

Frequency Interleaved Modulators to Support Channel Bonding in Satellite Communications

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Abstract—Next generation wireless communication systems such as high throughput satellites and fifth generation mobile communications have promised a step increase in the rate at which data can be transmitted. This would ideally require bespoke modulator designs for the ground stations with wide bandwidths employing expensive high throughput data converters. The next generation communications hardware also need to be backward compatible with legacy systems of lower bandwidths till they are rendered obsolete. In this paper we demonstrate a scheme to generate a wide bandwidth modulated baseband signal with multiple modulators of narrower bandwidths in a satellite communications ground station.

Keywords—Modulator Architectures;

I INTRODUCTION

Next generation high throughput satellite communication systems feature spot beams and channel throughputs up to 500Mbaud [1] with channel bonding and adaptive coding and modulation [3]. ‘Channel bonding’ in a satellite communication (SATCOM) system is a scheme where a single data stream known as the transport stream is transmitted on different RF channels through different transponders lying in the same frequency band.

The throughput of a user terminal at the edge of a SATCOM cell will be more likely to suffer in the event of rain fade or similar adverse conditions. Adaptive coding and modulation would enable the user terminal to change to a lower modulation scheme and higher number of error correction bits to mitigate the drop in the available carrier to noise ratio in the channel. In order to make the communication link more robust in this way requires an ability to transmit a wider bandwidth signal. It has been proposed to use adaptive modulation schemes with varying channel bandwidths in the emerging satellite communication standards [3]. This is not easily realised using conventional multiple narrowband ground station architectures.

Multi-Frequency Time Division Multiple Access (MF-TDMA) techniques on the forward link of a satellite channel also leads to in-efficiencies in the power amplification. In [3] it is proposed to use a wideband Single-Carrier Frequency Division Multiple Access (SC-FDMA) technique to mitigate this problem.

The bandwidth per beam of a Next Generation High Throughput Satellite (NG-HTS) is expected to be of the order of 500 MHz [6] i.e. 250 MHz per polarization. The Next Generation Satellite Ground Stations will also need to support legacy satellite communication systems till they are rendered obsolete. Realizing wide signal bandwidths can be achieved

with frequency interleaved modulators such that their modulated outputs are frequency translated in the same band to occupy the available spectrum in a continuous manner. Here we present a method to accomplish this task by using multiple modulators of relatively narrower bandwidths and up-converting their outputs to occupy a much wider bandwidth while avoiding interference between individual channels.

II SYSTEM DESIGN

The bandwidth per beam of a Next Generation High Throughput Satellite (NG-HTS) is expected to be of the order of 500 MHz [6] i.e. 250 MHz per polarization. In order to design a widebandwidth baseband modulator for these systems, we require a modulator to provide a single modulated signal continuous over the full frequency band and at low cost. An architecture that can provide this performance but at a lower cost than a single widebandwidth modulator is shown in Figure 1.

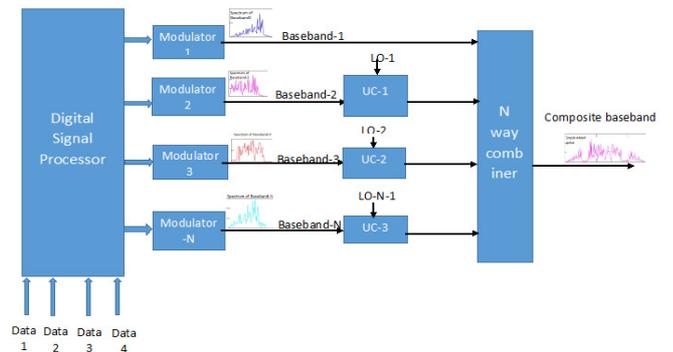


Figure 1 Block Diagram of the proposed scheme

A high level block diagram of the proposed scheme shows a DSP core which receives four individual bit streams as depicted in Figure 1. The DSP core performs the bit level operations on the bit streams such as multiplexing, encoding and interleaving. The N modulators shown in Figure 1 generate the constellation points and provide these to a Digital to Analogue Converter (DAC) to generate the N analogue basebands. Each modulator would need two DACs, one each for the In-phase and Quadrature components of the desired wideband complex modulated signal. Each up-converter is supplied with its respective DAC output and a local oscillator frequency which are mixed to produce a single sideband output signal shifted in frequency. A high level schematic of the Single Sideband Up-Converter is shown in Figure 2. Recent developments of single sideband mixing use poly-phase filters for the quadrature

combiner block. Image rejection factors greater than 80dB achieved with poly-phase filters over a decade bandwidth is presented in [4]. Finally an N-way combiner adds the individual frequency shifted baseband signals to form a single wideband signal.

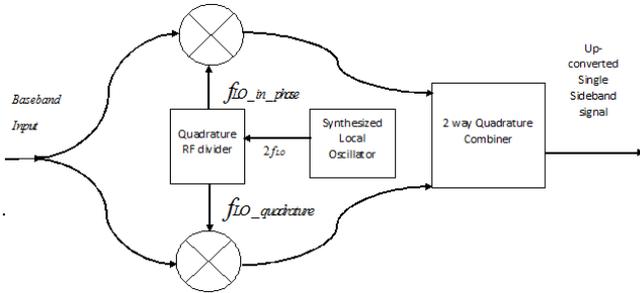


Figure 2 Single Sideband Up-converter

Modelling the mixer;

- a) The most critical element in an up-converter is the RF Mixer. This was modelled as a cascade of an ideal signal multiplier followed by a non-linear block on MATLAB. The non-linearity was modelled in the form of a third order polynomial whose co-efficient values were calculated by performing a curve fitting operation on an estimated set of input-output voltage characteristic of a practical mixer. The input and output voltages were calculated with input and output power levels in a 50 ohms system. The P1dB compression point of the mixer was considered to be +10dBm with a conversion gain of 0 dB. The estimated voltage I/O characteristics are shown in Figure 3.

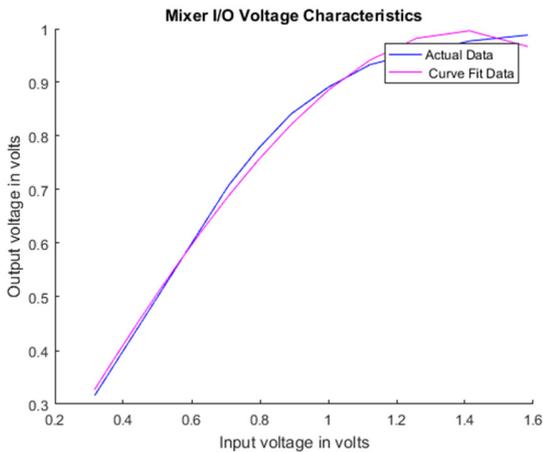


Figure 3 Mixer's Non-Linear Characteristics

- b) The mixer's model on ADS had the figures of +10dBm, +24 dBm and 0dB for the parameters P1dB compression point, conversion gain and third order intercept point respectively. The conversion gain was specified in complex values instead of 'dB' to

simulate the phase shift. The model used for the mixer on the tool ADS is as shown in Figure 4.

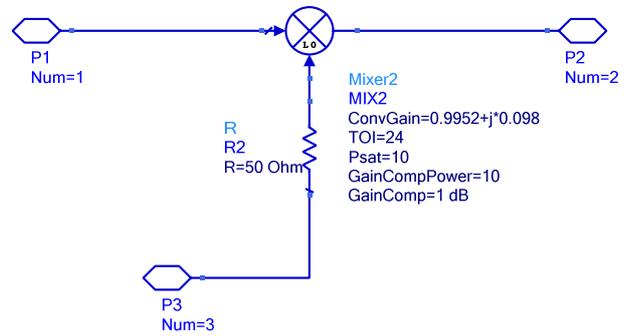


Figure 4: Mixer model used on ADS

Choice of LO frequency:

Let the bandwidth of the intended wide bandwidth baseband signal be 'X' MHz. The spectrum of the baseband extends from DC to the higher limit of the bandwidth. Considering the proposed scheme for a case of generating this wide bandwidth baseband signal with bandwidth two interleaved modulators of equal bandwidth, the two modulators would generate basebands in the spectral space DC to X/2 MHz and the output of the second modulator needs to be up-converted to the sub-band X/2 MHz to X MHz in order to accomplish the task of generating a single wide-bandwidth baseband occupying the spectral space between DC and X MHz. This could have two choices for the Local Oscillator.

- i) LO frequency selected at X/2 MHz: In this case, the mixing components at the output of the up-converter would fall in the sub-bands DC to X/2 MHz and X/2 to X MHz with the latter being the desired component and the former being the image. In this case, the image will occupy the same spectral space as that of the baseband generated by the first modulator which is undesirable since infinite image rejection is not practical.
- ii) LO frequency selected at X MHz: In this case, the mixing components at the output of the up-converter would fall in the sub-bands X/2 MHz to X MHz and X MHz to 3X/2 MHz with the former being the desired component and the latter being the image. In this case, the image will occupy the spectral space outside the band of interest. The image components now occupy a band which is less than an octave wide and could be rejected with relative ease using Single Sideband mixing. Image rejection factors greater than 80dB achieved with poly-phase filters over a decade bandwidth is presented in [4]. This will however result in spectral inversion of the baseband after up-conversion. This could be compensated by inverting the spectrum of the baseband components digitally before up-conversion, as illustrated in Section III.

The amplitudes and phases of the paths of in-phase and quadrature components of the basebands have to be balanced. It is also essential to maintain a common reference signal for all modulators. The modulators are built using digital to analogue converters (DACs) whose outputs are subject to sinc rolloff. The side lobes generated as a result of the sinc rolloff components of the primary and the secondary basebands (after up-conversion to adjacent sub-band) will fall in the spectra of one-another which can be compensated digitally [5]. The other critical parameters that affect the quality of the generated baseband are the quantization noise of the DAC, the timing jitter of the clock, the phase noise of the local oscillator and spurious mixing products of the mixer. The image rejection factor of each up-converter has to be better than the required carrier to noise ratio for the selected modulation scheme.

The advancement in digital up-converter technologies makes it possible to accomplish the task using digital up-conversion techniques. This is however an expensive approach at present considering the overall bill of materials which would be more than twice the cost of the proposed analogue system. The impairments in the proposed scheme may be compensated digitally as detailed in [5].

The proposed scheme could be applied to either generate a single carrier wide bandwidth baseband or a composite baseband with multiple phase-correlated carriers with varying bandwidths using legacy modulator hardware.

- i) Case for Single Carrier Wide Bandwidth Baseband Generation: Transmission of Ultra High Definition Video Transport Streams through a single wideband satellite transponder. This is expected to be a case with Next Generation High Throughput Satellites.
- ii) Case for composite baseband with multiple phase-correlated carriers: The DVB-S2X standard specifies ‘Channel Bonding’ as a feature to be supported with Next Generation Digital Video Broadcasting through Satellite. This involves transmitting the content through two or more channels in the same beam and same band. The receiver design would involve down-conversion and filter-banks to extract the frequency components of interest and their demodulation.

Other cases involve applications with dynamic bandwidth allocation and adaptive modulation and coding where the bandwidth allocated to a terminal could increase to support transmission at lower modulation schemes due to a drop in the available Carrier to Noise Ratio (CNR) caused by environmental factors such as rain fade. In addition, the proposed scheme could also be applied to generate wide-bandwidth basebands necessary for applications like digital pre-distortion.

III SIMULATIONS AND RESULTS

Simulations were carried out with MATLAB and Keysight ADS for the two cases described in the previous section. For convenience, no error correction schemes were employed to be able to study the errors caused by the simulated hardware.

The process followed to simulate the generation a wideband signal with two bandwidth interleaved modulators is as detailed below:

- a) Generate the intended wideband signal in MATLAB with the required modulation parameters.
- b) Plot the FFT of the generated baseband and extract the frequency components meant for each modulator.
- c) Invert the spectrum of the baseband frequency components meant for the second modulator.
- d) Generate the IFFT of the separated baseband frequency components and apply to the two modulators. Save the IFFT values in files to export to ADS or similar RF simulation tools.
- e) Up-convert the output of the second modulator and combine it with the output of the first modulator.
- f) This process needs to be carried out for both ‘In-phase’ and ‘Quadrature’ components of the desired complex modulated wideband signal.

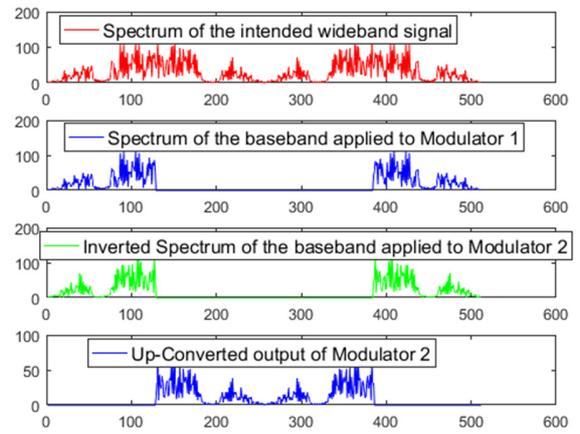


Figure 5: FFT Plots of the intended wideband signal, separated and up converted spectral components

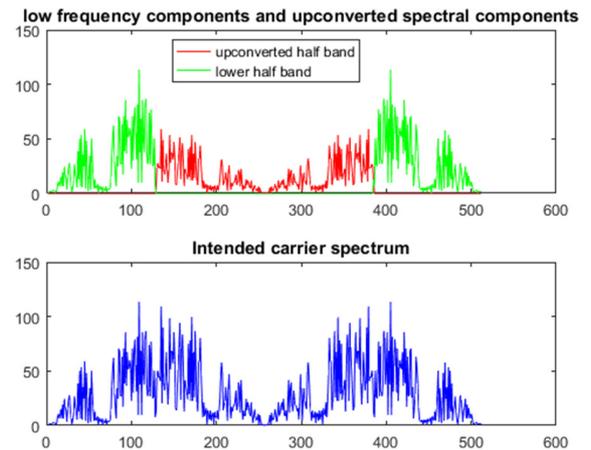


Figure 6: FFT of the spectral components combined to get the intended wide bandwidth signal

The proposed scheme was simulated successfully in MATLAB and ADS where four 8PSK modulated basebands were interleaved.

Baseband data files were created in MATLAB and exported to ADS where up-conversion and signal aggregation were performed. The up-converted signal was exported to MATLAB for comparison with an ideal composite waveform generated directly in MATLAB. Both signals were demodulated and their respective BER measured in each case in which no errors were detected.

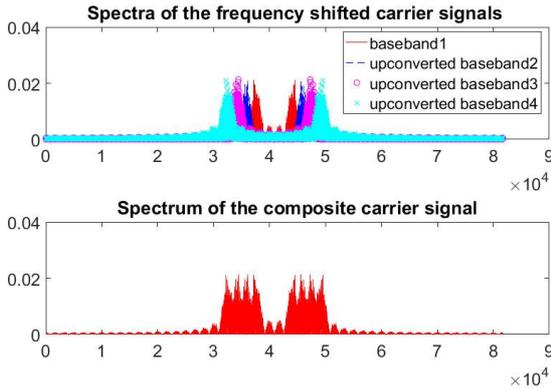


Figure 7 FFT plot (spectrum) of frequency interleaved 8PSK basebands

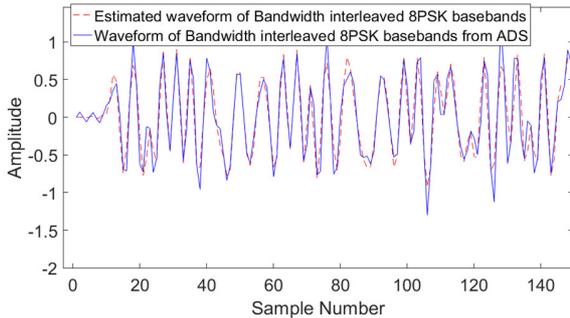


Figure 8 Waveform comparison of frequency interleaved 8PSK basebands.

The process of generating a single wideband 8PSK and 16PSK signals with interleaved modulators was also successfully simulated in a manner similar to that explained above. These modulation schemes were selected to study the suitability of the

proposed scheme to generate higher order modulated signals with circular constellations since the DVB-S2X standards recommend such constellations for next generation broadcast transmitters. In order to evaluate the sensitivity of the proposed approach to phase mismatches, a phase offset of $\pi/32$ radians was introduced in the up-conversion paths of the interleaved 16PSK and 8PSK modulators. This resulted in Bit Error Rate figures of '0.085' and '0.033' respectively on demodulation. It could be inferred that the maintenance of phase balance is critical to the quality of the signal generated. This could be achieved through digital phase compensation techniques.

IV CONCLUSION

The proposed scheme was demonstrated in simulation and comparable performance was achieved to that of direct wide bandwidth signal modulation. Inherent from its architecture, the proposed technique is scalable and adaptable as to increase the modulator bandwidth further requires only the inclusion of additional up-conversion stages.

V ACKNOWLEDGEMENT

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