New approach for estimation of harmonics in the electrical network

M. Benouareth, N. Doghmane, S. Djelel and A.Kihal

Département. D'Electronique,
Faculté des Sciences de l'ingénieur,
LAMA : Laboratoire des Matériaux Avancés
Université d'Annaba
BP.12, 23000 Annaba-
ALGERIA

Abstract: - Industrial and domestic equipments use non-linear electronic components. As examples of these non-linear loads: rectifiers, inverters, choppers or in a general manner, all equipments using the electronic switches and the junctions with semiconductors.
This creates non sinusoidal electrical currents which will be injected in the electrical supply network. These non sinusoidal currents present other frequencies added to the usual 50Hz. These parasitical frequencies, multiple entireties of the frequency 50Hz, will inevitably cause harmful effects on the electric installations, loads and even sources. It is called the pollution of the electrical supply network.
In this paper a new approach for estimation of the parasitical frequencies generated, as example by PC (Personal Computer) switching power supply, is proposed. The estimate of these parasitical frequencies is a preliminary phase which precedes usually their elimination.

Keywords: Pollution, Harmonic, Estimate, Cumulants, Music, Spectral, Eigenvalue.

1. Introduction

The harmonic currents are non sinusoidal waves. They contain other frequencies in addition to the usual 50Hz (or 60 Hz). All the values of these frequencies are multiple integers of the 50Hz (figure 1).
The harmonic currents can cause several types of nuisances to the electrical supply network users:
1. Impact on the electric installation:
Significant heating generated in the alternators, the transformers, the condensers and the cables.
2. Impact on the operation of the applications:
Accelerated ageing of the sensitive electronic components.
3. Inopportune opening of the circuit breakers.
4. Impact on the available capacity.
…etc
The goal of this paper, is the estimate of the parasitic electrical currents, due to nonlinear loads (example: PC switching power supply), in the electrical supply network [1,2,3]. This, to be able, in a second stage, to eliminate them.

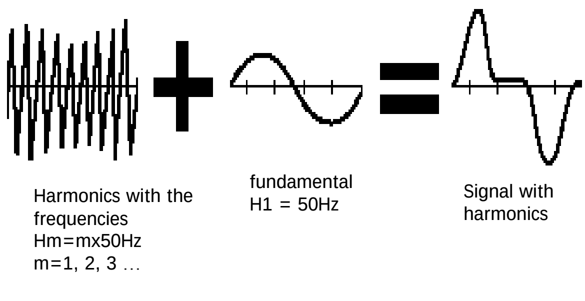

Figure 1: The result of the disturbance of the 50Hz by the harmonics of higher frequencies (nx50Hz : 100Hz, 150Hz, 200Hz, 250Hz etc…).

2. Problem formulation

The PC switching power supply is an example of nonlinear circuit which can produce frequencies with the usual 50Hz. Only, the number, always in growth, of personal computers and their generalization in all the fields, make them, one of sources of electric parasitical the most significant. This although the power of such a circuit is rather low (200 to 400 Watts), but the very high number of PC makes them very significant.

In the start, the current of switching power supply is measured and recorded in a digital form. Then, by using digital techniques of evaluation, will allow identifying the spectral components of this signal. Only, this measurement or this recording will be accompanied by an often colored additive noise.

This noise can be modelled by an auto-regressive filter (AR filter) of finite order.
The observed signal, u*(n)*, sampled at the frequency *Fe*, is a sum of :

- sinusoids, whose frequencies are multiples of 50 Hz,
- and a random component, *v(n),* representing the noise of measurement.

The aim of this paper is to analyze the methods ready to estimate the amplitudes *Ak* and the frequencies *Fi* of these sinusoids or harmonics. The observation, *u(n),* is blurred by a noise which has an unknown power spectral density (PSD). The colored additive noise *v(n)* may be generated by an AR filter of p order, where its entry *w(n)* is a centered white Gaussian process of variance $\sigma 2$. The coefficients ak of this AR filter are unknown and must be identified. But, the number *M* of the harmonic components as well as the order *p* of the filter *AR* are supposed known a priori.

To justify the performances of our technique, several forms of waves, obtained by experiments and representing typical examples of disturbances injected, by non-linear loads (PC switching power supplies), in the electrical supply networks, are used. The results of estimation and identification obtained are thus compared with the results obtained by other techniques in particular by Pizarenko, Prony, Music (**MU**ltiple **SI**gnal **C**lassification) and SVD (**S**ingular **V**alue **D**ecomposition) techniques. The robustness of our approach is justified, as well for its resolving power of frequencies very close but also to the quality of the estimation carried out even in the presence of a very intense colored noise.

3. Description of the experiment

The equipments of the experiment set-up is given in figure 2. The non sinusoidal electrical currents, created by the switching power supply, are visualized by a digital oscilloscope (Hameg), using one current Sensors. The digital signal obtained is then transferred to the computer by the liaison RS232C for further analysis.

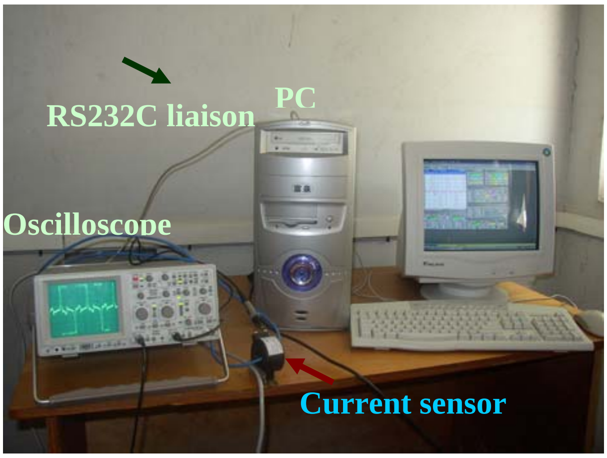

Figure 2: The experiment equipment

A PC (Personal Computer) switching power supply is taken and the shape of the electrical current which it absorbs (Inetwork) is recorded.
In spite of the existence, in all the power supplies of the PC, of a traditional filtering to decrease the effect of pollution in the electric sector, but the problem persists intensively as we can easily check it on the forms of acquired waves (figures 3, 4).

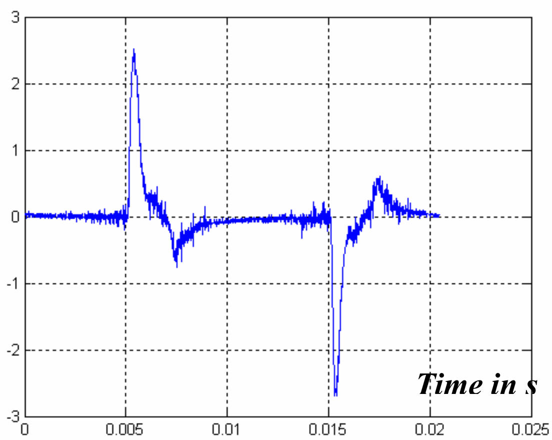

Figure 3 : The current of PC switching power supply (50Hz)

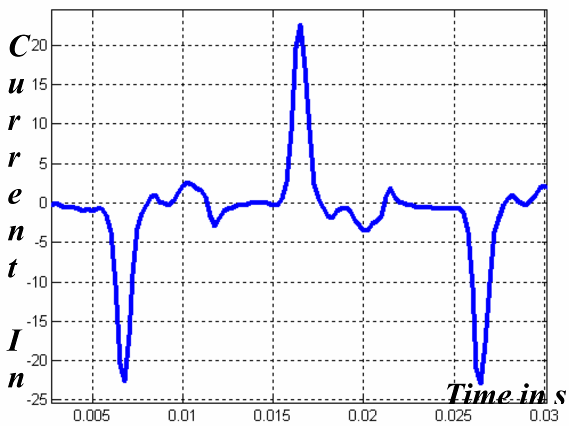

Figure 4 : The current of ten (10) PC switching powers (50Hz)

One notices on the current of the figure 4, a slight effect of smoothing due to an average (addition of several currents).

4. Frequency estimation problem

These non sinusoidal signals are harmonics. They are accompanied by an often colored additive noise.

The noise can be generated by an AR filter of finite order [4] [5]. The signal observed and measured will then take the following form:

$$u(i) = \sum_{l=1}^{L} A_l \cos\left(\omega_l i + \theta_l\right) + v(i) \qquad \textbf{(1)}$$

u(i) : the recorded or observed signal

A_l : various respective amplitudes of the various harmonics present in the measured signal.

v(i) : a noise of measurement, supposed colored. It is derived from autoregressive process of finite order:

$$v(i) = -\sum_{k=1}^{p} a_k v(i-k) + w(i) \quad \textbf{(2)}$$

w(n) is a centered Gaussian white noise of variance σ^2

In this article an estimate of the various sinusoidal frequencies present in the signal observed is carried out, using cumulants of higher order (in particular order four) [6,7]. The essential goal is to manage to carry out an estimate with a good resolution.

In fact, the various frequencies, present in the signal observed, are very close. This, makes their separation difficult by the traditional techniques of spectral analysis.

Indeed, matrix ***A*** of cumulants of fourth order will have as input :

- the observation composed by ***L*** sinusoids of frequencies multiple of the *50 Hz,*
- And an added colored noise modeling all the errors of measurement.

The size of matrix ***A*** is (*MxM*), where *M* is the number of ''cumulants'' to be calculated. Thus, the calculation of the eigen-values of this matrix ***A*** enables to state the two following observations:

1 - the space, occupied by the eigen vectors of matrix A, is composed of two disjoined sub-spaces. The first sub-space, called signal sub-space, defined by the **L** eigen vectors of A the most larges. The second, called noise sub-space, defined by the eigen vectors having the ***(M+1-L)*** smaller eigenvalues *of A*. These two subspaces are orthogonal.

2- The frequencies of the harmonics, presents in the observed signal, may be deduced knowing that they will be orthogonal with the Sub-space of noise.

5. Music algorithm

The theory leading to the development of the *Music* algorithm has been based on the unbiased cumulant matrix *A*. One may thus compute the *Music* spectrum by performing an eigen-analysis on the matrix *A. This,* gives the noise subspace represented by *VN* [8].

However, a more efficient approach is to perform singular value decomposition on the cumulant matrix *A* directly. The products of this decomposition are represented by :

- Singular values : ***σ1, σ2, …, σM+1***,
- Singular vectors : ***v1, v2, …, vM+1***
- and a set of left singular vectors.

For the application of *Music* algorithm, the left singular vectors of *A* are of no interest. In computing *Music* spectrum, the following points are noteworthy:

- Music algorithm supposes knowledge of the order of model, that is, the number of sinusoids contained in the input of transversal filter.
- The singular values of the cumulant matrix A do not actually enter into the computation of the Music spectrum. Rather, they are used merely as a tool for identifying those right singular vectors of A that constitute the noise subspace. Although this role may appear to be of a secondary nature, nevertheless, it is crucial to the success of the application on *Music* algorithm.
- Music algorithm requires knowledge of only the *M+1-L* smallest singular values of the cumulant matrix ***A***. For such a requirement a standard routine to compute the *M+1* singular values and associated singular vectors of the matrix A may be used. Then the *M+1-L* smallest singular values can be identified. Therefore, the associated right singular vectors are retained to be used in *Music* algorithm. However, a more efficient procedure, must to use the *SVD* algorithm; such an algorithm is described in [8].

The frequency estimation problem in the *Music* algorithm may be formulated as a calculus of ***ω*** (the frequencies) for which the spectrum $\hat{S}_{MUSIC}(\omega)$ attains its peaks. To do this, It is necessary to scan all the frequency interval $-\pi \le \omega \le \pi$. The need of a frequency scanning may be avoided by the use of a *Root-Music* approach. The complex exponential $e^{j\omega}$ is replaced by the complex variable *z* in the formula for the spectrum $\hat{S}_{MUSIC}(\omega)$. Let *T* denote the matrix product $V_N V_N^H$. Let the coefficient of the desired polynomial *D(z)* be denoted $d_{-M}\ d_{-M+1}\ ,\ \bullet\bullet\bullet\ ,\ d_{-1}\ ,\ d_0\ ,\ d_1\ ,\ \bullet\bullet\bullet\ , d_M$

Then ***$trace_i(T)$, i=-M, …, 0, …, +M*** can be written, where *$trace_i(T)$* is the trace of the *ith* diagonal of matrix *T*. Note that *i=0* corresponds to the main diagonal, where its zeros are: inside or on the unit circle. Those zeros of H(z) that lie on the unit circle (or are very close to), represent the signal zeros and the remaining ones represent extraneous zeros. The zeros of the other polynomial, $H^*\left(\frac{1}{z^*}\right)$, that lie on or outside the unit circle in the *z-plane,* exhibiting inverse symmetry with respect to those of *H(z)*. As an alternative to the computation of the spectrum $\hat{S}_{MUSIC}(\omega)$, for varying ω, the frequency estimation may be performed by extracting the zeros from the knowledge that they should lie on the unit circle in the *z-plane.* This frequency estimation procedure is referred to as *Root-Music* for obvious reasons.

6. Results of the estimation

To evaluate the performances of the proposed procedure of the *Music* and super-resolution algorithms using eigenvector-based projections (figure 5), two examples of signals (figure 3 and figure 4) are used, respectively for one and ten switching power supplies.

One notice from the singular value plot the presence of five real harmonics. The fourth-order cumulant based estimates display five sharp peaks at the significant frequencies of 50*Hz, 150 Hz, 250 Hz, 350 Hz* and 450*Hz*

Thus, the number of harmonics, and their parameters can be correctly estimated using fourth-order cumulants, even when the data are blurred by a colored gaussian noise. The curves, of singular values (figures 6c and 8c respectively for one and ten switching power supplies), show the presence of five real harmonics. Indeed, in This example, the five sharp peaks at the correct frequencies of [*50Hz, 150 Hz, 250 Hz, 350 Hz* and 450*Hz*] can be estimated (figures 6d and 8d). The figures 6b and 8b present, on a purely comparative basis, the frequencies estimated by EIG algorithm for the same signals. The values of different frequencies, estimated by the Music technique, is presented on table 1 for the current of one switching power supply and table 2 for current of ten switching power supplies. However, the *MUSIC* and EIG methods, lead to AR filters. These filters, thus determined, are stables (all theirs poles are inside the unit circle) (figures 7a, 7b, 7c, 7d, 9a, 9b, 9c and 9d for the two methods : *EIG* and *MUSIC and for the two signals*). The figures 7a and 7c present the impulse response of this AR filter for the two techniques (*EIG* and *MUSIC*) for the current of one only switching power supply. The figures 9a and 9c show the impulse response of this AR filter for the two techniques (*EIG* and *MUSIC*) for the current of ten (1) switching power supplies.

N°	Frequencies estimated in Hz
01	48.8534
02	149.5601
03	250.2444
04	349.9511
05	449.6579

Table 1: the frequencies estimated for one PC

N°	Frequencies estimated in Hz
01	48.8759
02	150.5376
03	250.2444
04	351.9062
05	451.6129

Table 2: the frequencies estimated for ten PC

7. Conclusion

In this paper an approach for the detection and the estimation of sinusoidal components, which are present in an observed signal, is proposed. This signal is blurred with an additive colored noise. The examples of these signals are the electrical currents of one or several PC (Personal Computer) switching power supplies. The number, increasingly increasing, of the PC in the world, makes them one of the most significant sources of the electric pollution. This type of power supply injects, in the electrical supply network, of the parasitical frequencies (others that the 50Hz). The estimate of these parasitical frequencies will then make it possible to eliminate them. The method of estimate used, in this article, is inspired from Music algorithm. The strong point of this technique, in the spectral analysis, is primarily its resolution. It’s able to detect very close frequencies, which are present in the observed signal.

The results obtained are very satisfactory and show well the effectiveness of this estimate method. The frequencies contained in examples of currents were detected correctly.

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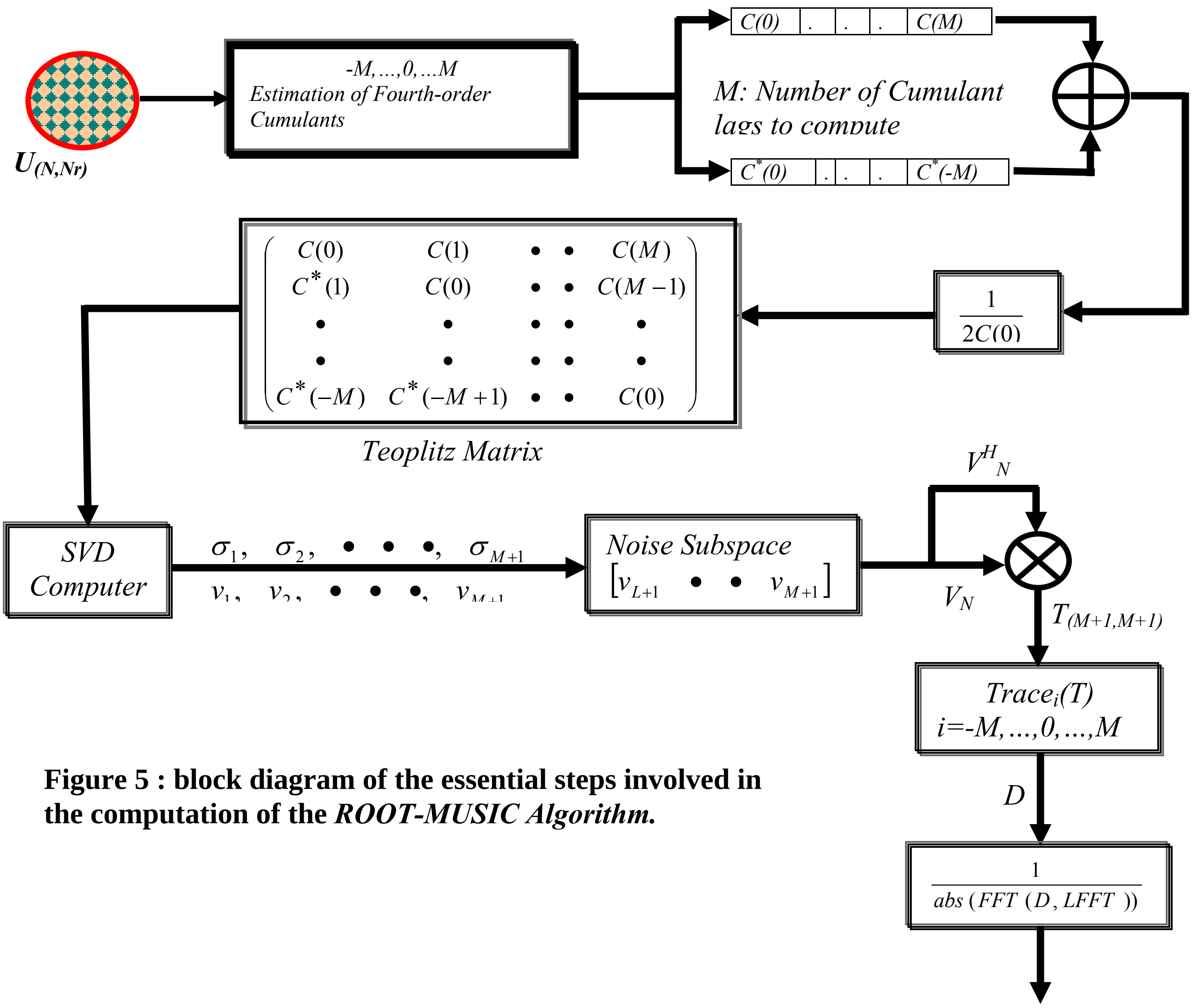
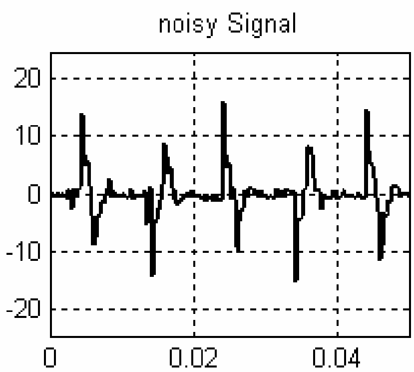


Figure 5 : block diagram of the essential steps involved in the computation of the *ROOT-MUSIC Algorithm.*



Figures 6a : current of ten switching power supplies

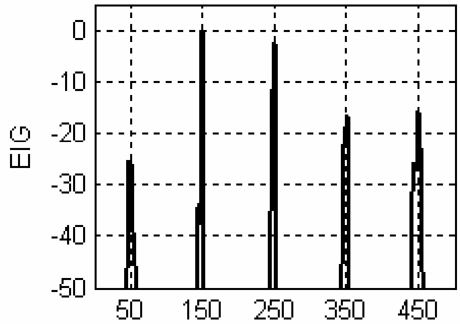
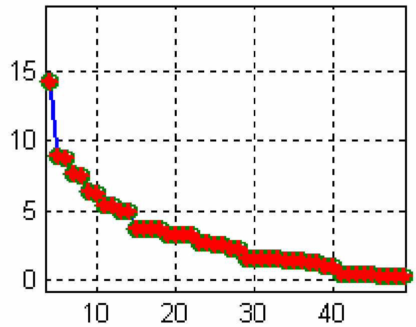


Figure 6b : frequencies estimation by EIG algorithm



Figures 6c : singular values curve

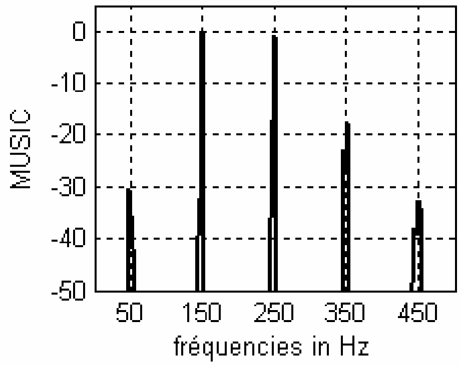


figure 6d : frequencies estimation by Music algorithm

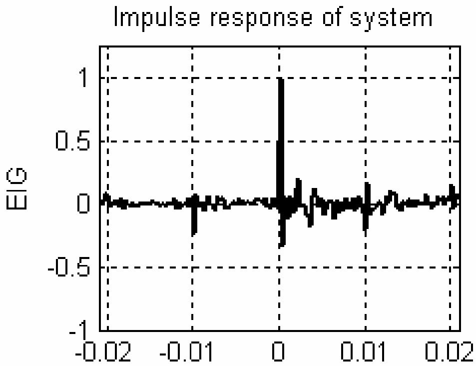


Figure 7a

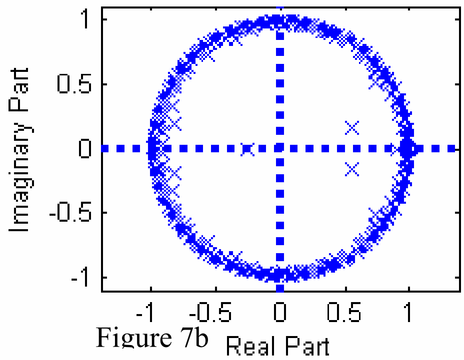
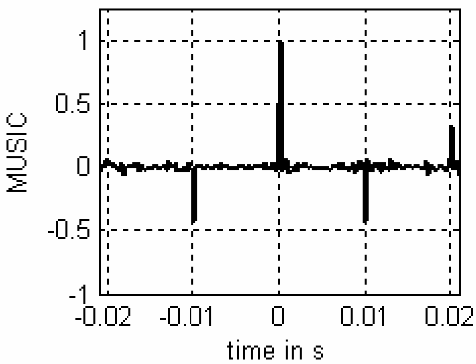


Figure 7b



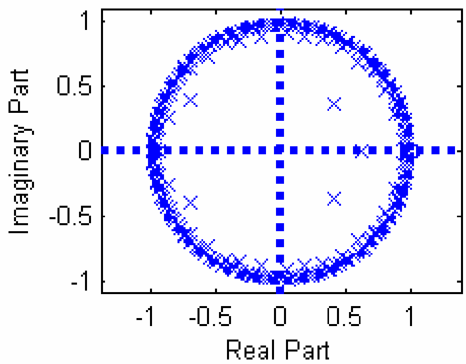
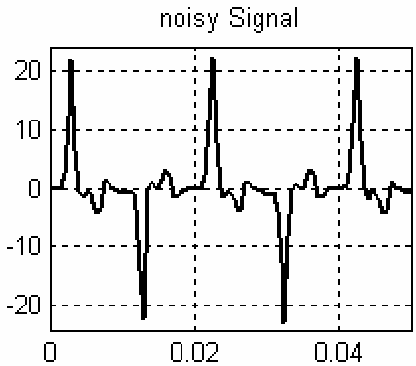


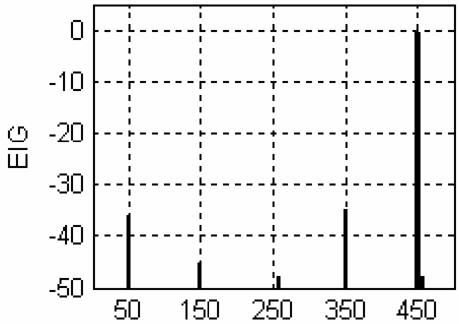
Figure 7c :

Figure 7a and 7c are respectively the impulse Response of AR filter obtained by EIG and Music

Figure 7d :

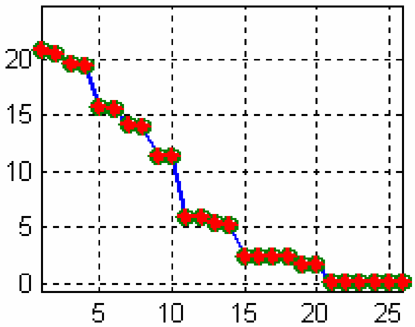
Figures 7b and 7d are the poles positions of AR filter obtained by EIG and Music

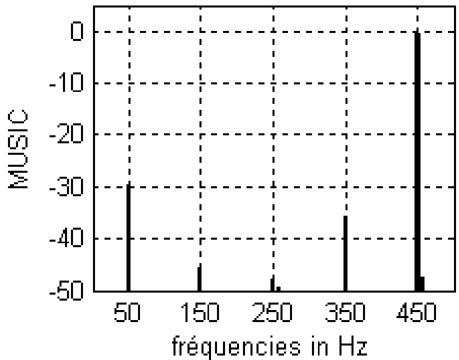




Figures 8 a : current of ten switching power supplies

Figure 8b : frequencies estimation by EIG algorithm





Figures 8c : singular values curve

figure 8d : frequencies estimation by Music algorithm

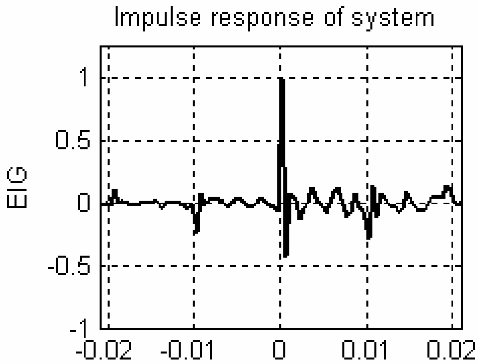


Figure 9a

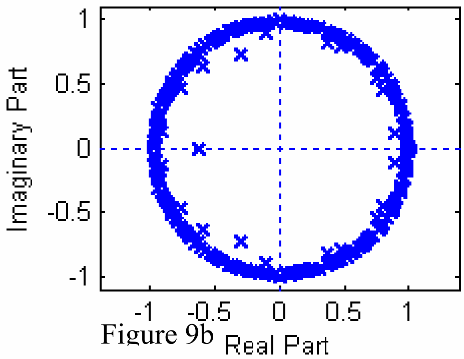
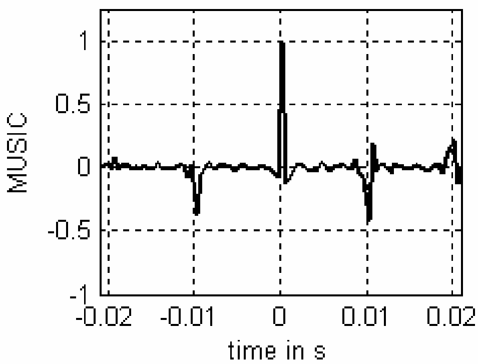
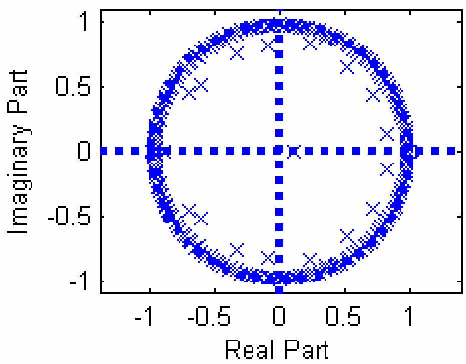


Figure 9b





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