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Crystal stability problem in wireless biomedical devices

Abstract. *The paper presents a wireless communication module designed for biomedical applications. The analysis of the impact of production and dispersion stability of quartz crystal devices commonly used in the microcontroller on the reliability of transmission was made. The measurements confirmed that the spectral dispersion of carrier frequency was caused by the projection of production crystals as well as temperature variations. The studies indicate a strong dependence of the precision of carrier frequency generation on the thermal coefficient of capacity changes.*

Streszczenie. *W pracy zaprezentowano skonstruowany moduł komunikacji bezprzewodowej do zastosowań biomedycznych. Dokonano analizy wpływu rozrzutu produkcyjnego i stabilności rezonatorów kwarcowych typowo stosowanych w urządzeniach mikrokontrolerowych na niezawodność transmisji. Wykonane pomiary widmowe potwierdziły niestabilność częstotliwości nośnej spowodowany rozrzutem produkcyjnym kwarców a także zmianami temperatury. Przeprowadzone badania wskazują na silną zależność precyzji generacji częstotliwości nośnej od termicznego współczynnika zmian pojemności kondensatorów odsprzęgających.(**Problem stabilności częstotliwości kwarcu w biomedycznych bezprzewodowych urządzeniach mikrokontrolerowych**).*

Keywords: crystal stability, microcontroller devices, wireless sensor, transmission disturbance.
Słowa kluczowe: stabilność kwarcu, czujnik bezprzewodowy, urządzenie mikrokontrolerowe, zakłócenia transmisji.

Introduction

Technological advancement over the past decade has enabled the use of small smart sensors in biomedical applications, especially with digital wireless communication on ISM (*Industrial, Scientific and Medical*) frequency band. Firstly, a simple RFID (*Radio Frequency Identification*) tag was proposed for patient and drug identification, but recently, many genuine devices were designed [1, 2, 3, 4] which enabled measurement of many more diagnostic parameters than simple ID recognition e.g. body temperature, blood pressure, oxygen saturation and so on [5, 6, 7, 8, 9].

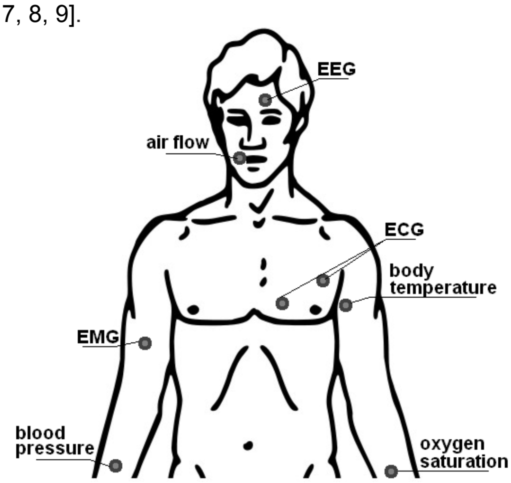

Fig. 1. Diagram of wireless biomedical sensors network

This complex network of multiple sensors, as shown in figure 1, helps in the treatment and diagnosis of various diseases. Its reliable operation is crucial, especially in critical care medicine.

Due to the lack of separation from the environment, the wireless sensor network is much more susceptible to interference than traditional wired sensors. For this reason, sensors should be insusceptible on external and internal disturbances as much as possible.

This paper presents a new designed wireless communication module and a crystal accuracy on generator stability problem which have a lot influence on reliability of RF communication in biomedical wireless sensors.

Problem formulation

As one can notice, a lot of sensors must often work together and thus some difficulties occur, especially if the network is built with tens of hundreds hospitalized patients, each of them connected to several sensors.

Proper operation of the wireless system requires the frequency synchronization between transmitter and receiver whereas selective input and output filters should be trimmed for the same band. Therefore, high selectivity receiver input filters providing good separation from the disturbances forces generation of stable carrier on the side of the transmitter. Even a small change in carrier frequency can result in going outside the band of the received signals when filters with very narrow frequency characteristics are used (several kHz e.g. in CC1120 transceiver [10]).

Other problems are interferences between devices working on adjacent channels. Due to limited ISM bandwidth, in a network of multiple sensors, spacing between channels is limited for example in WMBUS (*Wireless MODBUS*) standard. For this reason even small drift in frequency can provide disturbances in communication by overlapping channels.

Regarding to the above, factor limitations make the carrier frequency stability crucial in the case of biomedical devices. Indeed they must provide high reliability of the transmission and security of transmitted data.

Material and methods

In previous work simple wireless body temperature sensor was constructed (EXP868 - showed in fig. 2).

Construction of that module was based on CC1101 transceiver supplied by Texas Instruments. This choice was dictated by the possibility of independent configuration of many of transmission parameters e.g. power of emission, receiver filter selectivity, type of modulation, form of transmitted frame etc.

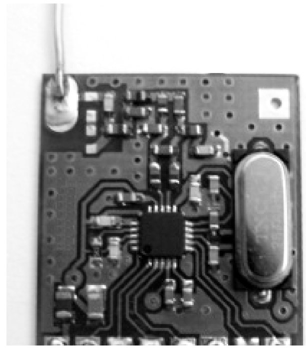

Fig. 2. Wireless body temperature sensor - EXP868

All construction hardware and software were trimmed to work with 868 MHz band.

Elements used in the measurements are summarized in Table 1. To increase communication range a quarter-wave dipole antenna was used.

Table 1. Elements used in the measurements [14,15,16,17,18]

Part	Designation	Frequency/ Capacity	Prod. Tolerance	Temperature stability
X1	ECS-270-18-9X	27 MHz	50ppm	30ppm
X2	ECS-270-20-3X-TR	27 MHz	30ppm	50ppm
X3	7M-27.000MEEQ	27 MHz	10ppm	10ppm
C1	C0805C100K BRACTU	12 pF (X7R)	10%	-
C2	GQM1875C2 E270JB12D	27 pF (C0G)	5%	30ppm

All spectra measurements were performed in open space located near to a city (GPS location N:51° 10' 4.5" E:17° 2' 2.56") from distance 5 m using a 3 GHz Sony Tektronix 3026 spectrum analyzer equipped with a calibrated biconical antenna BicoLog 20300 (Aaronia company). Outline of the measurement system is presented on figure 3.

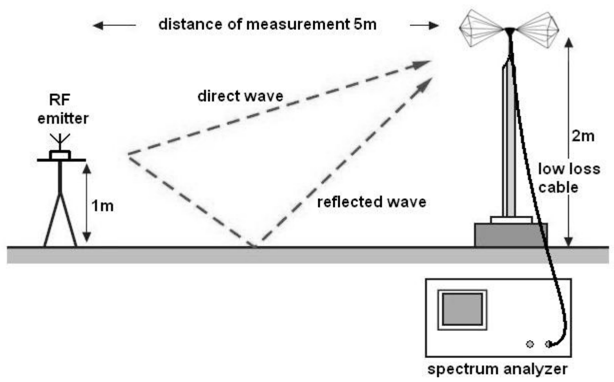

Fig. 3. Outline of RF test stand

Results

Knowledge on the disturbances in the electromagnetic field is needed to correct interpretation of measurement results. From that reason, background noise without ISM (*Industrial, Scientific, Medical band*) transmission was measured using previous system; results were presented on figure 4.

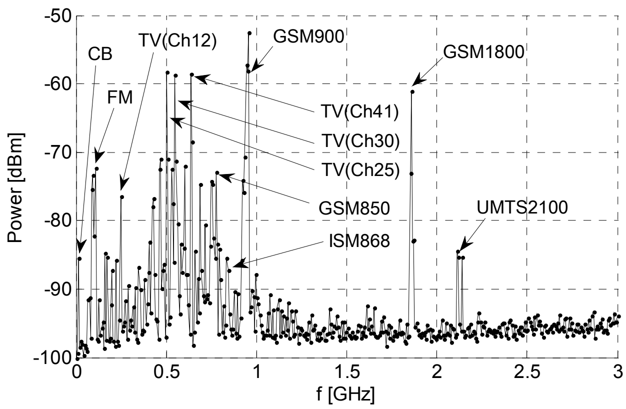

Fig. 4. Free field electromagnetic background

As one can see frequency area near to 868 MHz ISM band is strongly disturbed by different RF transmitters, especially by GSM.

After the initial background noise measurement, the transmitter was enabled and spectrum measurement was repeated. Figure 5 presents the simple spectra difference between spectrum with enabled transmitter and the background.

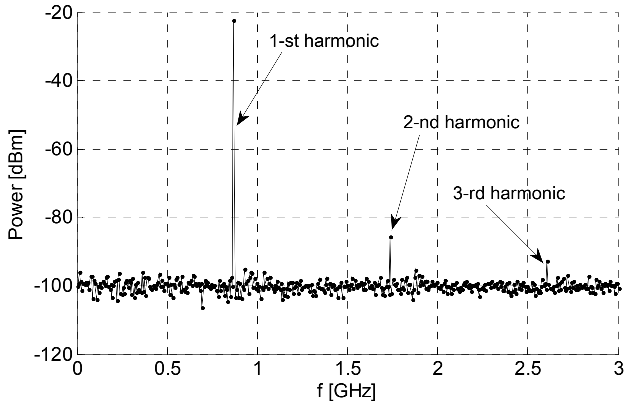

Fig. 5. Differential spectrum of constructed module

As one can see, this simple extraction method gives a very good results but is strongly sensitive to background changes in time. Measurements of the signal strength of individual harmonics can be considered accurate despite their occurrence in areas of strong interference. Power of the first harmonic may be encumbered with some error but it is almost 30 dB away from highest peak of the background. This suggests that the potential error is negligible.

The following research included measurement of radio frequency properties of constructed devices. In the first step of research the impact of crystal production inaccuracy spreading on the carrier was measured.

Results presented on figure 6 showed that 27 MHz crystals from different manufacturer, used as a reference to frequency synthesizer generator, cause small error in carrier generation.

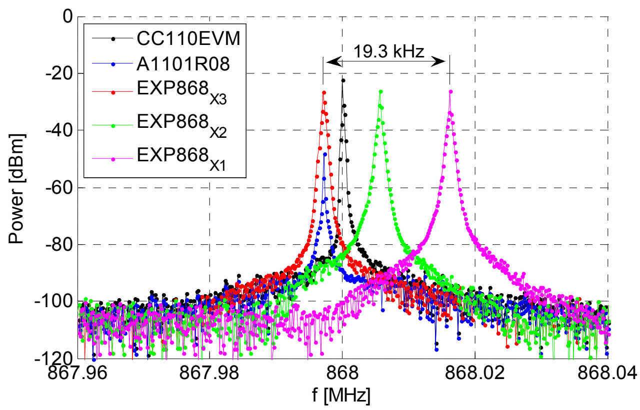

Fig. 6. Carrier shift induced by resonator inaccuracy

This small carrier shift error in transmitter implies using receiver filters with lower selectivity and thus exposes devices to electromagnetic interference with other devices working on different channel on the same band.

Amplitude of the first harmonic presented on figure 6 showed that constructed module has emission spectrum similar to commercial devices but with bigger link budget (calculated as difference between power of emission and receiver sensitivity in dBm) in comparison to A1101R08 module. Broader main peak than in commercial devices may indicate on inaccurate impedance matching between output of transceiver and antenna.

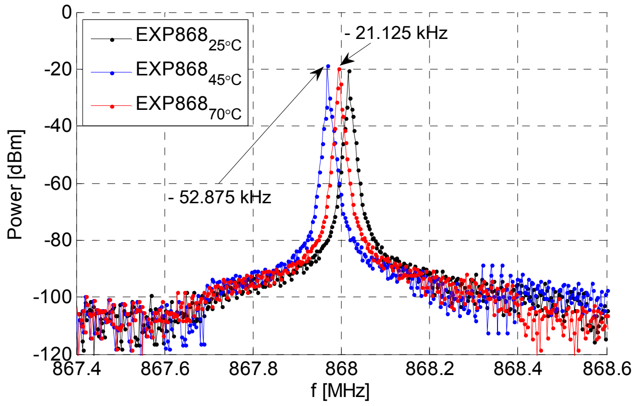

Fig. 7. Carrier shift caused by temperature rising

Next step of the research was measurement of the real influence of temperature on signal spectrum. As known from literature, crystal frequency is strongly dependent on temperature, especially AT cut quartz [11, 12, 13].

However, temperature real dependence on transceiver generator stability and possibilities of compensation of crystal frequency drift are unknown.

The results of spectral measurements at elevated temperatures in figure 7 show that temperature rise causes the decrement of carrier frequency.

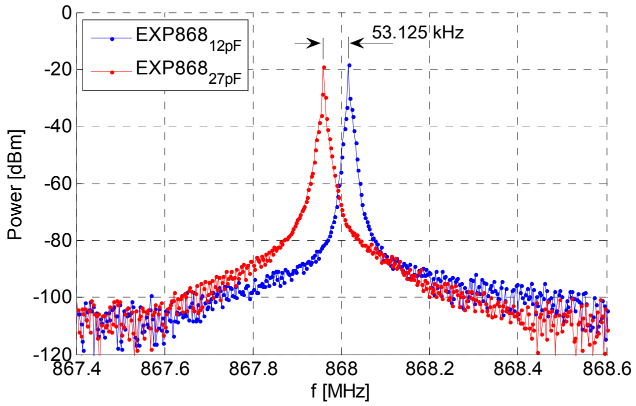

Fig. 8. Carrier shift caused by change of parallel capacitance

These results do not cover expectations because the main crystal frequency (X2 = 27 MHz) has in worst case 50ppm instability in operating temperature range (–10˚C÷70˚C) [15] and instability of carrier generation is a little larger, around 53 ppm as showed on figure 7.

Further studies showed that this trend is caused by a change of coupling capacity (known as crystal load capacitance). Even a small capacity change makes a significant deviation of the carrier frequency as shown in figure 8. The study of impact of capacity changes on carrier was conducted at the same temperature (25˚C) and crystal (X3) but with different capacitors (C1=12 pF and C2=27 pF).

Previous research leads to the conclusion that the thermal instability of load capacitance is responsible for overall instability of the carrier generation and cannot be ignored in the design of wireless devices.

The following figure (Fig.9) shows the measurement results of optimally selected crystal (X3) and capacitors (C2) for thermal exposure.

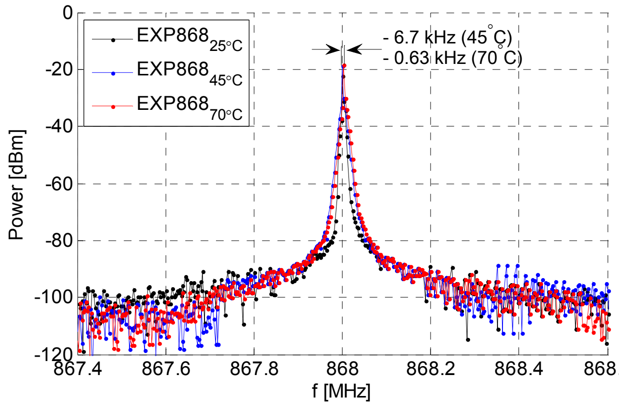

Fig. 9. Carrier shift caused by temperature rising for optimal selected components

As one can see by using of capacitors with low temperature coefficient (type C0G) and high stable crystal generation of carrier is achieved with high stability. This translates to a decreased interference across adjoining channel and improved stability of the transmission. Finally, obtained research results solve the problem of spectral overlap, even in case of densely stacked transmission channels in the 868 MHz band – standardized in Europe by ETSI regulations (EN 300 220-2).

An example of a real spectrum of 64 bytes of WMBUS frame is presented on figure 10. The base frequency was 868,95 MHz, modulation used – FSK with 50 kHz deviation.

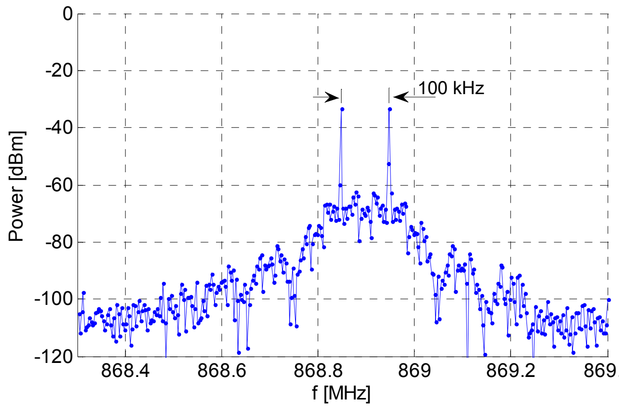

Fig. 10. Spectrum of real 64 bytes of WMBUS frame

Conclusions

The studies showed a strong correlation between the accuracy of generated carrier frequency and stability of quartz. An significant factor of carrier stability is the decoupling capacitance change with temperature. The selection of capacity in terms of thermal stability is crucial and may be responsible for transmission errors and interferences. This thermal shift may cause overlap of the transmission in equipment operating in adjacent channels.

It may be present in case of standard communication, e.g. WMBUS with 50kHz deviation of FSK modulation. Spectra overlap issue may occur even at a temperature increase of several Celsius degrees.

The research results clearly show that the use of capacitors with a high temperature coefficient error (e.g. X7R type) has significant impact on frequency of quartz resonators in terms of temperature variations.

Further studies showed that the measurement of differential spectra in the open space allows to obtain useful results, but strong sensitivity of this method to background changes in time should be noticed. If in the range of the measuring system are devices that emit short data frames (less than the time required for spectra acquisition and calculation), this method cannot be applied. In these studies, the differential method has proved to be useful because of the long time stability of the background and the ability to synchronize the transmitter and the measurement trigger system. The measurements indicate on the possibility of practical application of constructed devices into the simple digital wireless communication between biomedical sensors and diagnosis devices.

Future research should encompass a wider range of temperatures including subzero and the problems associated with long-term stability and aging of system components as well as transmission stability issue with the cooperation of many devices in a common network.

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