UNIVERSITÀ DEGLI STUDI FIRENZE

DINFO
Dipartimento di Ingegneria dell'informazione

Multi-stage pass-band filter with ultra-compact spiral-based elements

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OUTLINE

- **Introduction and motivation**
- **Spiral element design**
- **Multistage design**
- **Simulations and measurements**
- **Conclusions**

Introduction and motivation

Filtering at microwave frequencies is a task usually accomplished via transmission line and distributed parameter approach.

Several techniques are available, from the most basic stepped impedance to more complex ones.

Passband filters whit steep descent out of band are not easy to synthesize and usually requires several coupled resonating elements, of the size of about half a wavelength

This makes filters cumbersome, even if bent resonators are exploited, like in the hairpin setup.

Introduction and motivation

Recently an innovative pass-band filter based on a disk with a pair of spiral slot etched has been presented in literature [1].

Such a filter has an out-of-band steep descent of the transmission coefficient but a relatively poor insertion loss for frequencies far from the pass-band.

In this contribution a multi-stage set up of these filters is proposed to ameliorate the rejected bands insertion loss. The proposed filter is still extremely compact if compared to filters with similar behavior.

A. Cidronali, G. Collodi, S. Maddio, G. Pelosi, S. Selleri, "Quasi-elliptical band-pass filters based on compact spiral resonators for C-band applications," *Microw. Opt. Technol. Lett.*, 61, 2019, pp. 1983-1987.

Introduction and motivation

Design is done in C-band, which is extensively used for many applications: 802.11xy WiFi from 4.9 to 5.7 GHz, DSRC at 5.8 GHz, WAVE protocol at 5.9 GHz, Mid-Band 5G, just to name few.

Yet, the sheer number of services provided on different protocols exploiting narrowly separated bands can cause severe interference problems, especially in vehicular applications [1].

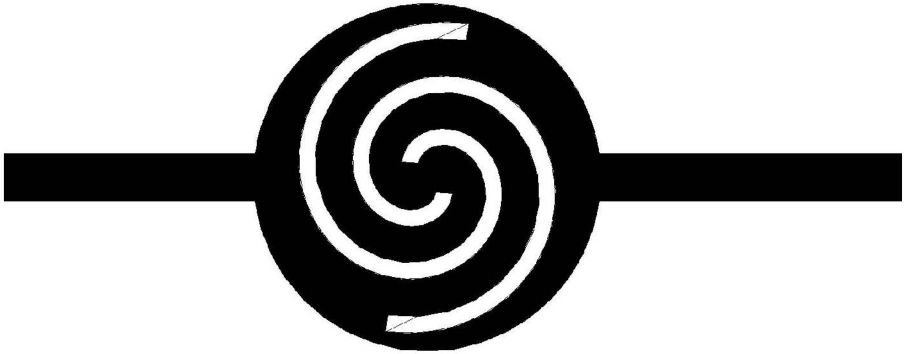
Several solutions are possible, ranging from active ones, such as leakage cancellers to passive ones, such as electronic band-gap material-enhanced structures, or even sharp roll-off filters which, as already stated, are bulky

G. Naik, J. Liu, J.M.J.Park, "Coexistence of dedicated short range communications (DSRC) and Wi-Fi: Implications to Wi-Fi performance," *INFOCOM 2017-IEEE Conference on Computer Communications*, 2017, pp. 1-9.

Introduction and motivation

The basic idea is hence to resort to the spiral filter presented in [1], with its sharp notches, and to enhance its poor performances far from passband by cascading two or three spirals.

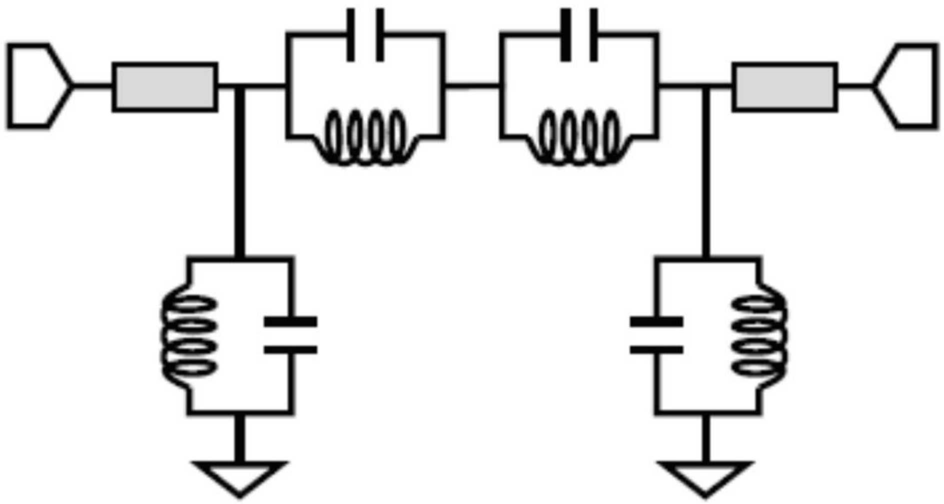
The single spiral filter layout is



A. Cidronali, G. Collodi, S. Maddio, G. Pelosi, S. Selleri, "Quasi-elliptical band-pass filters based on compact spiral resonators for C-band applications," *Microw. Opt. Technol. Lett.*, 61, 2019, pp. 1983-1987.

Introduction and motivation

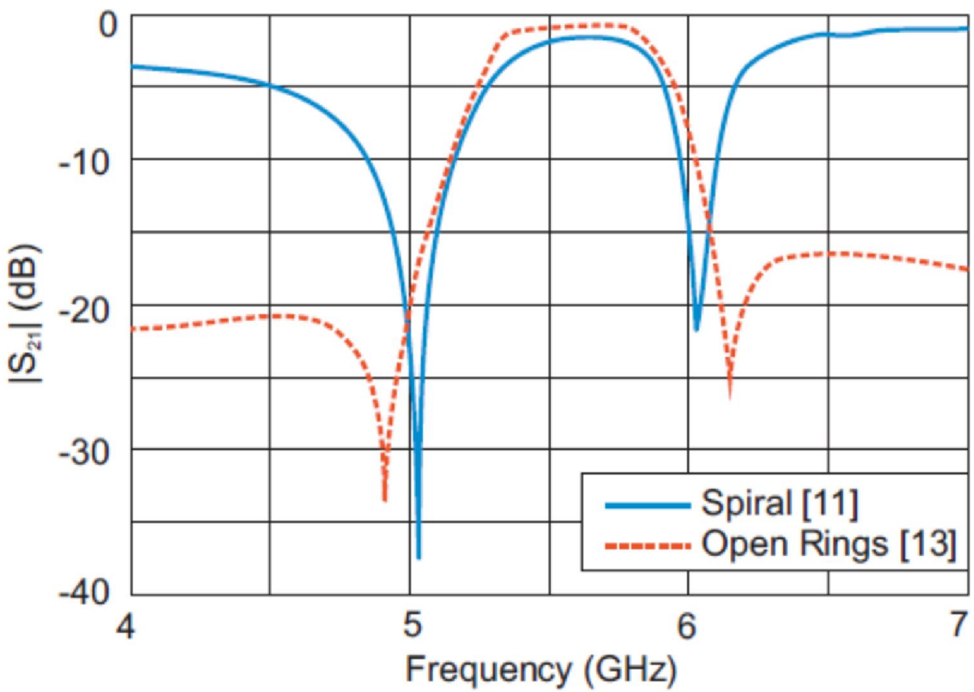
This design proved to have a quasi-elliptic behavior with an equivalent circuit which can be imagined as composed by four parallel resonators.

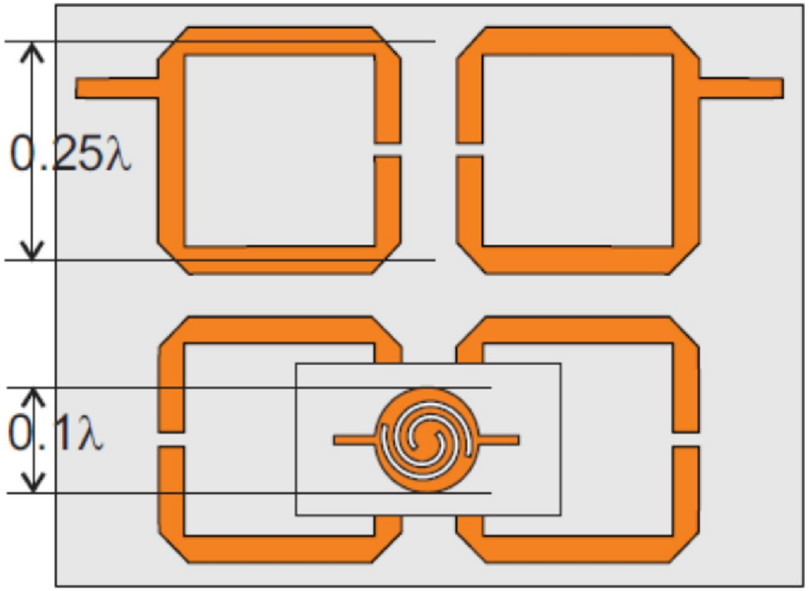


[. Cidronali, G. Collodi, S. Maddio, G. Pelosi, S. Selleri, “Quasi-elliptical band-pass filters based on compact spiral resonators for C-band applications,” *Microw. Opt. Technol. Lett.*, 61, 2019, pp. 1983-1987.

Spiral Element Design

The proposed single spiral has a frequency response very similar to an elliptic 4-split rings miscrostrip filter, yet it occupies about 1/25 of the area.



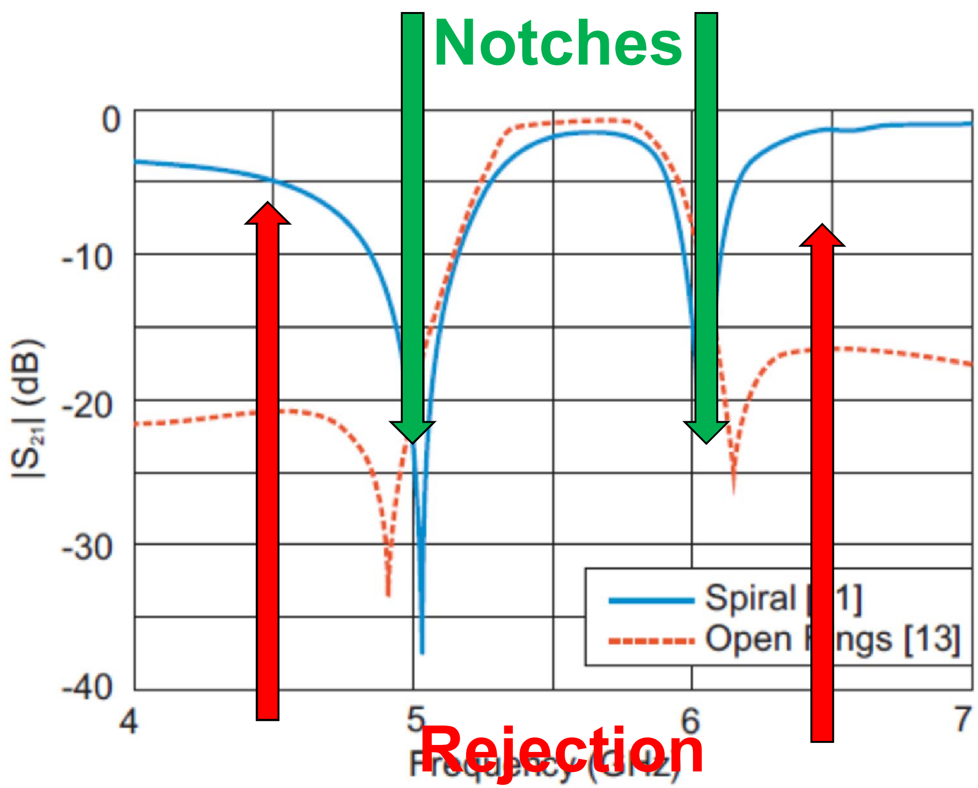


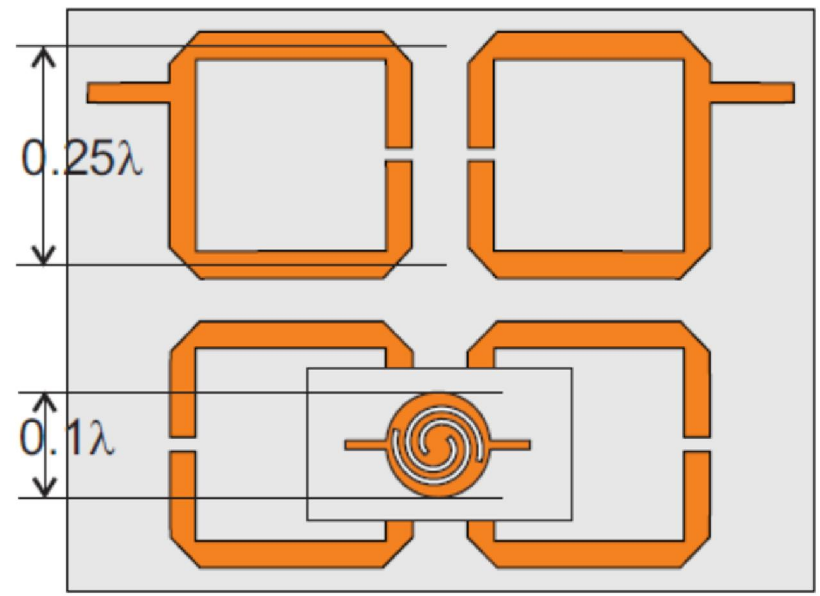
[11] A. Cidronali, G. Collodi, S. Maddio, G. Pelosi, S. Selleri, "Quasi-elliptical band-pass filters based on compact spiral resonators for C-band applications," *Microw. Opt. Technol. Lett.*, 61, 2019, pp. 1983-1987.

[13] J. Shivhare and B. Reddy, "Design and development of a single fold hairpin line microstrip bandpass filter at 3250 mhz for s-band communication systems," *Int. J. Advances Engin. Technol.*, 8, 3, 2015, p. 337.

Spiral Element Design

While notches are Ok, out-band rejection is poor!





[11] A. Cidronali, G. Collodi, S. Maddio, G. Pelosi, S. Selleri, "Quasi-elliptical band-pass filters based on compact spiral resonators for C-band applications," *Microw. Opt. Technol. Lett.*, 61, 2019, pp. 1983-1987.

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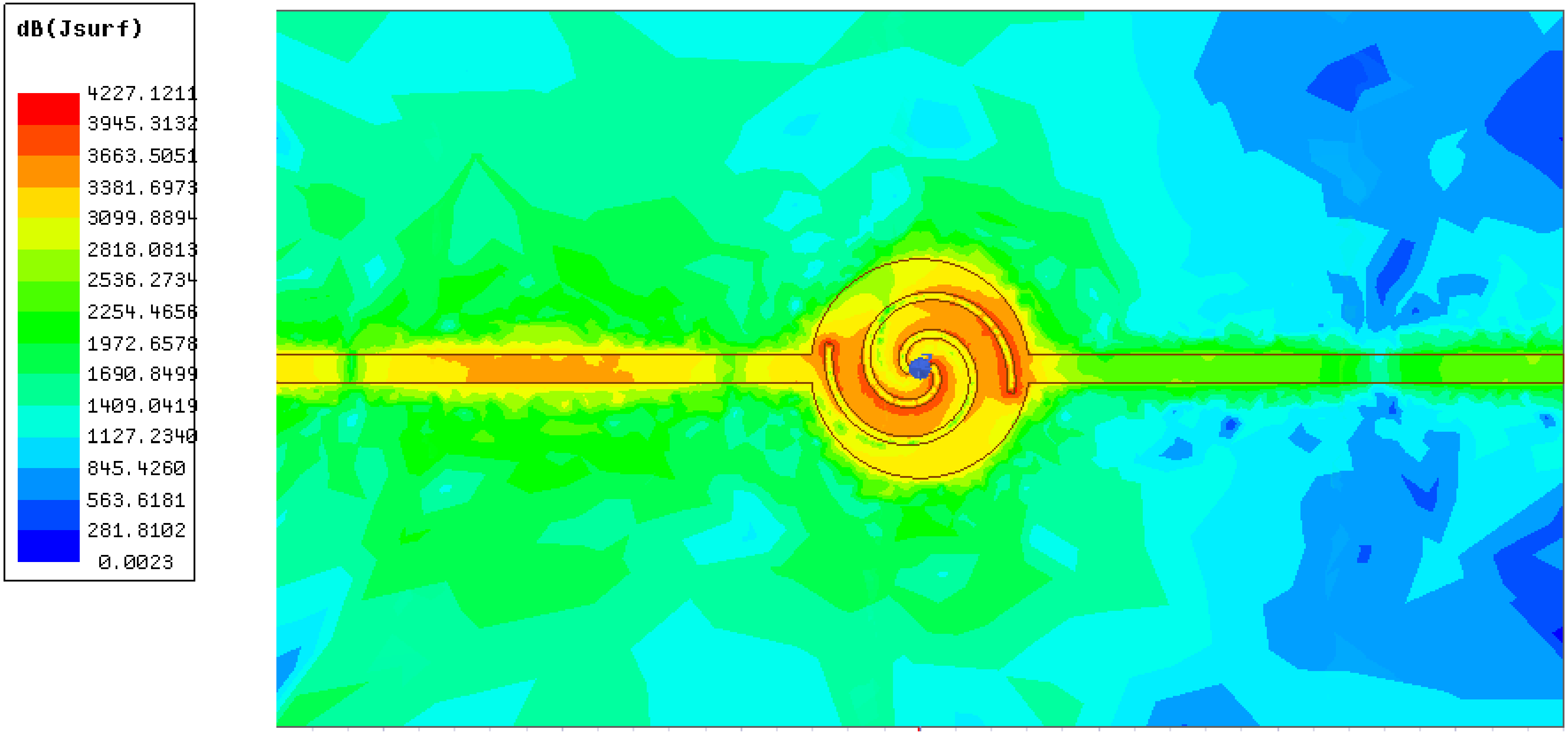
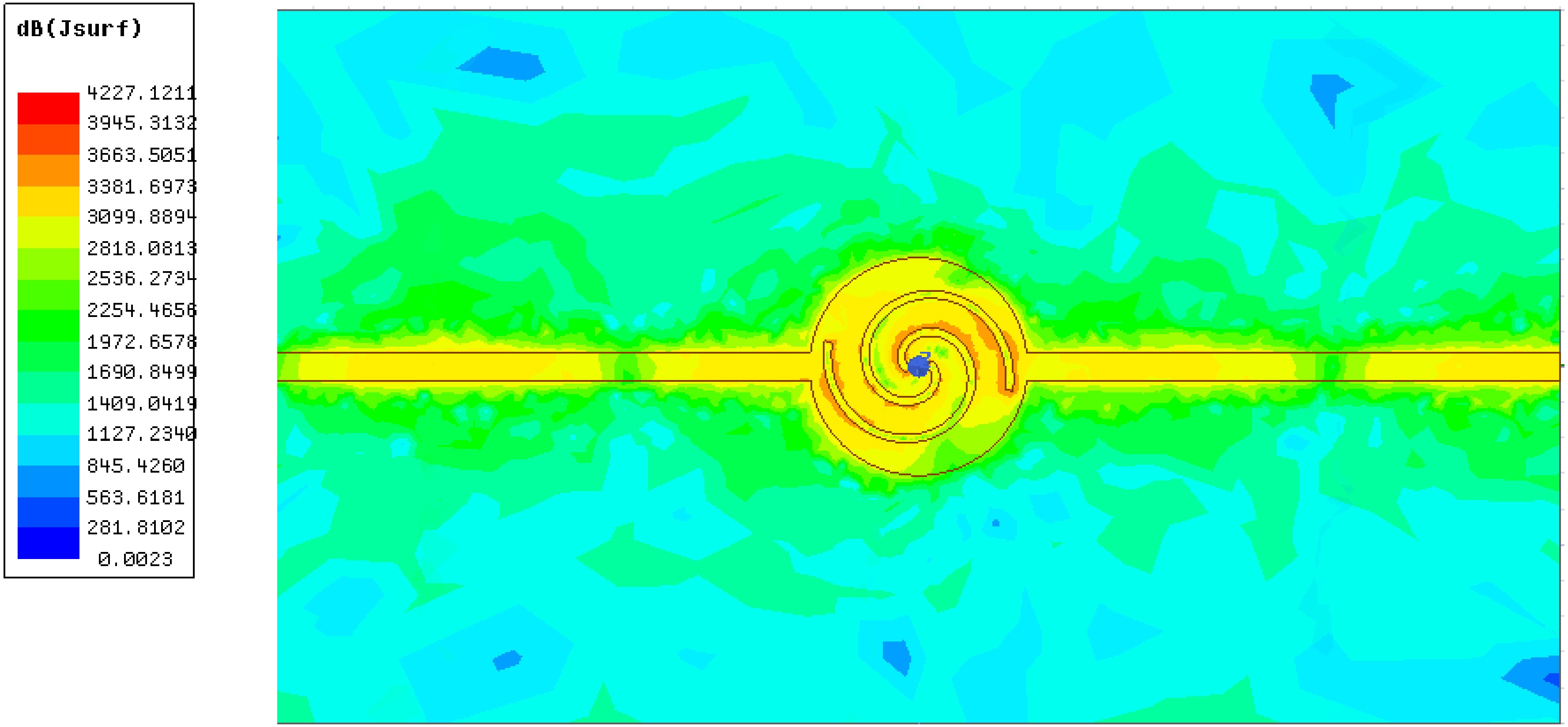
Spiral Element Design

freq = 5.05 GHz – first zero



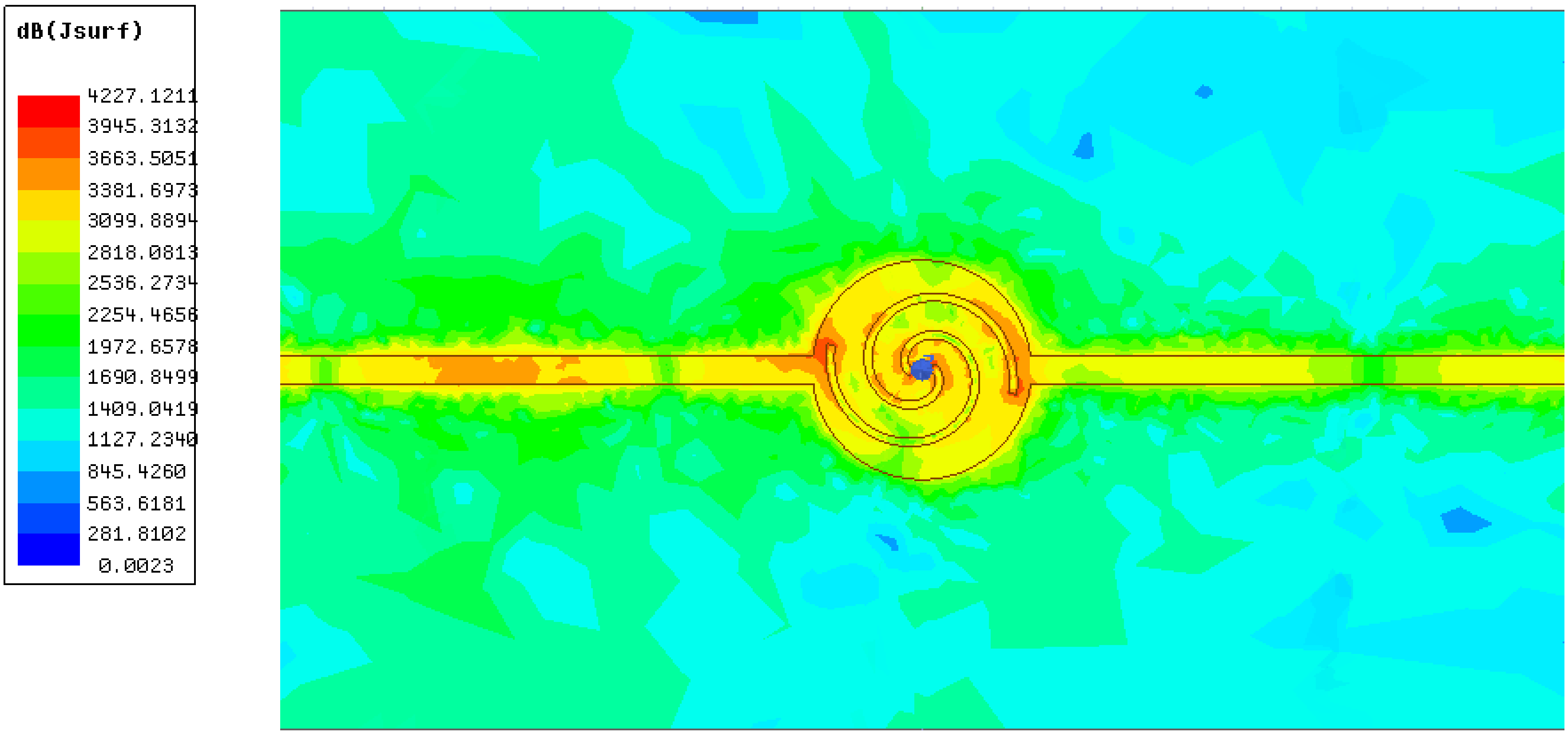
Spiral Element Design

freq = 5.70 GHz maximum transmission



Spiral Element Design

freq = 6.05 GHz – second zero



Spiral Element Design

How does this work?

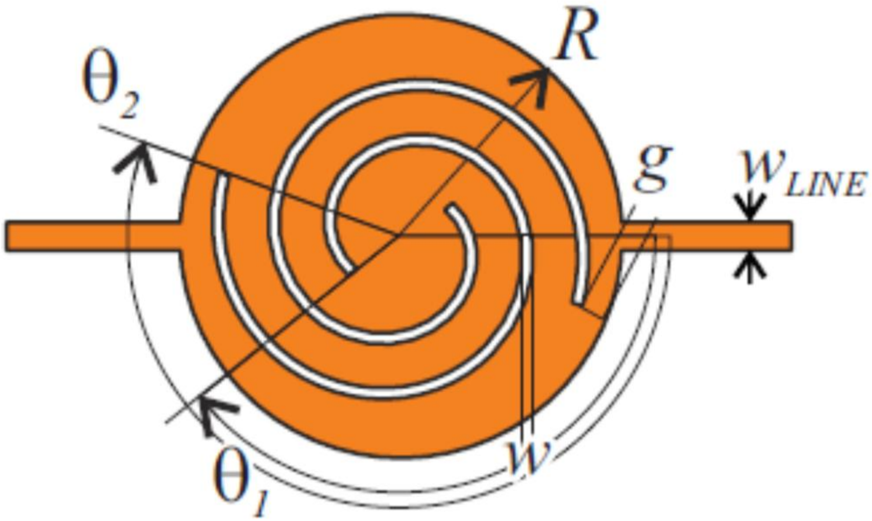
As it can be inferred from the previous fieldmaps, the spiral cuts effectively creates a pair of coupled winding lines.

Strong coupling between these lines, as highlighted by higher field levels at 5.05 and 6.05 GHz, causes signal rejection, the higher fields at 5.05GHz showing higher coupling and a deeper transmission zero.

At centerband coupling is very limited and signal passes through, as shown in the second fieldmap.

Spiral Element Design

How does we control coupling?

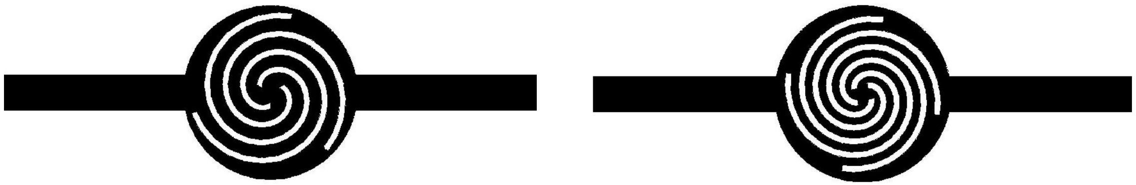


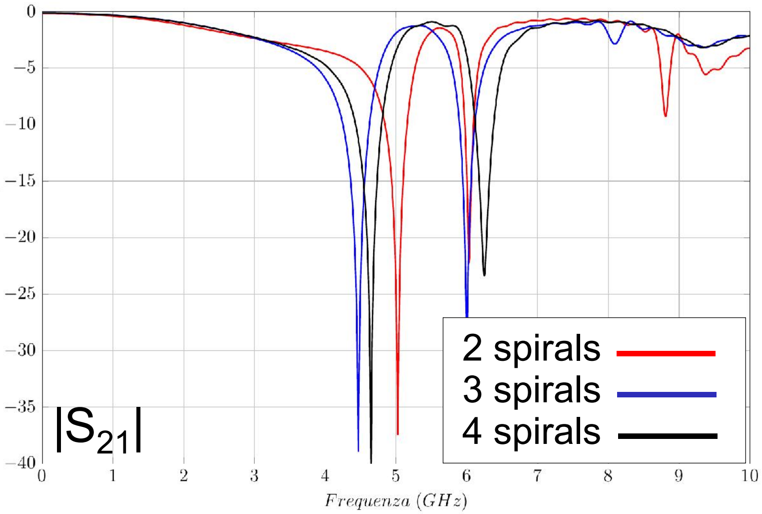
The filter geometry is shown here. The inner Archimedean spiral is defined by

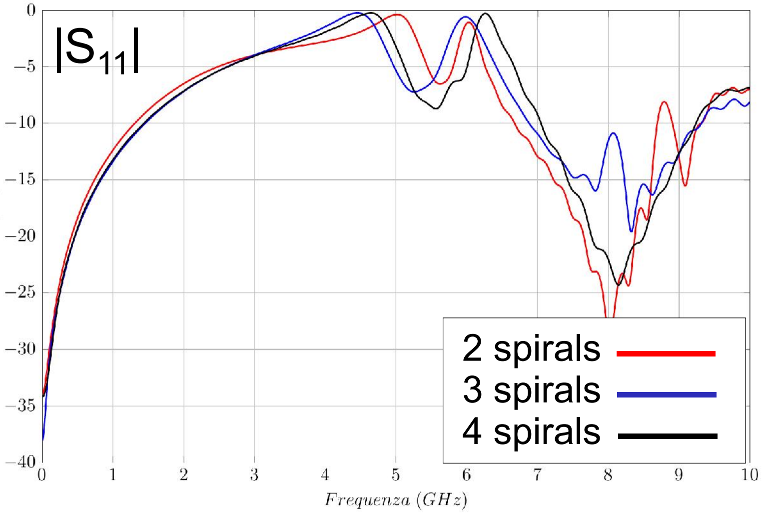
$$\rho(\theta) = (R - g)(1 - \alpha\theta) \quad \text{with} \quad \theta \in [\theta_1, \theta_2]$$

And the second one is obtained by 180° rotation. These geometrical parameters controls coupling

Spiral Element Design



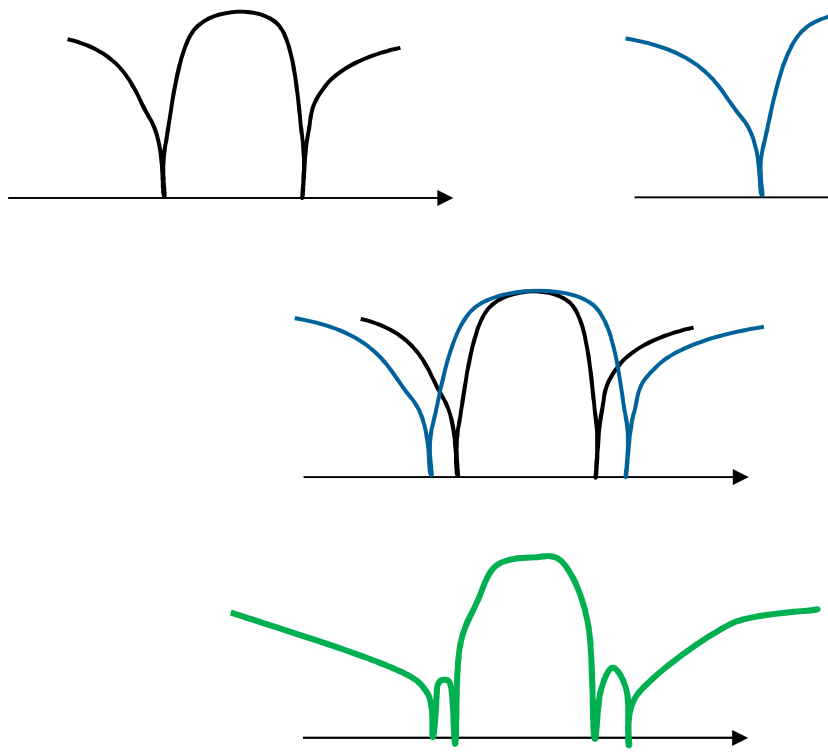




Augmenting to tree or four spiral slots does not carry substantial benefits.

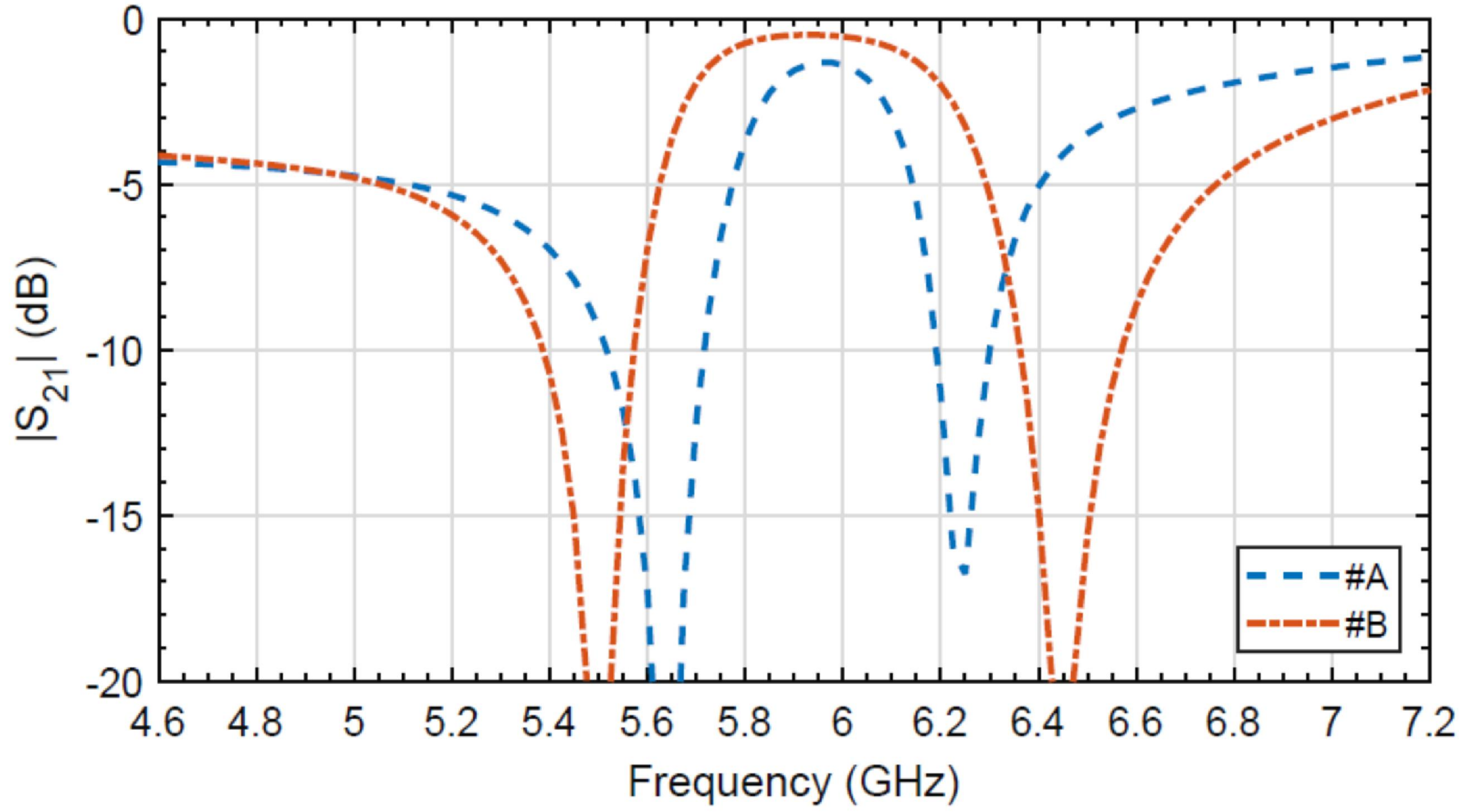
Multistage Design

The DC cannot be eliminated due to the electrical continuity of the conductor. But out-of-band rejection can be ameliorated by cascading two or more spiral filters with notches with increased distance.



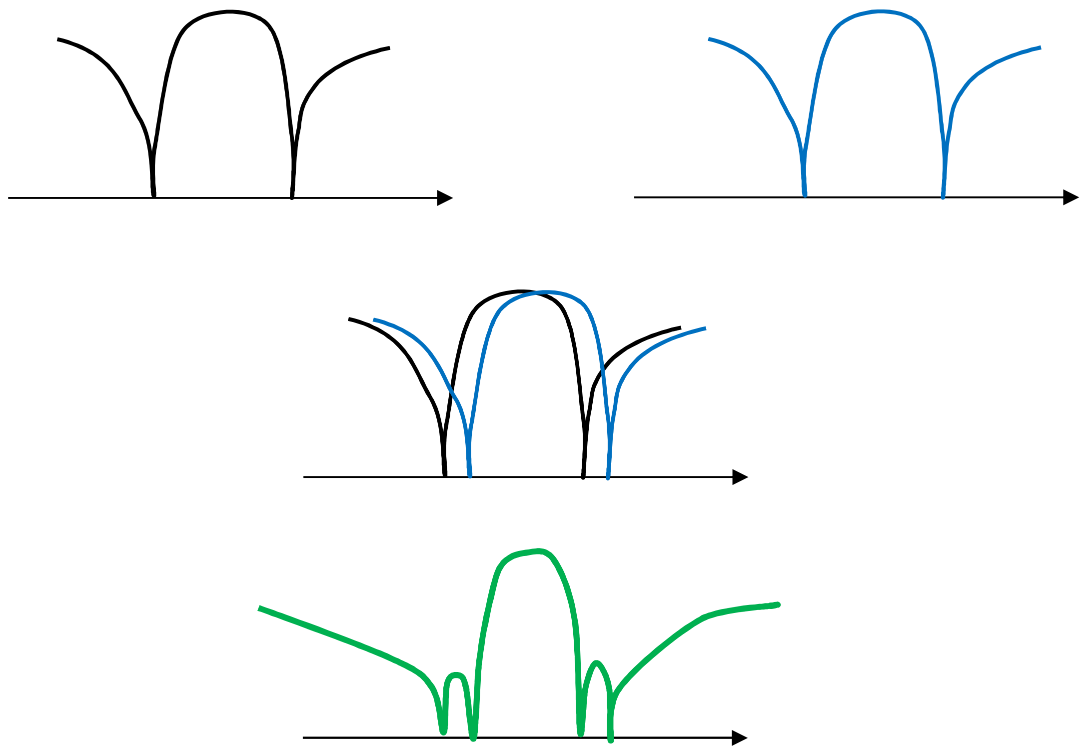
Multistage Design

For example:



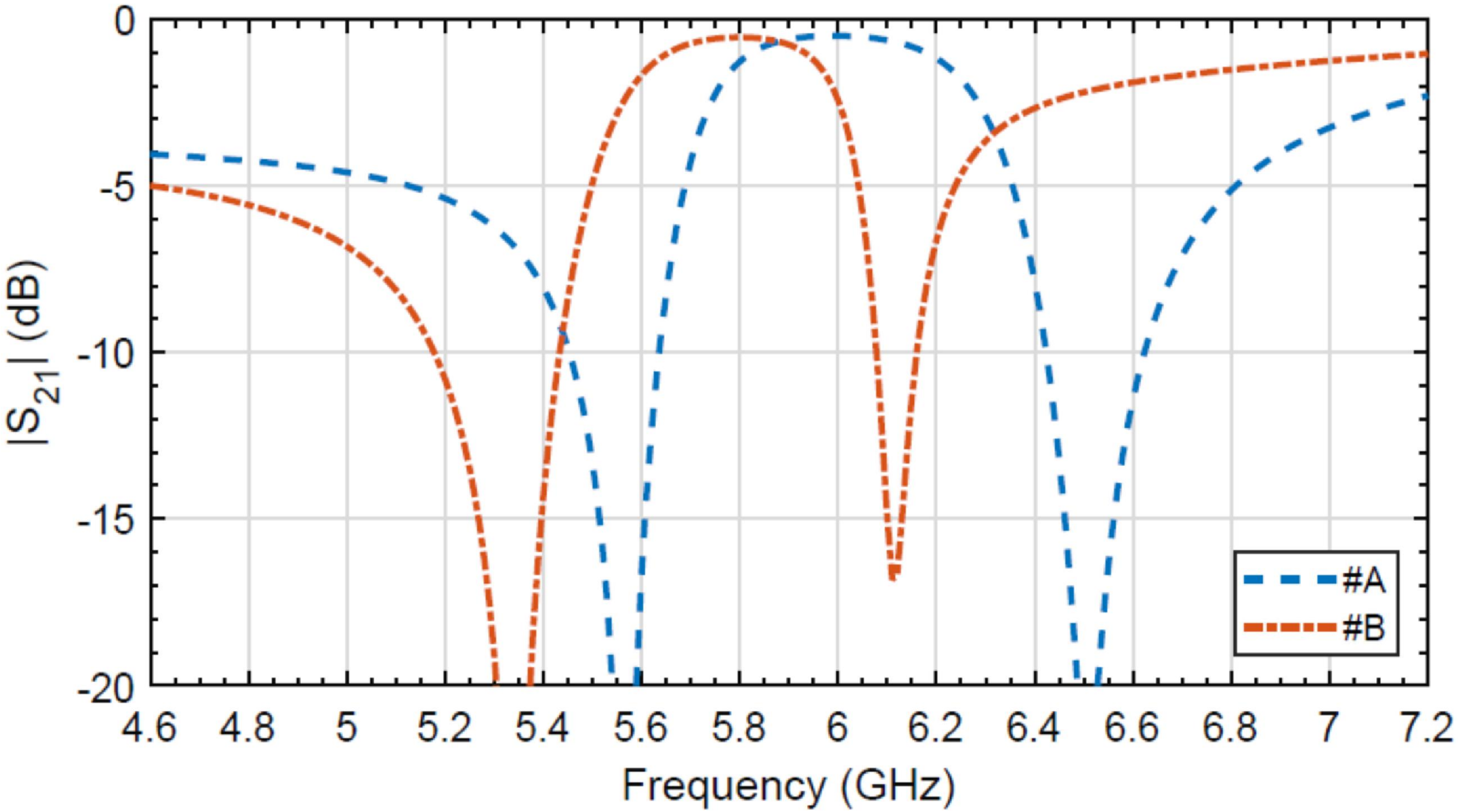
Multistage Design

Or either with filters with similar band but different center frequency



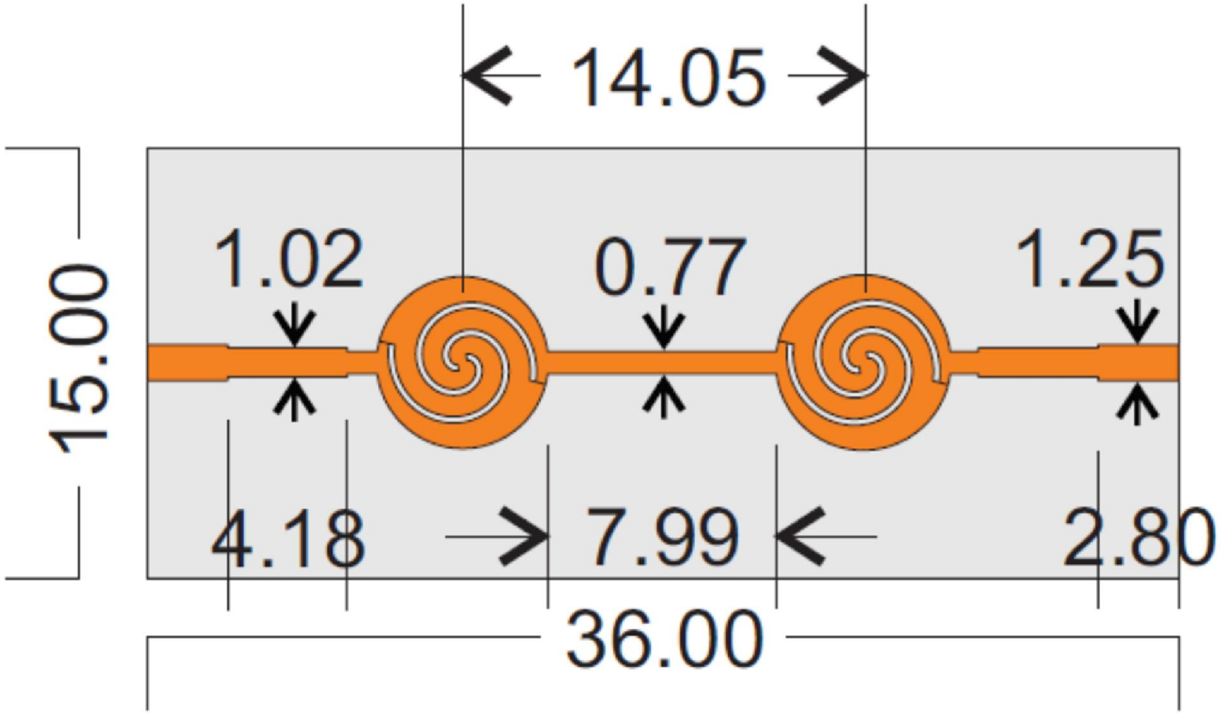
Multistage Design

For example:



Multistage Design

The final layout proposed here is (dimensions in mm, angles in degrees):

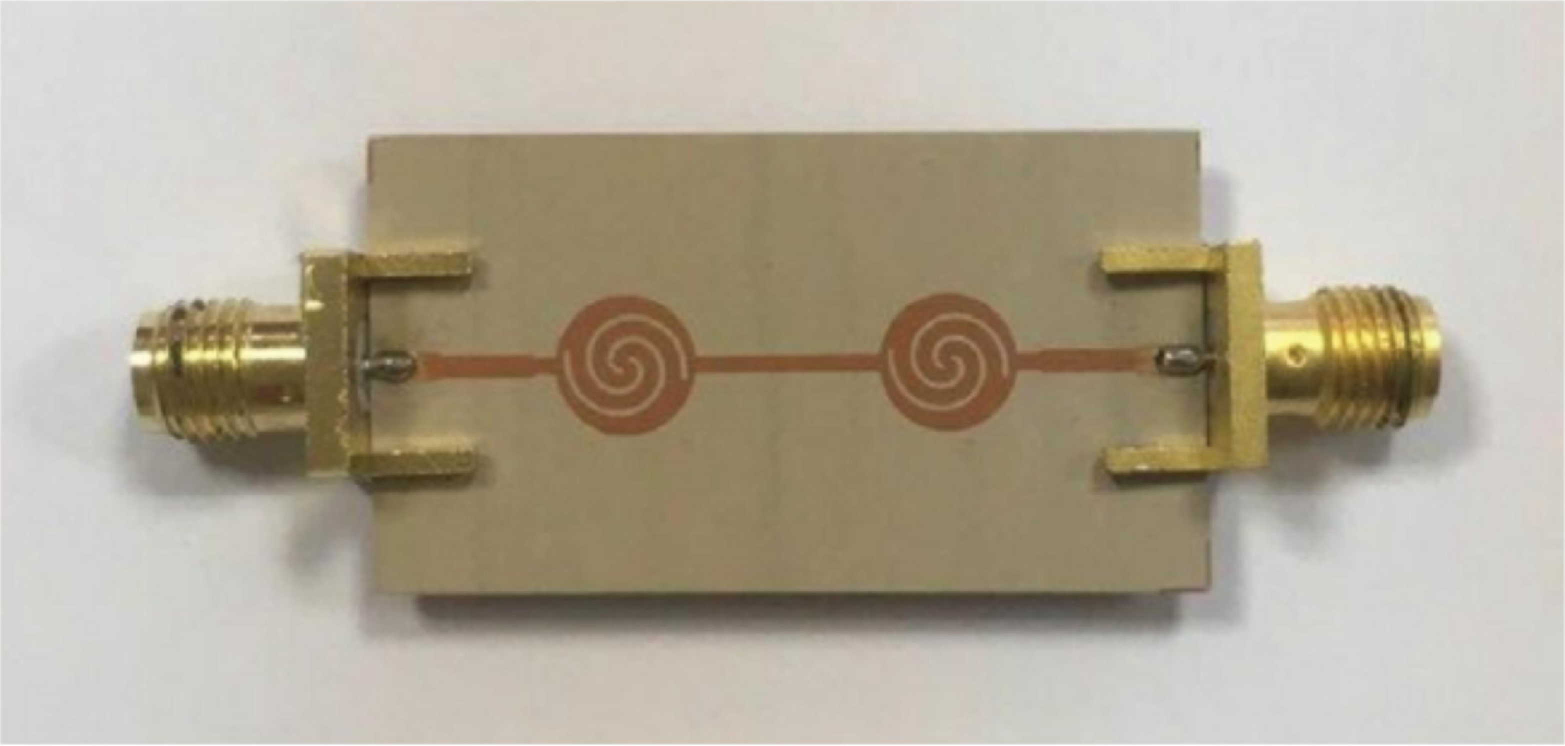


R_A	w_A	g_A	α_A	θ_{A1}	θ_{A2}
3.06	0.23	0.436	0.82	118	195

R_B	w_B	g_B	α_B	θ_{B1}	θ_{B2}
3.00	0.22	0.458	0.77	130	195

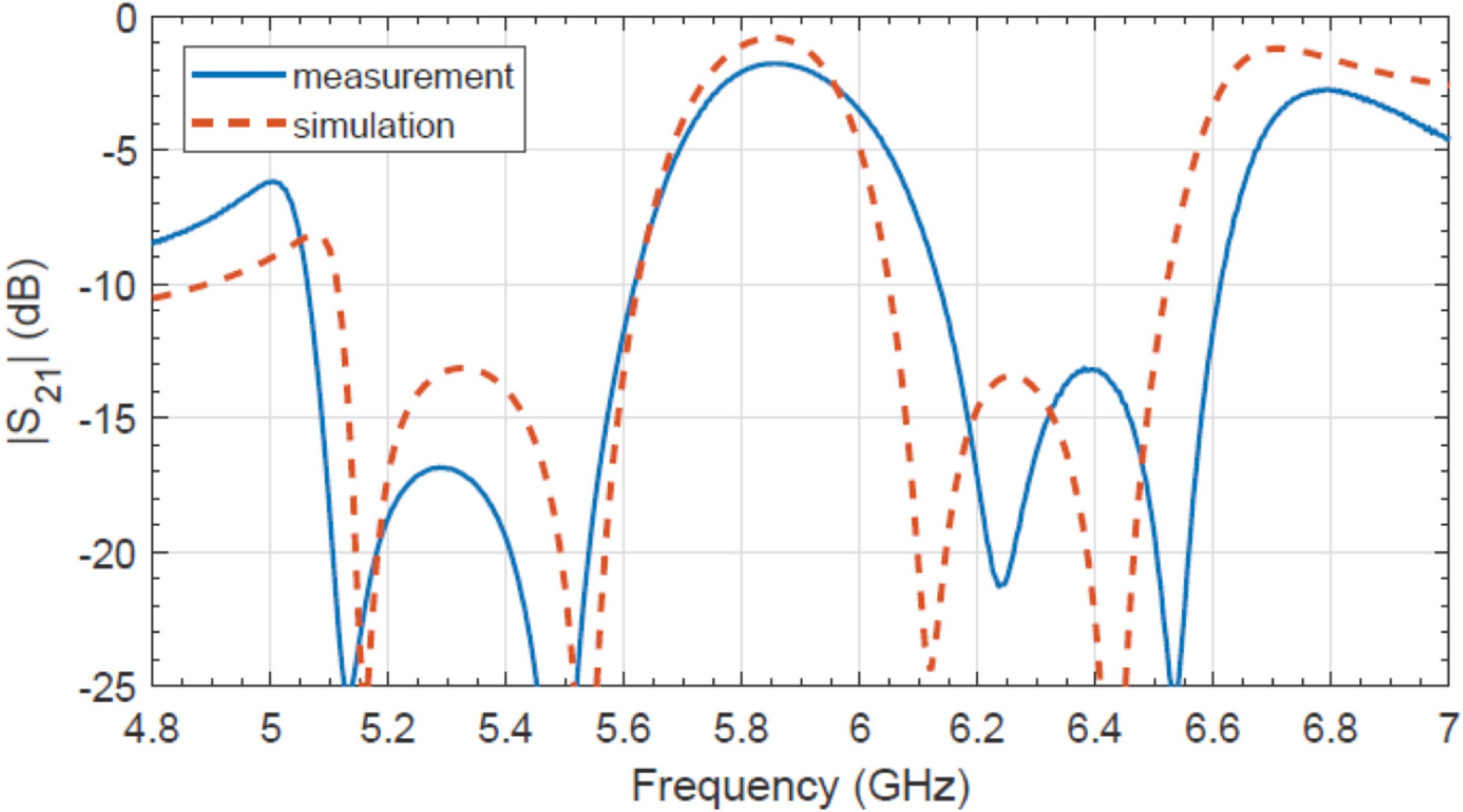
Multistage Design

And the built prototype is:

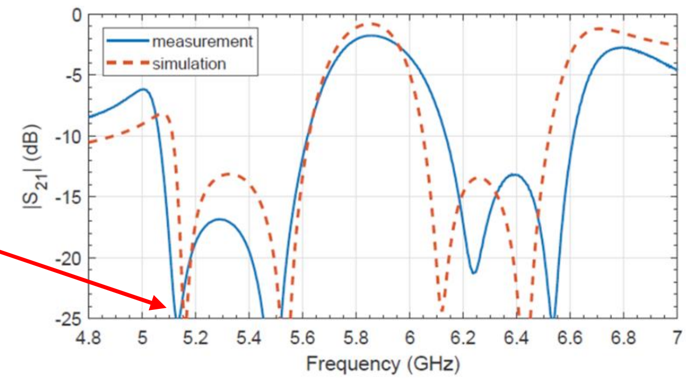


Multistage Design

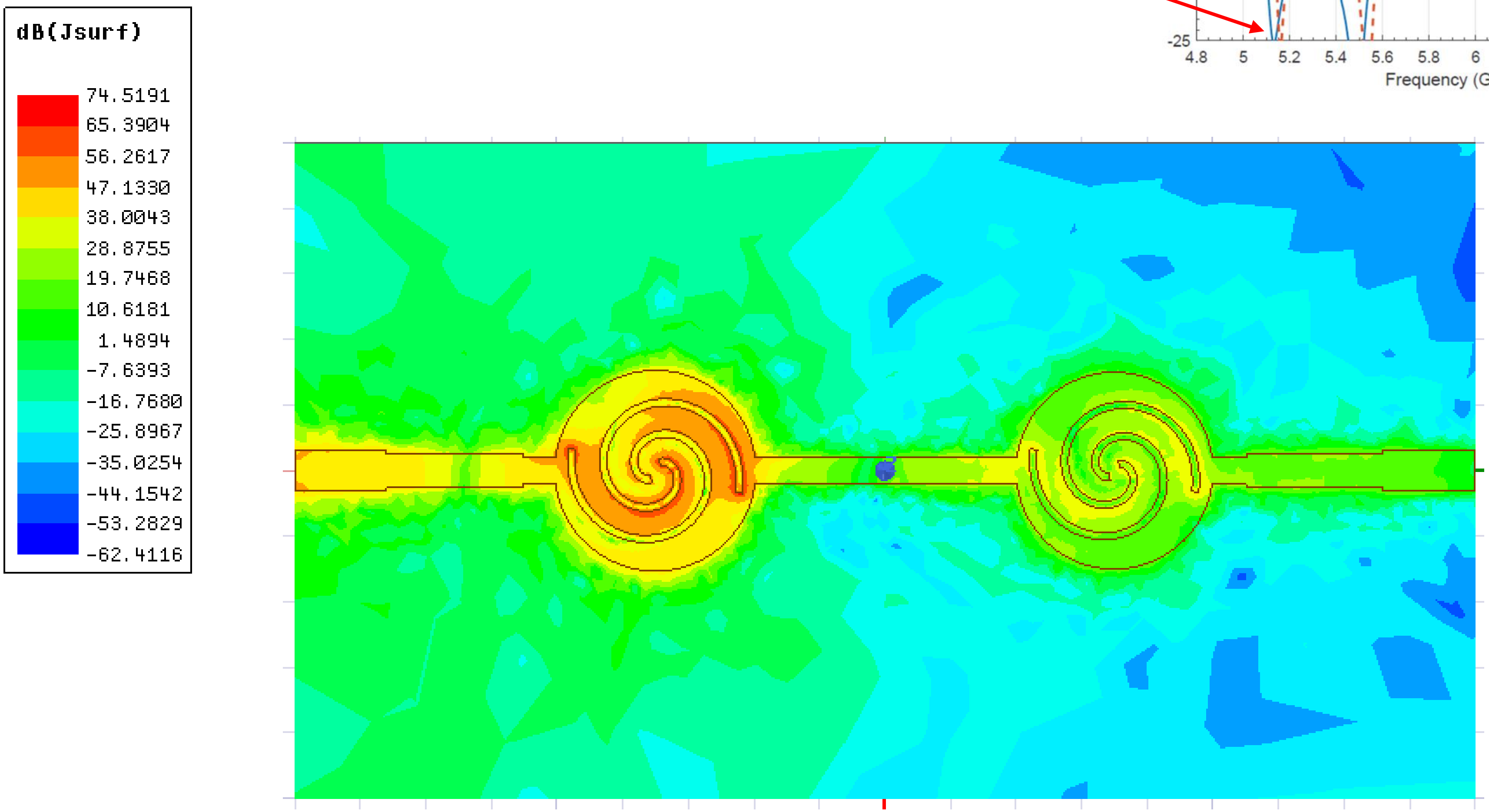
Giving two acceptably wide rejected band at the side of the passband, and measurements and simulations are anyway in a reasonable agreement.



Multistage Design

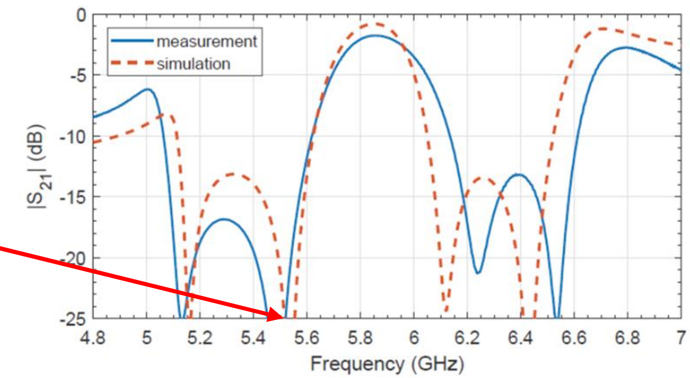


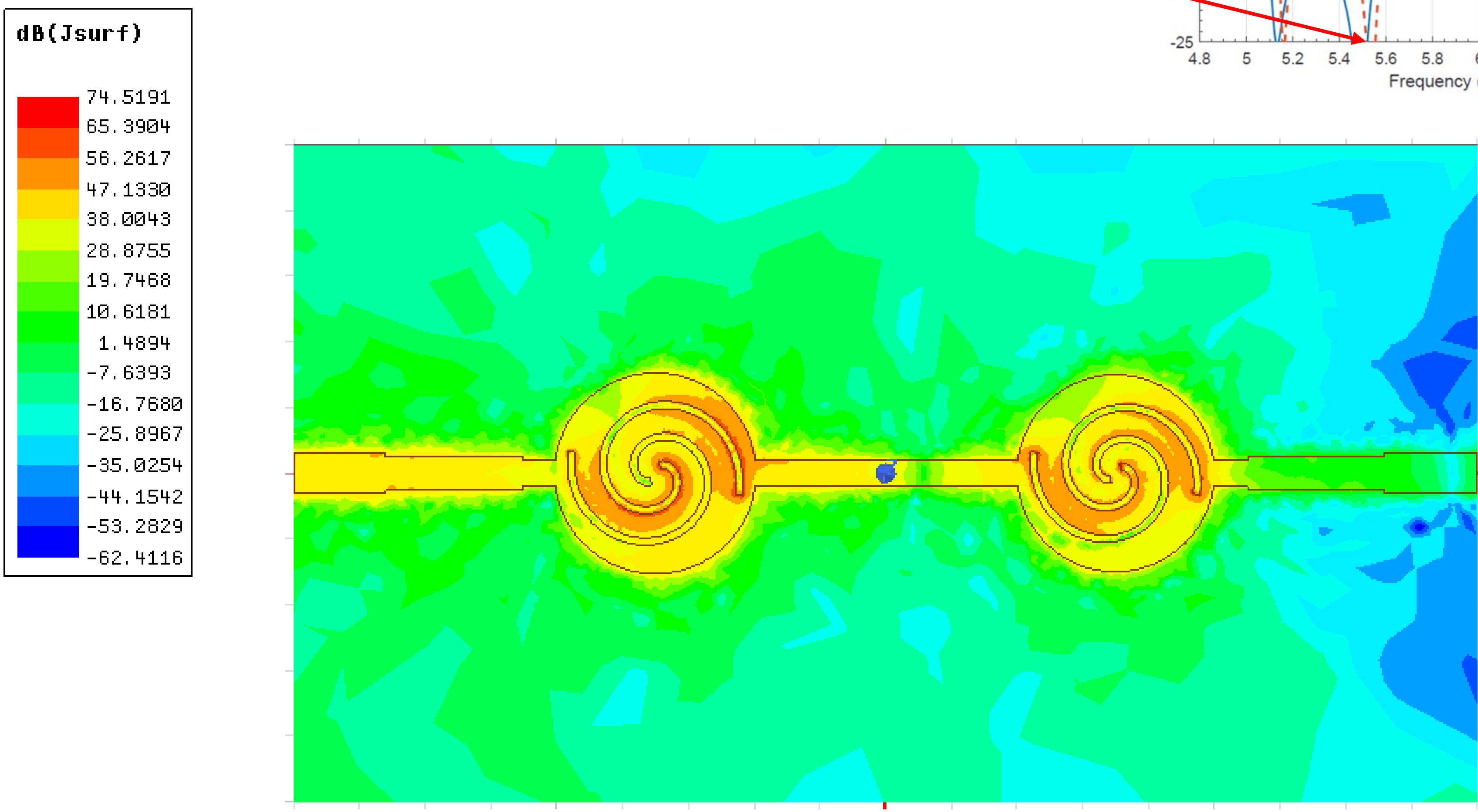
freq = 5.1 GHz



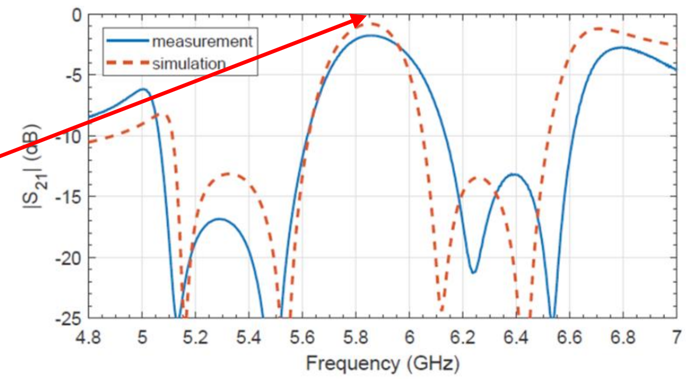
Multistage Design

freq = 5.5 GHz

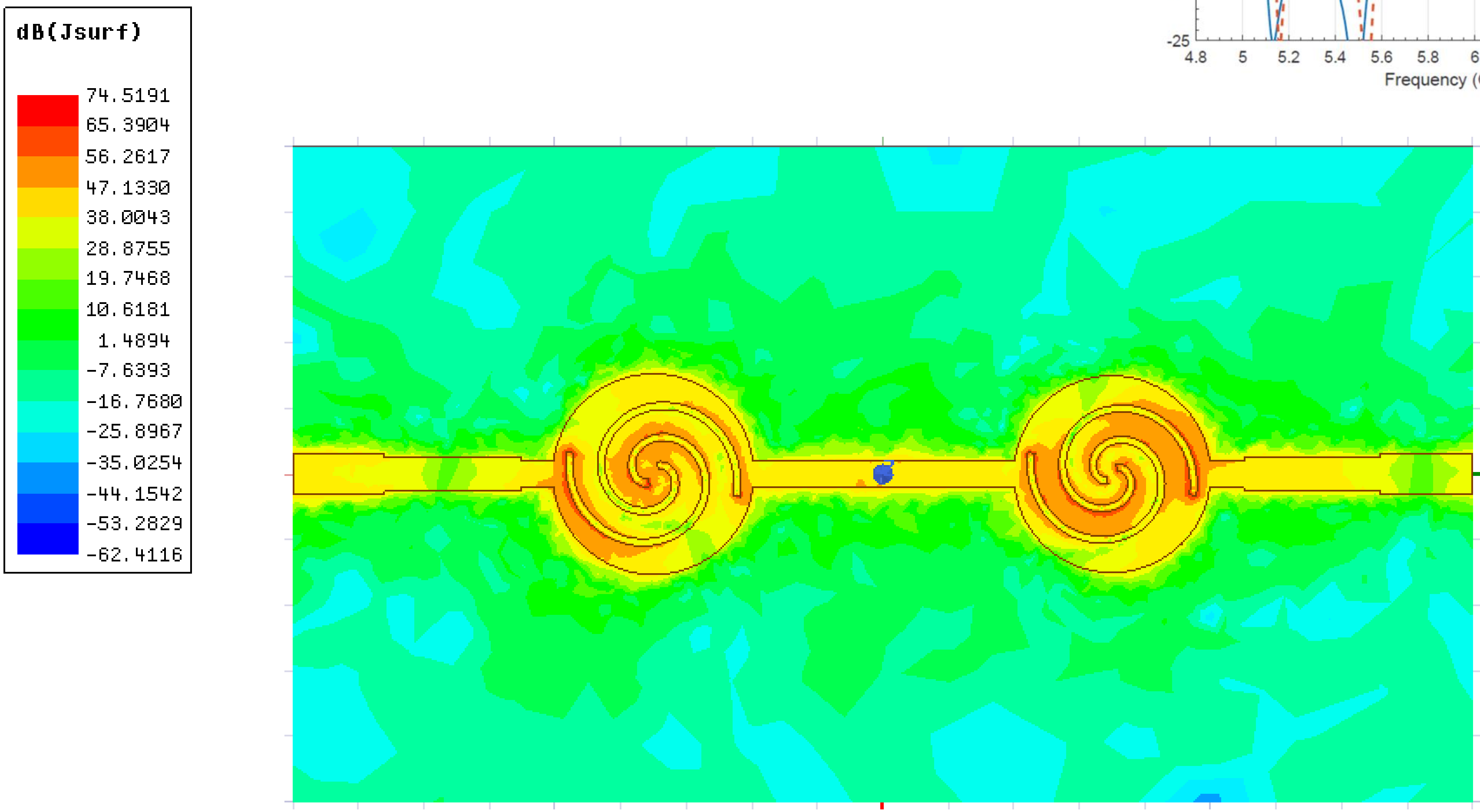




Multistage Design

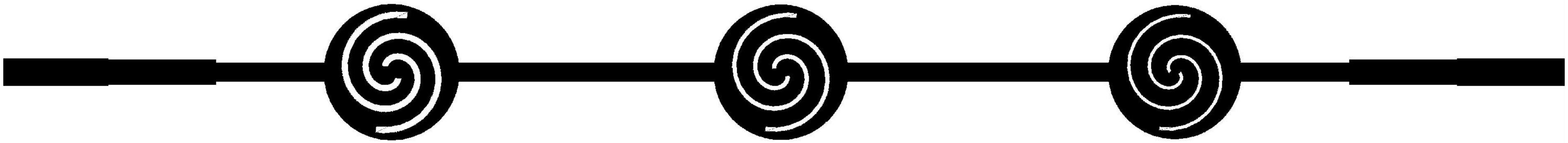


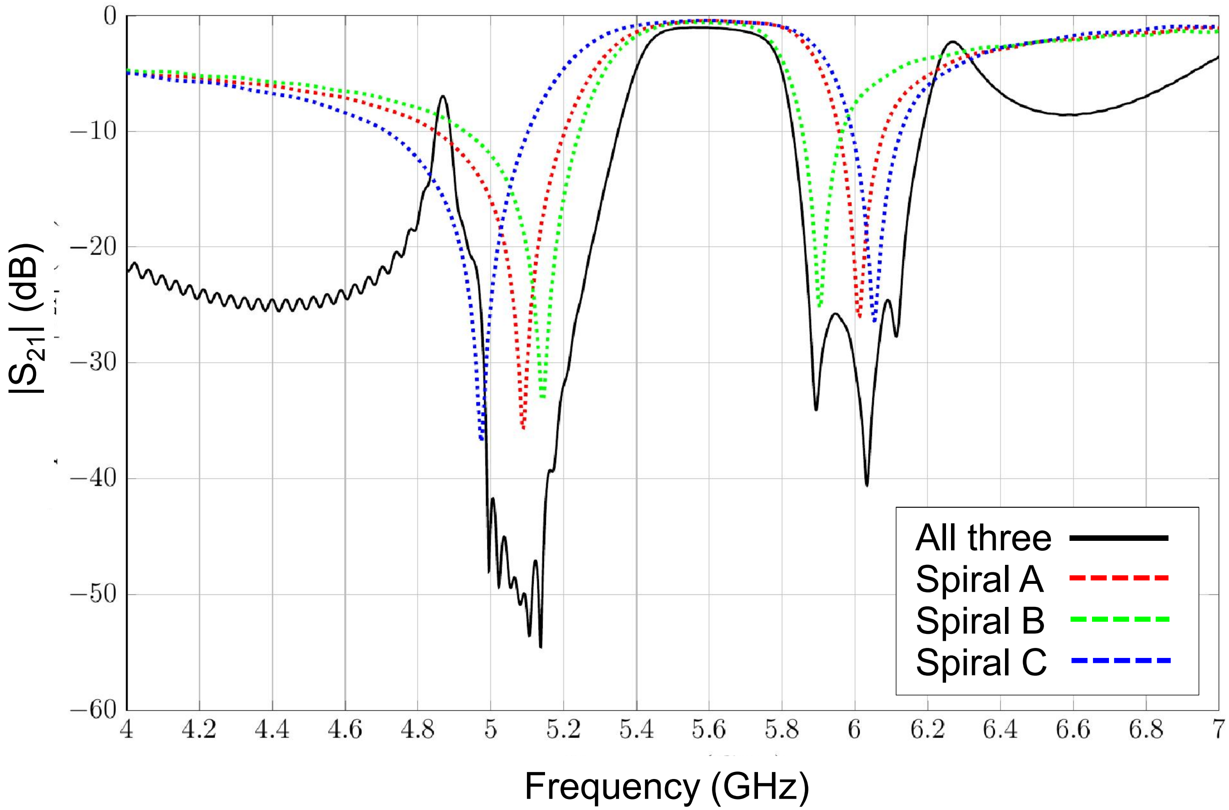
freq = 5.8 GHz



Multistage Design

And, of course, three can be cascaded (only simulations)





Conclusions

A two stage compact spiral-based filter has been designed, realized and measured.

The filter has the quasi-elliptic response of the single stage enhanced in its stop-bands by careful tuning of the notches of the single stages, achieving better than 18dB of rejection.

The two stage filter is anyway extremely compact, occupying a relatively small portion of the substrate used for realization, which has an area of 3.0x4.5 cm^2, that is about $0.525\lambda_0^2$ at center frequency (5.85GHz).

It is of course possible, as simulations showed, to use three stages to attain even better performances at the expense of a larger area.