Design of RF, Microwave and Millimetre-wave Resonators and Filters

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Abstract

Recent advances in microwave computer-aided circuit design technology, suggest the feasibility of interfacing electromagnetic simulations directly to sophisticated optimization systems. With the availability of powerful computers this optimization based approach to the design of microwave filters becomes a desirable tool. The central theme of this paper is the optimization oriented approach for the accurate design of RF, microwave, mm-wave, and submm-wave filters. It presents computer-aided filter design algorithms and provides examples of their applications. When implemented around an accurate circuit simulation the method can be used to include all the effects of discontinuities, junctions, fringing etc, to reduce the amount of tuning required in the final filters. The several actual filter and resonators implementations in waveguide and DR technologies are presented. Measurements on a fabricated bandpass filters confirm the accuracy of design procedure.

Introduction

Computer Aided Design of RF, microwave and millimetre-wave filter structures must be capable of handling the restrictions of a wide-spread application of low-cost precision fabrication methods, such as computer-controlling milling, spark eroding or photo-lithographic etching techniques, in which postassembly tuning is no longer economical or feasible. The filter design must also meet the demands of the expanding utilization of higher frequency bands (up to submm-waves), which need tighter tolerances. These conditions require

* Computer aided design,
* Rigorous electromagnetic simulation techniques
* Efficient computer optimization methods

that allow the computer aided filter design to take into account all of the significant design parameters.

Simulation software packages (see Table 1) provide different methods for optimization of filter elements. These methods are for general applications and do not provide the results that are required in the specific area of RF, microwave, mm-wave and submm-wave filters. Usually the response of an optimizable filter is sampled at a number of equally spaced frequencies and the error between this sampled response and the desired response is computed at each frequency. The optimization program, through an iterative process, reduces this error to a minimum, arriving at a final filter design in terms of the optimized filter parameters. These optimization techniques cannot be guaranteed to satisfy filter specifications and may even converge to a local minimum. The approach presented here requires less frequency sampling than previously methods. This method optimizes the passband of a filter with respect to the Chebyshev (or minimax) criteria. This relates directly to the way filters are fabricated in practice. This vector procedure has several advantages over the general purpose optimization routines previously applied to the design of microwave filters. Design of a E-plane waveguide bandpass filters and resonators using periodic metallic septa and DR bandpass filters with electromagnetic simulations driven directly and indirectly by DBFILTER [6] were used as examples.

Numerical and Experimental Results

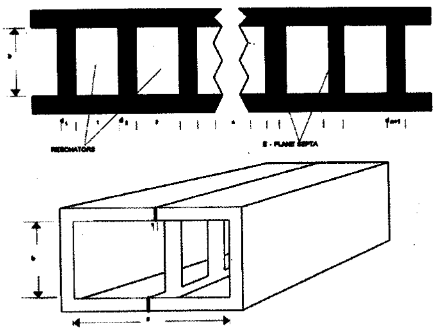
The following examples illustrate some of the capabilities of the DBFILTER software package. The DBFILTER software package achieves the accurate waveguide (rectangular, ridged and coplanar) resonator and filter on-line design. This is demonstrated by the following examples.

Example 1

First example includes a X-band rectangular waveguide (E-plane) bandpass filter with five resonators with passband specification $L_I(f) \leq 0.05$ dB, 9.25 GHz $\leq f \leq$ 9.75 GHz. Figure 2 shows the calculated and measured insertion losses of the fabricated waveguide bandpass filter at 9.5 GHz. The designed filter was fabricated using brass for the waveguide housing and copper for the metal insert. The calculated insertion loss of the waveguide E-plane resonator using periodic metallic septa at 9.475 GHz is shown in Figures 3.

Table 1.
Some Commercially Available Electromagnetic Simulators and Circuit Design Tools

COMPANY	*PRODUCT* *(all trademarks acknowledged)*	*TYPE*
HP-EEsof (HP range)	MDS MLS MNS Impulse Series IV/PC ADS (Advanced Design System) Momentum HFSS Designer MW Artwork Generator	Integrated package Linear Simulator Harmonic balance Time-domain Integrated package Integrated framework that combines the previous Series IV and MDS suites with DSP and communications system design modules) 3D Planar electromagnetic 3D Arbitrary electromagnetic with optimisation Layout
HP-EEsof (EEsof range)	Touchstone Linecalc Libra MicroWave Space (now in Libra) E-Syn Communications Design Suite	Linear Physical parameters Harmonic balance Time-domain Filter synthesis System simulation
Ansoft Corporation	HFSS Maxwell-Strata Maxwell Eminence MicroWaveLab Ensemble Serenade Symphony	3D Arbitrary electromagnetic 3D Planar electromagnetic 3D Arbitrary 3D Arbitrary electromagnetic 3D Planar Schematic capture (harmonic balance, device library, filter synthesis, nonlinear stability analysis) Integrated package, which like ADS incorporates analogue and DSP system analysis capabilities
Jansen Microwave	Linmic+ Linmic+/N Unisym/Sfpmic	Linear (integrated suite) Non-linear 3D Planar electromagnetic
Sonnet Software	em xgeom emvu *patgen/patvu*	3-D Planar electromagnetic Layout entry Current display Patch antenna patterns
Kimberley Communications Consultants	Micro-Stripes	3D Arbitrary electromagnetic (TLM)
Optotek	MMICAD	Linear
Eagleware Corp.	M/FILTER	Linear
Tesla Communications	DBFILTER	Filter synthesis, analysis and optimisation
Infolytica Corporation	FullWave	3D Arbitrary electromagnetic with optimization
Computer System Technologies	Mafia Microwave Studio	3D Planar
Zeland Software	IE3D FIDELITY	3D Planar electromagnetic with optimization 3D Arbitrary electromagnetic (FDTD)
IMST	EMPIRE COPLAN	3D Planar/Waveguide electromagnetic (FDTD) A design toll for coplanar circuits integrated within HP-EEsof Series IV
TeSoft, Inc.	TESLA	System simulation (linear and nonlinear analysis at a block-diagram level)



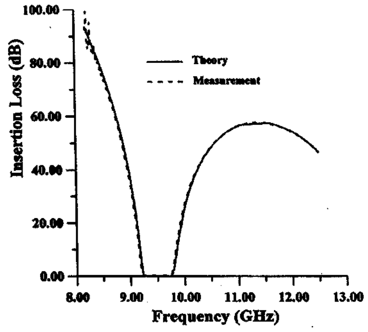


Fig. 2 Configuration, measured insertion loss (dashed line) and calculated insertion loss (solid line) of the E-plane filter.

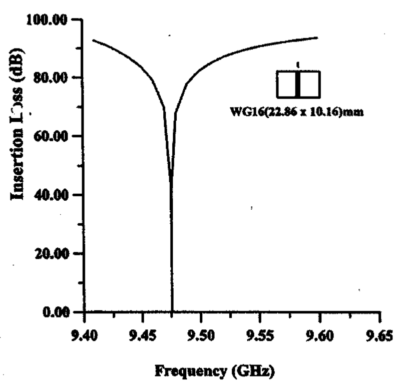


Fig. 3. Simulated insertion loss of waveguide E-plane resonator using periodic metallic septa

Example 2
Filters for Point-to-Point Digital Radio

Filter 1
Type: Bandpass
Waveguide WG23 (WR22): 5.690 x 2.845 mm:
Passband: 37.81 - 38.19 GHz
Bandwidth: 380 MHz (1%)
Passband flatness better than 0.2dB
Passband insertion loss <0.5dB
Passband return loss >23dB
Rejection at 37.0 GHz >30 dB
Connectors WG22

Filter 2

Type: Bandpass
Passband: 57.20 - 58.20 GHz
Bandwidth: 1.0 GHz
Passband insertion loss <2dB (smaller if possible)
Reject band 1: 50-56.25 GHz, Insertion loss >35dB
Reject band 2: 59.2-75 GHz, Insertion loss >30dB
Connectors WR15 (3.759 x 1.880 mm)

The calculated insertion loss of the waveguide E-plane filters and resonators using periodic metallic septa at 38 GHz, and 58 GHz is shown in Figures 4 and 5 respectively. The dimensions of the E-plane insert are given in the same. The calculated insertion loss of the waveguide E-plane resonator using periodic metallic septa at 42 GHz is shown in Figure 6. Figure 7 shows the measured transmission loss of the fabricated waveguide bandpass filter. Photograph of the E-plane filter (Filter1) is shown in Figure 8.

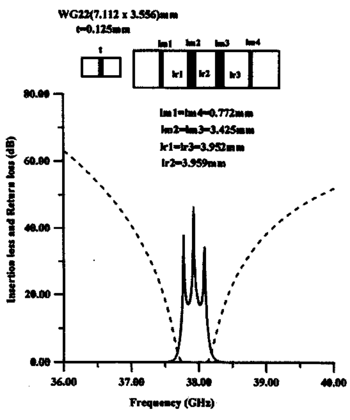


Fig. 4 Calculated insertion loss (dashed line) and return loss (solid line) of the E-plane filter (Filter1).

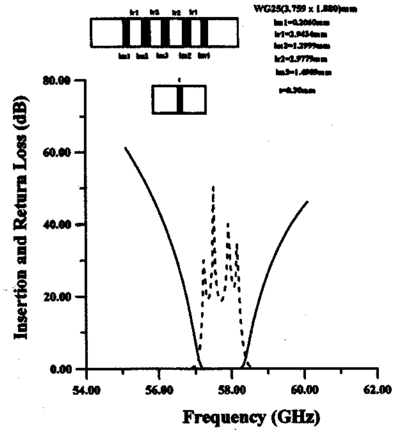


Fig 5 Calculated insertion loss (dashed line) and return loss (solid line) of the E-plane filter (Filter 2).

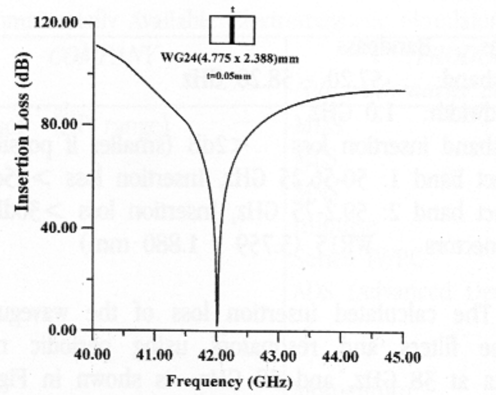


Fig. 6. Simulated insertion loss of waveguide E-plane resonator using periodic metallic septa at 42 GHz

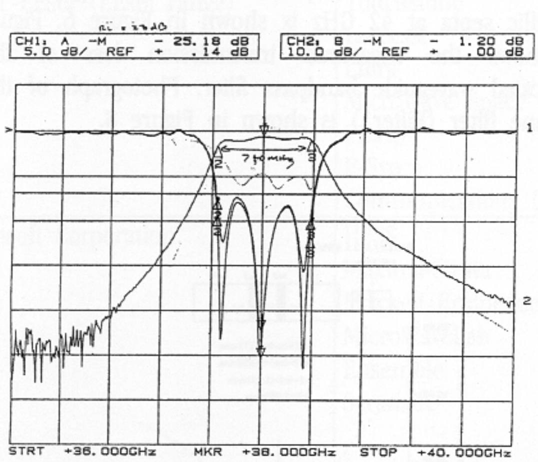


Fig. 7 Measured insertion loss (dashed line) and return loss (solid line) of the E-plane filter (Filter1).

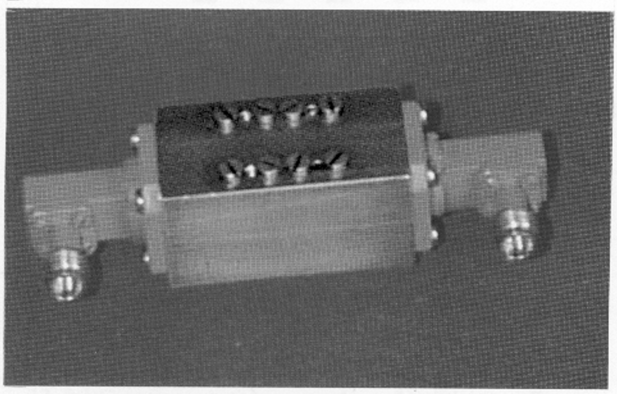


Fig. 8 Photograph of the E-plane filter (Filter1).

Example 3:

DR Filters for Mobile Communication Base Stations

In order to verify principles and refine design, dielectric quarter-ring-shaped resonator prototype filter for the PCN application was fabricated and tested. The performance of this filter is shown in Table below. Figure 9 shows the measured insertion loss and return loss of quarter cut resonator filter. Photograph of this filter is shown in Figure 10.

Resonant frequency:	1810 MHz
Bandwidth (BW):	20 MHz
Insertion loss (BW):	0.71 dB
Return loss (BW):	16 dB
Unloaded Q:	5500
Dielectric permittivity (resonator):	37.5
Dielectric permittivity (substrate):	8.5
Cavity size:	45 × 45 × 45 mm
Resonator size (quarter cut):	30mm radius × 18.5mm high

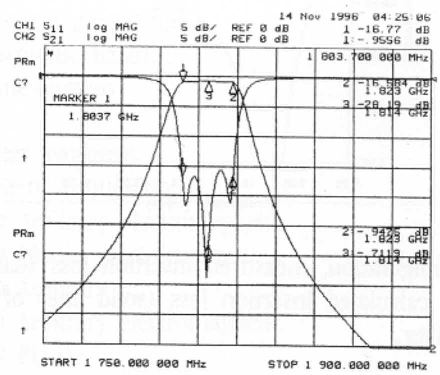


Fig. 9 Measured insertion loss and return loss of quarter cut DR bandpass filter.

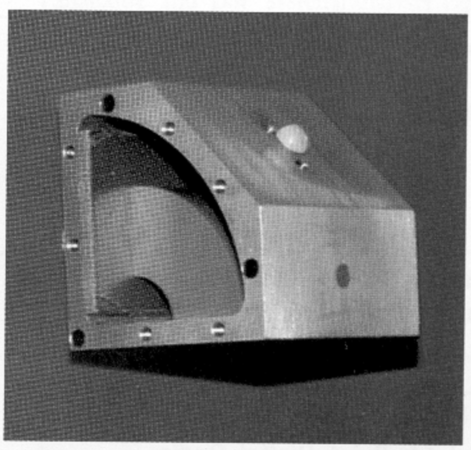


Fig. 10 Photograph of quarter cut DR

Conclusion

An optimization based CAD procedure for the accurate design of RF, Microwave, and Millimeter-wave, high-Q resonator and filter structures in waveguide and DR technologies has been used. The experimental results for quarter cut dielectric resonator filter at 1.81 GHz and calculated and experimental results for a air-filled metal rectangular waveguide filters and resonators using periodic quarter-wavelength metallic septa at 9.5 GHz, 9.475 GHz, 38 GHz, 42 GHz and 58 GHz have been given. Mode matching with 100 modes was used for electromagnetic simulation of the behaviour of the waveguide discontinuities throughout the design. E-plane waveguide resonators with periodic metallic septa are expected to find application particularly in the mm-wave, submm-wave and terahertz range circuits, e.g. in low phase noise oscillators and highly selective filters, diplexers and multiplexers, frequency selective surfaces and antennas.

References

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