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Development of the wiring diagram of the device based on the LoRa module RAK3172

The paper presents the results of the development of circuitry of electronic device for the acquisition and transmission of telemetry data. The purpose of this work is to design and develop circuitry of the device for data acquisition using LoRa technology. The integrated end-to-end design environment Altium Designer was used to develop the electronic part of the device. The STM32F407VGT6 series microcontroller was used as the central control unit. A LoRa RAK3172 radio module is provided in the circuit for receiving and transmitting data. Unlike previous series, this module is equipped with a UART interface, which greatly simplifies the process of designing and writing a program for control. In this article the relevance of developing device with the use of LoRa-technology is considered. The theoretical basis of LoRa-modulation is briefly considered. The main section presents the results of the circuit design of the device, in particular, the inclusion diagram of the module and the control microcontroller. The information presented in the paper reflects only that part of the developed device, which is related to LoRa technology. In general, this work is part of a much larger project, which involves the use of GSM, Wi-Fi, RFID technology. Circuit of power supply is designed for 220 volt AC voltage with further transformation to +12V.

Keywords: LoRa module, STM32 microcontroller, LFM modulation, electric circuit, modulation, gateway, design, circuitry, development, Altium Designer, radio channel.

Introduction

In the context of global digitalization, Internet of Things (IoT) technologies are gaining momentum [1-3]. New types of LPWAN (Low Power Wide Area Networks) have emerged to effectively solve the problems associated with energy consumption. Technologies that enable the connection of autonomous devices to the WAN appeared in 2015-2016 and are now rapidly gaining popularity [4]. The most polar among such technologies are LoRa, SIGFOX, NB-IoT, Weightless P, etc. In most of the published papers [5] it is noted that the use of LoRaWAN protocol in various industries and housing and communal services (HCS) has good prospects.

A module operating in the frequency range 868/433 MHz is embedded in each meter. These are the unlicensed frequencies used by the LoRa standard. LoRa (Long Range) modulation technology is a modulation method that provides a significantly greater communication range (coverage area) than other competing methods. The method is based on spread spectrum modulation and a variation of linear frequency modulation (Chirp Spread Spectrum, CSS) with integrated Forward Error Correction (FEC).

An important element of the system is the base station (gateway), the purpose of which is to collect readings from meters and transmit them over the Internet to the data collection server for further processing and analysis. Theoretically, in a city environment, the base station can cover a zone with a radius of up to 15 km. In practice, the coverage radius is about 2-3 km.

All of the meters from nearby houses that are within its range transmit data to it via radio channel. The base station transmits the received information to the data collection server, where it is further processed under the control of the software.

Application of LoRa technology makes it possible to assemble a variety of devices into a single system: security devices, lighting lamps, metering devices for resource consumption (heat, electricity, water, gas), vehicle sensors (which are used to control movement and fuel consumption), etc.

Thus, fundamentally new solutions in the field of communication services, monitoring, telematics, telemechanics, dispatching, Smart House, Smart City systems, etc. are created.

In the basis of the considered technology LoRa signals are oscillations with linear frequency modulation (LFM-modulation), the frequency of these oscillations can both linearly increase and linearly decrease. LFM signals are complex signals with a basis much larger than unity, respectively, their correlation function will be sufficiently narrow compared to the simple signals [5]. Mathematical description can be expressed by formula (1):

$$s = A * \cos * \left(2\pi \left(f * t_1 + \frac{mt^2}{2} \right) \right) \quad (1)$$

here f_l is the lower frequency (frequency at which the LFM oscillation begins); m is the signal frequency change rate, determined by the formula:

$$m = \frac{BW}{T_S} \quad (2)$$

where BW is the signal spectrum width (125, 250 and 500 kHz);

Ts — duration of one LFM oscillation:

$$T_S = \frac{2^{SF}}{BW} \quad (3)$$

here SF (Spreading Factor) — spectrum expansion factor, it takes the following values SF = 7...12. It determines the bit depth of the data symbol (in bits) transmitted during Ts, and also affects the signal base. Increase SF greatly increases noise immunity of the transmitted message up to transfer at a negative signal/noise ratio, but at the same time increases the transfer time. The signal base is calculated by the formula

$$B = BW * T_S = 2^{SF} \quad (4)$$

According to [6] the coded information symbol defines the frequency by the value of which the LFM oscillation is shifted. That is, the frequency with which LFM oscillation generation begins is determined by the value of the information symbol in decimal notation system (5):

$$df = \frac{k}{T_S} \quad (5)$$

here k is the current value of the information symbol.

At time T_S — T_0 (6) the LFM oscillation reaches the maximum frequency, after which the generation of a new LFM oscillation begins from the lower frequency f_l and stops when it reaches the frequency df. The duration of the new LFM oscillation is T_0:

$$T_0 = \frac{k}{BW} \quad (6)$$

In general, according to [7], the modulated oscillation is described by the expression (7):

$$s(t)=\begin{cases} A\cos\left(2\pi\left(f_0 t+dft+\dfrac{mt^2}{2}\right)\right), 0\le t<T_0 \\ A\cos\left(2\pi\left(f_0 t+dft+\dfrac{mt^2}{2}\right)\right), T_0\le t<T_S \end{cases} \quad (7)$$

Despite the presence of a large number of publications, currently there are no publications devoted directly to the development of devices based on LoRa-module. The review has shown [1-4] that practically all available developments are based on the application of ready-made modular solutions. Mainly based on the Arduino platform.

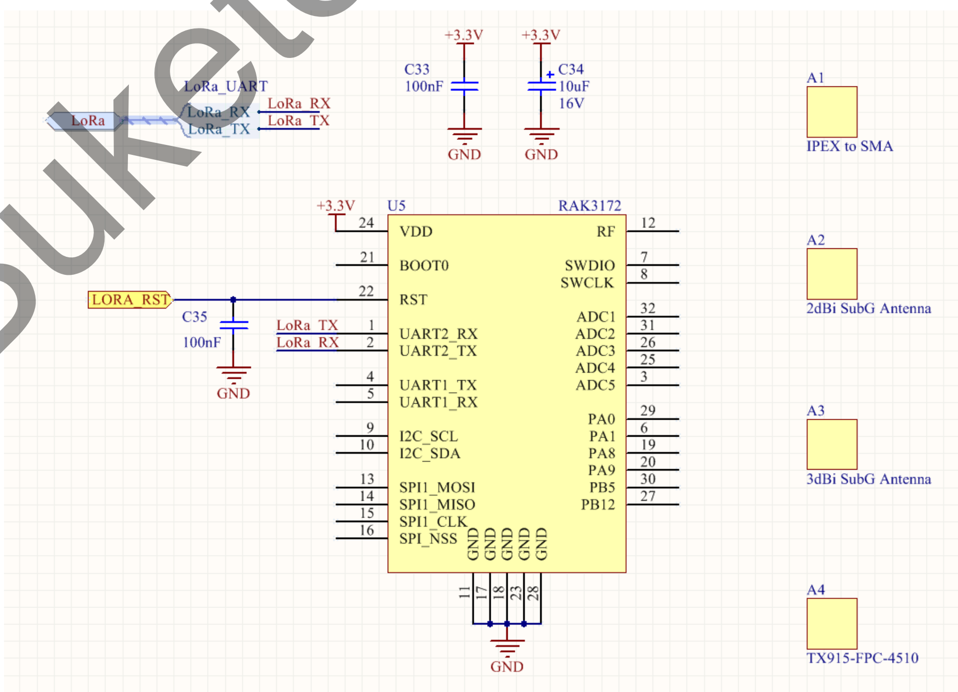
The purpose of this work is to develop and design the circuitry of a combined data acquisition device using LoRa technology.

This paper presents the results of design and development of a combined telemetry data acquisition and transmission device. In particular, one of the data acquisition-transfer interfaces is a LoRa module RAK3172. As the control unit used microcontroller series STM32F407XX. The development of the device circuit was performed in the integrated end-to-end design environment Altium Designer.

Experimental

The developed scheme of the device is designed for use in data collection systems from heat meters. Currently meters (water, gas, heat and electricity) have either pulse output or interface output. Pulse output is considered obsolete and has a number of shortcomings. Meters with an interface output are the most promising, but they are also more complex to implement. Unfortunately, there is no "universal" approach that provides zero-modem connection. The fact that counter manufacturers often do not care about minimizing traffic when developing their devices, which is very important for LoRa-technology. This will inevitably lead to loss of stability of LoRa-network even at its low density. Therefore, in the framework of the implemented work, we plan to solve these contradictions at the level of the "driver" of the developed device. In this paper, the primary results related to the circuit design of the device are presented. As the next stages are completed, we plan to publish additional materials.

Figure 1 shows the wiring diagram of the RAK3172 module. Two interfaces are provided for communication in this module. A high speed, synchronous SPI interface and a lower speed, two wire UART interface. There are two UART interfaces on board this module. As you can see from the figure, we have used UART 2 in the schematic.



The use of the module RAK3172 in this work is due to the fact that it provides the possibility of using the UART interface. In earlier versions of the module, the use of this interface is not provided, which in turn affected the volume and complexity of the control program.

Both hardware and software options are available to "reset" the module. In this case the output "LORA_RST" provides the possibility to reset the microcontroller programmatically. This function will be used when it is necessary to remotely re-flash or update the control program of the microcontroller.

As noted above, the circuits presented in the paper are part of a more complex combined device circuit. Accordingly, the component numbers in the circuits are also in through order. For example, the power supply circuit of the module, as a rule, includes the device protection for power supply and pulse filtering. And as we can see from this circuit (Figure 1), capacitors *C33* and *C34* are provided for this purpose. It should also be noted that the connection to the main components of the circuit is organized using the “Harness”, which increases the simplicity and at the same time clarity of the connections used in the circuit.

Figure 2 shows the appearance of the circuit, which can be conditionally called "basic". It combines the inclusion of both LoRa module and other functional units not reflected in this article (GSM, USB, temperature sensor).

Figure 1. LoRa module RAK3172 wiring diagram

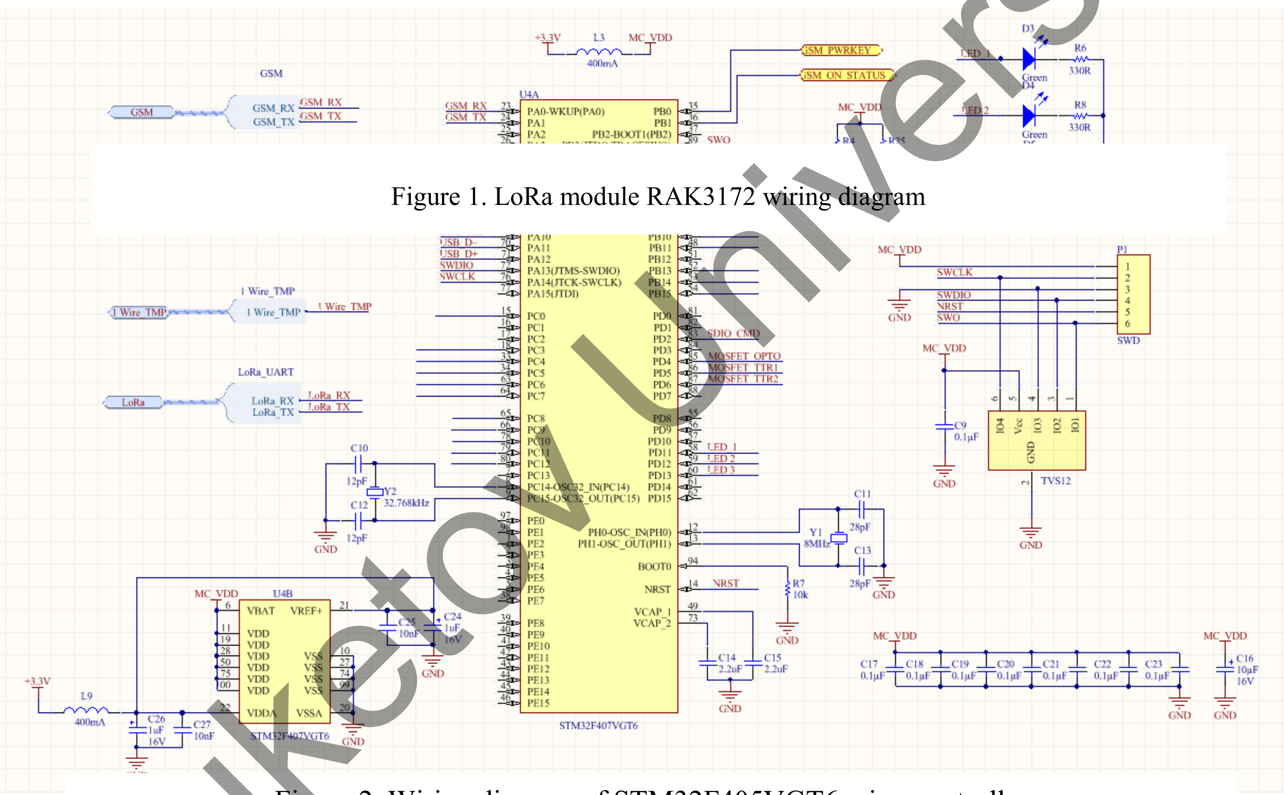


Figure 2. Wiring diagram of STM32F405VGT6 microcontroller

This schematic shows the inclusion of the LoRa interface discussed in the article, the programming node and components to stabilize the microcontroller power.

As can be seen from this figure, two quartz resonators are used in the circuit. One for 32.768 MHz (ECX-31B), the other for 8 MHz (ABM3-8.000MHZ-D2Y-T). According to the "technical documentation" it is recommended to install 12 pF capacitors on the 32.768 MHz resonator. However, at frequencies above 20 MHz quartz resonators are known to operate without interruption and require no additional tuning. In the case of low frequency resonators, the calculation of the capacitance of the used capacitors is required. In the "technical documentation" for the ABM3-8.000MHZ-D2Y-T resonator, it is noted that the load capacitance is determined by the parameters of the external capacitors C_{L1} and C_{L2} and the parasitic capacitance of the circuit board and connections (Cs). In this case the capacitance value for C_{L1} and C_{L2} recommended by the manufacturer is 18pF.

In order to accurately determine the parasitic capacitance of the microcontroller ports and the PCB capacitance, measurements must be made. To make preliminary calculations, manufacturers recommend assuming a *Cs* value in the range of 3 — 5pF. Manufacturers recommend these values based on requirements for keeping the quartz resonator as close as possible to the microcontroller's chassis. These *Cs* values accordingly take into account two specific cases. For shortest possible proximity *Cs* = 3pF. For the longest possible distant resonator position *Cs* = 5pF. The value *Cs* = 4 corresponds to the average position distance of the quartz resonator.

Thus, we have the following input data:

C_L = 18 pF, *Cs* = 3 pF, *Cs* = 4 pF, *Cs* = 5 pF

To calculate the capacity of external capacitors ($C_{L1,2}$) including parasitic capacitance, expression (8) recommended by the manufacturer was used:

$$C_L = \frac{C_{L1} * C_{L2}}{C_{L1} + C_{L2}} + C_S \quad (8)$$

It follows that the capacitance of the capacitors must be:

For *Cs* = 3 pF $\quad C_{L1,2} = 2(C_L - C_S) = 2(18-3) = 30\,pF$

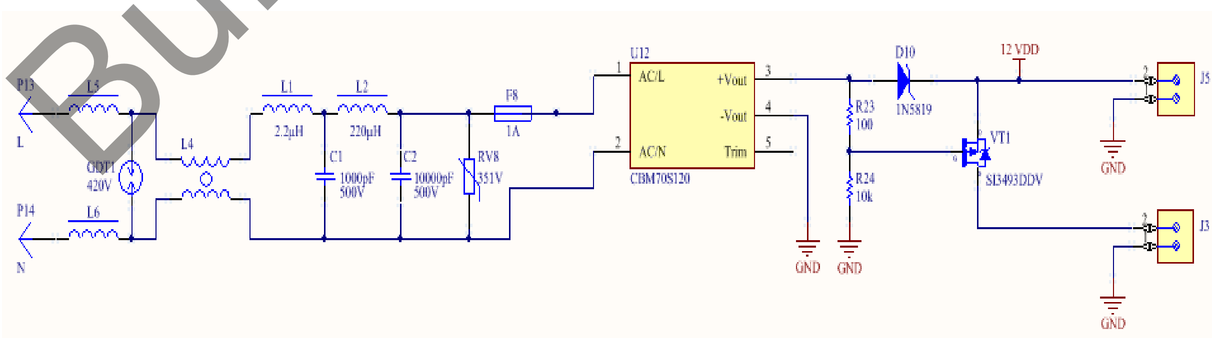
For *Cs* = 4 pF $\quad C_{L1,2} = 2(C_L - C_S) = 2(18-4) = 28\,pF$

For *Cs* = 5 pF $\quad C_{L1,2} = 2(C_L - C_S) = 2(18-5) = 26\,pF$

At this point, we have pre-included 28 pF capacitors into the circuit.

However, when testing the finished device, additional measurements will be taken to determine the loading capacity (C_L), since the manufacturer's recommended value is given as the maximum possible value.

Figure 3 shows a schematic of the electrical power supply. AC voltage from 220 volt mains is used as the main power supply. The circuit is provided with protection against electromagnetic interference and mains voltage ripple. As a converter of alternating voltage CBM70S120 (production Cincon) is used. Small dimensions (61x57.9x17 mm) allow installing the converter directly on the surface of a printed circuit board. The circuit node consisting of Schottky diode (*D10*), *p*-channel field effect transistor (*VT1*) and two resistors (*R23* and *R24*) performs the function of power switch to battery *J3.* The logic behind this node is as follows: when there is electrical power at the *+Vout* output of the *U12* converter, the «drain-source» channel of transistor *VT1* is closed. The device receives 12 volt electrical power from the *12_VDD* point. In the case where there is no 12 volts at the *+Vout* output of the *U12* converter, the «drain-source» channel of transistor *VT1* opens. In this case, the device receives electric power from the emergency battery pack. However, as noted in the technical documentation of *VT1* (Si3493DDV) transistor, the total turn-on and turn-off delay of the «drain-source» junction is less than 200 ns. This allows this transistor to be used as a high-speed switch.



Results and discussion

To create a network using LoRAWAN technologies it is necessary to use a base station for data collection, called — gateway. The device developed in this work is a kind of "end-device" that directly collects data from the connected sensors.

The central link in the chain "end-device — gateway — server" is the gateway. The gateway's task is to receive data from the "end device" and then transmit it to the server for further processing or storage.

As a base station, we use the gateway brand RAK7258. To use this unit as a base station, you need to register it on the network and attach it to a server. The server can be either private or public. In our case, we

Figure 3. Schematic diagram of the electrical power supply to the device

used "The Things Network" server. This server is provided for free by the LoRa technology manufacturers for their customers. After registration on the server, we received a "Key Gateway" key. With the help of this key we need to connect the "end device" to the base station.

Figure 4 shows the appearance of the registration page on the server.

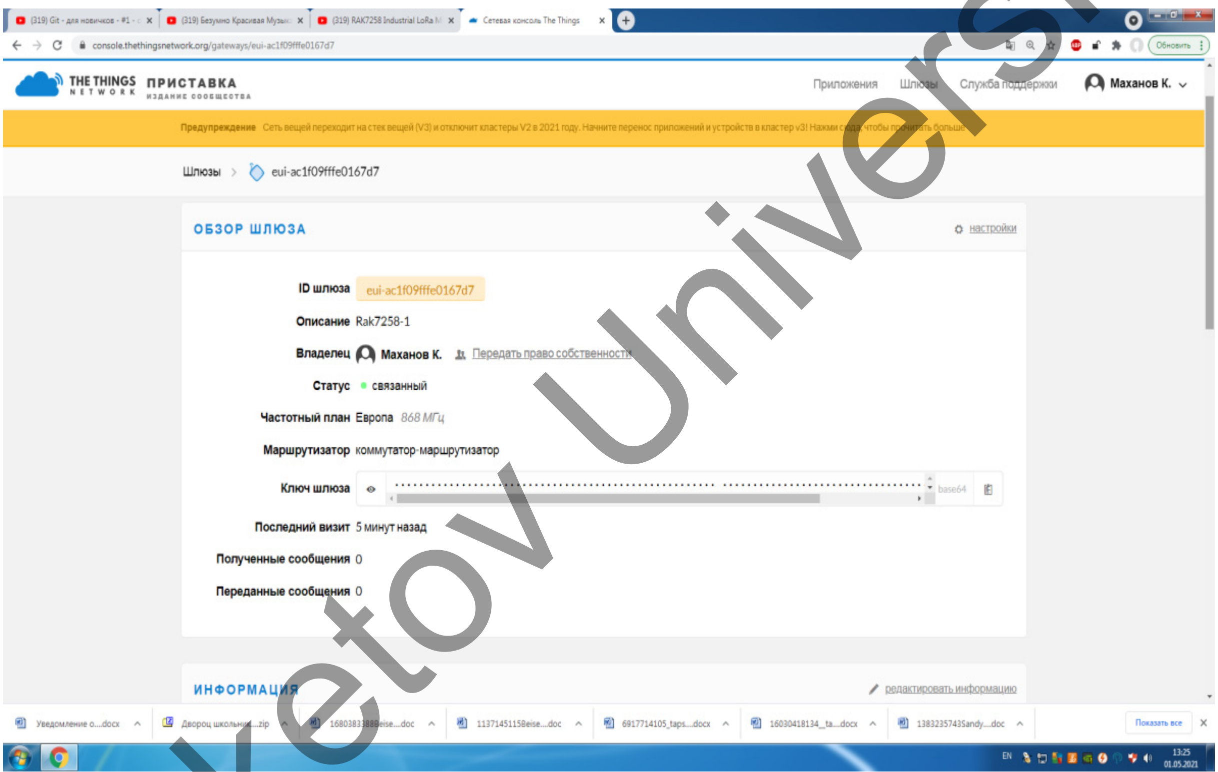


Figure 4. Registration on The Things Network server

Conclusion

In the course of the work the wiring diagram for the design of the circuit board and the whole device based on the wireless LoRa transmitter RAK3172 was developed. The choice of this series was due to the possibility of using UART interface and easier to implement AT commands.

The device power supply circuitry provides protection against electromagnetic interference and electrostatic discharges. Parameters of used components are calculated with regard to the requirements of GOST 30804.4.4-2013 (2 — degree of rigidity).

Because of limiting values of circuit board stray capacitance Cs = 3pF — 5pF and manufacturer's recommended load capacitance C_L = 18pF the capacitance of external capacitors ($C_{L1,2}$) is calculated for 8 MHz quartz resonator. However, it should be noted that the manufacturer has recommended limiting values *of* Cs. Hence it follows that in the process of making the PCB of the device it is necessary to make an additional value of *Cs*. And if necessary, make an additional calculation of the capacitance of external capacitors.

To control operation of the developed device and subsequent data collection, we carried out work on registration of the gateway RAK7258. At the moment, registration has been successfully completed and an access key from "The Things Network" server has been obtained to connect "end devices" to the base station.

References

1 Кучерявый А.Е. Интернет вещей / А.Е. Кучерявый // Электросвязь. — 2013. — № 1. — С. 21–24.

2 Кучерявый А.Е. Самоорганизующиеся сети / А.Е. Кучерявый, Е.А. Кучерявый, А.В. Прокопьев. — СПб.: Любавич, 2011. — С. 312.

3 Киричек Р.В. Эволюция исследований в области беспроводных сенсорных сетей / Р.В. Киричек, А.И. Парамонов, А.В. Прокопьев, А.Е. Кучерявый // Информационные технологии и телекоммуникации. — 2014. — Т. 4. — № 8. — С. 29–41.

4 Кучерявый А.Е. Перспективы научных исследований в области сетей связи на 2017–2020 годы / А.Е. Кучерявый, А.Г. Владыко, Р.В. Киричек, М.А. Маколкина, А.И. Парамонов, А.И. Выборнова, Р.Я. Пирмагомедов // Информационные технологии и телекоммуникации. — 2016. — Т.4. — № 3. — С. 1–14.

5 Сарьян В.К. Прошлое, настоящее и будущее стандартизации Интернета вещей / В.К. Сарьян, Н.А. Сущенко, И.А. Дубнов // Тр. Научно-исследовательского института: радиожурнал. — 2014. — № 1. — С. 2–7.

6 Талаев А.Д. Стандарты LPWAN для группового взаимодействия мобильных узлов / А.Д. Талаев, В.В. Бородин // Тр. Моск. авиацион. ин-та. — 2018. — № 99. — С. 22–28.

7 Белов С.П. Исследование функции неопределенности псевдослучайных сигналов с линейной частотной модуляцией / С.П. Белов, Е.Г. Жиляков, И.А. Сидоренко // Вопросы радиоэлектроники. Сер. «РЛТ». — 2008. — № 4. — С. 100–109.

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RAK3172 LoRa модулінің негізінде құрылғыны қосу схемасын әзірлеу

Жұмыста телеметриялық мәліметтерді жинауға және таратуға арналған электрондық құрылғының схемасын әзірлеу нәтижелері келтірілген. Бұл жұмыстың мақсаты LoRa технологиясын қолдана отырып, деректерді жинауға арналған құрылғы схемасын жобалау және әзірлеу. Құрылғының электронды бөлігін әзірлеу үшін басынан соңына дейін жобалауға мүмкіндік беретін Altium Designer ортасы пайдаланылды. Орталық басқару блогы ретінде STM32F407VGT6 сериясының микроконтроллері қолданылды. Деректерді қабылдау және тарату үшін схемада LoRa RAK3172 модулін қолдану ескерілген. Алғашқы сериялармен салыстырғанда, бұл модуль UART интерфейсімен жабдықталғандықтан басқару бағдарламасын жобалау және жазу процестері айтарлықтай жеңілдетілген. Мақалада LoRa технологиясын қолданатын құрылғыларды әзірлеудің өзектілігі талқыланған. LoRa модуляциясының теориялық негіздері қысқаша қарастырылған. Негізгі бөлімде құрылғының схемасын құрастыру нәтижелері берілген. Атап айтқанда, модульді және басқару микроконтроллерін қосу схемасы. Сонымен қатар мақалада келтірілген ақпарат LoRa технологиясымен байланыстырылатын құрылғының бір бөлігін ғана көрсетеді. Жалпы, бұл жұмыс GSM, Wi-Fi, RFID технологияларын қолдануды көздейтін әлдеқайда ауқымды жобаның бөлігі болып табылады. Қоректендіру тізбегі айнымалы 220 В кернеуден қоректендіріліп, кейін +12 В-қа түрлендіріледі.

Кілт сөздер: LoRa модулі, STM32 микроконтроллері, СЖМ модуляциясы, электр тізбегі, модуляция, шлюз, дизайн, схема, әзірлеу, Altium Designer, радиоарна.

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Разработка схемы подключения устройства на базе LoRa модуля RAK3172

В статье представлены результаты разработки схемотехники электронного устройства сбора и передачи данных телеметрии. Целью данной работы является проектирование и разработка схемы устройства для сбора данных с использованием технологии LoRa. Для разработки электронной части устройства использовалась интегрированная среда сквозного проектирования Altium Designer. В качестве центрального блока управления применен микроконтроллер серии STM32F407VGT6. В схеме предусмотрен модуль LoRa RAK3172 для приема и передачи данных. В отличие от предыдущих серий, этот модуль оснащен интерфейсом UART, что значительно упрощает процесс проектирования и написания программы для управления. В данной работе рассмотрена актуальность разработки устройств с использованием LoRa-технологии. Кратко изучены теоретические основы LoRa-модуляции. В основном разделе представлены результаты схемотехнического проектирования устройства, в частности, схема включения модуля и управляющего микроконтроллера. Информация, представленная авторами статьи, отражает только ту часть разрабатываемого устройства, которая связана с технологией LoRa. В целом, эта работа является частью гораздо более крупного проекта, в котором предполагается использование технологий GSM, Wi-Fi, RFID. Схема питания рассчитана на переменное напряжение 220 В с последующим преобразованием в +12 В.

Ключевые слова: модуль LoRa, микроконтроллер STM32, модуляция ЛЧМ, электрическая схема, модуляция, шлюз, проектирование, схемотехника, разработка, Altium Designer, радиоканал.

References

1 Kucheriavyi, A.E. (2013) *Internet veshchei [Internet of Things].* Elektrosviaz — Telecommunications, 1, 21–24 [in Russian].

2 Kucheriavyi, A.E. (2011). *Samoorganizuiushchiesia seti [Self-organizing networks]*. Saint Petersburg: Liubavich [in Russian].

3 Kirichek, R.V., Paramonov, A.I., Prokopev, A.V., & Kucheriavyi, A.E. (2014). Evoliutsiia issledovanii v oblasti besprovodnykh sensornykh setei [The evolution of wireless sensor network research]. *Informatsionnye tekhnologii i telekommunikatsii — Information technology and telecommunications,* 4, 8, 29–41 [in Russian].

4 Kucheriavyi, A.E., Vladyko, A.G., Kirichek, R.V., Makolkina, M.A., Paramonov, A.I., Vybornova, A.I., & Pirmagomedov, R.Ya. (2016). Perspektivy nauchnykh issledovanii v oblasti setei sviazi na 2017–2020 gody [Prospects for scientific research in the field of communication networks for 2017–2020]. *Informatsionnye tekhnologii i telekommunikatsii — Information technology and telecommunications,* 4, 3, 1–14 [in Russian].

5 Sarian, V.K., Sushchenko, N.A., & Dubnov, I.A. (2014). Proshloe, nastoiashchee i budushchee standartizatsii Interneta veshchei [The Past, Present and Future of IoT Standardization]. *Trudy Nauchno-issledovatelskogo instituta: radiozhurnal — Proceedings of the Scientific Research Institute radio magazine*, 1, 2–7 [in Russian].

6 Talaev, A.D., & Borodin, V.V. (2018). Standarty LPWAN dlia gruppovogo vzaimodeistviia mobilnykh uzlov [LPWAN standards for group communication of mobile nodes]. *Trudy Moskovskogo aviatsionnogo instituta — Proceedings of the Moscow Aviation Institute,* 99, 22–28 [in Russian].

7 Belov, S.P., Zhiliakov, E.G., & Sidorenko, I.A. (2008). Issledovanie funktsii neopredelennosti psevdosluchainykh signalov s lineinoi chastotnoi moduliatsiei [Investigation of the uncertainty function of pseudo-random signals with linear frequency modulation]. *Voprosy radioelektroniki. Seriia «RLT» — Questions of radio electronics. Series "RLT"*, 4, 100–109 [in Russian].