Design and Development of Ka Band Digital Beacon Receiver for Ka Band Propagation Studies Experiment
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ABSTRACT: India is planning to conduct its own Ka band propagation studies experiment in order to validate the existing ITU model and to develop a more accurate prediction model for its unique climate condition for guaranteed QoS. This experiment involves measurement of signal attenuation due to rain and development of appropriate mathematical propagation models. This requires a ground receiver to receive beacon signal at 20.2 & 30.5 GHz onboard GSAT-4. This paper describes a novel design philosophy of Digital receiver based Digital Beacon Receiver to receive and measure the amplitude of beacons at 20.2GHz and 30.5 GHz, both polarization (V&H), with accuracy better than +/- 0.7 dB with measurement rate of 1 Hz and better. This unique receiver receives all the four port data simultaneously using single antenna and does signal processing to achieve the desired accuracy. The test results obtained has been discussed.

1. INTRODUCTION

Ka band suffers attenuation due to rain and India being a tropical region, the impact of rain on Ka band propagation is more severe. None of the existing ITU models are validated for prediction of rain attenuation correctly and hence it calls for a new propagation experiment to validate the existing models and come out with more suitable and accurate models to have a guaranteed QOS. The experiment involves measurement of beacon amplitude, rain rate and other meteorological parameters. The Ka band digital beacon receiver is an integral sub-system of this experiment to measure beacon amplitude with greater accuracy over a large dynamic
range and to provide the amplitude data every second to the mathematical models for further prediction. The challenge involves co-polar and cross-polar amplitude measurement with higher accuracy over a large dynamic range at faster update rate. Since the beacon power is very low it calls for development of suitable hardware & software algorithm to process the data to achieve the desired accuracy over dynamic range. We have achieved simultaneous amplitude measurement of both beacon signal at 20.2 GHz & 30.5 GHz for every second with an accuracy of +/- 0.7 dB over a dynamic range greater than 30 dB using 1.2m single antenna system. The receiver has a highest sensitivity of -140dBm with +/-0.7 dB accuracy.

2. Related Work

Ka band Propagation studies experiment has been conducted by different countries [1], [2], [3] where the study is related to their frequency and mode of operation. Commercially available off the shelf receivers do not cater the requirements of Indian experiment and hence it calls for customized receiver design for this experiment. The receivers developed till date has been using traditional superhetrodyne radio architecture and have limitations for measurement accuracy over dynamic range. The digital receiver based system offers better sensitivity & large dynamic range [4], [5]. This receiver design incorporates the low noise RF front end with digital receiver based closed loop baseband architecture to achieve the desired amplitude accuracy with high sensitivity. Large cost reduction has also been achieved due to its novel architecture & design approach.

3. Proposed work

We have designed a unique low-cost Digital Beacon receiver capable of simultaneous reception of 20.2GHz and 30.5GHz frequency in dual polarization using a single antenna system. The designed receiver utilizes time-based auto-tracking over bandwidth using remote programmability of down converter with the divide and conquers approach for achieving better accuracy during weak signal conditions. This receiver is a unique example of intelligent utilization of filtering and decimation, modified windowing, FFT techniques and spectral averaging to achieve greater amplitude accuracy with fast measurement interval. This works becomes more important because of signal detection and amplitude estimation with greater accuracy under very low signal to noise ratio.

4. Organization of the rest of the paper

The rest of the paper is organized as follows. Section II contains the detailed description of the proposed work, section III describes the designed receiver test results and finally section IV concludes the paper.
5. PROPOSED WORK

1. Overview

The block diagram of the proposed digital beacon receiver is given in figure 1. The receiver consists of mainly four segments namely Antenna Segment, LNBC Segment, Down converter Segment (L Band to 70MHz IF) and Baseboard Segment along with a Storage & Display Segment (PC). The antenna segment consists of antenna, feed, OMT and diplexer. The same antenna will receive both the frequencies and both polarization. The diplexer and OMT will separate both the frequencies and polarization. The LNBC converts the Ka band input to L-band output which is then converted to IF of 70 MHz using L-band down converter. The 70 MHz IF is input to the Digital Receiver System which does the necessary signal processing to acquire and estimate the amplitude of beacon signal. This system also does tracking of beacon signal over a bandwidth of +/- 150 KHz.

![Figure 1. Block diagram of digital beacon receiver](image)

2. Implementation Details

Antenna Segment: This 1.2m Ka band antenna system having custom made feed & OMT in a single unit with four port output for 20.2 GHz (V), 20.2 GHz (H), 30.5 GHz (V) and 30.5 GHz (H) has crosspolar isolation more than 30 dB to cater the complete dynamic range. This antenna system has a gain of 46dB (20.2GHz) and 49 dB (30.5 GHz) with an insertion loss less than 1dB.

LNBC Segment: The LNBC used in this receiver has a noise figure better than 2 dB as this dominates the system noise. 30.5 GHz LNBC was designed to achieve gain of 60 dB with noise figure of 1.8dB, whereas the 20.2GHz LNBC
has a gain of better than 55dB with noise figure of 2dB. The gain variation over
temperature was managed within +/-0.2 dB under operating conditions to maintain the
overall amplitude measurement accuracy within limits.

Down Converter Segment: The L Band downconverter used in this receiver has a step size
of 1 KHz in order to narrow down the signal bandwidth to a very low BW to limit the noise
entering digital receiver and this unit is being controlled by digital receiver cum baseband
system remotely using RS232 link. This unit has a maximum gain of 30dB.

Baseband Segment: This segment consists of digital receiver system and host PC which
runs the control application software to acquire & store processed data while performing
intelligent tracking over bandwidth. The heart of this receiver is digital receiver system,
block diagram of which is given in figure-2.

Figure 2 Baseband digital receiver system

The 70MHz IF frequency is given to the base band digital receiver system. The digital
receiver digitizes the signal at 80 MSPS sampling rate, which is very high with respect to
+/- 150 KHz BW of interest and sends the 14 bit output to digital downconverter chip. Due
to the principle of undersampling the signal is then shifted to 10 MHz IF. The digital
donconverter used in this design provides processing gain by virtue of decimating the
signal to low sampling rate while providing the flexibility of having programmable digital
filter at input. The novelty of this implementation is the design of a very narrowband DDC
filters with very low passband ripple of less than 0.1dB while downconverting &
decimating the signal to baseband with very low sampling rate. Figure 3 shows the
observed passband ripple response of the digital receiver system.
The pass band has been kept low such that the decimated signal can be brought to low sampling rate and will help in achieving better resolution necessary for desired amplitude estimation. The DDC filter coefficient is programmed through DSP via FPGA. The timing diagram for DDC programmability has been implemented in FPGA. FPGA also has a FIFO implemented inside which helps DSP to fetch the data in real time. The DSP fetches the real time data in ping-pong manner from the FIFO and does the necessary signal processing.

```c
main()
{
    /* General Initialization */
    ....
    /* Initialize DDC parameters (sampling rate, NCO frequency, Filter coefficient, PGA Parameter, Count/Buffer Size etc.) */
    /* Enable 1 sec timer */ -----

    /* Main loop */
    while(1) {
        /* Wait for DMA Buffer to get filled */
        if(DMABUFF == FULL)
            /* Check for Signal presence using noise averaging & FFT */
            if(NoSignal) {
                Est_Amp = 999.99;
            }
        /* Do Frequency offset estimation & Signal presence validation */
        if(Signal) {
            if(FreqAcqBuf == FULL) /* needs FFTSZ no. of samples */
                window_mulQ, /* Generate window coefficient of
                FFT_SIZE & multiply with input data */
                freqoff_est Q; /* Find the maximum of FFT output wrt
                average noise and use this index to find frequency offset */
                amp_est Q; /* Take the maximum of FFT output wrt noise
                floor and add them up with neighboring samples to cater for
                spectral leakage & find Est_Amp */
        }
    }

    /* Timer interrupt service routine */
    TimerISR()
    {
        Init_timer();
        /* Check for host readiness and send data to host by handshaking */
        Host_Send(Est_Amp, freq_offset);
    }
}
```

---

**Figure 3. Observed passband ripple of implemented DDC filter**

![Observed Passband Ripple](image)
processing to achieve the desired amplitude accuracy. The Pseudo code for DSP processing is given in algorithm-1.

**Algorithm-1 : Pseudo code for DSP processing**

In order to achieve desired amplitude accuracy the signal was brought down to baseband with sampling frequency of 80 KHz. The decimation factor selected in DDC was kept at 1000. The FFT resolution is given by $F_S/N$, $F_S$ = Sampling Frequency and $N$= Number of FFT points. The FFT output was analyzed to found a peak and average noise floor was also calculated for signal presence detection. Once the signal presence was obtained, a modified Blackman-Harris window was applied to input signal. The selection of window was to achieve desired amplitude accuracy as the Blackman-Harris window gives maximally flat output after performing FFT [6]. The FFT output was spectrally averaged before finding the amplitude of input signal. In order to take care of spectral leakage few neighboring samples of FFT output were also included in amplitude estimation. The number of bins to be included depends on Number of input samples (N) and window fall/rise time.

Leakage width in bins = N / (Window rise/fall time)

The value of estimated amplitude was then passed to host via UART communication. The pseudo code for processing and intelligent tracking done by the host based on estimated amplitude data from DSP is given in algorithm-2.
main()
{

    /* General Variable Initialization */
    /* Initialize timers */
    if (cmd_execute = true) {
        /* send the command to L-Band downconverter prime channel for tracking
         * signal over bandwidth with 1 KHz step size i.e. count=300 for +/- 150 KHz
         * bandwidth */
        TR_LOOP:
            while (Count < 300) {
                sendcmd_DC (TR_DC);
                /* TR_DC= tracking channel Down Converter */
                Enable_2Sec_timer();
                /* 25 sec setting timer for downconverter */
                if (Flg_2secOver = true) {
                    Get_dsp_data(Ch-1);
                    /* store Est_amp data in array for future processing */
                }
            }
            /* Check_Beacon_Location (); /* Find the maximum amplitude recorded and its index
            to find frequency within BW of +/- 150 KHz */
            sendcmd_DC (TR_DC), /* Bring the beacon signal to 70 MHz */
            sendcmd_DC (SR_DC), /* Set the Secondary Channel (other polarization to
            same frequency for cross-polar measurement */
            Enable_1Sec_timer(); /* One second timer records beacon amplitude for both channel
            every second and stores in file on host for processing */
            while (Flg_Retrack = true){
                Timer_2Sec_SVC()
                
                Stop_timer(); /* disable present timer */
                Flg_2secOver = true /* make the flag true */
            }
        }
    }
    Timer_1Sec_SVC()
    
    if (Flg_dataReady_Ch-1 == true) {
        Get_dsp_data (Ch-1); /* get the Est_Amp data from Channel-1 tracking channel */
        if (Est_Amp = 999.99) {
            Enable_FadeTimer(); /* enable timer to wait for signal to reappear before retrack starts */
            Store (Est_Amp);
        } else
            Stop_FadeTimer(); /* If signal reappears stop Fade timer */
            Store (Est_Amp);
    }
When the host software is executed, it sends the command to tracking channel down converter to set its frequency to the beginning of the tracking bandwidth and waits for the down converter settling time before recording the estimated amplitude. The host subsequently sweeps through the tracking BW and finds the frequency where signal strength recorded is maximum. The Host then commands both the downconverters (channel V&H) for beacon frequency and continues the measurement of amplitude. The measured amplitude is stored in a file every second. When the host detects continuously no signal condition for a predefined period, it starts re-tracking the signal over BW periodically till it acquires the signal. The indoor rack which houses the four digital receiver systems with four L-Band down converter is shown in figure-4.

**Algorithm-2: Pseudo code for Host processing**

```c
If(Flg_data_ready_Ch2 == true) {
    Get_data(CH2); /* get the Est Amp data from Channel-1 tracking channel */
    Store(Est_Amp);
}

Timer_Fade_SVC()
{
    Stop_timer(); /* disable present timer */
    Flg_Retrack = true /* make the flag true */
}
```

**Figure 4. Indoor Rack of Digital Beacon Receiver**
6. TEST RESULTS

1. Test Scenario

This section describes the test scenario of the developed beacon receiver. Due to non-availability of Ka band Satellite Beacon, it was decided to perform the tests on integrated beacon receiver under Lab condition. The input from a Ka band signal generator was fed to LNBC using K-type adapters for WR-42 & WR-28 interface. The signal generator output signal level was set as per link calculations and with the help of noise generator, noise was added at IF level to simulate fading conditions or worst conditions with different C/No expected. The final output was recorded on the host for various input conditions over complete dynamic range.

During the test the input signal amplitude from the generator was varied from -140 dBm to -110 dBm. From the link calculations, -110 dBm signal level condition represents a clear sky conditions whereas -140 dBm signal level corresponds to attenuated signal conditions. The clear sky C/N₀ expected is 60 dBC/Hz and hence during measurement the input C/N₀ was varied from 60 dBC/Hz to 30 dBC/Hz for signal level of -110dBm to -140 dBm respectively. The measured amplitude data under various C/N₀ conditions was taken and analyzed.

2. Test Results and Analysis

The test setup is shown in figure 5.

![Figure 5. Test Set-up for Digital Beacon Receiver](image)
Figure-6 shows the snapshot data plotted for estimated amplitude accuracy. The 10 minutes data for different input conditions has been taken and plotted Vs their sample number after amplitude normalization. It was observed that amplitude accuracy remains within +/- 0.7dB including all variations. This result has also been validated by running the system for 72 hours continuously to account for any other variations. Figure-7 shows the maximum deviation observed with measurement interval being 4 Hrs or more on a single channel. The result holds good for all other channels.

<table>
<thead>
<tr>
<th>Input Signal Amp (dBm)</th>
<th>Input C/N0 (dB/Hz)</th>
<th>Amplitude Meas. Accuracy (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-110</td>
<td>60</td>
<td>+ 0.2915 dB</td>
</tr>
<tr>
<td>-120</td>
<td>50</td>
<td>+ 0.2573 dB</td>
</tr>
<tr>
<td>-130</td>
<td>40</td>
<td>+ 0.3007 dB</td>
</tr>
<tr>
<td>-135</td>
<td>35</td>
<td>+ 0.4419 dB</td>
</tr>
<tr>
<td>-140</td>
<td>30</td>
<td>+ 0.5017 dB</td>
</tr>
</tbody>
</table>

Figure 6. Measured Normalized Amplitude Plot

Figure 7. Amplitude Measurement accuracy

7. CONCLUSION AND FUTURE WORK

We have designed a unique low-cost Digital Beacon receiver capable of simultaneous reception of 20.2GHz and 30.5GHz frequency in dual polarization using a single antenna system using the low-noise RF front end and intelligent programmable signal processing blocks like digital down converters. We have tested the developed beacon receiver and the test results clearly shows the desired amplitude accuracy of +/- 0.7 dB over a dynamic range of 30dB. The receiver has a highest sensitivity of -140dBm.
The dynamic range/sensitivity of present receiver can be increased with higher gain antenna system. Also, there is short lived environmental phenomenon like scintillation needs to be studied and requires beacon amplitude measurement at faster rate of 10 Hz and 20 Hz with accuracies of +/- 0.5 dB. The receiver can further be equipped with efficient signal processing techniques to meet such challenges.

8. ACKNOWLEDGEMENT

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9. REFERENCES