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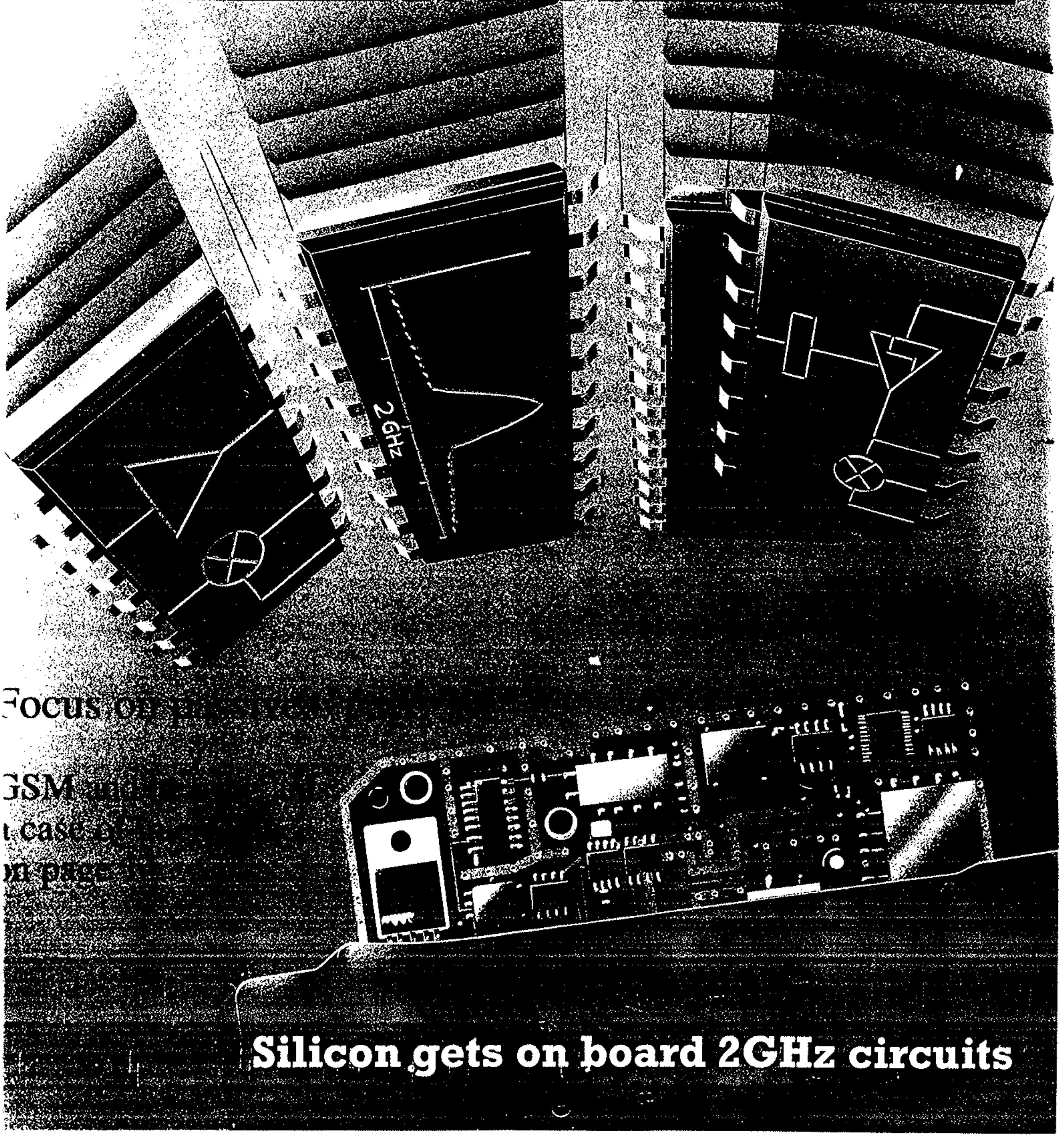

Focus on

GSM

Silicon gets on board 2GHz circuits

WIND: A CAD package for microwave filters based on thick inductive windows

The filter design package WIND, developed at ESTEC, is already in use by the European space industry. Marco Guglielmi, G Gheri and A Alvarez Melcon describe it's theoretical foundation and give examples where predictions closely match measured results. The authors are with the European Space Research and Technology Centre in Noordwijk, The Netherlands.

The European Space Agency has always considered fundamental the functions of providing technical support to the European Industries in the sector, and training of Young Engineers in space-related activities. In this paper we describe a novel CAD package for the analysis and design of waveguide filters, based on thick inductive windows in rectangular waveguide, that has been developed at the European Space Research and Technology Centre (ESTEC) in the context of technical support and training. The software package, called WIND, is based on a novel theoretical approach developed at ESTEC that allows for the implementation of very accurate and efficient CAD tools. In this paper the theoretical approach is outlined, the software package WIND is described in detail, and a few examples of actual filter implementations are presented.

The type of microwave filter which is the subject of this paper is shown in figure 1. This type of filter is commonly used in the output section of communication satellites where high power, multicarrier signals can be present. For some applications, it is particularly important for the output filter not generate Passive Intermodulation Products or discharge effects (multipaction) that could degenerate the characteristics of the communication channel. For these reasons, the use of tuning screws and metal-to-metal contacts must be reduced to the minimum. If no tuning elements are to be used in the final hardware, and if the development time and cost needs to be reduced as well, it is mandatory to dispose of fast and accurate CAD packages that can ensure satisfactory results in one go, without requiring costly experimental development or manual adjustments. The software package WIND has been developed with the specific goal of eliminating all experimental characterizations and manual adjustments traditionally required for inductive-type filters in rectangular waveguide, like the one shown in figure 1. In this paper we first outline the theory on which WIND is based and point out the key features that allow for the implementation of a very fast and accurate CAD package. We then give a detailed description of the software package itself, and finally describe several actual filter implementation, including comparisons between computed and measured filter performances.

Background

The first step in the design of a microwave filter is the selection of the proper transfer function and relative low-pass or band-pass equivalent network. For the case of Tchebyscheff filters, for instance, one can use the results give in [1] that relate the filter transfer function to proper resonance frequencies, values of external Q-factor Q_c and inter-resonator couplings k_{ij+1}. Shown in figure 2 is a typical single-mode equivalent network representation for a third order filter in terms of Q_ε and k_{jj+1}. Following this formalism, the problem is reduced to finding the coupling-aperture widths to obtain the proper values of Q_ε and k_{jj+1}, and the resonator lengths corresponding to the proper resonance frequency. The difficulty in obtaining the correct values is in that the various coupling apertures interact with each other trough the higher-order modes of the waveguide. The fundamental problem is then the accurate full-wave characterization of the inductive step in figure 3, the key discontinuity for this class of microwave filters.

The study of discontinuities in waveguiding structures has always been a subject of great importance and a large number of contributions in this area can be found in the technical literature (for instance [2] and [3] to cite a few). Many different valid approaches have been reported in the past, but the Network

Figure 1 Microwave filter based on thick inductive windows in rectangular waveguide

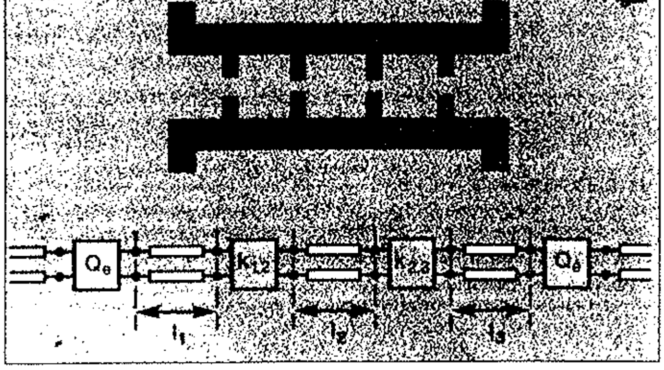

Figure 2 Single mode equivalent network representation of a third order filter

Representation has always been considered very useful both for its computational efficiency and for the physical insight it provides (a large collection of network representations can be found for instance in [4]). The results presented in [4] have been derived using the so called "Single-Mode Network Formulation". The strongest limitation of this type of results is that they can only take into account fundamental-mode interactions. With the advent of large and powerful digital computers, other numerically oriented approaches became more popular. In particular, for waveguide problems, the Mode Matching (MM) technique has established itself as a very flexible and powerful tool [5]. Although the MM formulation is indeed very powerful, it turns out to be computationally less efficient than the procedure described here.

The only results available so far in the technical literature (to the authors knowledge) that provide multimode network representations for waveguide discontinuities comparable to the ones presented here are [6] and [7]. Due to the nature of the theoretical formulations employed, CAD packages based on [6] and [7] would probably turn out to be less efficient than WIND, as it will be discussed in detail later in this paper. Recently, a number of multimode equivalent network representations have been developed for zero-thickness discontinuities which are rigorous and very rapidly convergent ([8] to [12]). In WIND, a similar network formulation is used for the step discontinuity [13]. The form of the multimode network representations turns out to be the one shown in figure 4, where the elements $z_{m,n}^{(\delta,\gamma)}$ are given by

$$z_{m,n}^{(\delta,\gamma)} = \frac{1}{2B}\left(\frac{a^{(1)}}{a^{(2)}}\right)^{(\delta+\gamma-2)/2}\int_{d_1}^{d_2} M_n^{(\gamma)}(x')\,\sin\left(\frac{m\pi}{a^{(\delta)}}(x'-d^{(\delta)})\right)dx'$$

$$B = \frac{[illegible]}{2\,\omega\mu_0}$$

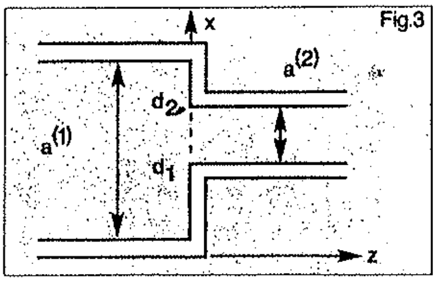

Figure 3: Centred inductive step in a rectangular waveguide (top view).

and the unknown function $M_n^{(\gamma)}(x')$ is specified via the integral equation

$$\sin\left(\frac{n\pi}{a^{(\gamma)}}x\right) = \int_{d_1}^{d_2} M_n^{(\gamma)}(x')\left[\sum_{m=1}^{\infty}\frac{m\pi}{a^{(1)}}\sin\left(\frac{m\pi}{a^{(1)}}x\right)\sin\left(\frac{m\pi}{a^{(1)}}x'\right) + \frac{a^{(1)}}{a^{(2)}}\sum_{m=1}^{\infty}\frac{m\pi}{a^{(2)}}\sin\left(\frac{m\pi}{a^{(2)}}(x-d^{(2)})\right)\sin\left(\frac{m\pi}{a^{(2)}}(x'-d^{(2)})\right)\right]dx'$$

where (γ) and (δ) can be equal to 1 or 2, indicating the waveguide to the left or the one to the right of the step in figure 3 respectively.

We can now appreciate the fundamental features of the multimode network representation developed. The first important point is that the equations presented above have been deriver following a rigorous procedure that effectively separates the dependence from the geometry from the dependence from the frequency. In fact, the only frequency dependent fact is B in (2). As a consequence, all of the multimode coupling matrix elements $z_{m,n}^{(\delta,\gamma)}$ need to be computed only once for each given structure.

Furthermore, as it is evident by inspection of (1) and (3), the final values of the $z_{m,n}^{(\delta,\gamma)}$ elements, only depend on the ratio $\left(\frac{a^{(1)}}{a^{(2)}}\right)$. The result of this last point is very important from the point of view of the computational efficiency. In fact, one can solve (3), and compute (1), only for a discrete set of values of $\left(\frac{a^{(1)}}{a^{(2)}}\right)$ for instance 20, and store in a file the relevant normalized coupling matrix elements. For the actual characterization of the various steps of a particular filter, one only needs to retrieve the data stored and performs a linear interpolation to obtain the required $z_{m,n}^{(\delta,\gamma)}$, without ever using again the complete integral equation formulation.

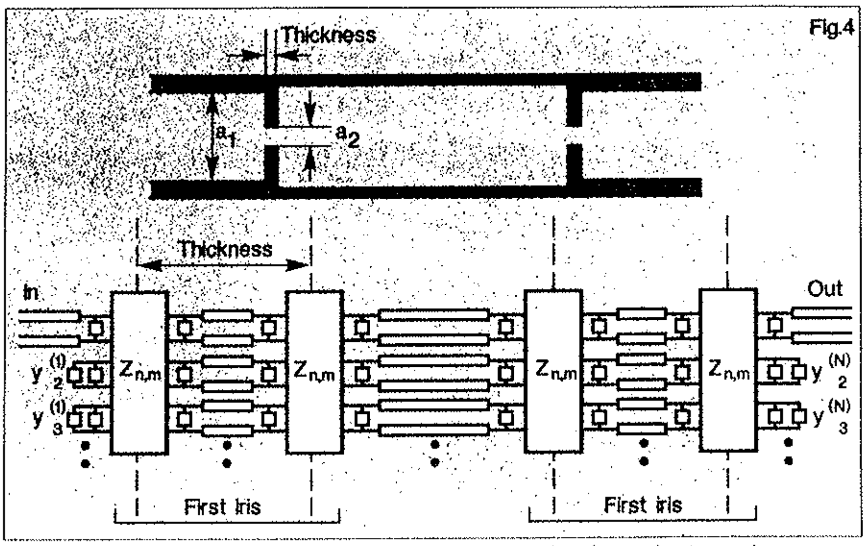

Figure 4: Multimode equivalent network representation for a single cavity.

What is left to do, in order to obtain the frequency dependent electrical characteristics of a specific filter, is to connect the various network representations of the steps with suitable lengths of transmission lines to obtain the global network representation of a filter (figure 4), and from that derive a linear system of equations to be solved. We find that, for a typical filter structure, including explicitly 10 modes in each waveguide section gives very good accuracy. The system to invert has then a diagonal band structure than results in a very rapid single inversion for each point in frequency.

Structure of WIND

The software package WIND has been developed according to the theory outlined in the previous section for the analysis of multicavity band-pass filters based on centred, thick inductive windows in rectangular waveguide. WIND has been implemented in mixed C and Fortran languages in order to provide a user-friendly input/output structure. WIND occupies less than 450Kb of memory and can run on any IBM compatible PC with a math coprocessor and (at least) a CGA graphic card.

The software package WIND can perform the following operations

* Generate input files containing the filter target specifications, the physi-

cal dimensions of the filter, the number of modes to be used and the frequency range specifications.

* Carry out the analysis of the filter.
* Produce an ASCII output file containing the numerical result of the analysis.
* Display graphics of $S_{1,1}$ and $S_{1,2}$ versus the frequency.

The input/output structure of WIND allows to specify the data for a maximum of ten inductive windows (ninth order filter). From the main menu we can control all of the operations performed by the software, and access the Input Menu (figure 5), where all necessary data can be entered, saved, and the analysis performed. At the end of the execution the program displays the Main Menu, from which the results can be viewed with option (7). Through option (7) we can display the graph of $S_{1,1}$ and $S_{1,2}$ (this graph can be re-scaled vertically and horizontally). By pressing F3, a window showing how the filter performs with respect to the target specifications is displayed.

Applications

In addition to performing the analysis of a given waveguide structure, WIND can also be used for the synthesis of microwave filters. This is, in fact, its most important and practical application. A patent application has been filed (ESA PAT271) describing a procedure that, based on the use of WIND, can completely replace all of the hardware development and manual tunings traditionally required for this type of filter thus resulting in significant savings in development time and cost. Figure 6 shows the comparison between measured and computed electrical performance of two filters developed using WIND. The hardware has been realized using spark erosion, without any tuning or manual adjustment. As we can see the agreement in both cases is indeed very good. The small frequency shift observed in both cases is mostly due to the fact that in the computation we assume the filter to be in vaccuum while the measurements have been done in air.

Conclusions

In this paper we have outlined the theoretical foundation of the software package WIND for the analysis and design of microwave filter based on thick inductive windows in rectangular waveguide. We have given a detailed description of the software package itself, and we have presented measured data indicating that WIND is indeed very effective. The software package has been developed at European Space Research and Technology Centre in the context of its technical support and training activities with the objective of reducing the development time and cost of this class of microwave filters.

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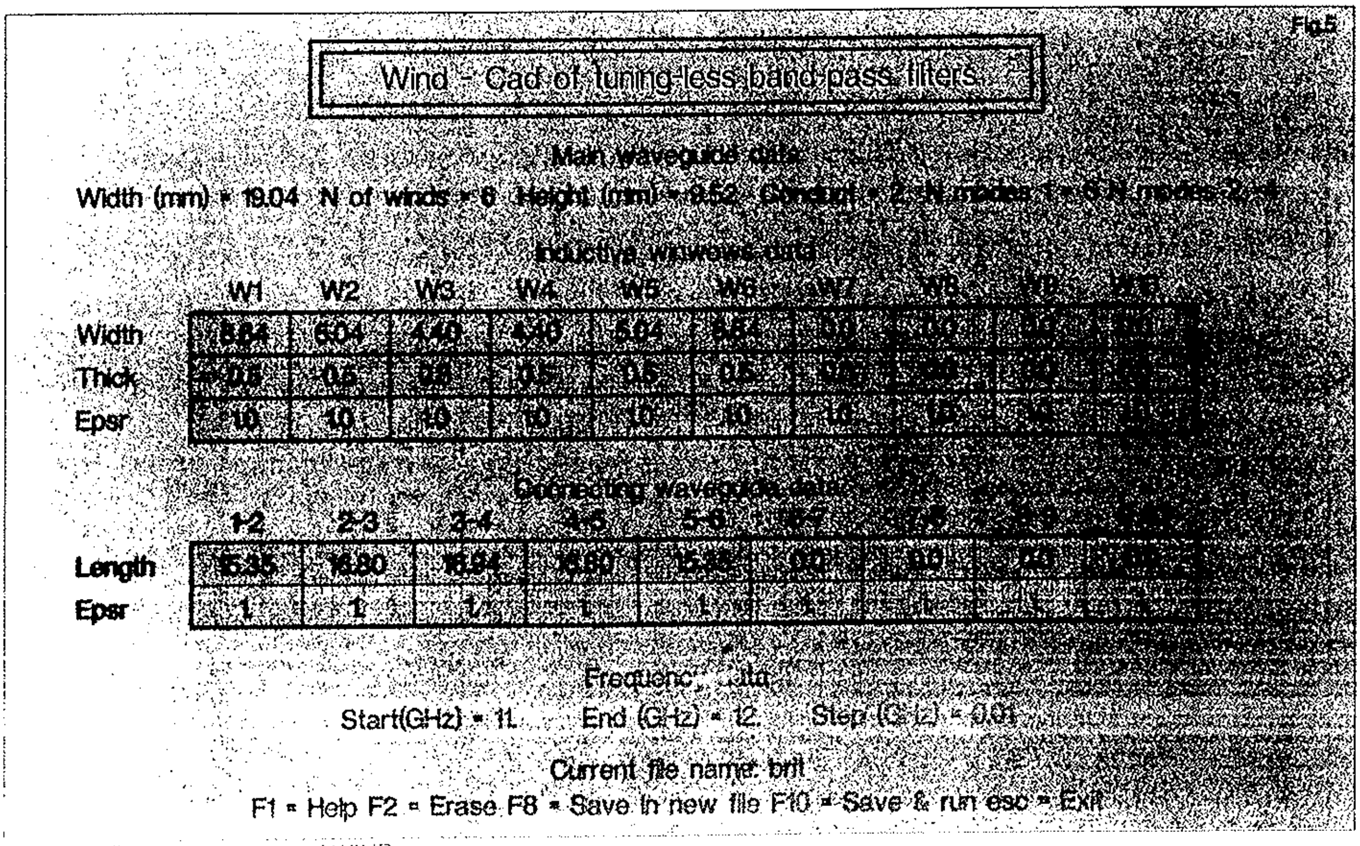

Figure 5. Data input screen of WIND

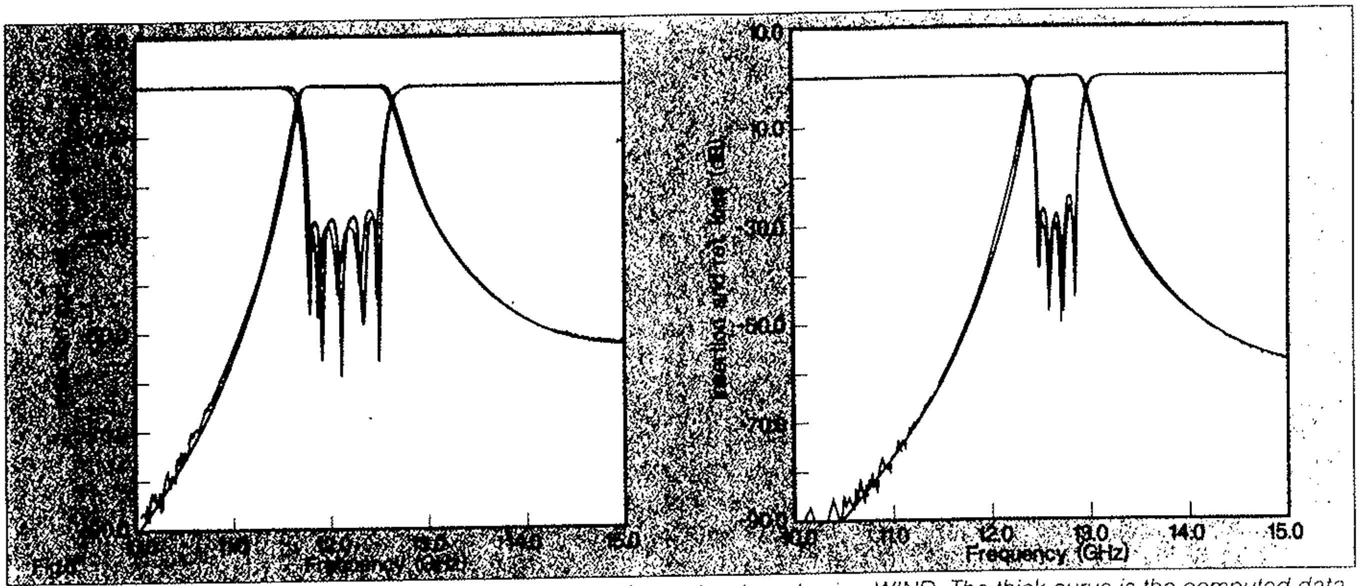

Figure 6: Measured versus computed performance of two filters developed using WIND. The thick curve is the computed data.

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