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Research Article

Improving data transfer efficiency in a gas field wireless telemetry system

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Abstract

Effective organisation of communication channels in autonomous information and measurement systems (AIMS) is a burning issue. It is particularly challenging for areas where, for a number of reasons (primarily unprofitability or immaturity of the wired infrastructure), telecommunications can rely only on wireless technologies, i.e., radio channels. Arctic regions of the Russian Federation, where most of Russia's gas and gas condensate deposits are located, constitute a typical example of such areas. The key challenges during construction of wireless communication channels are associated with the fixed range of frequencies that can be used without a licence. For the purposes of radio traffic, the frequency used by AIMS transmitters and receivers depends on the frequency of the quartz crystal resonators used in such devices. The stability of this frequency determines both the number of radio channels that can be used and the efficiency of data transfer. Key factors affecting the quartz frequency include temperature and "ageing" of quartz crystals. Known methods for increasing the frequency stability generally allow compensation for the temperature drift of the quartz frequency. In addition, such methods are increasingly energy-consuming, which is unacceptable in the Extreme North. This article suggests using GPS receiver data for frequency adjustment. With a minor increase in energy consumption, this technique enables full compensation for quartz crystal resonator frequency drift, no matter what the cause of such drift, eventually allowing operation of more radio channels within the authorised bandwidth with preserved channel separation. In general, it helps increase the efficiency of data transfer in the telemetry systems of gas field operations.

Keywords

quartz crystal resonator, gas field telemetry system, radio channel, GPS, carrier frequency adjustment

Wireless technologies are being employed increasingly during building of various autonomous information and measurement systems (AIMS). They are essential in all kinds of distributed process facilities, such as trunk pipelines and others. In some cases, for instance, for AIMS of gas fields located in Arctic regions, wireless technologies appear to be the only viable option owing to lack of a mature wired infrastructure. Employment of wireless technologies helps minimise the damage caused to the Arctic environment in the process of construction and operation of gas fields and significantly reduce project costs.

As an example, let us take a look at the process parameters monitoring system (PPMS) designed to monitor pressure and temperature in the mouths of gas and condensate wells, pipelines and process equipment. This system has been deployed on gas condensate fields of LLC Gazprom Dobycha Urengoy. Measurement data is transmitted via radio channel to the base station (BS) directly or by relay through process parameter recorders (PPR) constituting part of the data network (Fig. 1).

If beam antennae are used and the PPR devices are in the line of sight of the base station, the link between the devices and the base station will remain stable at the effective range of 12 km. The run time of a RTP-4 transducer on one battery at a 5-minute polling cycle and average yearly temperature of minus 5°C will be two years or more. A shortcoming of this system is the unstable performance of transceivers, which leads to losses of measurement data and reduced efficiency of data transfer. This shortcoming has the following causes.

In Russia, non-specialised wireless devices can officially be operated in two frequency bandwidths: 864.0 – 865.0 MHz with a maximum action period of 0.1% and denial of service near airports, and 868.7 – 869.2 MHz with no restrictions (this bandwidth is typically referred to as “868 MHz”) (Verkhulevsky 2017). Consequently, the AIMS designer has only as much as 500 kHz bandwidth to set up the communication channels. To enable arrangement of the maximum possible number of channels within this frequency gap, the bandwidth assigned to one radio channel must be as narrow as possible, especially since there are guard bands between adjacent channels. At the same time, the transmitter and receiver must be tuned to a certain fixed frequency to ensure reliable performance of the radio channel. Even so, owing to exposure to external effects, such

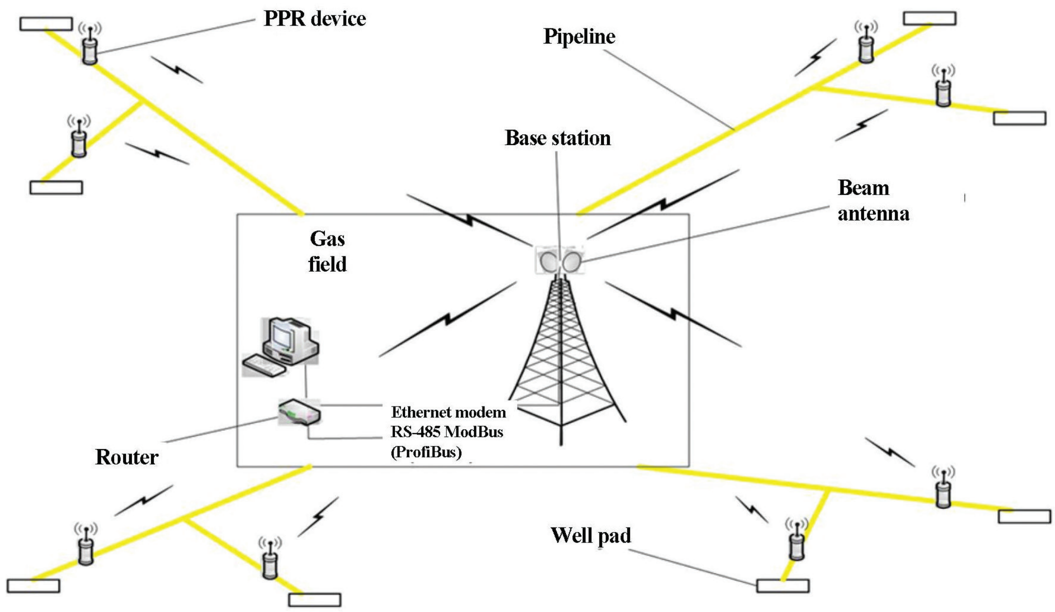

Fig. 1. Functional diagram of process parameters monitoring system

as temperature, the carrier frequency of oscillations at transmitter output varies over time, departing from the desired value. This leads to an increase in the resultant bandwidth of emitted signal oscillation, which requires the number of radio channels operating within that bandwidth to be reduced. Otherwise, if the transmitter's frequency wanders off from preset, its carrier frequency will come closer to the frequency of the transmitter of an adjacent channel, causing mutual interference on the receivers' side. If we expand the resultant spectrum of oscillations at transmitter output, we will also have to expand the bandwidth. This reduces the signal-to-interference ratio at receiver input, because a wider bandwidth means more interference, which reduces the quality of the received signal. We can obtain the original signal-to-interference ratio by using a more powerful transmitter, which needs more energy. For AIMS at gas fields, this is a critical factor owing to absence of reliable uninterruptible power sources at gas system facilities.

A transmitter's operating frequency is assigned to it by the quartz crystal resonator. Instability of its frequency, caused by numerous factors, leads to a significant drift of the transmitter's carrier frequency from the rated value (Anonymous 2017a). Reference (Anonymous 2017b) provides information allowing for a numerical evaluation of frequency deviation. For example, a standard crystal unit that operated at a frequency of 39 MHz has an average frequency stability of ± 25 ppm (parts per million of the resonator's nominal frequency), so when data are transmitted via a 869 MHz radio channel, the actual deviation of the transmitter's carrier frequency may reach ± 21.725 kHz. Based on real-life experience of operating the process parameters monitoring system deployed at Urengoy Oil and Gas Condensate Field (OGCF), no more than two radio channels can be used within a 500 kHz bandwidth for stable data transfer from the monitored facilities. This is explained by the fact that the crystal unit has an initial frequency dispersion of 20–30 kHz, and then temperature drift adds another 20 kHz (temperature dependence of the quartz crystal resonator is non-linear, which makes accurate assessment of this value impossible without special effort). Time drift accumulated over a year may be as much as 20 kHz. As a result, the system's transducers could guarantee stable data transfer throughout the operating temperature range only if the frequency deviation were 60 kHz, or in the bandwidth of 120 kHz. Thus, with a guard band approximately 2 deviations wide (in principle, high-quality signal can be obtained if channels are spaced with 5 deviations), only two channels can be set up using the frequency band in question – one in the top section of the bandwidth and one in the bottom section. This means that only two channels can be used simultaneously in a given area, which restricts the amount of traffic considerably and is unacceptable for the majority of AIMS. For example, the AIMS used at Urengoy OGCF sites must receive temperature and pressure data from each well at least every five minutes (Novikov et al. 2017). Based on the requirements of Engineering Communication Department (ECD) of Gazprom Dobycha Urengoy, radio channel width must not exceed 24 kHz. Since this parameter depends chiefly on the stability of the operating frequency of the quartz oscillator, further investigation into this issue is seen to be highly topical.

Many studies, including the research described in (Smith and Moore 2017, Fitasov et al. 2017, Kosykh 2008, Levchenko et al. 2007), are dedicated to the issue of increasing the stability of the operating frequency of the quartz crystal resonator. Possible ways to tackle this problem are either to improve the quality of the resonator or to somehow introduce temperature correction. In temperature-compensated quartz oscillators, reduction of frequency instability is achieved by making the circuit more complex, i.e., making it bigger, more powerful and more expensive. Solutions employed in such oscillators chiefly affect the shape of the oscillation of the resultant temperature-frequency curve, as well as the ease of oscillator adjustment. One possible way to stabilise the resonator's operating frequency by introducing temperature correction is described in detail in reference (Fitasov et al. 2017). The operation algorithm of an adaptive temperature and temperature variation rate meter involves measurement of the current temperature sample value *T*, calculation of the current sample value of temperature variation rate *V*, calculation of the characteristic temperature variation rate and optimal counting time, repeated measurement of the temperature variation rate, and calculation of the compensating action as a function of variables *T* and *V*. This solution requires a lot of hardware and results in higher energy consumption by the transceiver, which is not advisable for autonomous battery-powered systems.

Purpose of the study

The purpose of this study is to reduce the instability of the operating frequency of quartz crystal resonator, no matter what the cause of such instability (temperature-driven instability, ageing of quartz, etc.) by adjusting the carrier frequency with the help of GPS technology.

Materials and methods

The most reasonable approach to compensating for the temperature error would be to integrate a GPS receiver into the transceiver chip, thus allowing it to receive a signal from the satellite with a time mark accurate to a picosecond. Relying on the time signals acquired from the GPS receiver and comparing the length of message digit (number of pulses) to be transmitted over a certain period against the actual received length with reference to the GPS receiver's time marks, we can calculate the deviation of carrier frequency of the quartz oscillator and compensate for such deviation by introducing a corresponding correction into the operating algorithm. This method does not require any complex calculations or significant enhancement of the transceiver's hardware component.

Today, the market offers low-consumption modules intended for precision timing systems. One example is the Telit SL869-T module (Anonymous 2017c), which features high sensitivity, low energy consumption and quick cold-start timing. Its unique feature is support for TRAIM technology, allowing satellite signals carrying inaccurate data to be discarded, as well as capability to generate a reference frequency synchronised with coordinated universal time (UTC) with a deviation of less than $20*10^{-9}$ seconds. The reference frequency is generated even after acquisition of one satellite.

A functional diagram of the proposed device is shown in Fig. 2 below.

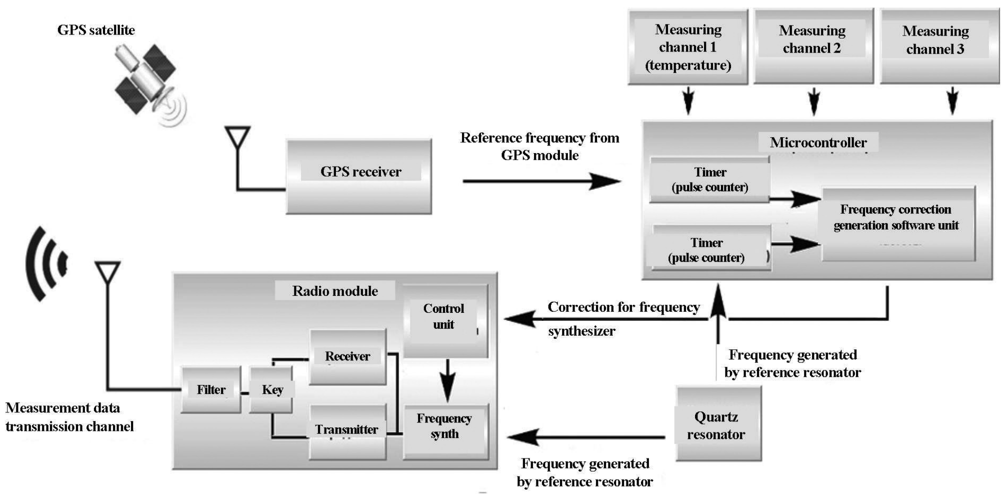

Fig. 2. Functional diagram of a device used for correction of a quartz crystal resonator's operating frequency based on GPS signal

Correction of a radio module's carrier frequency is performed in the event of link failure between the monitoring device and the base station, or if the ambient temperature departs by 10 degrees from the temperature value at the time of calibration or last adjustment session. Microcontroller issues command that the GPS receiver be enabled; the receiver starts up and begins issuing reference frequency signals, which triggers the operating algorithm of frequency correction generation software unit. Signals from GPS receiver and quarts resonator are captured by corresponding timers of the microcontroller during 500 milliseconds, and the results are recorded into the correction generation unit. At the end of the cycle, the microcontroller sends the calculated correction for the frequency synthesiser to the radio module's control unit. At the same time, the calculated correction is recorded in the microcontroller's flash memory, so data from the GPS receiver are not required at all during the next correction session in 60% of cases. The control unit's senders allow the frequency of the integrated synthesiser to be adjusted at 500 Hz steps. In turn, the integrated synthesiser generates both a heterodyne signal for the receiver and an FSK-modulated signal for the transmitter.

The results of experimental validation of effective adjustment of quartz resonator frequency based on a GPS signal are presented in Fig. 3. One RPT transducer of the AIMS was placed in a thermal chamber. The signal spectrum was obtained with the help of spectrum analyser.

Spectrum "a" matches the initial spectrum of a quartz unit with a 12 kHz deviation at normal temperature. Spectrum "b" was obtained at a temperature of minus 27°C in the thermal chamber, when communication failure with the RTP was registered. As you may see from the signal spectrum, communication with the RTP failed as a result of insignificant frequency drift. Spectrum "c" was obtained at a temperature of minus 30°C in the thermal chamber with correction by the GPS signal. The spectrum shows no frequency drift, as is also confirmed by the fact that communication with the RTP was restored.

Correction of quartz oscillator frequency by GPS signal will increase energy consumption. Pavlova et al. (2016) provides a formula for calculating the monitor's energy consumption. After introduction of an additional correction channel, the formula appears as follows:

$$e_i = T_1 \cdot e_s + t_m \cdot (e_m + e_w - e_s) + n \cdot t_c \cdot (e_w - e_s) + n \cdot t_w \cdot (e_w - e_s) + n \cdot t_p \cdot (e_w + e_r - e_s) + ((2n-1) \cdot t_r) \cdot (e_r + e_w - e_s) + ((2n-1) \cdot t_i) \cdot (s_i + n \cdot (e_w - e_s)) + ((2n-1) \cdot t_t) \cdot (z_i + e_w - e_s) + k_{gps} - t_{gps} \cdot (e_{gps} + e_w),$$

where: t_m – time spent by analogue-to-digital converter to measure all the necessary parameters;

t_c – time spent by microprocessor to process the values received from A-D converter;

t_w – time spent by microprocessor to switch on after hibernation;

t_p – time gap from engagement of data receiver to the start of data transfer by transmitter;

t_r – time spent by radio module to switch over to reception mode;

t_t – time spent by radio module to switch over to transmission mode;

t_{gps} – time spent on correction of the radio module's frequency;

e_s – current drawn by microprocessor in hibernation mode;

e_m – current drawn by A-D converter during measurement;

e_w – current drawn by microprocessor in operating mode;

e_r – current drawn by radio module in reception mode;

e_{gps} – current drawn by GPS receiver during operation;

T_1 – length of data acquisition cycle (actual);

n – average expected number of communication attempts;

k_{gps} – coefficient ranging from 0 to 1 determining the possibility of correction based on the values stored in the flash memory without engaging the GPS receiver;

s_i – total energy consumption by i-unit's radio transmitter during transmission of response signals to all units that transmit data directly to the i-unit, with regard to appropriate power levels;

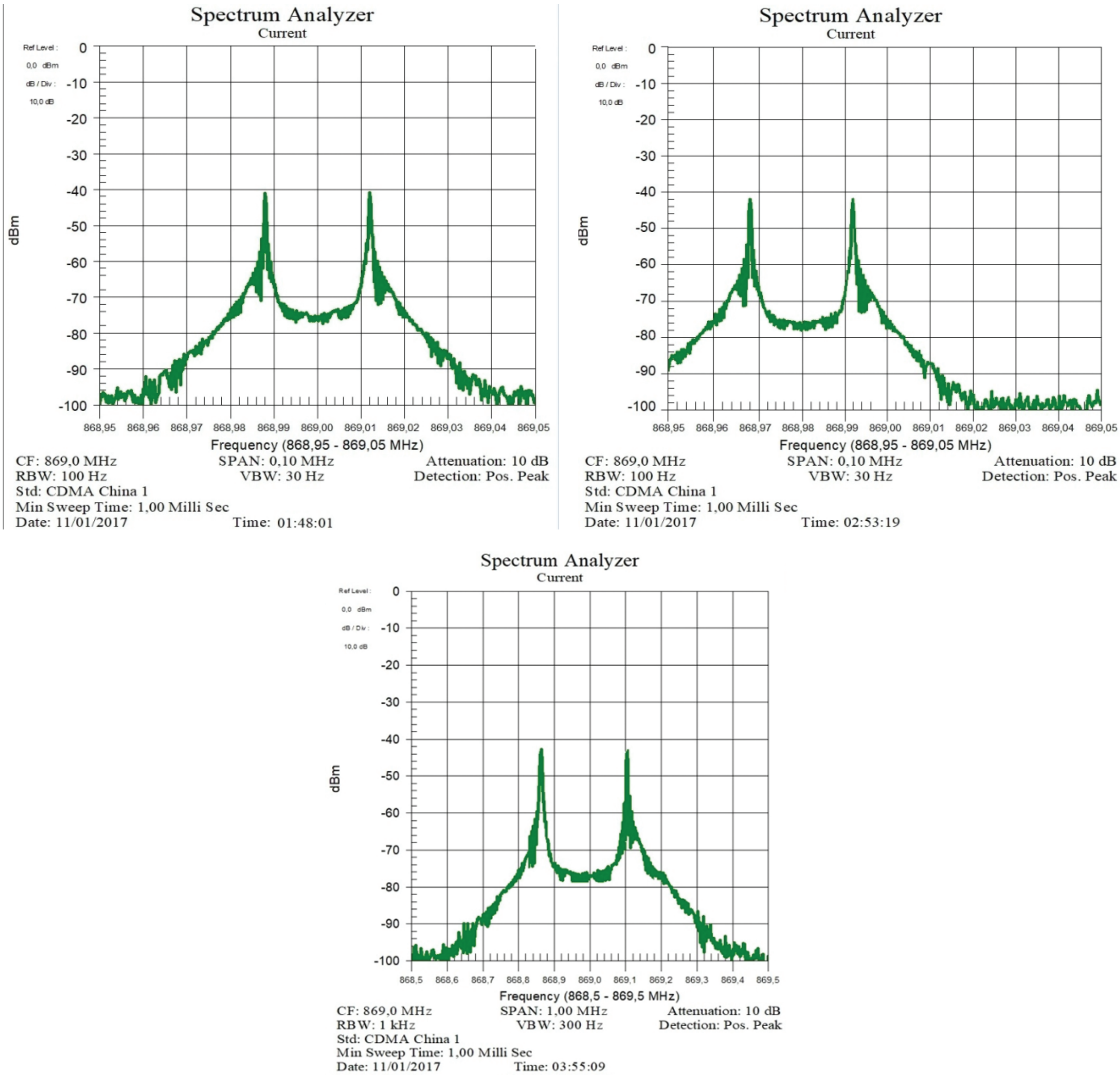

Fig. 3. Quartz resonator thermal chamber test results

z_i – energy consumption by i-unit's radio transmitter during transfer of measurement data packages, with regard to appropriate power level.

Simulation of monitor's operation with an additional frequency correction channel was performed in the Castalia low energy consumption networks simulator. For simulation purposes, the power source was represented by a standard lithium thionyl chloride battery. The simulation showed that the monitor can run autonomously on battery for 14,016 hours at a five-minute polling cycle.

Findings

The study revealed the following:

Experiments with test specimens showed that the suggested method for adjusting the carrier frequency of a quartz crystal resonator allows seven parallel channels to be organised;

Additional energy consumption by GPS channel leans toward an increase in the overall energy consumption of the monitoring device and reduction of battery run time by 20% of the rated run time, which is a reasonable sacrifice for increased efficiency of data transfer in the wireless system.

Discussion

Accurate maintenance of the carrier frequency will help reduce its deviation, allowing us to organise more communication channels within the employed frequency bandwidth, which is very important for AIMS with high data traffic, and increase the accuracy and reliability of signal transmission and reception.

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