Modeling of 1D Dc-SQUID Metamaterials

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Abstract- We have created and examined the properties of superconducting metamaterial consisting of direct current (dc-) superconducting quantum interference device (SQUID) and superconducting rod meta-atoms.

A new generation of artificial superconducting materials has opened up new opportunities for engineering the media with the specified properties 1,2] . The recent studies indicate that metamaterial structures with superconducting elements provide both loss reduction and wideband tunability by varying the temperature or an external magnetic field. In the present work we consider one-dimensional superconducting metamaterials that is tunable over a broad frequency range. The building block of this metamaterial medium is a direct current (dc-) superconducting quantum interference device (SQUID) made of a superconducting loop interrupted by two Josephson junctions (JJ). A sketch of such a device is presented in Fig.1 (a). The time-dependent magnetic field **H**(t) is applied perpendicular to the area of the SQUID loop. As long as dc-SQUID can be considered like a single junction with an effective critical current, the equivalent lumped circuit for the dc-SQUID in a magnetic field comprises a flux source Φ_{ext} in series with the geometric inductance of the SQUID loop and JJ shunted by effective capacitor C^* and effective resistor R^* (Fig.1(b)). In order to find the medium with simultaneously negative permittivity and permeability, we combine the dc-SQUIDs with superconducting rods (Fig.1(c)). The propagation of waves in a one-dimensional array of meta-atoms is considered. We have obtained the frequencies corresponding to the electrical and magnetic resonances. The dependence of the propagation characteristics on the parameters of meta-atoms was studied. Such metamaterials are tunable with dc magnetic field and frequency. Fig. 2 shows numerical results for transmission coefficient carried out by software package COMSOL Multiphysics.

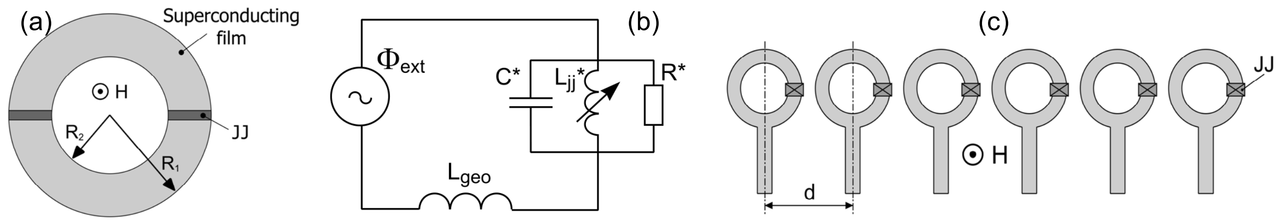

Fig.1. (a) – Schematic drawing of a dc-SQUID, (b) – Equivalent electrical circuit for a single SQUID, (c) – 1D SQUID metamaterials.

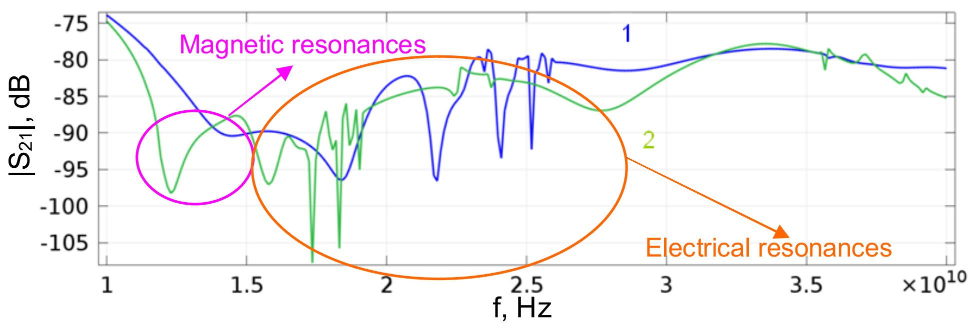

Fig.2. $|S_{21}|$ of the 12 dc-SQUID array as a function of frequency at w_r=250 μm (w_r is the thickness of the rod), R_1=400 μm, R_2=150 μm, d=2400 μm; 1 – l_r=4000 μm; 2 – l_r=6000 μm (l_r is the length of the rod)

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