Frequency sampling algorithm applied in microwave measurements based on step-size control method

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Abstract—Extending the microwave frequency measurement from very low to very high frequency requires improvements for the acquisition time. In this paper, a new sampling algorithm is presented with the main purpose to reduce the acquisition time by using a limited number of samples. The adaptive algorithm proposed in this paper computes only a limited number of samples and then reconstructs the entire circuit response using the interpolation model. This method uses an adaptive step-size control and has the initial step and the error predefined. The algorithm evaluates the difference between two consecutive S parameters. The adaptive step-size algorithm assumes that, when the distance between the current S parameter value and the previous one decreases (below a threshold e), the exploration step-size may be increased up to a limit in order to keep the step-size to a moderate value. Otherwise, it might overlook major S parameter variations. The biggest challenge here is represented by the correlation between S parameter domain, frequency domain and scaling values. This algorithm automatically finds the number of points needed to accurately evaluate high S parameters variations and it has a high speed computing.

Keywords – microwave measurements, vector network analyzer, S parameters, adaptive step - size, sampling algorithm, reduced number of samples.

I. INTRODUCTION

Measurement systems are characterized by exciting signal as input and a system response (output signal). Acquisition and control systems study the performances of a model in time domain and frequency domain. When the transfer function has a difficult form, Chebyshev rational functions approximation will reduce the model [1]. When the system is not linear, the problem of finding the response based on transfer function becomes hard to solve. There are various methods of sampling and approximation of the response, such as adaptive algorithms. One of the most famous adaptive algorithms is adaptive step-size (AS-S). The issue of this algorithm is the need of a carefully choosing of the initial step - size. For this reason, combining this algorithm with other method has led to good results for various applications. Latest research shows good results for Least Mean Squares algorithm combined with AS-S in adaptive line enhancement and active noise control [2]. However, when signals have very large or very small variations, the LMS resulted model can be inappropriate. Function approximation using artificial neural network [3] uses a baseline initial samples. According to this paper, one disadvantage is the large number of iteration and the stop criteria (desired solution). Another adaptive algorithm is Genetic Algorithm for optimization and learning in different areas. For instance, the paper [4] finds Genetic Algorithm as a measure of voltage optimisation of electric power system. However, this method requires a large number of trial sets of search.

The study of microwave propagation is one of the most difficult problems of engineering (systems) modeling because of the microwave unpredictable behavior. In recent years, next generation technologies, such as 4G facilitates the communication between people. The communication evolution involves electronic circuits in very small packages. Beside this, high – speed communications are encountered everywhere. For these reasons, the signal integrity domain is being tightly connected with other research areas such as: telecommunications, electronic, mathematic, etc. In microwave technology, the signal propagation is studied using vector network analyzer (VNA). This device describes the behavior of circuits interconnected in complex systems considering the distortion signal effect by analyzing the incident, transmitted and reflected wave that travel along a transmission line. The effect of the signal distortion inside any communication system must be analyzed in order to avoid the affecting of the signal integrity. As described in [5] “Analytic solutions for nonlinear systems are almost impossible to be found.”. According to [5], the unpredictable behavior of the systems is studied using extrapolation methods. Because real-world systems are nonlinear, our goal is to provide the device under test (DUT) discretisation response for a limited – range of frequencies and then reconstruct the entire response using interpolation and extrapolation. Finding an approach model capable of describing the device response reduces the time needed for the complete measurement, but the time necessary for the computing effort may exceed the time for the complete measurement. As a result, we
need to find this model in a simple manner in order not to increase the computational effort.

In this paper, we propose adaptive step-size algorithm (AS-S) to compute only a limited number of samples and then reconstruct the entire circuit response using the interpolation model. Adaptive step-size was successfully applied in different problems such as adaptive IIR notch filter [6], sound source separation [7], acoustic echo cancellation [8], etc.

Paper [9] proposes “a synthetic vector network analyzer measurement system” with “performance in terms of accuracy and speed compared with a modern traditional vector network analyzer, but it is more flexible due to its inherent software implementation.”. The new synthetic VNA has a different hardware setup and the results show good agreement with the original response. The biggest disadvantage is the need to replace the hardware concept of the traditional VNA.

The I/O (input – output system) responsible for the connection between computer peripheral and VNA is USB or Ethernet protocols. Depending on technology used, the transfer data between devices increases the acquisition time.

In this paper we compare the original DUT response with the AS-S DUT response using S – parameters. For a two port device we have four parameters: S_{11}, S_{12}, S_{21}, S_{22}. The number of the S – parameters is the same with the square of the number of ports. As previously mentioned, S - parameters, defined as the input and output reflection coefficients (S_{11}, S_{22}) and the transmission coefficients (S_{12}, S_{21}), represent a transfer matrix for the energy propagated through a multi - port network, usually two - port network. The network changes sometimes the input signal, so the magnitude and phase may vary. As a consequence, S parameters are complex numbers. A detailed documentation regarding S – parameters can be found in [10].

II. THE AS-S ALGORITHM PROBLEM

The S - parameters behavior will be approach using adaptive step-size algorithm (AS-S). This adaptive step-size algorithm proof - concept approximates the system response using a reduced number of samples. This algorithm involves some problems:

- The initial step-size estimation may avoid an important area of interests.
- The algorithm used to update the step-size should be convergent and needs to acquire critical points

It is a difficult task to predict where are maximum or minimum points (considered critical points for our representation) in a dynamic system such as microwave system, because of their unpredictable behavior.

The proposed method in this paper suggests adjusting the step-size value based on the evolution of the recent acquisitions related to the original axes Ox. Increasing the step-size linearly ensures that fast deviations will be detected. We proposed the same algorithm for step-size decreasing to preserve symmetry. For very large value of the step-size, measurement process will lose the accuracy, but will keep a good speed of convergence. Because of this, we update the step-size with small variation and within well-defined limits.

The AS-S has good results in microwave domain because the initial step-size does not need to be chosen as we can acquire the first three values using the standard measurement method.

We avoid the situation when the step-size would increase or decrease to infinity. To avoid this kind of situation, we impose limits for step-size. This idea will affect speed convergence, but will assure the measurement accuracy.

The advantage of this method is represented by the ability to provide a pertinent S-characteristic reconstruction when the step-size value is “optimal”. As previously stated, the major challenge at this point is to find a relation between frequency range – S parameter evolution – step-size. Other advantages of this method are: the time acquisition improvement and the high performance response.

The next section will explain how the step-size can be chosen when the trend is estimated through the last three samples.

III. THE AS-S SOLUTION

The objectives of the AS-S algorithm are:

- Finding the polynomial form that can describe the measured behaviour;
- Automatic computing the minimum number of samples required to evaluate the function;
- Reduce the time acquisition;
- Reconstruct the device response using the limited number of samples.

AS-S algorithm computes the optimal step-size variation to estimate the “local” measured -characteristic form by using a polynomial fitting method for the last 3 points, which is used to calculate the derivative value for the last acquired point. If this value is greater than an imposed limit that means the measured -characteristic has a significant evolution and, as consequence, the step-size needs to be decreased (in order to obtain an appropriate representation).

Due to large variations of the derivatives it is hard to find a direct dependency between it and the step-size value. This method has a granularity predefined (initial step-size). At the beginning, three points are acquired (corresponding to the minimum value input signal, minimum value input signal + step-size and minimum value input signal + 2-step-size).

Next, it has to be found the equation of a quadratic curve passing through those three points, which is a polynomial form. The first derivative of this form is a line in the plane which intersects the axis Ox when the angle is not zero.
If this angle is greater than an imposed value, the step will be decreased because measured quantity will have a major variation in the next interval. Otherwise, the step will be increased. The exploration step - size may be increased up to a limit in order to keep the step - size to a moderate value.

We update the step - size with respect to the ε threshold using (1) and (2):

\[ \text{Step} = \text{prev}_\text{step} \times \text{factor}_1, \text{threshold} < \varepsilon \]  
(1)

\[ \text{Step} = \text{prev}_\text{step} \times \text{factor}_2, \text{threshold} \geq \varepsilon \]  
(2)

\text{factor}_1 \text{ and } \text{factor}_2 \text{ have to be chosen in order to minimize the number of points, but also to avoid a too aggressive step - size increasing.}

The adaptive step - size algorithm assumes that, when the distance between the current S - parameter value and the previous one decreases (below a threshold ε), the exploration step - size may be increased up to a limit in order to keep the step - size to a moderate value. Otherwise, it might overlook major S - parameter variations. The advantage of this method is represented by the ability to provide a pertinent measured-characteristic reconstruction when the step - size value is “optimal”.

IV. THE AS-S BLOCK DIAGRAM

For the considered diagram (Fig. 1), \text{factor}_1 = \text{factor}_2 = 2. As it can be seen, the initial step and ε are the two inputs user - defined. Next, the three frequencies are computed and based on the condition \( \Delta > \varepsilon \), step - size is increased or decreased. AS-S algorithm computes new samples until the entire frequency range is evaluated. Next, we apply the interpolation method to reconstruct device response.

Real - time applications deal with high oscillations that can occur between points. Because we have always more than three points, the first and the second derivatives are continuous. The interpolating nodes are represented by the samples. To detect high oscillations we keep smooth step - size variations. As a consequence, cubic spline interpolation will do better than other interpolation methods.

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In this example, we try to recover a filter behaviour with a frequency range in: 4.7 GHz – 5.5GHz. You will see in Fig. 2 with continuous line the original measurement, the dotted line is the reconstructed response based on samples and with circles all samples. The original measurement is acquired with MS4640A Vector Star Anritsu – Vector Network Analyzer. The original measurements (results) are stored in the Touchstone format data file (*.s2p). Next, we analyze the signal propagated through the two ports network using scattering parameters (S - parameters). For high frequencies it is important to analyze the reflected signal (S11 and S22). Usually, the reflected signal has the same values for port 1 and port 2. Next, we present the response for the reflected signal at port 1 (S11).

The initial step - size was set to 0.01 and \( \varepsilon = 14 \) degree. The step has a variation in this example between 0.01 and 0.08.

The dotted line cannot be identified in this example, because the AS-S algorithm fully recovered the response. Depending on measurement accuracy needed, this response is not always good. In Fig. 3, you can see the result after interpolation.
In measurement, 0.3dB is a good error, but sometimes you might need a higher accuracy. Fig. 3 depicts a situation when the AS-S algorithm will never achieve some points. In order to solve this issue, the algorithm decreases the ε value. In practice, this parameter is the measurement tolerance and it is an index of the quality of the measurement. The disadvantage related to interpolation is the approximation result. An interpolated value may be different from the original value as one can see in Fig. 3.

The error of measurement is an indicator of the quality measurements. We use global error as a tool for measurement accuracy (3), where \( n \) is the number of samples.

\[
Global_{error} = \frac{\sum_{i=1}^{n} |\text{Interpolated}(i) - \text{Measured}(i)|}{\sum_{i=1}^{n} |\text{Measured}(i)|} \tag{3}
\]

In Fig. 4, the error distribution for filter example is presented. It can be seen that most of the errors is distributed in the area where the global error tends to zero: 7500 points. Next we have 2985 points with error = 0.002, 1415 points with error = 0.003. Errors distribution has an exponential representation and the biggest value is 0.14 in only one point.

In Table I are presented different results of using AS-S comparing with standard measurement.

### VI. Conclusions

In this paper, a new algorithm for high speed microwave measurements is suggested. The algorithm is dependent on the step-size and the error angle ε. AS-S is based on a limited number of samples. Spline interpolation is used to approximate the measurand at any point. AS-S algorithm automatically selects the additional samples to define the interpolation model. The algorithm is applied to several real measurements and the results show good agreement with the measured parameters. Every result has been verified by comparing interpolated and measured values. The results obtained with the new developed algorithm presented in this paper show to be competitive in terms of acquisition time and accuracy.

### REFERENCES


