2008 IEEE MTT-S International Microwave Workshop Series on Art of Miniaturizing RF and Microwave Passive Components

Dielectric Resonator Filters for UMTS Systems

(Invited paper)

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Abstract- **Dielectric Resonator filters can provide high selectivity and low insertion loss similar to cavity filters but with smaller size and weight. They have long been used in satellite communication and more recently became of significant interest in terrestrial applications. In this paper the design of two UMTS dielectric filters (transmit and receive) have been presented.**

I. Introduction

Telecommunication systems would have not existed without microwave filters. While the best performance in terms of insertion loss and skirt steepness is achieved with cavity filters, coaxial filters are most typically used in wireless communication due to low cost. In satellite communication, where size, weight and performance are of importance, dielectric resonator filters were utilised with notable advanced design research described in [1-3]. Application of dielectric resonators (DR) filters has enabled significant cost savings and system miniaturisation, the latter illustrated in Fig 1.

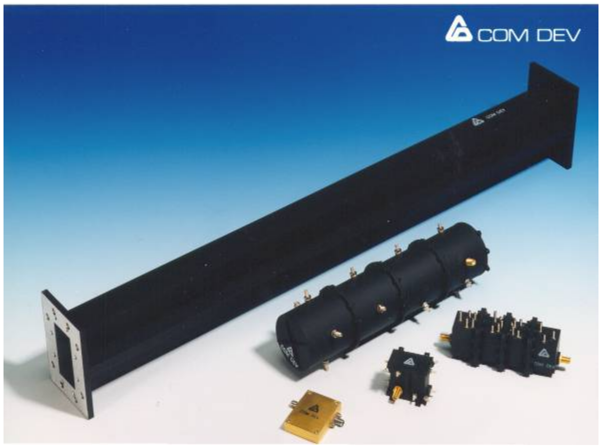


Fig. 1. Filter size comparison: (a) cavity, (b) dielectric, (c) dielectric in superconducting enclosure and (d) microstrip superconducting filters for satellite communication after [2]

The smallest filter size and weight can be achieved using High Temperature Superconducting (HTS) planar filters [8, 13]. Despite the requirement for a cryogenic cooling system, significant savings in weight can be achieved while ensuring excellent performance. Additionally, Low Noise Amplifiers (LNA) cooled to cryogenic temperatures together with HTS filters have a lower thermal noise figure. However this solution is considered expensive due to cost of cryocoolers and therefore is mostly used under conditions where there is the presence of strong interference close to the pass band.

Almost the same high selectivity and low insertion loss as exhibited by HTS filters can also be achieved by DR filters operating at room temperature. This solution can provide similar performance with only slightly reduced coverage and capacity, at a significantly reduced cost compared to HTS filters. At more than two times smaller than cavity filters, DR filters may be preferred by the industry. In the last few years several interesting DR filters for wireless base stations have been published [eg 4-7, 10-12] including multimode mode DR filters and monolithic DR filters. It is predicted that dielectric resonator filters will have a significant share of the overall wireless base station filter market [6].

A design of transmit and receive single mode dielectric resonator filters for applications in UMTS communication systems in Europe and obtained characteristics are described in this paper.

II. Development of UMTS Dielectric Resonator Filters

There is high interest in Europe in UMTS wireless systems. The UMTS receive band channels are in the frequency range: 1920 MHz – 1980 MHz, while the transmit band frequencies are: 2110 MHz – 2170 MHz.

The design of **Receive UMTS filter** has been based on a dielectric puck from Kyocera of frequency 1920 MHz. To facilitate the manufacturing and easy coupling of resonators a quadratic design was selected. Resonant frequency tuning of the dielectric resonator was achieved by using a metallic plunger of slightly larger radius than the dielectric puck inserted into the roof of the cavity (Fig. 2, right). To minimise the conductive losses and maintain acceptable costs the housing and tuning elements were made from silver coated brass.

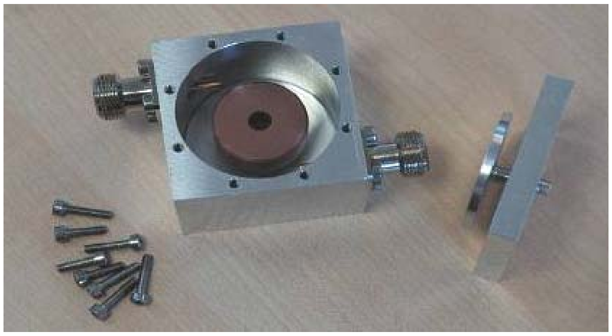


Fig. 2. Dielectric Resonator in a cylindrical cavity

To ensure accurate design of the DR filters it was necessary to measure precisely the relative permittivity, as ε_r stated by the manufacturer was given as between 39 and 42, and unloaded quality factor, as approximately 50,000. The measurements of the *Q*-factor were performed in a cavity of four times larger diameter than that of the dielectric puck to minimise the influence of the housing. The measured value of Q_0 of the dielectric puck was 28800 at 1.8888GHz and the relative permittivity (ε_r) was obtained as 40.42.

Measurements of the unloaded *Q*-factor of the manufactured DR as it was tuned to the UMTS range are presented in Fig. 3. The results show that the DR maintains a respectable Q_0 of over 19000 at 1.98GHz which confirmed that this resonator was suitable for the entire UMTS receive range.

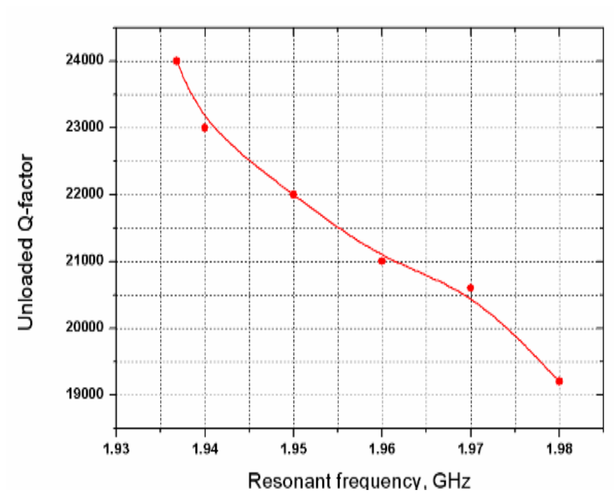


Fig. 3. Measured Qo-factor vs. Resonant Frequency of dielectric puck of base frequency 1.9GHz

In order to be applied to the European **UMTS Rx systems** the DR filter required an operational bandwidth of 9.15 MHz (to cover two neighbouring channels owned by one service provider) and an insertion loss of less than 1 dB. The attenuation was to be at least -40 dB, 1 MHz from the passband edge, in order to achieve the 30 dB isolation required between UMTS channels. As an initial design, a four pole filter has been chosen which provided insertion loss (IL) of max 0.2 dB and S11 better than -20 dB in the passband.

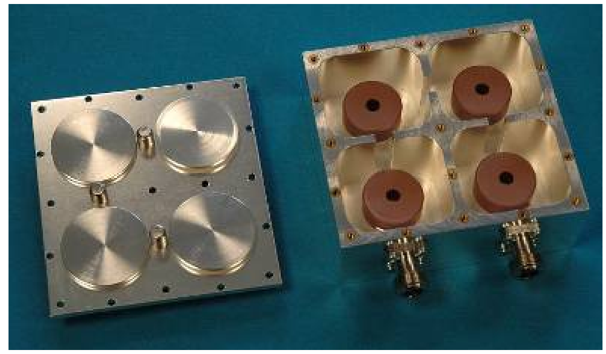


Fig. 4. Manufactured 4 Pole Rx DR Filter (Note coupling windows between resonators and corresponding adjustable trim rods and tuning plates in the lid)

Using a Chebyshev filter characteristic it was possible to achieve a selectivity of 17.9 dB/MHz with an 8-pole, 23.3 dB/MHz with a 9-pole and 28.6dB/MHz with a 10-pole filter design, none of which satisfied the requirements. A design with more than 10 poles would be physically large and parasitic losses in the resonators would have made it difficult to achieve the desired 1 dB insertion loss. Introducing a cross coupling to create a quasi-elliptic filter meant that an 8-pole filter with 1 cross-coupling produced a roll-off of 34.9 dB/MHz, 2 cross-couplings produced 56 dB/MHz, however, this solution was not selected due to the undesirable requirement to cross-couple using the port resonators in order to create the quadruplets.

The final filter design was selected to have nine poles with one cross-coupling to give a 51.1 dB/MHz roll-off (Fig.5).

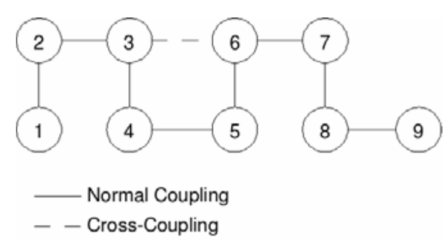


Fig. 5. Nine Pole Filter Design with one Cross-Couplings

The 9-pole DR filter CAD drawing is shown in Fig. 6 and its computed S_{21} characteristic in Fig. 7.

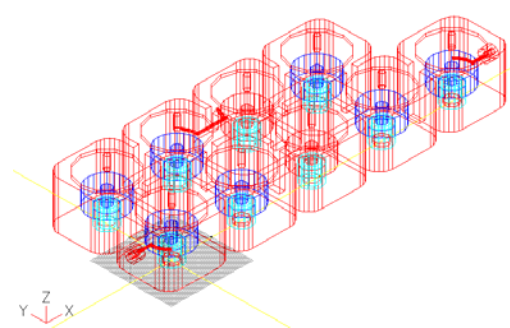


Fig. 6. CAD drawing of 9 Pole DR Rx Filter as seen in HFSS (square cavity with rounded corners)

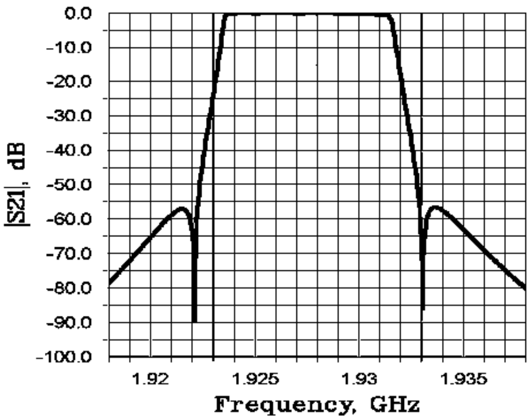
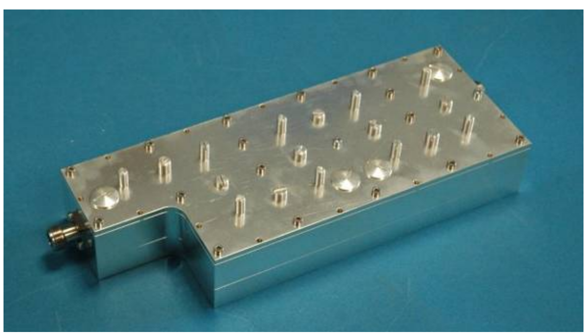


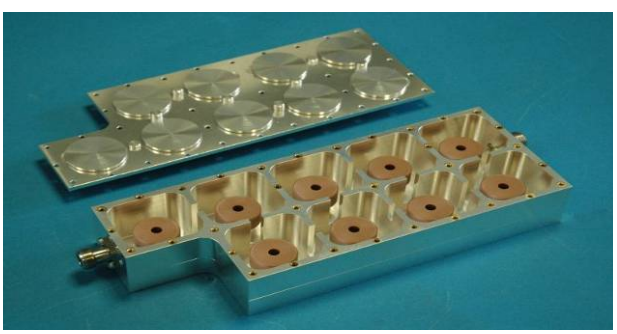
Fig.7. Simulated Response of 9 Pole Rx DR Filter

The design had the couplings pre-tuned to the lowest frequency channel in the UMTS receive band, tuning to higher frequency channels was achieved using tuning plungers. Port coupling was achieved through antennas which followed the curve of the puck.

Because the cavity was simulated as made of an ideal conductor (to reduce simulation times) the unloaded *Q*-factor of the manufactured filter was significantly lower than the simulated Q_0 values. The losses in the simulation are due to the loss tangent of the measured dielectric puck only. Despite this simplification to the simulation the measured and simulated responses look very similar, but the measured one has a lower Q_0.



(a) Complete package



(b) Open lid

Fig. 8. Photograph of the 9-Pole DR Filter for the UMTS Uplink

The UMTS transmit band frequencies (2110 – 2170 MHz) were achieved using a set of dielectric pucks of base frequency of 2.1 GHz. The manufactured transmit filter (Fig. 8) was tuned to give a Chebyshev response which exhibited approximately 20 dB matching across the passband.

The prototype filter characteristic centred at 2115 MHz with a 6 MHz bandwidth and better than 21dB matching across the passband (Fig. 9). The IL of 1dB and the steepness in the transition region suggested the *Q*-factor higher than 20000. The bandwidth was less than the target of 10 MHz due to the coupling being too weak between the resonators. This allowed for the opportunity to test a more exciting prospect of using this filter for channel selection of 5 MHz bandwidth, and not just for operator selection (10 MHz bandwidth).

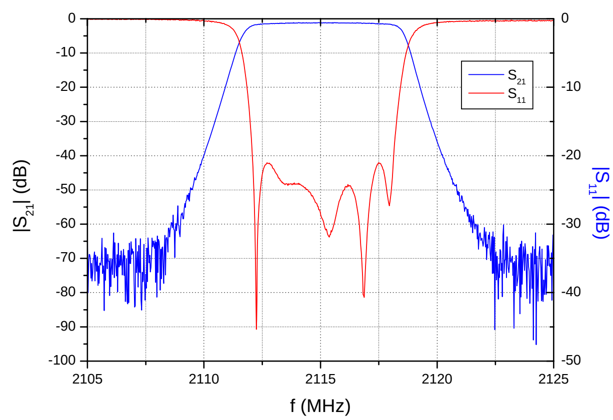


Fig.9. Measured Chebyshev Response of 9-Pole UMTS Tx DR Filter with 6 MHz Bandwidth

The cross coupling was added to the housing to obtain a quasi-elliptic response shown in Fig. 10. With the cross couplings this filter characteristic exhibited better than 21 dB matching across a 5 MHz passband with a centre frequency of 2116 MHz. The measured skirt steepness of the filter was 40 dB/MHz with two symmetric transmission zeros at the band edges.

Compared to the calculated ideal response of a Chebyshev filter described by Matthaei, Young and Jones [14] it is estimated that the insertion loss of 1.076 dB and rounding of the passband equates to a Q-factor of approximately 25000.

III. Conclusions

The designed Rx and Tx Dielectric Filters operating in the 1920MHz – 1980MHz and 2110MHz – 2170MHz bands respectively proved to be suitable for applications to UMTS cellular systems. The main benefits of DR filters employed in UMTS (and other types) wireless base stations include higher Q-factor than coaxial filters and smaller size than the cavity filters. An approximate comparison of the Q-factor and size of various types of filters is given below.

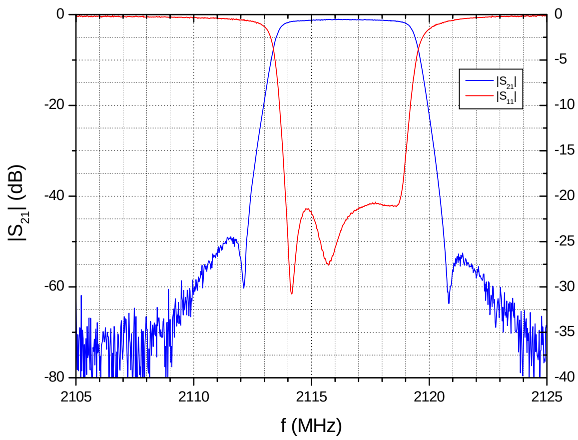


Fig.10 Measured Quasi-Elliptic Response of the 9-Pole Tx DR Filter with 5MHz Bandwidth

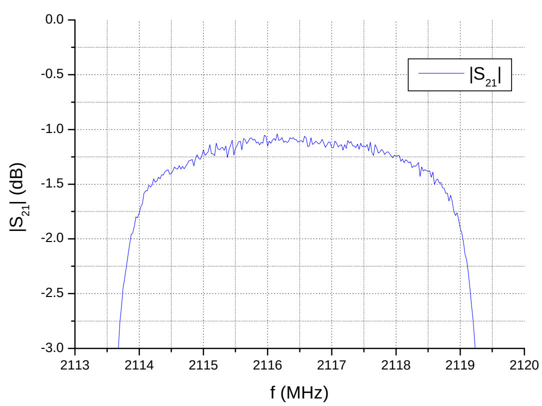


Fig. 11 Close-up of Fig. 10: Measured Quasi-Elliptic Response in the Passband of the 9-Pole Tx DR Filter

TABLE I

Resonator	Typical Q_0	Size
MTS DR	25,000	
Pill Box Copper Cavity	5,000 to 10,000	4 time DR
Coaxial (copper)	5,000	Similar to DR
Combline (copper)	4,000	Similar to DR

Further miniaturisation can be provided by dual triple and quadriple mode Dielectric Resonators Filters which may give extra 30% and 50% volume savings respectively [6]. A combination of coaxial and Dielectric filter approach can reduce spurious performance. However triple and quadruple mode DRs require use of irregular shape DRs, what will increase manufacturing costs [6].

Ultimate miniaturisation of DR filters can be achieved by developing monolithic technologies. Using a low cost monolithic dielectric resonator [7] the Q-factor of 5000 at 4 GHz was achieved for a four pole filter with a dielectric substrate of ε_r of 38.6 and un-plated copper housing. This type of monolithic DRs on high-K substrates will results in filters of very small size and excellent properties.

Dielectric Resonators can also allow for miniaturisation of duplexers. A DR duplexer that exhibits lower loss and higher selectivity than the cavity duplexers currently used on the main antennas of conventional cellular base stations can offer noticeable performance improvements. There are two possible applications of such a duplexer: the first to be used as an economical solution to replace the conventional cavity filters. The second possibility is to use the DR duplexer in combination with a Cryogenic Superconducting Filter and a Low Noise Amplifier to provide the ultimate in front end performance [13]. The latter also allows for a significant miniaturisation of base station electronics.

Additionally the DR filters can also be applied to an advanced Multi-operator Combiner (MoC). This would utilise the increased selection and low losses of DR filters and HTS filters to produce a greatly improved system when compared to currently available MoCs [13].

ACKNOWLEDGMENT

This work was funded by Cryoelectra GmbH with PhD scholarships from James Cook University and Massey University. The authors acknowledge the effort and work
done by the Cryoelectra team.

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