

Harmonic Phase Reference for Measurement of Modulated Signals with a Nonlinear Vector Network Analyzer

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Abstract—While performing measurements of modulated signals with the nonlinear vector network analyzer (NVNA), a harmonic phase reference (HPR) with known phase spectrum is needed. Up to now, comb generators are used to synchronize vector measurements of nonlinear signals. Dense amplitude spectra of modulated signals enforce low repetition rate of the comb train, thus, the signal-to-noise ratio of each frequency component becomes very small and deteriorates the measurements accuracy. In addition, the peak amplitude of pulses cannot be increased in order not to push the measurement receivers into a nonlinear operation. One of the solutions is to modulate the pulse train, which allows to concentrate energy in desired spectrum components of kilohertz spacing around the carrier (gigahertz) and its harmonics. However, there is a challenge to get to know the phase spectrum of modulation sequence, depending on the measurement task. The paper describes the research results of implementing the HPR as a modulated pulse sequence generator. This research was done in the framework of the MTT-S Undergraduate Scholarship.

Index Terms—comb generator, modulation, phase calibration, nonlinear measurements

I. INTRODUCTION

Measurements performed with nonlinear vector network analyzer (NVNA) allow to reconstruct a time-domain signals based upon measured spectra. Both amplitude and phase relationships are needed. Up to these days, comb generators are used to obtain broadband spectrum with certain frequency spacing. In order to accurately calibrate NVNA for modulated signals measurement at RF frequency, with modulation frequency tones of kilohertz level around the carrier and its harmonics of gigahertz frequency, phase reference is needed. Using periodic pulse-shaped signals, such as comb train, it is unworkable to provide required signal-to-noise ratio due to the long time space between pulses [1]. It is also impossible to increase the peak amplitude of single pulse, since the NVNA receivers need to work in the linear range. Hence, the accuracy of the measurement is very low.

The possible solution is to use modulated pulse-shaped signals, that significantly increase the required signal-to-noise ratio at desired frequencies [2]. It allows to concentrate the energy at interesting tones around certain carrier and its harmonics. There are some algorithms used to obtain the appropriate modulation bit sequence. Evaluated methods with best results are presented further in Section II of this paper.

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In order to perform accurate measurements, well-known phase standard is needed for all spectrum components. It allows to get phase relationships of desired tones in measured signal. To do this, phase spectrum of used modulated pulse-shaped signal has to be exactly known. However, bit sequence is changing from measurement to measurement, thus, phase spectrum is changing analogously. Evaluating amplitude spectrum of phase reference sequence does not have to be performed very accurately (just maximization energy of desired tones without exact values), whereas phases of interesting spectrum components have to be precisely determined. The results of calculating phase spectra of phase reference are shown in Section III.

II. COMPARISON OF SEQUENCE-SYNTHESIS METHODS

Four methods were considered: Pseudo-Random Bit Sequence (PRBS), Schroeder Phases sequence, Random Phase sequence, Genetic Algorithm sequence.

One can concentrate energy either in multitones, or in selected tones around the certain carrier. PRBS and Schroeder phase methods allow to maximize only multitones, whereas Random phase and Genetic Algorithms methods can be use also for selected tones.

Number of measurements were performed in order to evaluate available sequence methods. The sequences were calculated with computer using Matlab scripts for each method. Then, the sequence of bits was generated with an Arbitrary Waveform Generator (AWG) and the phase spectrum was observed on the spectrum analyzer. The power of desired tones was compared for each method. The results of methods comparison for the carrier frequency of 1 GHz and modulation tones of 20 kHz are set together in table I. All methods allow to attain comparable results in power spectrum.

PRBS method is relatively easy to implement in hardware. Average power of -43.51 dBm is close to best result for Random method. However, it is impossible to obtain arbitrary frequency components due to the discrete length of the sequences.

Schroeder phases method is relatively easy to implement in software. The calculations are fast and the obtained sequence is repetitive.

Random phase sequence allows to get high power components of -39.59 dBm average power, calculations are a bit complicated and not repetitive.

Genetic Algorithms method is the best for selected tones. The minimum power of -44.64 dBm is improved by around

Table I
RESULTS OF COMPARISON OF SEQUENCE-SYNTHESIS METHODS

Methods	Min. power [dBm]	Avg. power [dBm]	Calculation time [s]
PRBS	-47.02	-43.51	< 0.1
Schroeder	-47.40	-41.89	< 0.5
Random	-47.44	-39.59	< 0.5
Genetic Alg.	-44.64	-42.76	63

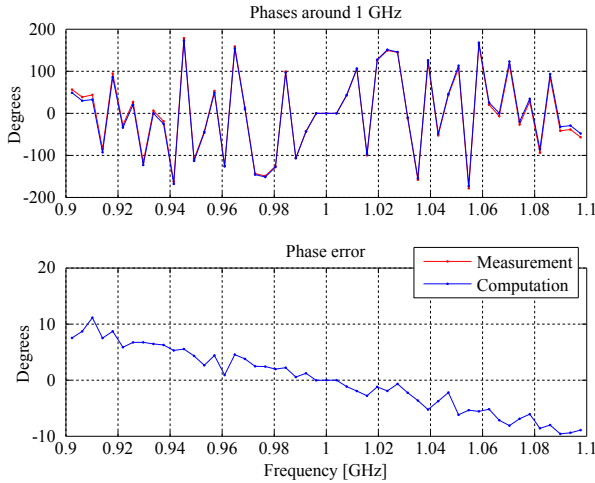


Figure 1. Phase spectra of synthesis sequence and measured signal with error

3 dB compared to other methods. One can concentrate energy in desired spectrum components. However, calculations are complicated and time-consuming.

In the further steps two methods are considered: Schroeder phases for multitones and Random phases for selected tones due to the reasonable power spectrum to calculation cost ratio.

III. PHASE SPECTRUM OF SYNTHESIZED SEQUENCES

Phase spectrum of the generated sequence is a key issue that should be precisely specified, as the sequence is used for the phase calibration of the nonlinear measurements of modulated signals. Spectral components are different for various modulated signals, thus, desired frequency tones can be different for other measurement task. That can enforce the change of using bit sequence, which causes phase spectrum change. The measurements of phase spectrum of sequence were performed with sampling oscilloscope, where the effective sampling frequency was over 40 GHz. After the time-domain signals had been captured, the data were proceeded with Matlab to calculate the phase spectrum using FFT.

The results of spectra measurements and computing for 1 GHz carrier and 15.6 MHz of modulation frequency are shown in figure 1. Phase error between measured and computed spectrum is about +/-10 degrees, which means there is some delay. However, there is the capability to get to know the phase spectrum of generated modulated pulse train. Hence, the phase calibration of nonlinear vector measurements for modulated signals is entirely possible. However, there is still much to improve.

IV. CONCLUSIONS

The paper shows capability of phase calibration of nonlinear vector measurements for modulated signals. HPR with modulated pulse train was proposed. Four methods to synthesize the bit sequence depending on the desired frequency tones were presented: PRBS, Schroeder Phase, Random Phase, and Genetic Algorithm. The measurements of generated sequences proved the possibility of phase calibration. The result of the work done is described in a paper submitted to IEEE Trans. Microwave Theory Techn. [3]

As a next step, implementing HPR with modulated pulse train in hardware is planning. The research is a part of my Master Thesis. Thanks to the MTT-S Undergraduate Scholarship the project could be pushed forward and the necessary results were obtained in order to build the bit sequence generator as the HPR.

REFERENCES

- [1] F. Verbeyst, M. Vanden Bossche, and G. Pailloncy, "Next-generation comb generators for accurate modulated measurements," in *81st ARFTG Microwave Measurements Symposium*, Seattle, Washington, June 3, 2013.
- [2] P. Barmuta, F. Verbeyst, A. Lewandowski, and D. Schreurs, "Optimization of next-generation comb generator for accurate large-signal measurements on a user-defined frequency grid," in *Proc. 2014 Int. Workshop. on Integrated Nonlinear Microwave and Millimetre-wave Circuits (INMMiC)*, Leuven, Apr. 2-4, 2014.
- [3] P. Barmuta, J. Szatkowski, A. Lewandowski, and D. Schreurs, "Optimization of a tone selective bit sequence for next-generation comb generators over a user-defined frequency grid," submitted to IEEE Trans. Microwave Theory Techn.