Design and implementation of fast moving object telemetry receiver

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Abstract. Increase in the development of missile technology and the need to control/monitor fast-moving prototypes for various purposes, forces the development of a ground station with automatic telemetry reception capability. The paper presents the preliminary results of the research of the automatic system of maintaining the continuity of communication between the ground station and the moving object. The advantage of the solution is the low weight and dimensions of the transmitting system and the resistance of the receiver to frequency shift resulting from the movement of the object. The receiving module was implemented on the basis of SDR technology together with an application using FFT. The application of the above solution allows for the implementation of the telemetry systems.

1. Introduction

Wireless telemetry systems are often needed during the design and testing of prototype projectiles in the field and in the laboratory. They are also used to monitor parameters during flight, i.e. moving at high speed. Such systems do not require a large range, especially during the first tests of prototypes. A small amount of power is sufficient to allow miniaturization and installation of these additional chips in each prototype. The aim of this study is to design and software a telemetry receiver that will be resistant to the Doppler effect of fast moving objects. The authors of the article formulated a thesis in the form of questions: 1) is it possible to decode FSK emission transmitted by available low power Si4xxx series radio modules with the use of SDR receiver and dedicated computer program? 2) Will the high speed of the transmitter's movement and the resulting Doppler effect not hinder the reception of telemetry data? There are many ready-to-use telemetry telecommunications systems on the market, but they are not immune to the frequency shifting effect of the transmitter (or receiver) moving at as high speeds as in the case of missiles or rockets. Appropriate systems are very expensive and not miniature. After reviewing the existing solutions, it was necessary to test the possibility of using miniature low-power radio modules and modern software defined radio (SDR) receivers.

2. Telemetry transmitter

The transmitter system should be as small and light as possible. This type of telemetry circuitry is used only at the stage of prototype testing. It will not be installed in the target structure. There will be no special place for him to build new missiles and. Its small size and weight make it suitable for small missiles and rockets. Together with the receiving system described below, they constitute a system of wireless transmission of telemetric data. This data is used to test prototypes. The Silicon Labs Si4xxx series has been selected. These are miniature low power transmission systems such as Si4012. Based on the manufacturer's catalog data [1], this system has the following parameters: frequency range 27-960 MHz, output power range 13 to +10 dBm, low power consumption FSK 19. 8 mA @ +10 dBm,
data rate: up to 100 kbaud FSK. Due to the needs of the designed telemetry system, these parameters are sufficient. Low-power signals will be received via an SDR receiver near the transmitter, at the flight test site. For longer flight path distances, an additional power amplifier will be required on board the test missile or rocket. The diagram of the transmitter system is shown in figure 1.

![Transmitter Diagram](image1)

**Figure 1.** Transmitter.

3. **Telemetry receiver**

The receiving system is based on a miniature RTL-SDR receiver (figure 2). This module connects to a portable computer via a USB interface. Inside there are R820T2 and RTL2832U chipsets. The operating range covers the 24-1766 MHz band in direct sampling mode: 500 kHz to 28.8 MHz. As you can see, the entire frequency range of the transmitter is covered. To operate the receiver, you need a computer application that has been specially developed for the telemetry chip. It is described below.

![Receiver Image](image2)

**Figure 2.** Receiver.

Software Defined Radio - a programmable radio is based on the use of a computer for signal processing (figure 3). Filtration, mixing, detection and demodulation is performed by a processor and not by complicated systems as in classical receivers. This solution significantly minimizes costs. Selected parameters and functionality are also improved. In the software it is possible to eliminate the harmful effect of frequency shift caused by the movement of the transmitter (Doppler effect). Tuning out of the receiver, or rather, following the signal is carried out by the application. According to the manufacturer's data, the system has high sensitivity of 0.2 uV (-121 dBm at 72 MHz, (S+N)/N = 3 dB).
4. Antenna system
Because the whole telemetry system can work in quite a wide frequency range (27-960 MHz), this paper assumes that the transmitting and receiving antenna will be made as 1/4 of the wavelength (for the selected frequency). Such “rod” antennas are widely used in telemetry systems. They can be made of thin steel wire or printed with copper on the board or flex.

5. FSK transmitter module
The telemetry system built on the basis of the Si4xxx series system uses FSK (frequency-shift keying) emission.

The configuration of the FSK transmitter circuit is initialized from the computer side. Default values, suitable for FSK emissions that do not need to be modified:
- modulation type (MODULATION_FSKDEV) default value is FSK,
- data rate (BITRATE_CONFIG) default value is 200 bps.
Encoder registers that require configuration (modification):
- upper frequency FSK (TX_FREQ) default is 433.965 MHz,
- crystal frequency (XO_CONFIG) default is 10 MHz.

At this point you should carefully check the recommended crystal capacity recommended by the manufacturer, because this register also configures it. The internal capacity of the system is between 3 and 5.5 pF, which should be subtracted from the recommended value. (c) power output current driver (PA_CONFIG). This register needs to be explained in detail. It has several properties:
- boost bias current to output DAC (digital analog converter),
- PA level,
- PA capacitance,
- PA temperature compensation and antenna reactance.

The correct values of the parameters will help us to calculate the spreadsheet prepared by the manufacturer [2]. It is worth noting the parameter for temperature variation compensation. If constant radiated power vs. temperature is desired, this constant may be used to compensate the PA drive strength. It can be calculated by measuring the output power at different temperatures while Alpha is set to 0. Assume 1 dB change in 50 °C temperature variation. The PA output power is programmable in 0.25 dB steps, so 1 dB change is a 4-step variation in PA level setting. Therefore, Alpha should be set to 4/50 = 0.08. This parameter has no effect if set to 0.

![Antenna Setup](image)

**Figure 5.** Antenna setup spreadsheet.

6. **C++ tools library**
In order to facilitate the Si4012 system operation from the host software (host MCU, figure 4), a set of data structures, macro commands (figures 6, 7) and functions has been prepared, of which the basic ones are presented below (it is not possible to include the entire code, the author will make the whole library available to interested parties by e-mail):

```c
#define MODE2 4, 0x60  
#define TUNE1INT 5, 0x11, 0x21  
#define MODUL2DEV 5, 0x11, 0x20  
#define Fsk1 0x01  
#define Fsk2Dev1ppm 0x01  
#define CHIP1CONFIG 4, 0x11, 0x10  
#define TX1FREQ 7, 0x11, 0x40  
#define _U4BYTE1(w) (((unsigned char)((uint32_t)(w) >> 24) & 0xFF))
```

**Figure 6.** Tools library definitions.
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7. Telemetry receiver
The FSK telemetry system described above should work under conditions resulting from the capability to test missile and rocket prototypes. Such objects move at high speeds. Distribution of the transmitter in a fast moving object and the receiver as a terrestrial station requires mutual visibility of antennas. The low power available to us for a selected transmission system is a limitation. With mutual visibility of antennas, the range will ensure testing and recording of telemetry signals. Due to the mutual movement of the transmitter and receiver in the receiver, the frequency variation resulting from the Doppler speed should be compensated for. For this purpose, a stable non-linear estimation based on the Kalman filter and the Doppler diversity module [3,4,5] can be used. Let's accept the receiving system based on the SDR receiver with a block of signal processing based on the computer. This is one of the advantages of the receiver described above.

The signal processing can be carried out on the computer side. Relative movement of the transmitter during flight causes the frequency shift. When the speed reaches the wastefulness of the speed of sound, in the bandwidth of the transmitter about a few hundred MHz will change the frequency to several hundred Hz. The receiver software must compensate for this. Dynamic change,
i.e. the pace of Doppler changes, is a big problem for the telemetry system. The second order loop with phase lock [3] should lead to accurate tracking of the Doppler frequency offset. On this basis, an SDR receiver application algorithm was implemented.

The proposed solution is characterized by a dynamic adaptation to the Doppler environment. Doesn't require a lot of computing. The implementation of telemetry communication algorithms for dynamic Doppler changes was compiled as the application in the .NET environment.

8. Application .NET
The signal from the SDR receiver output (figure 4) is processed by the computer (using sound card) by an application that allows you to decode the FSK signal (figure 9) and display it on a map. Objects moving at high speeds send the FSK telemetry signal using the transmitter described above. The application .NET (figure 8) allows to record signals received for further processing.

![Figure 9. FSK signal example.](image)

The telemetry system can transmit other data (temperature, vibrations, gyroscope data, etc.) in addition to the position data.

9. Conclusions
The goal has been achieved, the questions asked at the beginning: 1) Is it possible to decode FSK emission transmitted by available low power Si40xx series radio modules using SDR receiver and dedicated computer program? 2) Will the high speed of the transmitter's movement and the resulting Doppler effect not hinder the reception of telemetry data? Have been positively confirmed. During the examination of the telemetry transmitter and receiver system, basic data on the location of the examined object were sent. The data is shown on the map in figure 8. The application processes (decodes) the FSK signals as a result of which it receives a sequence of values. These values are messages transmitted from a moving object.

During the research, the proper depiction of the flight trajectory of the object was obtained. Thanks to telemetry, it is possible to locate an object after it falls to the ground. I would like to thank the authors of the quoted materials for making this project possible.

The telemetry system was physically constructed and tested. It proved to be very useful in designing prototypes of missiles and rockets.
References

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