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Distribution of official time on long waves, using the 225 kHz carrier wave of the First Polish Radio Program

Description of the design of an exemplary receiver module for encrypted official time signals

v. 1.0

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The Central Office of Measures (GUM) has launched a service for broadcasting encoded digital time signals on long waves, using the 225 kHz carrier wave of the First Polish Radio Program, from a transmitter located in the territory of Polish. It is a technique similar to the DCF77 system but based on signal phase modulation. As a result, it is possible to synchronize timekeeping devices in Poland and a large part of Europe with the official time using cheap, energy-efficient, and uncomplicated receiving devices. This technique makes it possible to synchronize many timekeeping devices with an accuracy of a few or several milliseconds to the official time in the territory of the Republic of Poland. The system will be an additional (redundant) source of time information for users located in Polish.

Using digitally coded time signals involves adding an appropriate device (modulator) to the infrastructure for emitting radio waves at RCN Solec Kujawski (PCSK-225) and implementing receivers. The receiver performs its tasks automatically (i.e., determines the official time based on the emitted time signals) after correctly receiving the received signal.

2 Technical requirements of the receiver, time signal parameters.

The receiver will be adapted to receive signals with the following characteristics:

1) frequency with a nominal value of 225 kHz, transmitted from the transmitter of the Radio Broadcasting Centre (PCSK-225) in Solec Kujawski, with amplitude modulation of the acoustic radio signal and a dynamic carrier wave level control system;
2) dynamically variable carrier wave level (in the range from 0 dB to approx. -6.4 dB relative to the maximum carrier wave level) depending on the depth of acoustic signal modulation (AM modulation) and the set operating mode;
3) possible periodic shutdown of the 225 kHz long-wave transmitter for the duration of inspections (on average once a year for approx. 20 hours) and maintenance (on average once every five years for approx. two weeks) and short-term interruptions in signal emission (typically less than 2 hours) for other reasons;
4) implemented PSK (Phase Shift Keying) modulation of the NRZ (Non-Return-To-Zero) type, binary signal with smooth linear phase changes of the carrier wave – with the possibility of changing (within a fixed limited range) selected coding parameters: the value of the depth of the (additional) phase shift of the carrier wave when transitioning to a new state (01 or 10), the time it takes to complete the transition to a new state (01 or 10), transmission speed;
5) possibility of periodic coexistence of additional frames with dynamically changed transmission parameters, length and content of the message – PSK modulation type NRZ – possibility of changed transmission speed, depth of (additional) phase shift of the carrier wave, time of transition to the new state, change of error correction code, frame length;
6) start of transmitting a group of frames: at every full minute and subsequent frames (start of sending) at intervals of 3 s, possible deliberate short-term interruptions in the

transmission of frames constituting multiples of the interval of 3 s;

7) no collision of frames transmitted for the needs of different systems (broadcasting schedules may overlap in time but do not coincide);
8) the transmission of each frame takes less than 3 seconds;
9) during the transition to the new state, the maximum deviation of the carrier wave frequency does not exceed ± 100 Hz;
10) adopted basic modulation format of encoded official time signals: PSK modulation type NRZ, transmission speed 50 bit/s, depth of (additional) phase shift of the carrier wave - 36° ± 3.6° (10 % of the carrier wave period), frame length – 14 bytes, synchronization bytes, some transmission parameters may be slightly modified over time, e.g. the depth of the (additional) phase shift of the carrier wave, or the time of the transition to a new state (01 or 10);
11) the level (surface wave field strength) of the received 225 kHz signal from the longwave transmitter in the PCSK-225 in Solec Kujawski in most of the Polish region is estimated to be above 78 dB (μV/m) – there are areas where the signal level decreases locally to the level of about 70 dB (μV/m).

3 Receiver concept

The receiver can be divided into two functional blocks;

- Frontend RF - Radio Frequency Receiver
- DSP demodulator

The RF front end is based on the SI4735 integrated circuit, whose block diagram is shown in Figure 1.

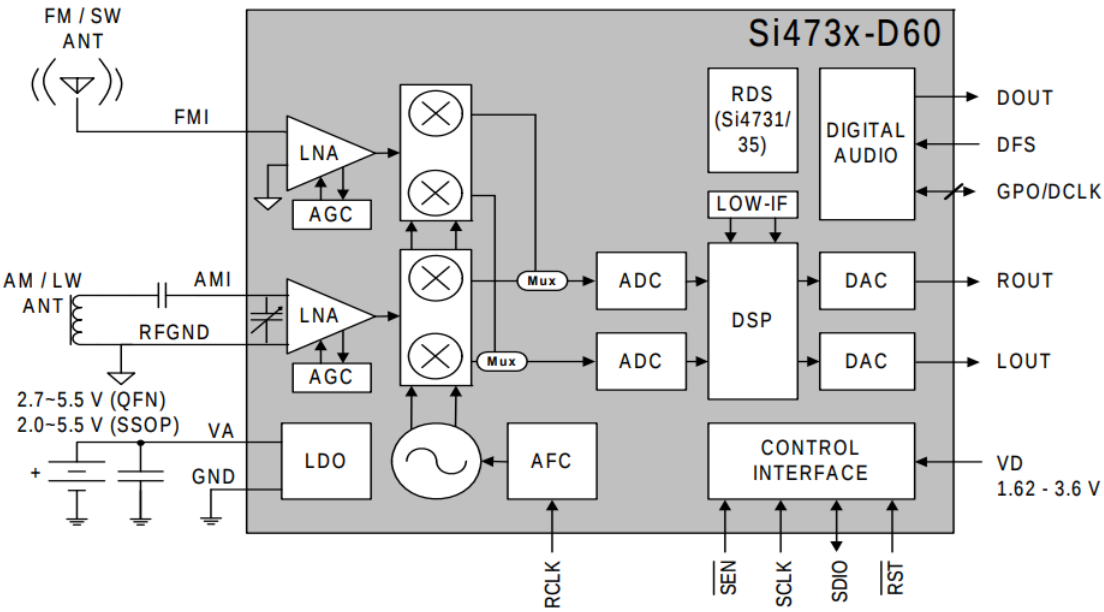

Figure 1. The RF frontend of the sample receiver module.

The device allows to receive long waves in the range of 153-279 kHz; thanks to the use of a DSP processor, it is possible to use the device in a non-standard way and use it as an SSB receiver (in this case, USB) working with BFO at a frequency of 224 kHz, which results in the reproduction of the transmitter's carrier wave output transferred to the acoustic band - in this case 1 kHz. In addition, the system provides automatic gain adjustment. The frontend layout is controlled by a frequency of 32.768 kHz obtained from a quartz generator.

The signal received this way is sent for further processing in the dsPIC33 signal processor. After initial filtering through a bandpass filter with a width of 200 Hz. Demodulator concept

During processing, the information from the PSK modulation signal is recovered in the DSP, and then, after passing through the packer, the frame classification takes place. When a keyword is detected, 0x60 subsequent bytes are written to the buffer, and R-S correction is performed. Then, the correctness of the received data is verified (the so-called "sanity checks") - whether there has been a "time shift" or a "jump into the future" more significant than it would result from predictions based on the observation of the local RTC.

Measurement of time intervals between successive received frames will allow determining the frequency difference and carrying out systematic correction of the time scale created in the receiver.

After verifying the received data, the processor controls the 1PPS generator.

4 DSP Block Description

The DSP block is based on the dsPIC33FJ128GP804 processor. The processor was chosen due to design requirements (according to the order, the platform should be expandable in the future). The signal demodulation process takes about 10% of the processor's time, leaving a large reserve of computing power for future applications.

The processor's analog-to-digital converter input is supplied with an audio signal from the tuner's output. This type of solution allows you to separate the radio part from the digital part. In very difficult reception conditions (e.g., on deep-sea vessels), a professional radio communication receiver can also be used, and the audio signal can be delivered directly to the DSP.

The process of demodulating time frames takes several steps. After filtering the signal through a bandpass filter with a center frequency of 1 kHz and a bandwidth of 200 Hz, the signal is fed to a software-implemented Costas loop, which allows for the detection of changes in the signal's phase. The data stream is then passed to the bit-slicer, and the resulting bitstream feeds the packetizer, which parses the synchronization bits and the keyword.

When a data frame is received, correction codes are calculated, and frame consistency tests are performed.

In addition, the DSP will act as the RTC clock.

5 Data Frame Description

The following frame applies to the system.

5.1 Frame format

Ramka ma następujący format:

0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
0	1	1	0	0	0	0	0	1	0	1	S0	S1	S2	S3	S4
S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
S21	S22	S23	S24	S25	S26	S27	S28	S29	TZ0	TZ1	LS	LSS	TZC	SK0	SK1
Reed-Solomon ECC byte 0								Reed-Solomon ECC byte 1							
Reed-Solomon ECC byte 2								CRC8							
0															

Table 1. The format of the official time frame.

It consists of 12 bytes, i.e., 96 bits sent at a bit rate of 50bit/s. This means that it takes 1.92s to send a total time frame. Frames are sent by the transmitter in Solec Kujawski in time slots every 3 seconds. This will give the receiver ample time to demodulate and decode the sent frame. After two synchronization bytes (55H), the 60H beginning marker is sent, which differs by 7 bits from the marker used by Enea's system to control lighting. In this way, both systems will not interfere with each other (Enea's receivers, after detecting another tag, ignore the entire frame. Then three "1-0-1" (5H) bits are sent, of which bit 0 specifies the 'conventional' moment of entering the sent time into the receiver registers – delayed by 0.5s (25 bits x 0.02s = 0.50s) about the moment of starting to transmit the frame. S0 ÷ S29 Bits (30 bits) specifying the number of three-second seconds counted from 1 January 2000, i.e. 3 x (S0 ÷ S29) = number of seconds counted from 1 January 2000.

TZ0 TZ1 The bits specifying the local time are shown in the table below:

TZ0	TZ1	Local Time
0	0	0
1	0	+1 hour
0	1	+2 hours
1	1	+3 hours

Table 2. Time bits.

5.2 Correction Codes

At the end of the time frame, 3 Reed-Solomon correction bytes are sent to allow correction of up to 24 bits of the frame.

The frame implements R-S encoding in the version:
4b - size of the codeword,
3b - correction strength.

What gives:
Data block: 9 words = > 36 bits,
Correction block: 6 words = > 24 bits.
The bits (S0 ÷ SK0) <= 36 bits are corrected - marked in the table.
The last bit of SK1 usage data has not been corrected.
The last free byte is assigned to the CRC-8 checksum.

5.3 Scrambling

The usage data is XOR with the binary string 0A 47 55 4D 2B which corresponds to: "\NGUM+"

5.4 NMEA RMC Frame Format

The receiver of the e-CzasPL system is designed to provide information about the official time.

The NMEA protocol was used to facilitate the transition from GNSS to e-CzasPL, which simulates the behavior of a GNSS receiver. The RMC (*Recommended Minimum Specific GNSS Data) sentence was used for time synchronization*. For obvious reasons, the receiver does not know its geographical location. The static coordinates of the Time and Frequency Laboratory of the Central Office of Measures (52.24183 N, 21.00084 E) are transmitted in the frame to maintain compatibility with GNSS receivers.

An example of the GPRMC sentence is presented below:

*$GPRMC,120000,A,5214.5098,N,02100.0504,E,0.00,000.021123,,E,A*CCCC*

NAME	EXAMPLE	DESCRIPTION
Operative part ID	$GPRMC	NMEA Heading of RMC Operative Part
UTC	120000	hhmmss
Status	A	A – valid data, V – invalid data
latitude	5214.5098	ddmm.mmmm – GUM laboratory position
N/S	N	N – north latitude, S – south latitude
longitude	02100.0504	dddmm.mmmm - GUM laboratory item
E/W	E	E – east longitude, W – west longitude
velocity	0.00	Speed in knots – in this case, static position
course	000.0	Course in degrees - in this case, a static position
date	021123	ddmmyy
Magnetic deflection		In this case, the static position
E/W	E	Direction of deviation mag. - Static position
Mode	A	A = Autonomous
checksum	*cccc	
<CR><LF>		End marker of the sentence

Table 3. An example of a GPRMC sentence.

The beginning of the NMEA sentence (the $ sign) is sent at the start of the second place in the sentence.

It is possible to modify the receiver firmware so that any geographical position can be entered during the receiver configuration.

5.5 5.5 DSP Firmware

The receiver software was written in C (central part) and Assembler (part of the demodulator) and was compiled with MPLAB XC16 PRO compiler version 2.10 on the Linux platform.

This documentation is accompanied by a HEX file that is ready to be uploaded to the DSP. One of the programmers must upload the software to the processor: PICKIT3, PICKIT4, PICKIT5, ICD-3, or ICD-4. The software can be uploaded to a microcontroller soldered to the PCB using the PICKIT connector.

6 Simple e-CzasPL Time Receiver

The e-CzasPL system's simple receiver has been designed to be built with a minimal set of tools. Manual assembly is possible, and only basic knowledge of working with SMD components is required. A properly built circuit does not require tuning or configuration. The device works immediately after connecting the power supply and is ready to receive the time signal.

The e-CzasPL signal receiver has been designed as an independent module that can be used as an official time standard on your devices. An exemplary receiver design can be used for one's needs in projects where information about the time related to the official time in force in the territory of the Republic of Poland is used.

The receiver provides time data in the form of NMEA RMC sentences, a 1 PPS signal, and a raw, unprocessed data frame for processing in an external system.

The receiver has a built-in RTC clock, which is designed to keep time for 24 hours from the last correctly received frame. After 24 hours, the "FIX" signal about time synchronization is extinguished. The system will still provide both time information (NMEA RMC sentence) and a 1PPS signal, but there is no guarantee that the required compliance with the official time will be maintained.

6.1 SV1 Diagnostic Connector

Similar to the basic version of the receiver, the SV1 connector has a UART port for the microcontroller operating at CMOS 3.3V levels—transmission parameters 115200 bps 8N1. Diagnostic information, including raw hexadecimal frames, is sent to the connector.

6.2 NMEA connector

Similarly to the basic version of the receiver, the SV2 connector is exposed to NMEA-compatible data carrying time information. The NMEA format was chosen for compatibility with GNSS-compatible devices. For a description of the NMEA frame, see Section 5.4. The connector operates at 3.3V CMOS levels

6.3 Antenna Connector

The antenna connector of the simplified receiver should be supplied with an RF signal from a ferrite antenna or an external antenna. The input circuit of the RF frontend is very tolerant and resistant to impedance mismatch.

6.4 Signaling the Operating Status of the Receiver

On the PCB of the Simple Receiver, 5 SMD LEDs indicate the receiver's operating status.

- LED1 – lit after correct receipt of the data frame, recalculated correction codes, and confirmed data correctness. The rising edge informs about the start of the second (transmitted in the data frame),
- LED2 – DCD – signaling of recognition of the beginning of the data frame (after the keyword is detected) – remains lit until the end of the frame transmission,
- LED3 – Informs about receiving the correct time and entering it into the RTC, if it is not possible to update the RTC from the radio transmission, the LED is turned off after 24 hours,
- LED4 – 1PPS 1PPS signal synchronized with the received time signal,
- LED5 – signaling the presence of a power supply to the system.

Remark! The 1PPS signal is valid (according to the official time) only when LED3 is lit.

7 7 Simplified Receiver Executive Documentation

The system was designed using Autodesk Eagle software. Schematic, mosaic, and GERBER files for PCB circuits are attached to this documentation. The circuit should be assembled, paying attention to the arrangement of electronic components, the integrated circuits' orientation, and the LEDs' polarity. The PCB is designed to facilitate the manual assembly of components.

It is not necessary to use a stencil to apply the solder paste. With some practice, installation can be done with tweezers and a classic soldering iron. A microscope or magnifying glass can be very helpful.

The time receiver has been designed so people without DSP programming or digital signal processing techniques can assemble and run it.

Figure 11 shows the schematic diagram of the time receiver.

7.1 7.1 Schematic diagram of the Time Receiver

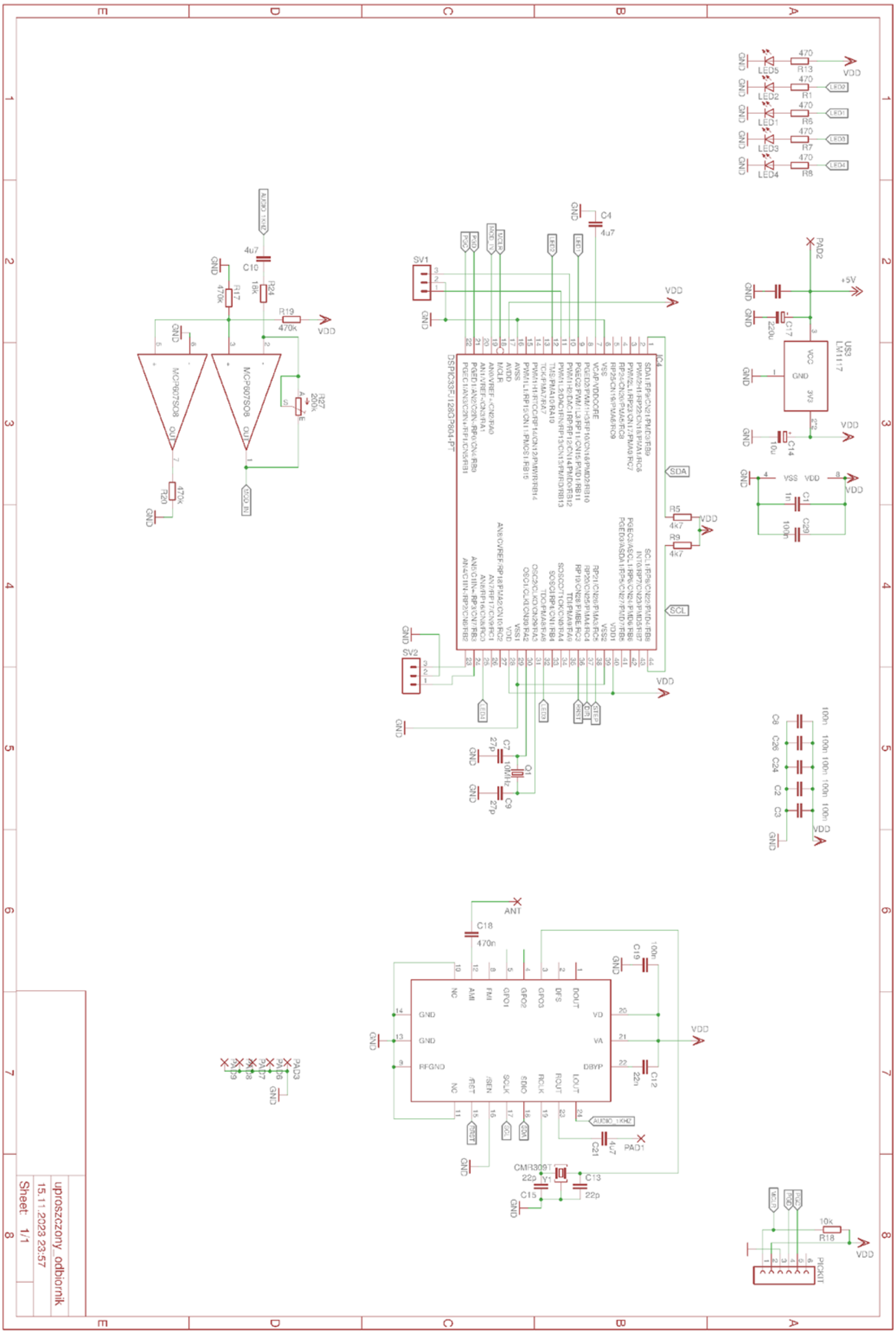

Figure 2. Schematic diagram of a time receiver.

7.2 Time Receiver PCB – Components Page

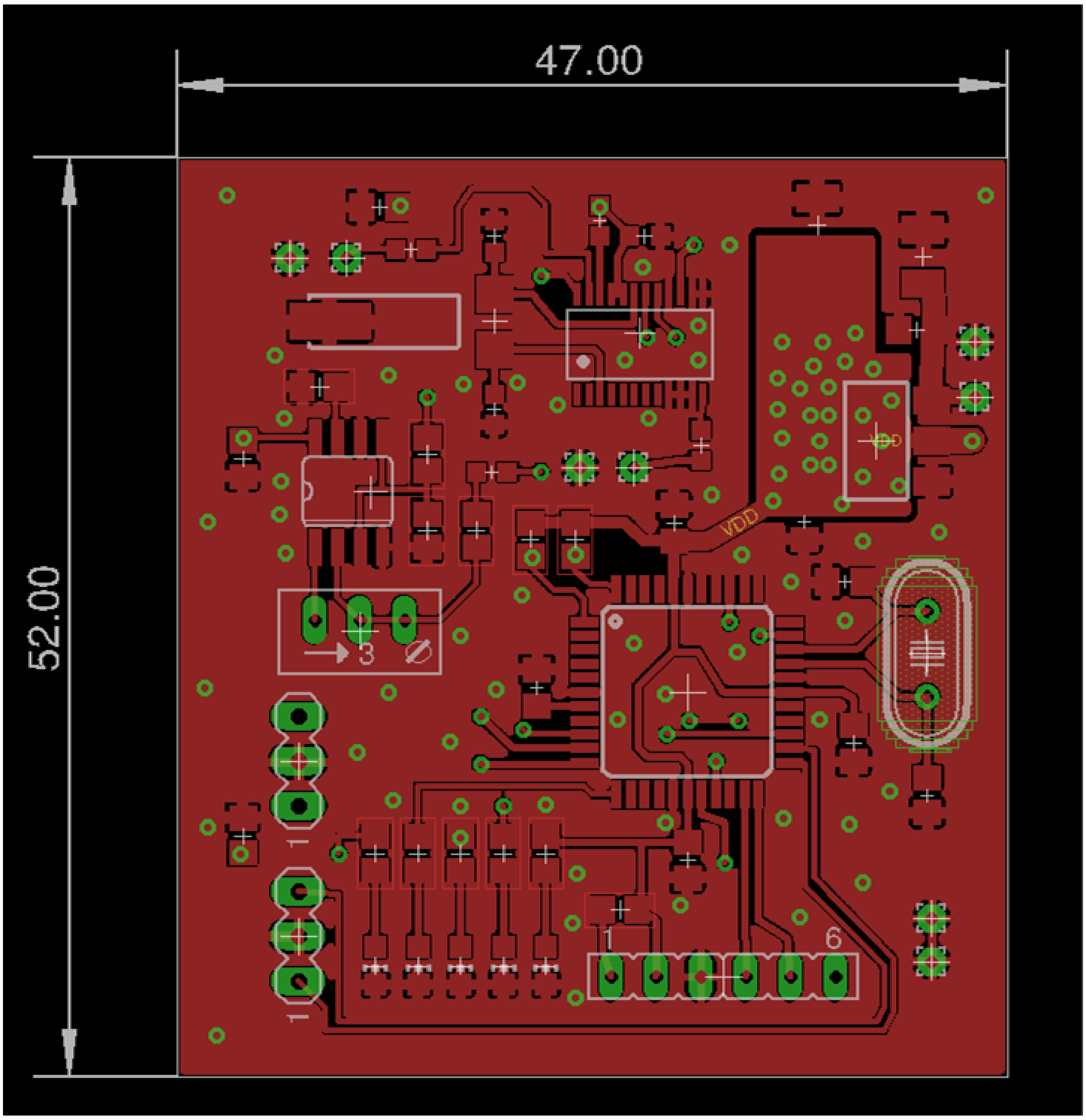

Figure 3. Time Receiver PCB – Components Page.

7.3 Time Receiver PCB – Print Side

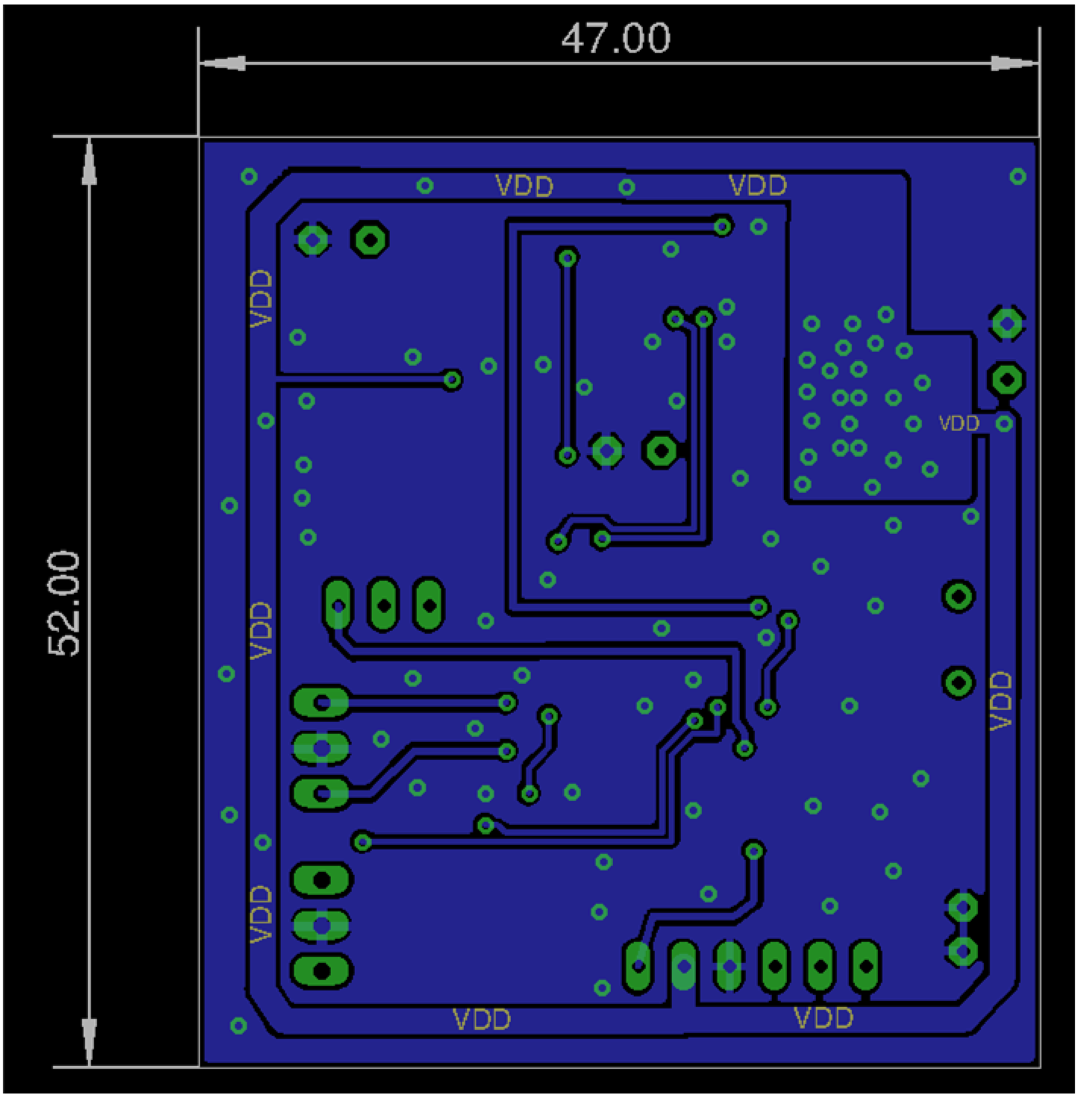

Figure 4. Simplified Receiver PCB – Print Side.

7.4 Time Receiver Bill of Materials (BOM)

Element	value	Device	Case
C1	1n	C-EUC0805K	C0805K
C2	100N	C-EUC0805K	C0805K
C3	100N	C-EUC0805K	C0805K
C4	4u7	C-EUC0805K	C0805K
C5	100N	C-EUC0805K	C0805K
C7	27p	C-EUC0805K	C0805K
C8	100N	C-EUC0805K	C0805K

C9	27p	C-EUC0805K	C0805K
C10	4u7	C-EUC0603K	C0603K
C12	22n	C-EUC0603K	C0603K
C13	22p	C-EUC0603K	C0603K
C14	10u	CPOL-EUSMCB	SMC_B
C15	22p	C-EUC0603K	C0603K
C17	220u	CPOL-EUSMCB	SMC_B
C18	470N	C-EUC0603K	C0603K
C19	100N	C-EUC0603K	C0603K
C21	4u7	C-EUC0603K	C0603K
C24	100N	C-EUC0805K	C0805K
C26	100N	C-EUC0805K	C0805K
C29	100N	C-EUC0805K	C0805K
IC4	DSPIC33FJ128GP804-PT	DSPIC33FJ128M	C804-PT TQFP44
LED1	LED	LEDCHIP-LED0	805 CHIP-LED0805
LED2	LED	LEDCHIP-LED0	synchronize any timekeeping device in Polish and a large part of Europe with the official time using cheap, energy-efficient,
LED3	LED	LEDCHIP-LED0	805 CHIP-LED0805
LED4	LED	LEDCHIP-LED0	805 CHIP-LED0805
LED5	LED	LEDCHIP-LED0	synchronize any timekeeping device in Polish and a large part of Europe with the official time using cheap, energy-efficient,
PICKIT	pin connector 2.54x6	FE06-1	FE06
Q1	Quartz 10MHz	CRYSTALHC49U	HC49U-V
R1	470	R-EU_R0805	R0805
R5	4k7	R-EU_R0805	R0805
R6	470	R-EU_R0805	R0805
R7	470	R-EU_R0805	R0805
R8	470	R-EU_R0805	R0805
R9	4k7	R-EU_R0805	R0805
R13	470	R-EU_R0805	R0805
R17	470k	R-EU_M0805	M0805
R18	10k	R-EU_R0805	R0805

R19	470k	R-EU_M0805	M0805
R20	470k	R-EU_M0805	M0805
R24	18k	R-EU_M0805	M0805
R27	200k	TRIM_EU-RJ9W	RJ9W
SV1	2.54 mmx3 pin connector	MA03-1	MA03-1
SV2	2.54 mmx3 pin connector	MA03-1	MA03-1
U$1	MCP607SO8	MCP607SO8	SOIC8
U$3	LM1117	LM1117	SOT223-3
U$5	SI4735-D60	SI4735-D60	SSOP24
Y1	Quartz 32.768 kHz	CMR309T	CMR309T

Table 2

7.5 Time Receiver Firmware

The Simplified Receiver works based on the same firmware as the basic version. Similarly to the basic version, the software should be uploaded to the DSP using one of the programmers: PICKIT3, PICKIT4, PICKIT5, ICD-3, or ICD-4. The software should be uploaded to the processor after it has been placed on the PCB by connecting the programmer to the PICKIT connector.

When the device starts, the software automatically recognizes whether it is working in the basic or simplified version of the receiver and takes appropriate action.