New Behavioral-Level Simulation Technique for RF/Microwave Applications. Part III: Advanced Concepts

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ABSTRACT: The quadrature modeling structure is widely accepted as an efficient tool for the nonlinear simulation of RF/microwave bandpass stages (power amplifiers, etc.) for wireless applications. The common belief is that this structure can be applied to model only bandpass memoryless nonlinearities (which, however, may exhibit amplitude-to-phase conversion). In two recent articles [1, 2] the authors have extended the application of the quadrature modeling structure to modeling broadband nonlinearities, which makes possible to predict harmonics and even-order nonlinearities, to take into account the frequency response, etc. This article completes the overview of the instantaneous quadrature technique. The authors discuss its application to modeling AM, FM and PM detectors, which are strongly nonlinear elements with large memory (both the strong nonlinearity and large memory effects are essential for the detector proper operation), thus removing the limitation of nonlinearity to be memoryless or quasimemoryless. The identification of nonlinear interference/distortion sources is of great relevance for a practical EMC/EMI design. In the second part of this article, we discuss the dichotomous identification method, which is much more computationally efficient than a simple single-signal method, especially for a large number of input signals. Individual spectral components of a complex-spectrum signal can also be considered as input signals and, hence, it is possible to identify the spectral components responsible for a particular nonlinear interference/distortion (say, for a particular intermodulation product). © 2002 Wiley Periodicals, Inc. Int J RF and Microwave CAE 12: 206–216, 2002.

Keywords: behavioral-level simulation; nonlinear modeling; quadrature technique

1. INTRODUCTION

In two companion articles [1, 2], we have considered a new behavioral-level technique (the instantaneous quadrature technique) for nonlinear modeling and simulation of RF/microwave circuits, its application to the power amplifier simulation and to the methods of nonlinear transfer function approximation. The primary application of this technique is the nonlinear simulation of RF bandpass circuits (such as wireless power amplifiers or receiver low-noise amplifiers). A typical assumption for such a simulation is that of bandpass nonlinearity. In fact, we deal with typical RF stages composed of a linear filter at the input, a memoryless nonlinear element at the

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middle and a linear filter at the output [1] (see Fig. 1). Thus, there exists a conventional opinion that such a technique can only be applied to nonlinear elements without or with small memory effects (like AM–PM conversion). However, the instantaneous quadrature technique can be used for the simulation of amplitude (AM), frequency (FM) and phase (PM) detectors, which are nonlinear elements with quite large memory [3, 4] (it should be noted that both the nonlinearity and large memory are essential for the proper detector operation). Actually, we do not need the assumption of memoryless in the instantaneous quadrature technique because the Hilbert transform gives us a possibility to model arbitrary-large memory effects. A particular modeling method depends on the specific memory effect under consideration (thus, for example, the methods of AM and PM detector modeling are different). Mixers can be modeled by the instantaneous quadrature technique in a way similar to RF amplifier modeling and taking into account spurious effects (it is possible because this technique uses directly instantaneous signal values rather than the complex envelope). The ability to model detectors enables one to simulate the entire receiving path, starting from the first front-end stage and up to the baseband signal processing. However, modeling automatic gain and frequency control loops requires some additional research efforts.

When dealing with electromagnetic compatibility/interference (EMC/EMI) problems, the analysis of the system performance under given input signals (including interference signals) is only the first step. The next step is to determine which interference signals in particular degrade the systems performance. It is not so simple when the interference or distortion is of nonlinear nature and when there is a large number of input signals. Usually, this task requires big computational power. Hence, some advanced computationally efficient techniques are required. In this article, we shall consider a computationally efficient method of the identification of nonlinear interference/distortion sources (intermodulation products, harmonics, spurious receiver responses, etc.), which is based on the instantaneous quadrature technique and can be used during the EMC/EMI analysis in a group of radio systems (frequency planning, for example).

The main purpose of this article is to complete the overview of the instantaneous quadrature technique and to discuss its prospects, some future research directions and application areas.

2. APPLYING THE INSTANTANEOUS QUADRATURE TECHNIQUE TO DETECTOR SIMULATION

Here we discuss how to apply the instantaneous quadrature modeling structure [1] to the nonlinear analysis of a detector. As it was already mentioned in Section 1, a big difference between a typical RF stage and the detector is that the nonlinearity of the latter is absolutely necessary for its proper operation and this nonlinearity is usually quite large (strictly speaking, there is no small-signal mode in the detector, when nonlinear effects can be neglected—the detector would not operate at all in this mode). The next big difference is that memory effects, which are quite large, are very essential for the proper detector operation as well. There are some memory effects in the typical RF stage, which are modeled by the linear filters in Figure 1. However, the main difference in this respect between the RF stage and the detector is that we neglect the impact of the output linear filter on the nonlinear element operation in the case of RF stage, and we cannot neglect this impact in the case of detector because it is very essential for detector operation. Thus, we need to modify the instantaneous quadrature modeling structure in such a way that it allows for modeling all the main detector features.

The main idea is to use the Hilbert transform to calculate the envelope amplitude (AM detector), the instantaneous phase (PM detector) and frequency (FM) detectors [3, 4]. The Hilbert transform of a time-domain signal $x(t)$ is [5]

$$\hat{x}(t) = \int_{-\infty}^{\infty} \frac{x(\tau)}{t-\tau}\, d\tau, \tag{1}$$

where $\hat{x}(t)$ is the Hilbert-conjugate signal of $x(t)$. A much more computationally efficient way to compute the Hilbert transform is to use the frequency-domain representation and the fast Fourier transform because it does not require numerical integration [1]:

$$\begin{aligned} \hat{x}(t) &= \mathrm{IFFT}(-j \cdot S(\omega)) \quad \text{for } \omega \geq 0, \\ S(\omega) &= \mathrm{FFT}(x(t)), \end{aligned} \tag{2}$$

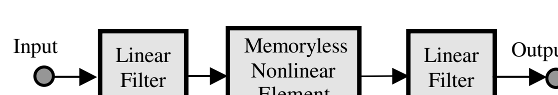

Figure 1. Typical RF stage (bandpass nonlinearity).

where $S(\omega)$-is the signal's spectrum, FFT and IFFT are the direct and inverse fast Fourier transforms.

In the following subsection, we consider in detail how to apply the Hilbert transform to the detector simulation [3, 4].

2.1. AM Detector Simulation

AM detector simulation using the instantaneous quadrature modeling structure has been discussed in detail in [4]. Here we outline the main steps and discuss essential modeling issues.

The primary function of an AM detector is the generation of the output signal, whose value is proportional to the input signal magnitude [6]. Thus, one needs to calculate the input signal magnitude to simulate the AM detector operation. Using eqs. (1) and (2), one obtains [7–10]:

$$A(t) = \sqrt{x(t)^2 + \hat{x}(t)^2}, \tag{3}$$

where $A(t)$ is the input signal magnitude. The output signal of the detector is

$$x_{\mathrm{out}}(t) = k_d(A) \cdot A(t), \tag{4}$$

where k_d is the detector transfer factor, which is a function of the input signal magnitude. When the input signal magnitude is large enough, k_d can be considered to be a constant. If this magnitude is small, then one needs to consider k_d as a function of $A(t)$. The following expression, which describes k_d quite accurately [4, 11], can be used for the detector transfer factor calculation:

$$k_d = \frac{1}{\overline{A}} \cdot \ln\left(\frac{1 + \beta \cdot I_0(\overline{A})}{1 + \beta}\right), \tag{5}$$

where $\overline{A} = A/\varphi_{te}$ is the normalized input signal magnitude, $\varphi_{te} = \alpha \cdot \varphi_t$ is the effective thermal voltage, α is a correction factor (it depends on the type of a detector nonlinear element, $\alpha = 1, \ldots, 3$), φ_t is the thermal voltage ($\varphi_t \approx 25\,mV$ for the room temperature), I_0 is the zeroth-order modified Bessel function of the first kind,

$$\beta = \frac{I_s R}{\varphi_{te}}, \tag{6}$$

R is the load resistance (see Fig. 2), and I_s is the diode saturation current. This expression characterizes the detector operation quite well both for small and large input signal values and when

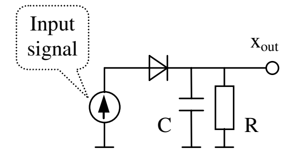

Figure 2. AM diode detector.

the load resistance is much smaller than the output detector (diode) resistance. It should be noted that the detector operation is somewhat opposite to the typical RF amplifier operation: the transfer factor k_d is a constant for large input signal magnitude (linear operation mode), and is a function of the input magnitude for its small value (nonlinear operation mode). For a transistor AM detector, the linear operation mode is limited by the DC supply voltage and, hence, this detector operates in a nonlinear fashion for a sufficiently large input signal as well. However, this limit is far beyond the normal operation conditions.

Using the approach discussed above, the detector simulation scheme can be organized as shown in Figure 3. This figure stresses the analogy with the instantaneous quadrature modeling structure [1]. However, the detector simulation scheme has a few important differences when considering the detector-specific features. The main difference is how the in-phase and quadrature-phase signals are combined: in the instantaneous quadrature modeling structure they are combined in a linear fashion, and in the detector simulation scheme they are combined in a highly nonlinear way (see eq. (3)). In this way, the detector simulation scheme models the nonlinear behavior of the detector. Note that in this scheme there is no small-signal mode in the sense that the nonlinearity cannot be neglected for any signal value—exactly the same as for the detector which it models. Comparison with circuit-level simulation and measurements shows that the accuracy of this simulation approach is quite good [3, 4]. Figure 4 gives an illustrative example of the simulation results for the input signal shown in Figure 5.

It should be noted that there is one important limitation for the above-discussed approach: the bandwidth of the input signal must be smaller than the cut-off frequency of a low-pass filter (RC-circuit in Fig. 2) at the detector output,

$$\Delta f_{\mathrm{in}} < F_{\mathrm{cut}}. \tag{7}$$

If this condition is satisfied, then the output signal follows the input signal magnitude at the same

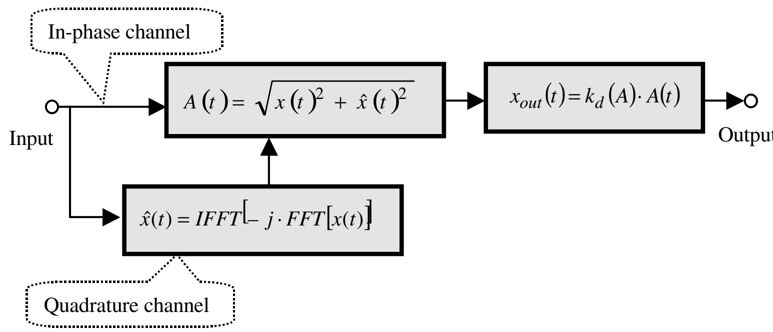

Figure 3. AM detector simulation scheme using the quadrature structure.

instant and the detector is said to be memoryless. This is a normal operation mode and the present method models it quite well. If not, then the output signal does not follow the input signal magnitude and depends on its value at the preceding moments of time and the detector is said to have memory. This is not a normal operation mode (it can be caused by some interfering signals). However, one may wish to analyze it to model the detector operation under interference conditions. A detail analysis of this operation mode is given in [4]. Here we outline the main results. Let us consider the input signal spectrum as shown in Figure 5. The spectrum consists of the required AM signal (f_c, $f_c + F_m$, and $f_c - F_m$) and the interference signal (f_{int}). In the practically important case of $u_{\text{int}} < u_c$, where u_{int} is the interference signal magnitude and u_c is the carrier magnitude, condition (7) may be relaxed as follows:

$$\Delta f_{\text{in}} < \frac{\pi}{2} \frac{u_c}{u_{\text{int}}} F_{\text{cut}}, \tag{8}$$

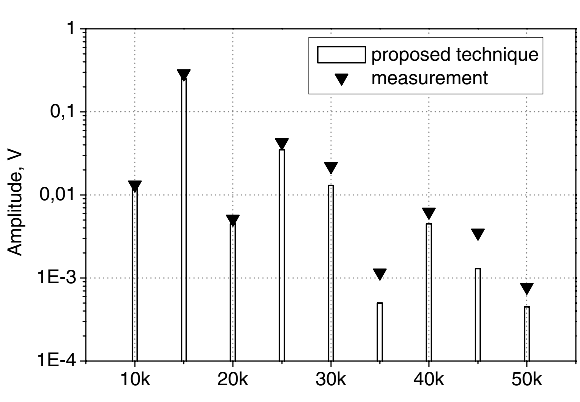

Figure 4. Spectrum at the AM detector output (the input spectrum is as in Figure 5, $f_c = 1$ MHz, $F_m = 10$ kHz, $m = 0.3$, $u_c = 100$ mV, $u_{\text{int}} = 300$ mV, $f_{\text{int}} = 1015$ kHz).

where $F_{\text{cut}} = 1/2\pi RC$ and $\Delta f_{\text{in}} = f_{\text{int}} - f_c$. Thus, the spectral component separation is limited (for the detector to be memoryless) not only by the cut-off frequency, but also by the components' magnitude ratio. Hence, when $u_c > u_{\text{int}}$, the input signal bandwidth can be larger than the cut-off frequency and still the detector will be memoryless (i.e., the output RC circuit will not suppress the beat component $f_{\text{int}} - f_c$). It is quite opposite to the conventional RC-circuit operation. The reason for this difference is that our RC-circuit is connected to a nonlinear device (the diode) and, consequently, the capacitor charge and discharge paths (and time constants) are different. During the detector simulation, one should ignore the RC-circuit if condition (8) holds.

From a practical viewpoint, spectral components of the detector input signal, which lie outside the intermediate frequency (IF) path bandwidth (which is approximately equal to the required signal bandwidth), will be strongly attenuated by the IF filters, therefore condition (8) will most probably be fulfilled. If, nevertheless, it is not, then it means that these spectral components have very large level at the receiver front-end stages and the receiver is completely blocked. If condition (8) is not true, then the output interference signal (the beat component) will be attenuated by the RC-circuit. However, the attenuation factor will be smaller than the trans-

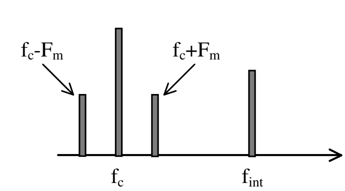

Figure 5. Signal spectrum comprised the required AM components and an interference component (f_c—carrier frequency, F_m—modulating frequency, f_{int}—interference frequency).

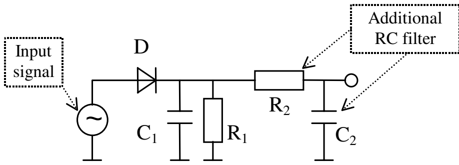

Figure 6. AM diode detector with an additional RC filter.

fer factor of the RC-circuit. Thus, the optimal decision is to ignore completely the RC circuit during the simulation. We should note that if an additional low-pass filter is connected to the detector output (as in Fig. 6), then this filter must be taken into account in a conventional way, using the complex transfer function of the filter (because the capacitor C_2 charge and discharge time constants are the same).

2.2. FM and PM Detector Simulation

The primary function of an FM detector is the generation of the output signal, whose value is proportional to the input signal instantaneous frequency [6]. Thus, to model this detector, one needs to calculate the input instantaneous frequency. First, using the Hilbert transform, we find the input signal phase [7–10]:

$$\varphi(t) = \tan^{-1}\left(\frac{\hat{x}(t)}{x(t)}\right). \tag{9}$$

Further, using this equation, the input signal instantaneous frequency can be expressed as:

$$\omega(t) = \varphi'(t)\frac{\hat{x}'(t)x(t) - x'(t)\hat{x}(t)}{x^2(t) + \hat{x}^2(t)}, \tag{10}$$

where prime means the time derivative. When carrying out a computer simulation, one deals with discrete time:

$$t_k = \Delta t \cdot k, \tag{11}$$

where Δt is the time sample interval. Then eq. (10) takes the form:

$$\omega_k = \frac{\hat{x}_k x_{k-1} - x_k \hat{x}_{k-1}}{\Delta t \cdot A_k^2}, \tag{12}$$

where $\omega_k = \omega(t_k), x_k = x(t_k), \hat{x}_k = \hat{x}(t_k)$ and $A_k = A(t_k)$. The choice of the time sample interval and the number of samples is discussed in [4] (this is also very important for AM detector simulation as well). Output signal of the FM detector is proportional to the difference between the instantaneous input frequency and the detector resonant frequency ω_0 and is expressed as:

$$x_{\text{out},k} \approx k_d \cdot (\omega_k - \omega_0), \tag{13}$$

where k_d is a constant. This equation is valid for the linear part of the detector input–output characteristic, when

$$|\omega_k - \omega_0| \leq \Delta\omega, \tag{14}$$

where $\Delta\omega$ is the linear part width, and for a sufficiently large input signal when its amplitude is constant (due to the limiter which is connected in front of the detector). This can be expressed as:

$$A_{\text{lim, in}} \geq A_{\text{th, in}}, \tag{15}$$

where $A_{\text{lim, in}}$ is a signal magnitude at the limiter input, $A_{\text{th, in}}$ is the limiter threshold level (the saturation level). In other cases, this equation should be generalized to take into account the nonlinearity of the detector transfer characteristic and its dependence on the input signal magnitude

$$k_d = k_d(\omega_k - \omega_0, A_k). \tag{16}$$

Appropriate approximations for the dependence of k_d on $\omega_k - \omega_0$ can be found in [6]. The dependence of k_d on A_k can be approximated by

$$k_d \approx c \cdot A_k, \quad c \text{ is constant} \tag{17}$$

for an FM detector with tuned-off circuits or similar, and by

$$k_d \approx c \cdot A_k^2, \quad c \text{ is constant} \tag{18}$$

for an FM detector with a multiplier.

Using this method, the FM detector simulation scheme can be organized as shown in Figure 7. Again, we would like to stress the analogy with the instantaneous quadrature modeling structure [1]. As the comparison with circuit-level simulation shows, this technique predicts the required signal compression and the threshold effect quite well. Predicted distortion component levels are smaller than in reality. Thus, some additional investigation is required to build more accurate models of $k_d(\omega_k - \omega_0, A_k)$. In doing so, a specific type of the detector and its nonlinear elements should be taken into account. A PM detector can be simulated in a similar way, using the discrete

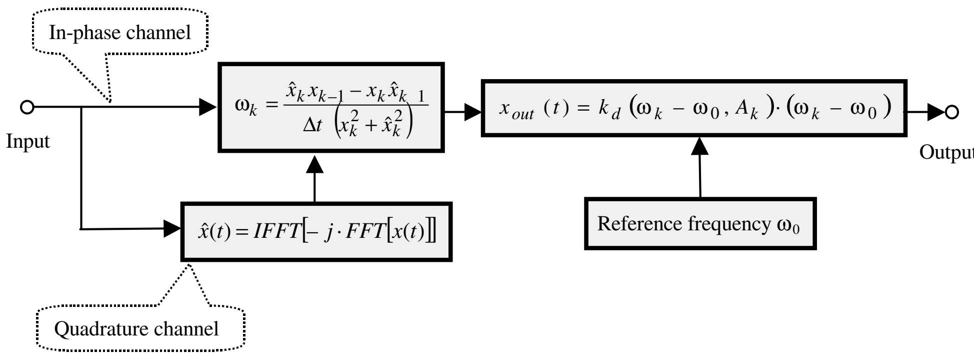

Figure 7. FM detector simulation scheme using the quadrature structure.

form of eq. (9). Figure 8 shows the simulation scheme.

It should be noted that the accurate modeling of nonlinear effects in PM/FM detectors is essential for high simulation accuracy. Equations (13), (15), (17), and (18) provide only a rough approximation. Much work remains to be done in this area.

3. IDENTIFICATION OF NONLINEAR INTERFERENCE/DISTORTION SOURCES

Let us now consider the identification of nonlinear interference and/or distortion sources [12–14]. A typical scenario under consideration is shown in Figure 9. There are N interference signals S_1–S_N, which affect a victim receiver (for definiteness, we shall speak about receiver, however another nonlinear system or stage can also be considered in this way) and generate nonlinear interference/distortion in this receiver. Our task is to find the sources of this interference/distortion (i.e., the specific signals in the set S_1–S_N, which cause the interference/distortion).

In the general case, the problem of nonlinear interference source identification is much more complex than that of linear interference. The general approach to the nonlinear interference source identification may be formulated on the basis of the fact that a nonlinear interference disappears when at least one signal that takes part in its formation is excluded (turned off). For example, a second-order intermodulation product (IMP) is proportional to the product of the signal magnitudes that generate this product: $\mathrm{IMP}_2 \sim U_1 \cdot U_2$. If $U_1 = 0$, then $\mathrm{IMP}_2 = 0$ (the same holds for U_2). A similar principle is also true for the case of higher order IMPs, which may be formed by more than two signals and for the whole class of other nonlinear interference types (desensitization, cross-modulation, local oscillator noise conversion, etc.) [15, 16]. This principle may be used as a basis for a number of identification methods, which consist of a repeated receiver simulation when one or several sources are excluded from the simulation.

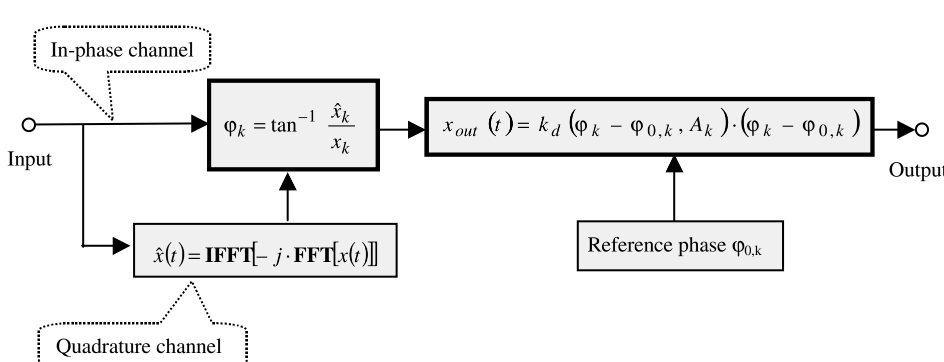

Figure 8. PM detector simulation scheme using the quadrature structure.

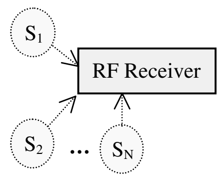

Figure 9. A typical scenario: interference signals S_1–S_N affect the victim RF receiver and generate nonlinear interference/distortion.

3.1. Single-Signal Identification Method

A direct identification method, which is based on the principle discussed above, is as follows:

1. Simulate the receiver when all the signals S_1–S_N are active (turned on),
2. Exclude (turn off) the signal S_1,
3. Simulate the receiver when the other signals (S_2–S_N) are active,
4. Check whether the interference disappeared. The interference magnitude A_{int} is an indicator of its disappearance:

$$A_{\text{int}} < \alpha \cdot A_{\text{int},0}, \tag{19}$$

   where $A_{\text{int},0}$ is the interference magnitude at the first step (when the signal S_1 was turned on), and α is a reduction in the interference magnitude, which indicates its disappearance ($\alpha \approx 0.5, \ldots, 0.1$). If the interference did not disappear, then S_1 is not its source; otherwise it is its source.
5. The procedure above is repeated for the signals S_2–S_N.

This method may be called the single-signal method. Its use is expedient when the signal number N is not large (practically, when $N < 10$), because the nonlinear receiver simulation itself requires much computational time. This time may vary from several seconds up to several hours or even days depending on the receiver complexity and a specific computer. The required number of simulation cycles is

$$n_s = N. \tag{20}$$

The single-signal method cannot be used if there is a large number of signals. In this case, one needs to use a more advanced technique, which should be much more computationally efficient.

3.2. Dichotomous Search Method

The essence of this method is that a subset of signals rather than each individual signal is turned off. If the exclusion of the signal subset does not cause the interference to disappear, then this subset does not contain the interference sources and can be discarded from further consideration. If the interference does disappear, then the subset contains interference source(s). In this case, the subset is to be split into several parts and these parts are to be analyzed with the use of the method described above. When the dichotomous method is used, the subset under analysis is split into two equal parts at each step. This process is repeated until each subset contains one signal whose exclusion makes it possible to determine whether or not this signal is an interference source. This method is schematically represented in Figure 10. In this case, the total number of signals is 8; S_2 and S_5 are the interference sources. First, the receiver is simulated when all the signals S_1–S_8 are active. Secondly, the total signal set is split into two equal subsets and the receiver is simulated for each subset separately. The interference exists for both simulations. Hence, on the third step, each subset is split into two equal subsets and simulations are repeated. The subsets that do not result in the interference ([S_3, S_4] and [S_7, S_8]) are excluded from further consideration. On the fourth step, the receiver is simulated for each of the signals S_1, S_2, S_5, and S_6 separately and this completes the identification.

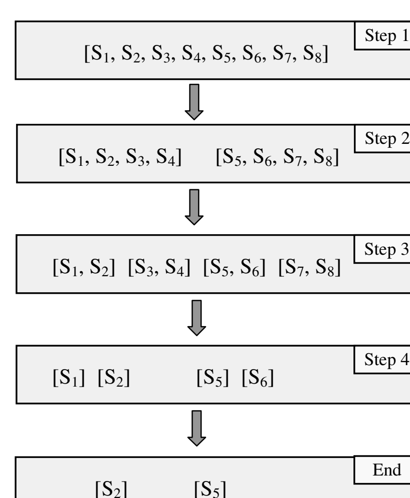

Figure 10. An example of the nonlinear interference source search by the dichotomous method. The total number of signals $N = 8$. S_2 and S_5 are the sources of nonlinear interference.

The number of simulation cycles required to identify an interference which has k sources is

$$n_s \approx 2k \log_2(N). \tag{21}$$

The comparison of (20) with (21) shows that the dichotomous search method provides considerable advantage over the single—signal method when there is a large number of input signals. Here is an example. For $k = 2$ and $N = 10^3$, the one-signal method requires for 1000 simulation cycles and the dichotomous method requires for about 40 simulation cycles . For larger values of N, this difference is even more pronounced. If one simulation cycle takes 1 minute to carry out, then the identification by the single–signal method will last for about 16 hours, and by the dichotomous method for about 40 minutes (this difference is similar to the difference between discrete Fourier transform and fast Fourier transform). In practical problems, N may be even larger because one may wish to consider a complex input spectrum and each of its spectral component as a signal, and to look for those components that cause a particular distortion or interference. The advantage of the dichotomous search method over the single–signal method is even higher in this case.

The search time can be significantly reduced if the signals are previously sorted in accordance with their power level and the subset which contains the smaller signals is excluded from the simulations in the first turn, because high-level signals are the most probable nonlinear interference sources. It is also expedient to take into consideration the intermodulation dynamic range (or the intercept point) of the receiver when making such sorting, and to determine whether the signals fall into the receiver front-end bandwidth (the signals that do not fall are excluded in the first turn).

3.3. Dichotomous Search Algorithm

The dichotomous search algorithm based on the method given in the previous section is presented in Figure 11. Let us now consider the algorithm main steps. First, all signals are sorted according to their power level. Then the user chooses an interference to identify and the current set of signals is equated to all the signals. After that the procedure HALF_SET is called. The main function of this procedure is to divide the current signal set (SET) into two parts (SET_1 and SET_2) in such a way that the first part contains smaller signals and the second one contains larger signals, to ⟨⟨turn off⟩⟩ the first part, to conduct the analysis, and to check whether the interference disappeared. If it did not disappear, then the turned-off part is excluded from the current signal set and the process of division is continued. If interference disappeared, then the second part (SET_2) is turned off (the first part remains to be turned on) and the analysis is repeated. If the interference did not disappear, then the interference source is in the first part only and the process of division is continued for this part (the second part is excluded from further consideration). If interference disappeared, then the second part contains interference sources.

In this case, the procedure HALF_SET executes a series of internal settings and checks whether the number of interference signals (L) exceeds the maximum admissible value (MNIS) which is set by the user. If it does not, then the search procedure is continued. If it does, then the process of the current interference sources search is stopped and the user can choose the next interference to search its sources. The limitation of the interference sources number is necessary to limit the time that the search process requires and the number of sequential calls to the nested procedure HALF_SET.

If there is only one signal in each part, then they are interference sources, and then the exit from the procedure is made. Otherwise the parts which contain more than one signal are divided into two parts and the above-mentioned operations are repeated. Two new sets of signals are introduced and the procedure HALF_SET is called again. After the exit from the procedure HALF_SET of the uppermost level the user can choose the next interference for identifying. If it is not necessary, then the algorithm is completed. The interference signals are saved into the interference file.

3.4. The Relation Between Identification and Optimization Problems

It should be pointed out that the problem of the interference source identification is similar to some optimization problems [17, 18]. If we define the goal function F as a function of several signals (each interference has its own goal function)

$$F = F(S_{n1}, S_{n2}, \ldots, S_{nk}), \tag{22}$$

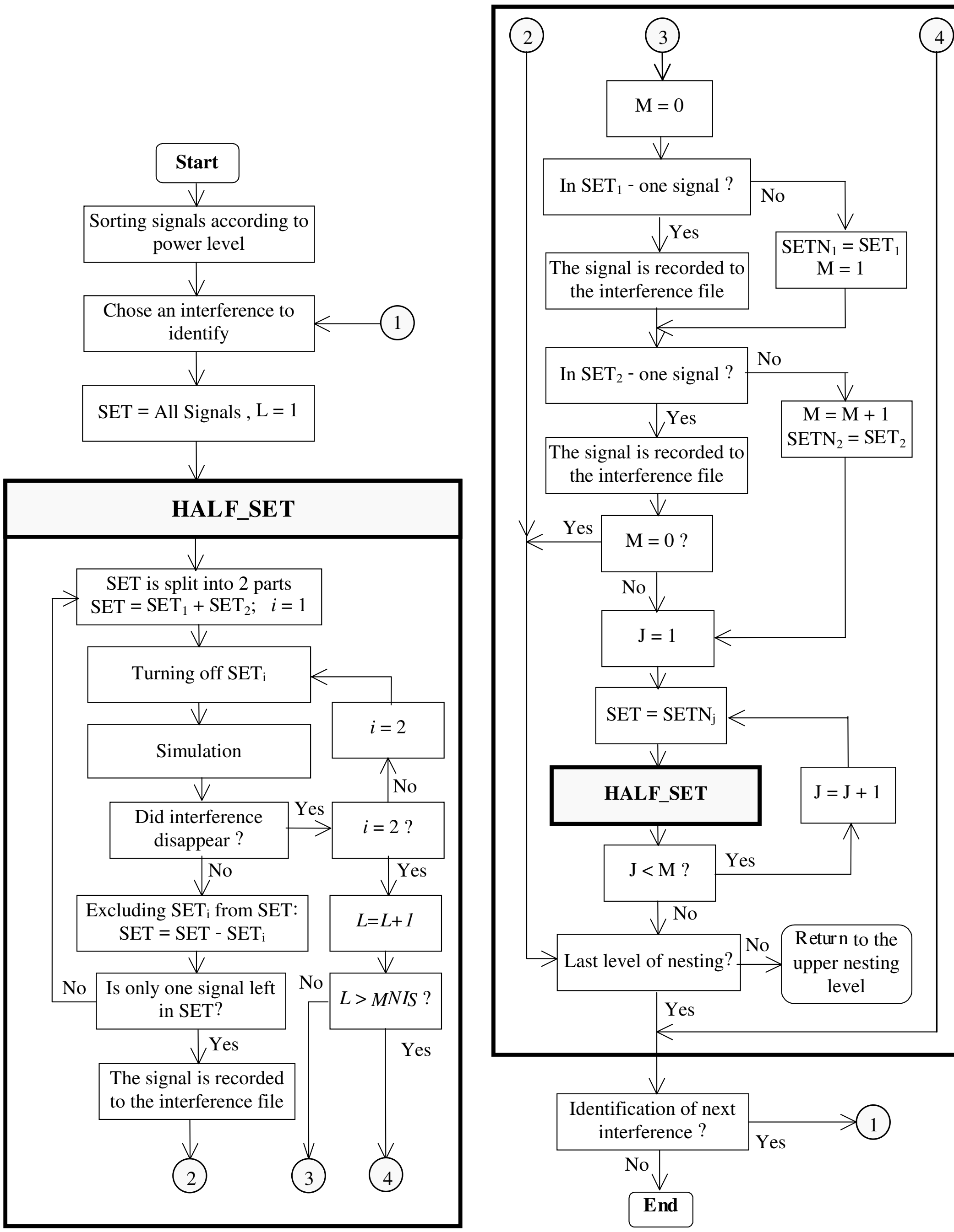

Figure 11. The Dichotomous search algorithm. SET—current sets of signals, MNIS—the maximum number of interference signals, L—its current value, i—internal variable; SETN—new sets of signals, M and J—internal variables.

where k is the number of interference sources, in such a way that this function is equal to 1 for the interference sources and to 0 for all other combinations of signals,

$$F = \begin{cases} 1 & \text{if } S_{n1}, \ldots, S_{nk} \text{ is the full set of} \\ & \quad \text{interference sources} \\ 0 & \text{otherwise} \end{cases} \qquad (23)$$

then the identification problem will be completely similar to the problem of maximizing F which can be solved with the use of a number of well-known techniques [17, 18], among which are the Fibonacci method, the golden section method as well as the dichotomous method. Genetic algorithm can also be used for such a problem [19].

4. CONCLUSION

In this article, we have completed the overview of the instantaneous quadrature technique by discussing its possible extensions. In particular, we have demonstrated how the instantaneous quadrature modeling structure can be applied to the simulation of AM, FM and PM detectors, which are nonlinear elements with large memory. Thus, the limitation of bandpass memoryless nonlinearity (with AM–PM conversion), which is frequently considered to be a substantial element of the quadrature modeling structure, is overcome in this way. It should be noted that an accurate detector simulation requires accurate models of the nonlinear detector transfer factor as well as its frequency response at the baseband frequencies. An accurate nonlinear model of the AM detector transfer factor, which can applied to both diode and transistor detectors, has been presented in Section 2.1. Much additional work is required to build such models for FM and PM detectors. One approach to this problem has been discussed in Section 2.2. Digital signal demodulators present an additional challenge for the behavioral-level simulation. We believe that the instantaneous quadrature technique is capable of attacking this problem as well.

Nonlinear simulation of the system performance is only the first step in many EMC/EMI problems. The next step is to find a way to improve the performance that may be degraded by nonlinear interference and/or distortions. The identification of the interference/distortion sources is of great importance on this step. In Section 3, we have presented a dichotomous search method, which is a computationally efficient tool for such a problem, especially when there is a large number of input signals impinging the system under consideration: the numerical complexity of the dichotomous search method is logarithmic in the total signal number as opposed to the single–signal method whose complexity is linear in the total signal number. Thus, a computationally efficient identification of the interference sources is possible for complex spectrum signals using the dichotomous method.

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