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A Novel Electronic Instrument for the Analog Direct Synthesis of Arbitrary Waveforms and Wavelets

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ABSTRACT
The electronic instrument studied in this paper is a novel model of arbitrary waveform and wavelet generator. Unlike most programmable instruments designed for the same purpose with high complexity and great cost unfortunately, the proposed testing instrument is founded on a direct synthesis of arbitrary waveform signals including wavelets, from a basis of elementary analog signals. A novel arbitrary signal generation scheme is presented and well tested using virtual simulation and experimentation. Then, the predicted and experimental results obtained under a wide variety of testing conditions are presented, in order to show the great challenge of building a cheaper and high quality workbench for arbitrary signal generators.
***Keywords* –** Electronic instrument, arbitrary waveforms, wavelets, virtual simulation, workbench.

I. INTRODUCTION

An arbitrary waveform generator (AWG) is an electronic test instrument, used to generate complex signals of any shape over a wide range of frequencies. Nowadays, most professionals AWGs encountered in industrial electronics engineering, are very expensive PC-based instruments. A few existing cheaper custom models are built as microcontroller-based systems for educational needs, at the expend of low performance and capabilities [1]-[3]. In all cases, the design technique of available AWGs is founded on the digital direct synthesis of arbitrary signals, to be converted into analog output using a digital-to-analog converter (DAC). As a result, the quality of the analog output wave is limited by a variety of factors due to digital-to-analog conversion constraints (conversion technique, main clock source, resolution, signal bandwidth, signal-to-noise ratio, sampling frequency and more).

Thus, the merit of this paper is to resort to the new principle of analog direct synthesis of arbitrary waveforms, in order to overcome drawbacks associated with commonly used digital synthesis techniques for the generation of arbitrary waveforms. The feasibility of this new principle is motivated by the realistic nature of a basic technique proposed in [4] as a low-cost multichannel interface for single oscilloscopes. However, the great challenge of this paper emerges from the development of new building principles and electronic schemes, with straightforward applications to the creation of novel analog AWG families.

The remaining Sections of the paper are organized as follows: In Section II, the principle of analog direct synthesis of arbitrary waves and wavelets is outlined, followed in Section III by the virtual simulation of a prototyping instrument. Furthermore, a complete custom instrument built is tested in Section IV using an instrumentation workbench and the experimental results obtained are presented. Finally, Section V deals with the conclusion in which of a few findings and related future research opportunities are outlined.

II. PRINCIPLE OF ANALOG DIRECT SYNTHESIS OF ARBITRARY WAVES

Let consider discrete times t_0, $t_1 = t_0 + T$, …, $t_k = t_0 + k\,T$, $t_{k+1} = t_0 + (k+1)\,T$, …, and a set of $N = 2^m$ basic analog signals $\{X_0(t), X_0(t), \ldots, X_{N-1}(t)\}$, where T is the clock period, and m being a given positive integer. Controlled offset values Y_k might be associated to each $X_k(t)$ if any. Then, the analog direct synthesis of arbitrary waves from the basis $\{X_0(t) + Y_0, X_1(t) + Y_1, \ldots, X_{N-1}(t) + Y_{N-1}\}$, is modeled in this paper as follows:

$$W(t) = X_k(t) + Y_k \quad (1)$$

if $k\,T \leq t < (k+1)\,T$ (2)

or equivalently,

$$W(t) = \sum_{k=0}^{N-1} (X_k(t) + Y_k)\left(u(t - kT) - u(t - (k+1)T)\right) \quad (3)$$

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where u(.) stands for Heaviside step function, and k = 0, 1, 2, …, N-1 = 2^m -1. Two important Theorems for remaining of this paper could be outlined from Equation (3).

Theorem 1: There exists a wave family *W(t)* in Equation (3), which behaves as a virtual simultaneous sampling process of $\{X_k(t)\}$ for k = 0, 1, …, N-1.

The proof of that Theorem 1 relies on the limiting properties of a pulse width function with finite amplitude encountered in the distribution theory [5]. As an implication, if T → 0, Equation (3) could be written as follows:

$$\begin{aligned} W(t) &= \lim_{T\to 0}\left(\sum_{k=0}^{N-1}\big(X_k(t)+Y_k\big)\big(u(t-kT)-u(t-(k+1)T)\big)\right) \\ &= \sum_{k=0}^{N-1}\big(X_k(t)+Y_k\big)\lim_{T\to 0}\big(\big(u(t-kT)-u(t-(k+1)T)\big)\big) \qquad (4) \\ &= \sum_{k=0}^{N-1}\big(X_k(t)+Y_k\big)\,\delta(t-kT) \end{aligned}$$

Structurally speaking, Equation (4) is similar to the sampling model of analog signals encountered in signal processing [6]. Here, W(t) could be displayed on the screen of a single channel oscilloscope, as virtual multiple signals.

Theorem 2 : A variety of wavelets falls within the wave families W(t) defined by Equation (3).

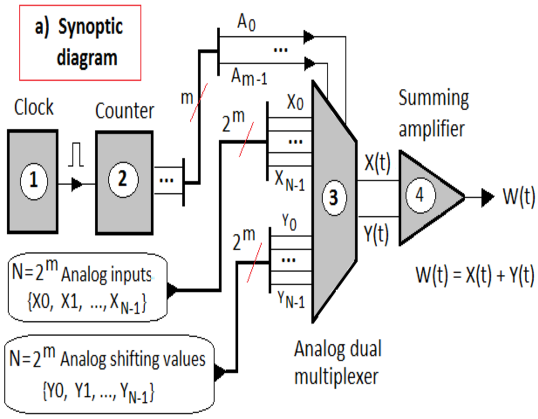
The proof of Theorem 2 is straightforward, since if the first p and the last q inputs signals can be set to zero over time, then the sequential cumulative effect of the remaining active inputs will produce an arbitrary wavelet given by:

$$W(t) = \sum_{k=p+1}^{N-q} X_k(t)\,\big(u(t-kT)-u(t-(k+1)T)\big) \qquad (5)$$

Thus, Equation (3) is a generalized model of the analog synthesis conditions of W (t) from the analog basis $\{X_0(t), X_1(t), \ldots, X_{N-1}(t)\}$. As an implication, the principle of the analog synthesis of arbitrary waves initiated in this paper could be implemented as shown in Fig. 1, where the synoptic diagram of a the proposed analog AWG is illustrated. It consists of: 1) a clock with time period T; 2) a m-bit counter allowing a maximum of N = 2^m discrete states; 3) two dual N/1 analog multiplexers for the simultaneous selection of both analog inputs X(t) and Y(t) to be processed; 4) a summing amplifier with arbitrary output wave W(t) according to the analog synthesis algorithm given by Equation (3).

The analog input basis $\{X_0(t), X_1(t), \ldots, X_{N-1}(t)\}$, can be generated with great ease using a simple analog integrated signal generator ICL 8038, since it might provide multiple outputs signals with different shapes (sine, square, triangle, and step).

a) Synoptic diagram



b) Multiplexer input-output signals

Clock cycles	MUX Adresses			MUX Outputs		W(t) (AWG)
	A_m	…	A_0	X(t)	Y(t)	
1	0		0	X_0	Y_0	X_0+Y_0
2	0		1	X_1	Y_1	X_1+Y_1
3	0		0	X_2	Y_2	X_2+Y_2
	0		1			…
…	…		0			
	1		…			
k	1		0	X_k	Y_k	X_k+Y_k
	1		1			
	1		…			…
	…		0			
N-1	1		1	X_{N-1}	Y_{N-1}	$X_{N-1}+Y_{N-1}$

Fig. 1 : Synoptic diagram of the proposed analog AWG.

III. VIRTUAL SIMULATION OF A PROTOTYPING INSTRUMENT

A prototyping AWG is implemented and simulated using Proteus software. As shown in Fig. 2, the main modules of the prototyping instrument implemented under Proteus software, consist of N = 4 analog inputs with corresponding analog shift values, and the following analog integrated circuits: a) CD4047 (clock); b) CD4018 (counter); d) CD4052 (Dual 4/1 multiplexer); e) LM318 (Audio operational amplifier).

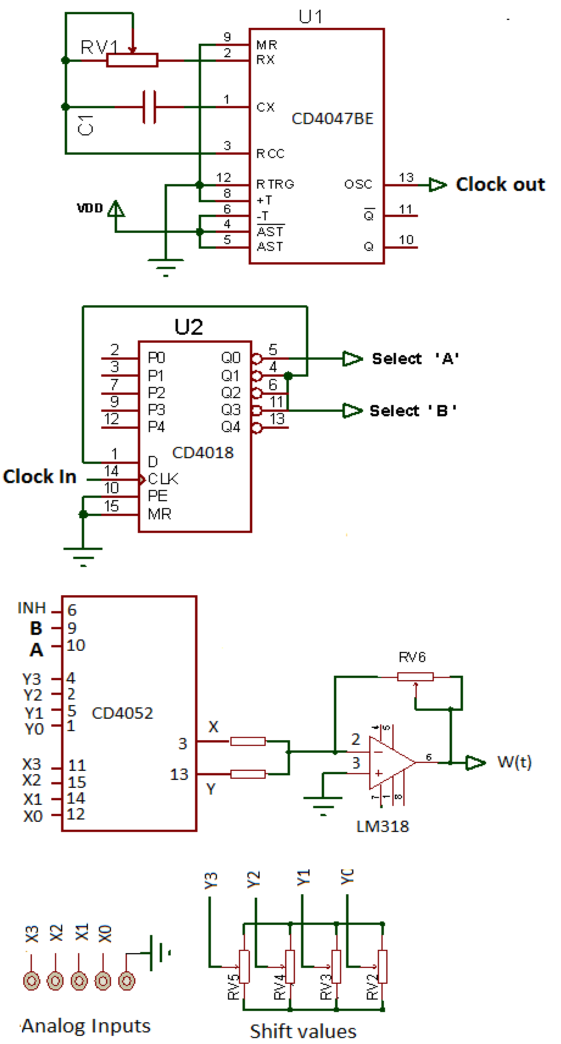


Fig. 2: Main modules of a prototyping instrument implemented under Proteus software.

A sample of virtual simulation results obtained under analog input signals with identical frequencies and independent amplitudes are illustrated in Figure 3, whereas all related shift values are set to zero without lost of generality. As predicted earlier by equation (1), the graph of the arbitrary wave W(t) shows that, it is synthesized over time from a serialization of ordered segments of waves $X_k(t)$, where $k = 0, 1, 2, 3, 0, 1, 2, 3, 0, 1, \ldots$ In addition, the case of analog inputs with identical amplitudes and independent frequencies are shown in Figure 4. Even in this case, the principle of analog direct synthesis of arbitrary waves also holds. The ranges of input frequencies used are 50.

In both cases, the graph of the resulting arbitrary signal is quite continuous since none of the analog inputs is identically zero over time.

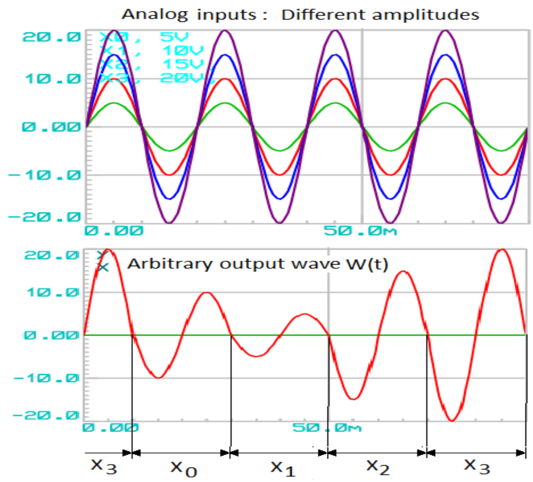


Fig. 3 : Simulation results for independent input amplitudes.

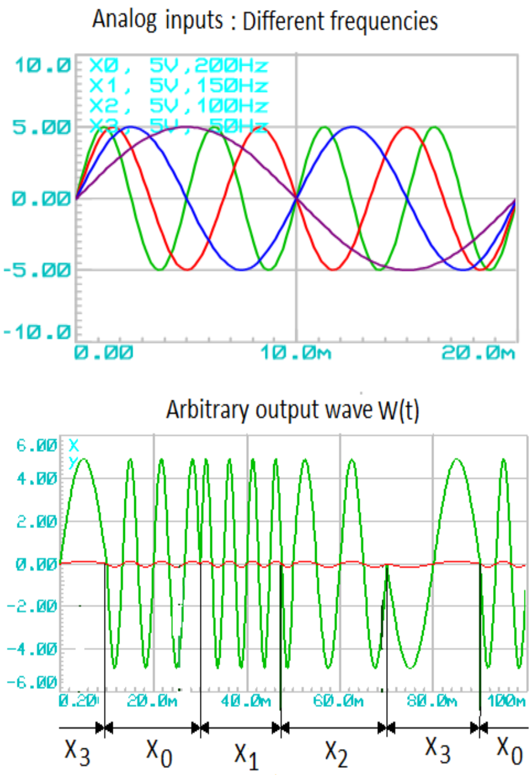


Fig. 4 : Simulation results for independent input frequencies.

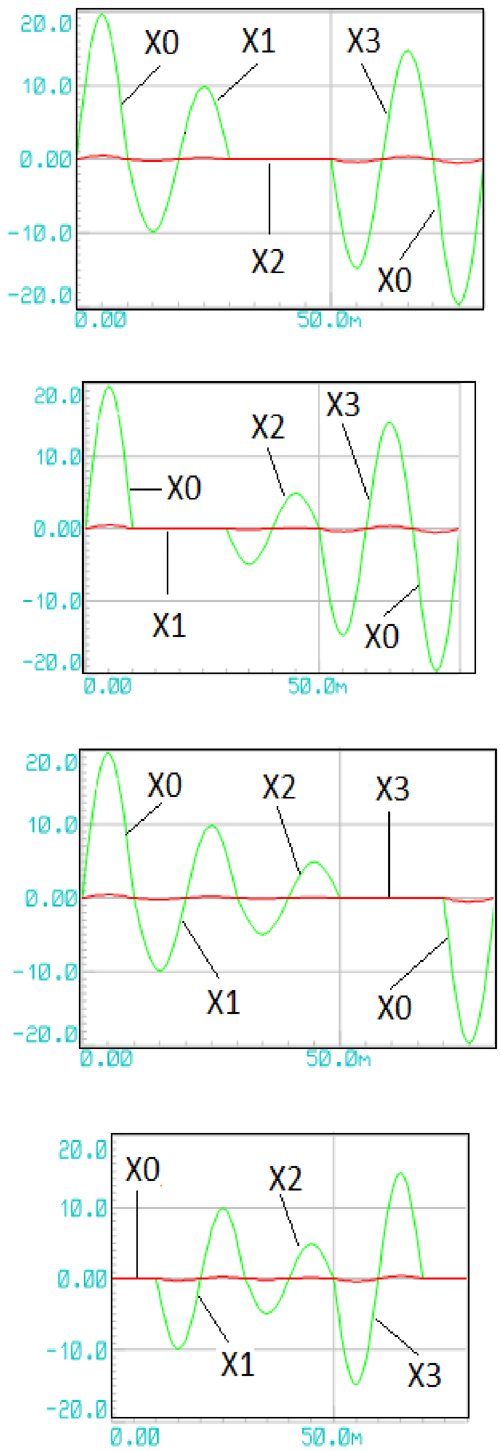


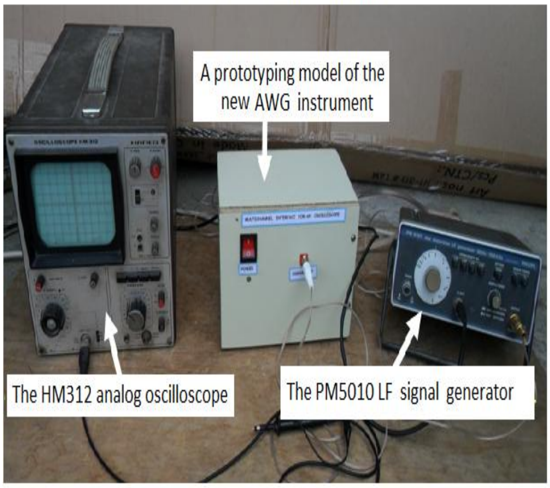
Fig. 5 : A sample of wavelets with arbitrary shapes obtained under virtual simulation.

Furthermore, Figure 5 presents a summary of additional simulation results obtained under a variety of special operating conditions. Clearly speaking, the first important finding emerging from these results is that, under the principle of analog direct synthesis of arbitrary waves, complex wavelet families with arbitrary shapes could be generated with great ease as predicted earlier in Theorem 2. The second important finding arising here is that, when maintain over time first and last signals (for example $X_0(t)$ and $X_{N-1}(t)$) to zero, then for a suitable choice of the parameters (amplitude and frequency) of the remaining intermediary signals, it might be possible to create standards wavelet shapes such as Mexican hat type, Mayer wavelet and more). However, this paper deals with the analog of arbitrary wave and wavelets.

IV. Experimental Workbench

A view of the experimental instrumentation setup built in order test a prototyping AWG model is presented in Figure 6. It consists of single channel and low frequency signal generator

a) Front view of the prototyping AWG model



b) Back view of the prototyping AWG model

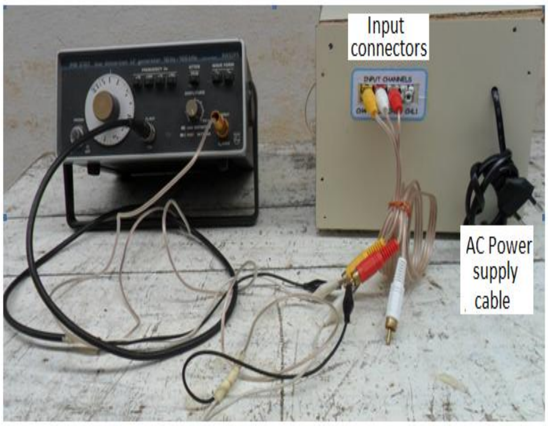


Fig. 6: Instrumentation workbench of the prototyping AWG.

(LF - PM510), a prototyping model of the proposed AWG (realized as a standalone instrument with 4 analog input channels with associated shifting thresholds), and a single channel analog oscilloscope (HAMEG HM312) used for the measurement of AWG signals produced under analog inputs.

The instrumentation workbench presented to test the new AWG studied in this paper, has a few technical limitations due only to the low performance and capabilities of both LF generator signal and testing oscilloscope. The best required testing instruments for a more suitable workbench should use a multichannel signal generator with independent outputs, and a single channel oscilloscope with a sufficiently wide bandwidth, in order to facilitate the realization of more attractive tests. Figure 7 shows a few typical results obtained when testing the new prototyping AWG instrument under conditions of Theorems 1 and 2. The active input channels are supplied from the same AC signal source (a single LF generator), whereas corresponding offset components are set to different values if any.

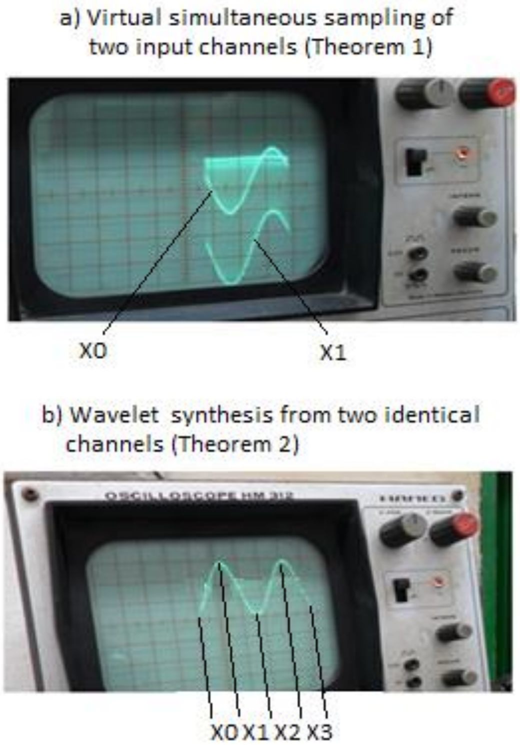


Fig. 7: Experimental results obtained under conditions of Theorems 1and 2.

In Figure 7(a), while $X_2(t)$ and $X_3(t)$ are set off, the result displayed viewed on the screen of the single channel oscilloscope, shows the realistic nature of Theorem 1with application in this case to the virtual simultaneous sampling process of two active inputs channels $X_0(t)$ and $X_1(t)$.

Furthermore, the result presented in Figure 7(b), shows a wave synthesized from identical input channels $X_0(t)$, and $X_1(t)$, $X_2(t)$ and $X_3(t)$. In this case, the clock frequency 1/T is four times compared to that of identical input signals. The whole simulation and experimental results presented, show the realistic nature of the analog direct synthesis of arbitrary waves and wavelets families initiated in this paper.

V. CONCLUSION

The new approach of analog direct synthesis of arbitrary waves and wavelets, is validated in this paper, using a mix of analytical reasoning, virtual simulation, and experimentation on a well tested prototyping model. However, most arbitrary waves and wavelets generated and presented in this paper according to the analog synthesis principle have complex shapes compared to that of commonly used cases encountered in electronic and communication engineering (i.e. Mayer, Morlet, Mexican hat, and more). Thus, it will be a challenge to produce these standard shapes from the proposed analog synthesis approach. This remark is a good opportunity for further researches.

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