Electrically Tunable Open Split-Ring Resonators based on Liquid Crystal Material

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Abstract

This work presents an array of tunable open split-ring resonators (OSRR) at 16 GHz with liquid crystal (LC) in microstrip technology. Simulations and measurements show the tuning of the Bloch impedance and dispersion diagram of the OSRR with an insertion loss of less than 0.3 dB per unit cell.

1. Introduction

Resonant structures such as split-ring resonators (SRR) [1] or open split-ring resonators [2] allow the design of compact loaded line filters or phase shifters compared to conventional unloaded transmission lines. For applications which require a tunable dispersion the capacitance between the rings can be tuned, e.g. by the use of varactor diodes [3]. However, varactor diodes limit the operation frequency to about 5 GHz. Another possibility, especially for frequencies above 10 GHz, is the application of liquid crystal as a continuously tunable dielectric layer [4].

2. Technology

Contradictory to [2] the rings of the OSRR in this work are broadside coupled with an LC layer between the rings. By applying a DC voltage to the rings the LC molecules can be continuously oriented, i.e. its permittivity can be tuned, which yields a tunable capacity C_s between the rings [5].

The OSRR unit cell in Fig. 1 yields a Drude dispersion for the effective permeability with a tunable magnetic plasma frequency and a non-dispersive effective permittivity. This results in the voltage tunable dispersion

$$k^2p^2 = \omega^2p^2\varepsilon_{\text{eff}}\mu_{\text{eff}}(V_{\text{DC}}) = \omega^2L_sC_s(V_{\text{DC}}) - \frac{C_0}{C_s(V_{\text{DC}})} + j\omega R_sC_0 \quad (1)$$

where L_s, C_s and R_s represent the series resonator in the series branch formed by the OSRR and C_0 is the shunt capacity between the signal layer and ground.

A top- and cross-section view of the microstrip line are shown in Fig. 1. The bottom copper metalization of the back substrate acts as the microstrip ground. The RF signal is alternating between the top gold metalization of the back substrate and the bottom gold metalization of the front substrate with a thickness of $2\,\mu\text{m}$. The high resistive nickel-chromium (NiCr) layer with a conductivity of $5 \cdot 10^5\,\text{S/m}$ and a thickness of 15 nm is used as an adhesive layer between the gold- and BF33 glass layer. Later the NiCr layer is used to pattern the bias lines. The glass substrates with a thickness of $700\,\mu\text{m}$ are separated by micropearls with a diameter of $100\,\mu\text{m}$ which define the height of the LC cavity between the top- and bottom signal metalization.

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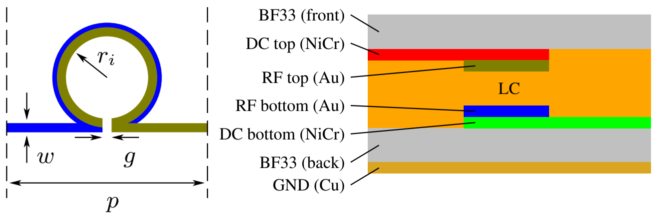

Fig. 1: Layout and substrate cross section of the unit cell ($p = 1\,\mathrm{mm}$, $r_i = 0.3\,\mathrm{mm}$, $w = g = 0.01\,\mathrm{mm}$).

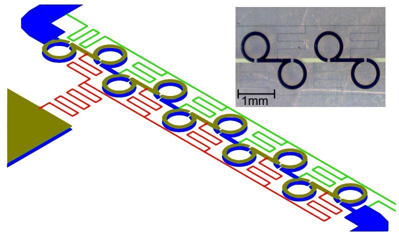

Fig. 2: 3D view and detail photo of the realized phase shifter.

A 3D view of the structure consisting of ten OSRR unit cells is depicted in Fig. 2. The rings on the back substrate (blue) are connected to the feeding line via the high resistive NiCr bias lines (green). The rings on the front substrate (brown) are connected to a biasing pad also via NiCr bias lines (red).

3. Simulation and Measurement Results

The LC used in this work has a permittivity range between $\varepsilon_{r\|} = 3.2$ (biased) and $\varepsilon_{r\perp} = 2.45$ (unbiased) with a loss tangent smaller than 0.006. The simulated Bloch impedance and dispersion diagram for the biased and unbiased state without the biasing lines are shown in Fig. 3 and Fig. 4, respectively. The magnetic plasma frequency is tuned between 12 GHz and 13 GHz. At the design frequency of 16 GHz the Bloch impedance is close to 50 Ω for the biased and unbiased state.

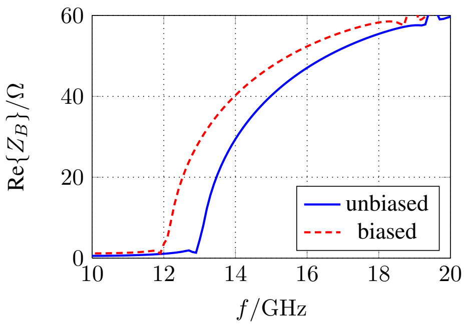

Fig. 3: Simulated Bloch impedance for the biased and unbiased state.

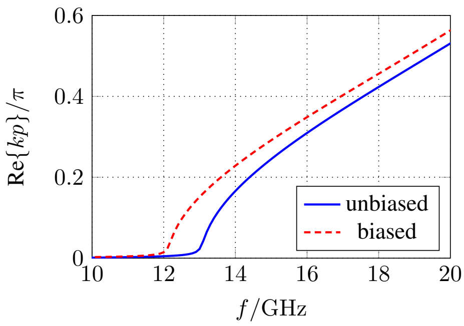

Fig. 4: Simulated dispersion diagram for the biased and unbiased state.

The measured transmission and reflection of the 10 unit cell array for different tuning voltages are shown in Fig. 5 and Fig. 6, respectively. The tuning of the lower cutoff frequency between 13 GHz and 14 GHz can be clearly observed. At the design frequency of 16 GHz the unit cell transmission is better than $-0.3\,\mathrm{dB}$/unit cell with a matching better than $-11\,\mathrm{dB}$.

The measured real part of the Bloch impedance for 0 V and 120 V is shown in Fig. 7. It is smaller in the transmission band than predicted by the simulation and shifts between 25 Ω and 40 Ω at 16 GHz. In Fig. 8 the measured dispersion diagram is depicted for 0 V and 120 V. The magnetic plasma frequency can be tuned between 14 GHz and 13 GHz.

4. Conclusion

A tunable array of open split-ring resonators at 16 GHz has been presented in microstrip technology. The tunability is achieved by applying liquid crystal as tunable dielectric layer. Measurements of the array consisting of ten unit cells show a tunable dispersion and Bloch impedance with an insertion loss of less

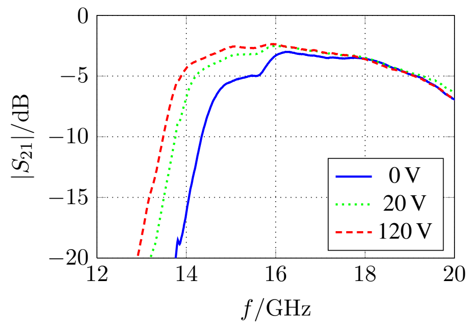

Fig. 5: Measured transmission for different biasing voltages.

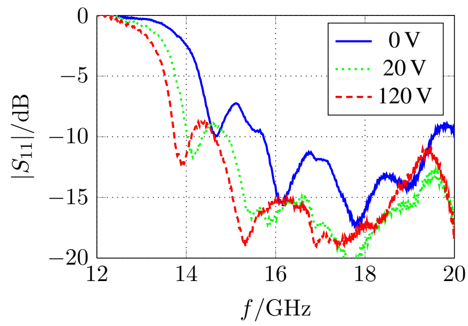

Fig. 6: Measured input reflection for different biasing voltages.

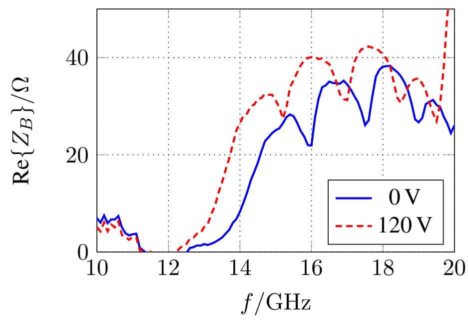

Fig. 7: Measured real part of Bloch impedance for 0 V and 120 V.

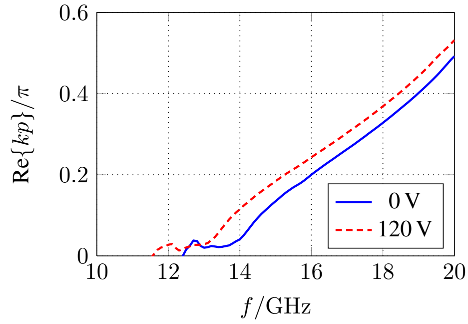

Fig. 8: Measured dispersion diagram for 0 V and 120 V.

than 0.3 dB/unit cell. The continuously tunable phase together with the Bloch impedance close to 50 Ω for all biasing states gives the possibility for applications in compact tunable filters or phase shifters.

Acknowledgement

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References

[1] R. Marqués, F. Mesa, J. Martel, and F. Medina, "Comparative analysis of edge- and broadside- coupled split ring resonators for metamaterial design - theory and experiments," *Antennas and Propagation, IEEE Transactions on*, vol. 51, no. 10, pp. 2572 – 2581, oct. 2003.

[2] J. Martel, R. Marques, F. Falcone, J. Baena, F. Medina, F. Martin, and M. Sorolla, "A new lc series element for compact bandpass filter design," *Microwave and Wireless Components Letters, IEEE*, vol. 14, no. 5, pp. 210 – 212, may 2004.

[3] I. Gil, J. Bonache, J. Garcia-Garcia, and F. Martin, "Tunable metamaterial transmission lines based on varactor-loaded split-ring resonators," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 54, no. 6, pp. 2665 – 2674, jun. 2006.

[4] S. Müller, A. Penirschke, C. Damm, P. Scheele, M. Wittek, C. Weil, and R. Jakoby, "Broad-band microwave characterization of liquid crystals using a temperature-controlled coaxial transmission line," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 53, no. 6, pp. 1937 – 1945, june 2005.

[5] F. Gölden, A. Gäbler, S. Müller, A. Lapanik, W. Haase, and R. Jakoby, "Liquid crystal varactors with fast switching times for microwave applications," *Electronics Letters*, vol. 44, no. 7, pp. 480 – 481, 2008.