

No. 123/22,18–31  
ISSN 2657-6988 (online)  
ISSN 2657-5841 (printed)  
DOI: 10.26408/123.02

Submitted: 18.05.2022  
Accepted: 24.05.2022  
Published: 30.09.2022

## SIMULATION OF FOUNDATION FIELDBUS MANCHESTER CODED 31.25 KBPS H1 BUS USING MATLAB AND SIMULINK

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**Abstract:** The purpose of this article is to provide an understanding of possible techniques through which a H1 31.25 kbps Foundation Fieldbus Manchester coded signal can be modulated or demodulated. This understanding will be rendered through MATLAB and SIMULINK models, simulating both ideal and practical as well as noiseless and noisy conditions during the modulation/demodulation process. The simulation models will differentiate between the modulation methods adopted to generate ideal rectangular as well as practical trapezoidal waveforms for the Manchester coded signal. The analysis of the simulation results will describe the mechanisms through which distortion induced by additive white Gaussian noise can be eliminated during the demodulation process either by using recursive filters, such as a Kalman filter, or by calculating wave energy levels in specific time intervals.

**Keywords:** Foundation Fieldbus, Manchester Coding, Kalman Filter, Trapezoidal Waveform, SIMULINK, MATLAB.

### 1. INTRODUCTION

Foundation Fieldbus (FF) is a digital communication protocol, one of various protocols based on which smart transmitters are built. The basic principles of Foundation Fieldbus protocol are explained in [Viegas and Pereira 2000; Tooley 2009; Verhappen and Pereira 2012; Mehta and Reddy 2016; Abotaleb et al. 2022]. Smart transmitters based on digital communication protocols are considered a good alternative for analogue measurement and control standards as they provide additional diagnostic information to improve the performance of the measurement and control processes. Communication tasks in Foundation Fieldbus protocol are

performed synchronously and administrated by LAS (Link Active Scheduler), which supervises scheduled as well as unscheduled communication along the field bus. A detailed description of the communication process in Foundation Fieldbus can be found in [Tooley 2009; Verhappen and Pereira 2012; Mehta and Reddy 2016; Abotaleb et al. 2022; Mendez 2022].

The communication signal adopted by Foundation Fieldbus for interfacing with field devices on the H1 bus is a 31.25 kbps Biphase-L Manchester-coded signal [Hu and Sun 2010; Jameel 2018] with a base current of 10 mA increased by 9 mA when modulating ones or decreased by 9 mA when modulating zeros. These transitions during modulation take place at the falling edge of the system clock signal, which means that the clock signal information is embedded into the modulated signal (Synchronous Serial Communication). This article provides an understanding of the modulation and demodulation process for Foundation Fieldbus 31.25 kbps Manchester coded signal through simulation models rendered by MATLAB and SIMULINK. The discussion is based on the idea of differentiating between ideal theoretical and practical operational conditions during the modulation/demodulation process where ideal Manchester-coded waveforms take a purely rectangular shape; however, in practice, these waveforms take a trapezoidal shape (Fig. 1) due to the time delay induced by the modulation and demodulation circuitry (LC circuits).

On the other hand, the article discusses the concept of how to perform the modulation/demodulation process for Foundation Fieldbus Manchester signal in a noisy transmission medium where the practical waveform can be slightly or severely distorted by various noise sources.

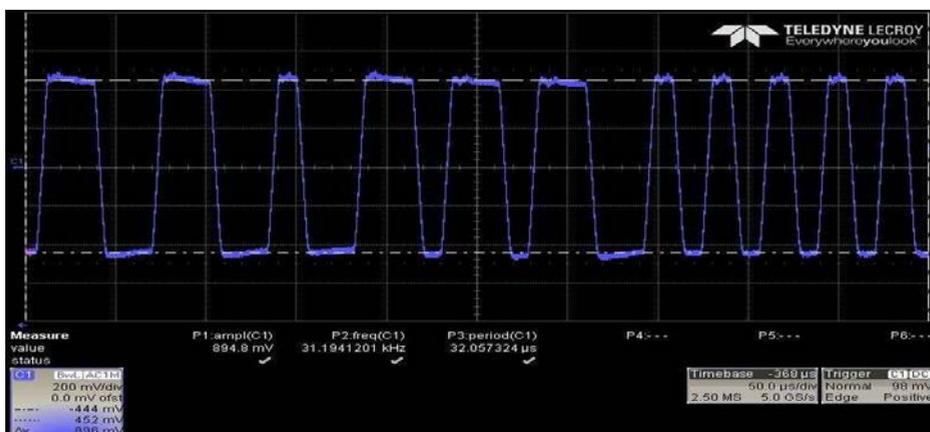


Fig. 1. Real-time shape of FF Manchester coded signal [Satterfield 2019]

Two important methods are suggested in this article to eliminate the effect of noise on the Manchester coded signal. The first method is based on the idea calculating the average energy of the signal in specific time intervals. These time

intervals are related to the frequency of the system clock signal and also related to the periods of time at which transitions or changes in the modulated trapezoidal waveform are taking place. The second method discussed here to eliminate the effect of noise on Foundation Fieldbus Manchester coded signal is to consider using Kalman filter before the demodulation process.

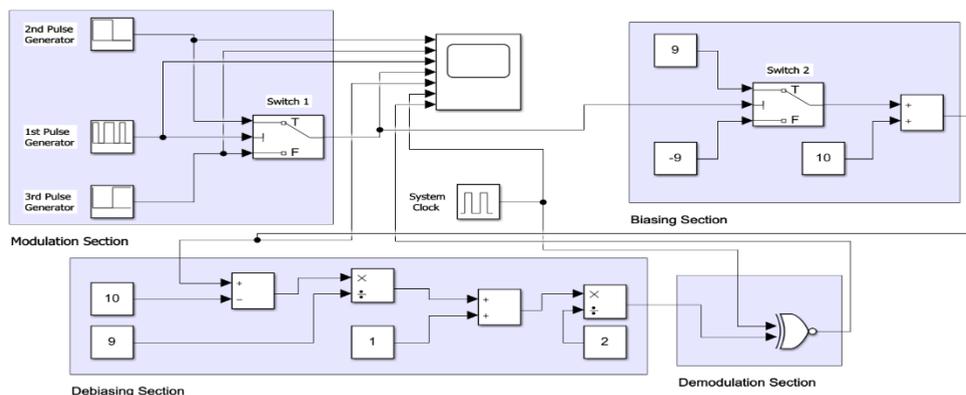
Kalman filter is an efficient recursive filter based on estimation theory. It adopts an estimation algorithm to predict unknown measurements observed over time out of noisy, distorted measurements. The main advantages of Kalman filter are both its simplicity and low computational power. The ability of Kalman filter to restore an original signal out of a noisy signal depends on updating the estimate of the output signal based on the previous estimate and the new input data. Therefore, Kalman filter has a recursive mechanism in which only the previous estimate of the signal is needed to estimate the output signal instead of storing the whole previously measured data. More detailed description for Kalman filter is provided in [Haykin 2001; Welch and Bishop 2006; Youngjoo and Hyochoong 2018; Pei et al. 2019].

Three simulation models for modulation/demodulation of Foundation Fieldbus Manchester coded signal are presented in this article. The first model is a SIMULINK model dedicated to the modulation/demodulation of the FF signal under the ideal condition where the effect of noise is not taken into account. The second model is MATLAB based, to simulate the modulation/demodulation process of an FF signal in practical conditions where both the trapezoidal waveform of the FF modulated signal and the distortion induced by noise are taken into consideration. The second model also includes the previously mentioned solution, intended to eliminate the effect of noise on the FF trapezoidal signal by detecting the average energy of the signal at specific periods of time and comparing it with each other to restore the transmitted bit stream.

Similarly to the second model, the third model is SIMULINK based, simulating the modulation/demodulation process of an FF trapezoidal signal taking into account the effect of noise; however, the third model adopts Kalman filter to eliminate the distortion induced by noise. The Manchester coded signal in the second model is an interpretation of a whole FF data frame with 2 bytes of data from the datalink layer; however, for the SIMULINK models and for simplicity purposes, one byte of data is taken into consideration without considering other sections of the FF data frame (preamble, start delimiter and end delimiter). Ultimately and based on the description and simulation results of the three simulation models, different demodulation mechanisms are suggested in the conclusions for Foundation Fieldbus Manchester coded signal distorted by a source of additive white Gaussian noise.

## 2. FF MANCHESTER CODED SIGNAL MODULATION AND DEMODULATION UNDER IDEAL CONDITIONS

The SIMULINK model illustrated in Figure 2 simulates how a Manchester coded 31.25 kbps FF signal can be generated in the ideal condition where both time delays (induced by modulation/demodulation electronic circuitry) and signal attenuation due to noise are not taken into consideration. The model includes three pulse generators. The first of them is used to generate the binary code (8 bits of data), which are modulated using Manchester coding. The frequency of the generated bit stream is 31.25 kbps. The second pulse generator is used to generate a bit stream of high to low transitions with a frequency of  $2 \cdot (31.25)$  kbps. Similarly, the third pulse generator is used to generate a bit stream of low to high transitions with a frequency of  $2 \cdot (31.25)$  kbps. Each binary bit of 1 generated by the first pulse generator is replaced by a high-low transition from the 2nd pulse generator, while each binary bit of 0 generated by the first pulse generator is replaced with low-high transition from the 3rd pulse generator. Switch 1 administrates the process of Manchester modulation by identification of ones and zeros generated by the 1st pulse generator. After the 31.25 kbps Manchester coded signal is generated, it will be applied to switch number 2, the output of which is a simulated signal similar to the Foundation Fieldbus bus current signal with a base current of 10 mA, increased by 9 mA for ones while decreased by 9 mA for zeros.

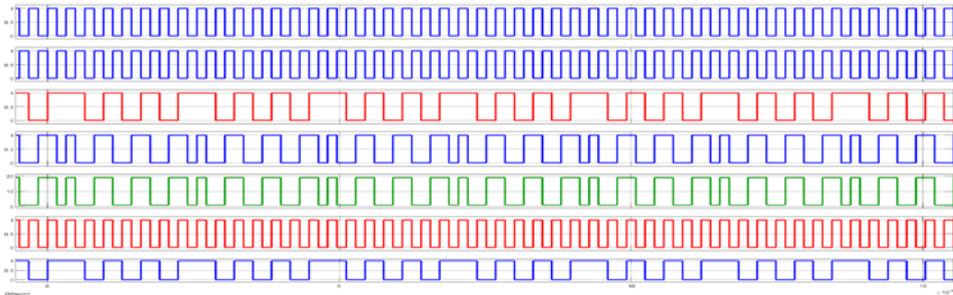


**Fig. 2.** SIMULINK Model used to simulate modulation/demodulation of a Foundation Fieldbus Manchester coded Signal in an ideal condition

In order to demodulate a Manchester coded signal in the ideal case, the demodulation section of the model first restores the output signal from the biasing section to its origin by eliminating the effect of the 10 mA base current with increments/decrements of  $\pm 9$  mA. The restored signal consists of High-Low and Low-High signal transitions corresponding to the modulated bit stream. In order to

recover the modulated bit stream generated by the 1st pulse generator, only XNOR logic gate is needed.

The input signals of the XNOR gate are the unbiased Manchester coded signal and the system clock signal of 31.25 kbps. Figure 3 illustrates the waveforms obtained from the simulation process in the SIMULINK model, see Figure 2.



**Fig. 3.** Waveforms obtained from SIMULINK model in Figure 2. The 1<sup>st</sup> and 2<sup>nd</sup> waveforms are pulse trains replacing the ones and zeros in the binary code respectively. The 3<sup>rd</sup> waveform represents the binary bit stream. The 4<sup>th</sup> and 5<sup>th</sup> waveforms are the output signals of modulation and biasing sections respectively. The 6<sup>th</sup> waveform is the system clock signal. The 7<sup>th</sup> waveform is the recovered binary code bit stream at the output of the demodulation section

### 3. FF MANCHESTER SIGNAL MODULATION / DEMODULATION IN PRACTICAL NOISY CONDITIONS USING MATLAB

In order to provide more realistic simulation for the Foundation Fieldbus 31.25 kbps Manchester coded signal of the H1 bus, a MATLAB code was used to simulate the modulation and demodulation process of a Foundation Fieldbus frame of data. The Foundation Fieldbus data frame consists of four sections, see Figure 4. These sections are a preamble, start delimiter, data from data link layer and end delimiter. Other than the purely ideal rectangular Manchester coded signal generated by the first SIMULINK model, the MATLAB code in this section generates a Manchester coded signal, which takes the shape of a trapezoidal waveform similar to practical operational conditions. The model also provides a method by which a Foundation Fieldbus Manchester coded signal can be demodulated in a noisy medium. The distortion induced by a noisy medium is simulated by an embedded additive white Gaussian noise signal (AWGN) added to the Foundation Fieldbus Manchester coded signal. The sampling frequency adopted by the MATLAB model is 10 MHz (greater than 31.25 kbps) which allows better detection of waveform changes in the Manchester coded signal as the period between samples is much less than the period of the Manchester coded signal.

Figure 5 illustrates the output waveform of the modulation process and the distortion induced by the AWGN noise on it, in addition to the fixing process for the distorted signal (1st phase of averaging). The demodulation index is a value resulting from the division between the sampling frequency and the Manchester coded signal frequency ( $f_s/f_m$ ), which is equal to 320 samples. In order to recover the binary bit stream of the FF data frame, another train of samples is generated with a period between the samples equal to 32 microseconds, which is equal to the demodulation index multiplied by the period between the samples generated by the main sampling frequency of 10 MHz. The distorted Foundation Fieldbus Manchester coded signal can be demodulated to its original binary code by averaging the signal in specific periods of time during which changes in the trapezoidal waveform take place. A Manchester coded trapezoidal signal takes different forms according to the value of the modulated binary bit and also according to the value of the bit that precedes it.

Generally, the FF Manchester coded trapezoidal waveform for a 32 microsecond time interval can be divided into four periods ( $32/4 = 8$  microseconds), during which four types of change can be detected (rising edge, falling edge, high logic value and low logic value). Therefore, the Manchester noisy signal is averaged every 8 microseconds and compared to each other every 32 microseconds, so that the location of the maximum and minimum values of the averaged fixed signal can be detected. In other words, there can only be four averaged fixed values corresponding to the four types of change in the waveform between the samples generated every 32 microseconds (Figure 6, upper part). The binary modulated bit can be restored by detecting the location of the maximum and minimum values among these four averaged fixed values. If the maximum detected averaged value preceded the minimum detected averaged value, the demodulated binary bit will be one. However, if the minimum detected averaged value preceded the maximum detected averaged value, the demodulated binary bit will be zero.

In order to detect Non-Data positive and negative bits, the four fixed averaged values can be averaged to a single fixed value (Figure 6, middle part). The minimum 4 detected values along the data frame will indicate the location of Non-Data negative N- bits based on which the Non-Data positive N+ bits can also be detected. Finally, it would be important to explain that such a demodulation technique based on averaging of the signal values at specific periods of time is simply equivalent to calculating the average energy of the received signal at these time intervals and according to the periods with maximum or minimum energy levels, hence the transmitted bit stream can be recovered.

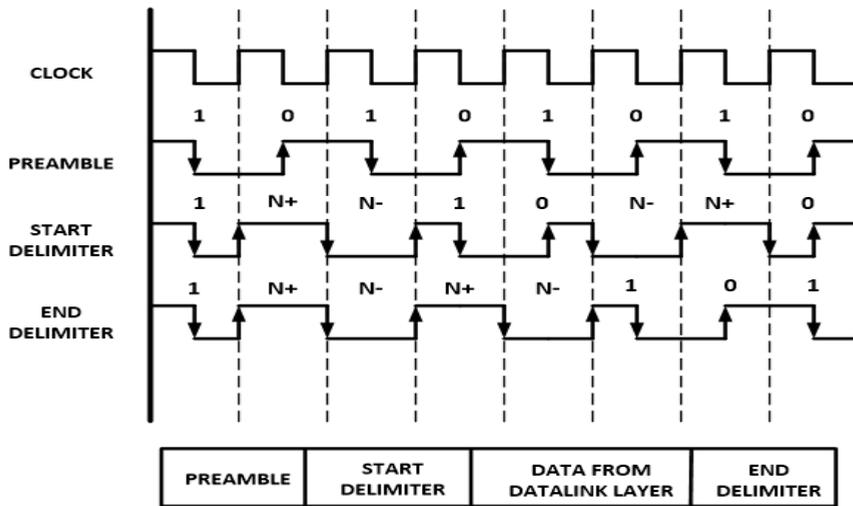


Fig. 4. Foundation Fieldbus Data Frame

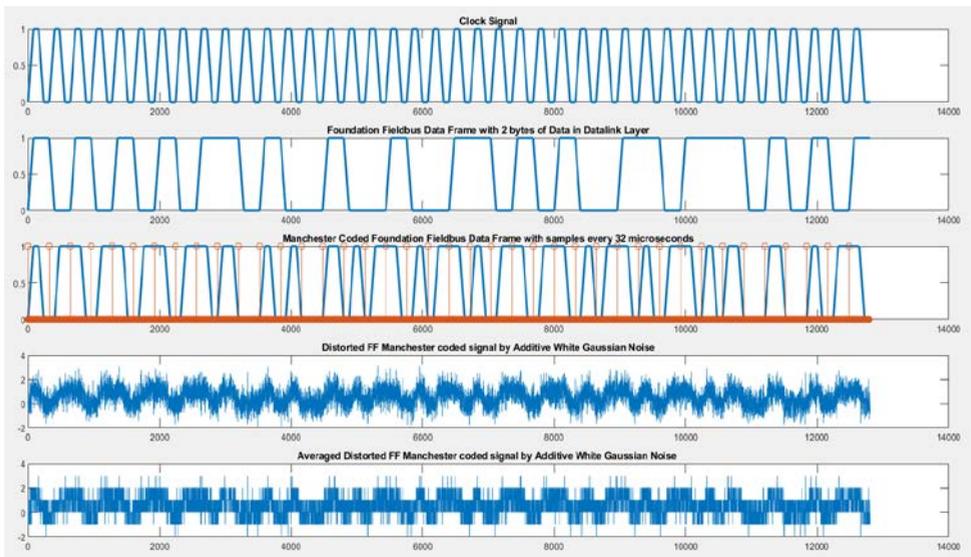
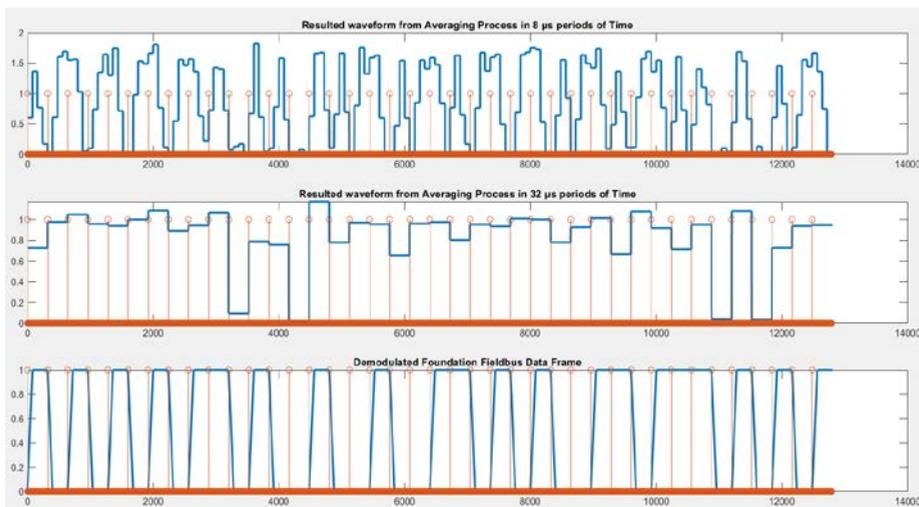


Fig. 5. MATLAB model waveforms of the clock signal, Foundation Field bus Data Frame Binary bits stream with samples every 32 microseconds, FF Manchester coded signal, Distorted FF Manchester coded signal and the averaging process of this distorted signal



**Fig. 6.** MATLAB model waveforms of Averaging Process in 8  $\mu\text{s}$  periods of time (used to detect zeros and ones of the modulated signal), Averaging Process in 32  $\mu\text{s}$  periods of time (used to detect Non-Data positive N+ and Non-Data negative N-bits) and demodulated FF data frame

#### 4. FF MANCHESTER SIGNAL MODULATION / DEMODULATION IN PRACTICAL NOISY CONDITIONS USING SIMULINK

The SIMULINK model illustrated in Figure 7 simulates a possible approach that could be adopted to modulate/demodulate a Foundation Fieldbus Manchester coded bit stream with a rate of 31.25 kbps. Similarly to the previous MATLAB model, the model takes into account that the generated waveform is not a purely rectangular waveform (as was discussed in the first SIMULINK model) as it is actually a trapezoidal waveform. The model takes also into consideration the effect of the signal distortion induced by a source of additive white Gaussian noise during the demodulation process. In order to eliminate the effect of the additive white Gaussian noise, Kalman filter is used to restore the originally modulated signal.

The model consists of four sections:

- Signal Generation;
- Manchester Signal Modulation;
- Kalman Filter;
- Manchester Signal demodulation.

#### 4.1. Signal generation

In this section, pulse generators are used to generate the basic required pulse streams or bit streams used for the other sections of the model. The 1<sup>st</sup> Pulse Generator generates the 8-bit binary bit stream with a frequency of 31.25 kbps, which is then modulated later using the Manchester coding. Another two pulse generators are used to generate the system clocks at frequencies of 31.25 and 2 x (31.25) kbps. Both of these clock signals are processed logically using logic gates, time delay blocks and SR latches in order to generate the required signals for modulation as well as the demodulation process. Additionally, the signal generation section also generates the trapezoidal waveforms used in the modulation process based on equations (1) and (2) [Stackoverflow 2014]. Switching (switch 1) is used to generate a preliminary representation of the binary bit stream based on the trapezoidal waveforms obtained from equations (1) and (2), where equation (1) represents the waveform which replaces the ones in the binary bit stream, while equation 2 represents the waveform which replaces the zeros in the binary bit stream. Figure 8 illustrates the most important signals generated by the signal generation section.

$$Y_1 = \arcsin(\sin 2\pi ft + 2) + \arccos(\sin 2\pi ft + 2) \quad (1)$$

$$Y_0 = \arcsin(\sin 2\pi ft + 3/2) + \arccos(\sin 2\pi ft + 3/2) \quad (2)$$

#### 4.2. Manchester signal modulation

In this section, the Manchester coded signal of the bit stream is generated using the preliminary representation obtained in the signal generation section. A time delay 2 of 8 microseconds is applied to the bit stream preliminary representation signal. The time delayed preliminary signal can then be applied to switches 2 and 3, which are both activated by the SR latch flip-flop which is activated by pulses generated by the logical circuits and time delay blocks in both the signal generation and Manchester signal modulation sections. Figure 9 illustrates the most important signals and waveforms in the section.

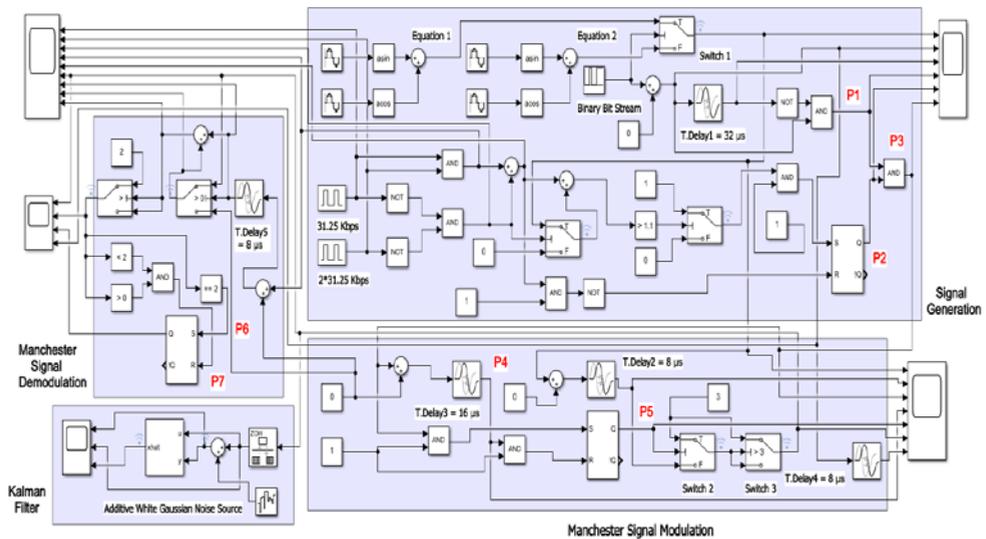
#### 4.3. Kalman filter

Kalman filter is used to eliminate the distortion in the Manchester coded signal obtained from the modulation section, see Figure 10. This distortion is induced by the additive white Gaussian noise source to simulate the noise that an FF Manchester coded signal might endure along the H1 bus cable.

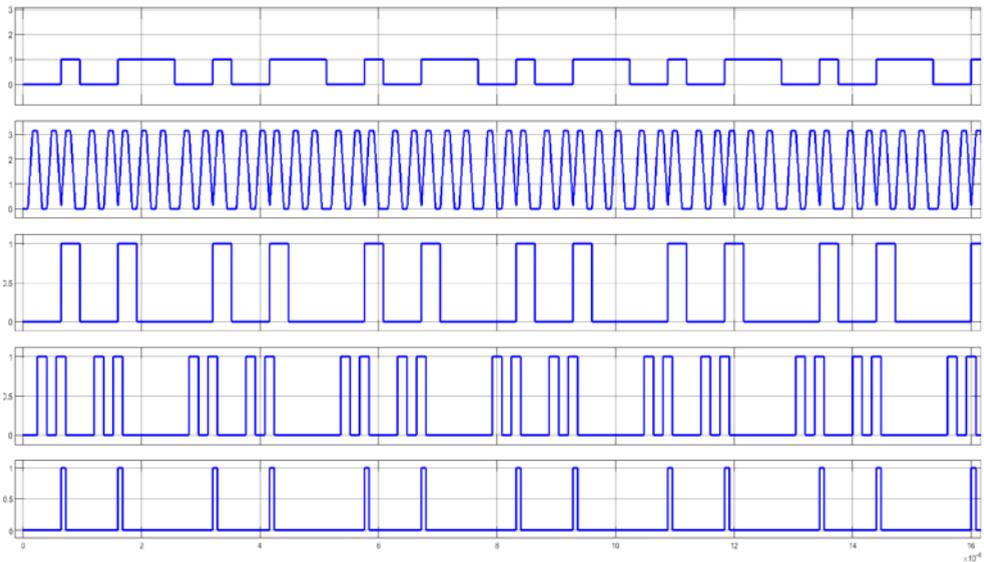
#### 4.4. Manchester signal demodulation

In this section of the model, the Binary bit stream is recovered from the Manchester coded modulated signal. Switches 4 and 5 are activated by pulses obtained from signal generation section applied to time delay 5 of 8 microseconds. The obtained signal from switches 4 and 5 is processed logically to generate the set and reset signals of the SR latch flip flop. The obtained signal from the SR flip flop represents the recovered demodulated binary bit stream. The idea of demodulation is essentially based on detecting the high or low level of the Manchester coded signal during a specific time slot of 8 microseconds. The time slot pulse stream is a 2-level pulse stream where pulses with higher level output pulses represent the set signals for the SR latch flip flop if the detected value of the Manchester coded signal was a high-logic value during this time slot. The 2-level lower-level output pulses are used to reset the SR latch flip flop if the detected value of the Manchester coded signal was a low-logic value during that time slot.

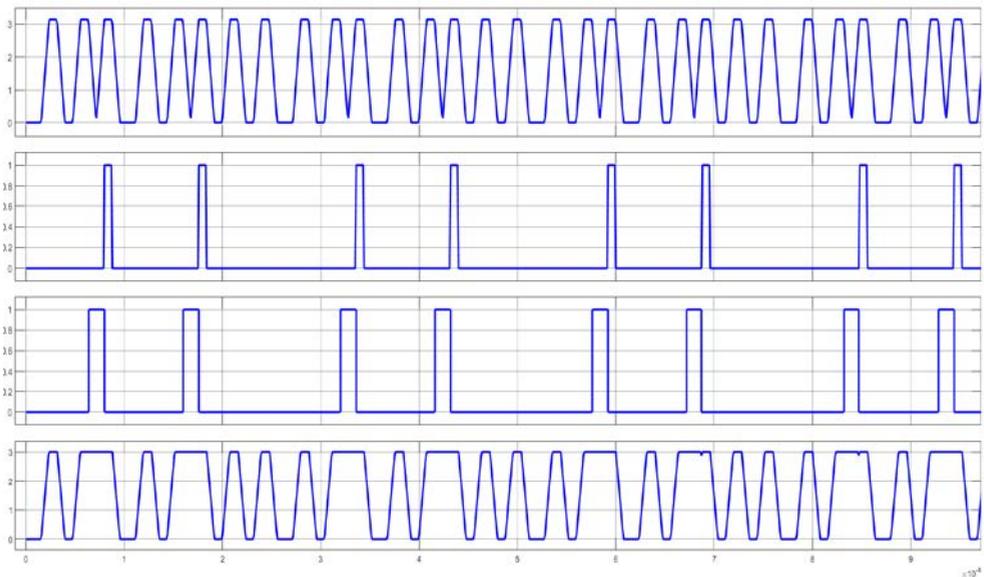
Figure 11 illustrates the most important signals used in the demodulation process as well as the demodulated bit stream.



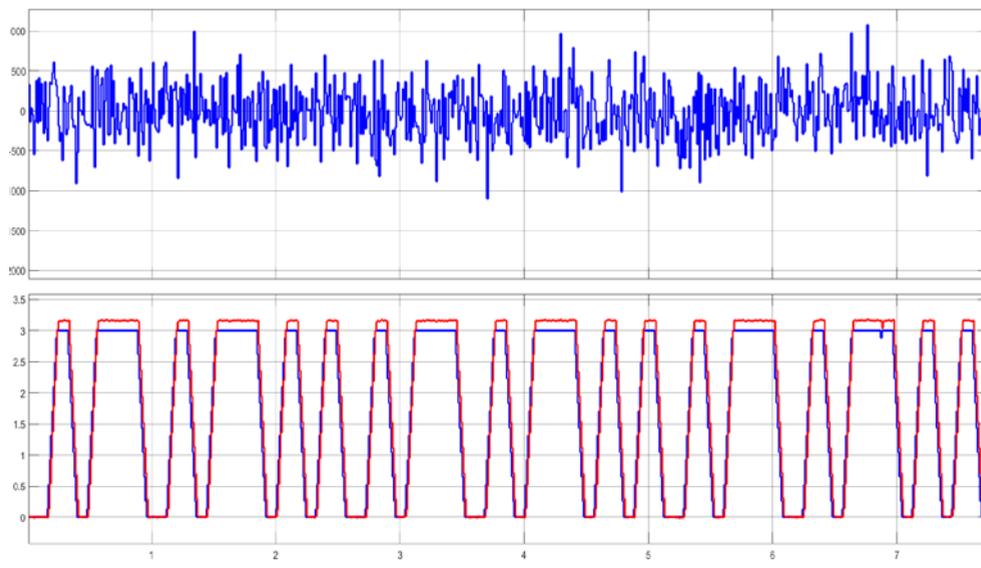
**Fig. 7.** SIMULINK Model used to simulate modulation/demodulation of Foundation Fieldbus Manchester coded signal in a noisy operational condition



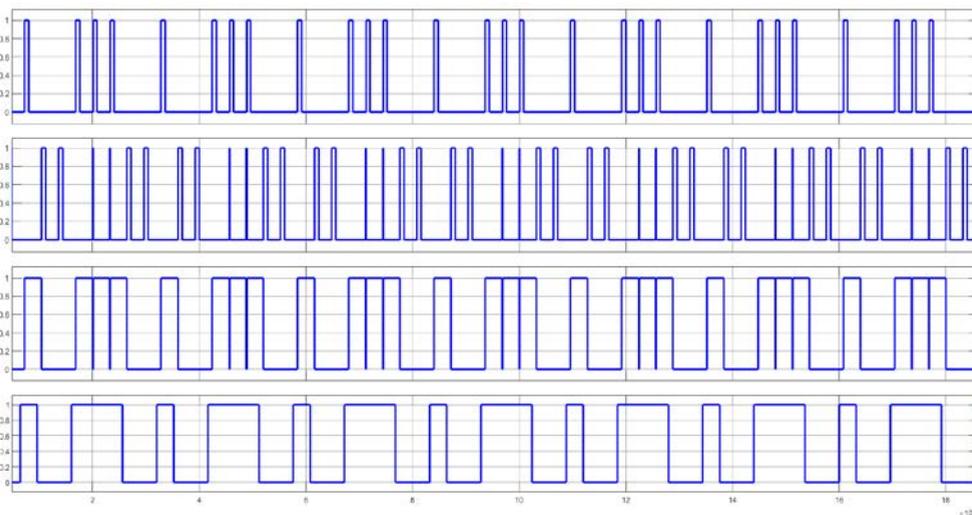
**Fig. 8.** Waveforms generated from the signal generation section. From top to bottom, FF binary bit stream and preliminary Manchester coded signal in addition to pulse trains generated at points P1, P2 and P3 respectively



**Fig. 9.** Waveforms generated from modulation section. From top to bottom, preliminary Manchester coded signal time delayed by 8  $\mu$ s in addition to pulse trains generated at points P4 and P5 respectively. The last waveform is the FF modulated Manchester signal



**Fig. 10.** Upper waveform illustrates the distortion induced in the FF Manchester coded signal by the additive white Gaussian source at the Kalman filter section. The lower plot illustrates the modulated FF Manchester coded signal without the effect of noise and the output filtered FF Manchester signal in blue and red colors respectively



**Fig. 11.** Waveforms generated from the demodulation section. From top to bottom, the set and reset signals for the SR latch flip-flop at points P6 and P7 respectively in addition to the demodulated binary bit stream of the FF data frame compared to the original binary bit stream at the last waveform

## 5. CONCLUSIONS

Eventually and after providing a description as well as the simulation results for each of the three models discussed in this article, conclusions can be summarized in the following points:

1. In ideal conditions, where purely rectangular noiseless waveforms are considered, the FF Manchester coded signal can be easily modulated and demodulated, as shown in the first SIMULINK model whereas modulation process will require only switching circuit between clock signal and pulse generators signals, while demodulation process will only require a XNOR logical operation between the modulated signal and the clock signal.
2. Under noisy operational conditions, where trapezoidal waveforms are considered, the modulation process requires more complex circuitry to perform the switching and time delay operations in order to generate the modulated FF Manchester signal as described in the third SIMULINK model.
3. As described in the second MATLAB model, a noisy Manchester FF signal distorted by an AWGN source can be demodulated by calculating the average energy of the wave in specific periods of time every 8  $\mu\text{s}$ . Afterwards, four calculated energy levels collected every 32  $\mu\text{s}$  will be compared among each other to indicate the location of the maximum and minimum energy levels according to which the demodulated binary bit will be 1 (if maximum energy preceded minimum energy) or 0 (if minimum energy preceded maximum energy).
4. As described in the second MATLAB model, negative Non-Data bits of FF data frame can be demodulated out of a noisy FF Manchester coded signal by calculating the average energy of the wave every 32  $\mu\text{s}$  to detect the minimum four energy levels in the FF data frame. The position of these minimal calculated energy levels indicates the position of Non-Data negative bits, and by knowing their location, the position of the Non-Data positive bits can also be detected.
5. As described in the third SIMULINK model, the Kalman filter can be used at the stage prior to the demodulation stage to eliminate the effect of noise induced into the FF Manchester coded signal by an AWGN source by providing continuous updated estimation of the output signal based on the previous estimates as well as the input noisy signal.

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