Metamaterial-Inspired Bandpass Filter for the Terahertz Goubau Line

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Abstract

Recently, it has been shown that a single wire Goubau line that supports surface wave propagation can be used as an effective terahertz waveguide with low attenuation and low dispersion. In order to fully exploit Goubau lines in terahertz systems, for example for communication applications, structures such as different types of passive filters are required. This paper demonstrates that metamaterial elements can be used as building blocks for realization of compact bandpass Goubau line filters.

1. Introduction

Despite the emerging interest in terahertz systems and their applications in sensing, imaging and communications, there is still a need for efficient low-loss waveguides in the terahertz regime. Even though hollow waveguides and two-conductor transmission lines such as coaxial cables and microstrip lines are efficient for low to moderate radio-frequency operation, scaling these waveguides for terahertz applications is not an efficient solution because of the finite conductivity of metals at this higher frequency range. On the other hand, in spite of their high efficiency, conventional optical interconnections such as optical fibers are bulky and can not be integrated in planar technologies [1, 2]. Surface electromagnetic waves that propagate along the interface of a dielectric and a conductor, so-called surface-plasmon polaritons (SPPs), are one possible solution that has been proposed for realization of high speed on-chip interconnections, where thin metal circuitry can be used for carrying both the optical signals and electrical currents [1]. In particular, it was shown in [3] that a bare Goubau-like single metal wire that supports the propagation of surface waves [4, 5, 6] can be used as an efficient terahertz waveguide with low attenuation and low dispersion.

In order to exploit the propagation of surface waves on single wire in real applications, effective passive structures such as various types of filters are required. A bandstop filter based on the corrugated planar Goubau line (PGL) has been studied in [7]. It was shown that the structure provides a stopband characteristic for surface plasmon polariton propagation. More recently, an application of metamaterial resonators for filtering was investigated in [2]. A stopband in the transmission characteristics of the guided surface electromagnetic waves on a PGL was demonstrated computationally and experimentally. Also, split ring resonators (SRRs) and complementary split ring resonators (CSRRs) have been used for the design of bandpass or bandstop filters in microstrip and coplanar wave guide technologies [8, 9]. However, to the authors' knowledge, no study has been conducted on bandpass structures for PGL. In this paper we present a metamaterial-inspired bandpass filter for a modified PGL operating at sub-terahertz frequencies around 200 GHz.

2. Bandpass Filter for the Terahertz Goubau Line

In previously published work [10] Akalin et al. have presented a high-efficiency planar launching structure for a plasmonic wave on a PGL. The structure consists of a coplanar waveguide with a tapered section, which effectively converts the coplanar waveguide mode to the Goubau mode. It was also shown that adding a gap in the Goubau line results in almost no energy transmission, proving that the transmitted energy in the original structure is not due to the direct coupling of the launching sections. In the present paper, it is shown that if the gapped Goubau line is properly coupled to a pair of SRRs, as illustrated in Fig. 1, the surface wave can be transmitted across the gap via coupling through the SRRs at the resonant frequency of the ring resonators. Therefore, the resonance condition of the SRR creates a narrow passband, and there is virtually no transmission of energy in the rest of the spectrum.

The concept has been investigated with full-wave 3D electromagnetic simulation using a $400\ \mu$m thick quartz crystal with a relative permittivity $\epsilon_r = 3.78$ as the substrate. The dimensions of the coplanar waveguide to Goubau line launching structure are $w = 50\ \mu$m, $w_{\mathrm{gnd}} = 190\ \mu$m, $s = 5\ \mu$m and $l_l = 650\ \mu$m. The Goubau line has a width $w_G = 5\ \mu$m and a total length $l_G = 2100\ \mu$m including the $50\ \mu$m gap in the middle. The gap is loaded with a pair of SRRs with $a = 140\ \mu$m, $g = 10\ \mu$m and $c = 10\ \mu$m. Since the electromagnetic wave along the PGL propagates in a quasi-TEM mode, which is strongly confined around the line and decays exponentially in the

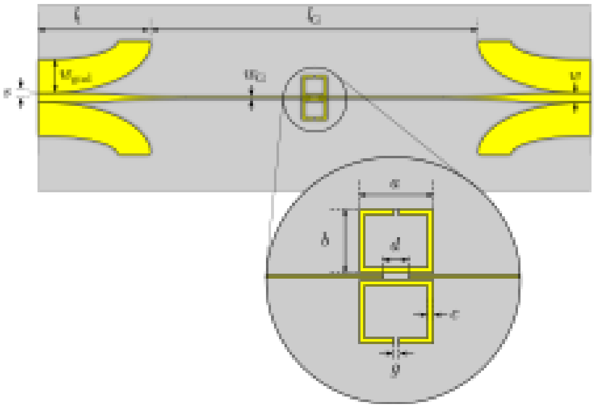

Figure 1: (a) Top view of the metamaterial inspired bandpass Goubau line structure excited by coplanar waveguide launching sections.

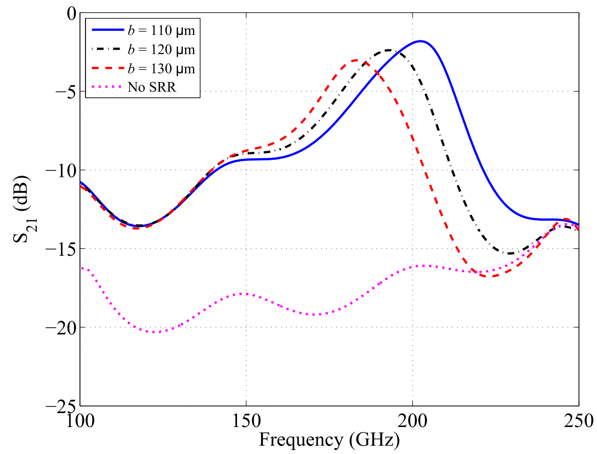

Figure 2: Simulated normalized transmission coefficients of the structure for three lateral dimensions of the SRRs, i.e. $b = 110\ \mu\text{m}, 120\ \mu\text{m}$, and $130\ \mu\text{m}$ as well as the structure without SRRs.

transverse plane, the pair of single-ring SRRs are placed close to the PGL in order to maximize the magnetic coupling between both structures.

Fig. 2(b), depicts the simulated transmission coefficient of the structure for three different values of the SRRs' lateral dimension b. Note that in order to exclude the launching sections loss, the transmission coefficients of the bandpass structure are normalized to that of a structure without the gap and SRRs. Simulation results clearly demonstrate the bandpass behavior of the proposed structure with a with a central frequency that can be controlled by tuning the SRRs dimensions. More details about higher order bandpass filters for PGL and controlling the filter's bandwidth will be presented elsewhere.

3. Conclusion

This paper presents an application of metamaterial elements in the realization of bandpass filters for the PGL at sub-terahertz frequencies. Due to the exponentially decaying transverse electromagnetic field in the Goubau mode, a pair of SRRs needs to be placed in close proximity to a gapped Goubau line for strong coupling. This strong coupling results in transmission of energy exclusively in a narrow band around the SRRs resonance. The frequency and bandwidth of the passband can be controlled by optimizing the dimensions of the SRRs. Ongoing work includes structure fabrication and measurement.

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