一、实验目的

1.熟悉 pluto 的使用方法。在发送端产生信号，并采用多种调制方法对发送信号进行调制处理。

2.接收机进行信号的接收，并对所获信号进行调制方式的自动识别。

二、实验原理

本实验实现的调制方式识别有单音信号、FM 调制、BPSK 调制、QPSK 调制、2FSK 调制、4FSK 调制，通过信号调制后频谱的变化来判断调制方式。单音信号只有一个频率即频谱只有一个尖峰；由 2FSK 调制和 4FSK 调制原理可知，2FSK 调制信号对应 01 序列有两个不同的频率，调制后有频谱会出现两个尖峰，而 4FSK 信号调制后出现 4 个尖峰。FM 调制、BPSK 调制、QPSK 信号调制后信号频谱均会有一定带宽，因此判断 FM、BPSK、QPSK 调制方式需要有进一步的处理如下。

1.FM 调制方式识别方法

FM 线性调频后信号可以表示为

$$x_1(t) = \mathrm{A}\cdot \mathrm{e}^{\mathrm{j}\pi \mathrm{k}t^2+2\mathrm{j}\pi \mathrm{f_c}t+\varphi_0} \tag{2.1}$$

其中k为调频率，$k = B/T$，（B为带宽，T为时宽），将$x(t)$平方后可以得到新的信号

$$\mathrm{x_2(t)} = \mathrm{A}^2\cdot \mathrm{e}^{2\mathrm{j}\pi \mathrm{k}t^2+4\mathrm{j}\pi \mathrm{f_c}t+2\varphi_0} \tag{2.2}$$

可以看到，经过平方后信号由原信号$x_1(t)$调频率k、中心频率f_c变化为$x_2(t)$的$2k$调频率、$2f_c$中心频率，所以信号频谱会发生搬移并且带宽变大。

2.BPSQ 调制方式识别

BPSQ 调制原理为，对于一段 01 序列，信号遇到 1 时会产生大小为 pi 的相位变化。原信号为

$$\mathrm{x_1(t)} = \mathrm{A}\cdot \mathrm{e}^{2\mathrm{j}\pi \mathrm{f_c}t+\varphi_0} \tag{2.3}$$

若接收到的码元为 0 信号不发生变化，若码元为 1，则原信号相位加π变成

$$\mathrm{x_2(t)} = \mathrm{A}\cdot \mathrm{e}^{2\mathrm{j}\pi \mathrm{f_c}t+\pi+\varphi_0} \tag{2.4}$$

此时产生的信号频谱有一定带宽f_w，旁瓣带宽较大。若将 BPSK 调制后的信号平方，码元为 0 所对应的信号：

$$y_1(t) = A^2\cdot e^{4j\pi f_c t+2\varphi_0} \tag{2.5}$$

码元为 1 对应的信号为：

$$y_2(t) = A^2\cdot e^{4j\pi f_c t+2\pi+2\varphi_0} \tag{2.6}$$

将该信号欧拉变换后可以得到，信号$y_1(t)$与$y_2(t)$相位相差2π，所对应的值不变，即$y_2(t)$与$y_1(t)$可认为是相同信号，因此，BPSK 调制后的信号平方，信号由原来两个信号$y_1(t)$，$y_2(t)$的叠加，变成可视为同一信号的$y_1(t)$或者$y_2(t)$。带宽由平方前的信号f_w转为一个尖峰，带宽变小。

3.QPSK 调制方式识别：

根据 QPSK 调制原理，两列 01 码元序列分两路输入，每一路一个码元相加后形成 2bit 的码元组，对于接收到的码元组 00，01，10，11 分别对应相位为$0,\frac{\pi}{2},\pi,\frac{3\pi}{2}$，中心频率为$f_c$的信号$y_1(t)$，此时带宽为$f_w$。将 QPSK 调制后的信号平方之后可以得到中心频率为$2f_c$，相位为$0,\pi,2\pi,3\pi$的信号$y_2(t)$，此时的信号运用欧拉公式展开，可以认为是相位相差π的两个信号结合，即 BPSK 调制后的信号，旁瓣带宽较大。再将$y_2(t)$平方即 BPSK 信号平方，原理同上述 BPSK 信号调制识别，最终信号 QPSK 调制后的信号$y_1(t)$经过四次方后信号频谱变为一个

尖峰，中心频率变成 4 倍。

综上所述，区别 FM、BPSK、QPSK 信号调制方式，FM 调制后的信号平方后带宽变宽，BPSQ 调制后信号的频谱有一定带宽，旁瓣带宽较大，信号平方后频谱的带宽变窄只有一个尖峰;QPSK 调制的信号平方后有一定带宽，旁瓣较大，四次方后变成一个尖峰。

三、实现过程

本项目通过平方等一系列操作观察信号频谱来识别信号，目前可实现单音、线性调频、2FSK、4FSK、BPSK、QPSK 等六种信号。并通过 ADALM-PLUTO 作为发射机和接收机实现信号的收发。

本项目的架构分为用于收发的主函数 main.m，集成信号生成器函数 Signal_generation.m，其中引用了生成单音信号的函数 Single_Signal.m、生成单音信号的函数 Single_Signal.m、生成单音信号的函数 Single_Signal.m、生成线性调频信号的函数 LFM_Signal.m、生成 2FSK 信号的函数 FSK2_Signal.m、生成 4FSK 信号的函数 FSK4_Signal.m、生成 BPSK 信号的函数 BPSK_Signal.m、生成 QPSK 信号的函数 Single_Signal.m，以及信号识别函数 SignalRecognition.m，其中引用了计算带宽的函数 calc_B.m 和峰值检测函数 FindPeakNum.m。

单音信号我们通过将信号进行平方后，对平方前后信号的带宽进行比较，若带宽的变化不大，即在我们设置的动态范围之内，可以认为该信号为单音信号。

LFM 信号我们通过将信号进行平方后，对平方前后信号的带宽进行比较，若带宽的变宽，即大于我们设置的动态范围，可以认为该信号为 LFM 信号。但是此方法误差较大，容易与其他信号混淆，因此本项目还结合了频谱的阈值，即在 LFM 信号带宽范围内所有频率的峰值都大于阈值，以及 DFT 算法，即将原信号与延时信号共轭卷积后只剩下一个单音信号，即可认为该信号为 LFM 信号。

2FSK 信号与 4FSK 信号我们都是通过检测信号发峰值来进行检测的，当检测出来有两个峰值时，我们认为该信号为 2FSK 信号，当检测出来有四个峰值时，我们认为该信号为 4FSK 信号。

BPSK 信号和 QPSK 信号我们通过将信号进行平方后，对平方前后信号的带宽进行比较，若带宽的变窄，即大于我们设置的动态范围，可以认为该信号为 BPSK 信号。但是该检测方法易与 QPSK 信号混淆，因此我们还对信号进行四次方处理，QPSK 信号在平方后变为一个单音信号，再次平方后信号频谱带宽几乎没什么变化，而 QPSK 信号平方后变为 BPSK 信号，再次平方后变为单音信号，四次方后信号频率带宽还是会变窄。通过比较原信号、平方后信号，四次方后信号的频谱带宽的变化来识别，若平方后带宽变窄，但是四次方后与平方后带宽变化不大，则该信号为 BPSK 信号，若平方后带宽变窄，且四次方后与平方后带宽依旧变窄，则该信号为 BPSK 信号。

四、结论成果

我们生成了上述的六种信号了，通过 ADALM-PLUTO 进行数据传输和接受，并将接收到的数据进行了识别，最终得到的六种信号的结果如下图所示：

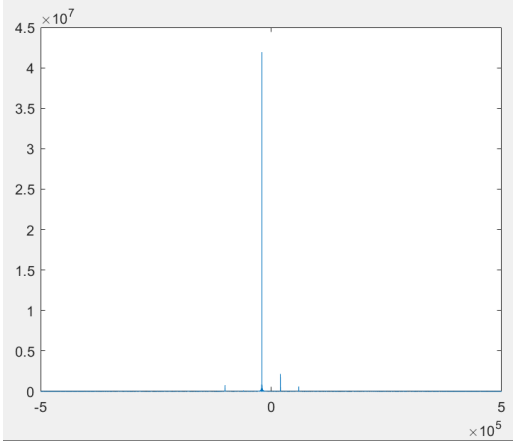

图 4.1 单音信号接受频谱

```
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
单音信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
```

图 4.2 单音信号识别结果

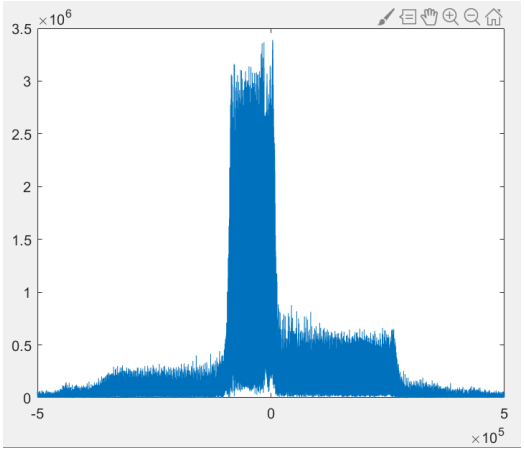

图 4.3 LFM 信号接受频谱

```
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
FM信号
```

图 4.4 单音信号识别结果

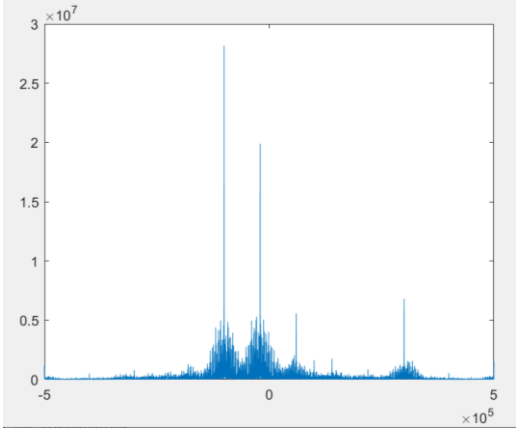

图 4.5 2FSK 信号接受频谱

```
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
2FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
```

图 4.6 2FSK 信号识别结果

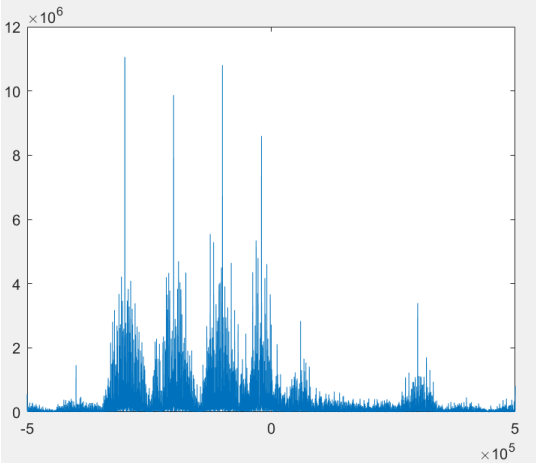

图 4.7 4FSK 信号接受频谱

```
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
函数 findpeaks>findLocalMaxima 末尾。
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
4FSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
```

图 4.8 4FSK 信号识别结果

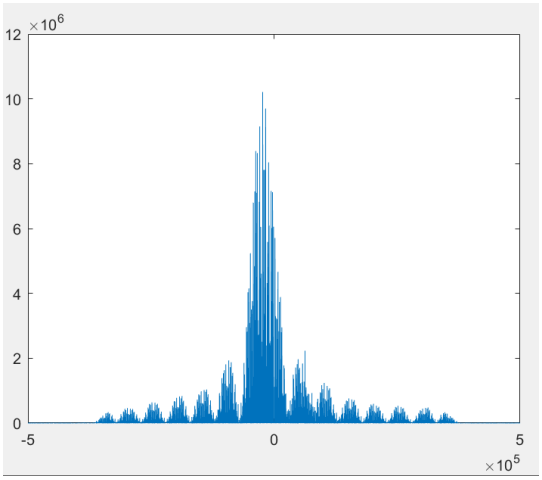

图 4.9 BPSK 信号接受频谱

```
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
BPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
```

图 4.10 BPSK 信号识别结果

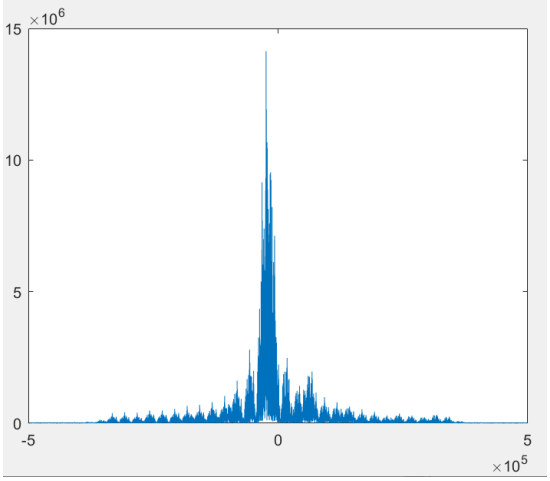

图 4.11 QPSK 信号接受频谱

```
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
## Call the release method to stop the transmission.
QPSK信号
## Waveform transmission has started successfully and will repeat indefinitely.
```

图 4.12 QPSK 信号识别结果