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MAGNETICALLY TUNABLE LOW-INSERTION LOSS MICROWAVE AND MM-WAVE BAND-PASS FILTERS WITH HIGH-POWER CAPABILITY

Jaroslaw Uher*, Jens Bornemann**, and Fritz Arndt***

*) Department of Electrical Engineering
University of Ottawa, Ottawa, Ontario, Canada K1N 6N5
**) Department of Electrical and Computer Engineering
University of Victoria, Victoria, B.C., Canada V8W 2Y2
***) Microwave Department
University of Bremen, D-2800 Bremen 33, West Germany

Abstract

For the CAD-design of magnetically tunable E-plane microwave and mm-wave filters the modal S-matrix method is applied. The theory includes both, higher order mode interactions of all discontinuites involved , and finite thicknesses of metal inserts and ferrite slabs. Optimized data are given for magnetically tunable metal insert Ku-band (12GHz - 18GHz) and Ka-band (26GHz - 40 GHz) filters with double and single lateral ferrite slabs. Excellent filter characteristics in tuning range (1dB insertion loss or less and constant filter response shape) are achieved.

Introduction

Tunable waveguide filters, with the desired properties of nearly constant bandpass characteristics in the tuning range and the insertion losses as low as possible, are of considerable practical interest for many applications [1]. Common techniques include sliding walls [1], varactor diodes [2], single cristal ferrite resonators (YIG, spinels and hexagonal ferrites) [1], [3], and ferrite-slab loaded evenescent mode waveguide sections [4]. Although providing wide tuning ranges - the application of YIG-tuned filters may often be restricted by the relatively narrow-band selectivity available and and by the low power handling capability. Recently, a new class of magnetically tunable filters was introduced [5], [6]. Both large gap finline filters on a ferrite substrate, and double ferrite slab loaded metal insert filters were described. The presented design combines the advantages of printed circuit technology with those of high power capability of ferrite slab loaded waveguide components. However, the undesirable narrow-stopband characteristic as well as the filter bandwidth variations in the tuning range have considerably limited the commercial application of these filter types.

In this paper the improved design of E-plane metal insert filters with multiple ferrite-slab loading is presented. An excellent behaviour of the filter frequency responses (filter bandwidth remains constant in the tuning range, stopband characteristics are comparable with those of unloaded filters, insertion losses are lower than 1.5dB), enables the commercial application in such high-power microwave systems as troposcatter radar or navigation links. The theory is veryfied by measurement using Ku-band wavequide housings. The theoretically predicted values agree well with measured results. Therefore, the proposed method enables filter designs in any frequency band up to 60-70 GHz , where the relatively low magnetic saturation of the accessible ferrite materials leads to significant limitations in the filter tuning ranges.

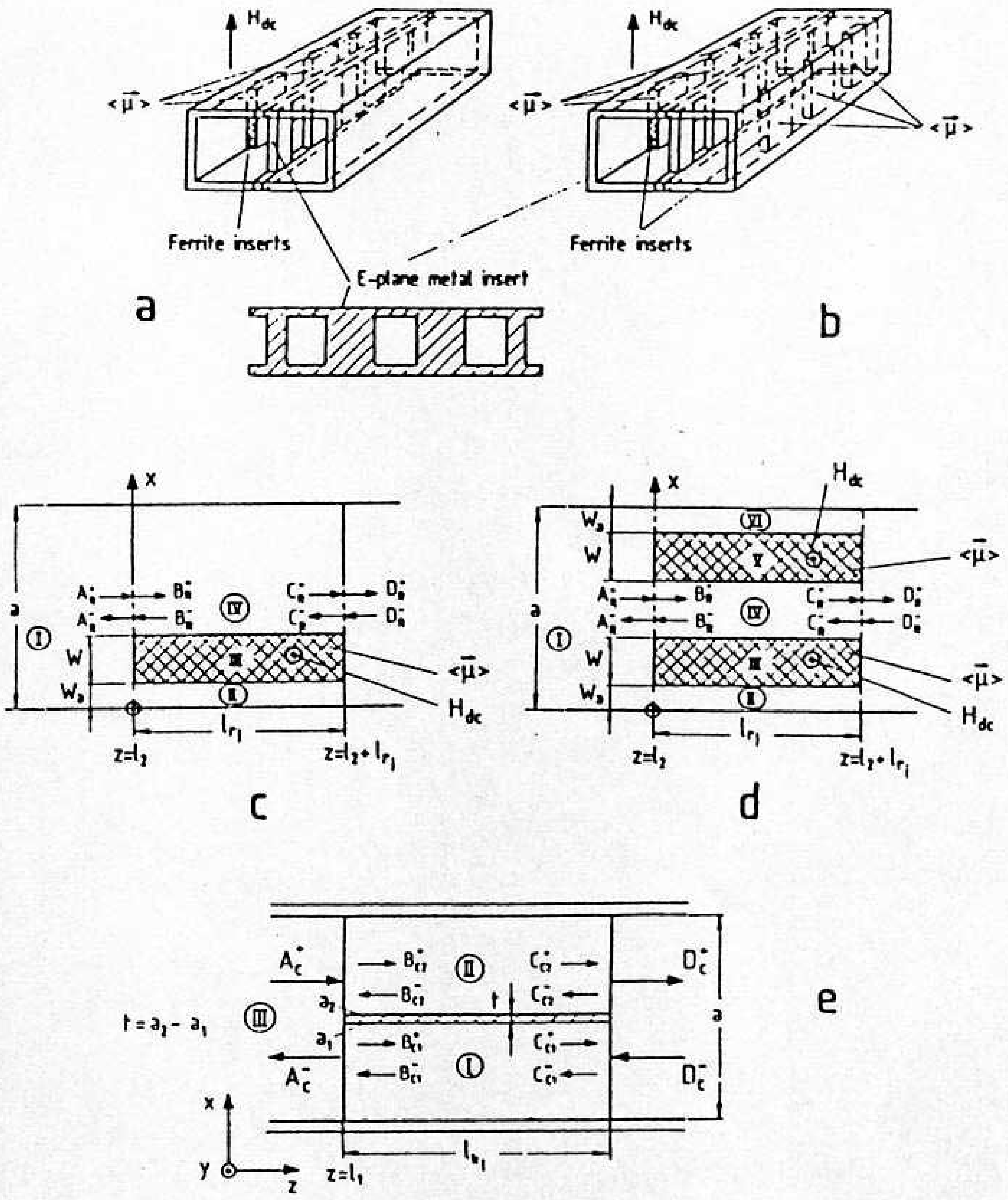

Fig. 1. Magnetically tunable E-plane metal insert filter.
a) E-plane metal insert filter with single-sided ferrite-inserts
b) E-plane metal insert filter with double-sided inserts
c) resonator region of a)
d) resonator region of b)
e) coupling section of a) and b)

Theory

For the field theory treatment, the filter structures (Fig. 1a, 1b) are subdivided into appropriate key building blocks: septate waveguide coupling sections [7], and either double (Fig. 1d) or single (Fig. 1c) ferrite slab loaded resonator region including the air gap of witdh w_a. For each homogenous subregion ν = I to IV (Fig. 1c) the field components of the TE_{mo} modes involved are derived from the electric field component $\vec{e}_y E_y^{(\nu)}$, which is expressed as a sum of N eigenmodes [8], satisfying the vector Helmholtz equation and the boundary conditions at the discontinuites in the x-direction. In the homogenous ferrite region magnetized in y-direction the Maxwell equations take the form

$$\nabla \times \vec{H} = j\omega\varepsilon\vec{E}\,, \qquad \nabla \cdot (<\vec{\mu}>\vec{H}) = 0$$
$$\nabla \times \vec{E} = -j\omega<\vec{\mu}>\vec{H}\,, \qquad \nabla \cdot \vec{E} = 0\,, \qquad (1)$$

where the Polder tensor $<\vec{\mu}>$ components for the saturated ferrite

$$<\vec{\mu}> = \begin{bmatrix} \mu_1 & 0 & -jx \\ 0 & \mu_r & 0 \\ jx & 0 & \mu_1 \end{bmatrix} \qquad (2)$$

are calculated from well known formulas [9], and the scalar permeability of the demagnetized ferrite may be determined from experimental relations given in [10]. The propagation constants in the ferrite-slab loaded resonator regions are obtained by numerically solving the related (depending on single or double slab loading) transcendental equation in the complex plane [11].

The modal scattering matrix of the coupling section is derived in [7]. Additionally, the computation of the overall filter performance requires the calculation of the resonator S-matrices. The field matching procedure as well as the transformation of the related linear equations system into S-matrix parameters is given in [11] and [5] for the single and double ferrite slab loading, respectively. The S-matrix of the complete filter structure is calculated by directly combining the appropriate single scattering matrices of the key building blocks [7].

Results

Fig. 2 shows the calculated and measured response of a Ku-band computer optimized three resonator magnetically tunable metal insert filter, where merely the resonators are partly filled with ferrite inserts. The operating midband frequency of the filter may be tuned from about 14.65 GHz to 15.55 GHz. The tuning efficiency of 4.3 MHz/$\frac{kA}{m}$ ist almost linear up to 16.6 GHz. The upper tuning range limit for the presented filters is caused by increasing ferrimagnetic resonance losses with higher magnetic bias. The insertion loss of 0.8 - 1. dB is extremely low for this filter type. The bandwidth of about 1.7% (H_{dc} = 0) varies only very slightly in the tuning range (1.65% for H_{dc} = 2.1 · 10^5 A/m).

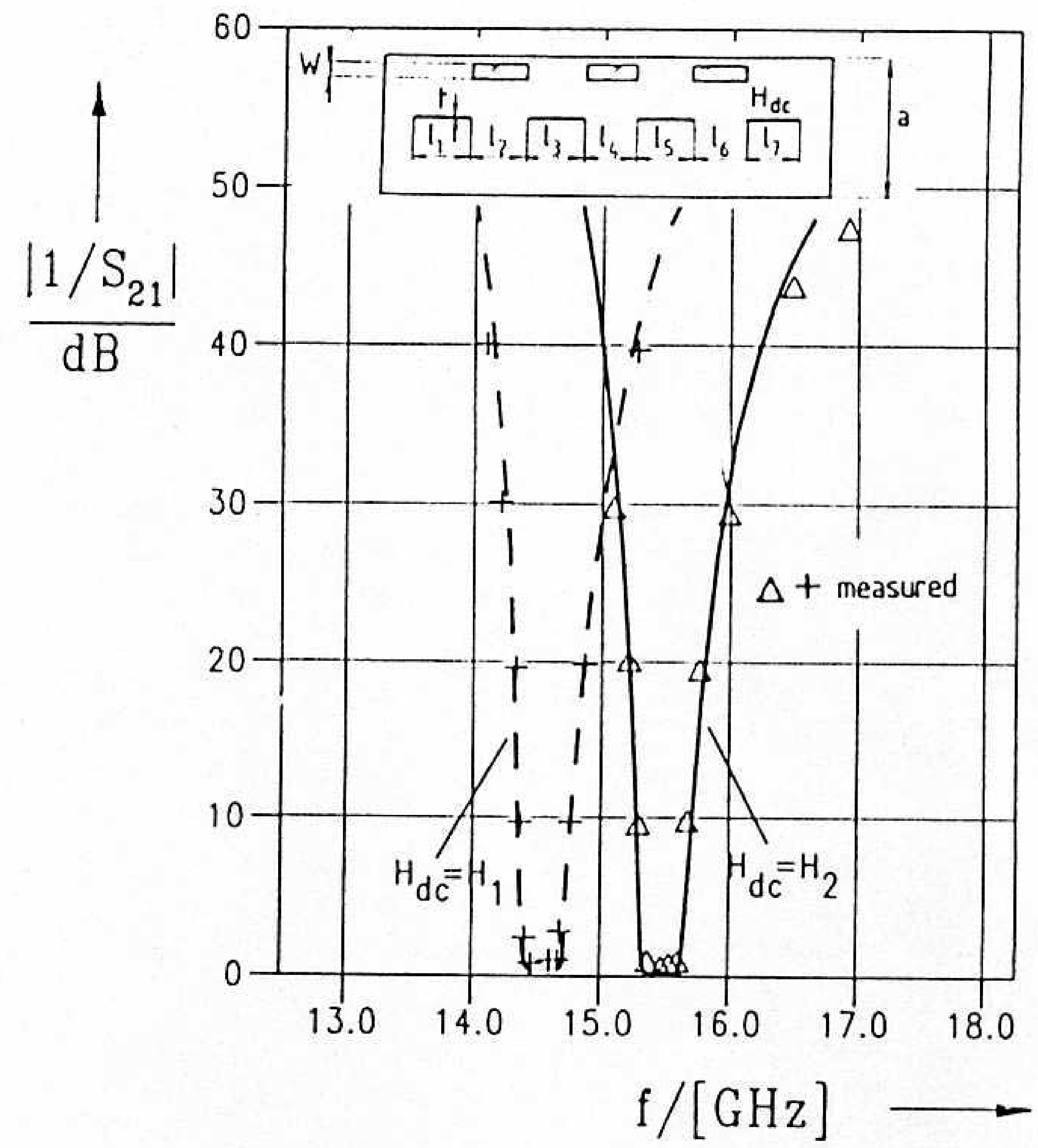

Fig. 2. Computer optimized Ku-Band magnetically tunable E-plane metal insert filter. Calculated and measured filter response of the single-sided ferrite loaded design
Design data: Ferrite TTI - 2800, a = 2b = 15.799 mm, t = 0.19 mm, w = 1 mm, H_1 = 0, H_2= 2.1 · 10^5 A/m

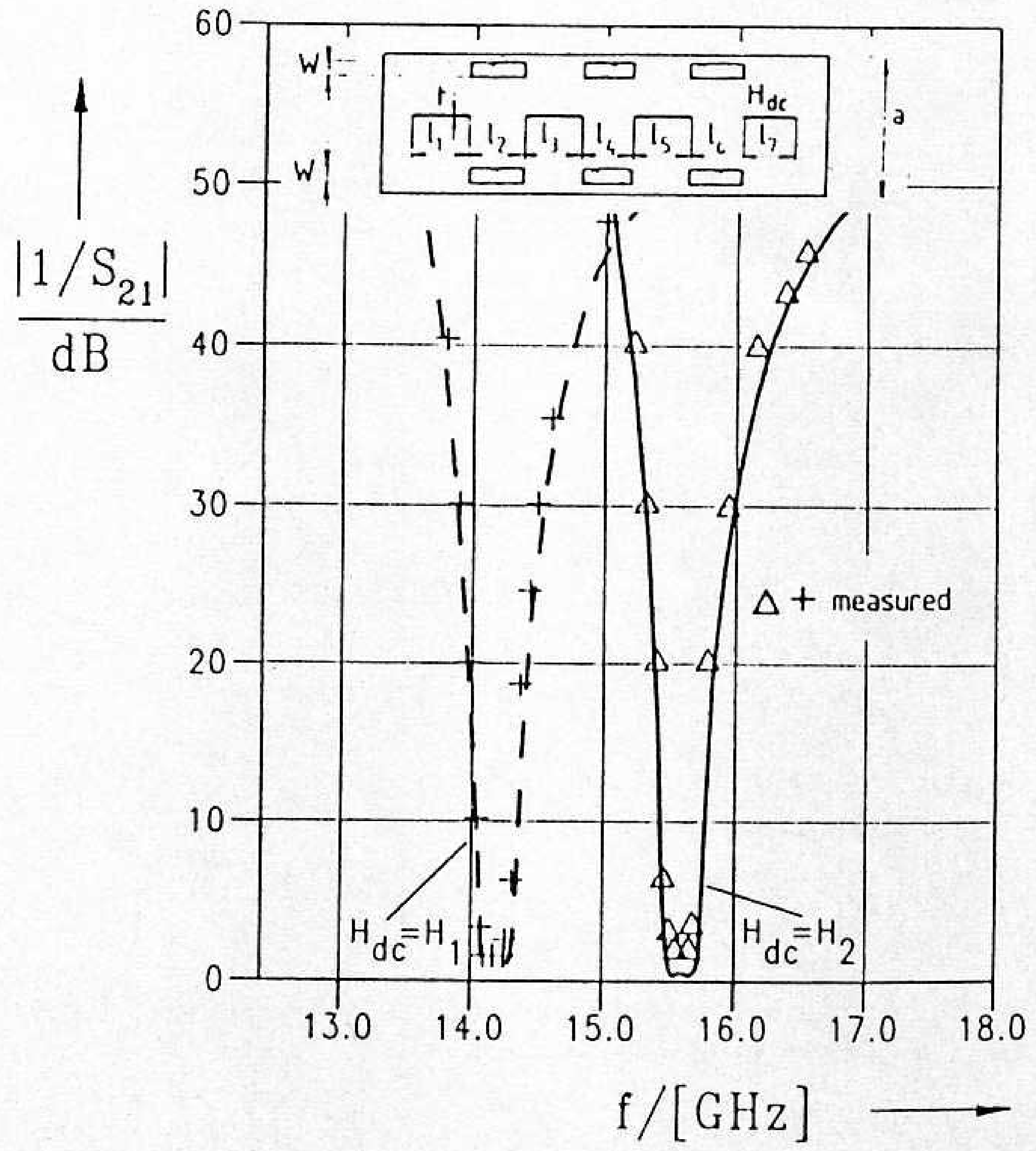

Fig. 3. Computer optimized Ku-Band magnetically tunable E-plane metal insert filter. Calculated and measured filter response of the double -sided ferrite loaded design. Design data as in Fig. 2.

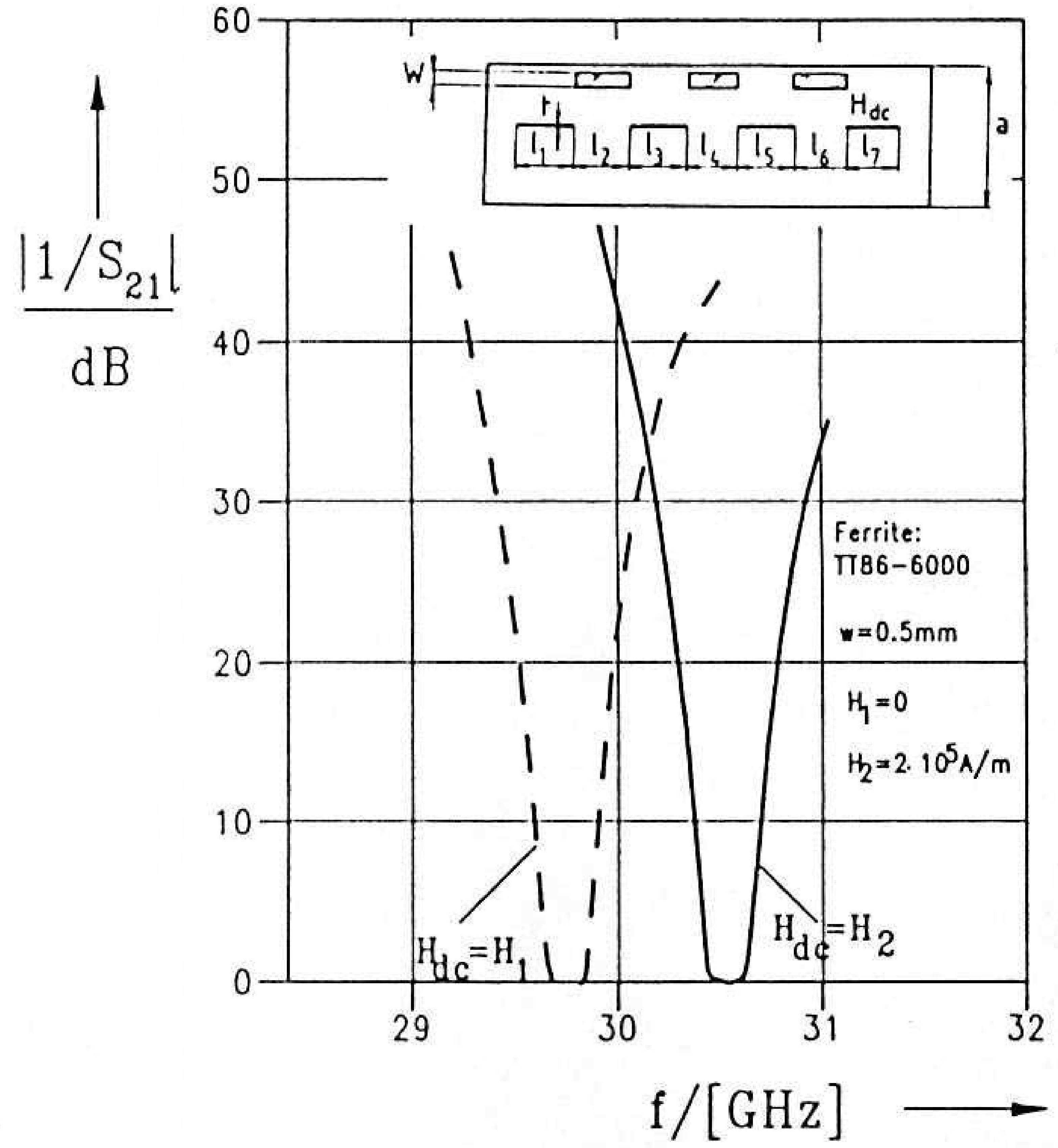

Fig. 4. Computer optimized Ka-Band magnetically tunable E-plane metal insert filter. Calculated filter response single-sided ferrite loading.

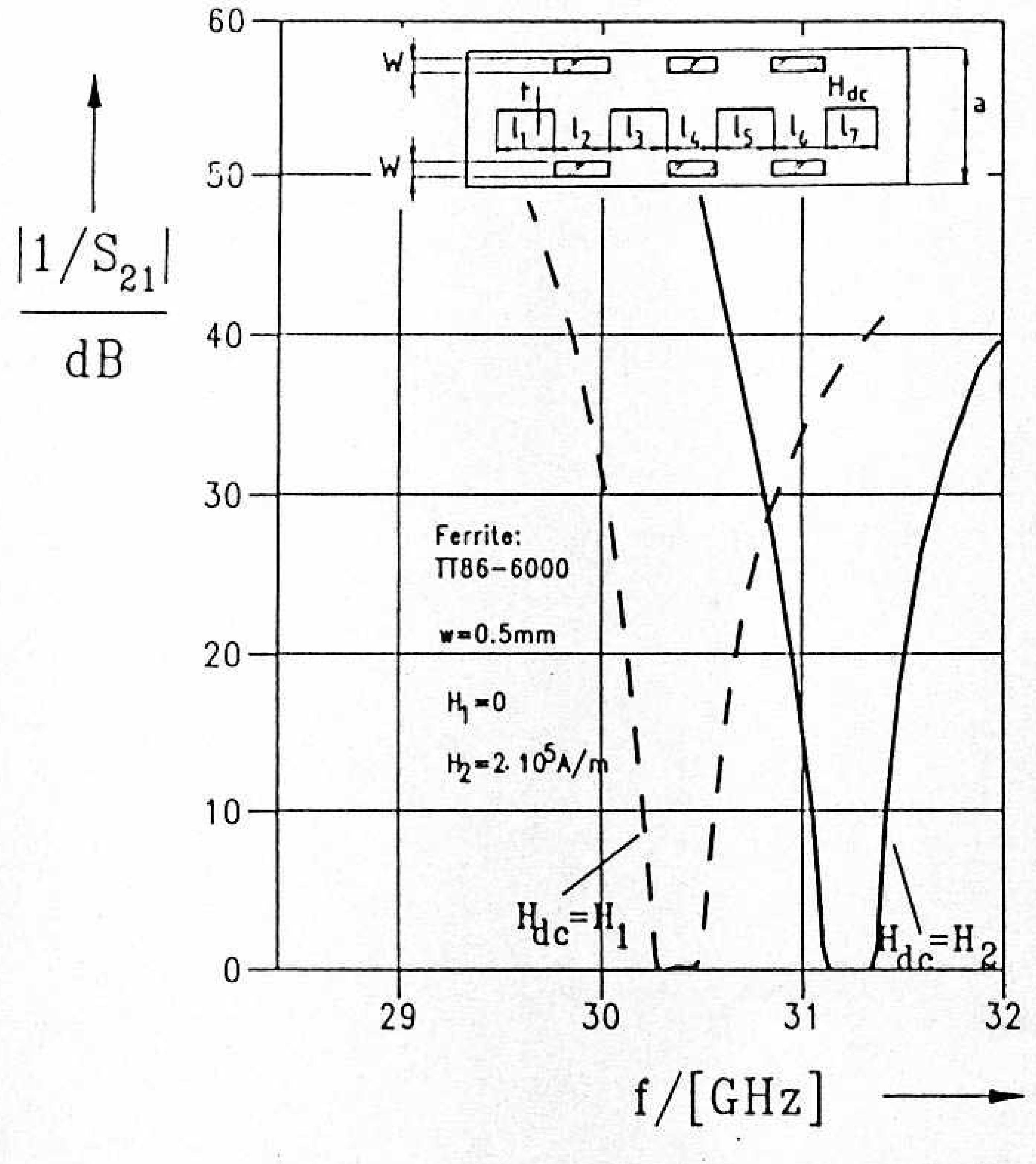

Fig. 5. Computer optimized Ka-Band magnetically tunable E-plane metal insert filter. Calculated filter response, double-sided ferrite loading.

An improved tuning efficiency of 7.6 $\mathrm{MHz}/\frac{kA}{m}$ is achieved by double ferrite- slab loading of the resonator sections (Fig. 3). However, the insertion loss increases to 1. - 1.5dB for this filter variant. Since the filter coupling sections are not filled with ferrite material, the cut-off frequencies in this region remain relatively high. Therefore very good stop-band behaviour for both filter types was achieved. In Fig. 4 and 5. the filter responses of computer optimized magnetically tunable three resonator E-plane metal insert filters with multiple single and double ferrite slabs loading, are shown respectively.

The Ka-band design provides the tuning efficiency of about 3.25 $\mathrm{MHz}/\frac{kA}{m}$ for the single loaded and 4.75 $\mathrm{MHz}/\frac{kA}{m}$ for the double loaded filter. With increasing frequency higher magnetic bias is required for efficient tuning. Therefore, the application of hexagonale ferrite materials is recommended in the mm-wave region.

Conclusions

A rigorous field theory method is used for the optimum design and improved performance of microwave ferrite-loaded magnetically tunable E-plane metal insert filters. The performance characteristics of the designed filters include many desired features for commercial applications, e.g. low insertion loss, improved stop-band behaviour, good constancy response shape as the center frequency is varied, and high-power capability.

Since all relevant parameters, such as higher-order mode interactions, the influence of additional air gaps between ferrite slabs and waveguide walls, and the finite metal insert thickness are taken into account, the theoretically predicted values agree well with measured results.

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