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Conversion of a Ku Band Link Ground Station for Ku/ S Band Satellite Ranging & Time Transfer

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Abstract

The dissemination of time using Two Way Satellite Time and Frequency Transfer (TWSTFT) between National Standards Organisations has been a routine activity for over thirty years [1]. The established protocol [2], and methods use Ku-Band ground station equipment for digital-mode transmission and reception. Whilst not prohibitive to commercial metrology services, the recurrent cost, and contractual obligations in the matter of obtaining satellite bandwidth, may adversely affect or compromise satellite telecommunications research in this field. This work requires ad-hoc satellite access over an extended period. Typical contracts for bandwidth supply make this restrictive and cost inefficient to the researcher. During the author's early research, approaches were made to international geostationary satellite operators for a flexible service of the type described above. All approaches were unsuccessful.

This paper describes reversable changes to an existing Ku/Ku band satellite ground station for the purposes of TWSTFT research using the Es'hail 2 satellite Ku/S-Band wide-band transponder.

Keywords – Two Way Satellite Time and Frequency Transfer, Software Defined Radio, Satellite Time and Ranging (SATRE) – A brand name of Time Tech GmbH, Stuttgart, Germany, Universal Software Radio Peripheral (USRP.

1 Introduction

The authors' main research is the application of Software Defined Radio (SDR) to Two Way Satellite Time and Frequency Transfer. The signal processing algorithms are implemented using complex sampled baseband (I/Q) data and a Universal Software Radio Peripheral transceiver provides the conversion between baseband data and radio signals. This is in contradistinction to most current and comparatively inflexible hardware based TWSTFT modem equipment of the SATRE type.

Since 2003 TWSTFT data exchange using SATRE modem equipment has been the generally accepted method of coordinated universal time (UTC) determination. Architecturally, the SATRE modem is industrial PC based, but uses conventional analogue circuitry in the 70 MHz transmitter and receiver RF stages and elsewhere for signal conversion and processing. In 2014 SDR receiving equipment was used in parallel with SATRE modems over regular TWSTFT circuits. This demonstrated that the SDR receiver largely eliminated the observed diurnal reduction in SATRE measurement precision, across some but not all TWSTFT links [3]. The reason for the diurnal reduction remains inconclusive, but advancement in software carrier phase tracking methods used in the SDR receivers can be shown to eliminate the carrier signal power dependency in its transfer-function [4].

Taking advantage of the flexibility that SDR offers, the authors have trialled other software carrier acquisition and tracking implementations. These include the adaptive management of the loop-bandwidths used in carrier-phase and code loop tracking. These measures can help reduce measurement noise, without causing instability or the loss of received carrier phase lock. Importantly and in contrast with the SATRE system, these algorithms can be implemented in software and evaluated.

Our research takes the implementation of a TWSTFT modem a stage further, by incorporating the transmit and receiver sections into a combined SDR system. While much of the transmitter and receiver software component testing can be completed in the laboratory and the intrinsic limitations of an SDR system determined; a programme of testing over a satellite link is a necessary and purposeful objective.

2 Satellite link equipment for TWSTFT.

Satellite link equipment is a necessary part of any TWSTFT ground station. Modem and satellite link are connected using runs of coaxial cable, which carry the transmitter and receiver intermediate frequency (IF). The IF commonly applied in TWSTFT radio laboratory modems is 70 MHz. The satellite link equipment mixes the modem transmit IF signal with a stabilised local oscillator for Ku Band transmission and conversely mixes the incoming Ku Band down to a receiver IF. Typical Ku-Band frequencies are in the range 10.95 - 12.10 GHz (downlink) receive and 14.00 - 14.50 GHz (uplink). This frequency difference is small enough to eliminate most atmospheric propagation anomalies from the time differencing equation [1].

Individual parabolic dish antennas for transmit and receive are commonly used by the National Standards laboratories. As well as providing a level of equipment redundancy, this arrangement improves the transmitter to receiver isolation by physical separation. The degenerative effects that high levels of wide-band transmitter noise can have on receiver performance can therefore be reduced. This is important as TWSTFT time differencing is only possible with full-duplex operation.

Single antenna full-duplex working is possible at reduced performance if sufficient isolation between transmitter and receiver can be achieved at the antenna feed-point. A cross coupled waveguide provides isolation and when used with large (~ 200 MHz) frequency separation and filtering, sufficient isolation can be achieved. However, the resultant losses associated with these components must be factored into the satellite link-budget. These components can be seen immediately behind the on-axis feed point clamp in **Figure 1** showing the present offset-fed 1.8 metre diameter dish antenna at the University of Limerick. It is common to find filters and isolators of this type in broadcast installations that share antenna resources.

3 Alternative satellite service considerations.

The Qatar Es'hail 2 geostationary satellite [5] at 25.9°E was launched in November 2018. In addition to its main commercial payload, it carries an amateur-radio service transponder manufactured in Japan by Mitsubishi Electric (MELCO). This transponder differs from convention and uses Ku-Band for downlink and S-Band for uplink across two distinct segments of bandwidth, with "bent-pipe" characteristics. The wide-band segment; see **Table 1**, is intended for digital television modes such as DVB-S2 and derivatives.

Table 1. Es' hail 2 Transponder Wide Band Segment.

Wide Band digital modes		
BW 8.0000 MHz		Polarisation
2401.500 – 2409.500 MHz	Up link	RH circular
10491.000 – 10499.000 MHz	Down link	Horizontal

Figure 1. UL Ku/Ku Antenna Equipment.

The satellite is continuously controlled and monitored in Germany by AMSAT-DL. WebSDR receivers allow independent monitoring of the transponder down-link segments over the internet [6]. When used in conjunction with the transponders' beacon reference transmissions, the up-link signal bandwidth and signal strength can be comparatively assessed using these alternative receiver systems.

TWSTFT transmissions use BPSK digital modulation at nominal chipping rate of 1 Mbps. The Es'hail 2 wideband transponder is capable of TWSTFT data throughput, occupying bandwidth comparable or narrower than digital television. Spread spectrum sequence codes used in TWSTFT are proprietary to users and do not comply with any amateur radio data modes. Reception (de-spreading) and recovery of any modulation contained therein is impossible without prior knowledge of the spreading code and other parameters. Compliance with station identification licensing requirements can be achieved using the dialogue pane section of Web-SDR [6]. Es'hail 2 satellite is positioned over central Africa and strongly illuminates most of Europe, Africa, and the Gulf. **Figure 2**, gives bearing and pointing information from Limerick.

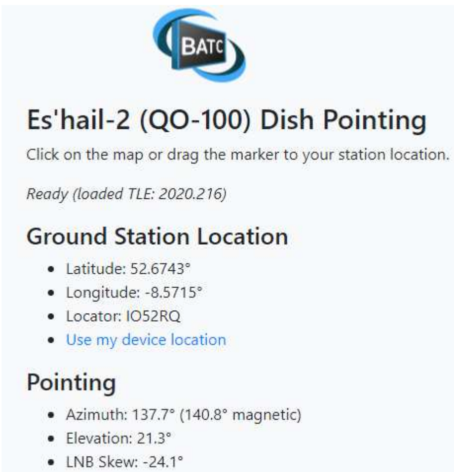

Figure 2. UL location and pointing data.

4 Ku/Ku ground station modifications.

Figure 3 shows a schematic block diagram of the satellite link system at the University of Limerick before modification. The roof-top antenna equipment is connected to the laboratory using two 50 m lengths of low-loss coaxial cable. The multiple port Bias T networks provide the means for DC power, intermediate frequency (IF) signal and reference signal combination.

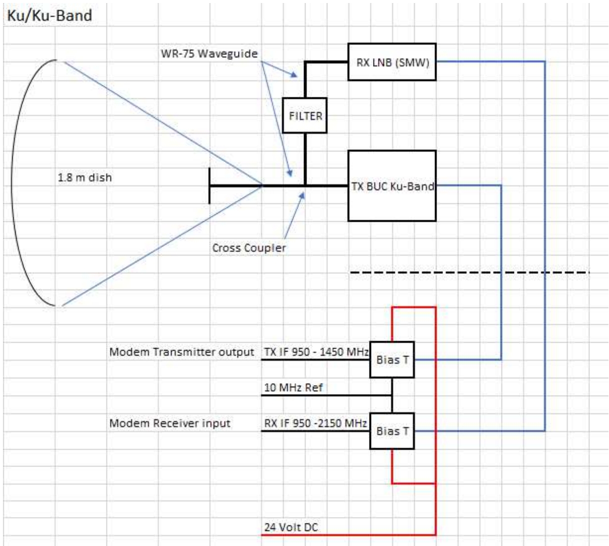

Figure 3. Schematic for Ku/Ku-Band satellite link.

By necessity, the Ku uplink RF power is generated in the block up converter (BUC) and coupled to the antenna feed point using short flexible WR-75 waveguide.

Having satisfied that the Es' hail 2 wideband transponder can be used for experimental TWSTFT transmissions and other research measurements. The following set of modification instructions may be applied incrementally to a single dish antenna Ku/Ku Band satellite station of the type and construction shown in **Figure 1**.

1). Direct LNB trial replacement. Mid-priced PLL stabilised LNB block converters are available, with reduced performance at Es' hail 2 down-link frequencies (~ 10500 MHz). A local oscillator of 9750 MHz produces an IF of 750 MHz. - Replace LNB and obtain downlink signal for initial positional alignment.

2). Replace LNB with a WR-75 waveguide to coaxial converter and Kuhne Electronics MKU LNC 10 QO-100 low-noise converter. The local oscillator is stabilised using a 10 MHz reference through a Bias-T network and is supply voltage dependent requiring DC in the range 18 – 23 VDC. This produces a local oscillator frequency of 9240 MHz converting Ku-band RF input (10490 – 10500 MHz) to (1250 – 1260 MHz) IF. This IF is suitable for SDR reception and for general signals monitoring using a commercial satellite modem such as a Comtech CDM-570AL.

3). Replace existing Ku/Ku waveguide system feed from the antenna focus. Replace with a dual band Ku/S-Band antenna feed such as the one shown in **Figure 4**. This dual antenna feed system is designed for use in front of a prime focus dish with an f/D = 0.4. It comprises a circular horn for 10 GHz linear polarisation and is fitted with orthogonal SMA connector ports on the horn body. A conical PTFE dielectric lens, shown fitted, improves energy concentration on dishes with f/D > 0.6 and may be removed if required. The circular patch antenna immediately in front of the larger circular reflector when energised from a 2.4 GHz source produces left hand circular polarisation (LHCP) which becomes right hand circular polarised after reflection from the dish surface. The 2.4 GHz SMA feed point is immediately behind the large diameter circular reflector plate. This combined antenna feed design is optimised for best return loss (50 Ohm impedance match) at the transmit and receive frequencies and to present common foci to the reflector.

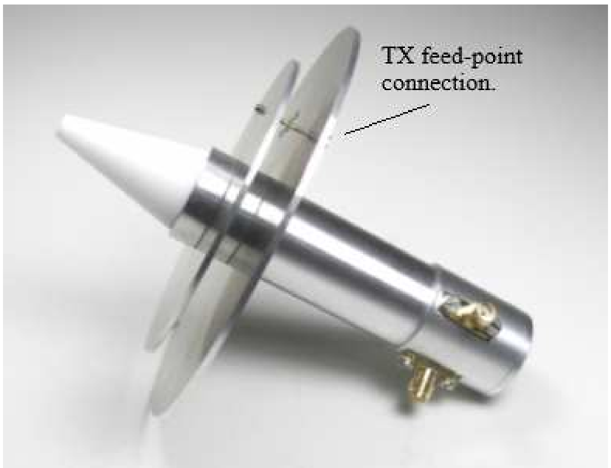

Figure 4. Dual band Antenna showing position of the transmitter connection.

4). S-Band uplink transmission necessitates replacement of the BUC and waveguide section, as no IF is used. The S-band signals are produced at low level (< 0 dBm) directly by the SDR transceiver (or satellite modem) and are carried by low-loss coaxial cable to the antenna installation. See **Figure 5**. The SDR transceiver is frequency stabilised, so no 10 MHz reference or Bias-T is required. The output from the SDR may be combined with signals from a satellite modem and the output bandpass filtered (~2400 MHz) and monitored using a coupled spectrum analyser before power amplification.

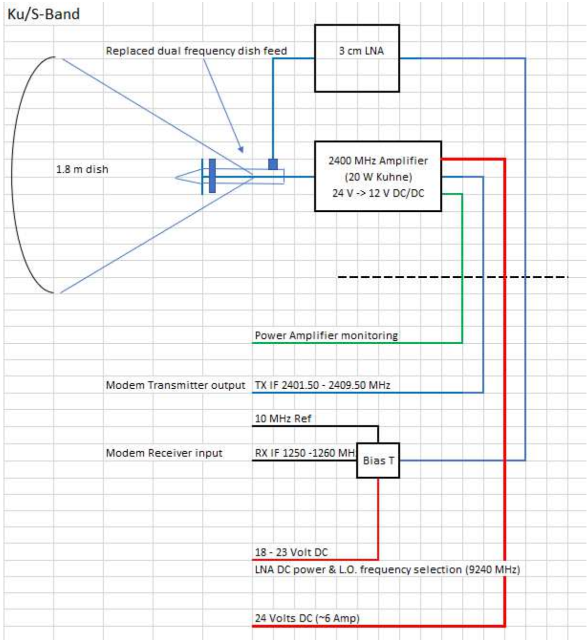

Figure 5. Schematic for Ku/S-Band satellite link after modification.

The S-Band transmitter power amplification is two stages, with a low noise pre-amplifier contributing about 14 dB of gain to overcome cable and component losses and 54 dB gain in the main amplifier block. The Power Amplifier, a Kuhne Electronics KU PA 230250-20 is a GaAs FET amplifier operating in class A, with a supply voltage of 12 -14 Volts.

Table. 2 shows the accumulated gains and losses in the S-Band transmitter chain. This demonstrates that the saturated power amplifier outputs (-1 dB compression points) can be achieved, with SDR or satellite modem operating at well below their maximum rated outputs of +20 dBm and 0 dBm respectively.

Table. 2. S-Band transmitter chain gain/loss.

transmitter chain components f = 2400 MHz (S-Band)	Gain/ - Loss	power (dBm)	power W	power (-1dB) W
SDR/Sat_modem output		7.0		
2 W splitter/ combiner	4.5	11.5		
bandpass filter (2400 MHz)	2.0	13.5		
transmission line coupler	1.0	14.5		
(-10 dB) coupled port to analyser		24.5		
coaxial cable (50 m length)	10.5	25.0		
TX gain stage 1	14.0	11.0		18.5
TX gain stage 2 (main)	54.0	43.0	20.0	24.0

The arrangement for providing DC power to the RF power amplifier requires a separate multicore cable between laboratory and RF power amplifier and conversion from the 24 Volt DC laboratory supply using an isolated DC/DC converter. The isolation barrier eliminates any DC offset caused by the power cable resistive loss and allows the cable to carry RF power amplifier output monitoring signals back to the laboratory.

5 Conclusions

The proposed S-Band transmission and Ku-Band reception satellite terminal comprises a single box and replacement antenna feed. It is capable of full duplex operation using the Es'hail 2 geostationary satellite using an SDR transceiver or satellite modem. An additional screened power and signal cable is required, in tandem with the coaxial cables. This delivers indicative RF power amplifier output monitoring signals to the laboratory.

The use of significantly different uplink and downlink radio frequencies in TWSTFT links compromises reciprocity in the transmission paths. It does however offer further experimental scope for propagation studies using satellite links.

6 Acknowledgements

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