Oscillator Designer – CAD of Microwave Oscillators

Wladimir Furuashi Viana – Paulo Henrique Portela de Carvalho – Luis Afonso Bermudez*

Abstract - In this paper we present the Oscillator Designer, software created in order to provide the necessary support in the design of microwave oscillators at a fixed and stable frequency. This application’s main focus is to motivate the project designer to follow a fixed sequence. This application is made up of a main platform where the oscillator’s layout can be set up step by step in a sufficiently didactic manner. Each step of the design must be simulated and in certain cases, there exists the option to calculate automatically the optimum values for the circuit in question. The software was developed through the Borland Delphi Client/Server Suite version 3.0.

Index Terms – Microwave Oscillators, Trew, Van der Pol and Gewartowsky's models, Computer Aided Design

I. INTRODUCTION

Microwave oscillators form part of all microwave systems such as radars, communication systems, as well as navigation and electronic war systems. Due to rapid advances in technology, there is the growing need to improve the oscillators’ performance. Focus has been given to oscillators that are low noise, reduced in size, and low cost, very efficient and high in stability and reliability.

The initial step in the design of an oscillator is to choose an active element that has all the appropriate characteristics that fit the specifications required. The next step is to generate negative resistance through a feedback network. Next, choose a matching structure with a load that gives maximum power to the device’s output port. Finally, a resonator circuit must be used (dielectric resonators, resonator cavities etc.) to obtain oscillation at a determined frequency. Generally, it is a passive circuit with some loss.

In light of this, the Oscillator Designer was developed as an auxiliary software in the design of microwave oscillators. Through this software, it is possible to apply simulation techniques based on the circuit’s scattering parameters.

In order to test this software’s applicability, two devices were projected entirely through the Oscillator Designer.

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II. THE OSCILLATOR DESIGNER’S STRUCTURE

In this section, we will present the Oscillator Designer’s operational structure. Figure 1 shows the elements that make up the software. Each one of the blocks represents one step that can be analysed individually or together.

![Fig. 1 – Basic microwave oscillator plan.](image)

A. Active Element

The Oscillator Designer can be worked with two types of transistors: bipolar and FET. These are characterised according to their scattering parameters, \([S]\), which are available in manuals or file types such as *.s2p, provided by the manufacturers.

The software allows the user to choose an already existing data file, or even have access to a transistor editor. Also, it is possible to carry out simulations from all the S parameters as well as from the device’s input and output impedances.

B. Biasing

The use of transistors must involve an adequate biasing of the same since the \([S]\) parameters provided by the manufacturers are only valid for a specify bias point.

In this way, the Oscillator Designer allows for the carrying out of both a DC and an RF analysis. The user can choose structures that guarantee the transistor’s point of operation as well as the structures that protect the DC’s feed source from the RF’s signal, Figs. 2 and 3.
C. Feedback Network

Once the active element and the appropriate biasing topology are selected, a feedback structure can be used to obtain a reflection coefficient module greater than the unit in the device’s input port (|S_{11}| > 1).

The degree of excess to the |S_{11}| unit is taken as a merit factor in the evaluating of the topology of the active circuit to be used in the oscillator. For, the greater the unit for |S_{11}|, the greater the guarantee that the oscillations will be initiated and that the active device’s oscillatory process will be maintained.

In Fig. 4, there is an example of a feedback structure proposed by the Oscillator Designer. It is a parallel feedback topology that uses microstrip lines. It is possible to simulate only the feedback network or the whole circuit.
Next, maximum output power must be supplied to the device’s output port. In the Oscillator Designer, this can be accomplished through the matching of impedances, by using open and short stubs.

In Fig. 5, we indicate the screen that is used in the matching of impedances. The user can choose the simulation option, the type of matching structure and can even select the automatic optimisation option that offers three different possibilities:

1) Using the ideal reflection coefficient proposed by Trew for the feedback circuit’s output port[1]:

Setting up a matching network at the active device’s output port with reflection coefficient $\Gamma_L$ means altering the reflection coefficient’s value for the input port $S_{11}$:

$$S'_{11} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$$  \hspace{1cm} (1)

Where,

$S_{11}$, $S_{12}$, $S_{21}$, $S_{22}$ are the [S] parameters for the active device with feedback network;

$S'_{11}$ is the new reflection coefficient for the active device’s input port;

$\Gamma_L$ is the reflection coefficient for the output port’s matching network.
\[ X = \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \]  

(2)

Gives:

\[ S'_{11} = S_{11} + X \]  

(3)

Given a resonator circuit with no loss, the circuit will oscillate according to the following:

\[ |S'_{11}| > 1 \]  

(4)

According to Trew’s observations [7], if (3) is used, the following can be equated:

\[ X = \frac{1}{S_{11}} \]  

(5)

The correspondent \( \Gamma_L \) will be on the add curve in phase with \( |S'_{11}| \) with \( X \). Thus (5) and (2) can be calculated through what Trew calls the *Reflection Coefficient’s Ideal Load* (\( \Gamma_{L,\text{ideal}} \)) taken as:

\[ \Gamma_{L,\text{ideal}} = \frac{1}{S'_{11}S_{12}S_{21} + S_{22}} \]  

(6)

Such a value for the \( \Gamma_{L,\text{ideal}} \) implies that the \( |S'_{11}| > 2 \), for any \( |S_{11}| \) value, thus confirming the topological criteria for the project. It is necessary to point out however, that the \( \Gamma_{L,\text{ideal}} \) is not always feasible, for example, when part of the curve is outside of Smith’s Chart.

2) A load analysis can be carried out through Van der Pol’s model:

Van de Pol showed that the oscillator provides maximum output power when the resistance load is half of the small signal negative resistance from the nonlinear active element used.

Since the resistance load has a fixed value of 50Ω, the double of this value 100Ω was chosen for the resistance at the device’s output port. This means a negative resistance of 100Ω.

3) A load analysis can be made through Gewartowsky’s model:

Although in many practical applications Van der Pol’s model can undergo an interesting simplification, this same simplification was initially proposed by Gewartowsky [3].

For him, ideal load resistance to obtain the maximum output power should be 1/3 of the negative small signal resistance’s value to the active device.

In this way, the format of the result was the same as that obtained by Van der Pol. Numerically, both differ from each other but both conclude that the resistance load for maximum output power is less than the small signals negative resistance’s module. For Van der Pol this module is half, whilst according to Gewartowsky’s linearisation, this module is a third.
On Fig. 5, it is also possible to use an auxiliary tool to calculate the matching of impedances. The user must enter the impedance to be matched ($Z_1$), the impedance ($Z_2$), to be obtained at the output port, the operation frequency, the substrate data (h, t, $\varepsilon_r$) and the matching topology structure, as shown in Fig.6.

![Fig. 5 - Matching Network Screen](image)

**Fig. 5 - Matching Network Screen**

![Fig. 6 – Tool for calculating the matching of impedances](image)

**Fig. 6 – Tool for calculating the matching of impedances**
E. Resonator

Once all the previous steps have been completed: active element, biasing circuit and the matching circuit, the next step is to choose a structure that provides the desired operation frequency.

The resonator is the passive element responsible for determining oscillation frequency. From the various existing topologies, a microstrip line can be chosen that provides a reflection coefficient in an unitary form and in opposition to the reflection coefficient’s phase for the active device’s port.

Hence:

$$\theta_R = \theta_{S11} \text{ for } \theta_R + \theta_{S11} = 0$$ (7)

The Oscillator Designer provides a choice of optimum values for the resonator’s lengths and widths. However, the user also has the opportunity to choose his/her own values. This screen is shown in Fig. 7.

![Resonator Screen](image)

**Fig. 7 – Resonator Screen**

F. Smith’s Chart

Smith’s Chart [4] is one of the graphic help tools most used in circuit projects for determining scattering parameters. This chart was therefore incorporated in the Oscillator Designer.

In all the steps previously described, it is possible to simulate circuits, carry out a stability analysis of the circuit in terms of [S] parameters obtained by using the so-called stability circles shown in Fig. 8.

This results in the following: there are all [S] parameters for the frequency in question, as well as for the simulated circuit’s input and output impedances and for some stability parameters (K, B₁ e B₂).
The user still has the possibility of varying the frequency in small measures in order to check what is happening with the stability circles and in so doing to find the best point of operation.

![Stability Circles](image)

**Fig. 8. Analysis of the stability circles**

**G. Graphical Outputs**

In each design step, it is necessary to perform an analysis of the calculated values. The Oscillator Designer has a main screen (Fig. 9) which allows the display of data graphically or through tables.

The [S] parameters and the input and output circuit impedances can be simulated alone or all together. The simulation process is based on the same principle used by MrKirchhoff software [ ].

Figure 10 shows the graphical display of the $S_{11}$ parameter. It is possible to personalise the graphical output by a tool menu in the upper part of the screen. There is also the zoom and x,y positioning capabilities.
Fig. 9 – Graphical output main screen.

Fig. 10 – Output screen.

III. RESULTS OBTAINED

The complete layout for the circuit oscillator is shown in Fig. 11.
Fig. 11 – Complete topology for the microwave oscillator obtained through the Oscillator Designer which uses microstrip technology.

Based on the dimensions obtained in the simulation, it was possible to develop the circuit’s layout. Figures 12 and 13 show respectively the oscillators developed through Trew’s and Van der Pol’s optimisation.

Fig. 12 – Oscillator with matching circuit optimised according to Trew’s theory.
Fig. 13 - Oscillator with matching circuit optimised according to Van der Pol’s theory.

The devices measured through a Spectrum Analyser gave the results shown in Figs. 14 and 15. Tables I and II show the data referring to biasing and the oscillation frequency results, as well as to the oscillator’s output power.

Fig.14 – Spectrum Analyser Screen for the oscillator constructed according to Trew’s theory.
TABLE I

<table>
<thead>
<tr>
<th>Biasing</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{CC} (V)</td>
<td>9.9</td>
</tr>
<tr>
<td>I_{C} (mA)</td>
<td>13.0</td>
</tr>
</tbody>
</table>

**Fig. 15 – Spectrum Analyser Screen for oscillator constructed according to Van der Pol’s theory.**

TABLE II

<table>
<thead>
<tr>
<th>Biasing</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>V_{CC} (V)</td>
<td>9.0</td>
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</tr>
</tbody>
</table>

IV. CONCLUSION

The *Oscillator Designer* has proven to be a very useful tool in the projecting of microwave oscillators since the functioning of the two oscillators projected reflects this software’s efficiency. Another positive aspect is the *Oscillator Designer’s source* code, which allows for the adding of new topologies, thus guaranteeing the continuity of work in this area.

Among the possible applications of the software, it can be pointed: teaching on microwave courses and practical laboratory designs.
REFERENCES


