Designing an S Band Receiver for LEO Applications

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Abstract: - In this paper we describe a generic receiver as a single channel S-band receiver and it is composed of two modules. The first module (down converter) consists of an input band pass filter, LNA, image rejection filter and down-converter with a PLL local oscillator. The second module consists of the IF module derived from the VHF receiver. The IF module consists of a low pass filter, 20MHz band pass filter, a LNA, narrow band pass filter and FM receiver IC with associated circuitry.
The number of S-Band Receivers to be flayed on the LEO microsatellite is the main issue here. It is safer to include two (02) receivers as dual redundancy because it is the minimum requirement and the best option in terms of risk against cost and complexity.
The study here is concentrate on the design and test results of an S-band receiver which receive commands and software from Earth.

Key words: -S band receiver, single channel, redundancy, requirements, performance.

1 Introduction

The LEO microsatellites to be used should be in the range of 100-200 Kg of mass, stabilised 3 axis for imaging mode [1-4]. The spacecraft is designed for the earth observation purpose. The imaging system allows windowing and it is supported by a total storage capacity of two 0.5 Gbytes of data which could be downloaded to a ground station at high data rate (e.g. 8 Mbps). The downlink and the uplink, both operate in S band use high data rate/low data rate in normal operation (e.g. 8Mbps/9.6Kbps), reasonable data rate/low data rate (e.g. and 38.4/9.6 Kbps) during commissioning for the downlink and uplink respectively [5, 6] .

2 Receiver Overview

The s-band receiver consists of three distinguishable modules: the front-end band pass filter, the s-band down converter PCB and the IF module. The front-end filter and s-band down converter PCB are fitted into the same nano-tray, while the IF module is housed in its own nano-tray. The S-band down converter PCB consists of a LNA, BPF and frequency mixer. The LO port of the mixer is driven by a frequency synthesizer.

The IF module is divided into two sections, a RF section separated by a screening CAN from the digital circuitry. The RF section consists of a LPF, 20MHz band pass filter, a LNA, narrow band pass filter and FM receiver IC with associated circuitry. The IF module digital circuitry includes the CAN controller that is responsible for telemetry, telecommands and command decoding. A FSK demodulator is used to recover the FSK clock before data distribution to the OBC's and SSDR's. Refer to fig. 1 for the receiver block diagram.

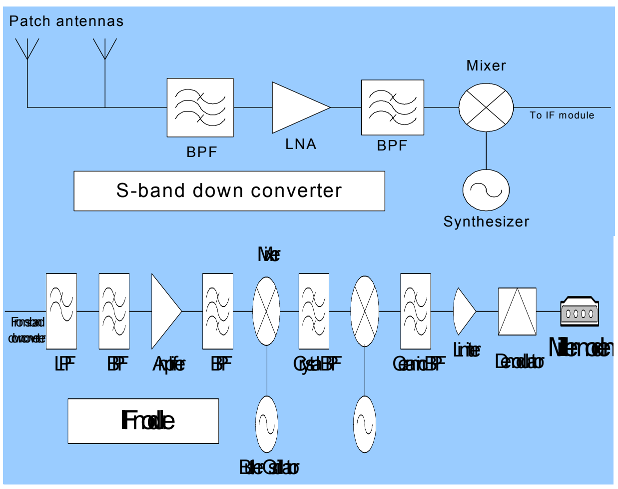

Fig. 1 System block diagram

3 Operational Frequency

Two hot redundant receivers should be flayed on microsatellite. There is a primary s band frequency allocated to each receiver [7]. Both receivers modules have the capability of switching operational frequency in flight by controlling the synthesised PLL in the S-band down converter module.

4 Detail Description of the S Band Down Converter

In the following sections, the s-band down converter will be described in detail [8].

4.1 Front end band pass filter

The front-end filter has a low insertion loss of less than 1dB at the commercial S-band receiver frequencies. The BPF has a bandwidth of 80MHz centred on 2060MHz and 60dB/decade roll off. This provides excellent rejection at the S-band transmitter frequencies. Once the BPF filter has been fitted the s-parameters and 3dB bandwidth of the s-band front-end has to be tested, It was found that the bandwidth is 115MHz and the insertion loss is 1dB.

4.2 LNA

A Low Noise Amplifier is used to provide 23dB of gain at commercial s-band and less than 1.7dB noise figure. The U-shaped amplifier input track serves as an adjustable inductor by moving a small fragment of metal between its legs. It was found that S11=10dB, S21=22dB, and S12=40dB, values were obtained across the uplink s-band frequency band, 2025 – 2110MHz [8]. The noise figure value was found equal to 1.8 dB at the operating frequency.

4.3 Band Pass Filter.

The second filter is used to eliminate any harmonics or non-linear products caused by the LNA or spurious signals that could cause problems during the frequency mixing stage. The filter used is designed with a pass band insertion loss of 0.7dB and a 120MHz bandwidth centred round 2070MHz. The filter will attenuate the transmitter frequency with 18dB and the synthesizer frequency by 25dB.

4.4 Frequency mixer

A passive frequency mixer is used to convert the commercial s-band input to 145MHz. The mixer has a maximum insertion loss of 8.5dB, minimum LO-IF isolation of 8dB and a minimum LO-RF isolation of 20dB. The synthesiser drive level is +8dBm.

4.5 Frequency synthesizer

A PLL design is used to obtain a stable local oscillator.

To realise phase lock the counters that divides the two input frequencies need to be programmed for the required synthesizer output frequency. The s-band receivers are hot redundant and all the PLL synthesizer counters need to be refreshed to prevent receiver failure due to a single event upset. The default s-band receiver frequency is uploaded from the EPROM into the CAN micro-controller RAM from where the synthesizer counters are refreshed.

4.6 Frequency calibration and spurs removal

The reference 10MHz oscillator is trimmed until the desired synthesizer frequency is obtained.

The 10MHz and 1MHz reference frequency spurs observed on the synthesizer output can be partially removed by inserting a short to ground on the track between the VCO and LMX2326 chip. This will act as a short to lower frequencies (1MHz and 10MHz) but will be high impedance at 1.917GHz (see fig. 2).

4.7 Loop filter

The component values used in the passive loop filter circuit were arrived at using the National Semiconductor PLL design software. The loop bandwidth is about 9.96KHz. The analysis was performed with a VCO gain of 35MHz/V, Charge Pump Gain of 1mA, comparison frequency of 1MHz and a VCO output capacitance of 30pF (estimated). The results show that the loop will have good stability and reasonable lock time.

4.8 Voltage controlled oscillator

The VCO delivers +5dBm+/-1dB output power. The output from the VCO is fed into a resistive splitter network. A resistive pad produces an output of about -10dBm.

4.9 Local Oscillator Buffer

The local oscillator buffer will compress with a RF input power of more than –10dBm. Two resistors are used form a voltage divider to ensure a RF input power of about –12dBm. With a gain of approximately 20dB, the local oscillator buffer will drive the frequency mixer LO port with +8dBm, right on specification.

4.10 S-band to VHF down conversion

By applying a signal generator to the down converter and keep the spectrum analyser on its output, we should measure the conversion gain and IF frequency (17dB). The $F_{S\text{-}BAND}$ carrier should not be modulated and have an amplitude of –80dBm.

4.11 Noise figure and gain

The noise source is connected to the RF input. The receiver IF output should be filtered before fed into the spectrum analyser pre-amplifier to filter the synthesizer leakage frequency that will saturate the amplifier. It was found that the gain and noise figure are equal to 17dB and 1.8dB respectively.

5 Detail Description of the IF Module

In the following sections, the intermediate frequency module will be described in detail [8].

5.1 DC-DC converters

It is useful to note that the 28V to 5V DC-DC converters are tested with no load to ensure correct operation eliminating the possibility of damaging the receiver circuitry. The 28V can be applied to the IF module converters.

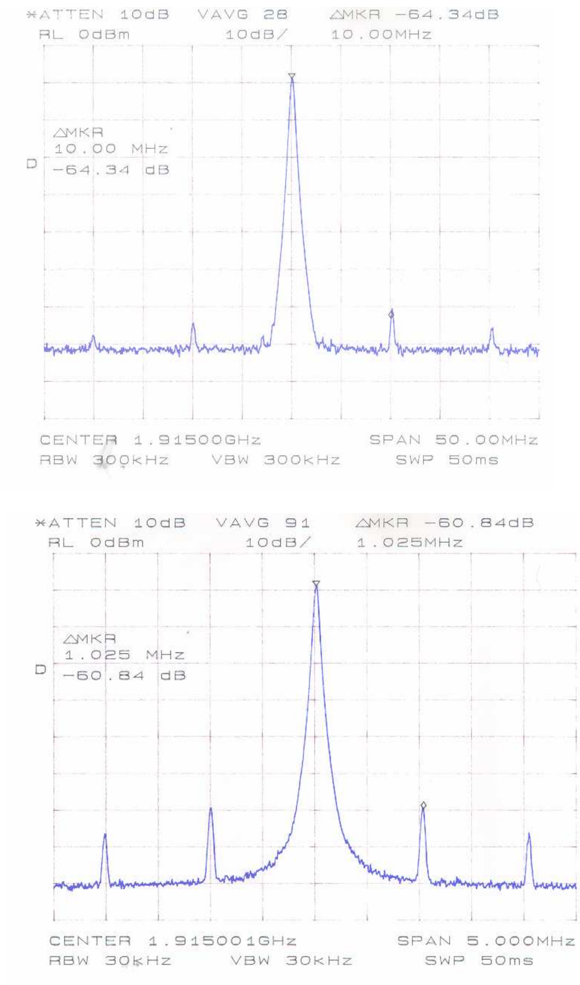

Fig. 2 Phase Noise, 10MHz spurs and 1MHz spurs

5.2 Low Pass Filter

The LPF was designed using Microwave Office. It has a better than 15dB in band return loss with a negligible insertion loss and cut-off frequency of approximately 250MHz. The LPF was designed to combat interference from the spacecraft transmitters on VHF receivers and to provide protection from the launch vehicle. Fig. 3 shows the front end filter response. The insertion loss and return loss are -3.46 dB and -8.5 dB respectively at centre frequency of 145MHz.

5.3 Wide band pass filter

The WBPF was designed using Microwave Office. The bandwidth is approximately 20MHz and the in-band insertion loss is 1.9dB. The band pass filter also has a better than 12dB in band return loss. The WBPF is used to eliminate the majority of non-linear products caused by the s-band mixer before the IF amplifier. (see fig. 4).

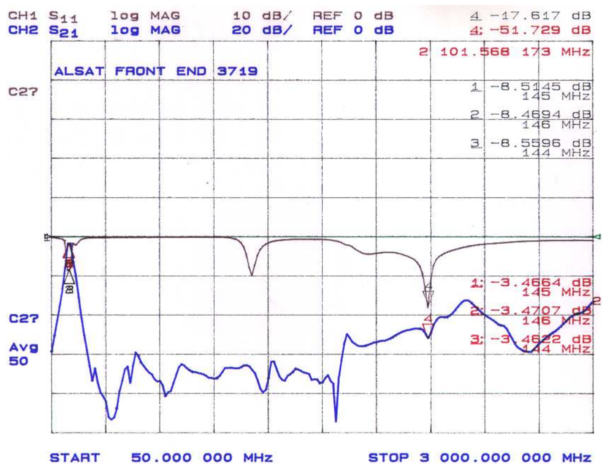

Fig. 3 Front End Filter Response

5.4 Intermediate Frequency Amplifier

This circuit was simulated using Puff/Microwave Office. The IF Amplifier has between 13-18dB gain and <1.5dB noise figure, with +15dBm output intercept point.

5.5 Narrow-band BPF

The Insertion and return losses, bandwidth of the narrow band BPF are 4.5 dB, 20 dB, and 4MHz respectively. The tuning of the narrow band pass filter can be cumbersome. The coupling capacitor can then be implemented to improve bandwidth and insertion loss (fig.5).

5.6 Dual conversion FM receiver

The FM receiver is a Motorola MC13136 SMD integrated circuit, comprising of a VHF/UHF doubly balanced active first down-conversion stage to 21.4MHz, a second mixer/oscillator for conversion down to 455KHz, a limiting amplifier with received signal strength indication (RSSI), and a Quadrature detector mixer with built in phase shifting capacitor.

The Receiver chip provides good mixer linearity and third order intercept without increased noise. The gain on the output of the first mixer starts to roll off at about 20MHz, so this receiver can be used with a 21.4MHz first IF.

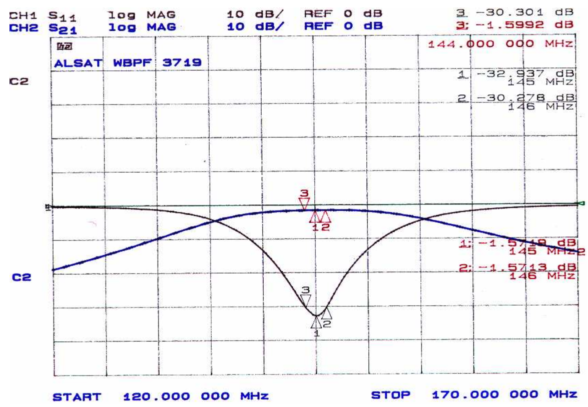

Fig. 4 Wide band-pass filter

It is decided to use a ceramic discriminator because the temperature variation will cause less of a variation in centre frequency and distortion and recovered audio will be improved. The MC13136 has a buffered RSSI output, which has about 70dB of range.

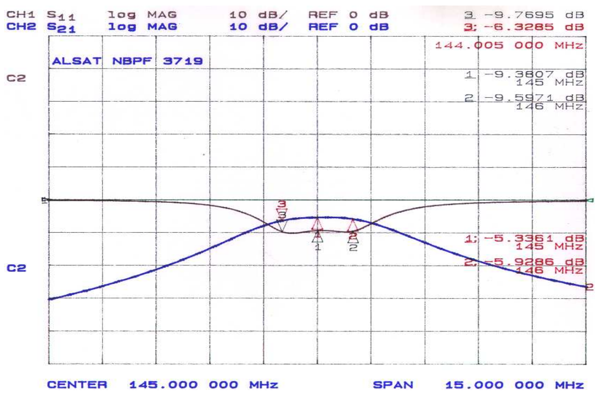

Fig. 5 NBPF response

5.7 RSSI

The RSSI is an indication of the received RF signal strength into the receiver module. The gain of the internal op-amp is adjusted so as to achieve the full 0 - 4.1V range of the micro-controller analogue input pins. Inside the micro-controller the RSSI voltage is then converted into a count. Using the TLMCAN software, this converts the count to an input power level.

5.8 FSK Demodulator

This circuit is similar to the 9k6 FSK demodulator used by the micro satellite bus systems in the past, except implemented using the latest SMD technology, saving volume and mass. The uplink modulation scheme to be used is 9600baud FSK. The received data can be either asynchronous or synchronous, with a recovered clock being generated by the FSK demodulators.

5.9 CAN Bus

The receiver is connected to the spacecraft CAN bus system. The CAN architecture consists of a CAN micro-controller (SIEMENS C515C) and an external Eprom. The Eprom is programmed with the firmware that provides the micro-controller with all its information on start-up. The CAN micro-controller on the Receiver module provides a serial bus interface through which system telemetry data can be monitored and telecommands can be issued.

5.10 Butler Oscillator

The required local oscillator frequency for the first I.F is calculated, i.e. $F_{LO} = F_C$ - 21.4MHz. Fine-tuning the L.O. is made to obtain the required calculated frequency. It might notice an area where the Butler oscillator output disappears. If this area is close to the required LO frequency, some redesigning of the Butler oscillator might be necessary. Both the second IF oscillator and butler oscillator frequency offset is 50 Hz. The 'sniffer' test for the second LO is repeated. The LO frequency is near to correct and the frequency offset from the desired LO frequency is recorded, then F_{LO2} = 20.945MHz.

The Butler oscillator stability is tested over temperature from –20°C to +50°C. The Butler oscillator leakage through the RF front-end is therefore displayed on the spectrum analyser and the frequency offset from the oscillator frequency at ambient is measured (fig. 6).

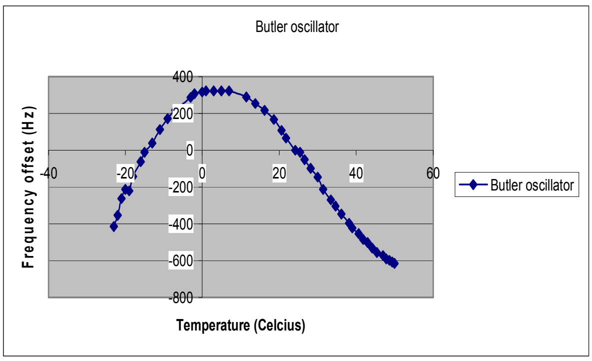

Fig. 6 Butler oscillator stability over temperature

5.11 Front End Sweep

S11 and S21 measurement are performed for the full front-end section up to the FM RX chip IC400 (MC13136). The input power level is set to -60dB. By connecting the network analyser to the front end part , a plot is taken as shown by fig. 7.

6 Test Results for the S Band Receiver

The s-band down converter and VHF IF module are connected together. The s-band receiver functional tests are as follow:

6.1 Carrier vs. BER

By adjusting the carrier power around the BER bend point we sould denote the value on TLMCAN. The BER test should be performed at ambient, -20°C and +50°C (see fig. 8).

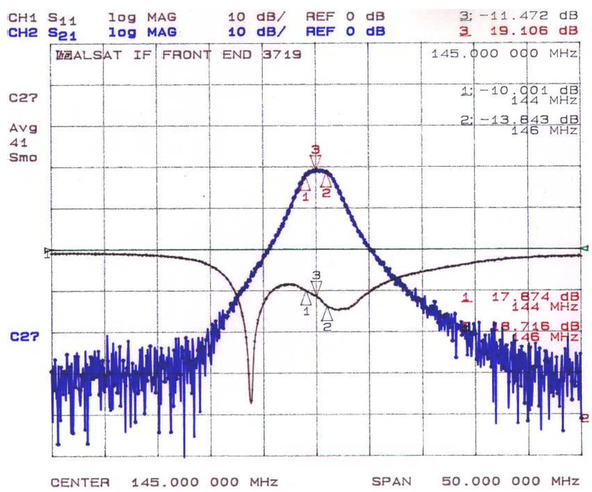

Fig. 7 Front End Sweep

6.2 RSSI Profile

By adjusting the carrier power with 1dB increments/decrements and record the RSSI data on TLMCAN. The RSSI test should be performed at ambient, -20°C and +50° (see fig. 9).

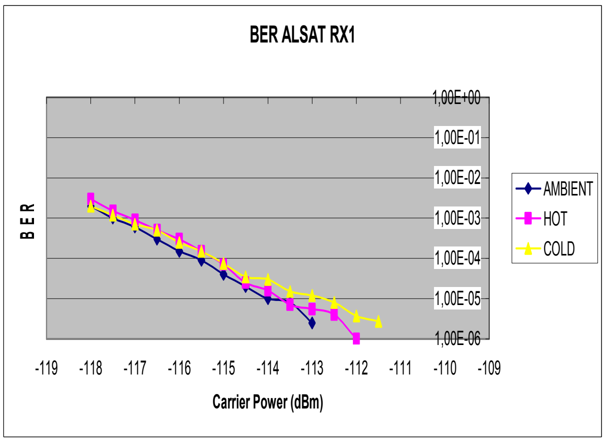

Fig. 8 BER curve

6.3 Discriminator profile

By varying the input carrier frequency in 0.5kHz steps from F_C to F_C +/- 5kHz, the discriminator telemetry from the TLMCAN software is recorded. The discriminator test should be performed at ambient, -20°C and +50° (see fig. 10).

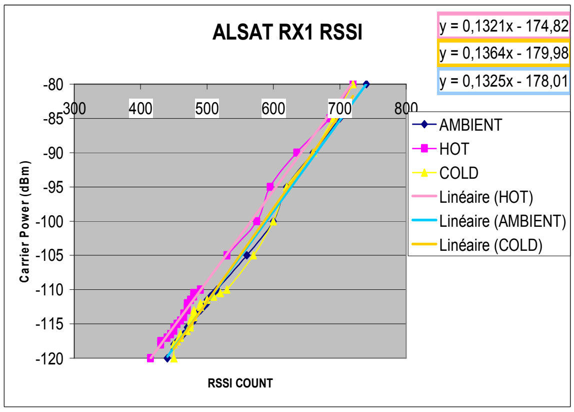

Fig. 9 RSSI profile

6.4 Eye Pattern

The eye pattern quality (fig. 11) is checked on the analogue oscilloscope. We note the 'tight' sampling point. The oscilloscope needs to be set for external trigger.

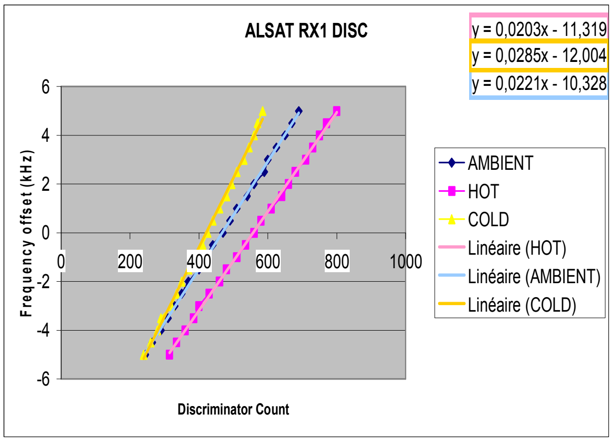

Fig. 10 Discriminator profile

7 S-Band Receiver Characteristics

The s-band receiver is characterised by the following measurements.

7.1 S-band transmitter frequency blocking with inter-digital filter

This test has to be performed with the inter-digital front-end band-pass filter. The transmitter front-end band-pass filter is also required.

The Alsat-1 s-band transmitter is tested to transmit between 34dBm and 38dBm of power. Assuming

20dB antenna isolation, by connecting a +18dBm carrier at the transmit frequency through the transmitter and receiver filters to the s-band receiver, no degradation in the receiver performance was recorded.

7.2 Image signal rejection

By applying the image carrier frequency at $f_C - 2*f_{IF}$ to the s-band receiver with the inter-digital front-end band pass filter still fitted, and increasing the image frequency power level until a known RSSI centre frequency level is obtained, the image frequency rejection obtained is 109 dB.

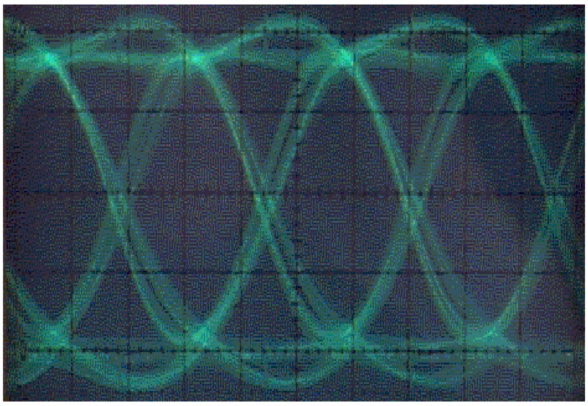

Fig. 11 Eye pattern

7.3 Compression

By increasing the centre frequency carrier power in 1dBm steps we can measure the RSSI values. The inter-digital front-end filter should still be fitted. The obtained input compression point is –55dBm (see fig. 12).

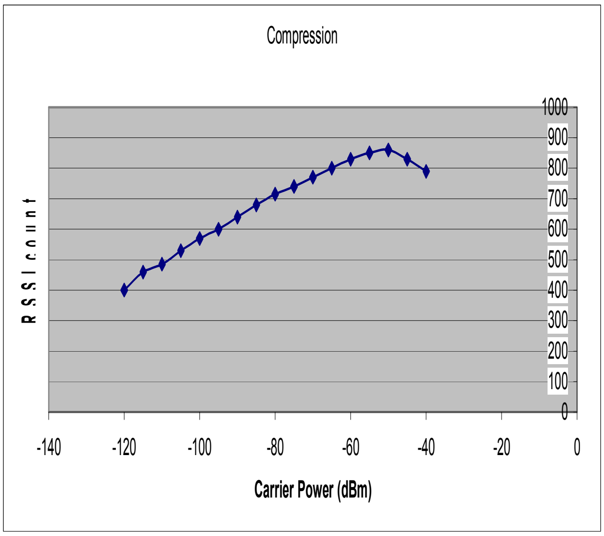

Fig. 12 Compression

7.4 BER measure and noise figure

The S-band RX should have a BER of 10^{-5} at an input carrier level of –113dBm. A BER of 10^{-5} corresponds to an Eb/No of 12.5dB on the SSTL discriminator recovered FSK curve (see fig. 13). The noise figure of the S-band receiver can be determined from the BER, Eb/No and carrier power level. The S-band receiver should have a noise figure of less than 8.5dB.

8 Power Consumption

The satellite have a 28V power bus and the IF module utilises two 28V-5V screened DC-DC converters to provide the complete receiver with the required 5V. One converter supplies the CAN circuitry while the remaining one supplies the rest of the receiver. An EMI filter is used on the 28V input to ensure a noise free power rail. The power consumption for the whole s-band receiver is 1.4W.

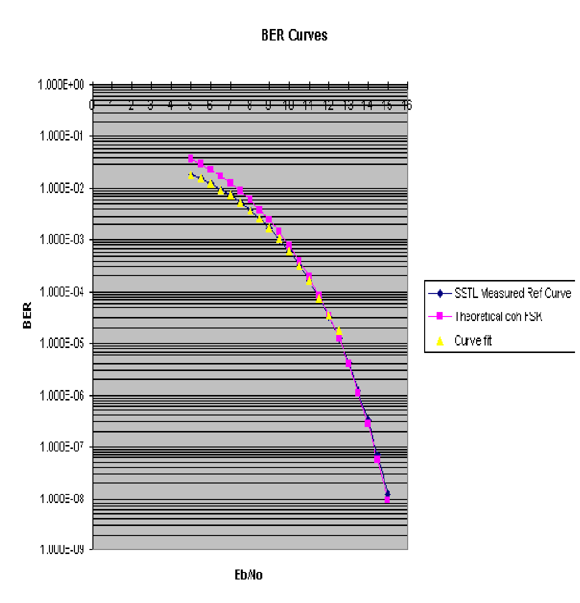

Fig. 13 Measured 9.6Kbps FSK reference curve.

9 Conclusions

In this paper, we have described an S band receiver for LEO microsatellite, an earth observation enhanced microsatellite. The uplink data rate used is derived from the radio amateur application (e.g. 9.6Kbps) using as modulation format CPFSK. Laboratory test results show that the receiver sensitivity is about –113dBm at ambient temperature. The S band receiver draws about 50 mA at 28V voltage supply which corresponds to 1.4 W as power consumption. The measured image signal rejection is 109dB and the input compression point is less than –55dBm. Finally, we should note that the BER of 10^{-5} corresponds to Eb/N0 of 12.5dB and a noise figure less than 8.5dB.

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