From radiofrequency to infrared antennas: downscaling a rectangular loop geometry

Daniyal Khosh Maram, Joan Garcia, Raul Ruiz, Xavier Cartoixà, Gabriel Abadal
Dept. Enginyeria Electrònica, Campus UAB, 08193-Bellaterra, Spain;
e-mail: Daniyal.KhoshMaram@uab.cat

ABSTRACT

A millimeter scale rectangular loop antenna has been selected as a reference geometry to analyze the effects of downscaling to the infrared range on the impedance and resonance frequency of the antenna. CST and COMSOL numerical simulators have been used to calculate impedance and S_{11} vs. frequency curves of the reference loop antenna, to calibrate their predictions with measured curves. Once model simulators have been calibrated, the reference antenna has been downscaled by a 10^5 scaling factor to predict the behavior of the resulting IR nanoantenna.

INTRODUCTION

In the design process of an antenna, impedance vs. frequency calculation in the range of interest will give information about antenna's resonances and antiresonances. Zero crossing frequencies of the impedance imaginary part (antenna reactance, X_A) define antiresonances when crossing is produced from positive to negative X_A values and resonances in the opposite case. Only in resonances, a constructive interference effect (which is destructive in the antiresonance case) is produced on the antenna's current stationary wave since the loop perimeter is a multiple of the wavelength. Consequently radiation of the antenna is in this case maximized. Reactance, resistance (R_A, real part of the impedance), as well as the reflection coefficient curves (S_{11}) derived from impedance can be obtained numerically by standard electromagnetic simulations (CST) or analytically from RLC models [1]. In the present work we want to analyze the effect on the impedance curves and resonance frequencies of the dimensional reduction to the nanometer scale by means of CST simulations, but also using COMSOL simulator because it allows coupling to other relevant domains as mechanics [2]. This kind of coupling will be useful to describe novel transduction mechanisms between electromagnetic and mechanical domains, such as the ones reported in MEMSTENNA structures [3].

RADIOFREQUENCY RECTANGULAR LOOP ANTENNA

A 2.5 GHz cylindrical Cu wire rectangular loop antenna has been chosen as a reference structure to calibrate the simulated predictions of CST and COMSOL with S_{11} measured curves. The geometry of the antenna, as defined in figure 1, is characterized by its perimeter, p, and the radius of the wire, r. A slenderness ratio, p/r, can be defined to parametrize the relative thickness of the cylindrical wire. In figure 2 the measured and simulated S_{11} vs. frequency curves are shown. As predicted by classical RF antenna theory, the first resonance frequency, f_{res}, is produced when its corresponding wavelength, $\lambda_{res}=c/f_{res}$, equals the loop perimeter, being c the speed of light. This is evidenced by the notch frequency in the S_{11} curve or by the second zero crossing of the reactance curve (fig.3).

INFRARED RECTANGULAR LOOP ANTENNA

The 2.5 GHz reference structure has been uniformly reduced by a scaling factor $k=10^5$. Consequently, the loop perimeter is reduced from 120.4 mm to 1.204 μm, wire radius is also reduced from 0.5 mm to 5 nm and the classically expected resonance frequency would be expected to increase from 2.5 GHz to 250 THz (wavelength decreased from 120 mm to 1200 nm). However, as it was previously reported [1], the first resonance, as indicated by the second zero crossing of the reactance curve (fig. 4), is produced at a lower frequency, 170 THz, or, equivalently, at a larger wavelength, 1765 nm. Such a shift in the resonance frequency is due to the different phase velocity of currents at optical frequencies in metals. [4]

CONCLUSION

A COMSOL model of a 2.5 GHz wire rectangular loop antenna has been calibrated from CST simulated and measured S_{11} vs. frequency curves. The reference antenna has been subsequently downscaled to the IR region and the effects of metal properties at optical frequencies on the resonance frequency have been analyzed.

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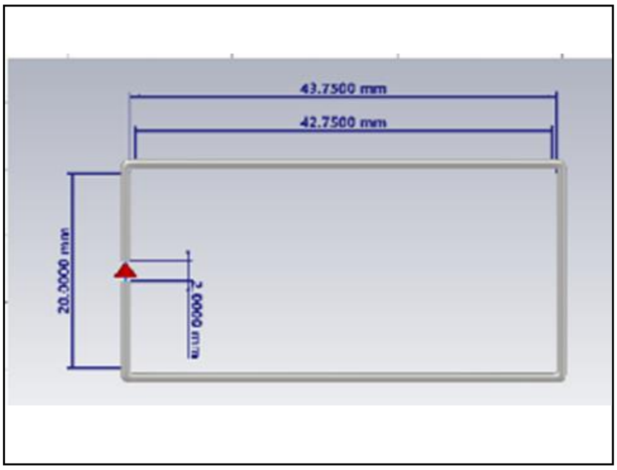

Fig. **1**. Rectangular loop antenna geometry designed to resonate at 2.5 GHz.

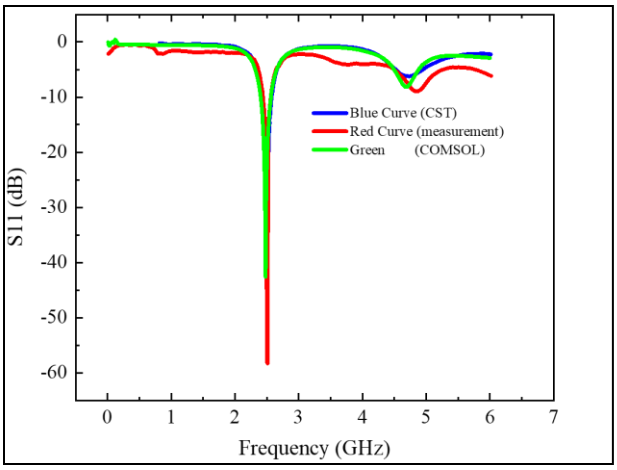

Fig. **2**. Measured and simulated S_{11} vs. frequency curves of the 2.5 GHz rectangular loop antenna defined in figure 1.

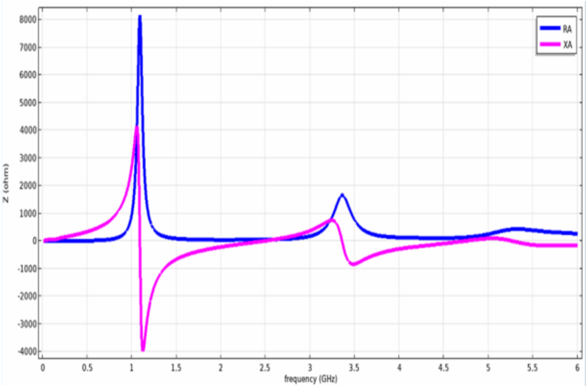

Fig. **3**. Real (R_A) and imaginary (X_A) parts of the impedance vs. frequency curves obtained by COMSOL simulations, corresponding to the reference 2.5 GHz antenna of figure 1.

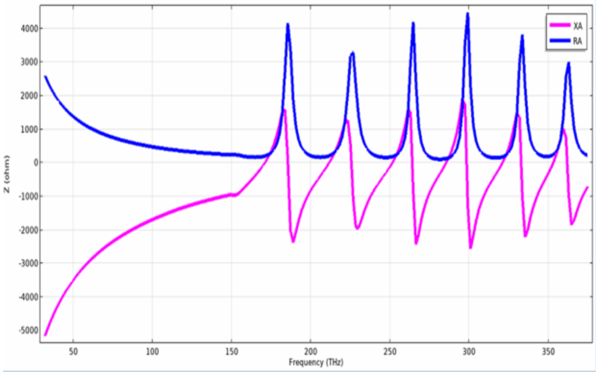

Fig. **4**. Real (R_A) and imaginary (X_A) parts of the impedance vs. frequency curves obtained by COMSOL simulations, corresponding to the IR antenna.