

# Review of Filter Techniques

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**Abstract**— The paper focuses on filter fundamental along with different types of filter and its technology. Design of Filters, its analysis tools and its application has been discussed in detail.

## I. INTRODUCTION

The fundamental use of filters in electrical engineering is to shape signal spectrum, which is especially crucial in reducing input signal noise in receivers and spurious emissions in transmitters. Microwave filters have traditionally been built using waveguide and coaxial lines. Printed circuit filters have advantages over rectangular or coaxial waveguide filters in terms of low cost, repeatability, high accuracy, and compact size. Repeatability and high accuracy are achieved through the use of photolithographic techniques. By selecting high dielectric constant substrates, the size of the printed filters can be reduced significantly, which provides compact size. In addition, with the advances in fullwave electromagnetic simulation techniques, printed filters can be characterized accurately and rapidly. Another advantage of printed filters is their easy integration with active circuits; filters can be fabricated on the same substrate with transistor amplifiers, oscillators, and other circuits. Perhaps the main disadvantage of regular printed filters (i.e., nonsuperconducting) is the high insertion loss associated due to metallization and dielectric losses in some situations. For this reason, printed filters may not be suitable for applications where high power and very low loss are required.

## II. FILTER TYPE

An analog filter is typically a single-input single-output system. The input-output relationship is governed by the network function in the complex frequency domain. There are five ideal filter magnitude characteristics as (a) *lowpass*, (b) *highpass*, (c) *bandpass*, (d) *bandreject*, and (e) *allpass* filters. The first four types of characteristics are used for their frequency-selective properties. The allpass filter is used chiefly for its phase-linearization or delay-equalization capabilities. These ideal characteristics are not realizable with finite networks. Hence all real-world filters can have only magnitudes that approximate these characteristics.

Lumped element filters used at microwave frequencies up to 18 GHz. forms a large percentage of microwave filters produced by the industry. The major advantage of microstrip filters is low production cost and smaller dimension compared to the distributed filters. The large distributed filters are used when insertion loss and power handling is of major concern, unless superconductor technology is employed

## III. FILTER DESIGN

Most lumped-element filter designs are limited to realizations up to only a few hundred megahertz before element values become impractically small. To design filters for use above 500 MHz, it is more practical to design distributed filters, that is, filters using distributed structures, such as lengths of transmission lines, as resonant elements.

For a filter designer a standard literature [1] is available which contains an excellent introduction to filter theory with numerous examples of both lumped element and distributed filters. It includes practical effects such as coil winding and the element Q's that are practically realizable. The design of a filter usually starts with a set of parameters that will satisfy the requirements of an application. We shall call this step the *specification*. The next step is to find a network function that satisfies these requirements. After the network function has been determined, the next task is to find a suitable network that will realize this network function. Theory and techniques have been developed in the area of *network synthesis/realization*, both active and passive. Usually the solution of this step is not unique as many networks can be used to realize the same network function. Standard lowpass characteristic is the Chebyshev lowpass characteristic. This class of characteristics makes use of the Chebyshev polynomial and produces an equal-ripple variation in the pass band. Outside the pass band, the gain also decreases monotonically, but at a faster rate than the Butterworth characteristics. The Butterworth filter is known as maximally flat filter since no ripple is permitted in the attenuation profile. The order N of a filter is equal to the number of poles and zeros in its transmission

response. For a lumped-element filter,  $N$  is equal to the number of nontrivial elements in the filter network. Nontrivial elements are those which alternate in type between  $L$  and  $C$  elements. In a filter, nontrivial  $L$  and  $C$  elements each produce a pole at

zero frequency and a zero at infinite frequency or vice versa. In a filter network a resonator consisting of one  $L$  in series or in parallel with one  $C$  element counts as two nontrivial elements. Such a resonator produces a pole or zero in the filter response at a finite frequency. Lumped-element bandpass and bandstop filters can be designed by starting with the low-pass and high-pass prototypes. Filters that have equal-ripple variations in both the pass band and the stop band are called *Cauer filters*.

The Butterworth lowpass magnitude characteristic has the property that the response is flat. Because of this, all available degrees of freedom are utilized to make as many derivatives as possible zero at that point. One consequence of this property is the fact that the rate of increase of attenuation for higher frequency is rather low. The chief attribute of this class of characteristics is the simplicity of their mathematical development. However, in accepting this mathematical simplicity, we pay a high price in the relatively poor performance of these filters. This class of characteristics is usually used only when the filtering requirement is not very demanding - high passband variation, low stopband attenuation, or large transition-band ratio. The Chebyshev lowpass magnitude characteristics exhibit equal-ripple variation in the pass band and monotonic increase in attenuation outside the pass band. The performance of these characteristics is greatly improved over the Butterworth characteristics. It has been observed that if the numerator of the transfer function is a constant, Chebyshev characteristics give the most rapid increase in attenuation outside the pass band. For the same filter section the filter complexity of both the Butterworth and the Chebyshev filters is the same. Hence, the Chebyshev filters are always preferable from the standpoint of the magnitude performance of a network of a given complexity.

The elliptic-function filter characteristic has equal-ripple variation in both the pass band and the stop band. It offers further improvement in the magnitude characteristic for a given filter order. In fact, the elliptic-function characteristic gives the lowest possible transition-band ratio, of all lowpass magnitude characteristics. The structure of an elliptic-function filter is usually only slightly more complicated than a Butterworth or Chebyshev filter of the same order.

The major sources of filter design under different categories like combline, interdigital and parallel coupled band pass and bandstop ring, patch filters and stepped impedance filters are available in literature(1).The several media for implementation include waveguide, dielectric

resonator, coaxial line, evanescent mode filters and various printed circuit filters in microstrip, stripline, suspended substrate. Acoustic filters is used as miniature filters for high volume production, for use in wireless telephones. Superconducting filters has extremely high unloaded  $Q$  due to the virtual elimination of resistive losses.

Printed filters can be designed using microstrip or striplines. Stepped-impedance, interdigital, and coupled-line filters are the most commonly used forms of printed filters. In the first method, the widths of the transmission lines are changed in a periodic manner to replicate series inductance and shunt capacitance to implement lowpass filters. In the second method, quarter-wavelength-long transmission lines are arranged in an interdigital fashion where on one end the lines are shorted to ground in an alternating manner. In the last method, cascaded sections of quarter-wavelength-long coupled transmission lines are used to implement bandpass filters. The design of bandstop filters using coupled-line sections first requires calculation of slope parameters for each distributed resonator section that will be realized [10]. The slope parameters can be obtained directly from the lowpass prototype filter values, which are determined for a desired filter response. Then, the lumped circuit is converted to a transmission line equivalent using short- or open-circuited stubs and slope parameters. Finally, the transmission line circuit

with stubs is converted into the coupled-line microstrip equivalent.

- 1) MICROSTRIP FILTERS-1) Computer Aided Design (CAD)
- 2) HTS 3) MEMS (Micromachining
- 4) LTCC 5) PBG 6) Ferrite and Ferroelectrics 7) Hybrid /Monolithic Integrated Circuit 8) RF/Microwave Education

Prior to the ready availability of computers, designers were constrained to employ established techniques to design filters and other circuits. Random changing of variables or cut-and-try tuning in the lab could quickly become impractically laborious. Presently, however, even the most basic personal computer can perform thousands of insertion loss evaluations (or other calculations) per second for circuits having 10 or more elements and can be directed through optimizer software to vary the element values to better satisfy a set of performance goals.

A frequency diplexer is a network that connects two networks that operate at different frequencies to a common terminal. For example, two radios operating at different frequency bands could be connected to a common antenna using a frequency diplexer. One commonly used realization of a frequency diplexer consists of two complementary filters connected to a tee junction. One filter is a high pass and the other a low pass. For the diplexer function, both filters have the same 3-dB cutoff frequency. Frequencies above the cutoff

are directed along one side of the tee junction; frequencies below the cutoff are directed along the other side of the tee junction.

Filters having a ripple in the stopband can be realized using elliptic filter designs. The sharp increase in isolation just outside the passband can be very advantageous for some applications and it comes at the price of reduced isolation at frequencies considerably higher than the filter's cutoff frequency.

Narrow band filter design for simple Chebyshev response are carried out by appropriate susceptance slope parameter. The pseudo elliptic filters design is carried out by suitable low pass prototype followed by low pass to band pass transformation and same susceptance slope parameter. The Combline filters are most widely used types of coaxial filters below 10 GHz and capacitive end loading of the resonators gives a useful size reduction compared to those based on quarter wave resonator. A array of parallel resonator which is short circuited at one end and capacitors at the other side. The drawback lies in the asymmetry of the insertion loss, which is much weaker on the low frequency side, specially for broad bandwidths.

Interdigital filter consist of parallel-coupled quarter wavelength or which alternate between the short and open circuited lines. This filters are most applicable at higher microwave frequencies above 8 GHz and for broad bandwidth. The ideal interdigital filters has characteristics having perfectly arithmetical symmetry which can be considerable advantage compared with combline filters. This gives better phase and delay characteristics. The gaps between resonators bars is larger and the dimension becomes small at high frequencies.

Parallel coupled line filters are realized mainly in microstrip or occasionally stripline at higher microwave frequencies. It is necessary to take account of different phase velocities between the even and odd modes in the coupled – line regions. Ceramic resonator filters provides low loss and give a substantial gain.

TEM mode coaxial cavity dielectric – resonator filter is of small size, suitable for use in mobile telephone and consist of coaxial cavities coupled by either by series capacitor or by magnetic field coupling through the dielectric.

Suspended Substrate stripline design is very low loss and useful for broad band filter and multiplexer can be feed with coaxial or propagating waveguide. For narrow bandwidth applications waveguide filters are suitable and used in satellite communication and some terrestrial system. Waveguide low pass filters are important used for harmonic rejection. Waffle-iron filters are used for very broad passband. When the passband are narrower tapered corrugated low pass filters are preferred as they have low loss, smaller size and higher power handling capacity. It is important to taper both broad and narrow dimensions of the waveguide to give high rejection of higher order modes in the stopband.

Suspended stripline (SSL) is a suitable transmission medium with moderate loss and a wide range of possible circuit configurations, especially for filters [1]. SSL consist of a dielectric substrate suspended symmetrically between two ground planes. The attractive features of SSL compared to conventional stripline or microstrip are reduced ohmic/dielectric losses over wide bandwidth, better temperature stability over a wide temperature range, low dispersion and good fabrication tolerances. The SSL structure can be used for synthesis of broadband filter in a broadside coupled resonator printed on a substrate suspended in a shielded channel. Broadside coupled resonators are basically an arrangement of strip elements on both sides of the substrate for improved coupling between filter elements. Thus the use of two layer configuration for the filter makes the design flexible and compact. The bandpass filter using SSL uses quarter wavelength resonators and the capacitive coupling is realized through the supporting dielectric, thereby eliminating the need for precision etching.

A common assumption when designing combline or interdigital filters is that coupling between nearest lines can be ignored. For configurations where ground plane spacing becomes larger than 30 degree at midband and when bandwidth is such that spacing between any two lines is less than about 1.5 x diameter of the either line, propagation can no longer be TEM. The computation of coupling between lines must include the effects of at least the cutoff dominant waveguide mode (due to large ground plane spacing) and for bandwidths typically in excess of 40% or less than 2% must include the other cut off mode as well. Considering the cut off waveguide mode the filter design technique is called evanescent mode design technique. The evanescent mode filters can be implemented with coaxial or propagating waveguide input and output. The filters are practical for bandwidths from 1% to 70%. The filters can be folded with cross coupling used to implement pseudoelliptic design. This type of filters can be combined with lumped, dielectric or propagating waveguide resonator to form the composite or hybrid structure with low loss and wide stopband. Multiplexers are combinations of filters connected in such a way to provide access to the passband and stopband characteristics of each filter from a common connection. Such a device permits the use of single antenna with several receiver or transmitters. The common port must have low VSWR and isolation between different filters has to be maintained. If the adjacent passband of each channel cross over at a level of about 3 dB, the device is called contiguous multiplexer. The frequency separation between channels is called the guardband frequency. A diplexer is termed duplexer when it combines a transmitter and receiver. So a duplexer can be designed as a diplexer, but duplexing can be carried out using TR modules that reflect high power signals, but transmit low power ones.

Filters can be multiplexed by parallel combination at both ends. The two bandpass filters are diplexed at both input and output and the resulting network provides one input and one output. Practically attenuating everything else except pass

bands, essentially two isolation provides one input and one output.

Superconducting devices made use of niobium at liquid helium temperature(4.2K). The requirement introduced a very severe limitations for this very low operating temperature.

Waveguide filter requirements with reflection and transmission zeros and/or very flat group delay on the passband are examples of the frequency responses to be handled. There are well known analytical synthesis procedures for obtaining the coupling matrices and the circuit representation of many of these kinds of filters. References [1]–[3] are a brief list of papers describing some synthesis procedures developed during last years. Once the circuit elements are obtained, the following step in the design process is its implementation in waveguide technology. This step usually involves a great computational cost for two main reasons:

a) the geometrical dimensions of the waveguide structure must be obtained after an optimization process with usually a high number of variables (geometric dimensions) and with a complicated error function. Independently of the optimization algorithm, the number of function evaluations is proportional to the number of variables.

b) the evaluation of the error function requires the evaluation of the error function requires an accurate analysis of the structure. All the software tools involved in this task, commercial or home-made, employ the so-called "fullwave" electromagnetic methods, which provide a rigorous solution to the Maxwell equations. Electric and magnetic fields are accurately computed on the waveguide structure and, therefore, a reliable electrical response is obtained. An accurate analysis method saves many valuable resources (materials, time,) in the final tuning process of the filter at the laboratory.

#### **IV. FILTER SYNTHESIS**

The traditional methods of filter synthesis are based on various prototypes from the circuit theory with concentrated or distributed parameters. Their basic disadvantage is that they don't account for higher wave types induced on filter discontinuities. So it seems necessary to take a combined approach where parameters of prototype models serve as input to a numerical optimization procedure using gradient methods based on rigorous electrodynamics models [4,5]. Lately one can notice the intensive attempts of effective search numeral and numeral analytical algorithms of solving this problem [6,7], including technologies of artificial intelligence [8-10]. However much considerable progress nevertheless cannot be achieved, both in areas of universal algorithms development construction and in the applied tasks, concerning this class of devices. The attempts of filters design simplification to the level proper to CAD possibilities are even undertaken on occasion [11]. The common drawbacks of direct and combined numerical optimization methods are insolvability of the problem of finding the global extremes of the objective

function and exponential growth of calculation time with the increase in the number of resonators or the accuracy of calculations

#### **V. FILTER APPLICATION**

Filters play important roles in many RF/microwave applications. Emerging applications such as wireless communications continue to challenge RF/microwave filters with ever more stringent requirement of higher performance, smaller size, lighter weight, and lower cost. The recent advances in novel materials and fabrication technologies, including high-temperature superconductors (HTS), low-temperature cofired ceramics (LTCC), monolithic microwave integrated circuits (MMIC), microelectromechanical system (MEMS), and micromachining technology, have stimulated the rapid development of new microstrip and other filters for RF/microwave applications. In the meantime, advances in computer-aided design (CAD) tools such as full-wave electromagnetic (EM) simulators have revolutionized filter design.

Many novel microstrip filters with advanced filtering characteristics have been illustrated and published in the standard literature[1-3]. Standard text books offers[1 ] unique and comprehensive treatment of RF/microwave filter techniques based on the microstrip structure, providing a link to applications of computer-aided design tools and advanced materials and technologies. Many novel and sophisticated filters using computer-aided design are available in open source[ ]where, from basic concepts to practical realizations of many novel microstrip filter configurations with advanced filtering characteristics, new design techniques, and methods for filter miniaturization are illustrated. Conventional microstrip lowpass and bandpass filters such as stepped-impedance filters, open-stub filters, semi-lumped element filters, end- and parallel-coupled half-wavelength resonator filters, hairpin-line filters, interdigital and combline filters, pseudocombine filters, and stub-line filters are widely used in many RF/microwave applications.

High-temperature superconductors (HTS), ferroelectrics, micromachining or microelectromechanical systems (MEMS), hybrid or monolithic microwave integrated circuits (MMIC), active filters, photonic bandgap (PBG) materials/structures, and low-temperature cofired ceramics (LTCC) are among recent advanced materials and technologies that have stimulated the rapid development of new microstrip and other filters.

High-temperature superconductivity is at the forefront of today's filter technology and is changing the way somebody design communication systems, electronic systems, medical instrumentation, and military microwave systems [1–4]. Superconducting filters play an important role in many applications, especially those for the next generation of mobile communication systems [12–17]. Most superconducting filters are simply microstrip structures using HTS thin films [18–28].

Superconductors are materials that exhibit a zero intrinsic resistance to direct current (dc) flow when cooled below a certain temperature. The temperature at which the intrinsic



resistance undergoes an abrupt change is referred to as the critical temperature or transition temperature, denoted by  $T_c$ . For alternating current (ac) flow, the resistance does not go to zero below  $T_c$ , but increases with increasing frequency.

However, at typical RF/microwave frequencies (in the cellular band, for example), the resistance of a superconductor is perhaps one thousand of that in the best ordinary conductor. It is certainly low enough to make significant improvement in performances of RF/microwave microstrip filters.

The growth of HTS films and the fabrication of HTS microstrip filters are compatible with hybrid and monolithic microwave integrated circuits. Although there are many hundreds of high-temperature superconductors with varying transition temperatures, yttrium barium copper oxide (YBCO) and thallium barium calcium copper oxide (TBCCO) are by far the two most popular and commercially available HTS materials.

Coupled resonator circuits are of importance for design of RF/microwave filters, in particular the narrow-band bandpass filters that play a significant role in many applications. There is a general technique for designing coupled resonator filters in the sense that it can be applied to any type of resonator despite its physical structure. It has been applied to the design of waveguide filters [1–2], dielectric resonator filters [3], ceramic combline filters [4], microstrip filters [5–7], superconducting filters [8], and micromachined filters [9]. This design method is based on coupling coefficients of intercoupled resonators and the external quality factors of the input output and resonators.

There have been extraordinary recent advances in computer-aided design (CAD) of RF/microwave circuits, particularly in full-wave electromagnetic (EM) simulations. They have been implemented both in commercial and specific in-house software and are being applied to microwave filter simulation, modeling, design, and validation.

Microstrip filters are themselves already small in size compared with other filters such as waveguide filters. Nevertheless, for some applications where the size reduction is of primary importance, smaller microstrip filters are desirable, even though reducing the size of a filter generally leads to increased dissipation losses in a given material and hence reduced performance. Miniaturization of microstrip filters may be achieved by using high dielectric constant substrates or lumped elements, but very often for specified substrates, a change in the geometry of filters is required and therefore numerous new filter configurations become possible which include some novel concepts, methodologies, and designs for compact filters and filter miniaturization. The new types of filters include ladder line filters, pseudointerdigital line filters, compact open-loop and hairpin resonator filters, slow-wave resonator filters, miniaturized dual-mode filters, multilayer filters, lumped-element filters, and filters using high dielectric constant substrates.

In general, the size of a microwave filter is proportional to the guided wavelength at which it operates. Since the guided wavelength is proportional to the phase

velocity  $v_p$ , reducing  $v_p$  or obtaining slow-wave propagation can then lead to the size reduction. It is well known that the main mechanism of obtaining a slow-wave propagation is to separate storage the electric and magnetic energy as much as possible in the guided-wave media. It has been seen that conventional line does not store the electromagnetic energy efficiently as far as its occupied surface area is concerned. This is because both the current and the charge distributions are most concentrated along its edges. Thus, it would seem that the propagation properties would not be changed much if the internal parts of microstrip are taken off. A ladder microstrip line can have a lower phase velocity as compared with the conventional microstrip line, even when they occupy the same surface area and have the same outline contour.

Microstrip pseudointerdigital bandpass filters [8–9] may be conceptualized from the conventional interdigital bandpass filter. A conventional interdigital filter structure consist of resonator element quarter-wavelength long at the midband frequency and is short-circuited at one end and open-circuited at the other end. The short-circuit connection on the microstrip is usually realized by a via hole to the ground plane. Since the grounded ends are at the same potential, they may be so connected, without severe distortion of the bandpass frequency response, to yield the modified interdigital filter. Then it should be noticed that at the midband frequency there is an electrical short-circuit at the position where the two grounded ends are jointed, even without the via hole grounding. Thus, it would seem that the voltage and current distributions would not change much in the vicinity of the midband frequency, even though the via holes are removed. This operation, however, results in the so-called pseudointerdigital filter structure. This filtering structure gains its compactness from the fact that it has a size similar to that of the conventional interdigital bandpass filter. It gains its simplicity from the fact that no short-circuit connections are required, so the structure is fully compatible with planar fabrication techniques.

In order to reduce interference by keeping out-of-band signals from reaching a sensitive receiver, a wider upper stopband, including  $2f_0$ , where  $f_0$  is the midband frequency of a bandpass filter, may also be required. However, many planar bandpass filters that are comprised of half-wavelength resonators inherently have a spurious passband at  $2f_0$ . A cascaded lowpass filter or bandstop filter may be used to suppress the spurious passband at a cost of extra insertion loss and size. Although quarter-wavelength resonator filters have the first spurious passband at  $3f_0$ , they require short-circuit (grounding) connections with via holes, which is not quite compatible with planar fabrication techniques. Lumped-element filters ideally do not have any spurious passband at all, but they suffer from higher loss and poorer power handling capability. Bandpass filters using stepped impedance resonators [14], or slow-wave resonators such as end-coupled slow-wave resonators [15] and slow-wave open loop

resonators [16–17] are able to control spurious response with a compact filter size because of the effects of a slow wave.

RF MEMS technology is highly suitable for filtering application and offers real benefits over other competing technologies. The low-power consumption and high linearity of RF MEMS [17] combined with the reduced component count and cost resulting from their tunability make them ideally suited to application in modern RF systems. Deployment of this technology would be quite advantageous in electronically scanned arrays where a radar system operates in a quasi-continuous wave mode and as in-line pre-selectors or channelizers. The use of RF MEMS components in these systems can reduce radiated out-of-band energy, provide added protection to the receiver from the transmitter, simplify the system design, and significantly reduce the cost, weight, and power consumption of future systems.

Most HTS microwave filters use microstrip form using thin film HTS ground plane at the bottom of the substrate and HTS photoetched circuitry on the top. The substrate being mounted in a normal metal housing. The substrate used for HTS circuit materials must have a good crystal lattice match with the HTS in order to obtain a good band. The commonly used HTS materials are YBCO and TBCCO and that of the substrate are  $\text{LaAlO}_3$ , MgO, and sapphire with a buffer layer to provide a lattice match. These substrates are usually available in small sizes with diameter of 2-3 inch. This limits the size of the HTS circuits. Improves performance,

HTS filter design is very challenging and complex circuitry is required to realize this complex filters. To get the best system performance, regions of high current density in the circuit must be minimized to keep the system power level at which significant non-linear effects are begin to occur.

Due to nonlinear effects planar HTS filters are useful in low power application (mW or less). This type of filter is useful where High Q circuit is required

The UWB filter with multiple mode stepped impedance resonator having good in band performance and advantage of compact size, wide passband and wide upper stopband with insertion loss more than 20 dB. The coupled line sections of this filters are modified by lengthening and folding one or two coupling arms.

Waveguide filters with complicated frequency response are widely employed in many microwave systems and particularly on board of satellites for spatial communication systems due to their very low insertion loss.

Microwaves are used in telecommunication (and radar) systems of centimeter and millimeter wave bands, which effectively support information channels in computer networks and networks of mobile cellular communication. Characteristics of microwave repeaters depend significantly on electric parameters of band pass filters they contain. Among known microwave filters, the designs based on leucosapphire and quartz waveguide-dielectric resonators (WDR) are distinguished due to their general quality parameters, such as high unloaded Q's, sparse spectrum of

parasitic modes and usable level of transmitted power [1,2]. Cross-shapes of the cut-off waveguide cross-sections enable to fix there E- and H-plane resonance size dielectric inserts by means of projections [3]. Quartz and leucosapphire monocrystals are used as dielectric materials in designing band-pass filters for millimeter wave band, thus ensuring that the dimensions of inserts are suitable for manufacturing process and un-loaded Q of the working type electromagnetic modes is induced in the inserts.

For many applications it is necessary to deal with wide band frequencies, for which WDR-based filters seem to be very promising too. However no complex studies have been performed in this area yet, which makes the development of theoretical approaches to solving this problem rather actual now.

#### **VI. Microwave waveguide filter**

A design approach for microwave waveguide filters with complicated response uses a combination of analytical filter synthesis theory, a very efficient "fullwave" analysis method of the structure and the Simulated Annealing (SA) optimization algorithm. Instead of a single optimization of the whole structure, the knowledge of the analytical synthesis of the filter allows to divide the optimization into more straightforward partial problems. In this way, the filter is segmented into sections that are optimized to match the partial frequency responses obtained from the analytical synthesis procedure. These optimized sections are a very useful starting point to overcome the difficulties of the final optimization of the whole structure.

Waveguide filters with complicated frequency response are widely employed in many microwave systems and particularly on board of satellites for spatial communication systems due to their very insertion loss. Filter requirements with reflection and transmission zeros and/or very flat group delay on the passband are examples of the frequency responses to be handled. There are well known analytical synthesis procedures for obtaining the coupling matrices and the circuitual representation of many of these kinds of filters. Once the circuit elements are obtained, the following step in the design process is its implementation in waveguide technology. This step usually involves a great computational cost for two main reasons :a) the geometrical dimensions of the waveguide structure must be obtained after an optimization process with usually a high number of variables (geometric dimensions) and with a complicated error function. Independently of the optimization algorithm, the number of function evaluations is proportional to the number of variables.

b) The evaluation of the error function requires an accurate analysis of the structure. All the software tools involved in this task, commercial or home-made, employ the so-called "fullwave" electromagnetic methods, which provide a rigorous solution to the Maxwell equations. Electric and magnetic fields are accurately computed on the waveguide structure and, therefore, a reliable electrical response is obtained. An accurate analysis method saves many valuable resources (materials, time,) in the final tuning process of the filter at the laboratory.

Among the well known "fullwave" electromagnetic methods used in the characterization of waveguide structures The Finite Element method (FEM), the Finite Difference Time Domain (FDTD), the Transmission Line method (TLM), the Mode-Matching method (MMM). These methods, separately or combined into hybrid techniques, are used to simulate the waveguide structures, but unfortunately, although with slight differences, all of them consume a lot of CPU time. a rigorous knowledge of filter synthesis theory, in order to be able to obtain not only the global response of the filter, but rather any of the electrical responses of the different sections that make up the global filter/

An accurate and efficient method for the electromagnetic analysis of the waveguide structure is Mode-Matching. This method is employed to obtain the Generalized Admittance Matrix (GAM) and the Generalized Scattering Matrix (GSM) of the different sections and discontinuities of the waveguide filter structure, respectively [4]-[6]. The accurate electrical response of the filter is obtained linking these matrices. The use of an optimization algorithm that needs a moderate number of electromagnetic evaluations and is able to avoid the local minima of complicated error functions. Three different algorithm has been tested as Gradient techniques, Genetic Algorithms (GA) and Simulated Annealing algorithms (SA).It has been seen that the SA has shown an excellent performance due to a good compromise between the number of evaluations of the error function and the searching for minima beyond the local minima. It must be stressed that a suitable definition of the error function is essential to accomplish the optimization.

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