Channel extractor for UAV PPM signals

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Abstract

The problem solved in the work is important for understanding the operation of modern unmanned systems. It shows how different components interact with each other to achieve the common goal of providing effective UAV control and real-time video transmission. The obtained results are especially important for solving tasks where high precision and responsiveness are required, such as reconnaissance missions, environmental monitoring and rescue operations. The proposed scheme helps improve existing technologies and develop new approaches to UAV control, making it a valuable tool for engineers and researchers in the field of unmanned aerial vehicles. Studies of pulse-position modulation were carried out, for which each pulse in the sequence of carrier pulses changes over time, but without changing the shape and amplitude of the pulse signal. In this paper, a PPM-to-PWM system is designed. The transformation of PWM signals for several devices, the so-called scaling of the scheme, was investigated. during simulation, the appearance of the so-called "glitch" after the received pulse of the PWM signal was detected – a small drop of the pulse over time, which is caused by the reset time of the triggers, and will not affect the control process.

Keywords

channel extractor, reservoir reconnaissance, signal processing, pulse-position modulation, unmanned aerial vehicle

1. Introduction and literature review

Nowadays, the design and modeling of drones is an actual, dynamic and extremely complex field of work, and a lot of research is being conducted in this direction [1, 2]. In work [3] optical camera communication (OCC) has emerged as a promising alternative technology for radio frequency (RF)-based communication systems. However, existing OCC approaches only consider transmitting data through broadcasting, without any ability for point-to-point communication. Deep neural networks (DNNs) [4] have become a relevant subject in the classification of radio frequency signals and remote sensing data. A primary challenge is a tradeoff between obtaining data that are suitable for DNN training and the effort that making experimental measurements requires.

Represents results on the bit error probability (BEP) of Reed Solomon (RS) codes for an optically pre-amplified pulse position modulation receiver [5]. Analytical relations for the BEP calculation of the RS coded system were derived and validated via Monte Carlo simulations. The analytical relations are then utilized to assess the BEP performance of the system in the presence of weak and strong fading. Khallaf et al. [6] presents accurate approximation expressions for the outage and secrecy outage probabilities of relay-assisted free-space optical (FSO) communication links utilizing unmanned aerial vehicles (UAVs).

Nowadays, automatic modulation classification (AMC) has become a key component of next-generation drone communication systems, which are crucial for improving communication efficiency in non-

cooperative environments [7]. Computational imaging breaks the limitation of traditional digital imaging to acquire the information deeper (e.g., high dynamic range imaging and low light imaging) and broader (e.g., spectrum, light field, and 3D imaging) [8]. Driven by industry, especially mobile phone manufacturer medical and automotive, computational imaging has become ubiquitous in our daily lives and plays a critical role in accelerating the revolution of industry. As various unmanned autonomous driving technologies such as autonomous vehicles and autonomous driving drones are being developed, research on FMCW radar, a sensor related to these technologies, is actively being conducted [9].

The mainstream Global Navigation Satellite System (GNSS) constellations in Medium Earth Orbits (MEO), Inclined Geo Synchronous Orbits (IGSO) and Geostationary Orbits (GEO), which are primarily used for Positioning, Navigation and Timing (PNT) can only provide positioning accuracy that varies from several to dozens of meters, when no Precise Point Positioning (PPP) techniques are used [10].

Lin et al. [11] developed a low-phase-noise, high-sensitivity linear-frequency-modulated continuous-wave (LFMCW) airborne radar for counter-UAS (unmanned aerial system) applications. Ciesielski et al. [12] presents research on using multiple signal processors operating simultaneously with different coherent processing intervals. The papers focuses on considerations related to drone detection. Theoretical analysis of the problems arising in FMCW radars is provided and a solution utilizing multiple signal processors is proposed. Results of field trials are also presented.

Lloyd and Korenberg [13] show improved radar range and velocity resolution is achieved using fast orthogonal search in place of the standard fast Fourier transform. The method reliably detects targets that are close either in range or in velocity, which is relevant today given recent advances in target swarms. WiFi based passive sensing is attracting considerable interest in the scientific community for both research and commercial purposes [14]. In this work, we aim at taking a step forward in an endeavor to achieve good sensing capabilities employing compact, low-cost, and stand-alone WiFi sensors.

Drone-monitoring radars typically integrate many pulses in order to improve signal to noise ratio and enable high detection performance [15]. Over the course of this coherent processing interval (CPI), many components of the drone signature change and the signature's amplitude and Doppler modulations may hinder coherent integration performance, even in the absence of range-Doppler cell migrations.

The use of WiFi signals for sensing purposes has attracted a lot of interest from both the radar and communications communities and several techniques have been explored [16]. In the attempt of meeting the requirements for small sensor size, compactness, and easy deployment, the authors consider reference-free approaches, namely approaches that do not require a good copy of the transmitted waveform to be available at the radar receiver. Automatic modulation classification (AMC) is a signal processing technology used to identify the modulation type of unknown signals without prior information such as modulation parameters for drone communications [17]. In recent years, deep learning (DL) has been widely used in AMC methods due to its powerful feature extraction ability.

Safa et al. [18] investigates unsupervised learning of low-dimensional representations from FMCW radar data, which can be used for multiple downstream tasks in a drone navigation context. To this end, we release a first-of-its-kind dataset of raw radar ADC data recorded from a radar mounted on a flying drone in an indoor environment, together with ground truth detection targets. A work by Di Seglio et al. [19] deals with the short-range monitoring of small radar cross section targets using commercial WiFi transmitters as source of opportunity. UAVs or drones as an alternative solution to providing high-quality Internet service in difficult terrain are environmentally friendly and do not consume electricity during the day as is the case with communication towers [20]. Kim et al. [21] proposed a drone classification method for polarimetric radar, based on convolutional neural network (CNN) and image processing methods. We compared the result from the proposed method with conventional polarimetric radar image structure and achieved similar accuracy while having half of full polarimetric data.

2. Theoretical background

The structural diagram of the UAV communication system is shown in figure 1. The structural levels of the user, the UAV and the direct communication and interaction between them are separately allocated. The operation of the system begins with the User controls element in the user group, which can be implemented as a control panel or simulated using a personal computer. This device generates a PPM signal that contains information about the desired state of the UAV: speed, angular velocities, additional information from the configuration channels. This signal is coded by the modulator for transmission over the radio control channel and enters the UAV receiver.
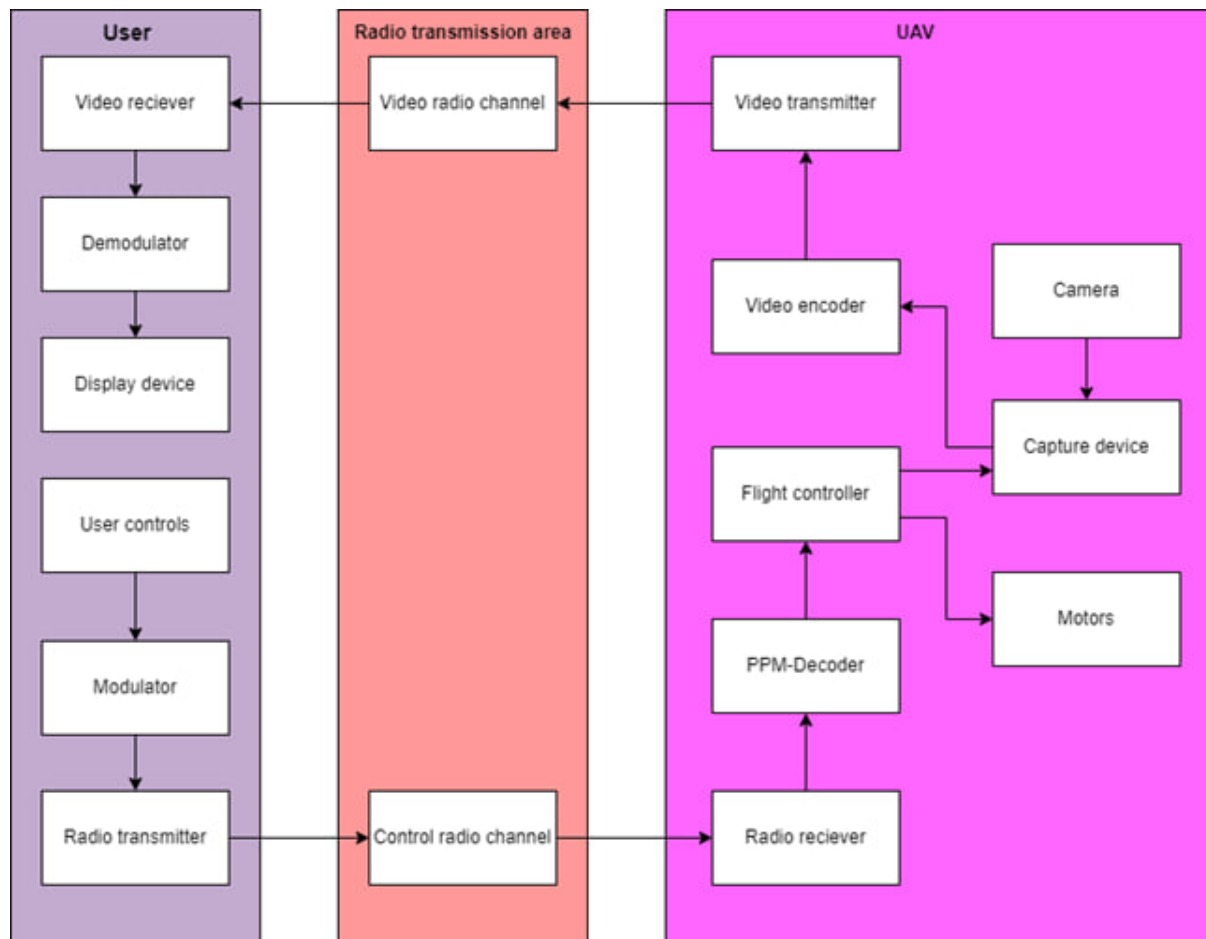
**Figure 1:** Structural diagram of the UAV communication system.

Further, after decoding the signal, the flight controller receives information from the remote control and distributes the load on the motor group to meet the user's requirements. The video from the camera is used as feedback, which is formed taking into account both the frame from the camera and the telemetry indicators of the flight controller [22].

Similarly, to the transmission of the signal to the UAV, this frame is forwarded to the user output system in the form of a display. Drone research is a modern need for technology development. Processing of data and images by drones to perform the necessary functions requires the construction of certain structures and algorithms that meet the requirements of speed, reliability and a limited number of resources.

Controlling drones is complicated by the presence of a large number of obstacles of various origins and nature. Taking this fact into account when building control systems and data processing algorithms necessitates the use of signal modulation and, accordingly, the construction of processing models based on the use of different types of signal modulation. The work is devoted to the study of drones intended

for the study of reservoirs, capable of taking water samples in hard-to-reach places, performing patrols and carrying out customs supervision.

The task of transmitting an analog signal from potentiometers on a control panel with digital means is relevant, widespread and important. The parameters of sensitivity, accuracy and speed are very important here. It should be noted that the analog signal is formed, transmitted and processed precisely by digital technologies in order to ensure the requirement of speed and improve the clarity of the processing of the control signal, which in turn can be implemented precisely by pulse-position modulation (figure 2). Controlling the device with the help of the model illustrated in this article makes it possible to ensure control quality parameters through certain signal processing and data transmission (encoding) using the appropriate modulation, which in turn ensures multi-channel control of the device.
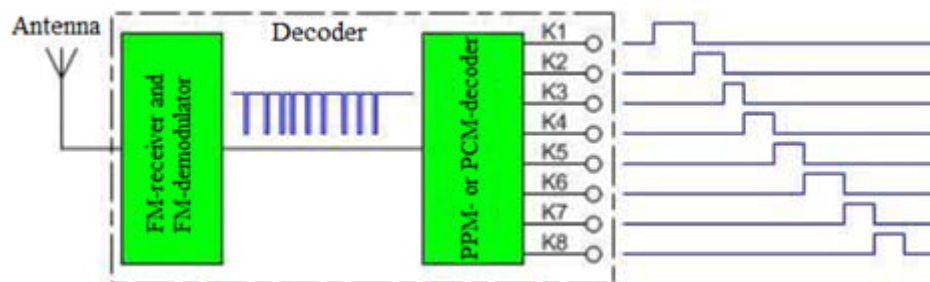

Figure 2: Signal decoding [23].

Pulse-Position Modulation (PPM) signals are necessary to control devices that use separate Pulse Width Modulation (PWM) signals. For example, when there are several devices and you need to connect them to one data line. In this way, the signals will be separated in time. Without the use of signal modulation, there may be complications with the transmission of commands and control of the drone. Modulation allows the transmission of digital commands and data, which simplifies the interaction between the drone and the operator. The use of signal modulation makes it possible to increase resistance to noise and other disturbances in the communication channel. Without modulation, there can be problems with clarity and reliability of communication, which can lead to signal loss or errors in data transmission. Signal modulation allows the transmission of various types of information, including control commands, drone status data, instructions for performing various tasks, etc. Without the use of modulation, the possibility of effective and advanced control may be limited. The lack of signal modulation can make the communication channel less resistant to attacks and unauthorized access. Modulation can provide a certain level of confidentiality and security of information transmission.

In general, the use of signal modulation is a key aspect for reliable and efficient communication with a drone, especially in the unmanned airspace environment, where immunity to interference and control accuracy are of great importance. When the operator sends a command, a specific time interval is allocated for each command, and the position of the pulse indicates the specific command or state. This method allows many different commands to be efficiently transmitted in a single data stream, making it useful for unmanned aerial vehicles and other remote-control systems.

Nowadays, great variety of electronic modules are controlled with PWM signals, that allow conversion from digital to analog signals or eases control on duty cycle. Especially it is relevant in terms of drone technologies almost every part of a drone is controlled with some kind of PWM signals: motors, servos, analog+ camera interfaces, DC converters. But the main flaw of PWM is that each channel for each device requires separate wire in order to perform. This problem was solved by using different encodings of signals. Three main types of encodings are PWM – pulse-width modulation, PPM – pulse-position modulation and frequency modulation and FM – frequency modulation. Since a lot of devices are standardized to use PWM signal with length of 20 ms and max duty cycle of 10 percentages it allows us to pack up to 10 PWM signals in a single period of PPM. But decoding of such signals may cause some troubles: if there is a line with PPM signal and it is required to separate a single channel from

this line and give it to specific device available solutions are either to give signal to microcontroller and program it for purpose of separation a single channel or use ppm decoders that usually channel specific devices and decode all of channels at the same time and so leads to some pins being unused. PPM signal example (at the top) and desired circuit outputs per channel (figure 3).
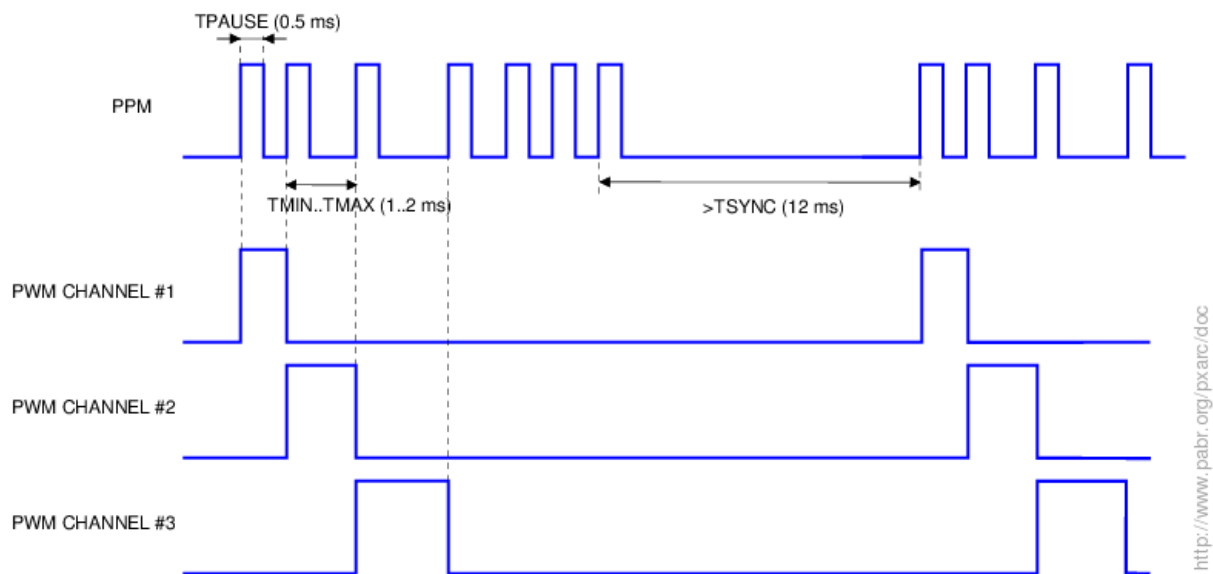
Figure 3: PPM and PWM signal examples [24].

In PWM, the pulse width varies, but the frequency remains constant. Usually, a high pulse width indicates a large signal, and a low pulse width indicates a small signal. In PPM, the width of the pulses is fixed, but the moment of their occurrence (position) changes. The width of the pulses may remain the same, but their position on the time axis changes. Coding is done by changing the pulse width. For example, a wider pulse may indicate a large or maximum signal, and a narrower pulse – a small or minimum signal. Coding occurs by changing the position of the pulses. Each pulse represents a separate signal or channel, and its position on the time axis indicates the value of the signal. Each channel uses its own PWM signal, and the number of channels is determined by the number of individual PWM signals. In PPM, the whole signal includes several channels, and each channel is defined by the position of the pulse on the time axis. The modulator converts the output data into the PPM form of the signal, determining the time points for the pulses in the transmission interval. If the signal was modulated during transmission, optional performs demodulation to restore the original PPM signal. Demodulator determines the value of each pulse relative to time intervals. When processing the received information, the received data is used to perform appropriate operations or control the drone or other system. The modulation architecture for the drone includes various components for effective control and communication. The description of the main ones is given below. The Flight Controller is responsible for controlling the movement and stabilization of the drone. Its functionality may include navigation systems, autopilot, stability control, and the like.

The Wireless Communication Module is used to transmit data between the drone and the ground department or other devices. This may include radio modems, Wi-Fi, Bluetooth or other technologies. The Signal Processing Module is designed to process signals from various sensors and systems, as well as to implement stabilization and control algorithms. Antennas and Transceiver Modules provide uninterrupted communication between the drone and the controller.

3. The proposed hardware solution for PPM channel extraction simulation results

The system indicated in the figure is an example of the use of the device in a system with a single PPM signal line. Model of controlled system is presented in figure 4.
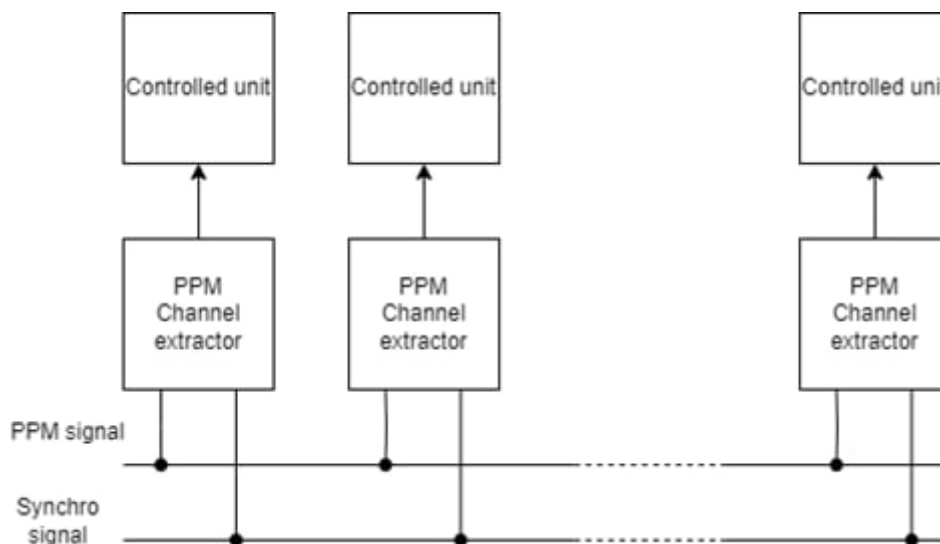

Figure 4: Expected system for designed circuit.

Model of PPM Channel extractor consists of 3 main blocks (figure 5): counter register, user input channel register, where user can define channel index and compare circuit that changes his state when required period is reached.
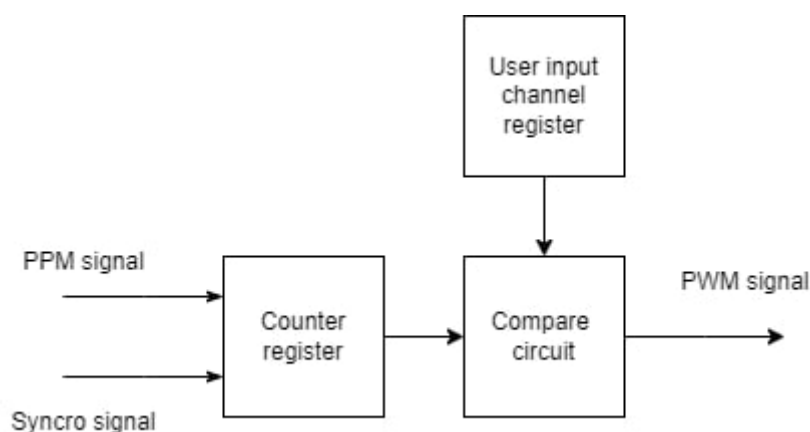

Figure 5: PPM channel extractor system.

3.1. DC component signal conversion

The constant signal component of the DC component in pulse-position modulation is calculated as the average value of the signal over the period. In general, the formula for the DC component of the PPM signal looks like this [25]:

$$DC = \frac{1}{T} \int_0^T s(t)\, dt, \tag{1}$$

where DC is the constant component of the signal, $s(t)$ is the instantaneous value of the PPM signal at time t, T is the period of the signal.

The PPM signal consists of pulses, the position of which changes depending on the modulation signal. During the analysis of DC components, both the pulses themselves (their shape) and the duration of the pauses between them are taken into account. DC component depends on the pulse width and frequency.

If the signal $s(t)$ is represented by periodic pulses, then the constant component can be simplified to:

$$DC = A \cdot \frac{\tau}{T}, \tag{2}$$

where A is the pulse amplitude, τ is the pulse width, T is the signal repetition period.

The PPM signal is formed by shifting the position of the pulses in time according to the value of the modulating signal. The general appearance of the signal can be presented as follows:

$$s(t) = \sum_n p(t - nT - \Delta t_n), \tag{3}$$

where $s(t)$ is the PPM signal, $p(t)$ is the shape of one pulse, T is the pulse repetition period, Δt_n is the time deviation of the pulse of the n-th period, which is determined by the modulating signal.

The time shift of the pulse Δt_n is directly proportional to the instantaneous value of the modulating signal:

$$\Delta t_n = k \cdot m(nT), \tag{4}$$

where k is the scaling factor, $m(nT)$ is the value of the modulating signal at the moment nT.

The power spectral density of the PPM signal can be calculated taking into account the contributions of the base pulse and the modulating signal. For a harmonic modulator, the main energy is concentrated on the harmonics corresponding to the repetition rate $f = 1/T$.

A signal-to-noise ratio formula that takes into account the effects of sampling and pulse width is often used to estimate PPM performance in a communication channel.

$$\text{SNR} = \frac{\text{Signal Power}}{\text{Noise Power}} \tag{5}$$

3.2. Schematic primary description

Micro-Cap is used for analog and digital modeling of electrical and electronic circuits with an integrated visual editor. Allows you to analyze analog, digital and mixed (analog-digital) devices, as well as synthesize passive and active filters. In atypical situations, it is possible to create your own macromodels that perform simulation without losing information about the behavior of the system. As it can be seen in this case there is no need to use extra circuits and extra wires for PPM-PWM conversion and so less resources are used. Synchro signal is not used commonly in PPM transition but in our case, we need to synchronize counter registers reset and that can be done either with addition of extra synchro line or adding extra circuit to module that will compare number of reeded channels with total number of channels in signal. Example of input signals is presented in figure 6.

In the Micro-Cap system, a circuit based on inverters, XOR, JK flip-flops, XNOR, power cells and reference voltage sources were modeled. Modelling results is presented in figure 7.

When PPM (blue color) and the RESET signal (red color) are applied to the input of the specified circuit, after conversion, the output will be a PWM signal from the coded channel (figure 8).
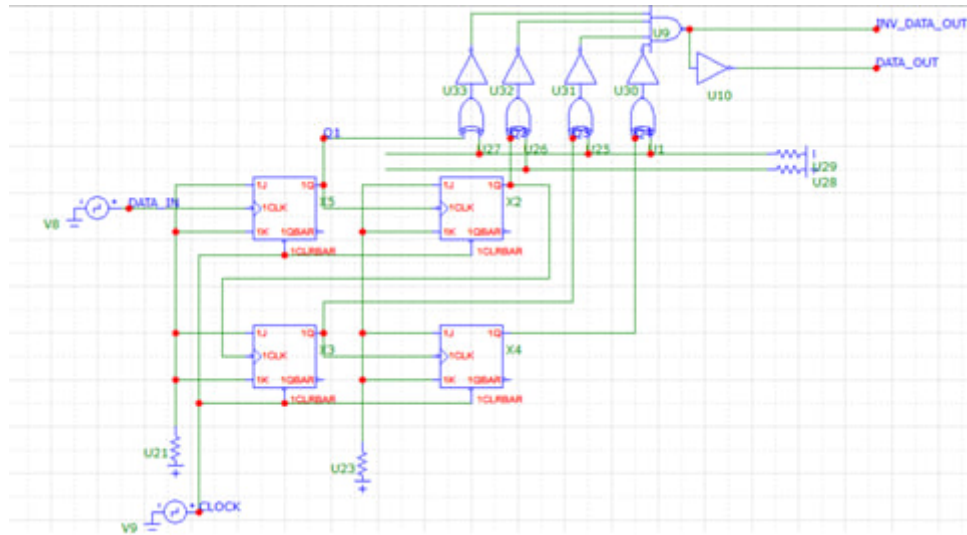
The above diagram shows the conversion of PWM signals for several devices, the so-called scaling of the scheme (figure 9).
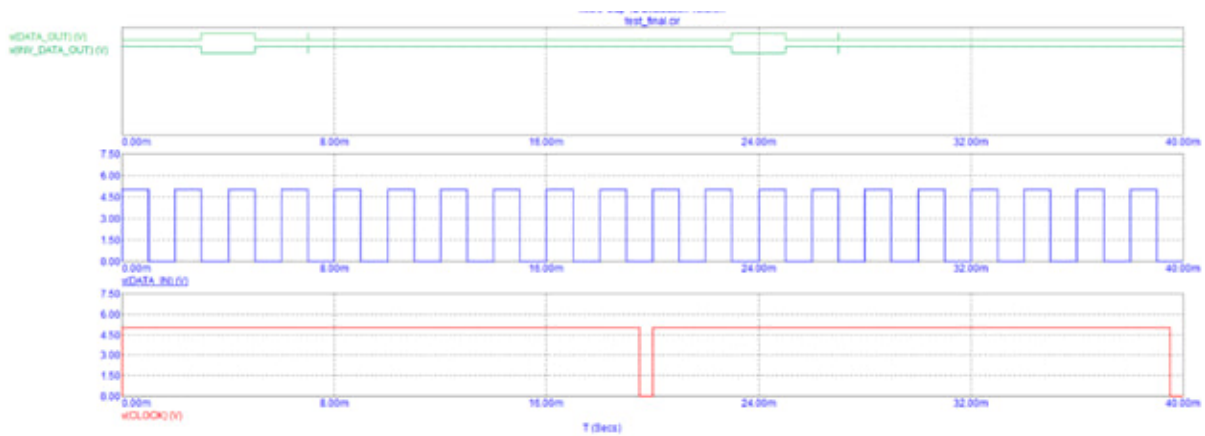
3.3. Results

When applying PPM (blue color) and RESET signal (red color) on the third graph from the bottom (figure 10), after conversion, the output will be PWM signal for two different channels.
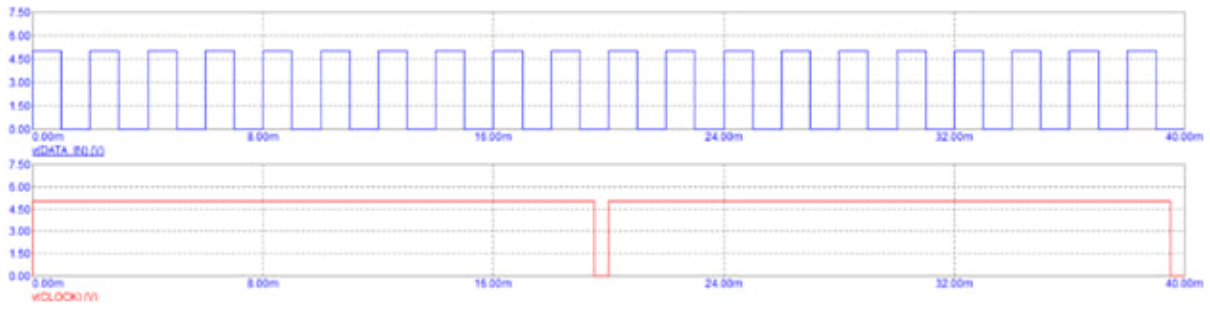
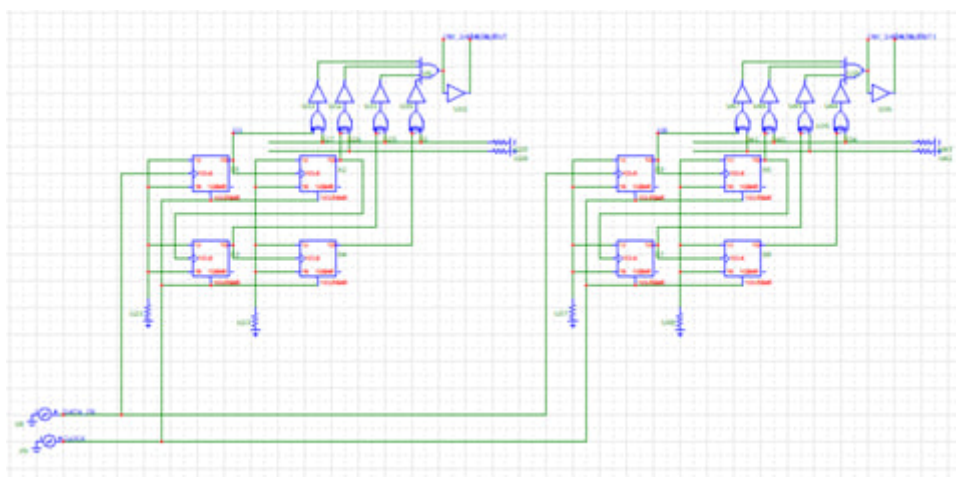**Figure 6:** Circuit inputs (10-channel PPM and synchro signal).
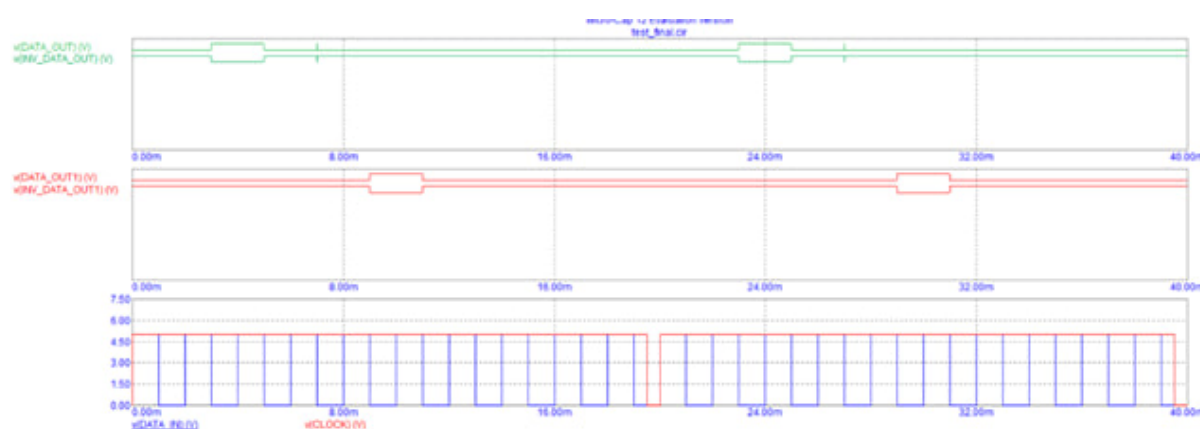

Figure 7: Test circuit.

Figure 8: Modeling result. Green time table at the top – output.

Also, in both cases, we can see the appearance of the so-called "glitch" after the received pulse of the PWM signal – a small pulse drop over time, which is due to the reset time of the triggers and will not affect the control process.

Figure 9: System of circuits.

Figure 10: Multi circuit example.

4. Discussion

The task of transmitting an analog signal from potentiometers on a control panel with digital means is relevant, widespread and important. The parameters of sensitivity, accuracy and speed are very important here. It should be noted that the analog signal is formed, transmitted and processed precisely by digital technologies in order to ensure the requirement of speed and improve the clarity of the processing of the control signal, which in turn can be implemented precisely by pulse-position modulation. Controlling the device with the help of the model illustrated in this article makes it possible to ensure control quality parameters through certain signal processing and data transmission (encoding) using the appropriate modulation, which in turn ensures multi-channel control of the device. The results of the work can be used in systems in which it is necessary to control many devices with PWM modulation, that is, it is necessary to transmit a large number of signals over one communication line.

The obtained results have technical limitations due to the design and conditions of use. The developed device shows great flexibility and scalability in integration into systems where processing of a large number of PPM signals is required. This enables its use in a variety of applications and scenarios. The resistance of the device to various types of interference and noise in the signal transmission environment was analyzed and confirmed. This makes it reliable and effective in real operating conditions.

The developed device is easily integrated with existing communication systems, which allows it to be used in large numbers in one system without significant modifications or reconstructions of the communication system.

Also, ways of further improvement were defined: get rid of synchro signal by adding an extra

block that will automatically reset the circuit while reaching with counter block pre-defined value that represents the number of encrypted in PPM channels.

5. Conclusions

The transformation of PWM signals for several devices, the so-called scaling of the scheme, was investigated. During simulation, the appearance of the so-called "glitch" after the received pulse of the PWM signal was detected – a small drop of the pulse over time, which is caused by the reset time of the triggers, and will not affect the control process. The results of the work can be used in systems in which it is necessary to control many devices with PWM modulation, that is, it is necessary to transmit a large number of signals over one communication line.

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