Modelling and Measurement of Nonlinear Amplifier System

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Abstract: An improved model for non-linear amplifiers (*NLA*) is presented using the MATLAB® software. The model is identified from time domain measurements. Time domain modelling, simulation and frequency domain characteristics are used throughout the procedure. The Modelling of non-linear amplifier is divided in two subsystems, obtained by pulse measurement which offers considerable saving in measurement time. The derived model is not based on an equivalent circuit and offers flexibility and saving in the amount of data stored and in simulation time.

1. Introductio n

In this paper the model for non-linear amplifier system in the time domain is improved by using the MATLAB® Simulink software and optimization program. This model is identified not as an equivalent electrical circuit but as a system using non-linear functions, adders and subtractions transport delays and switches. In the developed procedure, subsystems of *NLA* are identified separately and then connected together to complete the system. The $f_{minsearch}$ optimization program was used to find the constant values of the non-linear amplifier system. The measurement setup is based on Hewlett Packard Microwave Transition Analyzer "*MTA*" (40 GHz), Series Synthesized Sweeper (10MHz-20GHz) and Pulse Generator (3 GHz). The advantages of the method are the efficient measurement procedure, which results in fewer measurement data compared to frequency domain measurements, more accurate response of the identified model since the identified model is not restricted to realizable electrical equivalent circuits, considerably shorter simulation time and large systems can be divided into smaller subsystems, which are identified separately and a library of models can be stored and the storage requirement is very low [1]. Measurements on *NLA* system are performed and compared to the results of the simulations.

2. Time Domain Model Identification of Non-linear System

An example of time domain non-linear model structure is shown in Figure 1.

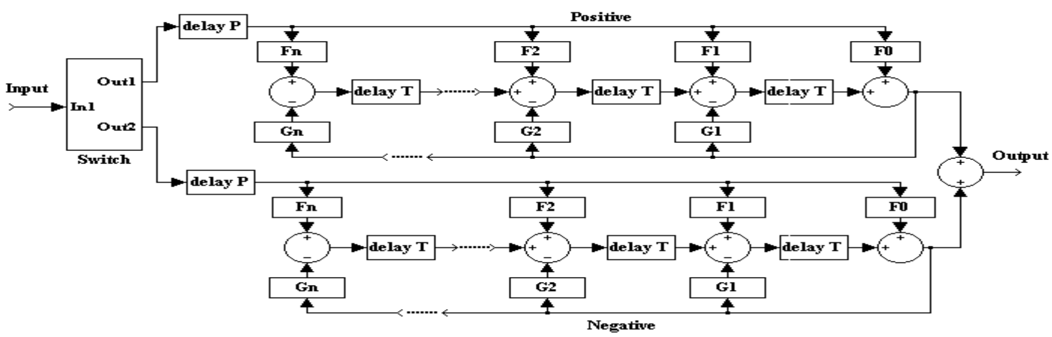

Figure1. Non-linear System Model.

Where F0, F1, F2…Fn and G1, G2…Gn are non-linear functions. The delay T is the sampling time interval and the delay P is the propagation delay from the input and the output port. This general non-linear model structure can simulate linear and non-linear systems. The modelling process is to extract the parameters and the non-linear functions. This modelling method treats the subsystem as a black box [2] and no internal information of the subsystem has to be known only the external measurable characteristics.

3. Time Domain Scattering Function Meas urement System

The incident, reflected and transmitted waves that are used to identify the scattering functions of the subsystem, are measured in the time domain. The measurements of the *NLA* system is shown in Figure 2 with an amplifier as the device under test.

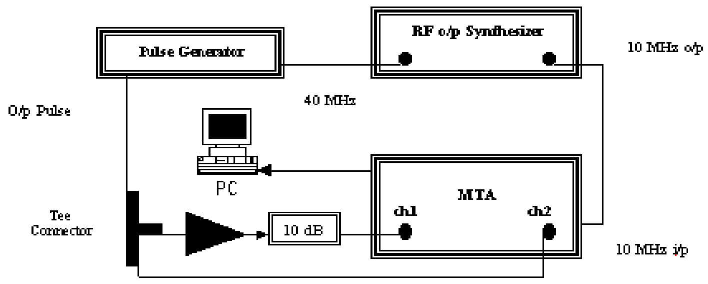

Figure 2. Time domain scattering function measurement system for amplifier.

The incident pulse from the generator travels towards the tee connector and splits into equal parts. One part travels through the amplifier and enters channel 1 of the *MTA* oscilloscope as the transmitted wave. The other part travels towards the channel 2 as the incident wave. The reflected wave from the amplifier travels back to the tee connector. One-part returns to the generator, another part travels to channel 2 as the reflected wave. The measured waveforms are shown in Figures 3 and 4. Averaging sixty-four measurement samples minimizes the measurement noise. The system is calibrated using a short circuit and matched termination to remove the errors introduced by the tee connectors and the transmission lines. The measured responses to large signal positive and negative inputs are different. That is why we use two sets of the incident pulses and measure the corresponding responses. All the measurements are made in time domain.

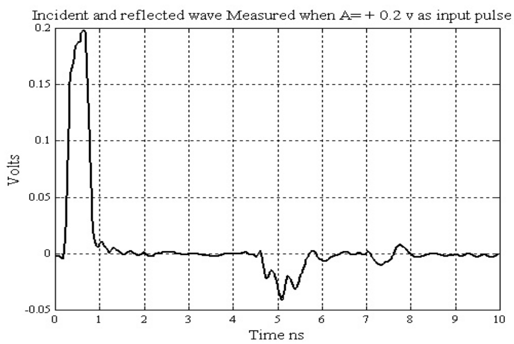

Figure 3. Measured incident and reflected waveforms.

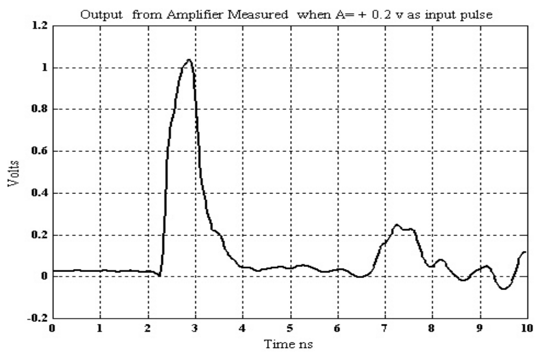

Figure 4. Measured transmitted waveforms.

4. Nonlinear Amplifier Model

A *Mini-Circuits ZFL-1000LN* non-linear amplifier two port has been modelled in the time domain. The four scattering functions are non-linear time domain transfer functions as shown in Figure 5. For this amplifier, a hyperbolic tangent *tanh* (x) function, which resembles the non-linear saturation characteristic of the amplifier, is chosen as the non-linear function. Measured responses to large signal positive and negative input are different; therefore two different non-linear functions are used for positive and negative inputs. This requires a switch at the beginning of the model to switch the signal according to its polarity as shown in Figure 6. The non-linear transfer function, which models the S_{21} scattering function in time domain is:

$$y(t) = \sum_{i=0}^{n} F_i(x(t-iT)) - \sum_{i=1}^{n} G_i(y(t-iT)) \qquad (1)$$

Where T is the sampling time interval and the non-linear function are given by:

$$F_i = \begin{cases} b_{ip}\tanh(k_{p1}x(t)) & \text{if } x(t)\geq 0 \\ b_{in}\tanh(k_{n1}x(t)) & \text{if } x(t)< 0 \end{cases} \qquad (2)$$

$$G_i = \begin{cases} a_{ip}\tanh(k_{p2}x(t)) & \text{if } x(t)\geq 0 \\ a_{in}\tanh(k_{n2}x(t)) & \text{if } x(t)< 0 \end{cases} \qquad (3)$$

And b_{ip}, b_{in}, a_{ip}, a_{in}, k_{p1}, k_{n1}, k_{p2}, k_{n2} are constants.

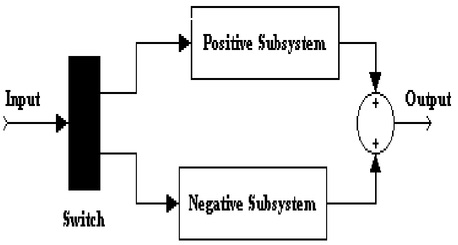

Figure 5. The model of the nonlinear amplifier system.

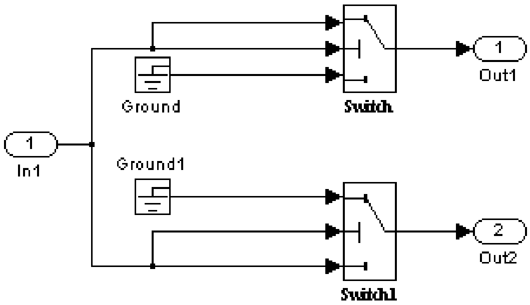

Figure 6. The block diagram for the switch subsystem.

Modelling the amplifier identifies the parameters b, a, and k from the measured time domain responses. The optimizer that was used to find the constant values is called $f_{minsearch}$ [3]. The ninth order model given in equation (1) is used for modelling the non-linear S_{21} scattering function. The sampling time is 0.02 ns, equivalent to a 25-GHz Nyquist frequency, which is much higher than the 1-GHz operating frequency [4]. The time domain results are given in Figures. 7 and 8.

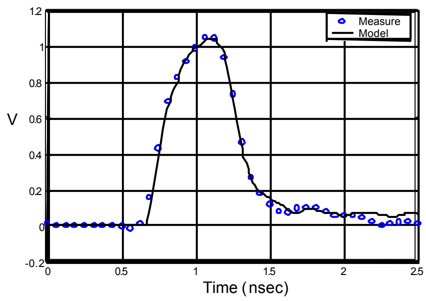

Figure 7. Positive pulse responses of the amplifier model.

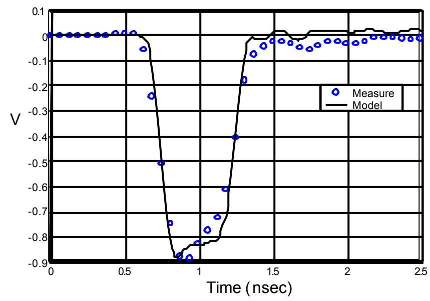

Figure 8. Negative pulse responses of the amplifier model.

5. Complete Simulation and Measurement of the Nonlinear Amplifier Model

The improved model for the non-linear amplifier system is examined by different ways:

- Choose the input two pulses one positive and another negative with the same amplitude and with step size 2.5/402 on 402 points. The output from the model shown in Figure 9.
- Apply the input four pulses two positive and another two negative, with a different amplitudes and with step size 2.5/804 on 804 points. The output from the model was shown in Figure 10.

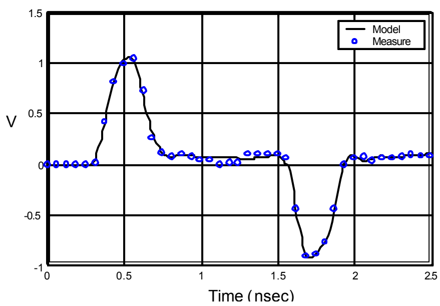

Figure 9. The o/p from the model when the i/p two pulses.

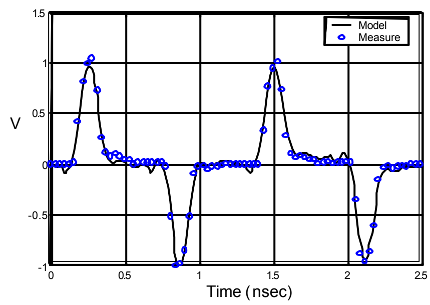

Figure 10. The o/p from the model when the i/p four pulses.

- Apply the input six pulses, three positive and another three negative, with a different amplitudes and with step size 2.5/1206 on 1206 points. The output from the model was shown in Figure 11.
- Finally test the model by using different amplitude of sinewave inputs. The result was shown in Figure 12.

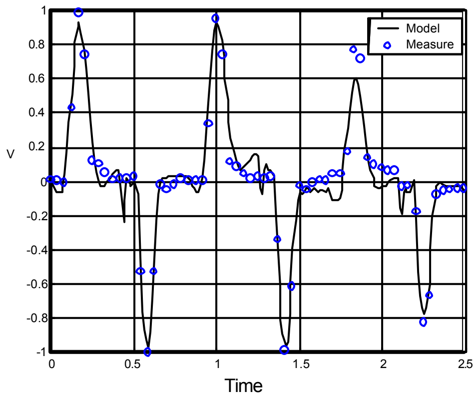

Figure 11. The o/p from the model when the i/p six pulses.

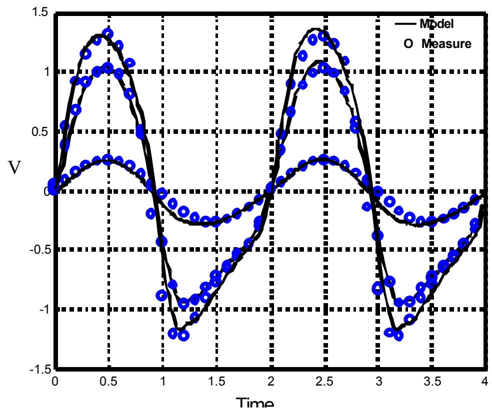

Figure 12. The o/p from the model when the i/p different sinewave.

The gain compression characteristics of the non-linear amplifier and the harmonic content of the model are compared to measured results in Figure 13.

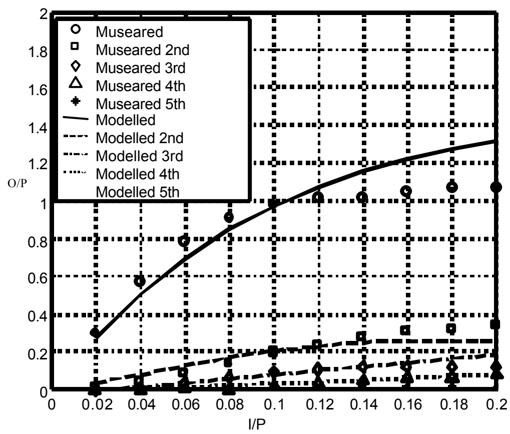

Figure 13. Input -output characteristics of the non-linear amplifier.

6. Conclusion

An alternative to conventional method of non-linear amplifier modelling and simulation has been developed and improved using the MATLAB® Simulink software. The method is based on the time domain modelling and time domain pulse procedure and sinewave perform simulation and the measurements. The improved model of the non-linear amplifier examines was done by using optimization $f_{minsearch}$ program and the simulation results agree very well with the measurements.

7. References

[1] M.I. Sobhy, E.A. Hosny, M.W.R. Ng and El-Sayed A. Bakkar, "Time domain measurement and identification of microwave systems ", Proc. 25th European Microwave Conference, pp. 641-645, Bologana, September 1995.

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