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Overview on RF Mixer Synthesis using Genesys Software

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RF Mixer Synthesis Using Eagleware-Elanix GENESYS Software

Ralph D. Ehrich and Randall W. Rhea

Eagleware-Elanix Corp, Norcross, Georgia

Abstract — **The Eagleware suite of synthesis products has been expanded with the addition of a mixer synthesis module. This synthesis module allows the user to design and analyze mixer configurations using a variety of topologies as starting points. The 11 topologies of the initial release range from simple passive configurations such as the "diode rat race mixer" to complex active models such as the "bipolar double balanced Gilbert mixer". For each configuration, supporting information provides insights into the theory of operation, applicable frequency range, and performance tradeoffs. The synthesis tool is fully integrated into the GENESYS design environment allowing the impact of the mixer on the total system performance to be evaluated.**

I. INTRODUCTION

The MIXER Synthesis Module assists in the design of various types of mixers. The 11 topologies presented can be used as prototypes for the synthesis and analysis of mixers for a wide range of applications. These topologies can easily be modified to meet particular requirements and constraints. The synthesis module is integrated into the GENESYS environment, which allows an extensive number of analysis tools to be employed. This is particularly important in the design of mixers where the nonlinear elements are an essential part of any configuration. The Harmonic Balance (HARBEC) nonlinear analysis tool, parameter sweeps, optimization and large signal s-parameter measurements are just a few of the features which can expedite the design process. Many libraries of commercially available passive and active devices are included.

Following are the 11 mixer configurations available. The designs employ generic models for the nonlinear and active devices. These can easily be replaced with a model from one of the libraries of parts from a variety of manufacturers.

1. Diode Single Ended Basic
2. Bipolar Differential
3. JFET Transformer Single Balanced
4. Diode Branch Line Single Balanced
5. Diode Transformer Single Balanced
6. JFET Single Ended
7. Diode Transformer Double Balanced
8. Bipolar Single Ended
9. Bipolar Transformer Single Balanced
10. Bipolar Double Balanced Gilbert
11. Diode Rat Race Single Balanced

The following sections provide a description of the basic module operation and available measurements and outputs.

II. BASIC OPERATION

The computer screen for a typical mixer synthesis session is shown in Figure 1. Notice that the mixer synthesis dialog box is simple, consisting of only a single page. The user can select from among the 11 mixer types. They include simple diode types, complex configurations with active devices such as bipolar or field effect (FET) transistors, and circuits which include transformers. Most of the most common topologies are represented. Unlike other GENESYS synthesis products, the mixer is essentially a nonlinear element. Therefore, each mixer must have either a passive (e.g. diode) or active (i.e. transistor) nonlinear element, and the design environment must include a nonlinear analysis engine. In this mechanization, a Harmonic Balance simulator (HARBEC) is available in the GENESYS suite of analysis modules. In Figure 1, notice that the dialog box includes the required set of input parameters for the particular mixer topology chosen. In the case of the "diode rat race single balanced mixer" shown, this includes both the common parameters (e.g. the frequencies of the input RF signal, the local oscillator signal (LO), and the IF output signal), but also the filter frequency for the IF filter. The program does error checking to assure that the 3 frequencies define a consistent set, i.e. the IF frequency is either the sum or difference between the RF and LO frequencies. Again, since this is a nonlinear process, the power levels for the RF and LO inputs must be defined. Notice the check box labeled "Default Values". If the user checks this box, the factory settings for all the parameters will be used. These are the values used in the examples in the HELP files. This allows the user to duplicate the results presented in these files. If the user modifies any of the input parameters, this box automatically becomes un-checked.

III. SIMULATION OUTPUTS

The simulation automatically generates plots of the power spectrums at the RF and IF ports (Figure 1). These graphs can be used to determine the conversion gain and the isolation between various ports. Also notice the levels of the spurious signals or "intermods" generated by the nonlinear element. In addition, the synthesis program will generate sweeps of RF and LO power. The resulting plots are used to determine the saturation level for the RF input and the desired LO drive level, respectively. These plots are shown as Figures 2 and 3, respectively.
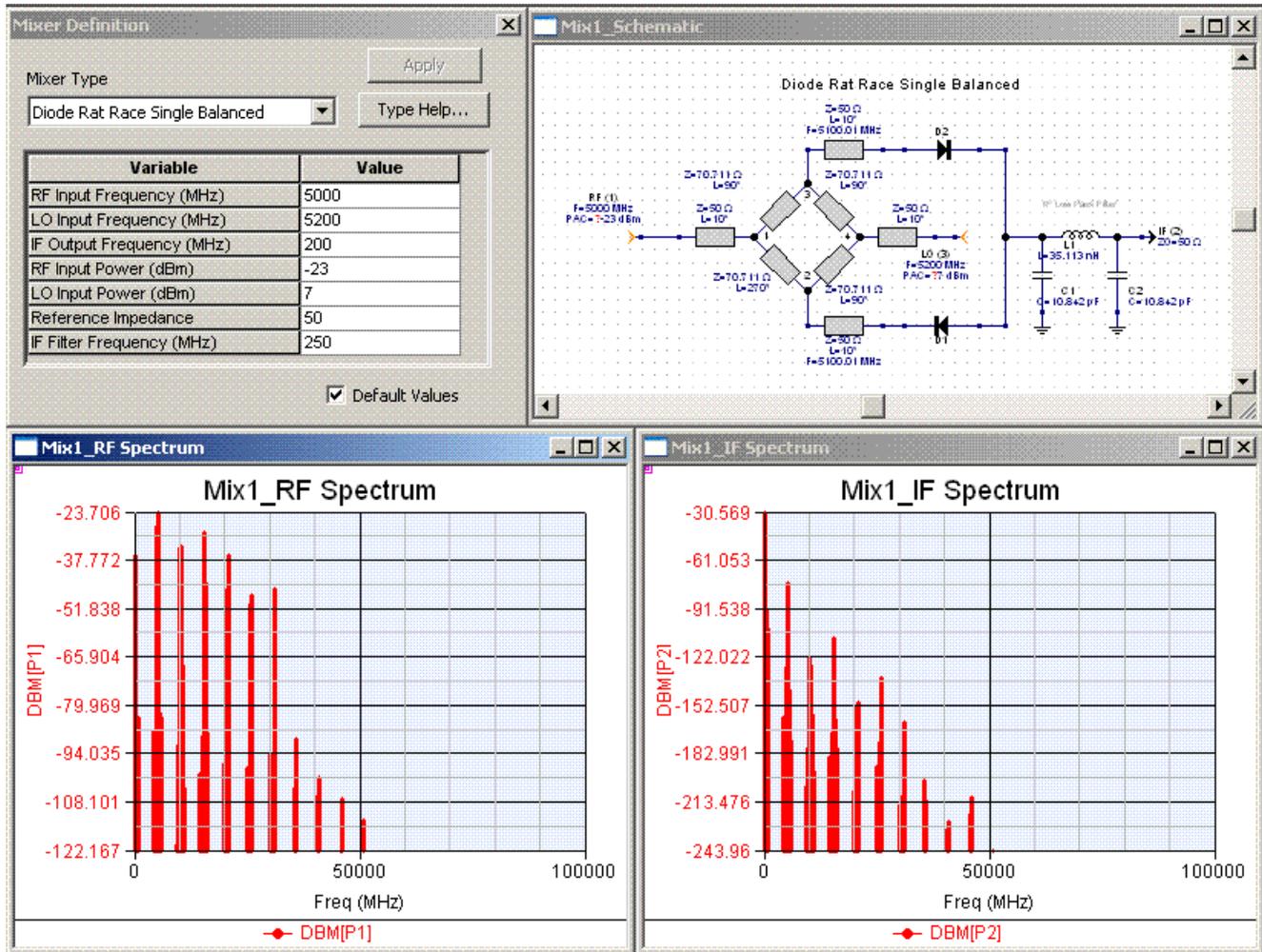
Figure 1. Computer Screen for Mixer Synthesis Module

The simulation provides the following output measurements:

IF Spectrum: This is a frequency domain plot of the power at the IF output port. The conversion gain of the mixer is the difference in the power level of the output signal at the desired IF output frequency and the RF input power.

RF Spectrum: This is frequency domain plot of the power at the RF input port is useful for determining LO radiation at the RF input port.

Intermod: This is frequency domain plot of the IF output with two input tones each at a level specified as PwrRF is used to determine the level of intermodulation products.

Intercepts: This table uses the level of a single tone in the two tone simulation and the lower frequency 3rd order InterModulation product to compute the mixer's Small Signal Conversion Gain and the 3rd order Output Intercept Point.

These two values are then used to find the 3rd order Input Intercept Point (IIP3).

LO Sweep: This is a parameter sweep with the LO level swept as the independent horizontal axis and the desired IF output level as the dependent vertical axis. This plot is used to determine an appropriate drive level to use for the mixer LO.

RF Sweep: This is a parameter sweep with the RF input level swept as the independent horizontal axis and the desired IF output level as the dependent vertical axis. The Conversion Gain as a function of the RF level is also plotted in this graph. This plot is used to determine the mixer output compression level and the saturated output power.

RF Impedance: This parameter sweep of the LO level with the RF input impedance plotted on a Smith chart aids in the design of an input matching network.

IV. UNDERLYING EQUATIONS

Figure 2. Sweep of RF Input Power (PWRRF) Resulting in IF Output Power (P2) and Small Signal Gain (SSGain)

For each mixer design, the simulation computes the values of all component parameters based on the user inputs or specifications from the dialog box. These are tested to assure a consistent set of requirements. Warnings are provided if there are discrepancies. In the example of the rat race mixer, the equations are relatively simple. The lengths of the transmission line elements of the rat race are fixed at 90 or 270 degrees. The simulation sets the frequency (f_{mixer}) for these lengths at the arithmetic mean of the RF and LO frequencies. The simulation schematic uses electrical models for the transmission lines. These lines are defined by the impedance (Z_{mixer}), length (L_{12}, L_{13}) and frequency (f_{mixer}). GENESYS provides the capability to automatically convert these electrical lines into physical lines of most topologies such as microstrip, stripline, etc. The equations also compute the element values for the low pass filter on the intermediate frequency (IF) output. The design yields a third order filter characteristic with a passband ripple of 0.0432 dB and corner frequency at a frequency 25% above the IF frequency.
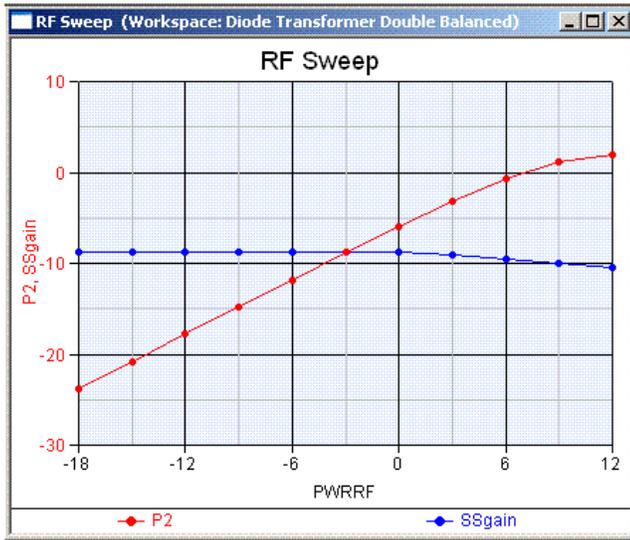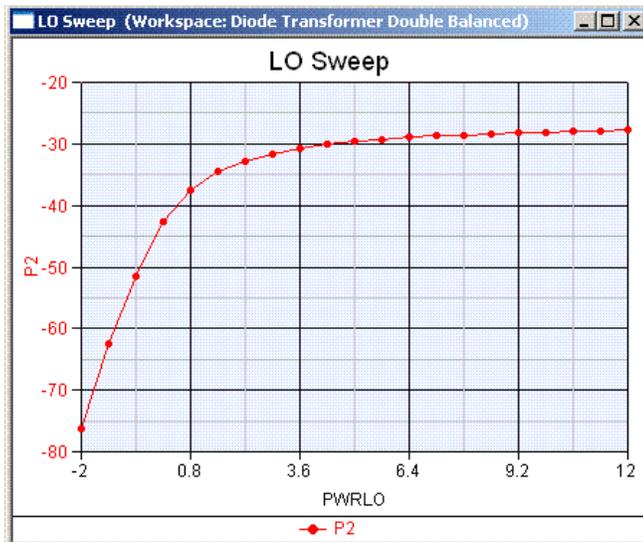

Figure 3. Sweep of Local Oscillator Power (PWRLO) Resulting in IF Output Power (P2)

Equations

Compute parameters for electrical transmission line models

$f_{mixer} = \sqrt{[f_{RF} * f_{LO}]}$
Lead = 10 degrees   {Length of leader lines}
L12 = 270°
L13 = L24 = L34 = 90°   {Lengths of rat race network}
Z_{mixer} = 1.414 * Zo   in ohms
Z_{lead} = Zo   in ohms

Compute Low Pass Filter values
    for 3rd order filter with 0.0432 dB passband ripple,
    corner frequency (fc) equal to 1.25 times f_{IF}
        (G-values: 0.8515, 1.1031)

fc = 1.25 * f_{IF} fc is user input:
                                    "IF Filter Frequency (MHz)"
ω_c = 2 * π * fc * 1e6
C = (0.8515 * 1e12) / (ω_c * Zo)   pF
L = (1.1031 * Zo * 1e9) / ω_c nH

V. Design Tradeoffs

The extensive HELP files contain information for the user describing the theory of operation and the design tradeoffs for each mixer type. They also explain the range of frequencies which are appropriate for each mixer . The following is a brief excerpt from the HELP file for the "diode rat race single balanced mixer" described above.

Diode Rat Race Single Balanced Mixer

This Diode Rat Race Single Balanced mixer is suitable for the higher frequencies where construction of transformers is impractical, and where the physical length of the transmission lines is not excessive. The RF and LO signals are controlled using a race splitter, sometimes referred to as a 180 degree hybrid. This dictates that both the RF and LO frequencies be within the bandwidth of the rat race, typically within 10 to 30 % of each other, depending on the performance requirements. The automated design in the MIXER module designs the rat-race for a center frequency arithmetically centered between the RF and LO frequencies.

The rat-race mixer has isolation between the LO and RF ports, making it somewhat more desirable than the diode branch line mixer because it reduces the LO radiation problem. The branch-line is somewhat smaller, but the lack of LO isolation at the RF is a significant problem in some applications. As with the branch line mixer, the IF lowpass filter which is required to provide a low impedance return path for RF and LO signals, significantly reduces RF and LO signals at the IF output.

The IF output port should provide a low-impedance ground return for the RF and LO frequencies. To provide this return, the MIXER module places a lowpass filter at the IF output with a shunt capacitor adjacent to the diodes. This filter is designed with a cutoff frequency equal to 1.25 times the specified IF frequency. For wide IF bandwidths, you may increase the cutoff frequency using the parameter in the dialog box and the MIXER module will automatically design this lowpass filter.

A lowpass filter assumes the IF is the difference of the RF and LO frequencies. For a sum mixer, you should replace the lowpass with a highpass or bandpass filter. This filter should also provide a low-impedance path to ground for the RF and LO frequencies.

The rat-race is designed with electrical models of the transmission lines. You may use the Advanced T/Line option to automatically convert the electrical lines into the line type of your choice, such as microstrip, stripline, etc.

Typical conversion gain is -6 to -7 dBm. This mixer requires about + 7 dBm from a 50 ohm source.

VI. Mixers With Active Devices

Six of the mixer topologies employ active devices as the nonlinear element. These designs include bipolar or field effect transistors. Although the frequency range may be more limited than the diode mixers, they do in general provide an improved conversion gain. The "bipolar differential mixer" in Figure 4. has a conversion gain of up to 20 dB at lower frequencies. Notice that the simulation also includes the computation of appropriate dc bias circuit resistors.
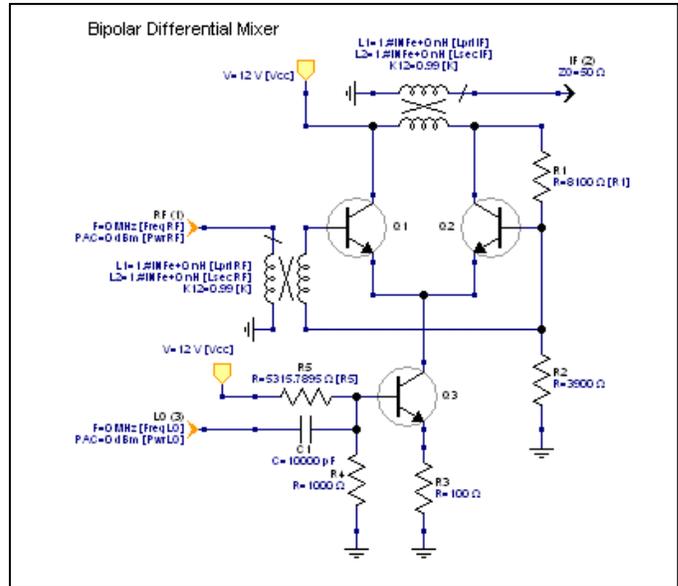

Figure 4. Bipolar Differential Mixer

VII. Conclusion

The Eagleware-Elanix suite of RF design software has been extended with the development of a mixer synthesis module. The module facilitates the design and simulation of many popular mixer configurations. It will facilitate the engineering development of mixers for both the novice and expert mixer designer. The synthesis tool automatically generates a design for the user selected set of requirements and mixer type. The documentation provides advice on the appropriate topology for a particular set of requirements.

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