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A Practical Approach to Design and Analysis Sinusoidal Oscillators

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Abstract - **In this paper, a practical approach to design and analysis sinusoidal oscillators are described. The proposed procedure is based on the design methods for analog circuits, the general methodology for application (re) engineering and the procedures for performing simulation projects. This practical approach is complete framework, which includes all activities, intermediate products, design procedures and relations between them, necessary for design and realization of a concrete analog electronic circuit. This procedure is applicable to a broad class of oscillation circuits such as basic LC oscillators, quartz crystal oscillators, phase shift oscillators, Wien type oscillators, VCOs, etc.**

Keywords – **Analog circuits, Sinusoidal oscillators, Circuit theory and design, Design methodology, Verification.**

I. INTRODUCTION

The sinusoidal oscillators have been found useful in many applications, such as telecommunications, control systems, analog signal processing and measurement systems. Additionally, the principals of oscillation can be extended to construct other types of oscillators, such as quartz resonator sensors, voltage controlled crystal oscillators, etc. [1-3]. A variety of sinusoidal oscillator circuits, using a discrete transistor or an op amp as an active element, are available in the literature [3-6]. For the most circuits are given some design recommendations based on the simulation modeling and the symbol analysis of the characteristic equations. The analyses of the analog circuit design literature and Internet resources show that there are no existing a general procedure to design sinusoidal oscillators. In this paper, using the best practice in the analog circuit design area, we try to compose a specific procedure intended for design and analysis of sinusoidal oscillators.

II. A GENERAL METHODOLOGY FOR APPLICATION (RE) ENGINEERING

"... The appeal of a methodology is that it directs the designers down a reasonable path with pointers for what to do, in what order to do it, and what to expect as inputs."

Amjad Umar

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The sinusoidal oscillators are fundamentally non-linear systems. In fact oscillator's non-linearity is the reason for their "stable" amplitude. For the sustained oscillation, *Barkhausen criterion* mandates that the gain around the loop, composed by amplifier and phase shift network is exactly unity and the phase shift around the loop is precisely 360 (or 0) degrees [2]. Starting point in creating a practical approach to design and analysis sinusoidal oscillators is the general methodology for application (re) engineering, developed by A. Umar [7]. The general "methodology pattern" is presented in Fig. 1. This pattern represents a template that can be customized for specific cases.

The key points of this methodology pattern are:

1. The methodology, shown in Fig. 1, covered the following core activities (stages): *analysis*, *circuit architecture*, *implementation* and *deployment/support*;

2. The methodology is built as an iterative process. The basic iterations *planning* (creating specification), *prototyping*, *implementing first* and *subsequent realizations* are oriented towards refinement and expansion of the core activities. In fact during the iterations the core activities are performed at different level of detail;

3. Some activities are more extensive than others in each iteration (represented by the width of activity triangle traversed in each iteration in Fig. 1). For example, the first iteration requires extensive analysis and architecture selection, but very little implementation, deployment and support activities. This is because the first iteration emphasizes business opportunity analysis and assessment of technical feasibility through architectural evaluations. However, later iterations successively reduce the time spent in analysis and architecture activities but increase the amount of implementation, deployment and support activities;

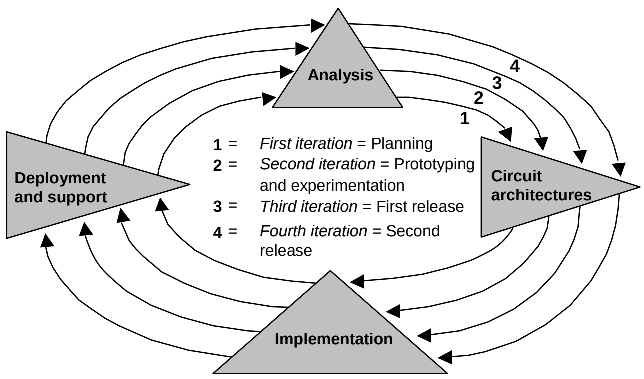

Fig. 1. A general methodology pattern for application (re) engineering.

4. For a subsequent realization or enhancement of a circuit (application), one may restart the entire process with the first iteration.

The first iteration (planning), discussed in the section above essentially concentrates on overall planning. It identifies the business drivers: basic electrical parameters, high-level requirements and cost/benefits based on a quick review of proposed solution architectures, implementation considerations and deployment/support issues raised. In the second iteration (prototyping and experimentation) is typically built prototypes and experiment with the architectures, implementations, and deployment/support aspects of a circuit or an application to gain insights into feasibility and effort sizing.

III. A General Practical Approach to Design and Analysis Sinusoidal Oscillators

In this section a specific practical approach to design and analysis sinusoidal oscillators is presented. The proposed design approach is based on the methods for analog circuits design, the methodology for application (re) engineering and the procedures for performing simulation projects [5-8]. The design approach diagram is shown in Fig. 2.

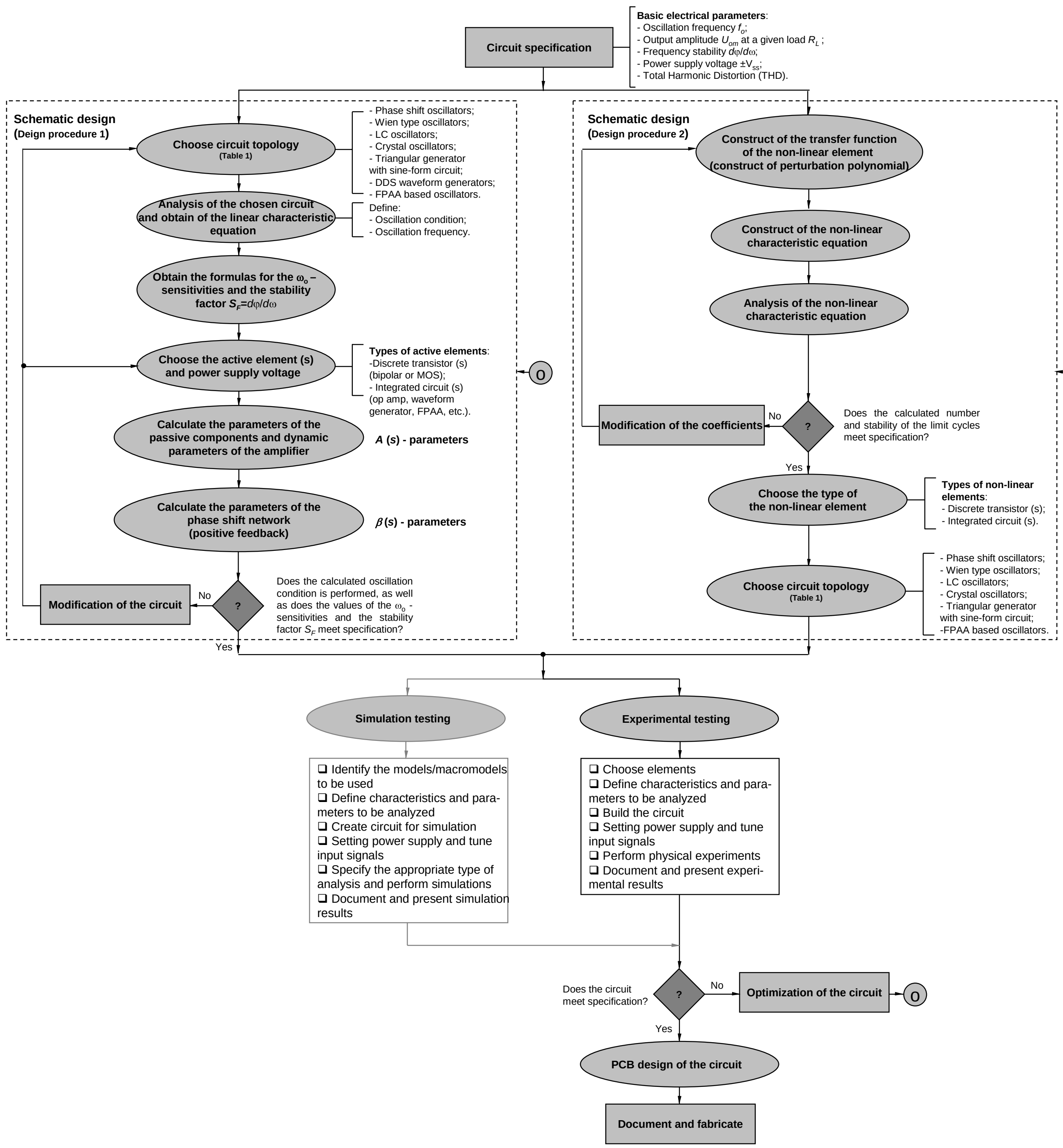

Fig. 2. A practical approach to design and analysis sinusoidal oscillators.

TABLE 1. BASIC TYPES OF SINUSOIDAL OSCILLATORS – TYPICAL RANGE OF THE ELECTRICAL PARAMETERS AND BASIC FEATURES

Type of oscillator circuit	Typical frequency range	Typical THD	Typical amplitude stabilization	Features
Phase shift oscillator	10*Hz* … 1*MHz*	1 … 3%	3%	The main features of these circuits are: small number of external components; wide output amplitude tuning range; the amplitude stability can be improved by adding to the oscillator an automatic gain control (AGC) circuit; convenient for LF (low frequency) applications.
Wien type oscillator	1*Hz* … 1*MHz*	0,01%	1%	The main features of these circuits are: small THD of the output signal; wide amplitude and oscillation frequency tuning range; the amplitude stability can be improved by adding to the oscillator an AGC circuit; especially convenient for high quality LF applications.
Triangular generator with sine-form circuit	1*Hz* … 500*kHz*	1 … 2%	1%	The main features of these circuits are: many external components (amplifier and sine-form circuit); sine-form circuit can be realized with a logarithmic amplifier based on a diode network or with a cascade structure, composed by a DAC and a low – pass filter; narrow amplitude and oscillation frequency tuning range; especially convenient for LF applications.
LC oscillator	10*kHz* … *GHz* - range	1 … 3%	3%	The main features of these circuits are: comparatively difficult is tuned the output amplitude in a wide range; higher Q-factor in comparison with RC oscillators; the oscillation condition is fulfilled faster than other oscillators; convenient for RF applications.
Crystal oscillator	30*kHz* … 200*MHz*	0,1%	1%	The main features of these circuits are: highest frequency stability factor; narrow oscillation frequency tuning range; high Q-factor is achieved for small input and output resistance of the amplifier, also the voltage drop across the crystal should be no greater than several tens *mV*; convenient for high stable RF applications.
FPAA (Field Programmable Analog Array) based oscillator	1*Hz* … 400*kHz*	0,1%	1%	The main features of these circuits are: digitally programmable oscillation frequency and oscillation condition; lack of external components; high frequency stability factor; narrow oscillation frequency tuning range; especially convenient for high quality LF applications.
DDS (Direct Digital Synthesis) waveform generator	1*Hz* … 400*MHz*	0,1%	0,01%	The main features of these circuits are: digitally programmable oscillation frequency; lack of external components; wide oscillation frequency tuning range; very good amplitude stability; small value of the THD can be achieved by connecting to the output pin a low pass filter; convenient for LF and RF applications.

This approach is a framework, which includes all activities, intermediate products, design procedures and relations between them, necessary for design of a concrete sinusoidal oscillator. The practical approach presented here is based on a Top-Down analysis approach. Generally, design and analysis of a sinusoidal oscillator can be resumed in six main activities (stages), which is performing in a linear fashion: (1) *circuit specification*; (2) *schematic design*; (3) *experimental and simulation testing*; (4) *circuit verification*; (5) *PCB design*; (6) *prototype fabricate and documentation*. Despite the fact that these have been shown in a linear fashion, moving from circuit specification to schematic design and so on, additional stages such as optimization and modification, aim to demonstrate the iterative nature of the process. For example, experimentation may identify some additional issues, which alter the circuit and require further circuit building before experimentation continues. The design approach must always start with a project definition and move towards prototype fabricate and documentation.

A. Circuit specification and schematic design procedures

The schematic design activity is the highlight of the proposed practical approach. In this activity analog circuit strategy for realization is chosen and the dc (ac) parameters of the amplifier (non-linear element) – $A(s)$ and the phase shift network (positive feedback network) – $\beta(s)$ are calculated. The dc and ac parameters of the designed oscillator circuit are calculated using pre-defined basic electrical parameters, given in the circuit specification.

The schematic design activity can be performed in two methods. Detailed descriptions of each design method are considered in the following subsections.

The first schematic design method, shown in Fig. 2, starts with choosing the oscillation circuit topology. The basic types of sinusoidal oscillators are summarized in Table 1. In this table for each oscillation circuit the typical values of the electrical parameters and the application area are defined. The sinusoidal oscillators basically use two main structures. The first structure includes an amplifier, realized with discrete transistors or op amps and phase shift network with RC or LC elements. The second structure is realized by using specialized ICs such as triangular generator with signal-form circuit (such as logarithmic amplifier), waveform generator with direct digital synthesis (DDS) of analog signals and FPAA based generator.

The typical frequency range for the RC oscillators (Phase shift and Wien type oscillators) are 0,1 … $10^5\,Hz$. In this frequency range the LC oscillators are not used, because the inductors are with big dimensions and mass. The LC oscillators are typically used in the frequency range 10^5 … $10^9\,Hz$. The main advantages of the RC oscillators are a wide amplitude and oscillation frequency tuning range and very small THD of the output signal (especially for the Wien type oscillator). The RC oscillators are especially convenient for high quality low frequency applications.

The highest frequency stability factor ($\Delta f / f_{res} << 1\%$) can be obtained with crystal oscillators, but they are with narrow oscillation frequency tuning range. The crystal oscillators are especially convenient for high stable RF applications.

The FPAA based sinusoidal oscillators are realized using FPAA ICs. These mixed-signal (analog/digital) ICs include fundamentally programmable analog cells, based on a SC technology and SRAM configuration memory. Each analog cell is composed by CMOS op amps, integrators, multipliers, etc. with programmable transmission coefficients and configurable electrical connection between them. The oscillation circuits based on FPAA ICs are convenient for low frequency (up to $400kHz$) electronic systems.

The DDS generators are composed as a cascade structure of an address counter, PROM (PROM stores one or more integral number of cycles of a sinusoidal wave), DAC and low pass filter [10]. The clock signal for the address counter is obtained by additional crystal oscillator. The main features of the DDS waveform generators are the very good amplitude stabilization (the typical amplitude stabilization is 0,01%), the lack of external components to define the oscillation frequency and the most extensive oscillation frequency tuning range ($1Hz$ … $400MHz$).

The alternative path for schematic design method (*the design procedure 2*), presented in Fig. 2, starts with establishing non-linear characteristic equation and obtainning the values of the coefficients, based on the given technical requirements [9]. This stage is called *approximation*. The next stage is *implementation* – the conversion of the non-linear equation. For this purpose, the equation is compared to the characteristic equation of a specific electronic circuit. The values of the elements in the circuit are based on formulas derived by comparing the coefficients of the equation (obtained by the approximation) and the characteristic equation of the concrete electronic circuit.

B. Testing, verification check and documentation

The verification checks of the created circuit are implemented in two stages. In the first stage in the end of the schematic design activity is check whether the oscillation condition is performed, as well as whether the values of the ω_o – sensitivities and the stability factor meet specification. In the second stage the simulation and the experimental results of the basic parameters for the prototype of the oscillator are compared with the technical requirements. In this stage the simulation and the experimental testing of the circuit is implemented in a parallel way. The border of each activity related with the simulation testing is marked in grey, because some of the active elements do not have simulation models or macromodels.

The proposed practical approach to design sinusoidal oscillators finishes with *PCB design* of the circuit and *documents* the basic electrical and constructional characteristics and parameters. Then on the basis of the documentation is transferred to production of the oscillation circuit with the achieved parameters.

IV. Conclusions

This paper presented the following achievements of the team of the developers:

- Development of the practical approach to design and analyse sinusoidal oscillators. The proposed design approach is based on the methods for analog circuits design, the methodology for application (re) engineering and the and the procedures for performing simulation projects;
- The basic types of sinusoidal oscillators are summarized and their typical values of the electrical parameters are given, as well as the application area is defined;
- The proposed procedure can be useful for design and simulation modeling of various analog electronic circuits such as phase shift oscillators, Wien type oscillators, LC oscillators, quartz crystal oscillators, VCOs, etc.

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