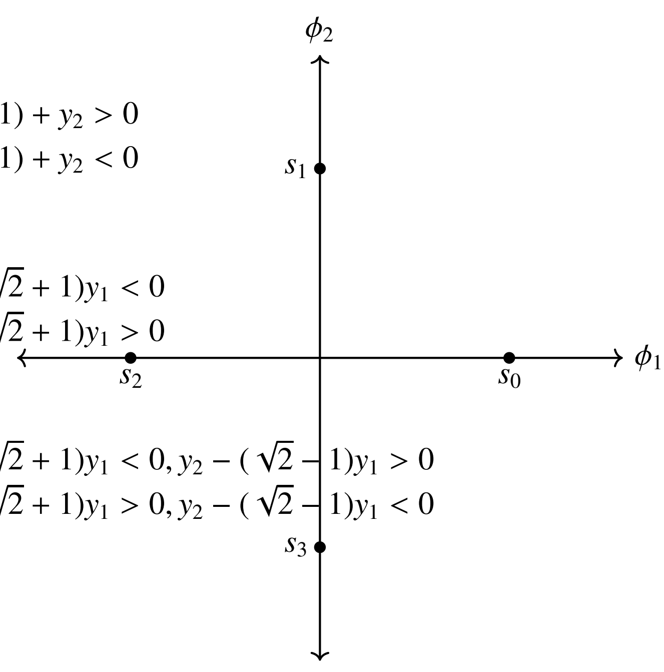

Fig. 3.1.1.1: constellation diagram

3.1.2. See Table **??** for the encoding scheme.

3.2 Demodulation

3.2.1. The received symbol is then obtained as

$$\mathbf{y} = \sqrt{E_s}\mathbf{s} + \mathbf{n} \tag{3.2.1.1}$$

where E_s is the symbol energy and

$$\mathbf{n} \sim \mathcal{N}\left(\mathbf{0}, \frac{N_0}{2}\mathbf{I}\right) \tag{3.2.1.2}$$

$$\mathbf{s} \in \{\mathbf{s}_m\}_{m=0}^{3} \tag{3.2.1.3}$$

3.2.2. The decision rule is given by Fig. **??** and can be expressed as

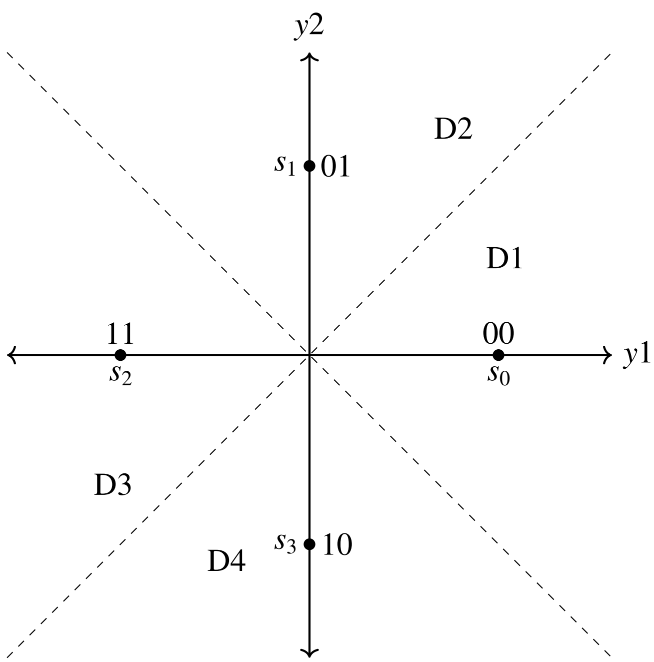

Fig. 3.2.2.1: decision regions

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

$$r_1 = \begin{cases} 0, & \mathbf{y} \in D1 \cup D2 \iff y_1 + y_2 > 0 \\ 1, & \mathbf{y} \in D3 \cup D4 \iff y_1 + y_2 < 0 \end{cases} \tag{3.2.2.1}$$

$$r_2 = \begin{cases} 0, & \mathbf{y} \in D1 \cup D4 \iff y_2 - y_1 < 0 \\ 1, & \mathbf{y} \in D2 \cup D3 \iff y_2 - y_1 > 0 \end{cases} \tag{3.2.2.2}$$

From eq.3.2.2.1 and eq.3.2.2.2
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 $y_1 > y_2$.

3.2.3. The following code has simulation of QPSk.

codes/qpsk.py