

## A DSP Based Satellite Beacon Receiver and Radiometer

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### 1. Introduction

In the design of satellite communication links knowledge of the magnitude of the attenuation and depolarisation of signals at the desired frequency is a prerequisite. Attenuation of satellite signals due to rain is very significant for frequencies above 5 GHz [1,2]. As the spectrum becomes more crowded, operators are forced to use higher and higher frequencies. To enable the higher frequency bands to be marketed, the probability of a communication channel not being available due to rain needs to be known for particular receiver locations and dish sizes. The most effective technique used to measure rain attenuation is to conduct an experiment, which monitors the received signal strength of a satellite beacon. A satellite beacon transmits a constant level, low power signal for the purposes of up-link power control, telemetry and research. To measure the attenuation due to rain all that is required is to constantly monitor the received beacon signal strength. INTELSAT satellites have Ku band beacons at 11.198 GHz and 11.452 GHz. The Australian Optus satellites have a Ku band beacon at 12.75 GHz. Ka band (20 GHz and 30 GHz) beacons are being included in many new satellites.

The Satellite Transmission Rain Attenuation Project

(STRAP) team at James Cook University (JCU) has been involved in microwave propagation research for many years. As part of this research an analogue Ku band beacon receiver was developed [3]. A simplified block diagram of the analogue receiver is shown in Figure 1. The beacon receiver detects a 12.75 GHz beacon with a clear sky received power level of 1.5 fW (-118 dBm). This receiver uses seven successive frequency shifting and amplification stages to place the beacon signal at the centre of the final Intermediate Frequency (IF) filter which is centred at 3.1818 kHz. To be able to detect the signal with a >35 dB dynamic range, a final IF bandwidth of less than 100 Hz is required.

In order to maintain a low noise figure and minimise the cost of the receiver, commercial Low Noise Converters are used for the front end of the receiver. Crystal locked Low Noise Converters have less than ±30 kHz diurnal variation in frequency. This frequency variation is still many times the 100 Hz final IF filter bandwidth and a sophisticated frequency control system must be used to keep the satellite beacon at the centre of the final IF filter. The original beacon receiver uses analogue circuitry for its frequency control and beacon amplitude detection and is expensive to construct and align.

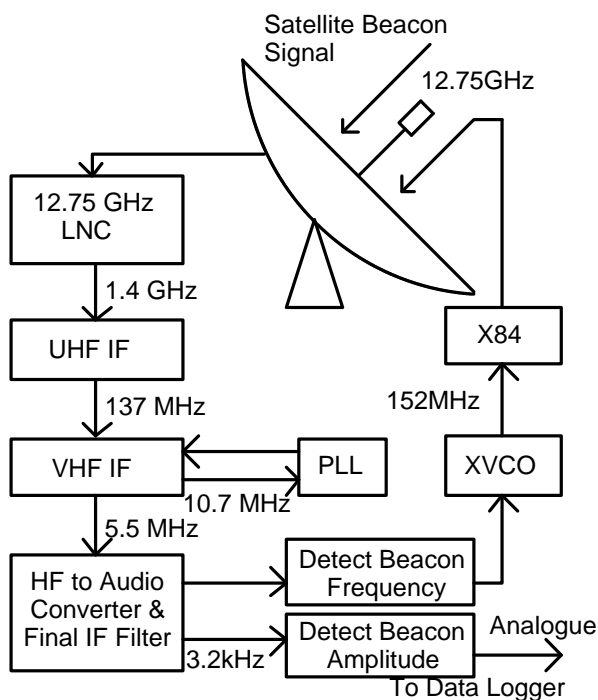


Figure 1. Original Beacon Receiver Block Diagram.

### 2. Digital Receiver Principles

The JCU Authors have designed a Satellite Beacon Receiver [4], which uses Digital Down-Conversion and Signal Processing Techniques to detect the satellite beacon signal. The beacon signal at the 5.5 MHz IF in Figure 1, is digitised using a 10 bit Analogue to Digital Converter (ADC). A sampling frequency of 20 MSPS satisfies the Nyquist rate and avoids any harmonic aliases.

#### Digital Down-Conversion

A Harris Semiconductor Digital Down-Converter (DDC) IC, the HSP50016, is used to produce a DC IF with both In-phase (I) and Quadrature (Q) components. The required frequency shift can simply be changed, by controlling the

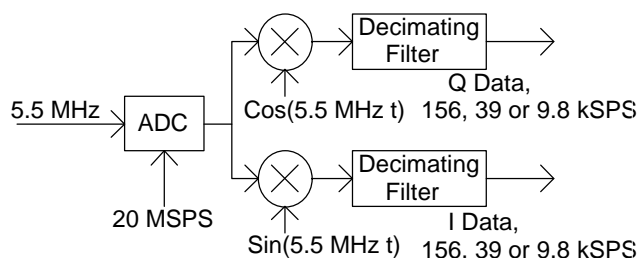


Figure 2 Digital Down-conversion Block Diagram.

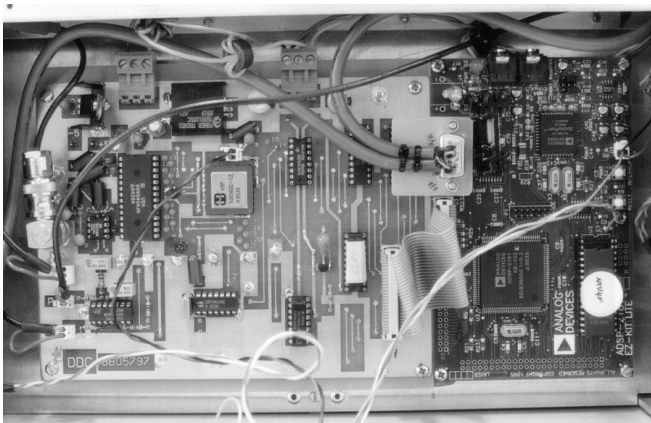


Figure 3. ADC, DDC and DSP hardware.

numerical oscillator in the DDC IC. Since the I and Q data are centred at DC, a decimating filter can be used to restrict the bandwidth to be analysed to the required resolution. The resulting block diagram is shown in Figure 2.

The I and Q data are then sent to an ADSP2181 DSP board to determine the satellite beacon signal amplitude and frequency. In a DSP system the detection of a satellite beacon signal can best be done using an FFT. The output from the FFT is then analysed to determine the exact frequency and amplitude of the satellite beacon signal. Figure 3 shows the resulting hardware.

#### Frequency Control

At start-up the signal must be located inside a 1.4 MHz bandwidth around 5.5 MHz. The DDC decimation is initially set to 128, which produces a useable output bandwidth of about 80 kHz. Initially the DSP board controls the frequency of the VHF local oscillator, which forms part of the VHF IF strip, to perform a series of frequency steps, which are about 40 kHz apart by changing the control voltage of this Voltage

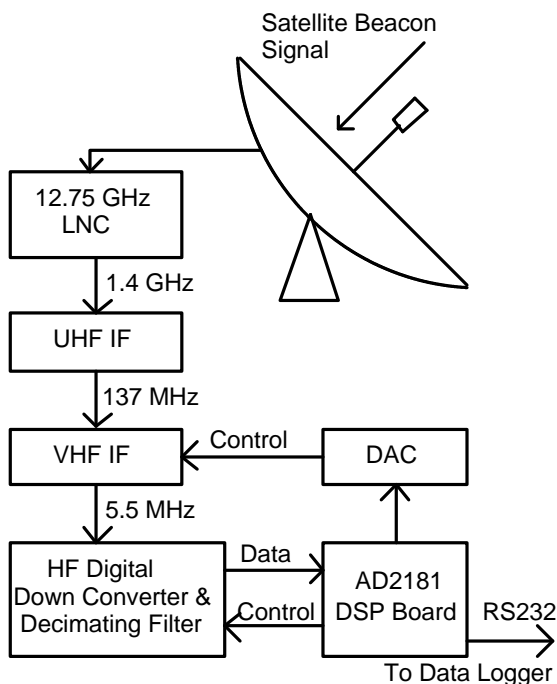


Figure 4. New Beacon Receiver Block diagram.

Controlled Oscillator (VCO). A complete sweep of the 1.4 MHz band is done and the peak signals encountered in each of the frequency selections is stored. By carrying out the full sweep of the spectrum and selecting the largest signal in the whole band, modulated beacon signals can be measured as well as unmodulated ones, provided the carrier signal is the largest signal. During this first scan the resolution bandwidth is 153 Hz/bin and the data rate is 156 kSPS.

Once the sweep is completed, the VHF VCO is set to the frequency corresponding to the largest signal. The beacon signal should now be within  $\pm 25$  kHz of the centre frequency of the 5.5 MHz IF filter. If after performing the next set of FFTs, the frequency error is larger than  $\pm 25$  kHz, a frequency correction is performed to place the signal closer to the centre frequency. If after digital down-conversion, the beacon frequency is more than  $\pm 1$  kHz away from the required zero frequency, a fine frequency correction is done by controlling the frequency of the 5.5 MHz numerically controlled oscillator, which is part of the DDC IC as shown in Figure 2.

When the coarse and fine frequency tuning have been completed, the decimation is changed to 2048. The output bandwidth is then about 4.8 kHz and the resolution 9.5 Hz/bin. The process of sweeping the VHF VCO and fine-tuning the DDC hardware to acquire the satellite beacon is completed in close to one second.

#### Digital Signal Processing

During each measurement, which occurs at least 8 times per second, 1024 I and Q values are sent serially to the Digital Signal Processor. A fourth order Blackman-Harris window is applied to the data and a 1024 point Radix-4 FFT is performed. A peak detection algorithm is applied and the magnitude and frequency of the largest signal, which is the satellite beacon, is determined.

Decimating by 2048 achieves a 33 dB increase in SNR compared with no decimation and thus gives a significant improvement in the dynamic range of the 10 bit Analogue to Digital Converter. As the beacon signal energy will be spread over several frequency bins of the FFT, the beacon signal energy is evaluated by summing the signal power over a number of bins. The number of bins used depends on the FM noise of the beacon and the FM noise of the receiver.

#### Radiometer Operation

The background noise power can also be evaluated by summing the noise over a number of FFT bins, away from the carrier. Since the noise figure of the Beacon Receiver is very low, the indicated noise is substantially due to the transmission medium. With suitable calibration, the noise level indication can be used like a radiometer, making this beacon receiver unique and allowing both the reduction in signal level and the increase in thermal noise during a rain fade to be measured along exactly the same path and at the same frequency.

#### Satellite Beacon Frequencies

The beacon receiver uses commercial low noise converters for its front end. As a consequence with minor changes to the UHF IF strip in Figure 4, satellite beacons in L band, C band, Ku band and Ka band can be measured.

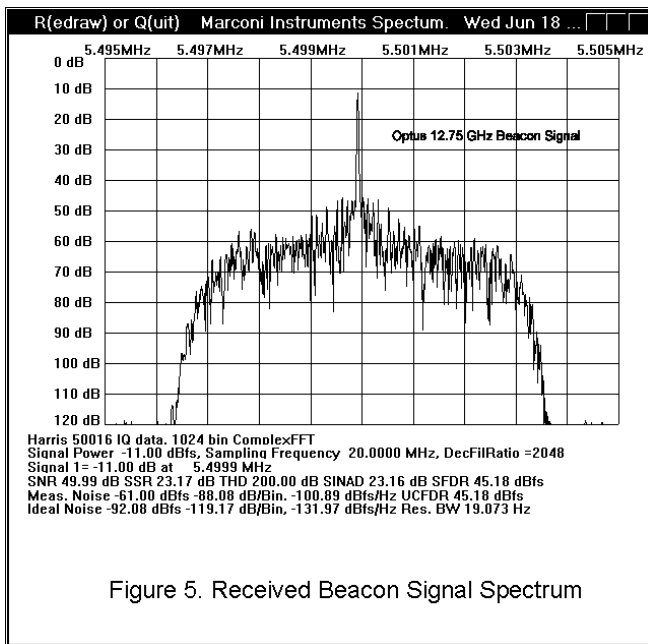


Figure 5. Received Beacon Signal Spectrum

### 3. Performance

With the decimation ratio of 2048, the receiver at JCU remains locked on a beacon signal with a greater than 35 dB fade, corresponding to a signal level of less than -153 dBm at the output from the 4m dish antenna. An actual satellite beacon signal as determined by the receiver is shown in Figure 5. It can be seen that the signal to noise ratio with a 19 Hz resolution bandwidth is of the order of 50 dB.

The dynamic range of the ADC and DDC can be evaluated by applying a sine wave to the input of the ADC and DDC hardware. A spectrum similar to that of Figure 5 results, except that the noise level is at 105 dB instead of 65 dB for Figure 5. The dynamic range is more than 80 dB. The linearity of the receiver is determined by the linearity of the ADC, which is better than 0.2% of the full output, resulting in an accuracy to within a fraction of a dB. Using a signal generator as input to the Beacon Receiver Indoor Unit, it can be verified that the noise produced by the Indoor Unit is more than 20 dB below the received noise of Figure 5. 99% of the detected noise is thus due to the received sky noise. The noise output of this beacon receiver can thus be used as an accurate radiometer.

Figures 6 and 7 show the performance of the prototype receiver, which is operating at James Cook University. Heavy rain occurred on the 30th of August 1998. Figure 6 covers the 27-hour period of the event. The beacon receiver output did not immediately return to the clear sky attenuation level, as the satellite dish partially filled with water, despite large drain holes being provided. The draining of the satellite dish can be clearly seen on the plot. Figure 7 shows a close up of the second large attenuation event of Figure 6. Some post logger filtering is used, to reduce the variation at the high attenuation levels. It can be seen that the beacon receiver tracks the fade and only loses lock when the fade becomes more than 37 dB. At the high attenuation levels, the received signal is of a similar level to the received noise and

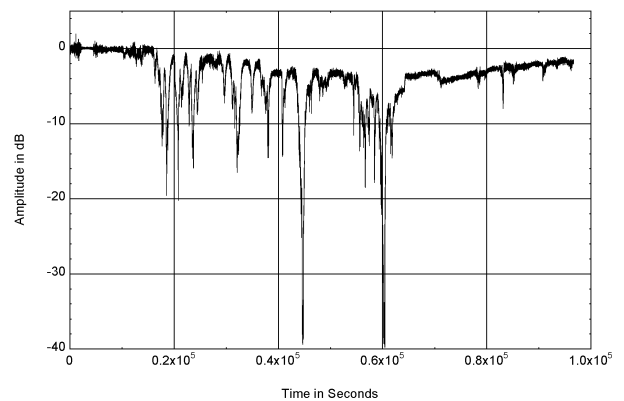


Figure 6. Rain Fade 30 August 1998, Whole Event

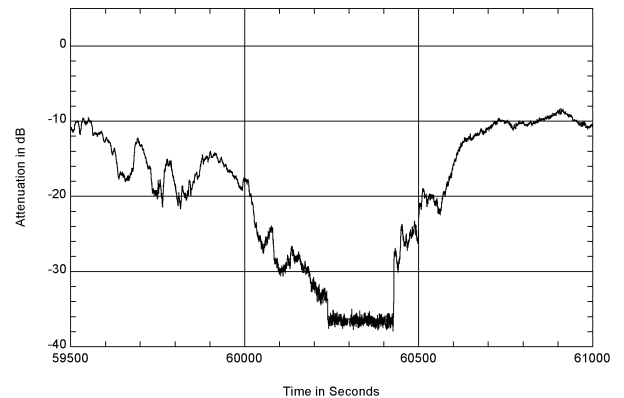


Figure 7. Rain fade 30-Aug-98, part event

special control strategies are used to keep the beacon receiver locked to the satellite beacon, even if its power spectral density is comparable to that of the noise. The deep fade of Figure 7 lasts more than 3 minutes. The software will initiate a search if no signal is found to be more than 6 dB above the noise level for more than 30 seconds. A DDC frequency sweep is done first and if no beacon signal is found, a VHF VCO sweep then done. Even if the receiver loses lock, the beacon signal is recovered within one second of it being more than 6 dB above the noise. As can be seen from Figure 7, the beacon receiver tracks the satellite beacon accurately as it comes out of the fade.

The dynamic range of this beacon receiver is significantly more than the dynamic range of conventional beacon receivers using analogue technology [3]. That analogue receiver would also take more than a minute to acquire lock, so that an important part of the event would not be measured accurately. The prototype beacon receiver was not fitted with the software for measuring the received noise during the events shown in Figures 6 and 7. As a consequence the Radiometer operation can not be shown for those events.

### 4. Bukit Timah Earth Station

One of the original beacon receivers of Figure 1 was installed at the Bukit Timah Earth Station in Singapore in December 1990 for Singapore Telecom. In March 1998 that



Figure 8. JCU-STRAP Receiver Dish at Bukit Timah

receiver was upgraded to utilise the digital down-conversion and DSP technology outlined in this paper. The DSP software for measuring the received noise was developed as part of the upgrade of the beacon receiver at Bukit Timah.

Figure 8 shows the original 3.7m JCU-STRAP receiving dish with an upgraded feed system. One of the 32m Earth Station C band antennae in the background. As a 6dB increase in rain fade margin requires doubling the receiving antenna size, accurate rain fade data are essential for the economical design of major earth stations.

Nanyang Technological University (NTU) operates a dual site beacon receiving system. The JCU-STRAP Satellite Beacon Receiver, described in this paper, a tipping bucket rain gauge and temperature monitoring are located at the remote site at the Bukit Timah Earth Station. A conventional Ku band beacon receiver, two tipping bucket rain-gauges, temperature monitoring and a Rutherford Appleton Laboratory Weather Radar are used at the main site. The data from the beacon receivers, rain-gauges and the temperature from both the main site and the remote site are logged using a data logger and modem link developed by the JCU STRAP team.

Figure 9 shows a rain fade obtained from the beacon receiver at Bukit Timah. To show the changes in the measured noise power more accurately, some post logger filtering was applied to the data. The measured noise power rises as the rain fade increases. The change in the measured noise power is much less than the change in the beacon signal. By comparing the received beacon signal and received noise at the 2900-second and 3500-second times, it can be seen that there is no strict one-to-one relationship between the beacon signal data and the radiometer data.

As a satellite beacon receiver directly measures the rain attenuation and a radiometer only provides an indirect measurement, a satellite beacon receiver is more desirable for gathering rain fade statistics. A radiometer however does not require a beacon signal and can thus be used prior to the introduction of satellite beacons. As a consequence there have been many radiometer experiments carried out and comparatively few satellite beacon measurements, this combined beacon receiver and radiometer is a valuable tool for developing models for correlating the radiometer and satellite beacon measurements at the same frequency and

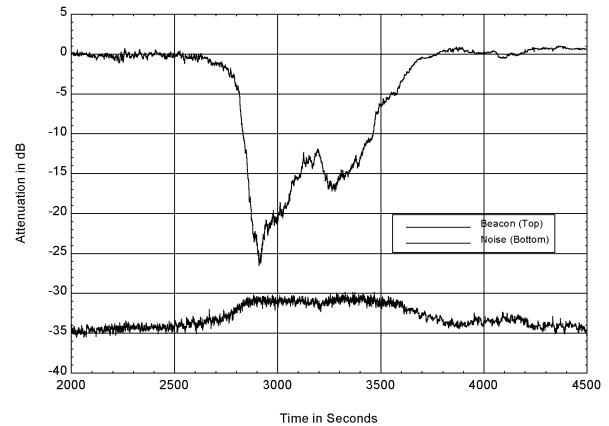


Figure 9. Rain Fade at Bukit Timah on 3 Sep 98

along the same transmission path. Path and Frequency coincident measurements have not been possible as the beacon signal would normally interfere with the radiometer. This receiver is however able separate the beacon signal and the received noise, by using an FFT.

The JCU-STRAP Satellite Beacon Receivers have been operating very reliably. The prototype receiver at JCU has been operating without the need for operator intervention since January 1998. An analysis of data from NTU covering nearly a month showed no packet errors in transmission between the main site and the remote site and the authors were unable to find any breaks in the received data. Equipment failure or loss of lock of the beacon receiver would normally cause such breaks.

From Figure 7 it can be seen that the noise level during a deep fade is close to 37 dB at JCU and from Figure 9, it is close to 31 dB at NTU. This is due to differences in satellite beacon power, receiver dish size and radiation pattern side-lobes and the satellite to ground station path length.

## 5. Conclusion

The JCU-STRAP satellite beacon receiver uses DSP technology to accurately measure of the attenuation of the satellite beacon due to rain and to measure the transmission medium noise temperature at the same time. This was not previously possible. The use of digital technology results in a larger dynamic range than is obtained by conventional beacon receivers. The receiver acquires the beacon in close to one second.

## 6. References

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