SCP-RPSC COHERENT TRANSPONDING SYSTEMS FOR IoT COMMUNICATIONS

SCP-RPSC ХОМОДИННИ СИСТЕМИ С ТРАНСПОНДЕРИ ЗА IoT КОМУНИКАЦИИ

Prof. M.Sc. Demirev V. PhD.

Faculty of Telecommunications – Technical University of Sofia, Bulgaria

demirev_v@tu-sofia.bg

Abstract: *5th generation mobile networks, abbreviated 5G, are the proposed next telecommunications standards. 5G research and development also aims at improved support of machine to machine communication, also known as the Internet of Things, at millimeter waves. The move to these extremely high frequency bands, as well as the new requirements to the 5G network parameters, need new approach for the future technical systems solutions. One of those is the use of microwave coherent transponding system. Spatial Correlation Processing – Random Phase Spread Coding is a new technology in the field of microwave beam forming antenna theory, developed by the author one decade before. Its application in millimeter wave coherent transponding systems is proposed in this report. The system advantages are considered in details too.*

Keywords: 5 G, IoT, SCP, RPSC, MICROWAVE COHERENT TRANSPONDING SYSTEMS

1. Introduction

5th generation mobile networks or 5th generation wireless systems, abbreviated 5G, are the proposed next telecommunications standards beyond the current 4G/IMT-Advanced standards [1, 2]. Rather than faster peak Internet connection speeds, 5G planning aims at higher capacity than current 4G, allowing higher number of mobile broadband users per area unit, and allowing consumption of higher or unlimited data quantities in gigabyte per month and user. This would make it feasible for a large portion of the population to stream high-definition media many hours per day with their mobile devices, when out of reach of wi-fi hotspots. 5G research and development also aims at improved support of machine to machine communication, also known as the Internet of Things (IoT), aiming at lower cost, lower battery consumption and lower latency than 4G equipment.

There is currently no standard for 5G deployments. The Next Generation Mobile Networks Alliance defines the following requirements that a 5G standard should fulfill:

- Data rates of tens of megabits per second for tens of thousands of users;
- Data rates of 100 megabits per second for metropolitan areas;
- 1 Gbit/s simultaneously to many workers on the same office floor;
- Several hundreds of thousands of simultaneous connections for massive wireless sensor networks;
- Spectral efficiency significantly enhanced compared to 4G;
- Coverage improved;
- Signaling efficiency enhanced;
- 1ms Latency;
- Latency reduced significantly compared to LTE.

The Next Generation Mobile Networks Alliance feels that 5G should be rolled out by 2020 to meet business and consumer demands. In addition to providing simply faster speeds, they predict that 5G networks also will need to meet new use cases, such as the Internet of Things (Internet connected devices), as well as broadcast-like services and lifeline communication in times of natural disaster. Carriers, chipmakers, OEMS and OSATs, such as Advanced Semiconductor Engineering (ASE), have been gearing up for this next-generation (5G) wireless standard, as mobile systems and base stations will require new and faster application processors, basebands and RF devices.

Although updated standards that define capabilities beyond those defined in the current 4G standards are under consideration, those new capabilities have been grouped under the current ITU-T 4G standards. The U.S. Federal Communications Commission (FCC) approved the spectrum for 5G, including the 28 GHz, 37 GHz and 39 GHz bands, on July 14, 2016. The move to these extremely high frequency bands, as well as the new requirements to the 5G network parameters, need new approach for the future technical systems solutions. One of that is the microwave Coherent Transponding System (CTS) [3,4,5,6]. The system consists of interrogators and transponders (tags), operating at microwave ISM bands. The transponder does not generate any microwave carrier frequency itself but uses the received carrier power from the interrogator to send information back by simple passive processing, including phase or amplitude modulation and reflecting. The use of directional antennas in such systems at millimeter frequency bands will improve the functionality of CTS,s, as well as the frequency sharing situation.

SCP-RPSC (Spatial Correlation Processing – Random Phase Spread Coding) is an entirely new approach in the field of microwave beam forming antenna theory. It was developed by the author one decade before. The goal was solving the problems of the tracking microwave antenna systems for mobile satellite communications. The application of SCP-RPSC technology in CTS is proposed in this report. The system advantages are considered in details too.

2. Coherent transponding systems

The systems consist of interrogators and transponders (tags) operating at microwave ISM (Industrial, Scientific, Medicine) bands. The interrogator comprises a microwave transceiver using

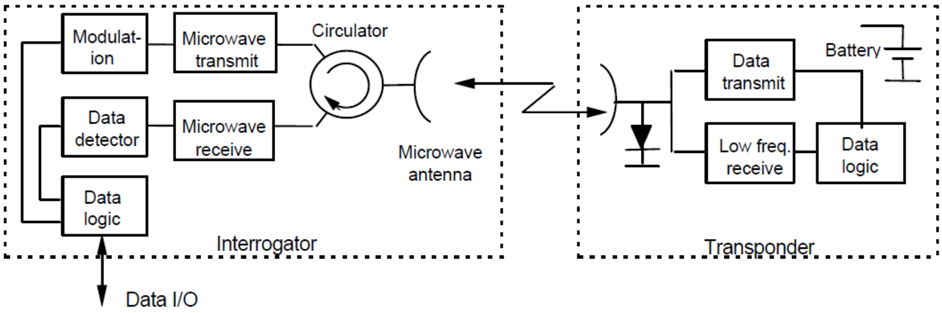

***Fig. 1.** Block scheme of a CTS transponder and interrogator*

ASK (Amplitude Shift Keying) transmit and PSK (Phase Shift Keying) receive modulation. The transponder in its simplest form consists of a low frequency data receiver, data logic circuits, a low frequency data transmitter, battery for the circuits, microwave antenna and diode (figure 1) [5]. The interrogator transmitted ASK modulation is AM-detected by the transponder microwave diode, amplified, decoded by the data receiver and validated by the logic circuits. When the interrogator transmitter is unmodulated, the transponder is able to respond to the interrogator by modulating the received carrier and the modulated signal is then re-radiated from the transponder. As the transponder is without any essential RF selectivity the transponder can interrogate within a wide frequency range. To prevent unwanted interrogations the transponder may be designed with an access protocol for the specific application and/or a RF level threshold. However, this is not the case for all of the present systems. The transponder does not generate any microwave carrier frequency itself but uses the received carrier power from the interrogator. Consequently, within the bandwidth limits, the transponder will automatically track the interrogator frequency when used in a multi-channel or spread spectrum scheme.

By means of the formulas, given in [5,7,8], it is possible to derive the equation (1) for Power Link budget analysis of a CTS system:

$$E_b / N_0 = EIRP - 2L + G_r / T_s + 2G_{tag} + CL_{tag} + 228{,}6 - 10\lg R_b \quad \text{(dB)}, \tag{1}$$

Where:

- E_b / N_0 (dB) is the Energy per Bit to Noise Density Ratio in the Interrogator receiver;
- $G_r / T_s = G_{rInt} - 10\lg T_{sInt}$ (dBi/K) is the Figure of Merit of the Interrogator Receiving System, G_{rInt} is the gain of the Interrogator receiving antenna, T_{sInt} is the Interrogator noise temperature;
- $EIRP = 10\lg P_{tInt} + G_{tInt}$ (dBW), is the Equivalent Isotropically Radiated Power of the Interrogator, P_{tInt} is the transmitted Interrogator power and G_{tInt} is the gain of the transmitted Interrogator antenna;
- $L = 20\lg R + 20\lg f + 92{,}45$ (dB) is the Free Space Path Loss, R is the distance between the Interrogator and the Transponder in km and f is the frequency in GHz;
- G_{tag} (dB) is Transponder (= tag) antenna gain;
- CL_{tag} (dB) is Transponder (= tag) conversion loss;
- R_b (bit/s) is the rate of the information in bit/s.

The estimated different classes and working distances R [5] for R_b = 10 kbit/s; 100 kbit/s and 1 Mbit/s in 2,45 GHz band are as follows:

- Class I: EIRP - 10 mW - 11 m, 6 m and 3 m;
- Class IIa2: EIRP - 100 mW - 18 m, 10 m and 6 m;
- Class IIb2: EIRP - 500 mW - 27 m, 15 m and 9 m.

Consider eq.(1) for the case when the working frequency is shifted up from f_1 to f_2 and the system parameters remain constant, which is not exactly true for the system noise temperatures and device losses:

$$E_b / N_0(f_1) = E_b / N_0(f_2) \tag{2}$$

Which leads to eq. (3), where the indexes (1) and (2) correspond to the frequencies f_1 and f_2:

$$G_{tInt1} - 40\lg f_1 + G_{rInt1} + 2G_{tag1} = G_{tInt2} - 40\lg f_2 + G_{rInt2} + 2G_{tag2} \tag{3}$$

Considering eq.(3) we can conclude, that the increasing of the working frequency, resp. the free space losses, could be compensated successfully by increasing the gain of the used antennas. It is well known from the theory, that the high gain antennas have directional beams. The last leads to necessity of scanning antenna beams in the case of mobile communication environment. The use of directional antennas will improve the functionality of CTS,s, as well as the frequency sharing situation. Different Multiple Access schemes could be used in order to increase Interrogator – multiple Transponders communication traffic capacity [6] (Fig.2).

3. *Possible SCP-RPSC coherent transponding systems*

3.1. *Introduction of SCP-RPSC approach*

The SCP-RPSC is an entirely new approach in the field of microwave beam forming antenna theory, developed by the author one decade before. The goal was solving the problems of the tracking microwave antenna systems for mobile satellite communications. First it was studied in receive mode (SCP technology) [9, 10], where its main objectives include:

- Receiving one or more radio signals coming from one or several spatially distributed sources (satellites), insuring high gain of the antenna systems and using fixed or mobile receiving terminals, equipped with SCP signal processing systems;

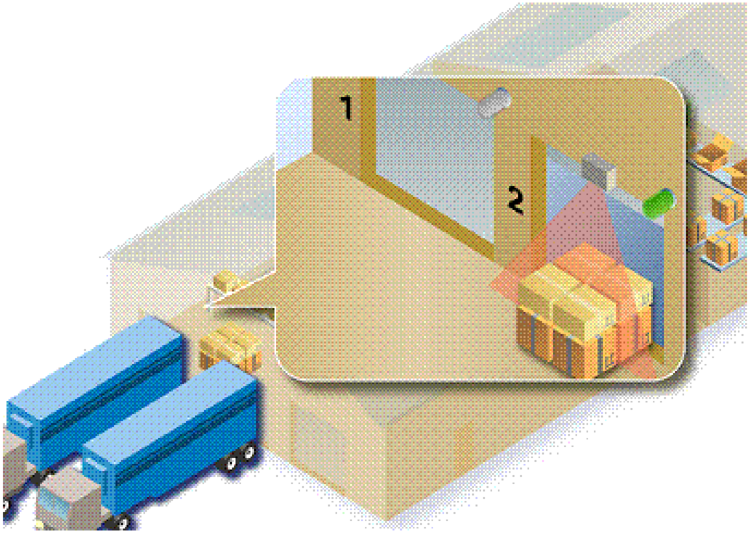

Fig. 2. *Confirming shipping contents*

- Insuring spatial selectivity high enough to cancel the same frequency channel interference, coming from different space directions, using simple one-channel receiver and patented signal processing principle.

The main features of the SCP approach are:

- Simple and cheap passive Radial Line Slot Antenna (RLSA), suitable for mass production in Ku and Ka frequency bands;
- One channel microwave receiver with simple signal processing;
- Omnidirectional for the cooperative satellite, but with high figure of merit G/T;
- Selection of different satellites and polarizations by PN-codes;
- Soft handover and virtual multi-beam features;
- Receive only system, but with possible applications in transmitting systems too;
- Applications in existing Digital Video Broadcasting – Satellite (DVB-S) systems with minor modifications of the ground transmitters, compatible with the existing satellite transponders.

The transmit mode (RPSC technology) [11,12] is based on transmission of broadband microwave signals in the open space by means of multi element random phased antenna arrays. The sum of the different elements signals in a given point in the space has Gaussian probability distribution and noise like properties. The sums in the different directions of the space are not correlated each other. In such way the proposed principle solves simultaneous the problems of signal spreading and beam forming of the future sophisticated microwave terrestrial and satellite communication systems with fixed and mobile applications.

The main features of the RPSC technology, when it is used in the up-links of the satellite communication links, additionally include:

- Omnidirectional for the cooperative satellite, but with high equivalent (at base-band) Equivalent Isotropic Radiated Power (EIRP);
- Selection of different terminals and polarizations by Pseudo-Noise (PN) codes;
- Soft handover and virtual multi-beam features;
- The coherent demodulation by means of pilots (specific property of SCP technology) cancels the Doppler shifts and phase jitter, introduced by local oscillators in the satellite system;
- Compatible with the existing bent-pipe satellite transponders;
- Providing of full duplex radiocommunication system with one simple and cheap transmit-receive antenna, using combined SCP-RPSC technology in both directions, particularly in Ku band;
- The transmitted random poly-phase spread signals will not cause significant harmful interference to the conventional satellites, using the same frequency channels. The interference will be similar to that, caused by the sidelobes of an antenna array with random elements distribution and main lobe, phased in another direction;
- RPSC up-links are protected against jamming, coming even from points, close situated to the earth stations – in the main lobe of the satellite up-link receiving antenna;
- The transmitted random poly-phase spread signals have low power spectral density and low detection probability for the conventional microwave receivers, leading to low active jamming probability.

In this report the “magic” properties of the SCP-RPSC technology, applied in the future sophisticated CTS,s, will be discussed in details.

3.2. SCP in the Interrogator

The application of SCP in the CTS Interrogator (SCP-I CTS) suggests that:

$G_{tInt1} = G_{tInt2}$ and $G_{tag1} = G_{tag2}$ in eq.(3) , which leads to:

$$G_{rInt2} = G_{rInt1} + 40\lg f_2 / f_1 \quad (4)$$

For example if $f_1 = 2{,}45GHz$ and $f_2 = 24{,}125GHz$ (standard ISM frequency bands) the receiving Interrogator antenna gain should be increased with about 40 dB for the higher frequency band. A 30 cm in diameter SCP antenna has about 36 dBi gain, so the compensation is good, but not complete. Another additional advantage of a SCP-I CTS is the possibility to resolve different several Transponders, spatially distributed at angles, higher than the zero beam with of the SCCF (Spatial Cross Correlation Function) [10]. In such case Space Division Multiple Access (SDMA) approach could be realized. For the particular values of the example this resolution angle is about 3 degrees.

3.3. SCP-RPSC in the Interrogator

The application of SCP-RPSC in the CTS Interrogator (SCP-RPSC-I CTS) suggests that:

$G_{tInt} = G_{rInt} = G_{Int}$ and $G_{tag1} = G_{tag2}$ in eq.(3) , which leads to:

(5) $$G_{Int2} = G_{Int1} + 20\lg f_2 / f_1$$

For example if $f_1 = 2{,}45GHz$ and $f_2 = 24{,}125GHz$ the transmit-receive antenna gain of the Interrogator should to be increased with about 20 dB. A 30 cm in diameter SCP-RPSC antenna at frequency f_2 has about 36 dBi gain in one direction, so the compensation is excellent. Another additional advantage is the possibility to resolve different several spatially distributed Transponders. The angular resolution is better than the previous case, but should be studied additionally in details.

3.4. SCP-RPSC in the Transponder

The application of SCP-RPSC in the CTS Transponder (SCP-RPSC-T CTS) suggests that:

$G_{tInt1} = G_{tInt2}$ and $G_{rInt1} = G_{rInt2}$ in eq.(3) , which leads to:

(6) $$G_{tag2} = G_{tag1} + 20\lg f_2 / f_1$$

For this particular example the transmit-receive antenna gain of the Transponder should be increased with about 20 dB and in the case of the use of 30 cm in diameter SCP antenna the compensation is excellent. The resolving of the different Transponders could be done by means of Random Phase Spread Coding - Multiple Access (RPSC-MA) approach [11].

3.5. SCP-RPSC in the Interrogator and the Transponder

The application of SCP-RPSC both in the CTS Interrogator and Transponder (SCP-RPSC-IT CTS) seems to be possible. This particular case, which promises many advantages, should be studied in details in the future.

4. Conclusions

An author proposal, dealing with possible application of SCP-RPSC technology in the next generations microwave Coherent Transponding Systems for 5 G IoT communications, is given in the report. The analyses shows very wide area of the different SCP-RPSC applications in CTS, when it is necessary to:

- Direct a narrow beam over a sector angle and give coverage like a sector antenna for Space Division Multiple Access of several Transponders;
- Obtain high antenna gains for the used Interrogators and Transponders in order to compensate the increased propagation losses at millimetre wavelengths;
- Narrow the antenna beam width in order to reduce multipath propagation problems;
- Create complex and dynamically re-configurable IoT radio networks exhibiting high spectrum efficiency;
- Reuse the frequencies and timeslots, using RPSC-MA;
- Obtain secure and reliable IoT government communications, resistive to enemy active jamming;
- Use “multiple spot beams” approach from unstable or mobile IoT platforms.

The practical SCP-RPSC principles implementations in millimetre wave CTS will solve successfully many of the existing problems of the future sophisticated 5 G IoT communications.

References

[1]. Wikipedia – 5G.

[2] Latha D., D. Reddy, K. Sudha, A. Mubeen, T. Savita, A Study on 5th Generation Mobile Technology - Future Network Service, IJCSIT International Journal of Computer Science and Information Technologies, Vol. 5 (6) , 2014.

[3]. King R., Microwave Homodyne Systems, London, Peter Peregrinus Ltd., 1978.

[4]. Демирев В., М. Гачев, СВЧ системи в промишлеността и бита, София, Техника, 1985.

[5]. Wireless Lans, IEEE P802.11, ERC Report, January 1998.

[6] Sikander J., Microsoft RFID Technology Overview, Internet, November, 2004.

[7]. Демирев В., Мобилни и персонални спътникови комуникации, София, изд. ТУ-София, 2010.

[8]. Jos R., Beam forming for 5G communication systems, Radio-Electronics.com, 07 Mar 2016.

[9].Demirev V., Spatial Correlation Processing - the New Approach in the Broadband Satellite Tracking Systems, Journal of Electrical and Control Engineering, V.3, N 5, 2013, pp. 55-64.

[10].Demirev V., Some Important Parameters of the Spatial Correlation Processing Technology, Journal of Electrical and Control Engineering, V.3, N 5, 2013, pp. 49-54.

[11].Demirev V., Random Phase Spread Coding - the New Way to Communicate with Noise Signals at Microwaves, Journal of Electrical and Control Engineering, V.4, N 2, 2014, pp. 1-9.

[12]. Demirev, V., Spatial Correlated Radiocommunication Technologies – The Bulgarian Contribution for a Better World, Science. Business.Society, V. 1, 2016, pp.18-21.