Wideband Interleaved Vector Modulators for 5G Wireless Communications

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***Abstract*—Next generation wireless communication systems such as fifth generation mobile communications and high throughput satellites have promised a step increase in the rate at which digital data can be transmitted. This requires wideband modulators consisting of high speed digital to analogue converters and RF up-converters to generate the wideband signal of interest. In this paper we demonstrate a scheme to generate a wide bandwidth modulated signal by bandwidth interleaving multiple modulators of narrower bandwidths. The proposed scheme is experimentally validated with measured results on an 8PSK signals of symbol rate 80 MSPS with modulation characteristics in accordance with DVB-S2 standard.**

Keywords—Modulator Architectures

I. INTRODUCTION

Modern wireless hardware employs digital modulation schemes where the digital data to be transmitted is vector modulated on Radio Frequency (RF) carrier signals. A block diagram of a typical vector RF modulator is shown in Fig. **1**. In general the wireless transmitter consists of a digital signal processor (DSP) that generates the vector modulation symbols in response to digital data applied to its input port that is intended to be transmitted. The digitally generated modulation symbols are applied to a pair of Digital to Analogue Converters (DACs) which generate the equivalent analogue baseband signals. These analogue baseband signals are up-converted to the required RF carrier frequency and the resulting RF carrier may be further processed for transmission.

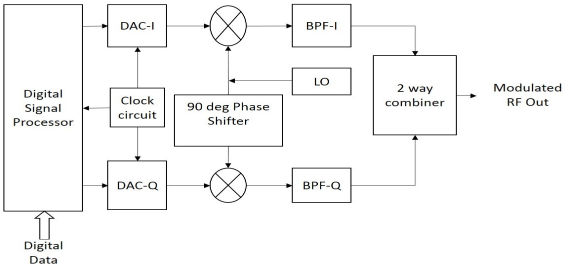

Fig. 1. Block Diagram of a Vector RF Modulator

The maximum bandwidth of the signal generated is limited by the maximum sample rate of the DACs. The bandwidth limiting filtering schemes such as Root Raised Cosine (RRC) filters also involve up-sampling the digital baseband before application to the DACs which further raises the requirement of the sampling rate of the DACs involved. Future radio communication systems such as 5G and High Throughput Satellite (NG-HTS) would feature bandwidths higher than 50 MHz per carrier [1, 2]. The cost of implementation of the system increases with increase in the speed of the DACs. A popular method to generate wide bandwidth signals is to employ multiple DACs of lower speeds by interleaving them in the time domain. An alternate method is to interleave the DACs in the frequency domain where each DAC is used to generate a part of the desired signal spectrum and the parts are frequency translated by up-conversion to occupy the required spectral space [3, 4]. Performing wideband signal generation in this way requires additional signal processing operations such as filtering and pre-compensation of mutual interference [3]. In this paper, we propose a scheme to implement generation of a wideband modulated RF carrier with bandwidth interleaved modulators without the need for an external filter and without the need for prior knowledge of mutual interference by an appropriate calibration of the paths.

The remainder of this paper is arranged as follows: In section II we describe the proposed wideband signal generation with path calibration to mitigate mutual interference and maintain the required gain and phase characteristics over the band of operation. The experimentally measured results to validate the technique are presented in section III. Finally in section IV we cover the main conclusions from this work.

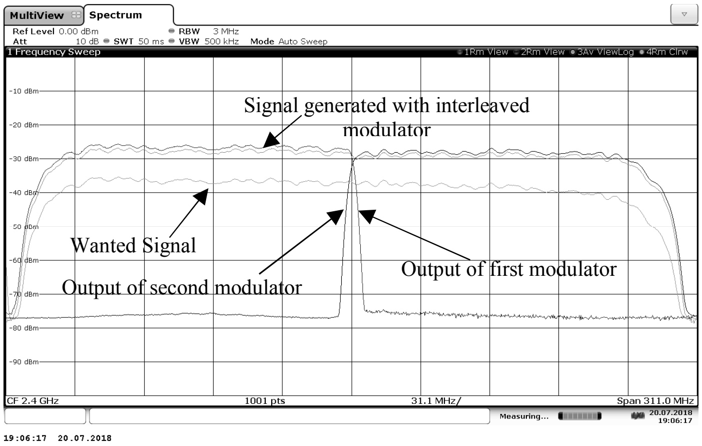
Ref Level 0.00 dBm
Att 10 dB SWT 50 ms
RBW 3 MHz
VBW 500 kHz
Mode Auto Sweep
CF 2.4 GHz
1001 pts
31.1 MHz/
Span 311.0 MHz

Fig 2. Wideband signal generated in parts and combined at 2.4 GHz

II. SYSTEM DESIGN

The proposed scheme of generating a wideband vector modulated signal with bandwidth interleaved modulators employing DACs of lower speeds is illustrated graphically in Fig **2**.

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Consider for example the generation of a bandpass signal which is 8PSK modulated at a symbol rate of 80 MSPS with RRC filtering requirement having a roll off factor ($\alpha = 0.2$) and an up-sampling factor of 4. This signal would have a resultant bandwidth of 96 MHz (80MHz X 1.2) and requires a DAC of sample rate of 320 Msps in the ‘I’ and ‘Q’ paths respectively of the modulator shown in Fig. 1. This signal could be generated using two bandwidth interleaved modulators such that the first modulator generates the lower half of the required spectrum and the second modulator generates the upper half of the required spectrum and the two parts are combined to yield the desired 8PSK signal employing the architecture depicted in Fig 3. DACs I1 and Q1 with the first pair of quadrature mixers and LO1 form the first modulator. DACs I2 and Q2 with the second pair of quadrature mixers and LO2 form the second modulator.

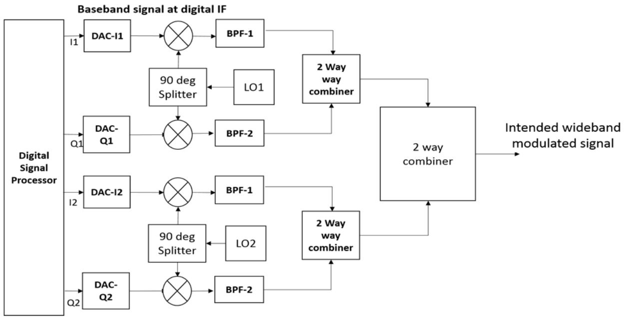

Fig 3. Proposed scheme of bandwidth interleaved modulators

The steps involved in generating the intended wideband signal are as listed below.

i) Frequency translate the digital baseband to a digital intermediate frequency (IF) centred at ¼ of the original sampling frequency ‘F_s’ by multiplying the real part of each complex baseband value with the cosine of the digitally generated carrier and multiplying the imaginary part of each complex baseband value with the sine of the digitally generated carrier. The resulting digitally frequency translated cosine and sine basebands are added. This signal is designated as ‘I_IF’.

ii) Generate the Hilbert Transform of the signal in step ‘i’ by multiplying the real part of each complex baseband value with the sine of the digitally generated carrier, inverting the sign and multiplying the imaginary part of each complex baseband value with the sine of the digitally generated carrier. Add the resulting digitally frequency translated cosine and sine basebands. Let this signal be designated as ‘Q_IF’.

iii) Obtain the Fast Fourier Transform (FFT) of the signal generated in steps ‘i’ and ‘ii’.

iv) Extract the frequency components at frequency bins from ‘0’ to ‘$F_s/4$, and ‘$3F_s/4$’ to ‘F_s’ from the FFT of signals generated in steps ‘i’ and ‘ii’. These represent the lower half of the spectral content to be generated. Obtain the Inverse Fast Fourier Transform (IFFT) of the extracted frequency components. Let these signals be designated as ‘I_Low’ and ‘Q_low’ respectively. Add the imaginary part of ‘I_Low’ to the real part of ‘Q_Low’ to form the signal ‘I_bb1’. Subtract the imaginary part of ‘Q_Low’ from the real part of ‘I_Low’ to form the signal ‘Q_bb1’. ‘I_bb1’ and ‘Q_bb1’ thus generated would have the same magnitudes but quadrature phases.

v) Extract the frequency components at frequency bins between ‘$F_s/4$, and ‘$3F_s/4$’ F_s’ from the FFT of signals generated in steps ‘i’ and ‘ii’. These represent the upper half of the spectral content to be generated. Obtain the Inverse Fast Fourier Transform (IFFT) of the extracted frequency components. Let these signals be designated as ‘I_High’ and ‘Q_High’ respectively. Add the imaginary part of ‘I_High’ to the real part of ‘Q_High’ to form the signal ‘I_bb2’. Subtract the imaginary part of ‘Q_High’ from the real part of ‘I_High’ to form the signal ‘Q_bb2’. ‘I_bb2’ and ‘Q_bb2’ thus generated the signal will have the same magnitudes but quadrature phases.

The next stage is to calibrate the four signal paths for consistency in their amplitude and phase relationship to maintain the integrity of the generated wideband signal.

vi) Apply the half bandwidth signals thus generated to the respective DACs. Set the frequency of Local Oscillator ‘LO2’ to the intended carrier frequency ‘F_c’ and the frequency of Local Oscillator ‘LO1’ lower than ‘F_c’ by an amount equal to the ‘IF’ chosen. LO1 and LO2 need to be phase locked to a common reference oscillator.

vii) Disable LO2 temporarily and observe the up-converted and combined outputs of DAC I1 and DAC Q1 on a spectrum analyzer. The quadrature relation between paths I1 and Q1 will ideally cancel out the up-conversion image that would fall at frequencies above that of ‘F_c’. If the image components have not fallen at least 55 dB below the desired frequency components, sweep the gain and phase of the signal in path Q1 till the image components are attenuated by at least 55dB below the wanted frequency components occupying the band between ‘F_c-BW/2’ to ‘F_c’ This calibrates the amplitude and phase relations between signal paths ‘I1’ and ‘Q1’. Record the tuned amplitude and phase shift values.

viii) Now disable LO1 temporarily and enable LO2. Repeat the calibration procedure illustrated in ‘viii’ with signal paths of ‘I2’ and ‘Q2’ The wanted frequency components in this case will occupy the frequency band from ‘F_c’ to ‘F_c +BW/2’ and the image will occupy the band between ‘F_c +BW/2’ and ‘F_c’. This calibrates the amplitude and phase relations between signal paths ‘I2’ and ‘Q2’. Record the tuned amplitude and phase shift values.

ix) As the next step it is necessary to calibrate the amplitude and phase relationships between the 2 modulators. Generate a single cosine wave digitally at a frequency equal to ‘(LO2-LO1)/2’ and apply to DACs in paths I1 and I2 in a time interleaved manner i.e. apply the tones to the DACs at mutually exclusive intervals. This will result tones that at a common frequency equal to ‘(LO1+LO2)/2’. Now acquire the tones using a vector down-converter or I-Q capture in a signal analyzer. Obtain the difference in the amplitudes and phases between the two sinusoids acquired. Append the difference in amplitude values in this step to those obtained in step ‘ix’ for paths ‘Q2’ ‘I2’. Rotate the complex basebands applied to paths ‘I2 Q2’ by the measured phase difference.

In addition to these, Bandwidth dependent amplitude and group delay calibration needs to be performed as illustrated in [5, 6]. Sinc response compensation is also required for the four DACs. This procedure is readily available from literature supplied by vendors of DAC components. Applying the calibration coefficients for amplitude and phase obtained in steps ‘viii’ to ‘x’ to the half bandwidth baseband signals generated in ‘iv’ and ‘v’, set the local oscillators to frequencies specified in step ‘vii’ to yield the desired wideband modulated RF carrier.

III. EXPERIMENTAL VALIDATION

The proposed scheme was employed to generate an 8PSK signal of bandwidth 96 MHz at a symbol rate of 80Msps, RRC filtering with roll off factor of 0.2 and oversampling ratio of 4 requiring a sample rate of 320 MSPS. The intended carrier frequency was set at 2.32 GHz for which a digital IF of 80 MHz was chosen. This was further up-converted to Ku-band at 14.23 GHz. This signal was generated using two calibrated and bandwidth interleaved modulators that employed DACs of 160MSPS. The demodulated constellations are shown in Fig 5. The Error Vector Magnitude (EVM) reported were observed were 5.44% and 5.96% respectively for the original signal generated with a wideband modulator and for the signal generated with bandwidth interleaved modulators. Additionally, the scheme was extended to generate a 300 MHz wide 8PSK signal at a symbol rate of 256Msps using bandwidth interleaved modulators at symbol rate 320MSPS whose spectrum captured on Rohde and Schwarz ‘FSW’ is shown in Fig 2. The original sample rate was 640 MSPS. Due to non-availability of demodulation option in the instrument, the internally down-converted and digitized I and Q components were captured at zero IF at a sample rate of 1.28 GSPS and exported to MATLAB where they were filtered, correlated digitally and plotted for comparison as shown in Fig 4.

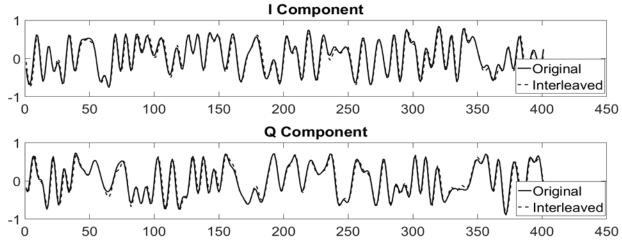

Fig 4. Comparison of down-converted IQ waveforms of the original signal and that generated with interleaved modulators.

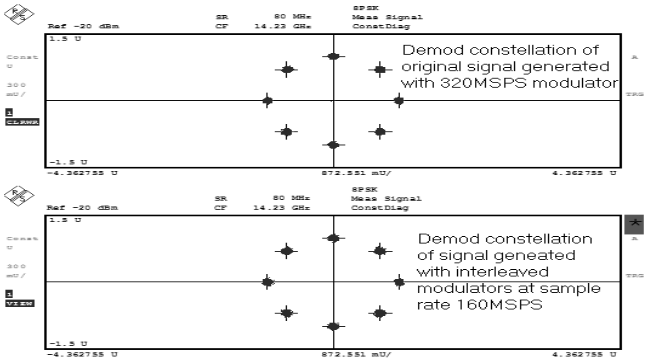

Fig 5. Demodulated Constellations observed on the Vector Signal Analyzer ‘FSQ’ of Rohde and Schwarz

IV. CONCLUSION

The proposed scheme for wideband signal generation using lower bandwidth modulators has been demonstrated. Comparable performance is achieved to that of direct wide bandwidth signal modulation. Inherent from its architecture, the proposed technique is scalable and adaptable to increased modulator bandwidths as it requires only the inclusion of additional up-conversion stages. This enables the use of existing low bandwidth modulators for wideband modulated signal generation where a high data rate DAC is prohibitively expensive or not available.

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