Challenges in Frequency Allocation for Telemetry Downlinks of Co-located Geostationary Satellites

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Abstract: Telemetry, Tracking and Command Subsystem is critical for a space mission that calls for dual redundancy of each of its elements at well separated spot frequencies. Increased number of geostationary missions along with dual redundancy philosophy resulted in scarcity of bandwidth for satellites to be co-located with existing ones in future. This paper describes the constraints related to closely spaced carrier frequency allocation within the bandwidth allocated to telemetry link in C-Band such that the ground station would be able to separate them and demodulate. Based on the experimental results, this paper recommends the minimum frequency separation between carriers of telemetry downlinks allocated to main and redundant units of the same Spacecraft or units of two collocated satellites.

Keywords: Bandwidth, Telemetry, Ranging, Transfer Orbit, On Orbit, Dwell.

Introduction

C-Band transmitters for geostationary missions are designed to downlink telemetry data to ground station in phase modulated format. Telemetry Data is encoded by Pulse Code Modulation (PCM) and modulated further by Phase Shift Keying (PSK) scheme to generate subcarriers that are fed to C-Band transmitter as modulating signals. Frequencies of subcarriers are 32 KHz for Normal mode Housekeeping (HK) data, 128 KHz for Dwell mode HK data and 27.777 KHz for Ranging tone.

As per old demodulation scheme of ground station, the separation of frequency between two downlink carriers should be at least 2 MHz for authentic demodulation of both signals simultaneously because the Surface Acoustic Wave (SAW) filter used at the output stage of IF down convertor in ground station has a bandwidth of 2 MHz [1].

Due to scarcity of bandwidth in C-band, the separation between the two downlink carriers had to be reduced to below 200 KHz for two of the upcoming geostationary satellites. At this separation, it is very difficult to separate and demodulate the two telemetry downlink frequencies because the SAW filter cannot separate carriers spaced by 200 KHz and modulated by subcarriers of frequency up to 128 KHz.

To get rid of the these issues, latest techniques of digital filtering can be used where the down converted modulated signal is converted to digital signal and a technique of vector demodulation is used to demodulate telemetry subcarriers and ranging tone [2]. Subcarriers are decoded by Viterbi decoder to get lock status and frame sync bits [3].

With the help of this setup for Demodulation, an experiment has been conducted to determine the minimum frequency separation between two telemetry downlink carriers in C-Band considering various aspects related to Demodulation and Reliability of Downlink [4].

Restriction in Bandwidth Allocation

Each of the geostationary Satellites has two C-Band telemetry transmitters with different carrier frequencies in the band of 4.18 - 4.2 GHz. The second transmitter provides redundancy in addition to protection of Telemetry (TM) downlink in case of jamming against the first carrier frequency. At the beginning of geostationary missions, the minimum separation between carrier frequencies at C-Band was chosen to be 500 KHz for transmitters of same Spacecraft or transmitters of two co-located Spacecrafts.

Two of the future geostationary satellites are going to be in the same orbit, which is the regular slot of geostationary Satellites launched by few other countries [5]. Due to this reason, four TM downlink frequencies should to be chosen within 1 MHz bandwidth ranging from 4199 to 4200 MHz. After modulation, the sidebands having significant power level should not fall below 4199 MHz and above 4200 MHz.

So an experimental analysis was carried out with Telemetry subcarriers from Telemetry card and ranging signal from Ranging Receiver to decide carrier frequencies for those four downlinks in the given narrow bandwidth without causing interference to each other.
Modulation Constraints, Difference of Output power level between transmitters during Transfer Orbit and On Orbit phases and Drift of Carrier frequency are the major factors taken into consideration.

Modulation Constraints

There are three modulation signals: Normal mode Telemetry on 32 KHz subcarrier, Dwell mode Telemetry on 128 KHz subcarrier and the Ranging tone at 27.777 KHz. The C-Band downlink carrier of frequency in the band of 4.18 - 4.2 GHz has to be modulated with these signals and transmitted to the ground station.
Under normal conditions, each transmitter transmits either one of the three or two of the three subcarriers. Under failure conditions, redundant transmitter alone can downlink all the three modulating signals without any deviation in specifications.
Normal mode Telemetry-1 is connected to Transmitter-1 and Normal mode Telemetry-2 is connected to Transmitter-2. Dwell Mode Telemetry-1 is cross coupled to Transmitter-2 and vice versa. Ranging Tones extracted by demodulation of Uplink Signal are fed back from Receiver-1 and 2 to Transmitter-1 and 2 respectively. Normal mode telemetry is hardwired to respective transmitters and is always ON whereas Dwell mode telemetry can be switched on or off as required for the mission control system.

Power Levels of Transmitter

During Transfer Orbit phase the transmitters are always operated in High Power mode. In this mode the output power of transmitters is 35 to 37 dBm. A Quadrifilar Helix antenna of 0dB gain is used to obtain Omni coverage.
During On Orbit phase, Transmitter-1 is operated in Omni mode, and Transmitter-2 is operated in low power mode. The output power of transmitter in this mode is 26 to 29 dBm. A Horn antenna of narrow beam width and gain of 20 dB is used for downlink in global mode.

Details of the Experiment

The experimental set up is shown Fig. 1. A Flight model transmitter was used as Transmitter-1 with a Temperature Compensated Crystal Oscillator (TCXO) as stable reference frequency source. An engineering model of telemetry transmitter made for geostationary missions was used as Transmitter-2 with Signal generator as reference frequency source since its frequency had to be variable for the experiment. Separate telemetry baseband cards are used for providing Telemetry to each of the Transmitters. Telemetry cards provide subcarriers of 32 KHz and 128 KHz in PSK format to transmitters.

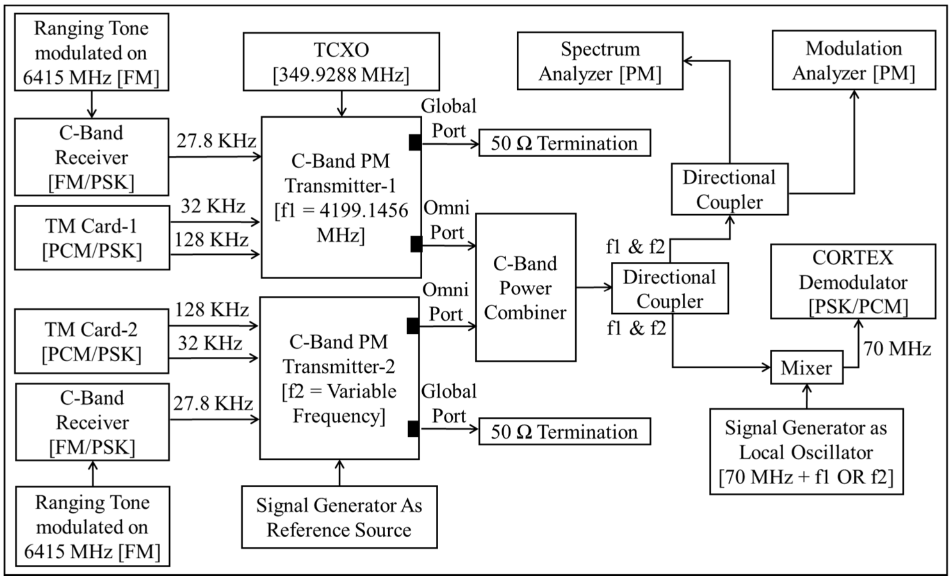

Figure1. Block diagram of the experimental setup

Ranging tones are generated in PCM format and modulated using PSK scheme followed by Frequency Modulation [FM] on a carrier frequency at 6415 MHz which is generated from a signal generator. This signal generator represents the ground station

that uplinks FM signal to onboard receivers. Frequency modulated signal is fed to C-Band receiver which demodulates and forwards ranging tone in PSK format to transmitter.
The initial frequency of TCXO used in Flight model transmitters can be set with an accuracy of ±1ppm. Variation of frequency due to temperature variation expected On Orbit from -25 °C to +55 °C is ±2ppm. Aging of TCXO can add further deviation of maximum ±5ppm over the mission life of 15 years. So the maximum variation in the output frequency of transmitter is always less than ±8ppm which is equal to ±33.6 KHz. Since the maximum modulating frequency is 128 KHz, the minimum required separation between two transmitters as per paper calculation is 161.6 KHz. The experiment was started with a frequency separation of 162 KHz between carrier signals of transmitter-1 and transmitter-2.
Apart from all regular combinations of modulating signal inputs, additional test of both Transmitters having 128 KHz modulating input with Transmitter-2 having 27.77 KHz modulating input was also done. In this case 32 KHz was removed from Transmitter-2.
The difference between carrier frequencies was increased in steps of 1 KHz till the Cortex receiver was able to separate them and demodulate. Further, the test was repeated in steps of 0.1 KHz close to the frequency difference determined in the first stage in order to find more accurate value.
There are certain limitations in the experimental Setup. Doppler Effect was not considered here. Noise due to downlink propagation and atmospheric interference is not added to carrier signals. Noise due to uplinking of ranging signal from ground station is not added on the carrier signal. Using Signal generator as reference frequency source for second transmitter instead of TCXO resulted in reduced phase noise. It was reasonable to conduct the experiment with these limitations as they would not contribute to relative drift of telemetry downlink carriers.

Analysis of Results

All combinational scenario of Transfer Orbit and On Orbit were analyzed. Minimum possible separation between two carriers is found to be 182.4 KHz. The spectrum in Fig. 2 shows the output of two transmitters with a carrier frequency separation of 182.4 KHz, Normal mode Telemetry fed to Transmitter-1 and Dwell mode Telemetry to the other. It shows that there is no overlap of side bands due to modulating signal.

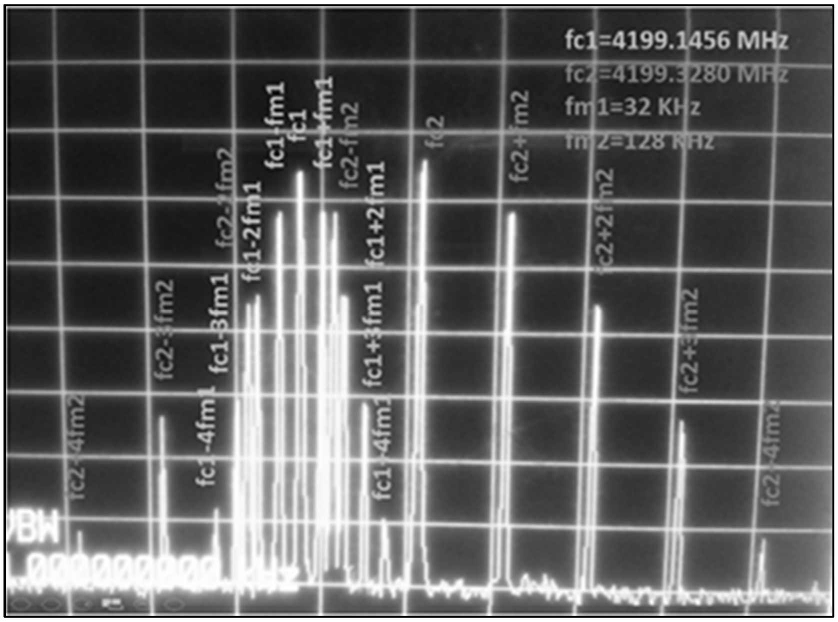

Figure2. Combined Spectrum of output signals from transmitter-1 is in normal mode and transmitter-2 is in dwell mode

Similarly Fig. 3 shows the output of two transmitters with a carrier frequency separation of 182.4 KHz and Dwell mode telemetry given to both. The side bands due to modulating signal are well separated in this case as well. Unlock of Ranging sub-carrier, frame un-sync, bit un-sync and carrier unlock were observed when the difference in power level between two carrier signals was more than 12 dB at minimum frequency separation. These problems were not seen when the difference between carrier levels was less than 12 dB. This shows that the output power of transmitter and gain of antenna are also critical for closely spaced frequency allocation. Four frequencies are selected from the band of 4199 - 4200 MHz such that, there would be no side band spill over below 4199 MHz and above 4200 MHz with modulation and separation between successive carrier frequencies is of maximum possible value with in the 1 MHz bandwidth.

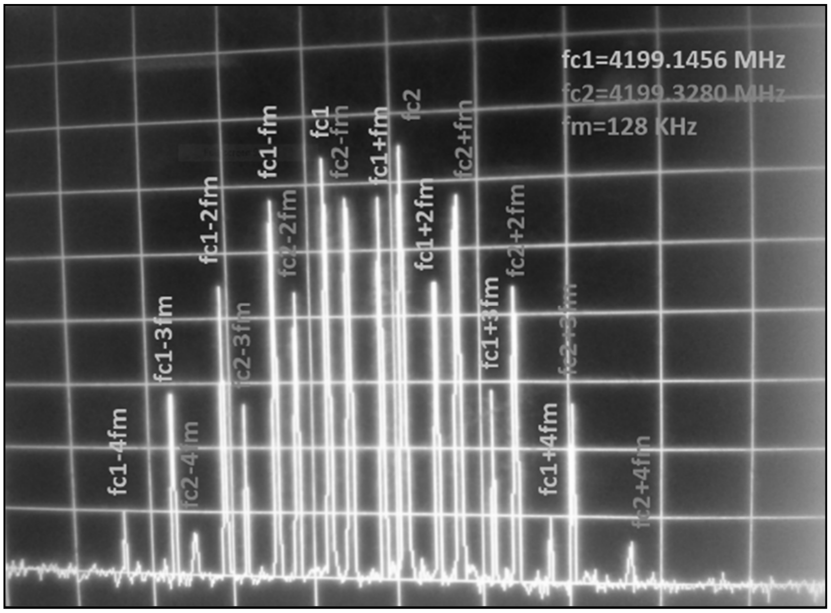

Figure3. Combined Spectrum of output signals from transmitter-1 & transmitter-2 when both are in dwell mode

Conclusion

For one Spacecraft, frequencies are assigned with a separation 182.4 KHz in the band of 4199 - 4200 MHz. If catastrophic noise conditions or high drift of frequency or power on one carrier results in unlocking or demodulation problems, that particular transmitter can be turned off and the mission can be managed with other transmitter with all three modulating inputs i.e. Normal mode HK data, Dwell mode HK data and Ranging tone. For second Spacecraft, frequencies are assigned with a separation of 252 KHz in the same band.

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