

Dual Bandpass Waveguide Filter Based on Spoof Surface Plasmon Polaritons

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Abstract — This paper introduces a dual bandpass waveguide (WG) filter based on spoof surface plasmon polaritons (SSPPs). Waveguide filters are inherently high-pass, and by incorporating an SSPP transmission line in the direction of the dominant mode wave propagation, a bandpass filter (BPF) can be achieved. The physical dimensions of the waveguide and SSPP transmission line respectively determine the low and high cut-off frequencies of the bandpass filter. Positioning the split ring resonators (SRRs) near the SSPP transmission line results in the formation of a notch band at the resonance frequency of the SRRs, thereby achieving the dual bandpass transmission properties of the waveguide filter. By altering the thickness of the SRRs, one can modify its resonance frequency and thus the frequency of the notch band.

The bandpass of the suggested waveguide filter remains under 0.5 dB within the frequency ranges of 8.05 to 9.75 GHz and 10.65 to 13.15 GHz, with a notch band frequency located at 10.45 GHz.

Keywords — waveguide filter, dual bandpass filter, spoof surface plasmon polaritons.

I. INTRODUCTION

Currently, wideband and multiband filters are in great demand for wireless communication, radar, and satellite applications. Waveguide filters offer minimal insertion loss, superior power handling, and outstanding electromagnetic shielding in comparison to microstrip and substrate integrated waveguide (SIW) filters. Researchers are examining various design techniques for waveguide filters, including classical mode matching, electromagnetic-based equivalent circuit approaches, and coupled mode theory.

This paper proposes a dual bandpass filter for operation within the Ku band. The design procedure includes two primary steps. In the initial one, a single bandpass filter is created for the operational bandwidth of 8-13.15 GHz. The lower cutoff frequency of the bandpass filter is defined by the cutoff frequency of the WR75 waveguide. Additionally, the higher cutoff frequency is defined using the cutoff frequency of the unit-cell dispersion diagram. In the following step, an SRR is positioned near the SSPP transmission line. Consequently, at the SRR's resonant frequency, a notch band forms. The notch frequency can be modified by altering the physical dimensions of the SRR.

In the optical and infrared frequency range, the electromagnetic (EM) characteristics of metals resemble those of dielectric materials but with a negative dielectric constant. This feature results in confining EM waves with a dominant TM mode at the boundary between metal and free space, referred to as surface plasmon polariton (SPP). This indicates that the

wave includes charge movement within the metal (surface plasmon) and electromagnetic waves in the air (polariton). In the millimeter wave frequency range, the dispersion diagram of periodically corrugated metal structures resembles surface plasmon polaritons (SPPs), and these are referred to as spoof SPPs (SSPPs). A range of different planar microwave components utilizing SSPPs are developed, including power dividers [1], filters [2], circulators [3], duplexers [4], and power amplifiers [5].

II. DESIGN OF DUAL BANDPASS WAVEGUIDE FILTER WITH APPROPRIATE UNIT-CELL

As we know, a WR75 waveguide functions as a high-pass filter with a cutoff frequency around 8 GHz. Conversely, an SSPP transmission line (TL) acts as a low-pass filter, with its cutoff frequency being defined by its dispersion curve.

Thus, combining a WG structure with an SSPP TL facilitates the development of a bandpass filter.

In this research, we use an SSPP TL constructed from H-shaped unit-cells to determine the upper cutoff frequency of the bandpass filter. The configuration of the ungrounded unit-cell printed on a 0.508mm thick Rogers RO4003C substrate, along with the appropriate boundary conditions for acquiring its dispersion diagram in CST software, is shown in Fig. 1. The dispersion curve for the unit-cell shown in Fig. 1 is illustrated in Fig. 2.

Consequently, by positioning the SSPP TL at the middle of the WG as illustrated in Fig. 3, and gradually altering the arm lengths of the H-shaped unit-cells, the requirements of impedance, momentum, and mode matchings can be satisfied within the 8-13.15 GHz.

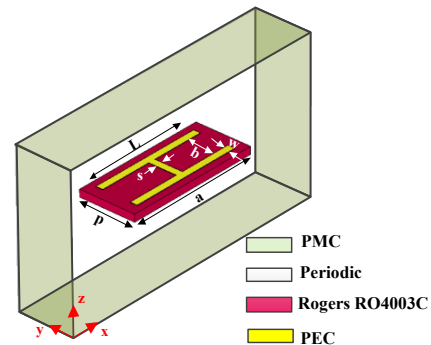


Fig. 1. Schematic of H-shaped unit-cell with appropriate boundary condition in eigenmode solver of CST software ($a=9.525\text{mm}$, $w=s=0.5\text{ mm}$, $b=2\text{ mm}$, $p=4\text{ mm}$).

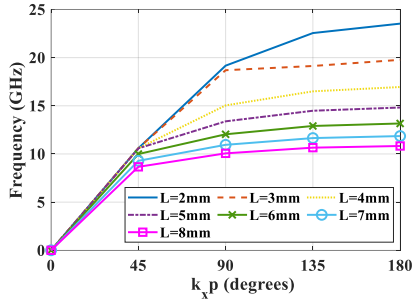


Fig. 2. Dispersion diagram of H-shaped unit-cell shown in Fig. 1.

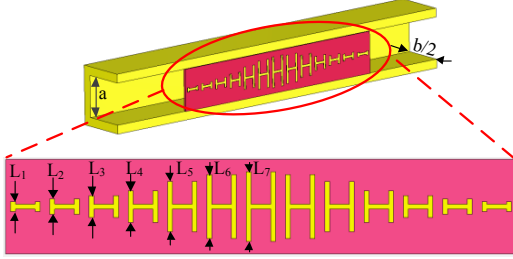


Fig. 3. Cross-section of the WG bandpass filter structure with an SSPP TL.

Table 1 and Fig. 4 provide the optimized arm lengths of unit-cells in the CST software and the frequency response of the bandpass filter, respectively.

Table 1. The optimal values of the physical parameters of the bandpass filter shown in Fig. 3.

parameter	value (mm)	parameter	value (mm)
L_1	1	L_6	6.424
L_2	1.568	L_7	6.524
L_3	2.215	a	9.525
L_4	3.18	b	19.05
L_5	5.072		

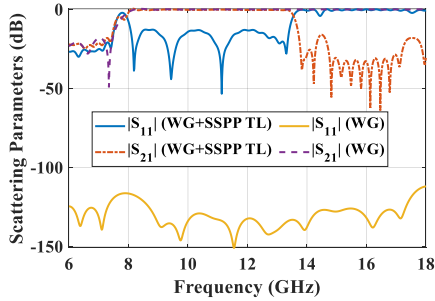


Fig. 4. Frequency responses of WG and WG+SSPP TL structures.

In the subsequent step, by incorporating two SRRs into the central unit-cell of the SSPP TL, we aim to form a notch in the bandpass filter response and achieve a dual-band filter. The schematic of the SRRs is depicted in Fig. 5. Additionally, the physical parameters of the SRRs as well as the frequency response of the dual-band filter are presented in Table 2 and Fig. 6, respectively.

Table 2. The values of the physical parameters of the SRRs.

parameter	g_c	L_c	W_c	t_c	s_c
value (mm)	0.1	2.4	1.3	0.25	0.1

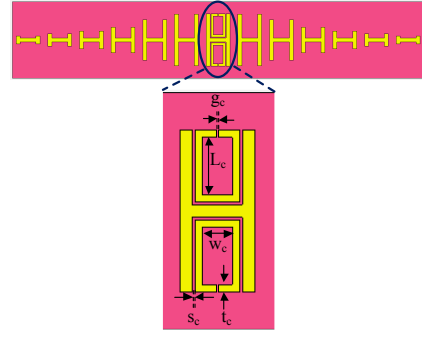


Fig. 5. Configuration of incorporating two SRRs into the central unit-cell of the SSPP TL.

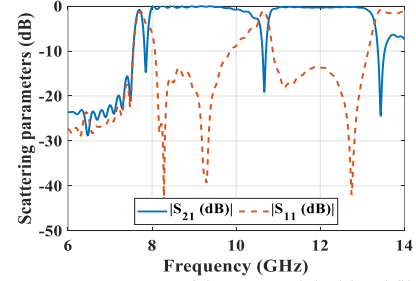


Fig. 6. Frequency response of the proposed dual-band filter.

Additionally, Fig. 7 demonstrates how the resonator thickness (t_c) affects the notch frequency.

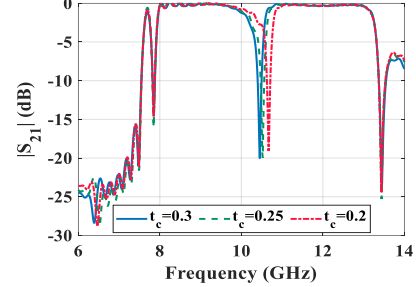


Fig. 7. Impact of the resonator thickness (t_c) on the notch frequency.

III. CONCLUSION

In this paper, a dual bandpass WG filter based on SSPP TL is presented. The notch frequency was implemented with SRRs, can be adjusted by altering the thickness of the SRRs.

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