# Technical Notes

## A High-Temperature Superconducting Notch Filter to Suppress Cellular-Band Interference in Radiotelescopes

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***Abstract*—An experimental high-temperature superconducting four-pole filter for mitigation of the IMT 2000 cellular band in radiotelescopes is presented. The filter uses a novel capacitive cross-coupling to achieve a quasi-elliptic response. Composite right/left-handed (CRLH) zeroth-order resonators are used to avoid harmonic generation throughout the UHF and L-bands.**

***Index Terms*—High-temperature superconductors, microwave filters, radioastronomy, radio frequency interference.**

### I. Introduction

The UHF and L-bands (300 MHz–1800 MHz) are widely used for radioastronomical observations, either for single-dish or interferometric arrays (such as VLBI). However, these bands face a rising problem due to human-generated radio frequency interference. A good alternative to cancel out unwanted frequencies is to insert high-temperature superconducting (HTS) notch filters in the radiotelescope front-end [1]. In [2], a Chebyshev notch filter is proposed to attenuate the digital television band (1.389 GHz–1399 GHz), and, in [3], a quasi-elliptic bandpass filter is proposed to suppress the 900-MHz cellular band.

Nevertheless, for systems where bandwidths in excess of 100% are needed, the usage of conventional resonators causes harmonic interference. One way to suppress harmonic resonances is to use Defected Ground Plane technique [4], [5]. However, multilayer circuits are required which are difficult to fabricate. Another methodology is to use composite right/left-handed (CRLH) zeroth-order resonators that do not produce harmonic resonances [6].

In this work, an HTS notch filter to suppress the IMT-2000 cellular band (806 MHz–960 MHz) for radiotelescope front-ends is presented. Due to the utilization of CRLH zeroth-order resonators, no harmonic resonances appear throughout the whole UHF and L-bands. In addition, the CRLH resonators use a capacitive patch to avoid via-grounding for the inductor [7]. Moreover, a novel capacitive cross-coupling is inserted between the first and last resonators to achieve a quasi-elliptic response. Simulation and experimental results are presented.

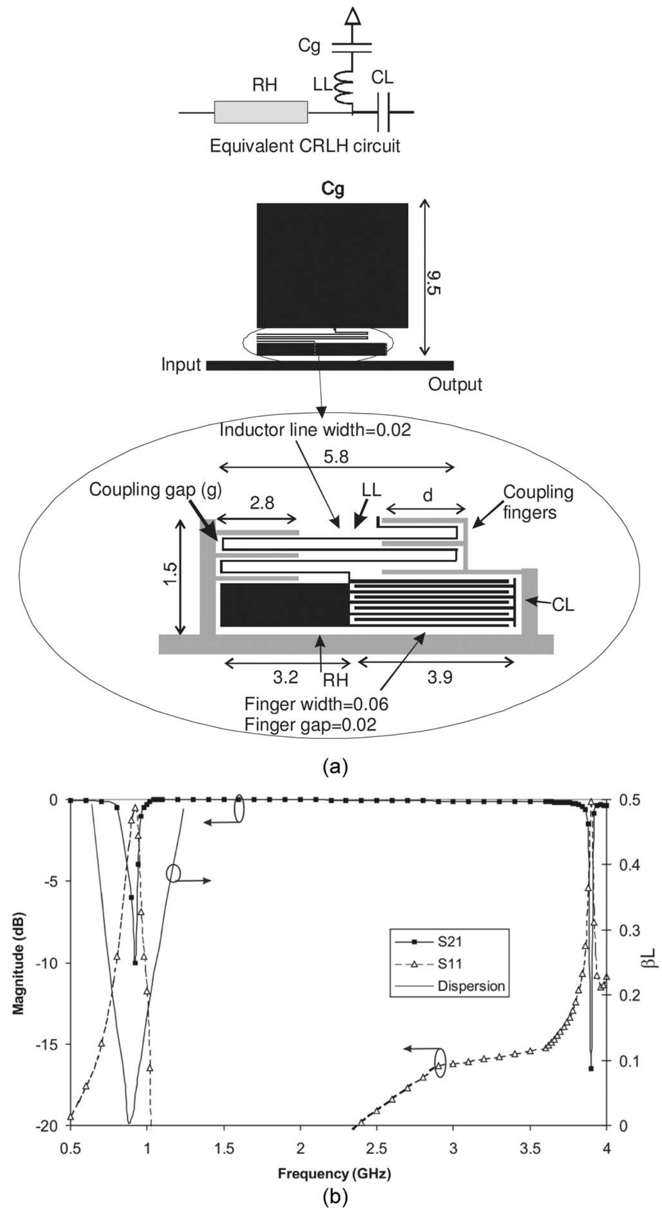


Fig. 1. (a) Single CRLH resonator coupled to a transmission line (all dimensions in millimeters). (b) Dispersion diagram of CRLH cell with S11 and S21 responses.

### II. Design Procedure

Fig. 1(a) shows the layout of the CRLH zeroth-order resonator. The circuit was implemented on MgO substrate with a permittivity $\varepsilon_r = 9.6$ and height $h = 0.5$ mm. The left hand (LH) section is realized with a series interdigital capacitor $(CL)$ and a shunt inductor $(LL)$. $LL$ is grounded by means of a capacitive patch $(Cg)$ [7]. The right hand (RH) is achieved with a $10^\circ$ conventional transmission line together with the parasitic shunt capacitance and series inductance of the interdigital capacitor. The cell is balanced to 40 Ω. The final dimensions of the cell were optimized in [8] and are shown in Fig. 1(a).

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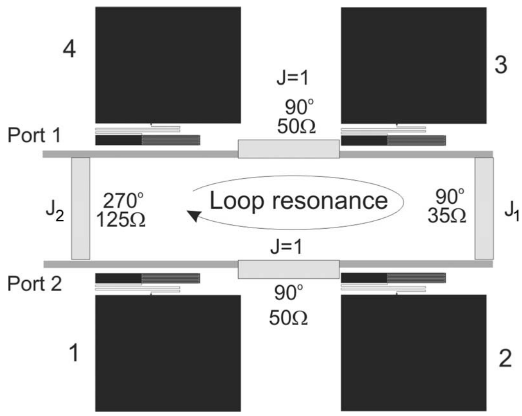


Fig. 2. Schematic of four-pole quasi-elliptic notch filter.

The dispersion diagram of the CRLH is shown in Fig. 1(b). As it can be seen, $\beta = 0$ at the desired frequency (883 MHz). Moreover, the resonator was weakly coupled to the transmission line [Fig. 1(a)] and its simulated response is shown in Fig. 1(b). The resonant frequency is 883 MHz, with the first spurious resonance at 3.7 GHz, which is well above the required spurious free band (300 MHz–1800 MHz).

The bandstop design follows the quasi-elliptic low-pass prototype synthesis and transformation technique shown in [9]. A four-pole synchronously tuned quasi-elliptic configuration should have coupling between adjacent resonators (1–2, 2–3, and 3–4) as well as from 1 to 4 as shown in Fig. 2. The couplings between 1–2 and 3–4 are achieved with admittance inverters of value $J = 1$. Resonators 2–3 are connected using an admittance inverter $J_1 \neq 1$ and non-adjacent resonators 1–4 are coupled with $J_2 \neq 1$. Furthermore, $J_1$ and $J_2$ must have opposite signs.

The low-pass element values for the quasi-elliptic configuration can be obtained from (1) to (4) [9]

$$g_1(\Omega_a) = 1.22 - 0.35\Omega_a + 0.18\Omega_a^2 - 0.04\Omega_a^3 + 0.004\Omega_a^4 \quad (1)$$

$$g_2(\Omega_a) = 7.22 - 9.48\Omega_a + 5.89\Omega_a^2 - 1.65\Omega_a^3 + 0.177\Omega_a^4 \quad (2)$$

$$J_1(\Omega_a) = -4.30 - 6.26\Omega_a - 3.67\Omega_a^2 + 0.99\Omega_a^3 - 0.103\Omega_a^4 \quad (3)$$

$$J_2(\Omega_a) = 8.17 - 11.36\Omega_a + 6.96\Omega_a^2 - 1.92\Omega_a^3 + 0.206\Omega_a^4 \quad (4)$$

where $\Omega_a$ represents the normalized frequency location of the transmission zero. If we take $\Omega_a = 1.38$ the respective values are $g_0 = g_5 = 1$, $g_1 = g_4 = 0.9781$, $g_2 = g_3 = 1.6328$, $J_1 = -0.4114$ and $J_2 = 1.3969$. Subsequently, a low-pass to bandreject transformation is implemented, in which the $J = 1$ inverters become quarter wavelength transmission lines (TL) with a 50 Ω impedance. $J_1$ is realized as a quarter wavelength TL with an impedance of 35 Ω and $J_2$ has a an impedance of 125 Ω with an electrical length of 270°. This latter assures opposite signs between $J_1$ and $J_2$. The normalized reactance slope parameter can be defined from the low-pass element values as described in (5) [9]

$$\frac{x_i}{Z_0} = \frac{1}{g_i \Delta FBW} \quad (5)$$

where $g_i$ corresponds to the quasi-elliptic low pass element values, $Z_0$ is the characteristic impedance, and $\Delta FBW$ is the 3-dB fractional bandwidth of the filter.

For resonators 1 and 4 the reactance slope parameter is $x_1/Z_0 = x_4/Z_0 = 5.57$, whereas for resonators 2 and 3 it is $x_2/Z_0 = x_3/Z_0 = 3.33$. To relate these values to the physical layout, the circuit of Fig. 1(a) was simulated in [8] and (5) was used to compute the reactance slope parameters for different coupling values. As it can be seen from Fig. 1(a), coupling fingers were added to the TL to obtain the required coupling value. The coupling gap ($g$) was left constant to 0.02 mm and the length of the coupling fingers ($d$) was varied. The final values are $d = 3.3$ mm for resonators 2 and 3 and $d = 0.1$ mm for resonators 1 and 4.

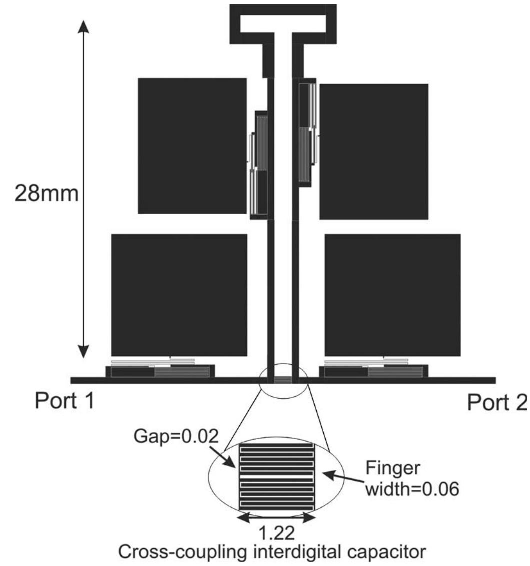


Fig. 3. Final filter layout. All dimensions in millimeters.

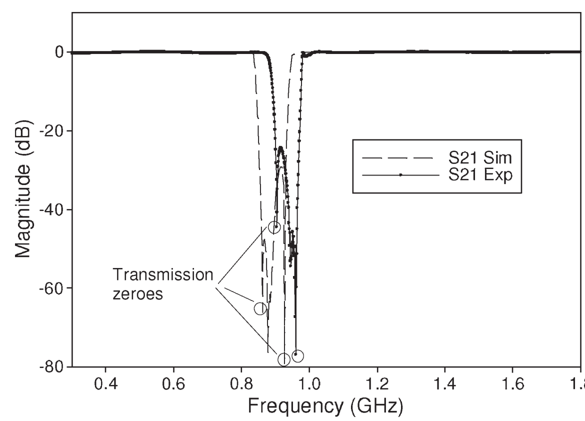


Fig. 4. Simulated and experimental insertion losses.

The final filter was simulated in [8] and it was observed that several spurious resonances appeared at 0.7 GHz, 1.4 GHz, and 2.1 GHz. These are caused by a loop resonance formed by the interconnecting lines of the resonators as shown in Fig. 2. For this reason, the cross-coupling line between resonators 1 and 4 was replaced by a capacitive element ($C$) which breaks apart the resonant loop without disturbing the negative coupling characteristic of $J_2$. The capacitance value ($C$) should be calculated from $C = 1/j\varpi Z_C$ where $Z_c = 125$ Ω. Which results in $C = 1.4$ pF at the center frequency. To obtain the layout of the interdigital capacitor the formulas presented in [10] were used, and then the structured was fine tuned in [8]. The final filter layout is depicted in Fig. 3. The filter size is only 28 × 28 mm. The filter was fabricated on MgO substrate coated with YBCO on both sides and gold contact pads were used to connect to the housing K connectors.

## III. Experimental and Simulation Results

The simulated and experimental insertion losses are shown in Fig. 4. As it is clear from the figure, no spurious resonances are excited throughout the band of interest (0.3 GHz to 1.8 GHz). The in band

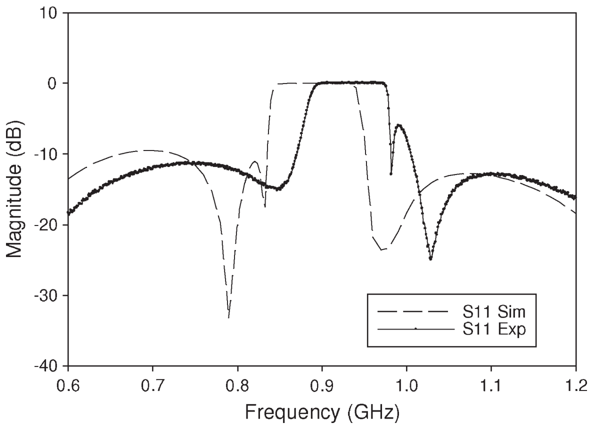


Fig. 5. Simulated and experimental return losses.

rejection is better than 20 dB for the experiment and 25 dB for the simulation. It is also observed that the transmission zeroes are clearly formed at 904 MHz and 960 MHz for the experiment, and 862 MHz and 927 MHz for the simulation. There was a 30-MHz frequency shift due to material tolerances such as height of the substrate and relative permittivity, as well as fabrication inaccuracies. For the return loss shown in Fig. 5, the simulation shows out of band rejection better than 10 dB and for the experiment it is better than 7 dB.

## IV. Conclusion

A novel quasi elliptic notch filter has been proposed for radioastronomy. The filter rejects the IMT 2000 cellular band and has no spurious harmonics throughout the spectrum of interest from 0.3 GHz to 1.8 GHz. The latter is due to the use of CRLH cells plus a novel capacitive cross coupling between first and fourth resonators. Good agreement between simulation and experiment was shown.

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