A NEW HIGHLY SPREAD SPECTRUM SLOTTED BURST (H3SB) PROTOCOL FOR SATCOM APPLICATIONS

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Abstract

This paper describes the development of a new version of the E-SSA (Enhanced Spread Spectrum Aloha) protocol [1] [2], namely H3SB (Highly Spread Spectrum Slotted Burst). The innovative feature is the ability to operate in the presence of very high interference, thanks to an ultra-high processing gain of 64.7 dB (theoretical value). This allows it to operate with values of C/(N+I) up to approx. -56 dB (measured in laboratory) and bandwidth up to 72 MHz. These features of the H3SB protocol were first employed in November 2012 to successfully perform antenna mapping of the on-board antennas on the Eutelsat satellite E21B during its In-Orbit-Test (IOT). Subsequently, the system was further evolved to add the ability to measure radiation patterns (Co-pol and Cross-pol) of remote earth stations during Earth Station Verification Assistance (ESVA). ESVA tests are designed to ensure the earth station and associated equipment comply with the relevant specifications defined by the satellite operator.
The new version of the H3SB platform has been successfully used by Eutelsat over the last two years during ESVA tests on a number of antennas located in several teleports across Europe. The test activities were carried out using the H3SB platform with high TRL (7), developed on the basis of the SDR (Software Defined Radio) architecture [3] already adopted by MBI to develop the first commercial E-SSA demodulator used by Eutelsat to operate its SmartLNB solution [4]. The starting point for the development of the H3SB platform was a deposited patent belonging to Eutelsat Communications [5].
A further adaptation of the H3SB platform is now being carried out to allow for the measurement of de-pointing events of Satcom-On-The-Move (SOTM) antennas. The ability to operate with such negative C/(N+I) means it will be possible to use the H3SB protocol for a variety of functions including secure communication and encryption key enhancements.
Keywords—E-SSA, ESVA, antenna mapping, radiation pattern

Measuring the radiation patterns (CO-POL and CROSS-POL) of earth stations

ESVA testing [6] is generally required for new earth stations prior to commencement of service, as well as for existing earth stations after major modifications (especially of the RF front end). Typical parameters which can be measured using an available satellite transponder are: earth station EIRP, transmit gain, transmit side-lobes, transmit polarisation isolation, receive gain, G/T, receive polarization isolation and receive side-lobe patterns. Most of these parameters are derived from the measurements of the transmitting and receiving side-lobes.
Measurements have been conducted between a EUTELSAT Reference Station (ERS) (i.e. ETS A&B at the EUTELSAT Téléport Rambouillet and the A1 Telekom Austria Earth Station AUT-AFL-005 at Aflenz - for Eutelsat), and a distant earth station under test (SUT) via a satellite space segment typically belonging to the satellite operator conducting the test. The mechanism usually adopted to perform this measurement is based on a clean carrier (CW) transmitted by the SUT, while its antenna is slewed in azimuth or elevation. The antenna position readouts are continuously communicated to the ERS. The ERS records the power level of the co- and cross-polar component of the received clean carrier using a spectrum analyzer. Prior to antenna measurement, it performs a calibration to compensate inaccuracies which may be caused by the non-linearity of the satellite transponder or the ERS RX chain. The ERS processes angular information, calibration data and the recorded levels in order to produce the antenna pattern. Fig. 1 (left) shows the typical measurement set-up:

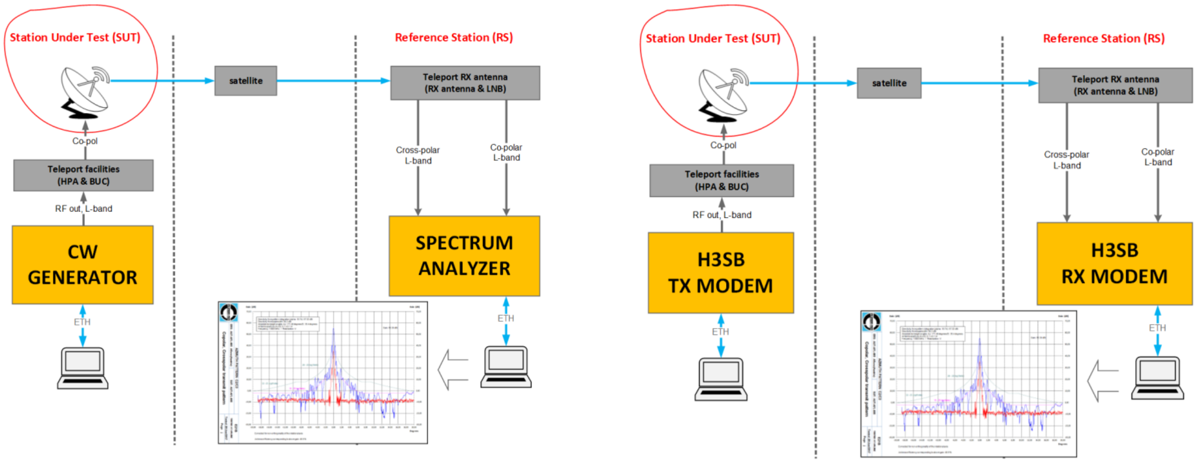

Fig. 1. The measurement process of transmitting side-lobes using a CW (left) and H3SB (right)

For example, to ensure the side-lobes have a value of at least 40 dB of dynamic range, the power spectral density of the CW is 40 dB above that of the noise or interference signal, thus potentially needing high EIRP levels transmitted by the SUT. This could, however, create interference on adjacent satellites during the SUT movements.
Due to the large number of satellites, it is increasingly difficult to find an interference-free orbital slot, particularly in Ku band where most telecommunication satellites are fully operated. Consequently the opportunity to carry out similar measurements using a CW is limited.
The features of the proposed Spread Spectrum (SS) modulation ensure both up-link and down-link interference can be tolerated. As a result, the emitted SS signal can also be demodulated with C/(N+I) up to –58,6 dB (theoretical value), where I represents the in-band power level of the signal which is using the transponder for commercial purposes (i.e. DVB-S2). In this case, it is possible to perform side-lobe measurements via a transponder. For instance, the SS signal can be received at 18.6 dB below the commercial carrier in order not to affect commercial services. At the ERS, the SS signal is then received with a C/(N+I)=-18.6 dB, thus allowing the side-lobes to measure 58.6-18.6=40 dB of dynamic range when the SUT is slewed.
The measurement set-up is very similar to that for the CW.

This time, a TX Modem emits H3SB bursts which are received and demodulated by the RX Modem. Side-lobes are then proportional to the power levels of the demodulated H3SB bursts.

The H3SB protocol

The Highly Spread Spectrum Slotted Burst is a technique derived from the E-SSA protocol on the basis of the following assumptions.
Firstly, the arrival times of the bursts are known (as in time-slotted communications). This is due to the fact that the transmitter continuously transmits SS bursts in a back-to-back mode and the length of the burst is fixed at the beginning of the transmission. Both the transmitter and the receiver are time synchronized using a GPS receiver. As shown in Fig. 2, only a TX Modem using H3SB is present. Secondly, in the above condition, the main cause of uncertainty regarding the time of arrival is the satellite physical oscillations around the geostationary orbit. Thirdly, the use of extremely long spreading sequences is adopted in order to obtain a high processing gain. This point is fundamental to obtain antenna mapping with higher resolution and which includes its notches. In addition, a CDMA signal allows much lower transmission of AWGN power. In fact, an ESVA test does not cause disturbance to any other contemporaneous transmissions within the same band.
As a consequence of the above, the role of the preamble detection defined in [1] changes. It is no longer necessary to search for the preambles along the length of stream, since the starting point of the packet, hence of the preamble, is understood to be within a narrow interval. It can be showed that a typical duration of the uncertainty window is 8000 chips. This is due to the satellite movement within which the preamble search can be carried out. Consequently, the preambles need to be searched for in 4 (over-sampling factor) × 8000 chips within each second, which is 2000 times less than in the case of an ESSA transmission, which would require searching for the preamble in all the 64 x $10^{\wedge 6}$ chips in one second. The beneficial effect of this reduction is twofold. Firstly, the reduction in the start time hypothesis

considered and, secondly, the release of the fixed-false-alarm-rate condition, hence reduction in preamble length.
The approach described above does not, however, rely on any tracking mechanism. Due to the periodic movement of the satellite, the uncertainty time window is determined during the warm-up and is then fixed, thus excluding the need to update it. The proposed approach could be further enhanced by tracking: the max radial speed of the satellite is usually lower than 25 m/s, which corresponds to a time compression of 5 chips within a second. This means that by looking for preamble in a 100 chip window around the estimated timestamp from the previous detection, it would be possible to reduce the computational effort by a further factor of 20, while still keeping a huge margin of error.
The consequence is a reduction in the computational effort required to run the preamble searcher, which allows the possibility to use bandwidth of the spread signal up to 72 MHz and to manage huge spreading factors.
Assuming 72 MHz bandwidth, the main features of the H3SB protocol are as follows:

- SRRC shaping with roll-off = 0.125
- Chip rate = 64 Mchips
- Info payload = 5 bits (info payload is fixed and used as pilot symbols) therefore control channel is not required.
- ML Code rate = 1/3 providing a code gain of about 7.5 dB
- First Level Spreading Factor (high spreading)= 32 * 1,024 (32,768)
- Second Level Spreading Factor (data spreading) = 16
- Preamble length = 120 symbols
- Packet Duration (preamble + data channel) = 184.32 msec
- H3SB packet rate (back-to-back transmission) = 5.425 p/s
- As a consequence of these features, the theoretical processing gain of the H3SB protocol at 72 MHz is equal to:

$$10 * Log_{10}(32{,}768 * 16) + 7.5 \text{ dB} = 64.7 \text{ dB}$$

The minimum C/N where the system still works can be obtained as:

$$\left.\frac{C}{N}\right|_{dB} = 6.1\ dB - 64.7 = -58.6\ dB$$

Where 6.1 dB represents the theoretical Eb/N0 threshold of non-encoded BPSK ESVA packet @ PER=10^{-2}
In addition to 72 MHz, the following channelizations are available (MHz): 36, 18, 9, 4.5, 2.25, 1.125, 0.563, 0.281 and 0.141. The spreading factors are scaled accordingly.

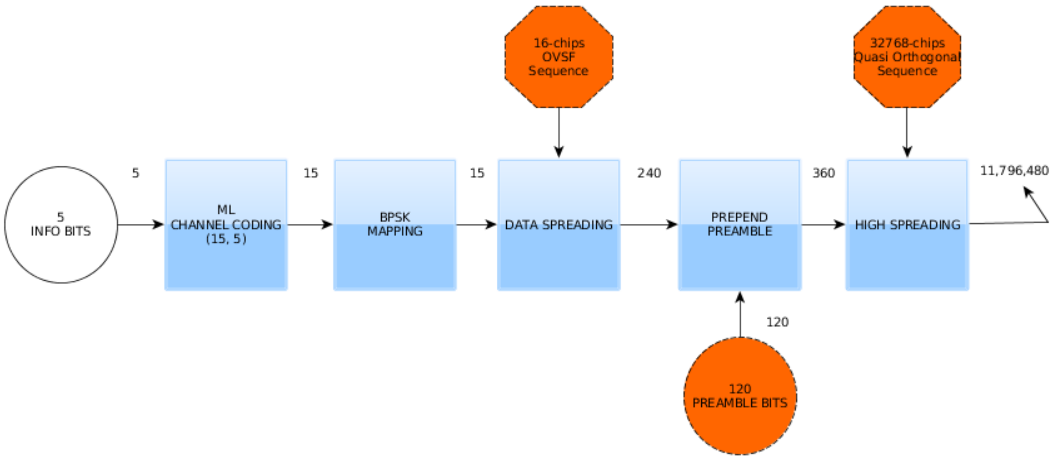

Fig. 2. The modulator

The H3SB transmitter (TX Modem)

The main block of the RX Modem is the preamble searcher which looks for preambles within the defined uncertainty windows. The timestamps found by the preamble searcher are then delivered to the power meter modules, which perform the power measurements of the received H3SB burst by calculating the sum of the product between the received complex samples and the complex conjugate of the transmitted burst (fixed payload is used). Samples used by the power meter are first compensated for the frequency and phase errors introduced by the communication channel. In order to compensate high frequency drifts, a coarse frequency estimator based on preamble is used before demodulation. In addition, after the first despreader, a fine Maximum Likelihood (ML) Data Aided (DA) frequency estimator is performed together with an ML DA phase estimator. The measured power levels are proportional to the gain of the transmitting antenna of the SUT.

The H3SB receiver (RX Modem)

The transmitting side-lobe is computed by correlating the measurement of the power levels of the received H3SB bursts with the position readouts of the antenna during the transmission of each H3SB burst.

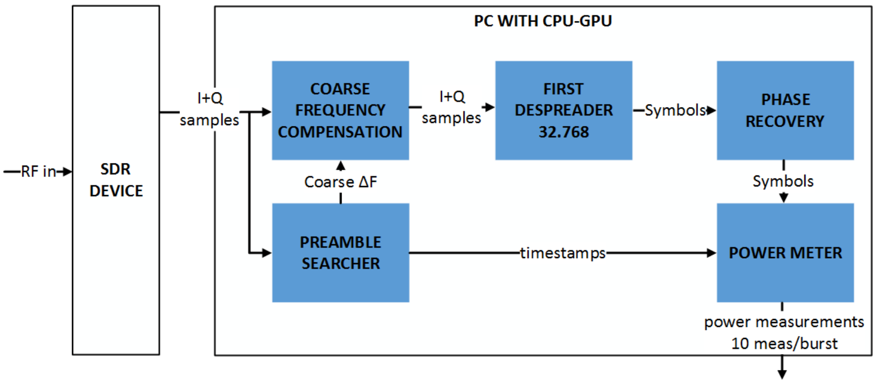

Fig. 3. Architecture of the demodulator

Prototype architecture

The E-SSA test-bed is based on an innovative SDR-GPU architecture composed of commercial hardware. The most up-to-date innovations in the fields of Software Defined Radio (SDR) and GPU technologies are employed. The use of a rack-mountable 19'' commercial PC equipped with Nvidia GPUs ensures the computational power required to perform the fully software-based de-modulation. Finally, the radio front-ends (TX SDR & RX SDR) are implemented using the SDR technology from Ettus corp. [2] in order to provide the radio interfaces with a flexible frequency between 50 MHz and 2.2 GHz.

Fig. 4. The SDR device (X310+WBX120MHz)

Fig. 5. The PC equipped with GPUs (RX Modem)

The platform is fully managed via a web-based graphical user interface. The developed platform also has embedded post-processing software tools which can process the collected data in order to post-compensate RF chain non linearity and variation in the power the SUT emits (i.e. due to the variation in output power of the SUT HPA). Finally, the collected data (measured power levels and antenna position readouts) can be processed in order to provide the SUT side-lobes.

Test activities

A test activity was performed using one channel during the ESVA test on the Eutelsat E21B satellite in June 2017. The TX side of the H3SB platform was connected to a 6 m antenna representing the station under test and pointed towards the satellite in order to uplink the Spread Spectrum signal. The RX Modem was able to receive the signal emitted by the satellite by means of accurate up- and down-converters and a TWT HPA.

The main connection parameters used were:

- 6 m TX antenna (SUT) located in Aflenz (Austria)
- EIRP uplink resulting in good C/N on the satellite
- Eutelsat E21B with 50 MHz transponder
- H3SB signal channelized within 36 MHz
- Eutelsat Reference Station AUT-AFL-005 at Aflenz (Austria)

The following diagram shows the side-lobes of the SUT obtained using the measurements obtained with the H3SB platform, which are very similar to the radiation pattern obtained using traditional methods.

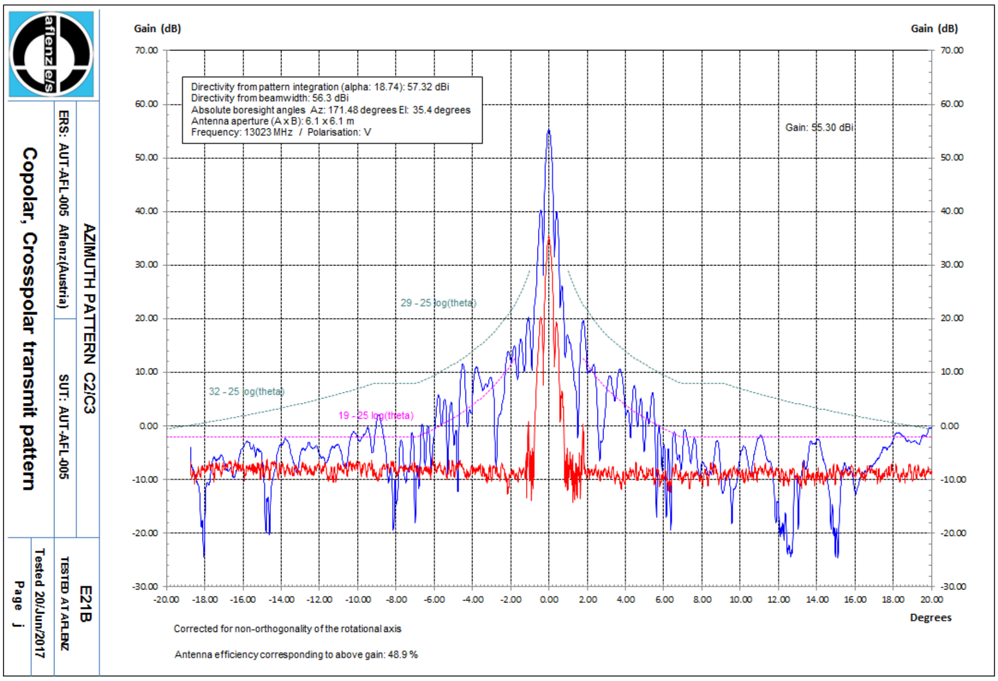

Fig. 5.   The azimuth pattern

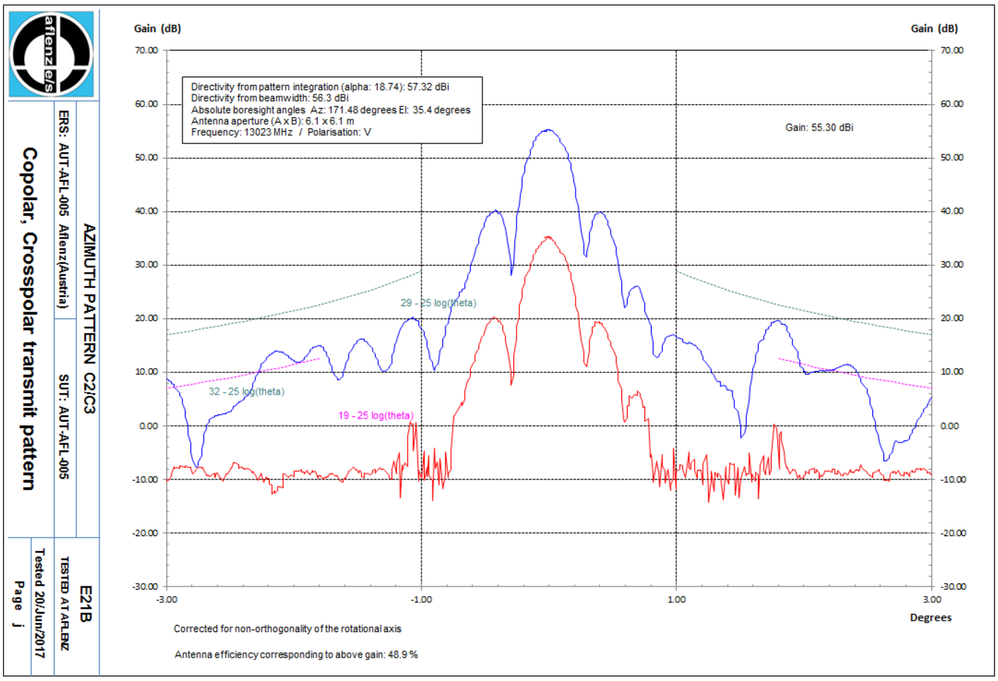

Fig. 6.   The azimuth pattern, zoom in

Conclusion

The prototype has demonstrated its ability to provide effective help in performing measurements of radiation patterns of earth stations. In cases where the transponder is not used and the CW method can be used, the results obtained with the H3SB platform and the measurements of the CW levels are in line. Instead, if the transponder is used, the high processing gain associated to the use of Spread Spectrum signals provides a real benefit compared with the use of the CW signal, which should have a totally inconsistent level.

Antenna mapping can thus be effectively carried out even in cases where the orbital slot and the presence of adjacent satellites with similar frequency plan would typically limit the possibility to take measurements.

Finally, the proposed test strategy and prototype can be efficiently used to perform depointing measurements of SOTM systems. Additional work is being conducted to upgrade the platform in order to improve its performance, as well as its operational capabilities. One new feature being studied is the introduction of amplitude frequency response measurements which could be conducted during the presence of ongoing operations. Some additional testing activities are going to take place in the near future at the EUTELSAT Téléport Rambouillet and at the Aflenz Earth Station with Eutelsat technical management. Progress towards a "turn-key" system also usable for measurement on SOTM antennas is on-going.

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