Plasmonic Metamaterial Based Dual-Band Filter

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***Abstract*- This paper reports the design, analysis, and characterization of a dual-band filter using the concept of plasmonic metamaterial. The designed filter consists of a multi-mode butterfly shape resonator, which is directly coupled through plasmonic transmission line with coupling gap *g*. The operational mechanism of the filter has been explained through the even-odd mode analysis. The designed filter has dual-band response with the center frequencies of *1.78* GHz and *2.59* GHz. Measured insertion losses are ~*1.5*dB and return loss are better than *15*dB for both the pass-bands. The proposed filter will pave an important role in the design and development of plasmonic circuits and systems.**

***Index Terms*- Dispersion, dual-band, plasmonic metamaterial.**

I. Introduction

Filters are one of the important building blocks of wireless transceiver and their performance parameters are greatly influenced by the technology used to develop them. Since, the conventional microstrip technology suffers from losses, so one of the possible solution can be plasmonic metamaterial i.e. spoof surface plasmon polaritons (SSPP's) technology due to their strong EM field confinement characteristics. Basically surface plasmon polaritons (SPP's) are special kind of electromagnetic modes which are found at optical frequencies and propagate along the interface of the metal-dielectric. The amplitude of the SPP wave decays exponentially in the transverse direction at the interface of the two materials [1]. The SPP provides highly confined tendency at the sub-wavelength scale. However, natural SPP is not supported by the metal-dielectric interface at THz and microwave frequencies due to the perfect electric conductor behavior of metal [2]. To engineer the characteristics of SPP at lower frequency regimes, plasmonic metamaterial has been proposed, that are the corrugated structured surfaces on the metal surfaces [3] and called as spoof surface plasmon polaritons. Due to strong field confinement, it has been found various promising applications in filters, power splitters and excitation of the antenna [4]. A number of researchers have proposed single-band filter designs like in [5], [6] but still, there is a lot of scope to design and development of compact multi-band BPF based on SSPP .

Here, in this paper, we proposed the design of plasmonic metamaterial based dual-band filter using multi-mode butterfly shape resonator with theoretical analysis and experimental characterization.

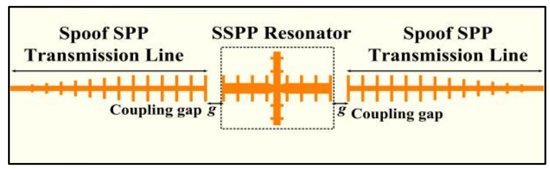

Fig. 1 Schematic of the proposed dual-band filter using spoof SPP.

II. Theory and Design Analysis

Fig. 1 shows the layout of the proposed dual-band filter, which consists of a multi-mode butterfly shape resonator, coupled to spoof SPP transmission line as the feeding element at its input and output port with a coupled gap *g*. It has been designed on substrate parameters with dielectric constant of *3.38*, the dissipation factor of *0.0016* and height of *1.524* mm; with the copper metal having a conductivity of 5.8×10^7 S/m. For the EM analysis CST microwave studio has been used.

A. Design of Feeding Network

The basic unit cell of spoof SPP based multi-mode resonator as shown in Fig. 2 (a) supports TM mode which is a highly dispersive mode and its dispersion characteristics significantly deviates from the light line (simple microstrip line) as shown in Fig. 2 (b).

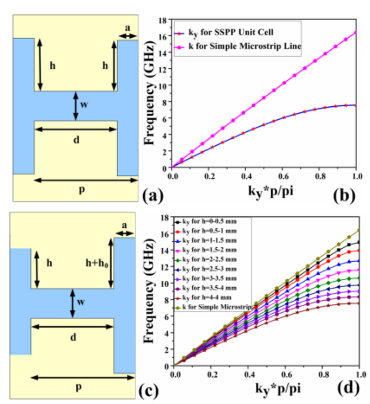

Fig. 2 (a) Schematic of the spoof SPP unit cell, (b) Dispersion diagram, (c) Schematic of one section of conversion, (d) Dispersion diagram

The optimized physical parameters that are used to design the unit cell are; w=2mm, d=4mm, h=4mm, p=5mm and a=1mm. However, to characterize this multi-mode resonator based BPF structure, we need a special feeding network which can efficiently convert the QTEM mode of microstrip to the TM mode of SSPP mode. Hence, a conversion section has been designed as shown in Fig. 2 (c) which gradually changes the QTEM mode to the TM mode as shown in Fig. 2(d) with gradient corrugated grooves whose height increases from $h_1=0.5$mm to $h_7=3.5$mm.

B. Even-Odd Mode Analysis of the Proposed Resonator

Fig. 3 shows the proposed layout of the SSPP based multi-mode resonator which consists of two cross coupled SSPP transmission line sections connected in butterfly manner having length and width (mm) of l_r, W_r and l_{stub}, W_{stub} with corrugated metal strip on them having length and width (mm) of Δl_r, ΔW_r, and Δl_{stub}, ΔW_{stub} respectively. Since, it is a symmetrical structure hence; its operational mechanism can be expressed as:

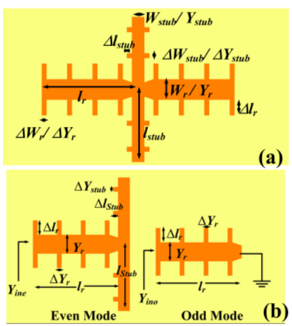

Fig. 3. (a) Proposed resonator, and (b) Its even-odd mode equivalent circuits.

$$Imag\,[Y_{ine}] = \frac{Y_r.(M + jY_r \tan(\beta l_r))}{Y_r + jM \tan(\beta l_r)} = 0$$

where $M = 2jY_{stub}\tan(\beta l_{stub}) + 4j\Delta Y_{stub}\tan(\beta l_{stub})$

for even mode (1)

$$Imag\,[Y_{ino}] = -jY_r \cot(\beta l_r) + 8\Delta Y_r \tan(\beta \Delta l_r) = 0$$

for odd mode (2)

According to the analysis of (1) and (2), its dual mode frequencies (even and odd) can be controlled by resonator's structural parameters. Like l_r controls both the even and odd modes frequencies while l_{stub} influenced only the even mode frequency. Along with it, l_{stub} can also control the frequency offset between even and odd mode frequencies. So by properly contolling the physical parameter of the proposed resonator, and coupling gap, dual-band response can be achieved through the proposed resonator.

III. Simulation and Experimental Results

To validate the proposed design, the SSPP based dual-band filter has been fabricated with optimized physical parameters of the proposed multi-mode resonator which are found as:

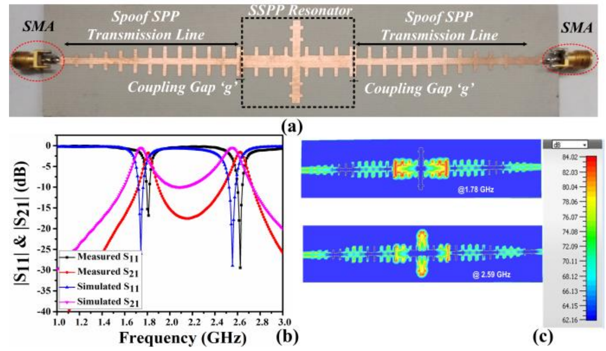

Fig.4 Proposed SPP dual-band BPF (a) Fabricated prototype, (b) S parameter response, (c) Electric field distribution at pass-band frequencies.

$W_{stub}=2.5$, $l_{stub}=14$, $\Delta W_{stub}=1$, $\Delta l_{stub}=1$, $W_r=4$, $l_r=19$, $\Delta W_r=1$, $\Delta l_r=4$. Fig. 4 illustrates the fabricated prototype of the proposed filtering structure, corresponding S parameter response and electric field distributions at both the pass-band center frequencies i.e. at 1.78 GHz and 2.59 GHz. From E-field distribution, one can observe that first band is obtained at 1.78 GHz using odd mode of the resonator while second band is obtained at 2.59 GHz using even mode of the resonating structure. Measured insertion losses are ~1.5dB and return losses are better than 15dB for both the pass-bands.

IV. Conclusions

In this paper, a SSPP based dual-band band-pass filter using multi-mode butterfly resonator has been designed and developed at microwave frequency. Operational mechanism of the proposed butterfly shape resonator has been described using the even-odd mode analysis. Subsequently, the proposed butterfly shape resonator has been used to develop the dual-band filter. The designed band-pass filter has been fabricated on a microwave laminate and characterized through Keysight Field fox analyzer *N9918A*. This proposed dual-band band-pass filter will pave an important role in multi-band plasmonic-based circuits and systems.

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