Design and simulation of Demodulator Based BELL-202 standard for NanoSatellite Communication Sub-system

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Abstract: in recent years a trend of using CubeSat-class nano satellites for commercial and scientific missions has taken the lead; this is due to the advantage of the available and low-cost products on the market without need for a large development and infrastructure investments. On our behalf, the advanced approach is to build a CubeSat platform dedicated to academic and engineering training on the different satellite subsystems, including development of a transponder based on products and software/hardware solutions accessible to the research and academic community in order to promote its use to engage in cross-team development on the basis of this platform and allowing the aggregation of a know-how.
In this context, the work presented in this paper, handles partly the problematic by a proposal of the communication system design, intended to be integrated on our platform; with a particular focus on the implementation of an FSK modulator based on the Bell 202 standard. The reported development project will include simulations, implantation and the validation tests performed to achieve our first prototype.

Keywords: Educational Nano-Sat, PEDAGO-SAT, BEL-202, AFSK, communication sub-system, academic & research community

1. INTRODUCTION

PEDAGO-SAT is a new kind of Satellite mission initiated at Algerian satellite development center to consolidate an eventual cooperation between the Algerian Space Agency (ASAL) and Algerian universities. The adopted approach consists on the development of an engineering training Cube Sat-class Nano-satellite platform which will be an open source academic and educational platform. The final objective to this project is the opening to students and trainees an era for satellite exploration and allows them to access various knowledge related to satellite development and tests.

The primary goal of the communication subsystem on Cube Sat is to provide a link to relay data findings and send commands to and from its ground station, so, the Cube Sat communication system is composed of the telemetry and command systems which send and receive data, respectively. Analog and digital data collected by the sensors and payload of the satellite must be relayed to the ground station via the telemetry system [1].

Typically CubeSat use amateur radio frequencies through FM for its data transmission, where one of the most applicable digital modulation methods to transmit the radio signal using FM radio carrier is the frequency shift keying (FSK)[2].The communication subsystem of PEDAGO-SAT is based on the described setup; where data is modulated into audio band using A-FSK(Audio Frequency Shift Keying) with Bell 202 specification standard at 1200 bit/s, using a mark tone of 1200 Hz and a Space tone of 2200Hz [3]. The resulting audio signal is then input into a Radio which in turn FM modulates the audio signal into the RF band.

In this work we focus on the realization of a home-made A-FSK Demodulator to be integrated in the described communication subsystem, most existing demodulation systems use a dedicated A-FSK modem chip such as the TCM3105 or MX614 that are generally unavailable to the student community. The proposed demodulator is a low-cost alternative in respect to the academic purpose, where most existing demodulation systems use specialized hardware generally unavailable to the student community.

2. COMMUNICATION SUB-SYSTEM ARCHITECTURE

One of the main requirements of the satellite is the ability to communicate by sending and receiving data between the satellite and the ground station for telemetry ,telecommand house-kipping and payload data transmission exchange ,the adopted architecture of our subsystem is depicted in Fig.1 , it chosen based on available commercial radio amateur systems for satellites downlink where data is FSK modulated with audio frequency FM transmitted on VHF/UHF, detailed description is given bellow.

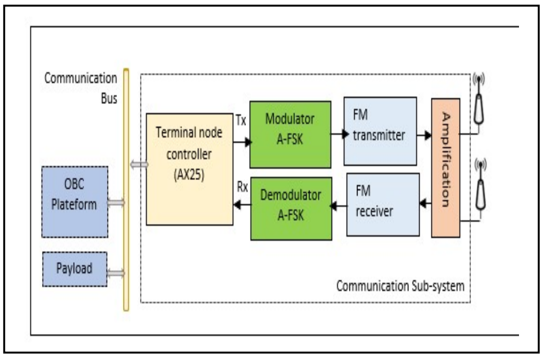

Fig. 1 Communication sub-system architecture for PEDAGO-SAT.

A. Terminal node controller(TNC):

The terminal node controller is the main interface between the on-board computer (OBC) of the satellite and the radio transmission system, thus, serving as data packetization platform, also, it performs a number of controls and information storage functions. Typical model of a TNC consists of a micro control unit, EPROM and software. In the Downlink path, the microcontroller will accumulate data to be transmitted and encode them into AX.25 protocol[4].*In the* uplink, *path received* will be decoded incoming and redirected to the OBC.The AX.25 is the most common communication protocol used on radio links between Nano-satellites and their ground stations. The protocol is implemented as data link layer for out of the microcontroller, it encodes data in small blocks called frames. Each frame is made up of several smaller groups called fields. Each field is made up of an integral number of bytes and serves specific functions [4].

B. A-FSKModulator/demodulator:

Modulation refers to the process of transforming information of digital data into analog signals for transmission. Once the data reaches its intended destination, demodulation is performed to transform the analog signal into digital data and recovers back the original information. In frequency shift keying (FSK), two carrier signals are used to produce FSK modulated waveforms. The reason behind this, FSK modulated signals are represented in terms of two different frequencies. The frequencies are called “mark frequency” and “space-frequency”. Mark frequency has represented logic 1 and space-frequency has represented the logic 0. Figure 2 visualizes the concept of an FSK signal generation.

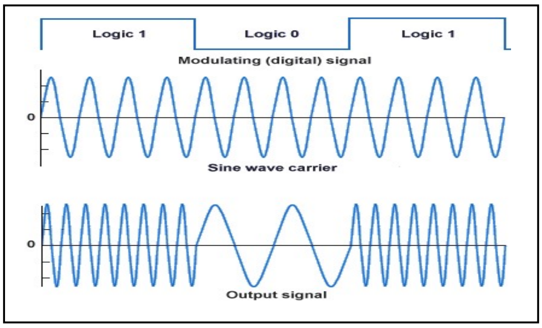

Fig. 2Frequency shift signal representation[5]

In radio-amateur Bell 202 A-FSK Standard is used over the FM radio link. In Bell 202 standard the digital data signal at 1200bits/s is modulated using two audio tones, a tone of 1200 Hz (‘1’ bit) for mark and 2200 Hz (‘0’ bit) for space. In the same way, the demodulator receives the analog modulated signal and restitutes the digital data and sends it to the TNC. In some works [2][4], implementation of AFSK and AX.25 together is also called a TNC.

C. FM transmitter-receiver:

Within the Nano-satellite community it is common to use the amateur satellite radio frequencies due to earth station equipment costs and licensing restriction, Amateur frequency bands would be used in VHF (145Mhz) for uplink and UHF (435Mhz) for down link. The FM uplink and downlink frequencies will be finalized subsequently in our case .

3. DEMODULATOR DESIGN

In order to realize the demodulator with bell 202 specifications at low cost and without any specific electronics we have adopted the non-coherent detection approach ,this method is preferred in our case because it does not require any phase reference information and is less complex than coherent detection [6] .The typical version of an FSK Non-coherent demodulator as shown in Fig.3,it is done by using two bandpass filters tuned to each frequencies carrying bit 0's and 1's. The output of each filter is envelope-detected and then baseband-detected through a comparator, the stronger of the two frequencies is the one that must have been present in the original signal [6].

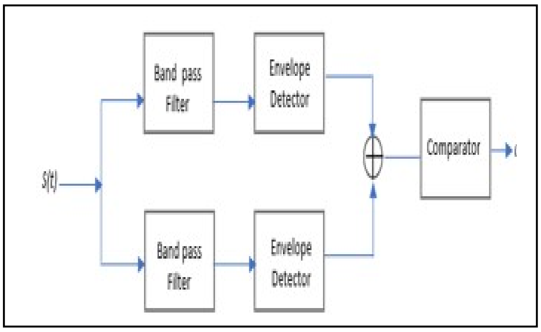

Fig. 3Typical FSK Non-coherent demodulator [2]

For a less, complexity and to reduce the analog circuitry of the final prototype sub-system we have chosen a single path for the input signal across a high pass filter, an envelope detector and a comparator stage. The design is then validated if performances are acceptable, Fig. 4 shows the simplified demodulator for our system.

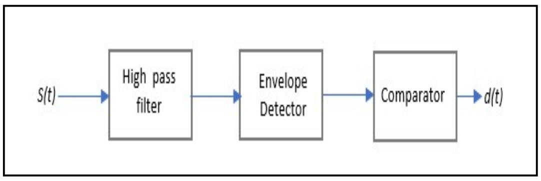

Fig. 4Proposed A-FSK Non-coherent demodulator.

A. Filtering:

The high pass filter used is a 5th order Butterworth filter type , it is designed around frequency of 2.2khz to reject frequency components under this value (principally the unwanted 1.2khz) ,after calculation of the filter parameters ,simulation of the circuit was done under Orcad-Pspice. Simulation of the A-FSK modulator was also done to be fed to the filter input, results are given in Fig.5 ,it is shown that the filter(due to its characteristics) does not totally suppress the 1.2Khz signal but it is *strongly attenuated in magnitude ,* which permit to 2.2Khz signal remaining the *strongest of the two frequencies that can be envelope detected. This result is substantially* similar to the one expected in section 3.1.

Once the signal is filtered it is fed to the amplification stage, it is amplified with a gain of 10 (*g=10*). result is alsogiveninFig.5.

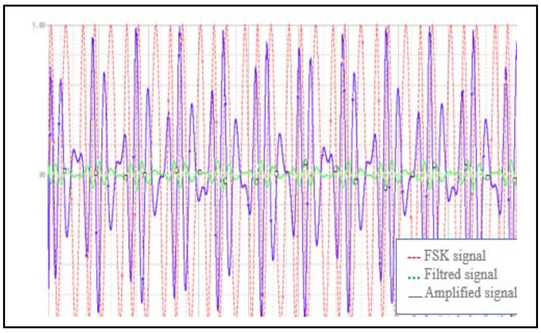

Fig. 5 FSK signal at the output of the 5 order Butterworth filter.

B. Envelope detection:

The envelope detector is designed to recover the envelope of 2.2Khz signal, this detector is a typical diode and RC components, *R* and *C* are chosen carefully with a time constant ***(τ)*** greater than the period of the carrier (T_c)and less than the period of the data(***Td***) as given in equation 1, when this condition is fulfilled the detector works properly.

$$T_c \ll \tau \ll T_d \quad (1)$$

The hole stage is than associated to a passive low pass filter for removing the output ripple. The cut-off frequency of the filter is selected in such way that it would be able to pass the message signal.

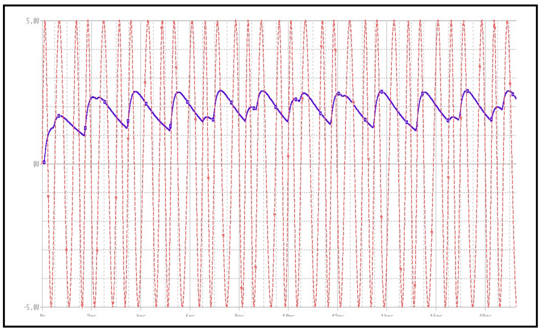

Fig. 6Output of envelope detection stage

C. Decision circuit:

The decision circuit consist on comparator operational amplifier that receive the signal at its inverting inputs, it will trigger on the signal if the latter reaches a certain amplitude called decision threshold, thus the comparator will output a symmetric square signal that represent the restored data signal. The test depicted in Fig.7, consist on recovering the sent pattern signal in circuit input, which is a successive tram of 0 and 1bit.

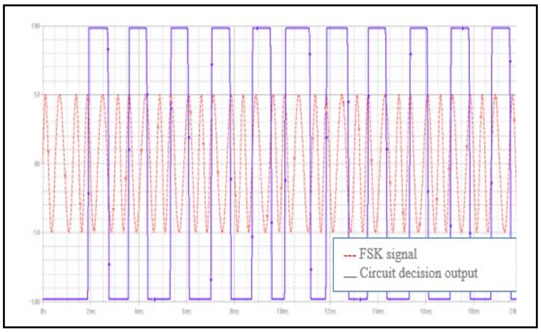

Fig. 7Restitued data signal at the decision stage

4. REALIZED CIRCUIT/TEST SETUP

In order to validate the demodulation proposed approach, a realization of the circuit was done and tested in laboratory. The test setup elaborated to this work is shown in Fig.8. In order to verify the operation of the A-FSK demodulator, the signal generator (Tektronix arbitrary function generator) was used in first to produce the A-FSK modulated signal ; when use option " FSK source internal" , the generator produce the pattern signal with periodic 1200 baud rate data , however for a more accurate test we have use option " FSK source external" .A simple program containing the sequence test is used to send data to UART Arduino witch is used to provide TTL signal to the external input data of the generator.

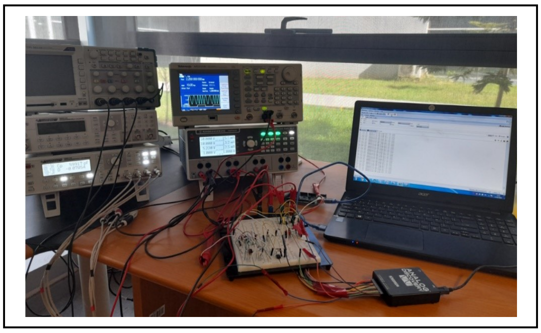

Fig. 8Realization setup for the demodulation process

As declared before, in PEDAGO-SAT development we have taking care to work with discrete components available in the market to the academic community,in this context RLC meter is frequently used to measure exact values of resistances (E12) and capacities (E12) and their possible combination (*serial and parallel*) to reach the desired theoretical value. A DC power supply instrument is used as source of(+/-12V) to provide *temporarily* power supply for the operational amplifiers of the circuit and set the *threshold value.*

A digital oscilloscope with two channels is used to visualize output signals during tests at any stage of the circuit; moreover, the instrument has digital (I/O) Pins that associated with its computer software offering an UART Protocol Analyzer which allows us to directly decode the transmitted sequence from the restored signal at the comparator output stage.

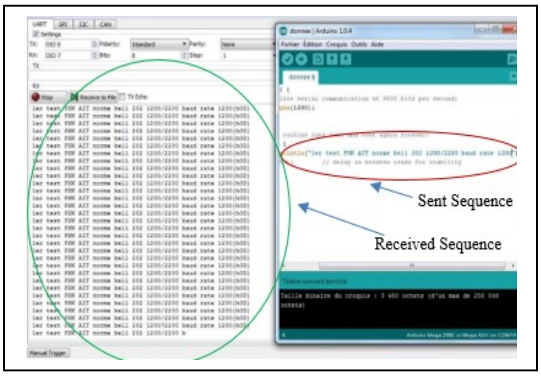

Fig. 9Restitued data sequence after demodulation process.

In Fig.9 is given the interpretation result of the UART protocol analyzer for the restored signal gathered with the Digital Pin at the output comparator stage. The original sequence sent from PC before passing the modulation/demodulation chain is also shown in the hyper-terminal.

The demodulated sequence is compared with the original sequence and both are completely identical, tests were repeated for different sequences, several times, with and without delay between each sequence sent, data is always correctly demodulated giving a successful result.

5. CONCLUSION

The work presented in this article describes the approach adopted for the development of an A-FSK demodulator that will be integrated into the transponder onboard the PEDAGO-SAT satellite training platform. During the selection of the components and the choice of the adopted methods, we ensured the simplicity and the accessibility of the solutions provided; in order to be reproduced by the Algerian academic community that often suffers from the unavailability of the technical products required for the aerospace applications.

After an assessment of the "RF" requirements identified for the PEDAGO-SAT project, the architecture of the proposed communication subsystem will include a terminal node for Ax25 coding, separating transmission and reception on 02 channels including A-FSK modulator/demodulator based on the Bell202 standard, followed by the transmission and reception in FM carrier. During the development part of the proposed design, several anomalies had to be overcome, namely a filtering problem, envelope detection and decision. Thus, we focused our work to achieve a first prototype circuit of a non-coherent A-FSK demodulation (no reference phase). As illustrated previously, the obtained results and the performed verifications are successful, encouraging us to implement this circuit in the final transponder solution.

The next step will be the test of PBC version of the designed demodulator circuit, with SMD components in a narrow configuration in order to reduce the perturbations phenomena. In parallel to ameliorate the decision stage, we will also prospect other methods. To remove the signal generator used in test, we will produce our A-FSK modulator. At the end, we will introduce the bit error rate criteria (BER) to analyzes and evaluate the performance of demodulator module.

References

[1] Guest A N.: Handbook of Satellite Applications ,Tracking, and Command (TT&C) . Springer, New York, NY ,2013.

[2] Ahmad A Y, Nazim J N,Yuhaniz S S: Design of a terminal node controller hardware for CubeSat tracking applications. IOP Conference Series: Materials Science and Engineering152,2016.

[3] Bell 202 Interface specification for transmission of binary data by frequency manipulation FSK, https://www.softelectro.ru/bell202_en.html, last accessed 2022/07/21.

[4] Chessab M, Hiba I, Zahraa R, Hussain k:Design and Simulation of Terminal NodeController for KufaSat NanoSatellite .International Journal of Scientific & Engineering Research, Vol. 6, Issue 4, 2015 .

[5] FSK,https://www.technologyuk.net/telecommunications/telecom-principles/frequency-shift-keying.shtml, last accessed 2022/07/26.

[6] Eric N O S,Performance Evaluation of M-ary Frequency Shift Keying Radio Modems via Measurements and Simulations: thesis Master of Science in ElectricalEngineering with emphasis on Telecommunications/SignalProcessing, Karlskrona,Sweden,2006.