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Extreme Wideband Arbitrary Waveform Generator Based on Frequency Multiplexing

Andreas Czylwik, Stefan Bieder, and Marius Sichma
Chair of Communication Systems, University Duisburg-Essen, Duisburg, Germany

Abstract

An arbitrary waveform generator with a bandwidth of 60 GHz is presented. The extreme wideband signal is created by frequency-multiplexing of three wideband signals with a bandwidth of 20 GHz, each.

1. Introduction

Systems enabling radio transmissions with 100 Gbit/s and beyond require measurement and test systems with bandwidths of multiple tens of GHz. For development purposes, signals may be generated off-line and created with arbitrary waveform generators (AWGs). Today, arbitrary waveform generators are commercially available up to bandwidths of 32 GHz using a sampling frequency of 92 GHz [1]. For highest date rate communications this may not be sufficient so that there is a need of AWGs with even larger bandwidths.

Current AWGs typically utilize time-domain signal processing, using non-interleaved digital-to-analog converters [2] as well as time-domain multiplexing of half-rate pulse sequences [3]. In [4] even four quarter-rate pulse sequences are multiplexed in the time-domain. These systems achieve sampling rates of 72 GHz, 80 GHz and 100 GHz, respectively. The correponding spectra achieve bandwidths of up to 40 GHz [3].

In contrast to these approaches in the time domain, the authors presented in [5] and [6] AWG systems with a bandwidth of 40 GHz by frequency-multiplexing of two extreme wideband signals. This work is continued in the present paper where a signal bandwith of 60 GHz is achieved by frequency multiplexing of three 20 GHz signals.

2. System concept

The proposed system is based on the commercially available AWG Keysight M8195A which provides four channels with a sampling rate of 65 GHz and output bandwidth of 20 GHz, each. The block diagram is shown in Fig. 1. Three channels of the AWG are used to create signals with a bandwidth of 20 GHz, each. The fourth AWG channel is used to create the 20 GHz and 40 GHz carrier signals which are used to up-convert the AWG output signals to the frequency ranges 20 GHz … 40 GHz and 40 GHz … 60 GHz.

The blocks to the left of the AWGs show the digital pre-processing. In the digital domain, the input samples are divided into three subbands, each with a bandwidth of 20 GHz. The combination of bandpass filter (BPF), mixer, and low-pass filter (LPF) creates an IF signal with frequency components between 0 and 20 GHz. The blocks AWG-comp compensate the frequency response of the AWGs.

On the right-hand side of the AWGs the analog hardware components are shown. AWG_1 directly creates the output frequency components between 0 and 20 GHz. The output of AWG_2 is up-converted by multiplying with a 20 GHz LO signal and high-pass filtering (HPF_2) so that only the upper sideband is fed to the final adding device. The task of the high-pass filter is to separate upper and lower sideband what cannot be done perfectly with a practical analog high-pass filter. Therefore, some distortions will be created in the frequency range 0 to 20 GHz.

Tfor compensation, these distortions are created in the digital domain in the same way as in the analog domain. Finally, only the distortions, which are separated by the low-pass filter (in the frequency range 0 … 20 GHz) are subtracted in the digital domain from the upper signal path.

The same concept of signal generation is used for the frequency range 40 GHz … 60 GHz. Also unwanted distortions created by the non-ideal high-pass filter HPF_3 (lower sideband) are compensated by creating corresponding signal components in the digital domain and subtracting them in the digital domain from the signal component created by AWG_2.

The compensation of unwanted signal components requires that these signal components are calculated very precisely. An amplitude error of 0.8 dB or a phase error of 6 degrees reduces the achievable compensation gain to approximately 20 dB.

3. Models and measurements of model parameters

Most components in the block diagram of Fig. 1 are linear components. These components can be measured with a regular network analyzer – also with the required high precision. The measurement precision is significantly better than required according to a compensation gain of 20 dB.

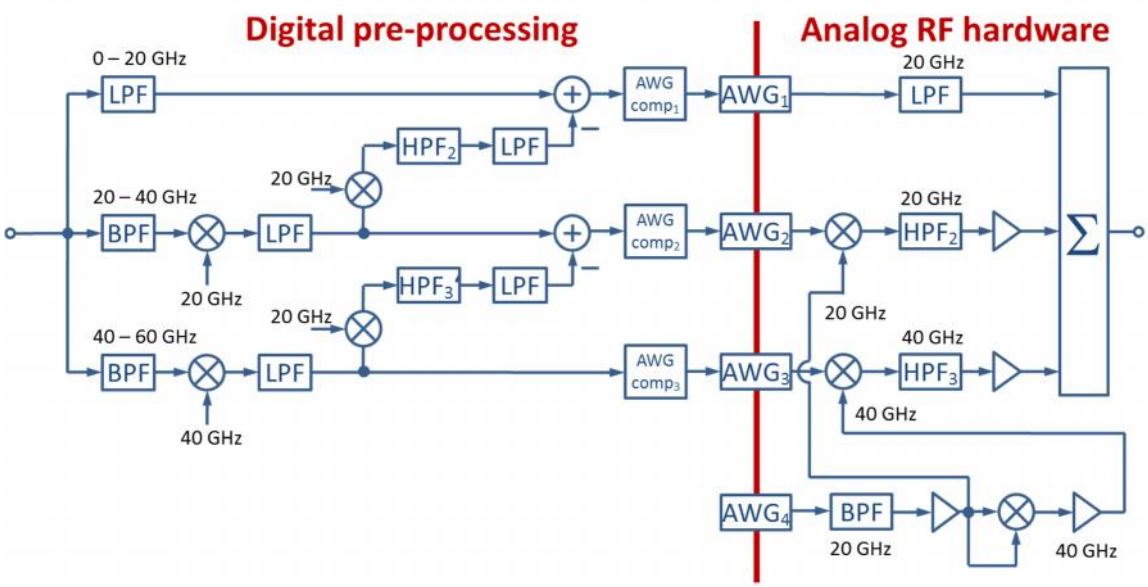

Figure 1. Block diagram of the extreme wideband AWG based on frequency multiplexing.

On the other hand, there are hardware mixers in the block diagram which have to be described corresponding to their frequency-shifting properties. This measurement has been carried out in the time domain by using a high-speed (60 GHz) oscilloscope and doing a Fourier analysis to find out the frequency response of upper and lower sidebands. The general model of a high-frequency mixer which is operated with a fixed LO frequency is shown in Fig. 2. The corresponding block diagram consists of two linear filters, one at the input , the second at the output of the mixer.

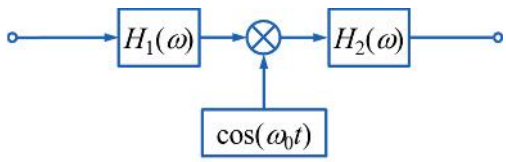

Figure 2. Model of a frequency-selective mixer.

A positive aspect with respect to the high reqired precision is that the bandwidth of high precision corresponds only to the bandwidth of the distorting signal components. Since they are created by the finite slope of the transfer function of the high-pass filters HP_2 and HP_3, practically a good compensation is necessary only for a bandwidth of less than 1 GHz.

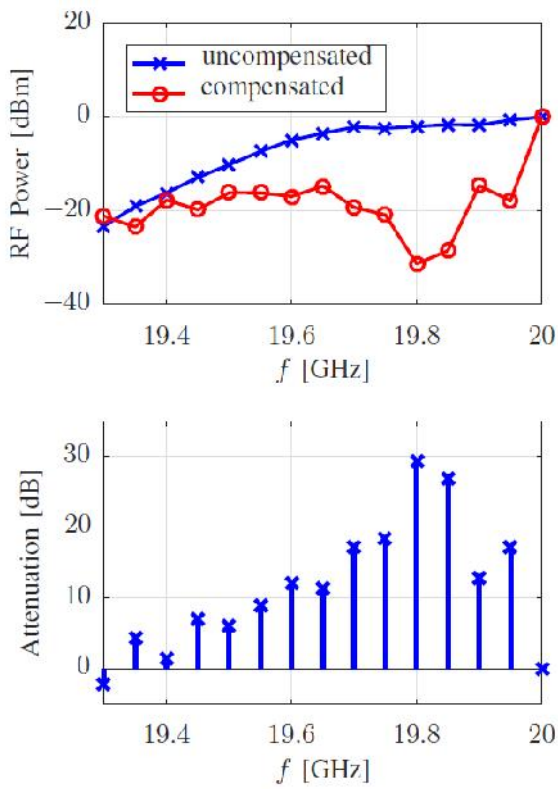

Figure 3. Measured distortion power created from the non-ideal highpass filter HP_2 creating lower sideband components with frequencies less than 20 GHz (top). Compensation gain (attenuation) of the lower sideband components versus frequency (bottom).

4. Performance measurement results

The upper part of Fig. 3 shows the lower sideband spectrum of the created distortion (blue) and the spectrum after compensation of the distorting components. Obviously, the distorting frequency components can be significantly reduced. The lower part of Fig. 3 shows the achieved compensation gain.

Clearly, most critical are signals which have their spectral components concentrated at the transition frequencies between the three frequency bands. Fig. 4 shows the spectrum of a test signal with frequency components close to 20 GHz.

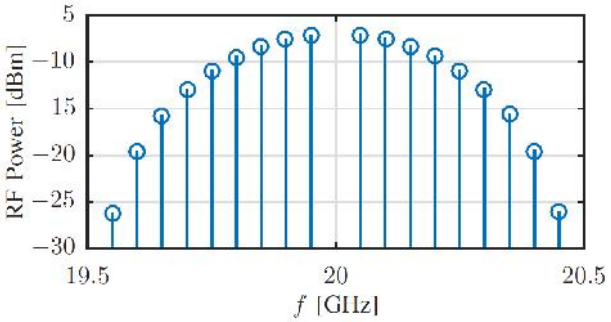

Figure 4. Test signal with frequency components close to 20 GHz.

For the test signal of Fig. 4, Fig. 5 shows the created power spectra without and with compensation of distortions in the lower sideband. Furthermore, due to the AWG frequency response compensation filters, also the spectrum at frequencies higher that the transition frequency is corrected.

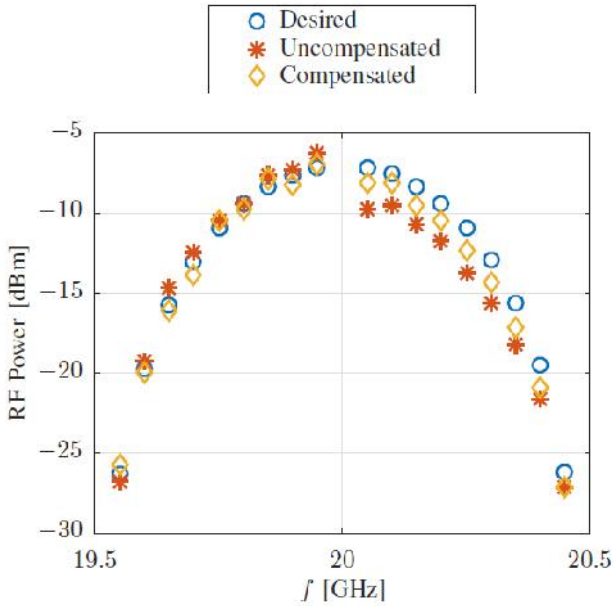

Figure 5. Measured output spectrum for the test signal according to Fig. 4.

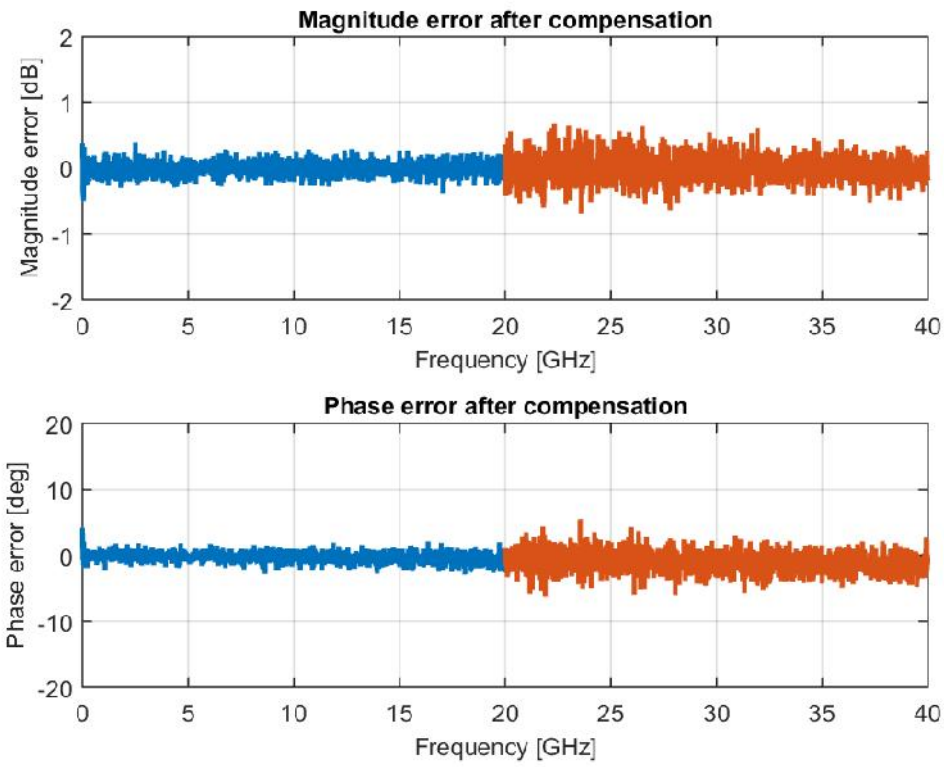

Figure 6. Overall frequency response for a wideband (white) multicarrier signal.

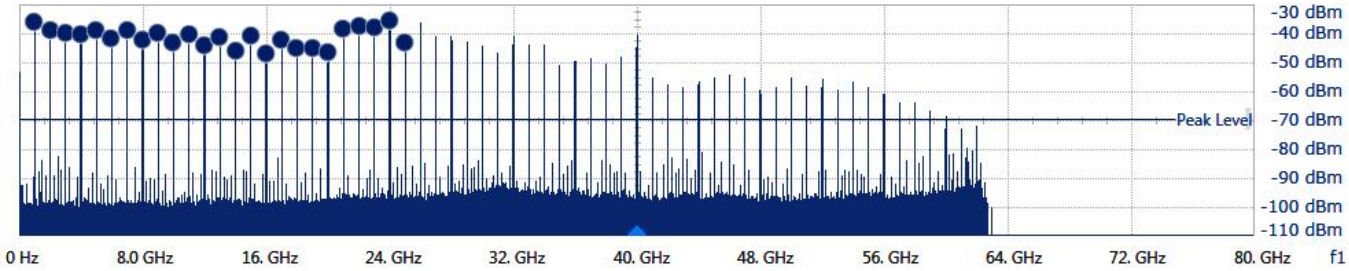

Figure 7. Measured output spectrum for a 60 GHz multicarrier signal.

Fig. 6 shows the overall frequency response for the double-band operation. It can be observed that amplitude errors are less than about 0.5 dB and phase errors are less than about 4 degrees over the whole frequency range from 0 to 40 GHz.

Finally, Fig. 7 shows a preliminary result for the three-band operation. Here, a spectrum with a 60 GHz bandwidth has been successfully created. The power density of this spectrum decreases with increasing frequency, since the frequency response compensation for the three-band operation has not been implemented yet.

5. Summary

The basic operation of an extreme wideband AWG with multiband signal generation has been demonstrated. The compensation of intraband distortions has been shown. Furthermore, a low frequency selectivity could be achieved by frequency response equalization.

6. Acknowledgements

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7. References

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