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Design and Realization of Data Transmitter for Video Streaming of On-board Deployments in Geostationary Spacecrafts

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Abstract

Recent geostationary spacecrafts are configured with video streaming feature during deployment of critical onboard mechanisms such as Solar Array Drive Assembly and Unfolding of Parabolic Antennae. To accomplish this, frames captured by the on board camera are to be transmitted to ground station through adata transmitter. This data transmitter has to share a narrow bandwidth of 20 MHz in C-Band with mission critical telemetry transmitters of the host spacecraft and other co-located spacecrafts without causing any interference.Since reliability and simplicity are the most important criteria in the design of a mainframe system for a satellite, an architecture based on Binary Phase Shift Keying (BPSK) modulation is chosen. RF carrier is generated through a compact X12 frequency multiplier that gets stable reference input signal from a Temperature Compensated Crystal Oscillator (TCXO). The design also involves RF alignment and packaging strategies to ensure the operation as per specifications through specified ranges of temperature and vibration levels. The performance of the transmitter is found to meet all specifications post launch.

IndexTerms: *Geostationary, BPSK, TCXO, Bandwidth, BER, Carrier Suppression*

INTRODUCTION

The data transmitter analyzed in this paper is designed to transmit video data from onboard camera to the ground station. It is capable of transmitting at data rates upto 10 Mbps. Apart from that, there are two telemetry transmitters in all Geo spacecrafts for downlinking health parameters of the spacecraft and performing ranging operations. Second transmitter provides hot redundancy and is at a different frequency from that of the first one.

The frequency of operation for data transmitter had to be chosen from the regular telemetry frequency band of 4.18 GHz to 4.2 GHz since separate frequency band was not allotted for data transmission. Thus a data rate of 3 Mbps and a frequency of 4.191 GHz was chosen for data transmitter so that the main lobe would occupy from 4.188 GHz to 4.194 GHz and higher end spot frequencies were allotted for telemetry transmitters.

ARCHITECTURE OF THE SYSTEM

Data transmitter has to downlink video data at maximum possible speed without interference to telemetry downlinks of its host spacecraft and other co-located spacecrafts. Specifications of the transmitter were chosen as shown in Table 1 in order to meet the data link requirements with a margin of 6 dB from Geostationary Orbit to Ground station.[1]

Table:1. *Specifications of Data Transmitter*

Parameter	**Specification**
Carrier Frequency	4191 MHz
Initial Settability of Frequency	±1 ppm at 25±2 °C
Temperature Stability of Frequency	± 2 ppm
Aging Stability of Frequency	< ±1 ppm / year
Output Power	≥ +35 dBm
Harmonic Levels	< - 50 dBc
Spurious Levels	< - 50 dBc
Modulation Input format	LVDS / NRZ-L
Input data rate	≤ 10 Mbps
Bit Error rate	$\leq 1 \times 10^{-6}$
Carrier Suppression with 1010 data	Better than -30 dBc
Amplitude Imbalance	±1 dB
Phase Imbalance	±5°
Side band Imbalance	±0.5 dB
Side band suppression	-13, -15 and -18 dBc
Input Voltage	26 to 42.5 V
DC Power Consumption	< 20 W
Operating Temperature	-25 to +55 °C

An architecture based on Binary Phase Shift Keying (BPSK) modulation with 3 Mbps data rate is chosen as a trade-off between reliability, simplicity, data rate and interference to telemetry downlinks. As shown in figure 1, Data transmitter consists of a carrier generation chain, an LVDS (Low Voltage Differential Signaling) interface card, a BPSK modulator and a power amplifier chain.

Carrier generation chain consists of a TCXO as a stable reference frequency source at frequency of 349.25 MHz. Output signal of the TCXO is amplified using a BJT device and passed to a compact step recovery diode based X12 frequency multiplier.[2] The multiplier generates output signal containing harmonics of input frequency.

12th Harmonic at the frequency of 4191 MHz is selected using a hairpin structured micro strip band pass filter while suppressing other harmonics. The output of filter at C-band is amplified by a BJT based two stage amplifier[3] and used as the Carrier signal.

LVDS interface card converts data received from camera at a level of +1.05 to +1.4 V into TTL format of 0 to 5 V using a LVDS receiver chip. Further the data is converted to bipolar format of amplitude -1 V to +1 V using an Opamp based level shifter circuit in the same card and fed to the modulator.

BPSK modulator consists of a mixer whose LO frequency is provided by Carrier generation chain and IF frequency is provided from LVDS interface card.

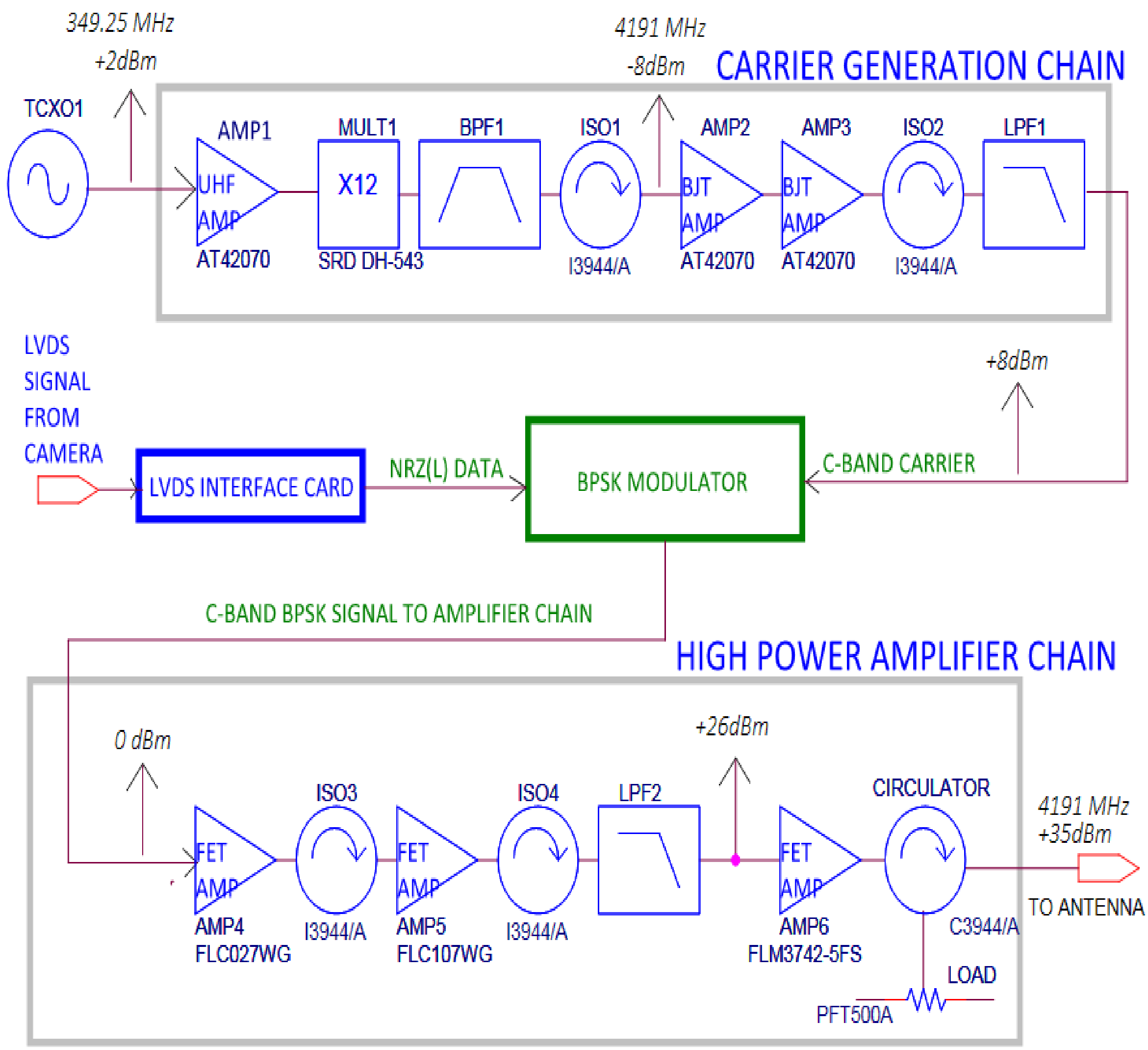

Fig:1. *Block Level Schematic of C-Band Data Transmitter*

Modulated output signal is fed to High power amplifier chain that consists of a two stage GaAsFET based driver amplifier followed by a high power GaAs FET amplifier with output power $\geq$ +35 dBm.

The transmitter is powered by a built-in DC-DC converter which provides secondary supplies of +15 V, +8 V and -5 V from the primary raw bus voltage of 28 V to 42.5 V.

IMPLEMENTATION OF X12 FREQUENCY MULTIPLICATION

X12 frequency multiplier is based on Step Recovery Diode as shown in figure 2. The circuit consists of a T-type input matching network, an impulse generator, an SRD (Step Recovery Diode), a bias network and a tunable capacitor for output matching. An impulse generator is realized using the capacitance of SRD under reverse bias condition along with micro strip line based inductors.[4]Generated impulse train consists of harmonics of input frequency. The amplitude of the required 12th harmonic is raised to -6 dBm by tuning the output matching capacitor. The sensistor in bias network compensates for variation in applied bias voltage with respect to temperature.

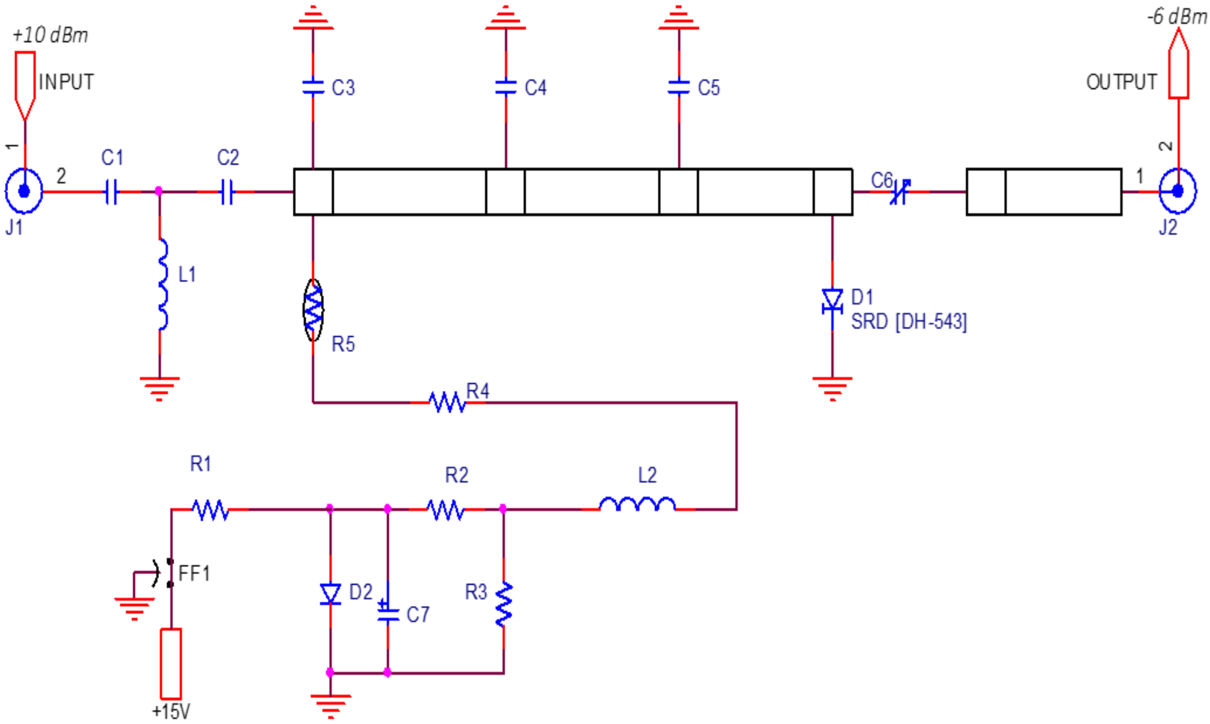

Fig:2. *Schematic of X12 Frequency Multiplier*

This multiplier is realized in a PCB of size 30 mm X 25 mm. The output of the frequency multiplier is passed through a hairpin line structured micro strip band pass filter to suppress unwanted harmonics further. The filtered output signal consists of only 12th harmonic of frequency of 4191 MHz at a level of-8 dBm. This signal is amplified using a two stage linear amplifier followed by a High power amplifier chain to get the required output power of +35 dBm which is sufficient to meet link margin requirements in combination with 18 dB gain provided by antenna.

DESIGN OPTIMIZATION

All the PCBs are tested individually over temperature range of -25° C to +55° C before mounting in their respective modules. Each of the individual modules is characterized for variation of power, harmonics and spurious components. The stability of final output frequency at C-Band is directly related to the frequency stability of TCXO. Fine power adjustment is achieved using fixed attenuator pads of required attenuation between each of the modules such that total transmitter meets specification over all the temperature conditions. Further all the individual modules integrated together using semi rigid RF cables and harness to realize the transmitter package.

The amplitude of input signal fed to the mixer input was optimized such that the schottky diodes in the double balanced bridge would get sufficient drive to achieve minimal modulation loss.

PACKAGING AND SHIELDING ASPECTS

The transmitter package houses a single deck with few of the elements mounted on the top cover plate as shown in figure 3. Bottom Deck consists of an UHF Amplifier, an UHF to C-Band Frequency Multiplier, BJT and GaAs FET Amplifiers of OMNI Stages. Top Cover Plate houses a TCXO, a LVDS Interface Card and a BPSK modulator, a DC regulator and a DC-DC Converter.

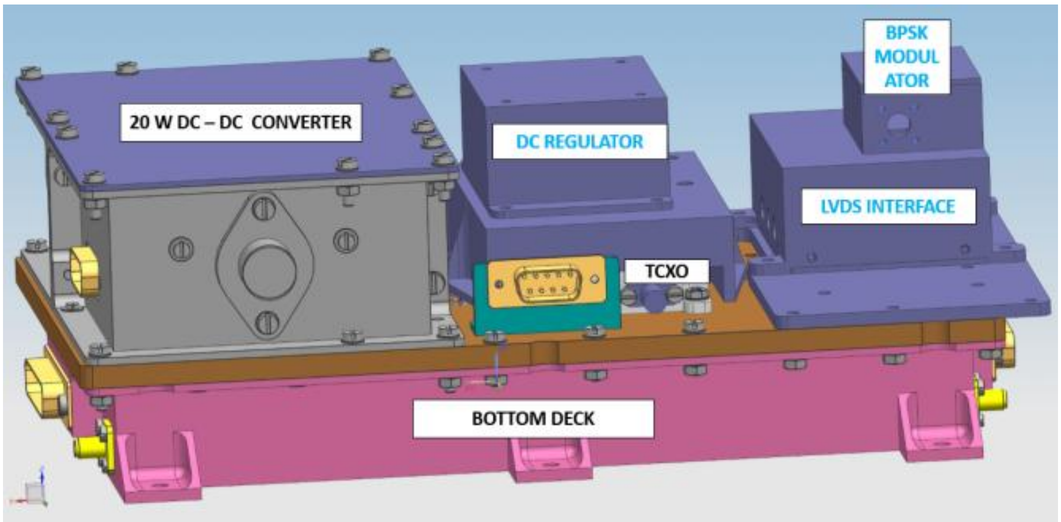

Fig:3. *3D View of C-Band Data Transmitter*

Mechanical housing is designed with Aluminium alloy of 2 mm thickness for side and top walls and 2.5 mm thickness of base. To withstand vibrations and shock experienced during launch phase. Radiation shielding material made up of Tantulum and Lead was placed as required for each of the diodes and transistors to ensure a minimum Total Ionization Dosage (TID) hardness of 100 Krad.

Semi rigid cables are used for interconnecting RF ports of different modules. A harness of optimal length is designed to route DC supplies and data input. The size of the entire transmitter is 240 X 160 X 88 mm and weighs around 2.5 Kg. Flight model transmitter with all semi rigid cables and harness which is mounted on spacecraft is shown in figure 4.

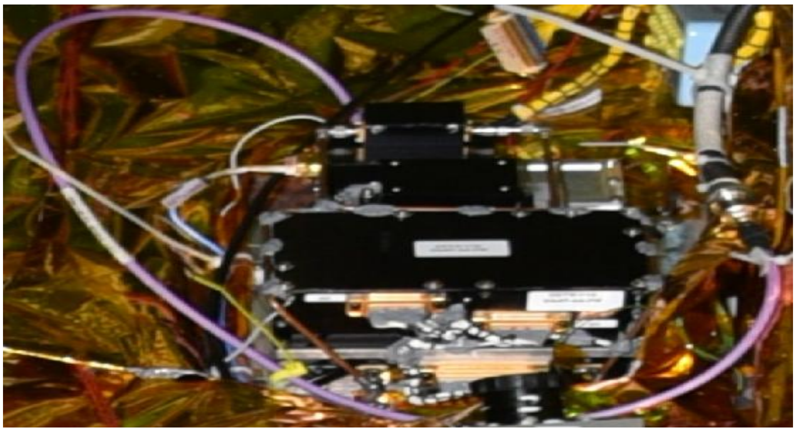

Fig:4. *Hardware of Data Transmitter mounted on spacecraft*

PERFORMANCE ANALYSIS

An initial bench test was performed on the package to ensure the specifications are met at ambient temperature on the realized hardware. Along with Raw bus current and RF output power measurement on Power meter, several spectral measurements were carried out which include Power of main lobe and Suppression of first, second and third side lobe suppression with respect to main lobe by feeding Pseudo random Binary Sequence (PRBS-7) input. Carrier suppression was measured with the 1010…1010 data as input.

Table: 2. *Performance of Data Transmitter over temperature*

Parameter	-25 ˚C (Cold)	+25 °C (Ambient)	+55 ˚C (Hot)
Raw Bus Current (mA)	470	455	460
Carrier Suppression	-30 dBc	-34 dBc	-29 dBc
Side Lobe Suppression	-15, -22, -29	-14, -20, -26	-15, -21, -25
Bit Error Rate	0	0	0
Power of Main lobe	+36.1 dBm	+36 dBm	+34.9dBm
Power on power meter	+36.4 dBm	+36.5 dBm	+35.2 dBm
Spurious Levels	< -50 dBc	< -50 dBc	< -50 dBc

Measurement of Bit Error Rate (BER) was carried out by interfacing with CORTEX receiver for both random data and 1010 data with data rate of upto 10 Mbps.

Operating Temperature Variation test was performed from -10 °C to +55 °C. Further, Burn-in Test was performed at +50 °C for 168 hours. After analyzing the variation of performance over temperature, all the screws and connectors were eco bonded. Further the package was subjected to Vibration test in both sinusoidal mode and random modes to test the ability to withstand vibration and shock effects experienced during launch phase and to detect any workmanship defects if present. Further, Thermal vacuum cycling test was performed in the temperature range of -25 °C to +55 °C. During both Testing & On-orbit stage the temperature of the transmitter is maintained by monitoring the temperature of the base plate using a thermistor. The test results at various temperatures are shown in Table-2. The spectrum of output signal with PRBS-7 data input at 3 Mbps data rate is shown in figure 5. Suppression of first, second and third side lobes by -14, -20& -26 dB respectively instead of theoretical values of -13, -18 & -24 dB shows the effect of narrow band response of amplifier on the output spectrum.The spectrum of output signal with 1010 data input at 3 Mbps data rate is shown in figure 6.

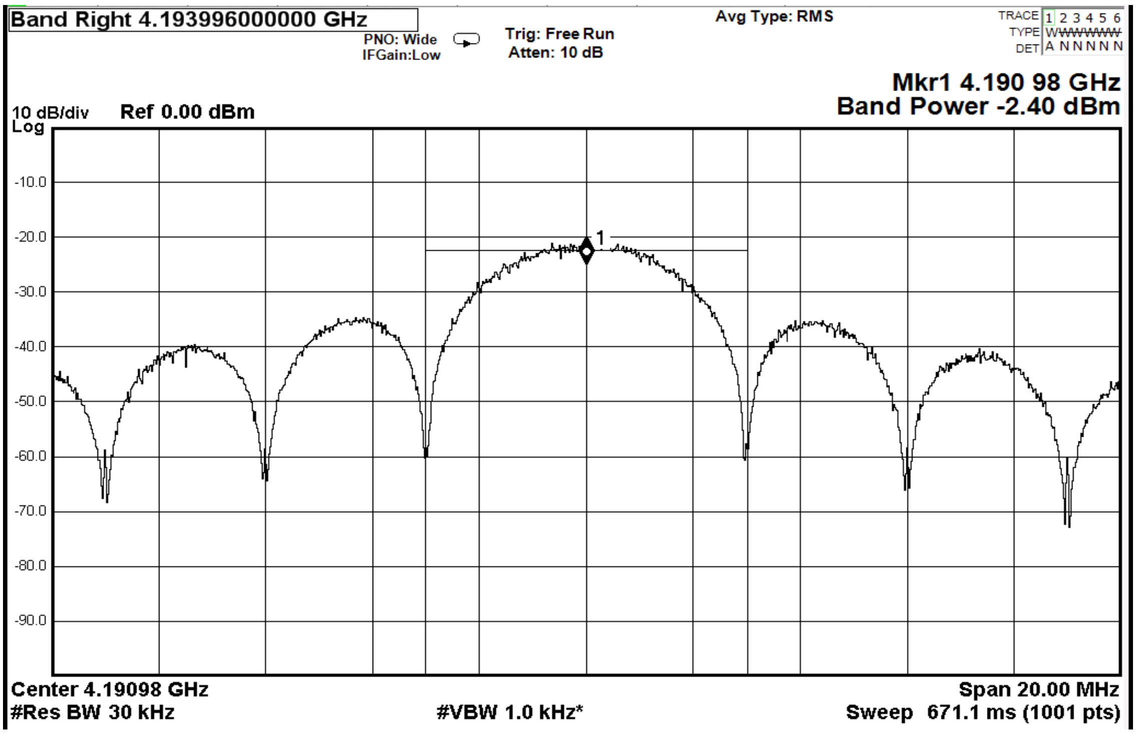

Fig:5. *Spectrum with PRBS Data Input*

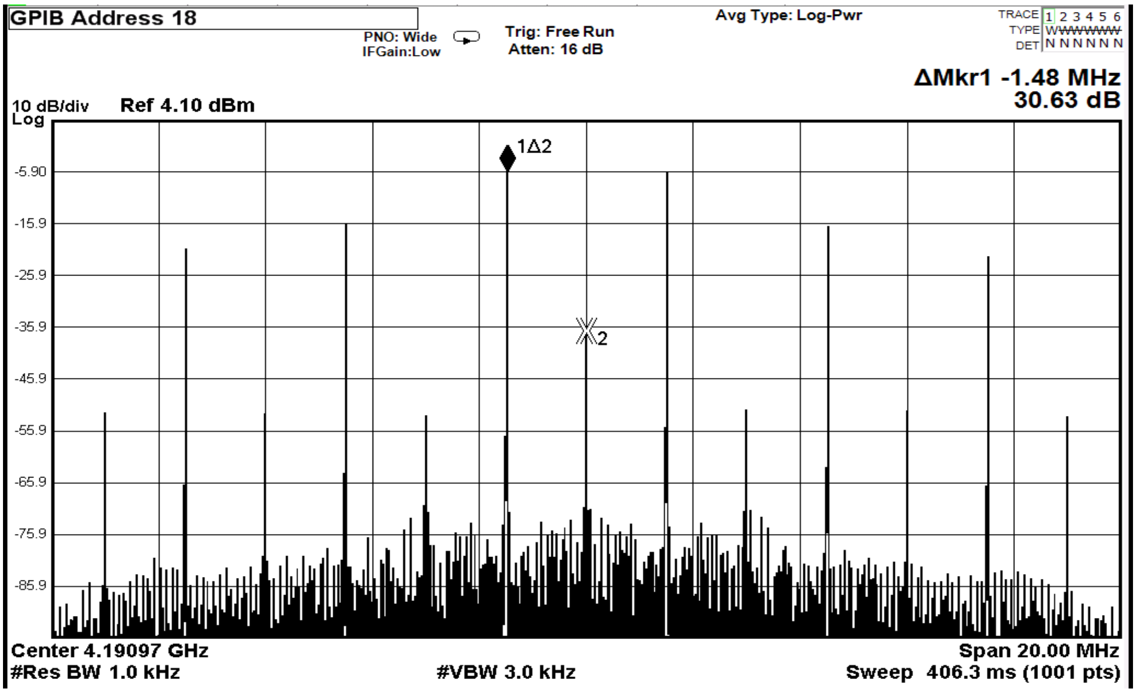

Fig:6. *Spectrum with 1010 Data Input*

CONCLUSION

The test results of C-Band Data transmitter in cable mode over temperature range of -25 to +55 °C met all the performance specifications. The results of radiation mode tests in CATF were satisfactory as well which proved the ability to operate simultaneously without any interference to telemetry transmitters of the spacecraft.

The package size can be reduced further by replacing C-Band BJT amplifier stages with a single packaged MMIC Amplifier die and using miniaturized version of DC-DC converters. Post flight of the first version of hardware has been satisfactory. It is planned to incorporate QPSK modulation scheme, data compression techniques and pre-mod filtering of baseband data[5]in the next version of the design for improving bandwidth efficiency.

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