DESIGN OF A UMTS MONOBLOCK FILTER USING AN EQUIVALENT CIRCUIT APPROACH

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Abstract

A computer-aided synthesis technique for a UMTS ceramic filter is presented in this work. The technique uses an accurate equivalent circuit (extracted from first electromagnetic principles) as the basic design and tuning tool. This circuit is subsequently modified and optimised to meet the desired frequency characteristics. The changes in the equivalent circuit parameter values provide useful information for the necessary structural changes.

Keywords: *ceramic filters; equivalent circuits; parameter extraction; CAD; UMTS.*

1. Introduction

The rapid development of today's mobile communications industry has produced a huge number of compact and inexpensive hand-held communication sets which employ very small sized filters suitable for GSM, DCS, UMTS and other technologies. One technique for the miniaturisation of these filters is the use of high dielectric constant and low loss ceramic materials. However, the performance of such components often departs from the desired frequency response during manufacturing and as a result a considerable amount of time is spent on trimming. In this work an improved CAD design technique is presented which can be employed to provide reliable components "straight out of the box".

Computer-aided analysis techniques of ceramic filters have been presented in [1-2]. A CAD synthesis technique has been presented in [3] for the design of a PCS ceramic filter. This technique makes use of an equivalent circuit as the basic design and tuning tool and it is expanded here in the design of a UMTS ceramic filter. The equivalent circuit is based on the extraction of equivalent circuit parameters from first electromagnetic principles [1-2] and provides an accurate model for ceramic monoblock structures. The desired frequency response characteristics are achieved by optimising and tuning the equivalent circuit without having recourse to a time consuming electromagnetic optimiser. Changes in the equivalent parameter values provide useful information for the necessary structural changes.

2. Synthesis Procedure

A typical layout for a ceramic monoblock filter structure is schematically illustrated in Figure 1 [4]. This consists of three coupled $\lambda/4$ coaxial resonators terminated in a common short-circuit plane. Individual coupling cup arrangements are placed at the open end. An equivalent circuit topology for this structure has been extracted in previous work using CAD electromagnetic techniques [2] and it is presented in Figure 2. The filter resonators are modelled in the ADS software package [5] using coupled transmission lines [6] and the coupling cups are represented using lumped capacitors. The middle cup is less deep than the outside cups (or may not exist) and therefore the middle resonator is longer which is shown by an extra transmission line length. Cup inductances and resonator-to-cup discontinuities are modelled using lumped inductors.

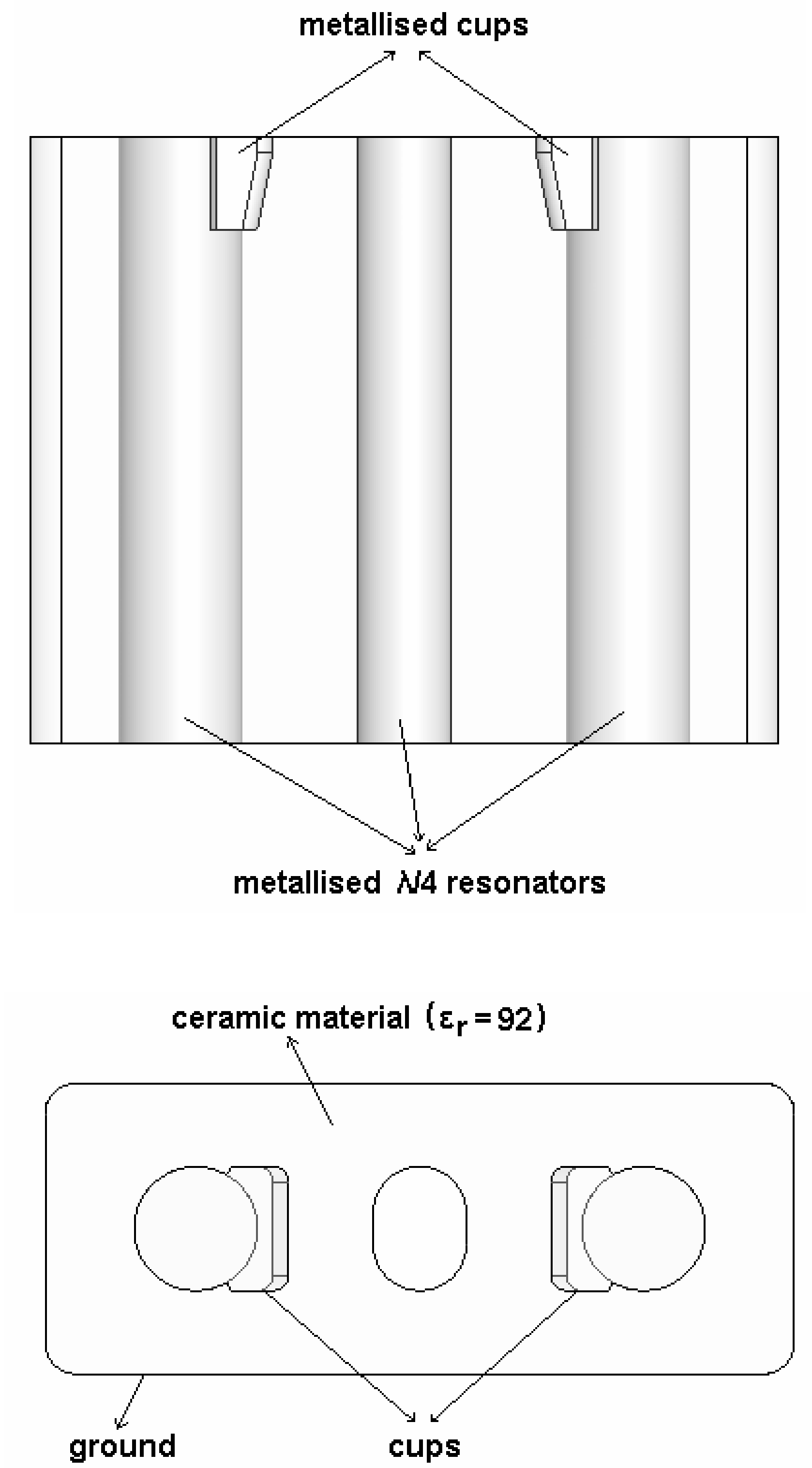

Figure 1: Ceramic monoblock filter layout.

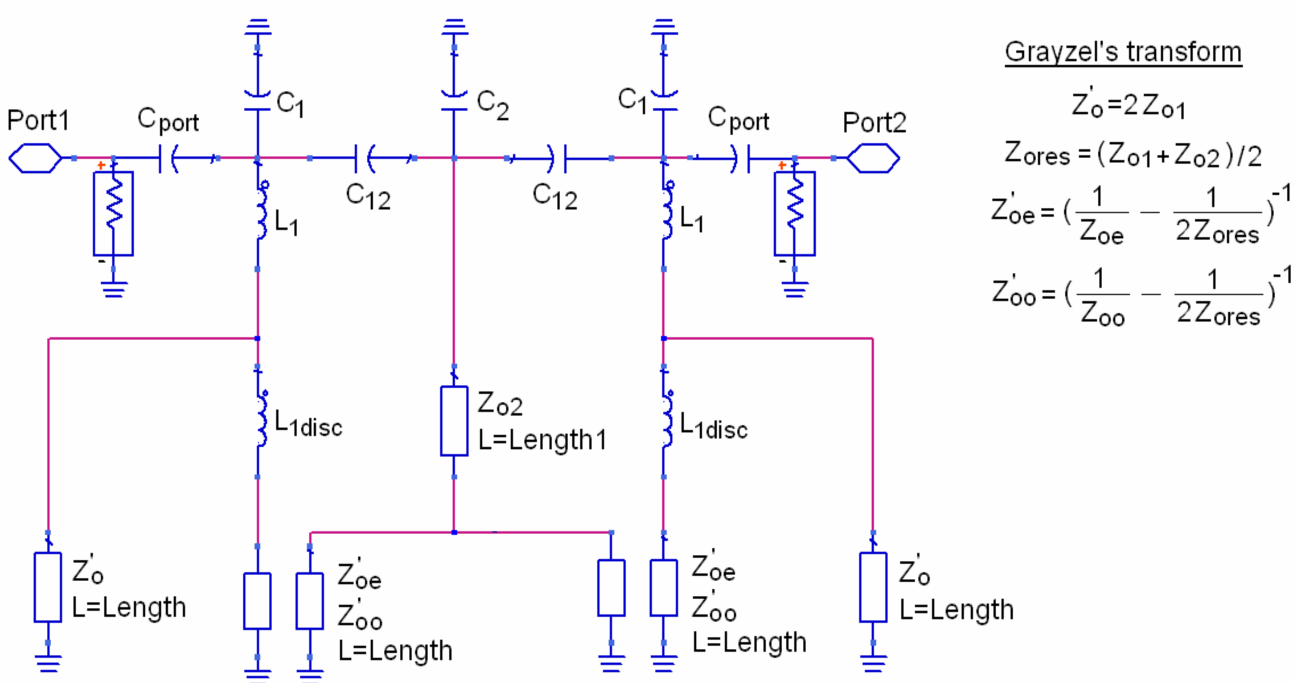

Figure 2: Equivalent circuit topology used for the synthesis of the UMTS filter.

The synthesis procedure is summarised as follows:

- Start from an existing equivalent circuit topology and optimise using a circuit optimiser according to the UMTS receiving band specifications (centre frequency: 2140 MHz, bandwidth: 60 MHz).
- From the optimised resonator impedance values extract approximate resonator dimensions and spacing [6]. Check impedance values using HFSS [8] and modify dimensions if necessary.
- Simulate resonator-only structure using HFSS and compare its response to the resonator-only equivalent circuit response. Modify dimensions if necessary.
- Add desired shape of coupling cups and extract new equivalent circuit using the HFSS post-processing Calculator.
- Optimise the new equivalent circuit to fit the design specifications.
- From the optimised values decide necessary structural changes.
- Parameterise structural dimensions and optimise using the HFSS electromagnetic optimiser.
- Simulate final design to calculate frequency response.

2.1 Initial equivalent circuit

The equivalent circuit topology of Figure 2 can be used as the synthesis starting point. ADS software is employed to optimise the equivalent circuit of Figure 2 according to the desired UMTS frequency response specifications. This response is presented in Figure 3. The optimised component values which correspond to the UMTS response are given in Table I. (The equivalent circuit inductances have a minimal effect in the circuit's performance and thus they do not appear in Table I).

Table I: Initial and optimised component values for the equivalent circuit topology of Figure 2.

Lumped component	Initial component value (PCS band)	Optimised component value (UMTS band)
C_1 (pF)	1.9378	1.5459
C_2 (pF)	0.4469	0.4147
C_{port} (pF)	0.7000	0.9744
C_{12} (pF)	0.7678	0.6000
Z_{01} (Ohms)	6.8808	7.6920
Z_{02} (Ohms)	7.3194	6.6759
Z_{0e}(Ohms)	7.0712	6.0077
Z_{0o} (Ohms)	5.3426	3.7004
Length (mm)	3.3300	3.1697
Length1 (mm)	0.4306	0.4494

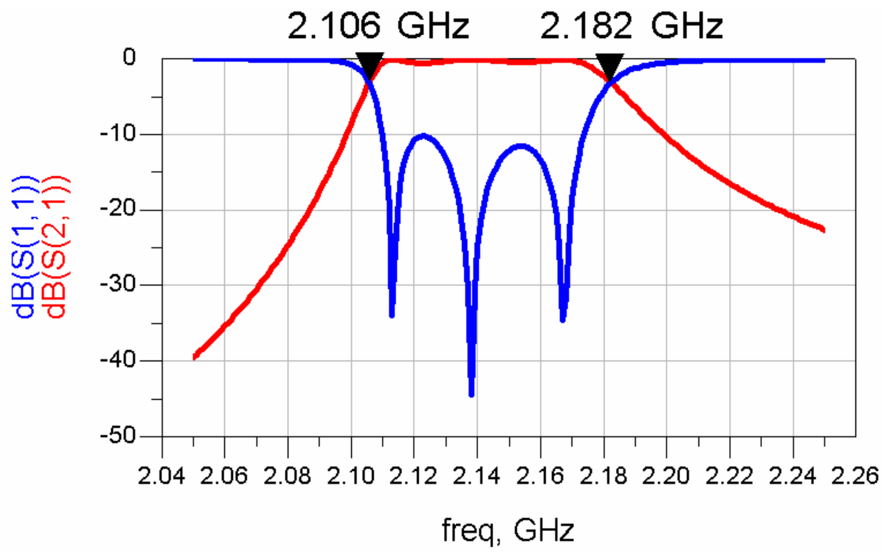

Figure 3: Equivalent circuit optimised response (UMTS receiving band).

2.2 Extraction of resonator dimensions

The coupled λ/4 resonators of Figure 1 are the critical part of the structure as they define the frequency performance of the filter. These resonators are dimensioned according to the optimised impedance values of Table I. Using these values and the approximate formulae given in [6], approximate initial resonator dimensions are extracted (Figure 4). The individual resonator impedance values and the even and odd mode impedances are then checked using the HFSS post-processing Calculator and the initial resonator dimensions are modified accordingly. Subsequently a resonator-only structure is modelled in HFSS (Figure 5). Its response is presented in Figure 6 and compared with the equivalent circuit (resonator-only) response.

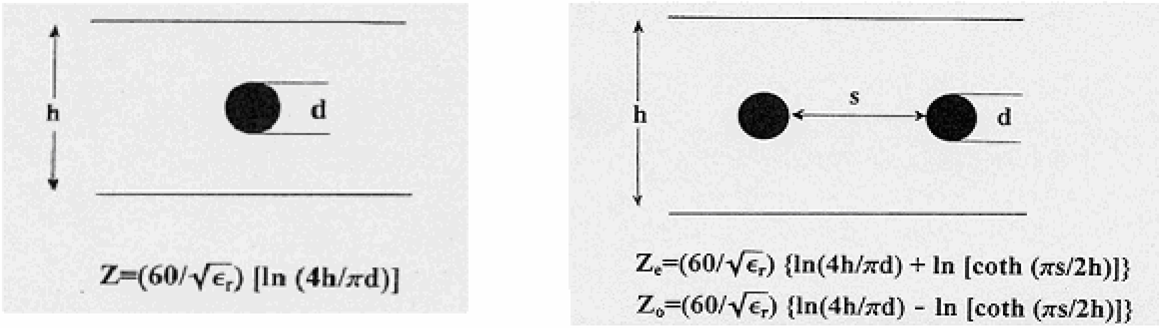

Fig. 4: Extraction of approximate resonator dimensions using the formulae of [6].

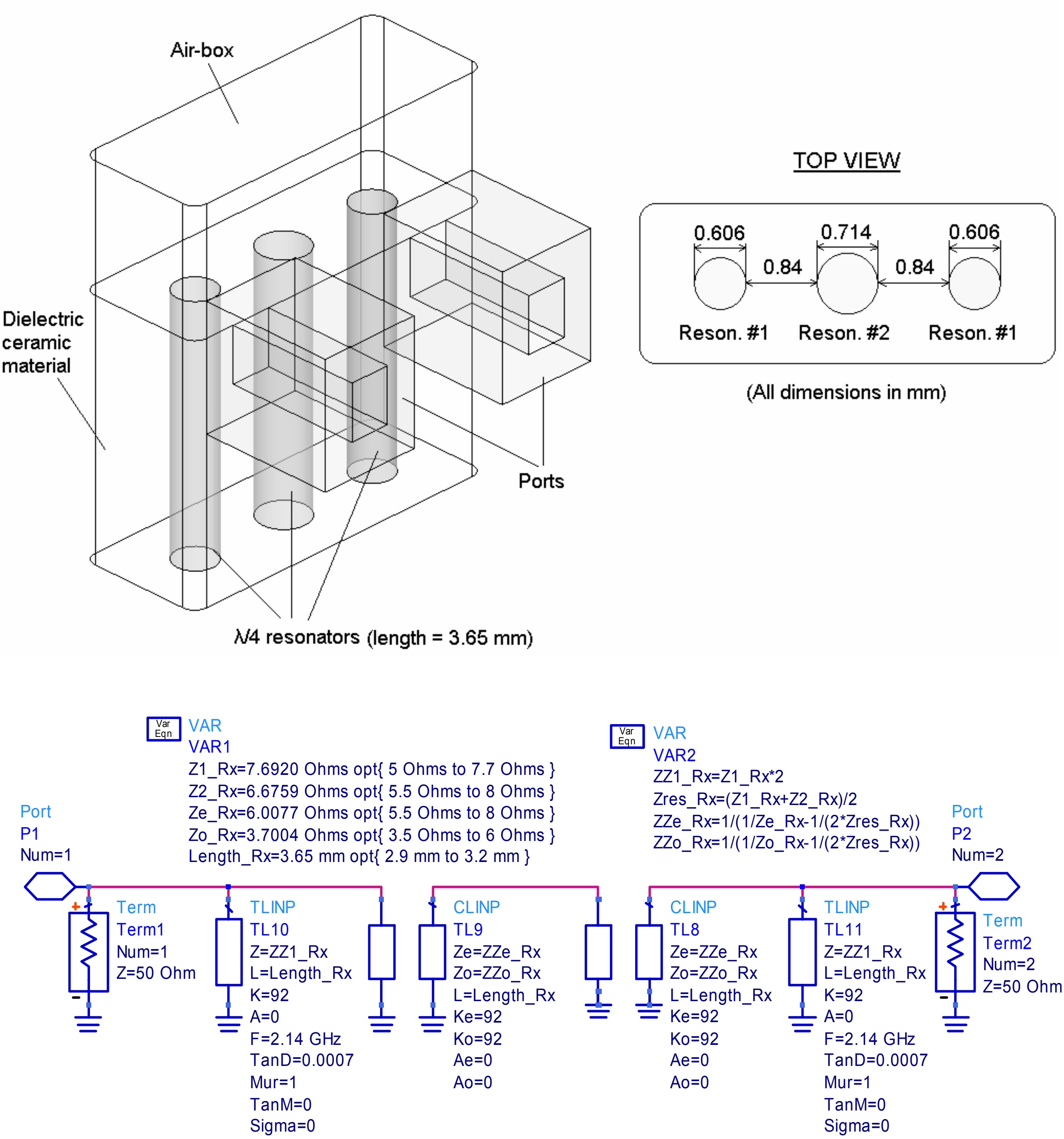

Fig. 5: Resonator-only 3-D structure (top) and resonator-only equivalent circuit (bottom).

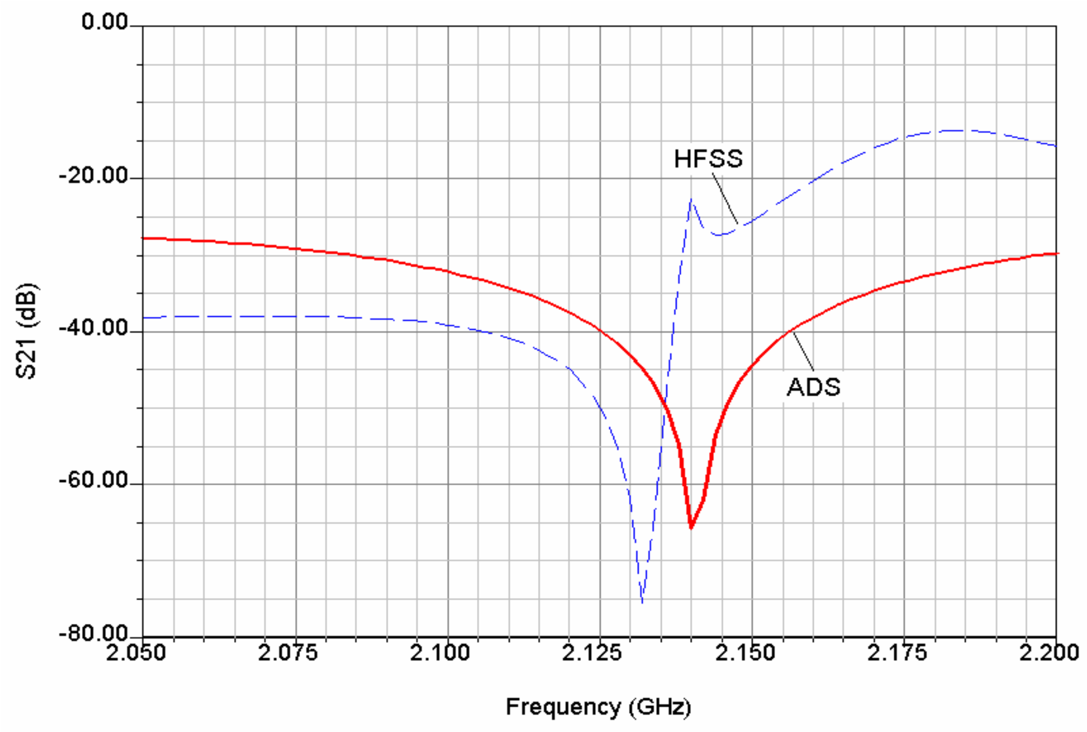

Figure 6: Frequency response of the resonator-only structure (dashed line) compared to the equivalent circuit resonator-only response (solid line).

2.3 Addition of coupling cups and extraction of new equivalent circuit

Coupling cups required by the structural specifications of Figure 1 are added in the resonator-only structure of Figure 5. A new equivalent circuit corresponding to this structure is extracted using electromagnetic CAD techniques [2]. The coupling cups are represented in the equivalent circuit using a network of lumped capacitors to embody the stray field capacitances between the cups and the cup capacitances to ground. Their purpose is to provide a design-tuning element to tailor the response to the specifications. The extracted component values of the new circuit are presented in Table II. The response of the new equivalent circuit is compared to the response of the 3-D model (Figure 7).

Table II: Extracted component values for the equivalent circuit topology of Figure 2.

Lumped component	Extracted component value
C_1 (pF)	1.5430
C_2 (pF)	0.7330
C_{port} (pF)	0.4960
C_{12} (pF)	0.9860
Z_{01} (Ohms)	7.6920
Z_{02} (Ohms)	6.6759
Z_{0e} (Ohms)	6.0077
Z_{0o} (Ohms)	3.7004

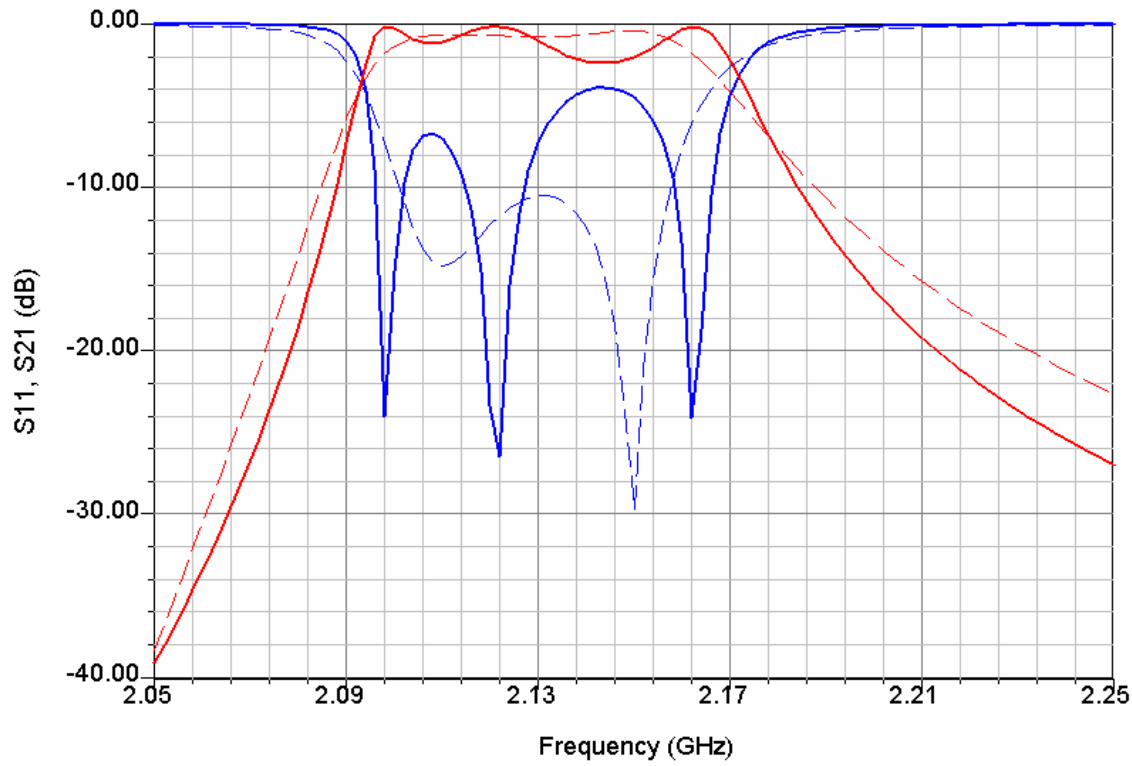

Figure 7: Frequency responses of the extracted equivalent circuit (solid line) and the 3-D structural model (dashed line).

2.4 Extracted equivalent circuit optimisation

The extracted equivalent circuit is subsequently optimised using ADS in order to achieve the desired UMTS receiving band response. During optimisation the resonator impedance values are fixed since these were modelled accurately in section 2.2. The optimised component values are given in Table III and the optimised response is illustrated in fig. 8.

Table III: Initial and optimised equivalent circuit component values.

Lumped component	**Initial component value**	**Optimised component value**
Cup #1 capacitance to ground, $\mathbf{C_1}$ **(pF)**	1.5430	1.6996
Cup #2 capacitance to ground, $\mathbf{C_2}$ **(pF)**	0.7330	0.8480
Capacitance to port, $\mathbf{C_{port}}$ **(pF)**	0.4960	0.5911
Coupling capacitance, $\mathbf{C_{12}}$ **(pF)**	0.9860	1.0163

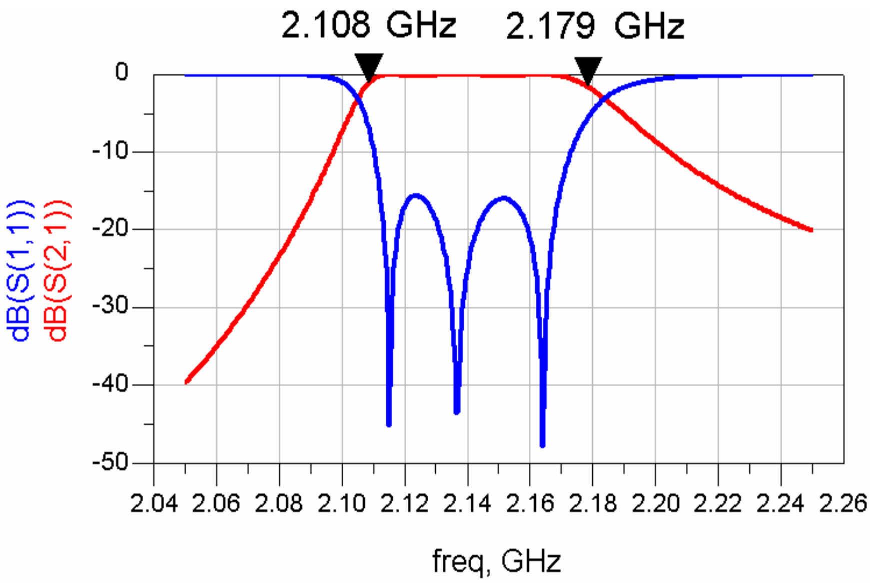

Figure 8: Optimised equivalent circuit frequency response.

2.5 Dimensional changes and structural optimisation

The optimised component values in Table III indicate that some dimensional changes in the cup shape are necessary in the structure in order to achieve the desired frequency response. For this purpose the structural optimiser featured in HFSS was employed. The optimiser allows the user to designate geometrical and material parameters as candidate variables for optimisation. The parameters set for optimisation are illustrated in Figure 9. The optimised structural response is presented in Figure 10 and the optimised dimensions are presented in Table IV. The filter's final block dimensions are 3.62×4.8×1.88 mm.

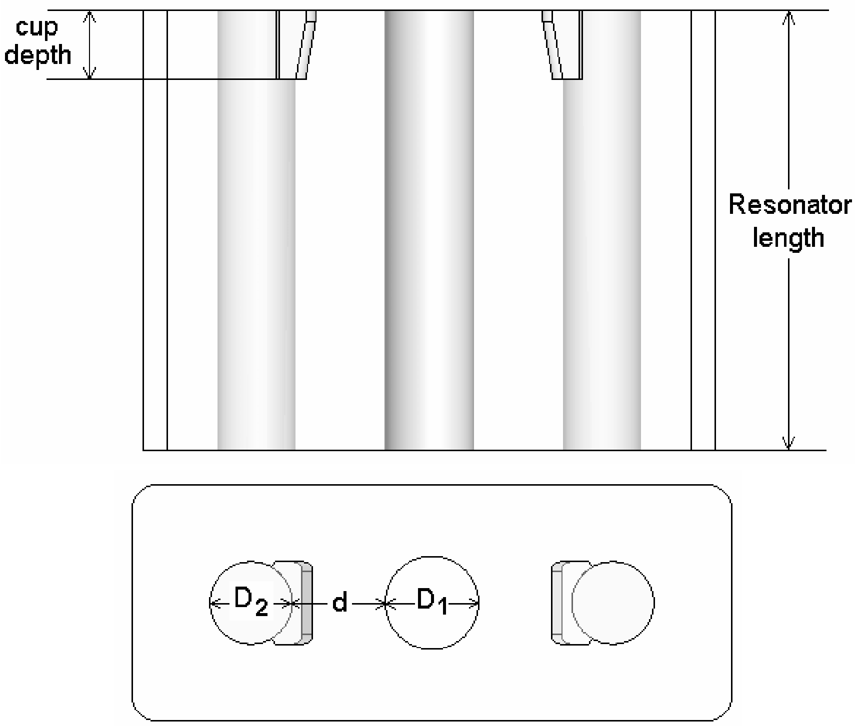

Figure 9: Parameterised dimensions used for structural optimisation.

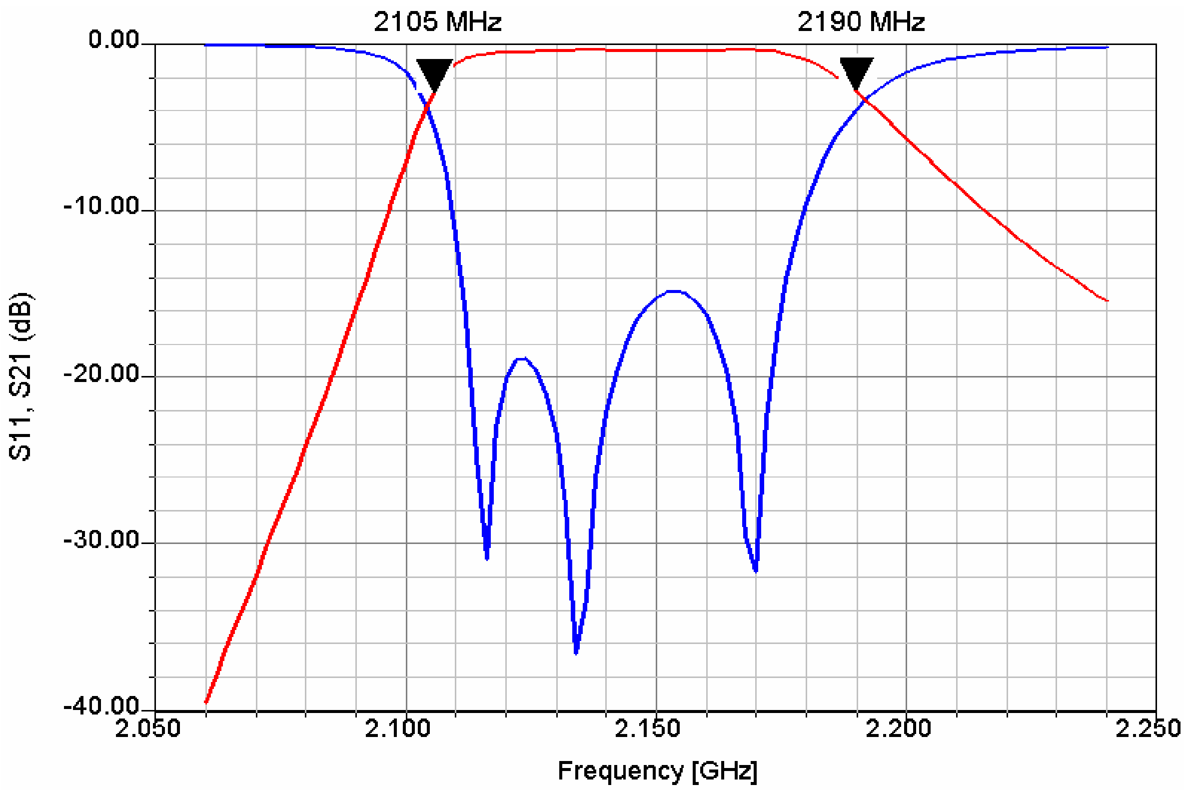

Figure 10: UMTS filter structural response.

Table IV: Initial and optimised 3-D structural component values.

Optimisation parameter	Initial value	Optimised value
Cup depth (mm)	0.670	0.570
Resonator #1 diameter (mm)	0.606	0.656
Resonator #2 diameter (mm)	0.714	0.744
Distance between adjacent resonators (mm)	0.840	0.743
Resonator length (mm)	3.650	3.618

3. Conclusions

In this work a UMTS filter was designed using an equivalent circuit topology. The equivalent circuit provides an accurate model for monoblock structures and can be easily optimised and tuned. It also provides useful information for the structural changes needed to be made in order to meet the desired specifications. As a whole the use of an equivalent circuit model combined with circuit and structural optimisers provides a very useful approach for the design of monoblock filters.

4. Acknowledgements

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5. References

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