A Frequency Tunable Double Band-Stop Resonator with Voltage Control by Varactor Diodes

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Abstract

In this paper, a frequency tunable double band-stop resonator (BSR) with voltage control by varactor diodes is suggested. It makes use of a half-wavelength shunt stub as its conventional basic structure, which is replaced by the distributed LC block. Taking advantage of the nonlinear relationship between the frequency and electrical length of the distributed LC block, a dual-band device can be designed easily. With two varactor diodes, the stop-band of the resonator can be easily tuned by controlling the electrical length of the resonator structure. The measurement results show the tuning ranges of the two operating frequencies to be 1.82 GHz to 2.03 GHz and 2.81 GHz to 3.03 GHz, respectively. The entire size of the resonator is 10 mm × 11 mm, which is very compact.

Key Words: Band-Stop Resonator, Dual-Band, Half-Wavelength, Transmission Line, Varactor Diode.

I. INTRODUCTION

Many high-performance radio frequency (RF) and microwave circuits are required these days for electronic systems. Attention has been given to low cost, miniaturized, multi-band, and frequency tunable propriety. A microstrip structure is cheap, easy to fabricate, and easy to be integrated into an electronic system. For size reduction, some novel topologies are applied [1, 2], and some metamaterial related composite right/left-handed (CRLH) transmission lines are used [3–5]. Multi-band devices are playing an increasingly important role in integrated circuits, as it can be realized for multi-functions without increasing the physical size significantly [6, 7]. For tunability, varactor diodes are used in many designs [8, 9].

In this paper, a compact frequency tunable dual-band band-stop resonator (BSR) is presented. The proposed resonator takes use of a distributed LC block structure as a shunt part of the circuit. The proposed resonator is compact and tunable, and its entire size is 10 mm × 11 mm with tunable double-resonant frequencies of 1.82 GHz to 2.03 GHz and 2.81 GHz to 3.03 GHz.

This paper is divided into the following parts. In Section II, the resonator design and the instruction are proposed; in Section III, the simulation and measurement results are discussed; and the conclusion will follow in the last section.

II. RESONATOR DESIGN

The resonator designed in this paper is based on a kind of shunted half-wavelength transmission line with a short stub, as shown in Fig. 1. The resonance condition is reached when its electrical length βl reaches nλg/2, where n is an arbitrary
integer. The resonator will show a stop-band characteristic at
these frequencies. In this paper, the distributed LC block
structure is inserted into a half-wavelength transmission line
and it provides a tunable phase response with a compact size.

Fig. 2 shows the geometry of the proposed resonator, and
Fig. 3 shows the related equivalent circuit. The distributed
elements are added in Fig. 3 (\(L_R\) and \(C_R\)), because they will
produce an unavoidable affect in the phase characteristic. The
structure is designed on a Teflon substrate with a thickness of
0.54 mm and a dielectric constant of 2.54.

In this shunt structure, as shown in Figs. 2 and 3, two inter-
digital capacitors and varactor diodes with bias voltages act as
tunable capacitive components (\(C_{L1}\) and \(C_{L2}\) in Fig. 3) in the
shunt part. The inductors are realized using distributed com-
ponents, and the RF choke inductor and bypass capacitor are
used to isolate the DC source from the RF signal. Lumped
elements are applied in the RF choke and bypass circuit for
good performance.

The capacitance of the capacitors \(C_{L1}\) and \(C_{L2}\) can be set
freely in this shunt circumstance to control the relationship
between the electrical length and the frequency. The com-
ponent value of the transmission line will affect this relation-
ship greatly; then, the electrical length in a specified fre-
quency will be changed rapidly while changing the component
values. The circuit shows frequency rejection when the elec-
trical length of the short-ended shunt stub reaches \(n\lambda_g/2\). The
simulation of the phase response for the distributed LC block
part with a different DC voltage supplied is carried out throu-
gh the combined simulation from AWR and ADS, and one of
the results is as shown in Fig. 4 for evaluation. The electrical
lengths in the frequency of 1.9 GHz and 2.9 GHz correspond
to 0 and \(n\lambda_g/2\), respectively. Furthermore, the tunable electrical
length of the shunt part can be realized by tuning the DC
voltages.

### III. SIMULATION AND EXPERIMENT RESULTS

The simulations are carried out using ADS 2012 and AWR
simulation software. The simulation results are shown in Fig.
5. Fig. 5 shows the \(S_{21}\) parameters as a function of the voltage
Fig. 5. Simulation results of the proposed resonator. (a) $S_{21}$ parameter as a function of DC1 with DC2 fixed to 4 V. (b) $S_{21}$ parameter as a function of DC2 with DC1 fixed to 1 V.

of DC1 and DC2 with the other DC supply fixed. The applied voltage range is from 1 V to 10 V, referring to the applied diode. The result calls for the operating frequency of the resonator to be tunable at two frequency bands: 1.72 GHz to 2.15 GHz and 2.76 GHz to 3.15 GHz, respectively, with an insertion loss of around $-20$ dB. The limitation of the frequency range depends on the capacitance tuning range of the varactor diodes.

A photograph of the proposed resonator is shown in Fig. 6. The two lighter wires connect to two DC supplies and the darker wire is to be connected to the ground. An Agilent vector network analyzer (VNA) is used to measure the resonator. All measurement results are listed in Table 1. For comparison, some of the DC supply conditions are picked and their $S$-parameters are drawn into two figures, which are shown in Fig. 7. They indicate that the first tuning range (operating frequency as a function of DC1 with DC2 = 1 V) is 1.82 GHz to 2.03 GHz, and the second tuning range (operating frequency as a function of DC2 with DC1 = 10 V) is 2.81 GHz to 3.03 GHz, where the tuning bandwidths are 10.91% and 7.53%, respectively. The DC supply condition we chose here differs from that of the simulation condition, however. The entire size of the proposed resonator is 10 mm

| DC1 | 1 V | 3 V | 5 V | 7 V | 9 V | 10 V |
|-----|-----|-----|-----|-----|-----|------|
| 1 V | 1.82, 2.81 | 1.82, 2.90 | 1.82, 2.98 | 1.82, 3.05 | 1.82, 3.06 | 1.82, 3.07 |
| 2 V | 1.87, 2.81 | 1.87, 2.90 | 1.87, 2.98 | 1.88, 3.05 | 1.88, 3.06 | 1.88, 3.07 |
| 3 V | 1.92, 2.81 | 1.92, 2.91 | 1.92, 2.98 | 1.92, 3.06 | 1.92, 3.07 | 1.92, 3.07 |
| 4 V | 1.96, 2.82 | 1.96, 2.91 | 1.96, 2.99 | 1.92, 3.06 | 1.92, 3.07 | 1.96, 3.07 |
| 5 V | 1.98, 2.82 | 1.99, 2.92 | 1.99, 2.99 | 1.98, 3.04 | 1.99, 3.07 | 1.99, 3.07 |
| 6 V | 2.00, 2.82 | 2.00, 2.92 | 2.00, 2.99 | 2.00, 3.06 | 2.00, 3.07 | 2.00, 3.07 |
| 7 V | 2.01, 2.82 | 2.01, 2.92 | 2.01, 3.00 | 2.01, 3.06 | 2.01, 3.07 | 2.01, 3.07 |
| 8 V | 2.02, 2.82 | 2.01, 2.91 | 2.02, 3.00 | 2.02, 3.06 | 2.02, 3.08 | 2.02, 3.08 |
| 9 V | 2.03, 2.82 | 2.03, 2.92 | 2.03, 3.00 | 2.03, 3.06 | 2.03, 3.08 | 2.03, 3.08 |
| 10 V | 2.03, 2.82 | 2.03, 2.92 | 2.03, 3.00 | 2.03, 3.06 | 2.03, 3.08 | 2.03, 3.08 |

Values are presented as freq/GHz ($f_1, f_2$).
**Table 2. Size comparison between the proposed resonator and other works**

| Ref.  | Operating frequency/frequencies | $\varepsilon_r$ | Size (mm) |
|-------|---------------------------------|-----------------|-----------|
| This work | 1.82–2.03 GHz and 2.81–3.03 GHz | 2.54            | 10 × 11   |
| [10]  | 850 MHz and 2.5 GHz              | 4.3             | 26.3 × 43 |
| [11]  | 1.494 GHz                       | 10.2            | 15.3 × 10.8 |
| [12]  | 3.5 GHz                         | 6.15            | 6.5 × 14  |

Fig. 7. Measurement results of the proposed resonator. (a) $S_{21}$ parameter as a function of DC1 with DC2 fixed to 1 V. (b) $S_{21}$ parameter as a function of DC2 with DC1 fixed to 10 V.

This work, with dimensions × 11 mm, is compact both physically and electrically compared to some other recent resonator designs, and it has an extra function of frequency tunability. The comparisons are shown in Table 2 [10–12]. The measurement results and size of the proposed resonator are in good agreement overall with the simulation ones.

**IV. CONCLUSION**

In this paper, a compact tunable dual-band BSR has been proposed. The shunt stub with a distributed LC block can be achieved for a tunable property in the frequency response. By setting the input voltages (from 1 V to 10 V) of the two ports, the operating frequency band can be easily tuned with a good frequency rejection. The simulation and the experiment results are in good agreement. This proposed resonator is compact and may achieve a self-tuning function with proper feedback when used in microwave circuit systems.

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