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ANALYSIS OF PLANAR SUPERCONDUCTING CIRCUITS INCLUDING EFFECTS OF MAGNETIC FIELD ON COMPLEX CONDUCTIVITY

Smain Amari, Jens Bornemann, Senior Member, IEEE

and Rüdiger Vahldieck, Senior Member, IEEE

Laboratory for Lightwave Electronics, Microwaves and Communications
(LLiMiC)
Department of Electrical and Computer Engineering
University of Victoria, Victoria B.C., CANADA V8W 3P6.

ABSTRACT

The inductive properties of superconductors, in addition to their exceedingly small ohmic losses, make superconducting thin films ideal for low-loss, low-dispersion transmission lines, interconnects and microwave filters. Also, the recent discovery of high-temperature superconductors has reduced the demands on bulky and costly cryogenics required to cool the system below already low critical temperatures. Despite these advances, accurate computer models are not only desirable but are rather necessary for any efficient investigation of the properties of superconducting devices for microwave applications. Cost effective and accurate design and analysis of superconducting microwave devices rely on adequate modelling of the electrodynamic properties of the superconducting material.

In this presentation, a modified Spectral Domain Approach to analyse lossy and superconducting planar circuits is discussed. The speed of the Spectral Domain Approach is preserved by incorporating the effect of the superconducting metallic surfaces in the theory through the concept of sheet impedances for the different LSE and LSM modes. The sheet impedances, defined as the ratio of the tangential electric field to the surface current density, being a response function, depend on the field distribution as well as on the physical parameters of the structures; different LSE and LSM modes have different sheet impedances especially for thin conductors which are sensitive to the electromagnetic field distribution surrounding them. The traditional Green's impedance dyadics of the Spectral Domain Approach are modified by metallic terms which contain both diagonal as well as off-diagonal elements, especially for thin conductors where thin films distinguish between LSE and LSM modes.
To take into account the effect of the magnetic field on the constitutive parameters of the superconductor, the complex conductivity of the two-fluid model is modified through a solution of the Ginzburg-Landau equations for thin films ($t/\lambda_0 << 1$). A complex conductivity $\sigma = \sigma_1 - j\sigma_2$

which depends on the temperature and the current carried by the planar circuits is derived from the requirement of charge conservation in the spirit of the Drude model and is given by

$$\sigma_1=\sigma_n\left(\frac{T}{T_c}\right)^4+\sigma_n\frac{\left(\frac{\lambda(0,0)}{t}\right)^2\left(\frac{I}{I_c}\right)^2}{1-\left(\frac{T}{T_c}\right)^2} \qquad \text{1.a}$$

$$\sigma_2=\frac{1-\left(\frac{T}{T_c}\right)^4}{\omega\mu_0\lambda^2(0,0)}-\frac{\left(\frac{I}{I_c}\right)^2}{\omega\mu_0 t^2\left(1-\left(\frac{T}{T_c}\right)^2\right)} \qquad \text{1.b}$$

Here, λ is the penetration depth, t the thickness of the film, I_c the critical current density, I the actual current density and σ_n the conductivity in the normal state ($T=T_c$). It is easily verified that equations (1) reduce to those of the two-fluid model if the effect of the magnetic field is ignored by setting the current density I to zero.

The complex conductivity thus defined depends on the magnetic field in such a way that when a threshold value is exceeded, $I \geq I_c$, the material systematically shifts from the superconducting to the normal state. For certain values of the normal conductivity σ_n, the propagation constant of a superconducting microstrip line attains a maximum when the real and the imaginary parts of the complex conductivity are approximately equal.

Results from the present work are compared to available experimental data to document the efficiency of the approach.