JACET Journal of Advances in Computer Engineering and Technology, 1(2) 2015

Typical Ka band Satellite Beacon Receiver Design for Propagation Experimentation

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Received (2015-01-23)
Accepted (2015-04-21)

***Abstract* — This paper presents the design and simulation of a typical Ka band satellite beacon receiver for propagation experimentation. Using satellite beacon signal as a reference signal in satellite wave propagation study, is one of the most important methods. Satellite beacons are frequently available for pointing large antennas, but such signals can be used for measuring the effect of natural phenomena such as atmospheric gases, water vapor, oxygen molecules, clouds, rain, dust and fog existing in different layers of the atmosphere, including troposphere and ionosphere.**

***Index Terms* — Beacon signal; Satellite beacon receiver; Satellite communications; Satellite wave propagation**

I. INTRODUCTION

In propagation path between the satellite and ground station, some natural phenomena such as atmospheric gases, water vapor, oxygen molecules, clouds, rain, dust and fog existing in different layers of the atmosphere, including troposphere and ionosphere, can cause some impairment on the availability and quality of satellite links during service period. This natural phenomenon caused errors and problems such as attenuation, changes in polarization, fading, delay and dispersion. Particularly at higher frequencies such as Ku and Ka bands the effects of those propagation phenomena will not be neglect able and they should be considered. For reliable and secure satellite communication, theoretical and experimental propagation study in different frequencies and regions is essential.

There are different methods to study satellite wave propagation such as radar, radiometer and signal beacon method. Satellite signal beacon method is one of the most important, reliable and inexpensive method in comparison with the other methods. Satellite beacon is a reference signal with a fixed frequency and power, and without modulation that is sent usually by satellites. This signal usually has its own specific transponder with telemetry satellite signal. In some cases, the signal is buried between the data transponders. Satellite beacon is usually created by a fixed crystal source that has low intermodulation and phase noise. This means that most energy exist in a narrow bandwidth in a center frequency [1]. Beacon signals can be as much as 40-50 dB below the composite carriers. Satellite beacon receiver has to locate the beacon signals and measure its power level. Since all of the signal energy is close

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to the carrier frequency, satellite beacon receiver has a narrow bandwidth on the earth. Therefore, the noise in the receiver that is proportional to the bandwidth is very low [2]. In this receiver, bandwidth of IF section should be low because the received signal power is very small which is achieved by high dynamic range.

In recent years, different designs of satellite beacon receiver (analog and digital) are proposed and implemented [3]-[7]. Beacon signals are used for various applications including precise orientation of the earth station to the satellite, automatic frequency control and satellite propagation research. These cases demonstrate the importance of using the reference beacon signal. To receive satellite beacon, an appropriate receiver is needed. Locking on satellite beacon signal is hard. Though conventional satellite receivers are also generally able to track the beacon signal, the nature of the signal is led to create a special receiver. In this paper, the design and simulation of a satellite signal beacon receiver have been done in Ka band.

II. DESIGNING OF SATELLITE BEACON RECEIVER

The proposed satellite propagation experimentation setup is presented in Fig. 1. As shown in Fig. 1, simultaneous measurement of satellite beacon signal and weather parameters should be done. In this paper design of a typical Ka band satellite beacon receiver for propagation experimentation is presented.

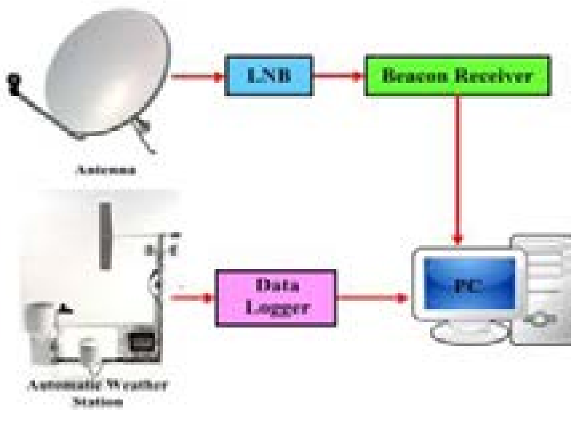


Fig. 1. The proposed satellite propagation experimentation setup

Considering attenuation of propagation that over 200dB in satellite signal path of fixed geostationary satellite orbit to the Earth, the received power level at the input of the antenna is smaller than -100 dBm. According to the parameters of this system; the receiver must have high gain, low noise factor, desirable frequency stability and appropriate phase noise. The designed receiver with a LNB as an input and a super heterodyne receiver are presented in Fig. 2.

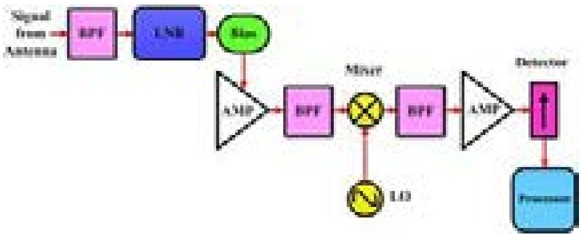


Fig. 2. Block diagram of the designed receiver

In Fig. 2, the LNB output is connected to the biasing block. IF and DC parts are separated and LNB supply is fed by a separator that includes bypass capacitors and RFC inductors.

The output of the biasing block is the IF signal that can be amplified by the IF amplifier and the intended band will be selected by the filter. Since the IF frequency is still considerable amount at this stage, therefore, an additional step is required to reduce frequency by a mixer and local oscillator in the 2 GHz range.

The advantage of this circuit is that amplifying and channel selection processes take place in several stages. This simplicity of implementation especially about the filters of the channel selection will remove the oscillation problem of the large gain in the RF and the contrast between sensitivity and image frequency. The employed LNB has standard waveguide input in the desired band, therefore in the antenna output after antenna feed we can use waveguide filter.

The LNB is fed by IF output. The appropriate gain, ultra-low noise factor and good internal consistency of the local frequency are its features. In Fig. 3, the received signal at the input antenna after entering into the LNB is given by a narrow band filter. Bandwidth of the filter forces a restriction on the size that can be implemented and manufactured. This filter should have as much as possible low attenuation in the pass band. Given that low bandwidth filters have more loss, it can be said that the system noise figure must be also considered in the design of filter bandwidth.

To compensate mixer conversion losses, attenuation of filters and increasing the signal power level, one or more IF amplifiers after IF filter can be used. After suitable amplification, the output signal applies to the detector that follows the square law. Therefore, the output voltage of the detector is proportional to the input power level. The detector voltage is sampled by analog/digital converter and conversions which are needed in the digital area implement on it.

In this block, because of ultra-low bandwidth and relatively high frequency of the beacon signal, stability of the used local oscillator is important. To build LO signal can be used very high stability and low frequency oscillator such as TCXO as frequency reference in the phase loop system and frequency is increased. If direct implementation of the LO signal was not possible by PLL, to achieve the desired frequency should be used of active or passive frequency multiplier such as SRD diode and desired LO frequency is separated of unwanted products by a band pass filter [8].

III. SIMULATION OF THE SATELLITE BEACON RECEIVER

The proposed block diagram is simulated for receiver. In this simulation most of the element models are derived from Datasheet parts. Simulation of the supposed signal beacon is done in the Ka band at the frequency of 21.215 GHz and the power about -110 dBm in the output of the receiver antenna. It should be noted, the selected components are chosen in such a way that is usable in frequency ranges of the LNB output in the Ka band.

Designed synthesizer has adjustable frequency which can be used in other than the frequency used in this article. Due to the input beacon frequency and LO frequency related to LNB, IF1 frequency is equal to 965 MHz. IF2 frequency is designed equal to 90MHz by designing LO2 equal to 965 MHz. Thus filters and other components are used proportional to the circuit position in these frequencies. Simplified LNB model in the simulation are presented according to LNB specifications of 9000HD model which is built in Norsat Company and shown in the Table 1 [9].

Simulation of used unknown parameters such as the gain distribution, local oscillator parameters, and characteristics of the filters is performed in accordance with conventional systems. Results of LNB simulation for different power levels of the input frequency 21.215 GHz are presented in Fig. 3. The output of the module is saturated when the input is greater than -50 dBm.

TABLE 1. LNB specification (9000HD Norsat)

Parameter	Value
Input Frequency	21.2~22.2 GHz
LO Frequency	20.25 GHz
Stability	± 70 KHz
LO Phase Noise	-70 dBc/Hz@1KHz -80 dBc/Hz@10KHz -100 dBc/Hz@100KHz
Output Frequency	950~1950 MHz
Conversion Gain	58 dB
Noise Figure	1.6 dB
Input VSWR	2.2:1
Output VSWR	2.2:1
Image Rejection	40 dB
Output Power	+5 dBm at 1 dB Compression
Output Connector	50 Ω N-Type

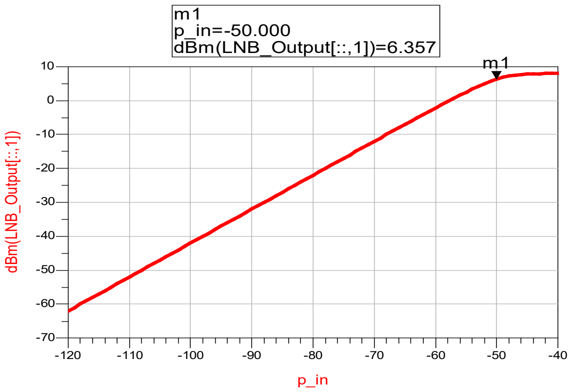


Fig. 3. Input-output characteristic of the LNB

To design the desired PLL, some specific software is applied. Used synthesizer is ADF4350 which is a product of Analog Devices Company [10]. The required parameters such as the desired output frequency are adjusted to suit the demands. The design is done for output frequency 875 MHz. Loop bandwidth and other parameters are selected to suit the needs of projects. In Figs. 4 and 5, the time response and phase noise of the PLL is represented respectively. As seen the PLL is locked after a very short time and has a low phase noise. AD8309 model which is a product of Analogue Device Company is used as log Amp detector [10]. This element has been modeled by nonlinear relationships and blocks. In Fig. 6, the response of simulation is presented which shows that above -70 dBm, the logarithmic functionality is achieved. Output slope is 20 mV/dB and TSS value is about -80 dBm.

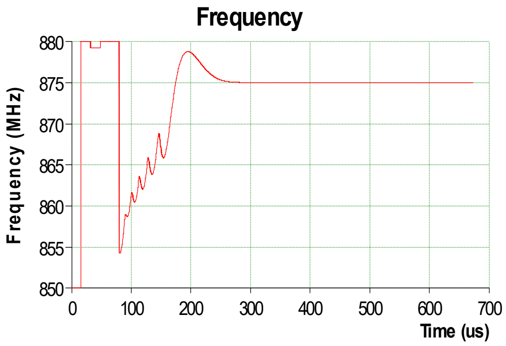


Fig. 4. Time response of PLL

Also IF1's filter is simulated. Because of the required narrow bandwidth, the designed filter must have low losses and high Q. For this reason mechanical inter digital filters is chosen as the best option. Due to the high gain of LNB, loss of this filter has little effect on the overall system noise figure.

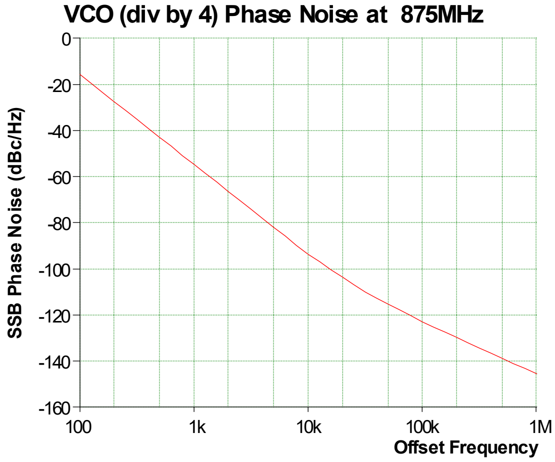


Fig. 5. Phase noise- of PLL

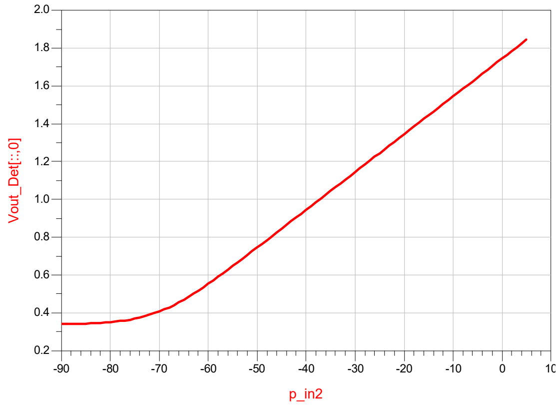


Fig. 6. Characteristic curve of Log Amp

Frequency characteristic of the designed filter is given in Fig. 7. As S21 curve shows, the insertion loss is negligible in the pass band. Integrated crystal filters have been used for IF2. These filters are typically used at frequencies below 100 MHz and features include a bandwidth that is ultra slim and low losses. According to the desired specifications of the filter, a response of the simulated model for this filter is as Fig. 8. In Figs. 9-12 harmonic responses of the system are presented at the output of each module. Level of the power of the primary carrier and largest spur are specified by markers m1 and m2.

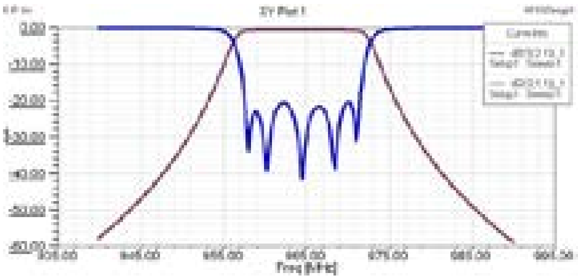


Fig. 7. Frequency specification of IF1 filter

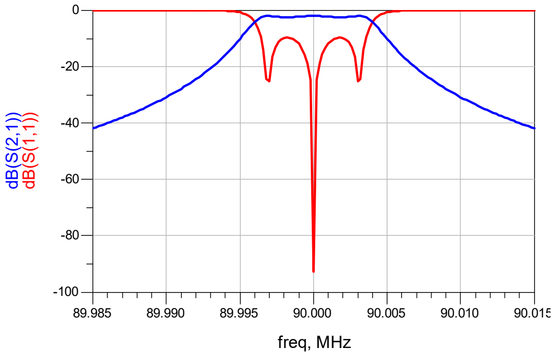


Fig. 8. Frequency specification of IF2 filter

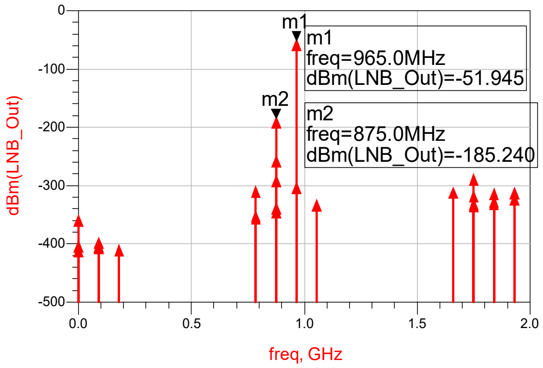


Fig. 9. Harmonic response at the LNB output

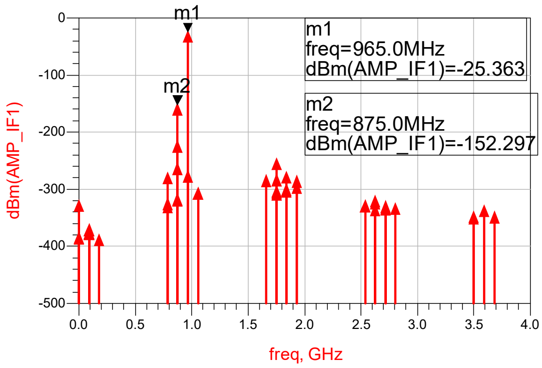


Fig. 10. Harmonic response at the IF1 output

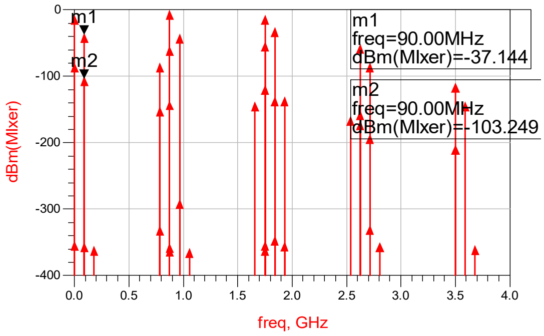


Fig. 11. Harmonic response at the Mixer output

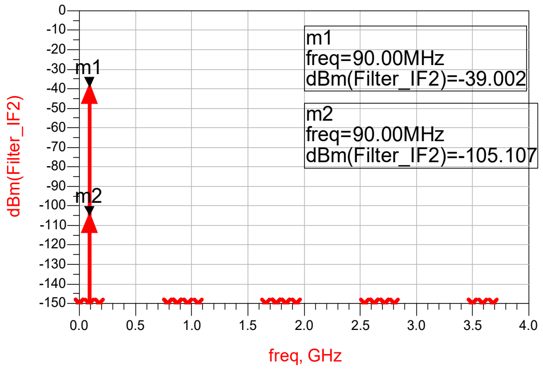


Fig. 12. Harmonic response at the IF2 output

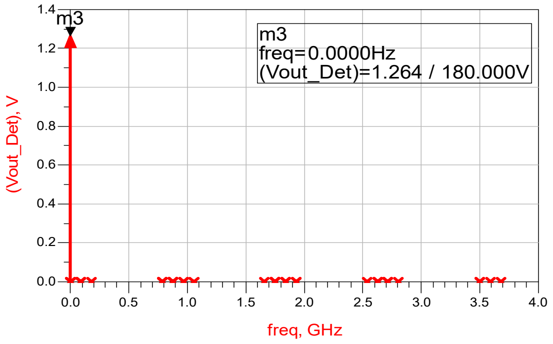


Fig. 13. Response of power detector

The curve in Fig. 13 presents the output voltage of the detector. Considering the saturation characteristics of the receiver, around -68 dBm input power saturate designed receiver. Also according to the characteristics of the system, dynamic range is about 90 dB. In Fig. 14, other features of the system such as NF, SNR, TOI, IM3, and P1dB are plotted relative to the output of each module. End points of each curve represent the final value of the parameter for the entire system. For example, the system gain of 95.27 dB and the noise figure of the system is 1.676 dB.

In Fig. 15 the output response (voltage level of output of power detector) is plotted relative to the carrier frequency shift. In this simulation, the carrier power is considered constant. It is observed that the response is very similar to response of IF2 filters. The amount of output ripple, carrier frequency shift in the system pass-band is about 1.7 dB that occurs between 2 KHz.

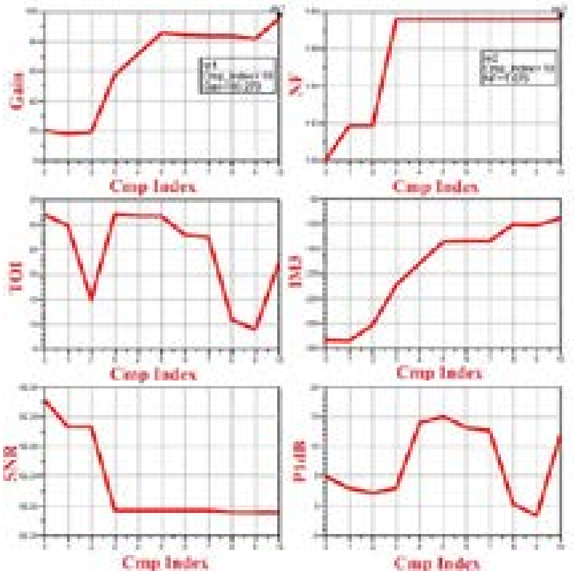
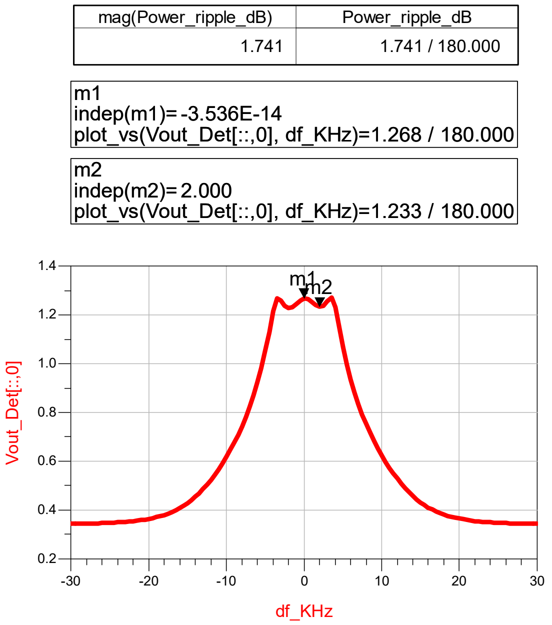


Fig. 14. Other specifications of designed receiver

IV. CONCLUSION

In this paper, the design and simulation of beacon signal receiver is presented at Ka band. Beacon signal due to low transmitter power and small receiver bandwidth, requires high precision and low cost receiver. Using a standard LNB that is out of signal receiver, and employing appropriate parts and filters can help to increase precision of the receiver and to reduce the cost of manufacturing.



mag(Power_ripple_dB)	Power_ripple_dB
1.741	1.741 / 180.000

```
m1
indep(m1)=-3.536E-14
plot_vs(Vout_Det[::,0], df_KHz)=1.268 / 180.000
```

```
m2
indep(m2)=2.000
plot_vs(Vout_Det[::,0], df_KHz)=1.233 / 180.000
```

Fig. 15. Voltage level of power detector

ACKNOWLEDGMENT

This work is supported in part ICT Research Centre (ITRC).

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