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A Tunable Band Stop Filter for Ku Band Communication Systems using DGS and MEMS Switches

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Abstract: This paper presents a tunable bandstop filter based on an interdigital defected ground structure (DGS) and microelectromechanical (MEMS) switches. The switches are positioned over the bends of the DGS. Depending the switch that is actuated, the effective slot length of the DGS varies and hence the resonant frequency. The resonant frequencies can be further varied by varying the individual branch lengths. The proposed design is modified with three additional MEMS switches in each branch to alter its effective length. The design procedure for varying the branch lengths, and mechanical design of the MEMS switches is also presented. The additional switches create a large number of switching states filling the entire Ku-band with closely spaced resonant frequencies.

Keywords: DGS, MEMS switches.

1. Introduction

Defected Ground Structures (DGS) [1, 2] function as band stop filters, and are widely used in communication systems [3, 4]. .Micro electro mechanical (MEMS) switches and PIN diodes are used for tuning filters based on DGS. MEMS switches can short out the etched regions in a DGS, altering its structure or dimensions, and thus control the frequency response. MEMS series switches reduce the width of a square shaped DGS [5]. MEMS switches short out a narrow slot between cascaded DGS [6]. MEMS switches alter the structure of a dumbbell shaped DGS, creating two resonant frequencies [7]. MEMS switches placed across gaps of DGS can eliminate the effect of the DGS. A reconfigurable impedance tuner uses periodic DGS and MEMS switches [8]. MEMS switches can also completely short out the DGS [9].

The proposed work uses MEMS switches for tuning, an interdigital DGS based band stop filter. The resonant frequency of an interdigital DGS has been shown to depend on the slot length [10] and the present work uses MEMS switches to vary the effective slot length. Depending on the switch that is actuated, different resonant frequencies are obtained. The resonant frequencies are further varied by varying the individual branch lengths. The proposed design is modified with three additional MEMS switches across each branch to vary the length of each branch. The design procedure for varying the branch lengths, and mechanical design of the MEMS switches is also presented. The proposed filter, results in a large number of closely spaced frequencies in the entire Ku-band and is suited for communication systems.

2. Defected Ground Structures

Defected Ground Structures (DGS) were derived from photonic band gap structures (PBG). At microwave frequencies, band stop response is obtained by DGS. The narrow slot or gap of the DGS accumulates charge, and acts as a capacitance. The defect increases the route length of current and acts as an inductance. The radiation losses are modeled by a resistor R. The RLC model of a DGS is given in [2].Varying the defect dimensions of the DGS can vary the inductance, and the resonant frequency. Since the inductance also depends on the field distribution within the DGS, an electromagnetic simulator is needed for DGS design.

3. Proposed Tunable Band Stop Filter using Interdigital DGS and MEMS Switches

The present work is a tunable band stop filter using MEMS switches positioned over the bends of an interdigital DGS. The resonant frequency of interdigital DGS depends on the slot length. Actuation of a switch eliminates the defect region after the switch. Depending on the switch that is actuated, the effective slot length of the DGS varies and hence the resonant frequency. The proposed design is further modified using additional MEMS switches for varying the individual branch lengths, and hence the resonant frequencies. The DGS shown in Fig. 1 has $k = 50\ \mu m$, $j = 65\ \mu m$, and $h = 555\ \mu m$ for a55/ 100 /55 um CPW built on silicon substrate ($\varepsilon_r = 11.9$), of thickness $500\ \mu m$. The branch lengths are

$$x = 353 \mu m;\ x_1 = x_2 = x_3 = (2x + j) = 771\ \mu m.$$

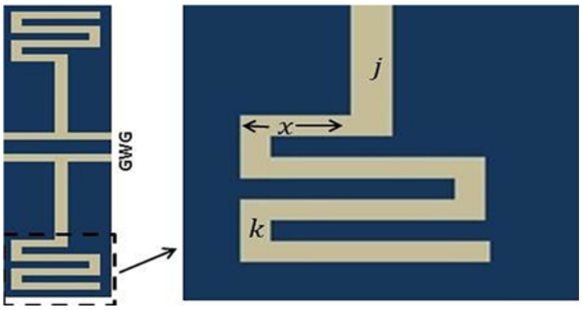

Fig. 1. Structure of the interdigital DGS on CPW. The defect structure and dimensions are shown in inset.

Fig. 2 shows switch S_1 loaded over the third bend of DGS. The contact area of the switch with the defect is marked red. The dimensions are given in Table 1.

The switches are designed in Coventorware.The actuation electrode of the switchis isolated from ground plane. The switch gap is $1.7 \mu m$ in the upstate.

Actuation of the MEMS switches placed over the bends of the uniform DGS creates unevenly spaced resonant frequencies. Desired frequencies of operation are obtained by designing the individual branch lengths using HFSS. The proposed structure of Fig. 3 with branch lengths$x = 303\ \mu m, x_1 = 465\ \mu m$, $x_2 = 610\ \mu m\ x_3 = 865\ \mu m$, results in a uniform spacing between the resonant frequencies.

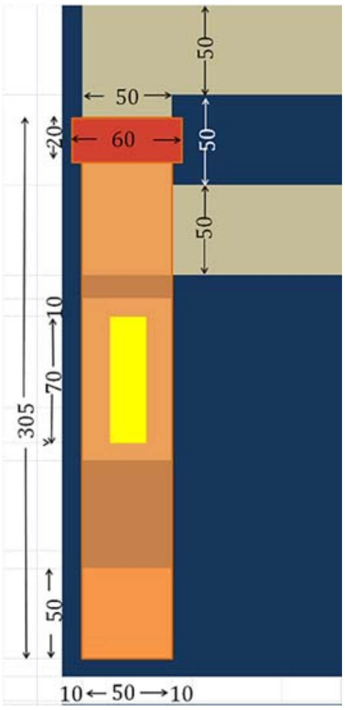

Fig. 2. Structure of MEMS switch loaded over DGS: Contact area of the switch touches the centre of the bend of the DGS.

Table 1. Dimensions of Mems Switches.

MEMS switch part	Length × Width
Whole switch beam (Al)	$305\ \mu m \times 50\ \mu m$
Contact area	$20\ \mu m \times 60 \mu m$
Anchor	$50\ \mu m \times 50 \mu m$
Actuation Electrode coated with $0.1\ \mu m$ SiN	$70\ \mu m \times 35\ \mu m$

The design procedure for varying the branch lengths is as follows. The largest frequencyf_3 corresponds to the smallest effective slot length, x . Similarly f_2 depends on $x + x_1$and is controlled by x_1; x_2 isvaried to satisfy f_1 and x_3 is varied for obtaining f_0.

The above procedure has a disadvantage. Reducing f_0 increases $x_3$and the filter length. Also, the operating frequencies are fixed at design stage and cannot be altered after fabrication. Hence the proposed design is modified, with three additional MEMS switches in each branch, e.g.; (S_A^1 to S_A^3) see Fig. 4, to alter the effective lengths of each branch of the DGS.

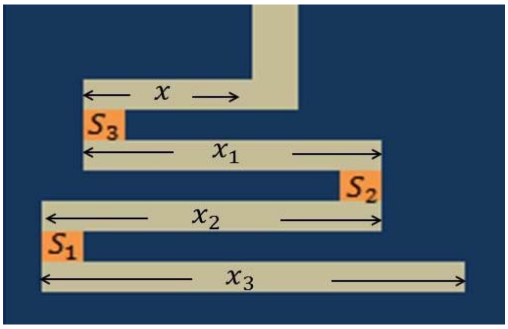

Fig. 3. Proposed DGS with unequal branch lengths for obtaining uniformly spaced resonant frequencies. The DGS is loaded by MEMS switches. Only the contact portion of the switches is shown in the fig.

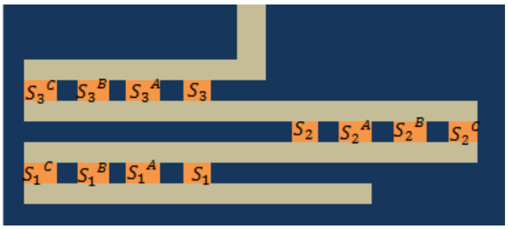

Fig. 4. Proposed DGS with three sets of additional switches for varying the individual branch lengths.

The additional switches contact the DGS at the centre of the bends of the DGS, similar to the switch in Fig. 2. Therefore if a switch is in downstate, electromagnetic fields can still propagate, if an additional switch is in upstate. The branch lengths are adjusted suitably to obtain the required total slot length for operation at Ku-band. The number of control inputs is large for this design, which is reduced by grouping the switches at equal distances from the bends-eg; (S_A^1, S_A^2,S_A^3) have equal control voltage.

4. Results

The proposed tunable bandstop filter designs using interdigital DGS and MEMS switches simulated in HFSS. The switch structures were designed in Coventorware and pull in voltage is 9.5 V.

For the uniform interdigital DGS with $x = 353\ \mu m,$ the frequency response is shown in Fig. 5. When all switches are in upstate, resonant frequency f_0 is 12.5 GHz. Resonant frequency increases, as the switches $S_1$to S_3 are actuated. The variation in frequency is larger at larger frequencies.

Fig. 6 is the frequency response of the proposed DGS structure of Fig. 3, which has been designed for equalizing the spacing between the resonant frequencies. For this structure,f_0 is 14 GHz. For operation at Ku-band, f_0 is reduced to 12 GHz using additional switches, and by adjusting branch lengths.

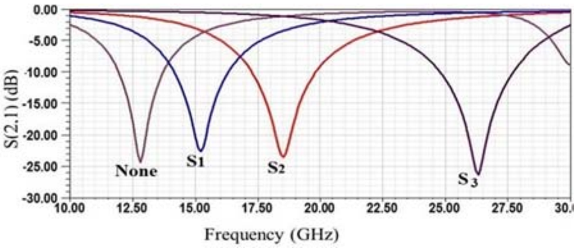

Fig. 5. Frequency responses of the uniform interdigital DGS, with MEMS switches. The resonant frequency shifts due to actuation of switches $S_1$to S_3.

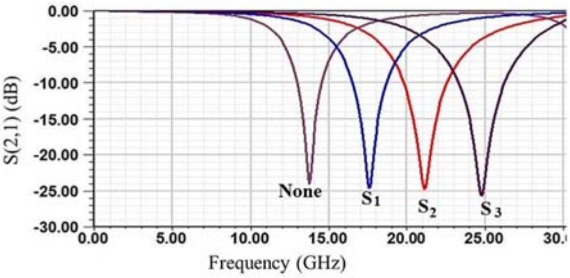

Fig. 6. The resonant frequencies of the proposed DGS of Fig. 3, depending on the actuation of switches S_1 to S_3.

The frequency response for various switching states the proposed DGS filter of Fig. 4 is shown in Fig. 7. The inputs given to switch groups (S_A^1, S_A^2,S_A^3) etcare so chosen that, at lower frequencies, more variation in slot length is obtained. Hence uniformly spaced resonant frequencies are obtained throughout the band. After choosing any of the given resonant frequencies, further fine tuning can be obtained by varying the actuation voltages applied to the individual switches within each group (S_A^1, S_A^2,S_A^3) etc. The frequency response of the proposed filter is tunable over a large number of closely spaced frequencies in the entire Ku-band.

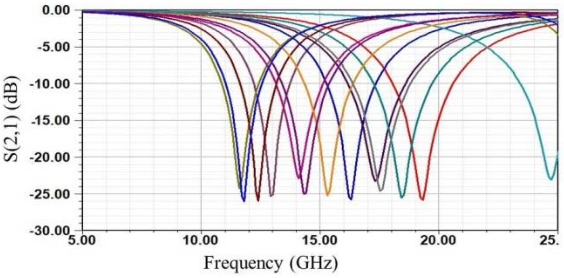

Fig. 7. Frequency response of the proposed DGS of Fig. 4, with three set of additional switches for varying the lengths of the individual branches.

The switches$S_1$to $S_3$and S_A^1 to S_A^3were designed using electromechanical analysis in Coventorware. Pull down voltage of the switch is 9.5 V. The up and down states of the switches is shown in Fig. 8.The beam heights of the switches for various actuation voltages was determined. The effect of switch beam heights (before pull in), on the frequency response of the filter was analyzed in HFSS. The resonant frequencies did not vary with the height of the switch beam.

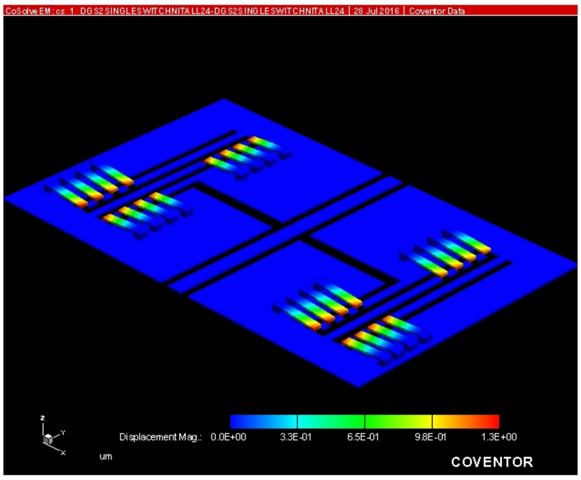

Fig. 8. Mechanical Analysis of the Coventorware, showing switches actuated state.

Conclusion

MEMS switches are loaded over the bends of an interdigital DGS, to obtain a tunable band stop filter. The effective slot length of the DGS, and hence the resonant frequency, varies with the switch that is actuated. It is observed that the resonant frequencies are not spaced uniformly, for the interdigital DGS with uniform branch lengths. A procedure is developed to obtain the required resonant frequencies by varying the lengths of the individual branches. Since the branch lengths of the DGS cannot be altered after the design stage, additional MEMS switches are introduced for varying the individual branch lengths. This allows fine tuning of resonant frequencies and results in a large number of switching states. The mechanical design of the MEMS switches is also presented. The proposed filter, with large number of closely spaced frequencies is suited for application in Ku-band communication systems.

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