

SECURITY OF THE B-MSS – THE NEW CHALLENGE FOR THE SATELLITE SYSTEM DESIGNERS

Assos. Prof. M. Sc. Demirev V.B. Ph.D
Technical University-Sofia, Bulgaria,
e-mail:demirev_v@tu-sofia.bg

Abstract: *The Broadband Mobile Satellite Services (B-MSS) are extremely important not only for government (army and police), but for many civil applications as car, aero, railway and ship communications. Probably they will be part of the future 5-G network development and their security work is very important too. The solving of the main B-MSS security problems needs entirely new approach. The aim of this paper is to analyze two new radio-communication principles, named Spatial Correlation Processing - Random Phase Spread Coding, from security point of view. They were proposed by the author a decade before as antenna transmit-receive beam forming methods with many applications in microwave frequency bands too.*

Keywords: SECURITY, MOBILE, SATELLITE, SPATIAL, CORRELATION, RANDOM, PHASE, SPREAD, CODING

1 Introduction

The Broadband Mobile Satellite Services (B-MSS) are extremely important not only for government (army, police, emergency care, disaster operations), but for many civil applications as car, aero, railway, ship and recreation vehicles communications. Probably they will be part of the future 5-G network development and their security work is very important too.

One of the biggest technical problems of the Vehicle Mounted Earth Stations (VMES), a very important segment of the B-MSS, is the antenna system. The tracking of a satellite in angular coordinates independently of mobile motion is an essential function for directional antenna systems in Ku and Ka frequency bands [1]. The angular tracking function needs two capabilities – beam steering and tracking control. A review of the beam steering and tracking control methods, used in B-MSS, is given in this report. Their advantages and disadvantages from security point of view are discussed too.

Another security problem for the B-MSS is the need to counter Space Terrorism. The most vulnerable components of the space systems are the VMES and the communication links. These components are susceptible to attack from widely accessible weapons and technologies.

Spatial Correlation Processing - Random Phase Spread Coding (SCP-RPSC) technologies were proposed by the author as antenna beam forming methods with many applications in microwave frequency bands. The possible improvement of B-MSS security is discussed too.

2 Satellite angular tracking and antenna beam steering in VMES

2.1 Antenna beam steering

The satellite angular tracking function needs two capabilities – antenna beam steering and tracking control [1].

There are two types of beam steering methods in microwave frequency bands. The first is mechanical steering, which physically directs the antenna to the satellite. The second is electronic steering, which directs the antenna beam by electronic scanning. A typical example of electronic steering is achieved through a phased array antenna. The main features of the two types of methods from security point of view are listed below:

- Mechanical steering

Advantages: Technically easy to fabricate; Wide beam coverage; Good axial ratios in wide beam coverage.

Disadvantages: Low reliability; Low speed beam scanning; Large in volume and heavy; Very high cost for civil B-MSS (in order of several thousand US \$).

- Electronic steering

Advantages: Light and low profile; High-speed beam scanning; High reliability.

Disadvantages: Technically difficult to fabricate, especially in the future B-MSS millimeter wave bands; Narrow beam coverage, Narrow frequency working band, very important for the broadband systems; Poor axial ratios in wide scanned coverage, canceling the frequency reuse by orthogonal polarizations; Excessive feeder loss, reducing the receiver Figure of Merit G/T; Extremely high cost (in order of hundred thousand US \$).

2.2 Satellite angular tracking

There are also two methods to control tracking. The first is the closed loop method, which uses a signal from the satellite to search for and maintain in satellite direction. The second method is the open loop method, which does not use signals from a satellite. It uses compasses and rate sensors and is not applicable for B-MSS in Ku and Ka frequency bands, where high gain narrow beam antenna systems are used.

The tasks, performed by the VMES satellite tracking system, include satellite acquisition and automatic tracking [1]. The acquisition system acquires the desired satellite by moving the antenna around the expected position of the satellite. Automatic tracking is initiated only after the received signal strength due to the beacon signal transmitted by the satellite is above a certain threshold value, which allows the tracking receiver to lock to the beacon. The automatic tracking ensures continuous tracking of the satellite. Figure 1 shows the generalized block schematic arrangement of the closed loop satellite tracking system. The VMES antenna makes use of the beacon signal to track itself to the desired positions in both azimuth and elevation. The auto track receiver derives the tracking correction data that is used to drive the antenna. The tracking techniques are classified on the basis of the methodology used to generate angular errors. Commonly used tracking techniques include:

- Sequential Lobing

In sequential lobing, the beam axis is slightly shifted off the antenna axis. This squinted beam is sequentially placed in discrete angular positions, usually four, around the antenna axis. The angular information about the satellite to be tracked is determined by processing the received signals. The track error information is contained in the signal amplitude variations. The squinting and beam switching is done with the help of electronically controlled feed and therefore can be done very rapidly.

- Conical Scan

This is similar to sequential lobing except that in the case of conical scan, the squinted beam is scanned rapidly and continuously in a circular path around the antenna axis. If the satellite to be tracked is off the antenna axis, the amplitude of the echo signal varies with antenna's scan position. The tracking system senses the amplitude variations and the phase delay as function of scan position to determine the angular coordinates. The amplitude variation provides information on the amplitude of the angular error and the phase delay indicates direction. The angular error information is then used to steer the antenna axis to make it to coincide with the object location. The technique offers good tracking accuracy and an average response time.

- Monopulse Tracking

Monopulse tracking creates the required information for the angular error by simultaneous lobing of the received beacon. Monopulse tracking technique offers very high tracking accuracy and fast response time. Due to absence of any mechanical parts, the feed system requires very little maintenance. The disadvantages include high cost, large and complex feed system and need to have at least two-channel coherent receivers and good RF phase stability. It is commonly employed in large fixed earth stations, as well as in those earth stations that require accurate tracking of nongeostationary satellites.

The main disadvantages of the above listed closed loop tracking methods from security point of view are:

- The use of satellite signals as essential factor. This is because received signal levels from satellites are not stable because of the severe propagation environment due to fading, blocking, shadowing and active jamming;
- Long acquisition time period during the starting procedures, which is in order of minutes in real B-MSS systems. The same acquisition time is needed after the loose of the signal due to blocking in urban environment;
- The listed methods can be used for tracking only one communication satellite. In some cases, where very high security and reliability of B-MSS is necessary (Aeronautical B-MSS), the space diversity approach is used. It includes simultaneous communications and tracking of several satellites, obviously not achieved by the known tracking methods and systems;
- Ability to maintain pointing accuracy: Vehicles can abruptly accelerate and decelerate as well as travel in rough terrain. Under these conditions, the B-MSS VMES may find it difficult or impossible to maintain their pointing accuracy. Of greater practicality may be the ability of the antenna systems to automatically mute transmissions upon deviation from the target satellite;
- Danger of using ultra small antennas: Vehicles cannot accommodate the larger antennas that can be installed on ships. Thus ultra small stabilized antennas are more practical for VMES. However, smaller antennas have greater potential for interference to adjacent satellites because they have wider main and side lobes that can radiate more energy to satellites on either side of the intended satellite;
- Ability to track potential interference: Because of the ubiquity of vehicles and their unpredictable driving patterns, a method to identify and correct interference issues is paramount.

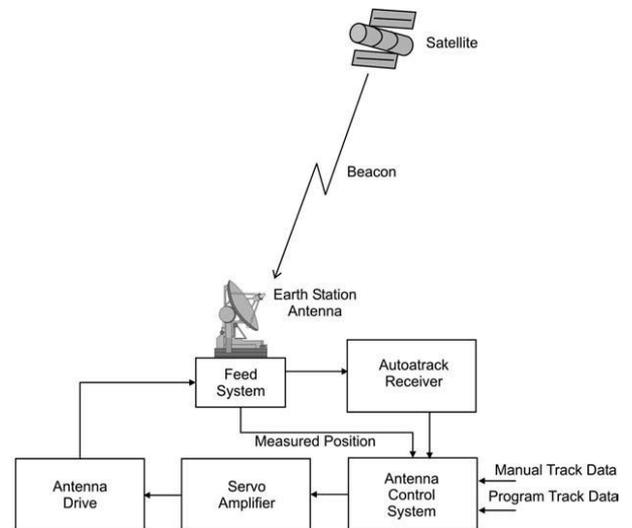


Fig.1 Block schematic arrangement of closed loop satellite tracking system with mechanical steering

3 SCP technology

3.1 SCP approach system objectives

The brief review of tracking antenna methods shows that the solving of tracking VMES problems needs entirely new approach. The name of the new technical proposal [1,3] is Spatial Correlation Processing (SCP).

The proposed SCP system objectives include:

- Receiving one or more radio signals coming from one or several spatially distributed sources (satellites), insuring high gain of the antenna systems of the fixed and mobile receiving terminals;
- Insuring spatial selectivity high enough to cancel the same frequency channel interference, coming from different space directions, using simple one-channel receiver and signal processing circuits.

The above mentioned SCP system objectives solve simultaneous the problems of virtually electronic antenna steering and multiple satellites closed-loop tracking system, providing the security requirements for the future government and civil B-MSS.

The objectives stated above are achieved by a method for radio communications, which proposes application of additional pilot signals transmitted in the band of information signals and available in the receiver by one of the known methods of access. The SCP receiver terminal Random Phased Antenna Array (RPAA) is with equal in amplitude and random in phase aperture excitation. The phase shifts of the signals, received by the different antenna elements, are random at the antenna output regardless of the information source direction. These phase spread signals correlate with the recovered pilot signals, phase spread in the same manner. Since the pilots come from the same direction and propagate in the same random environment to the antenna output they should have the same phase spread ("poly-phased" signature) as the information signals. The results of the correlation process are the recovered information signals at base band. The signals coming from other satellites will propagate from antenna aperture to the antenna output in different random environment. Their phase spreads will be different from these of the chosen pilots and they will not correlate during the signal processing. This lack of correlation insures the spatial and polarization selectivity of the SCP system.

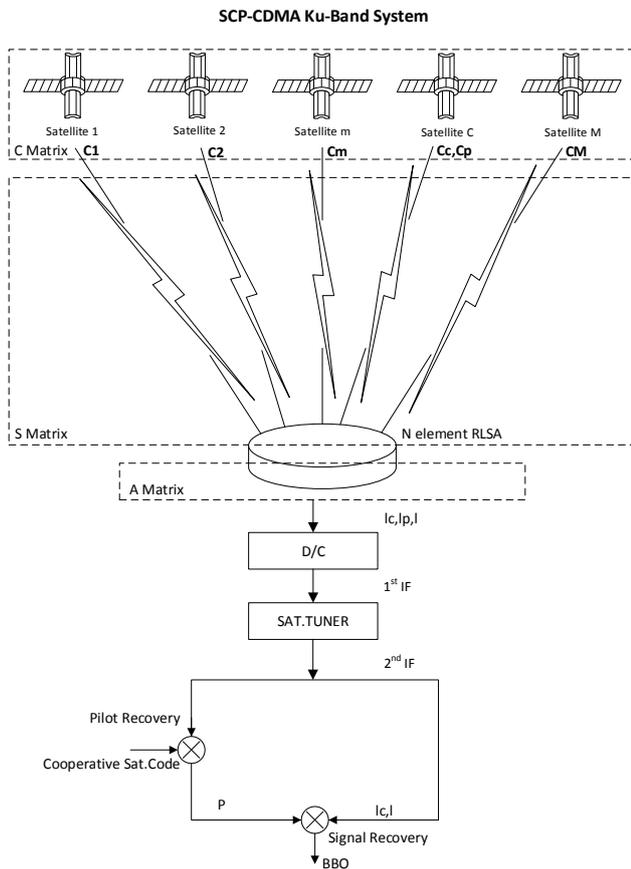


Fig.2 The basic SCP system architecture

3.2 The basic SCP system architecture

According to the basic SCP system architecture [fig.2], the cooperative satellite is chosen for communications by means of synchronized Pseudo-Noise (PN) code and the well known Code Division Multiple Access (CDMA). This specific SCP feature is of great importance when short acquisition time of the mobile B-MSS SCGS is required. Code synchronization, similar to angular tracking, consists of two steps - acquisition and tracking.

The most widely used algorithm for code acquisition is based on serial search strategy. Here the phase of the local code is changed step by step, in equal increments, resulting in serial search of the code delay uncertainty region until the synchrony position is found. For each value of the phase of the local sequence, a correlation between the input signal and the local signal replica is formed and compared to a threshold. A high value of the correlation (above the threshold) indicates the synchrony position. The acquisition time period is reduced in the modern CDMA systems by well developed methods of parallel and combined search up to several tenths milliseconds. It is incomparable with the acquisition time of the above mentioned, used in Ku and Ka frequency bands, classical methods.

The theory of code tracking in the modern CDMA systems is very well developed too. Similar to acquisition procedures, it is made by software and does not need multichannel RF coherent receiver as it is in classical monopulse tracking. This approach gives the possibility of simultaneous tracking of several cooperative satellites, insuring space diversity and very high degree of communication security.

4 RPSC approach

4.1 RPSC (SCP-transmit) – a new spread spectrum beam forming technology

Reliability, availability and security of real time communications are imperative in the context of wireless communication services. A popular technique used in this scenario is Spread Spectrum (SS). For a communication system to be considered a SS system, it is necessary that the transmitted signal satisfy two criteria:

- The bandwidth of the transmitted signal must be much greater than the message bandwidth;
- The transmitted bandwidth must be determined by some function that is independent of the message and is known to the receiver.

In SS systems, the spreading process is accomplished using a spreading code. Conventionally, it is used Pseudo-Noise (PN) sequences. These sequences are periodic with a long period and they have properties similar to noise. Besides the conventional method of PN periodic sequences generation, others methods can be used in SS systems. A promising one is the use of chaotic sequences as spreading codes.

An important parameter that is sometimes useful in specifying the performance of a SS signal in the presence of interference is known as Processing Gain (PG). It is defined as the ratio of the signal bandwidth to the message bandwidth.

The recent developments of the broadband terrestrial and satellite wireless communication systems leads to new problems in the field of the conventional SS systems. Because the used values of PG are in order of 20 or 30 db, the SS signal bandwidth grows to unpractical high values for adequate signal processing and transmission. The most sensitive to the super wide bandwidth of the SS broadband wireless systems are the antenna beam forming networks.

A new principle to create broadband SS systems was proposed by the author [2]. It 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 antenna element 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 the future sophisticated microwave B-MSS, dealing with signal spreading and beam forming.

4.2 Improvements of regulatory status of B-MSS VMES using RPSC antennas

Satellite connectivity while driving traditionally has been possible by using handheld personal terminal equipment with low gain omnidirectional antennas. Recently, the new satellite interactive broadband communication systems use high gain satellite tracking antennas, installed on vehicles. The VMES currently can operate on conventional Ku-band frequencies (14 GHz Uplink, 11-12 GHz Downlink) but only on a secondary basis. This means VMES cannot claim interference protection from primary services such as fixed satellite systems and Earth Station on Vessels (ESV). A co-primary allocation of VMES in the conventional Ku-band would be in the public interest, as it would address a growing commercial demand for on the move services. However, a co-primary allocation would also have to be conditioned on strict adherence to interference avoidance mechanism, which in the best way obviously is satisfied by the RPSC technology.

4.3 *RPSC technology – the new approach to protect satellite communications from space terrorism*

The European Space Policy Institute (ESPI) issued an article, titled "The Need to Counter Space Terrorism - a European Perspective", arguing for studies to introduce effective counter measures to protect satellites. The article lists several examples of jamming and piracy events that occurred in the commercial satellite sector. One of the conclusions is that the most vulnerable components space systems are the ground stations and communication links. These components are susceptible to attack from widely accessible weapons and technologies. The ESPI agrees with this and says policy makers must consider the system architecture as a whole.

SCP-RPSC technology is one the best technologies, satisfying the above mentioned requirements, as follows:

- SCP in down-links

In this particular case the down-links are well protected from jamming, coming from the side-lobes of the Spatial Cross-Correlation Function (SCCF). SCCF is the virtual SCP antenna pattern at baseband. As it was shown in [1], the level of the side-lobes is very low (in order of -25, -30 db). It leads to good protection ratios of SCP down-links against ground based terrorist jamming.

- RPSC in up-links

In this particular case 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 receiving RPSC circuits will not recovery the jamming signals because of the lack of correlation between the jamming signals, transmitted by conventional high gain antennas, and the recovered random phase spread pilot signals. Situation is similar to the case of CDMA protection against narrowband interference.

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

- Omni directivity for the cooperative satellite, but 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), cancelling the Doppler shift and phase jitter, introduced by local oscillators in the satellite systems;
- Compatibility with the existing bent-pipe satellite transponders;
- RPSC up-link protection against active jamming, coming even from points, close situated to the earth stations;
- The SCP-RPSC approach is a breakthrough technology, leading to unpredictable increase of the frequency reuse factor in B-MSS. Close situated B-MSS terminals could communicate with satellites, using the same frequency channel without interference. The isolation among the RPSC and convenient terminals is provided by their specific random phase spread coding.

5 Conclusion

The practical SCP-RPSC principles implementations in transmit and receive mode will drastically change the existing paradigm in the B-MSS communication business in general. Many of the existing problems of the proposed LEO, MEO and GSO satellite systems, dealing with frequency and orbital resource sharing, beam shadowing, terrorist jamming etc., will be solved successfully. In such way the B-MSS reliability and security will drastically be improved.

6 References

1. Demirev V., "Spatial Correlation Processing – the New Approach in the Broadband Satellite Tracking Systems", Journal of Electrical and Control Engineering, Volume 3, Issue 5, pp. 49-54, October, 2013.
2. Demirev V., "Random Phase Spread Coding – the New Way to Communicate with Noise Signals at Microwaves", Journal of Electrical and Control Engineering, Volume 4, Issue 2, pp. 1-9, April, 2014.
3. Demirev V., "SCP-RPSC – the Key Technology for the Next Generation Microwave Communication Systems", Machines, Technologies, Materials, pp. 13-16, N 6, 2015.