New Weakly-coupled Nearly Adapted Resonant Sensors for Microwave Range Measurements

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The SUSI measurement system [1], used for moisture content (MC) and salt detection in frescoes and wall paintings, is based on evanescent field dielectrometry [2]. The heart of the system is a resonant sensor allowing an estimate of the MC and of a salinity index (SI) through the measurement of the shift of its resonance frequency and of its quality factor. The original resonator consisted of a microstrip line terminating in an open coaxial, with the feeding and coupling lines coupled to the resonator through a coplanar gap.

The development of a standalone measurement system makes it necessary to design a probe having the lowest possible impedance mismatch in the feeding and coupling lines, to allow the generator (based on a PLL synthesizer) to work in proper conditions.

Moreover, coplanar gaps are not very reproducible with cheap consumer PCB technology.

The adopted solution is a different coupling method based on a slot aperture in a plane between the coupled lines. Terminating both lines on their characteristic impedance, allows the sensor to work in nearly matched conditions in all working situations. The coupling factor is tunable and reproducible with a quite high precision.

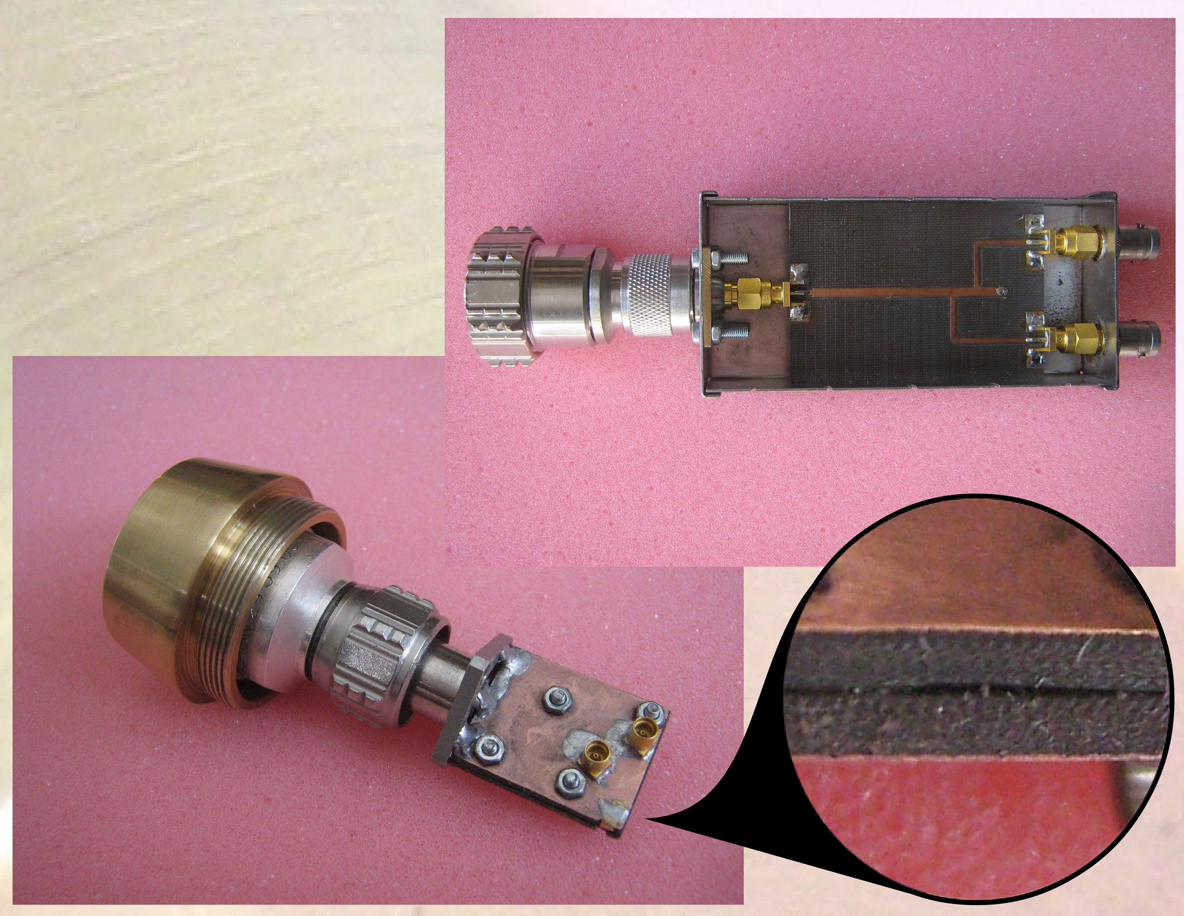

Fig. 1 – The first sensor prototype with resonant and coupling lines realized as microstrips and a more recent version realized with a stripline structure.

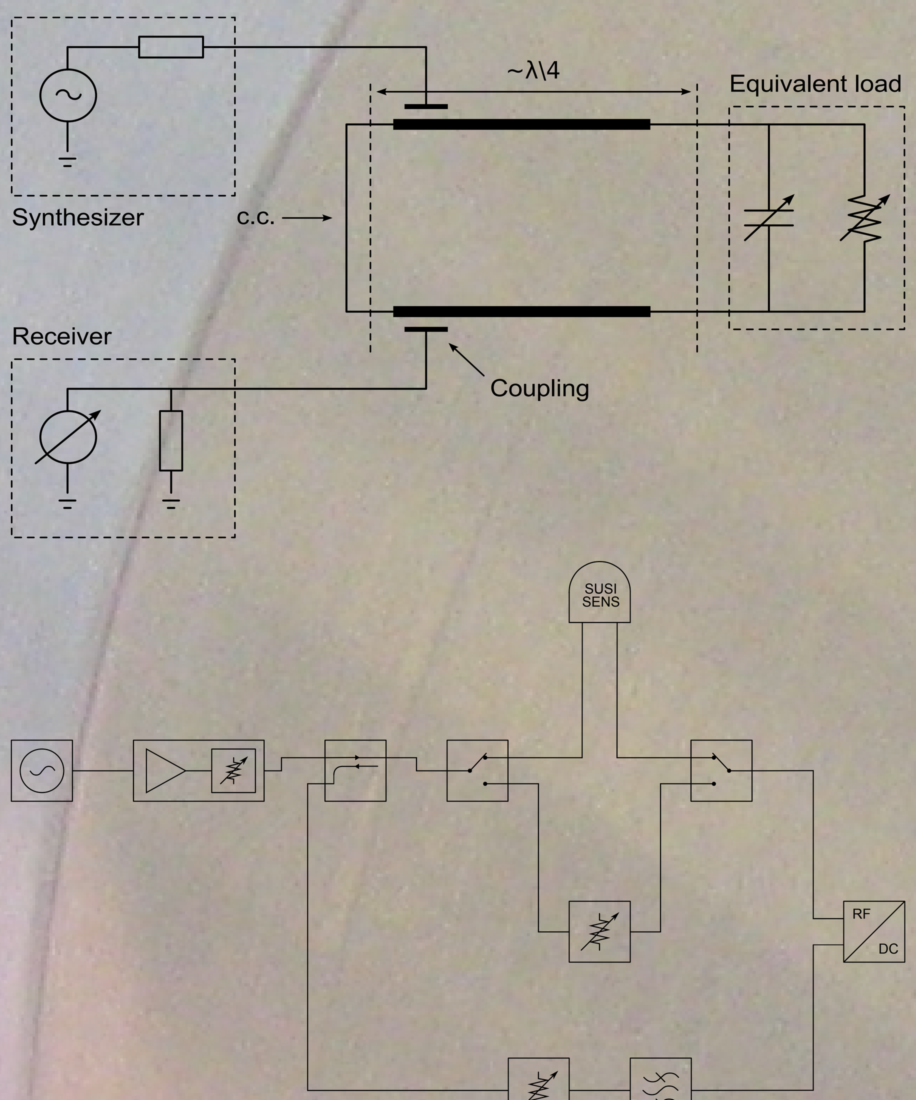

Fig. 2 – Two diagram of the measurement system representing respectively the sensor working principle on the top and the standalone system blocks on the bottom.

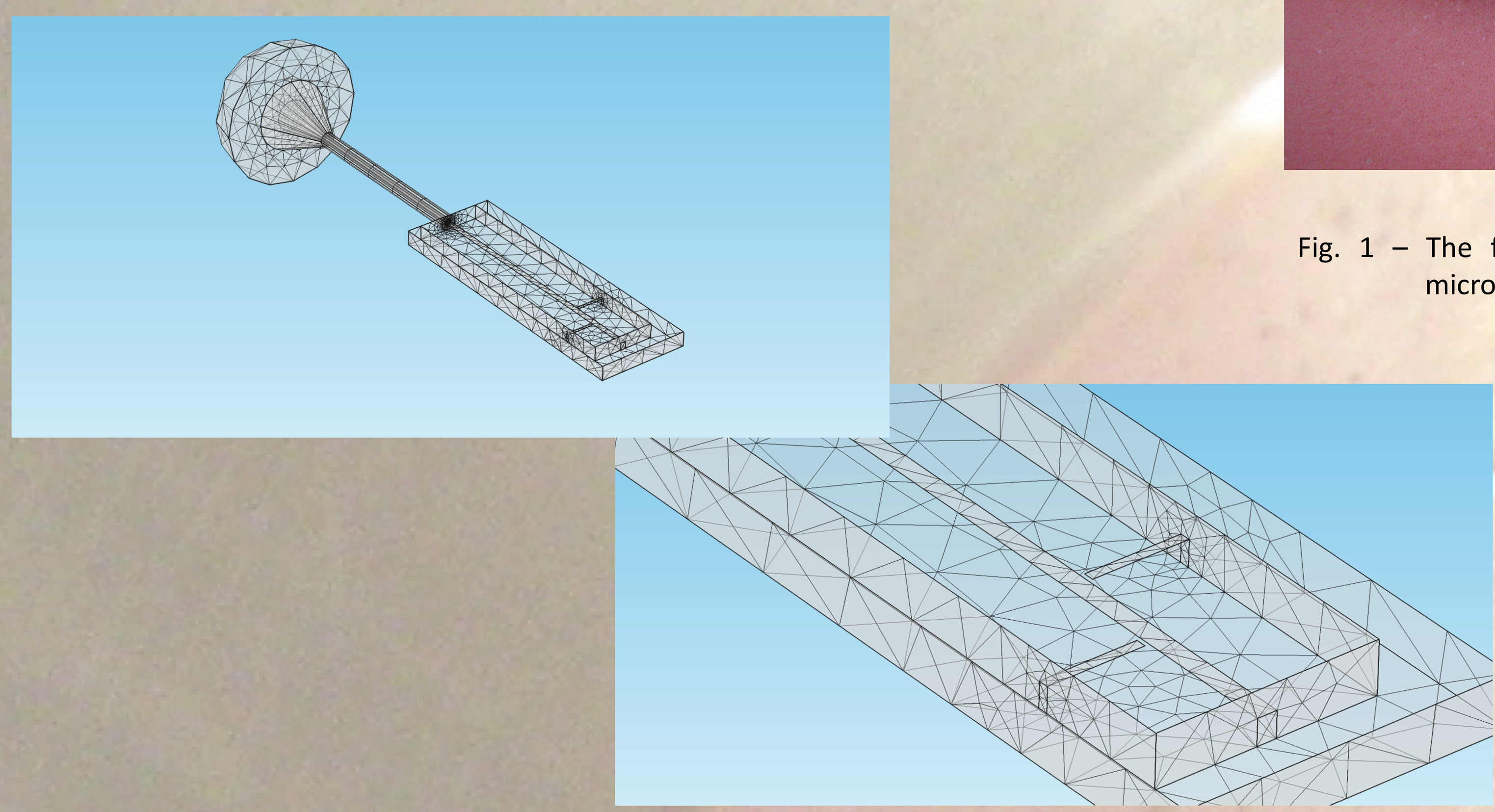

Fig. 3 – The model used for the full-wave simulation of the presently used sensor and a particular of the mesh on the coupling points.

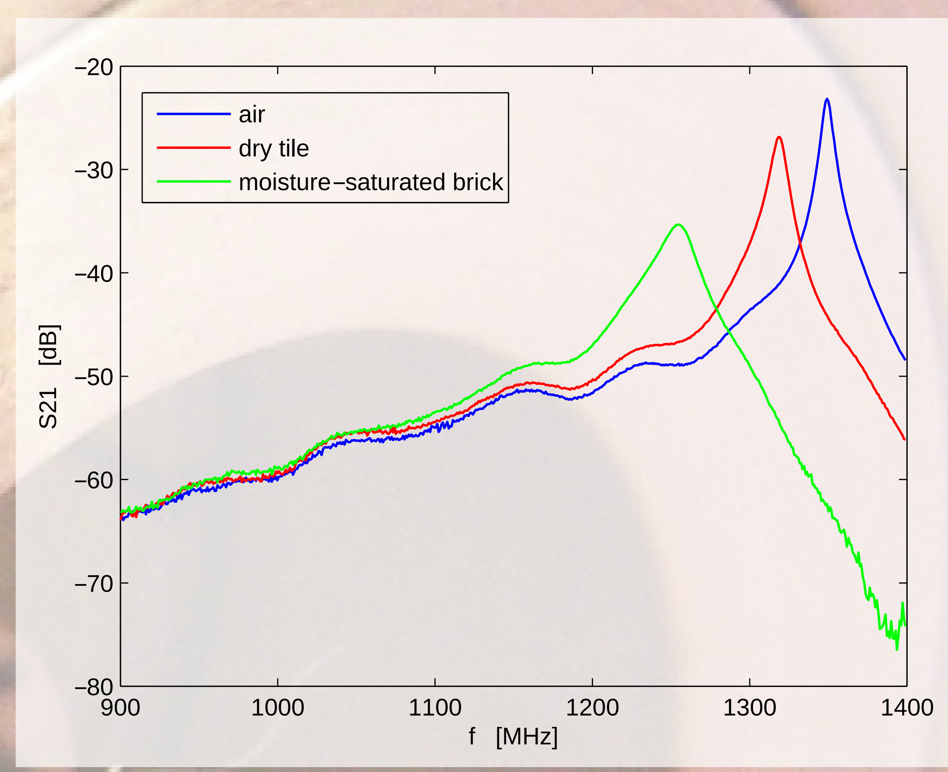

Fig. 4 – The sensor reply on different measurement conditions

The problem of two microstrip lines coupled through a slot on a common ground plane has been solved by several approaches, in particular by using the reciprocity theorem and the moment method like [3,4].

A fullwave analysis based on the finite element method shows that an approximated solution based on a parallel-plate waveguide transformation of the strips and the radiation of equivalent magnetic and electric dipoles as done in [5,6] gives reasonably accurate results for collinear lines and rectangular apertures, allowing us to express the coupling factor as a function of lines and slot dimensions.

$$C = \begin{cases} -20\log\left(\frac{\pi a^3\sqrt{\epsilon_{eff}}}{24w'h}\left(-\epsilon_0\eta_0 + 2\frac{\mu}{\eta_0}\right)\right) & a \le 2b \\ -20\log\left(\frac{\pi\omega\sqrt{\epsilon_{eff}}}{48w'h}\left(-\epsilon_0\eta_0 ab^2 + \frac{\mu}{\eta_0}\frac{a^3}{\ln\left(4\frac{a}{b}\right)-1}\right)\right) & a > 2b \end{cases}$$

$$w' = \frac{h}{Z_0}\frac{\eta_0}{\sqrt{\epsilon_{eff}}}$$

FEM simulations have been performed using COMSOL® Multiphysics 4.3 .

3D models of the resonant sensors (with different coupling methods) has been developed and the wave equation

$$\nabla \times \left(\frac{1}{\mu_r}\nabla \times \vec{E}\right) - k_0^2\left(\epsilon_r - j\frac{\sigma}{\omega\epsilon_0}\right)\vec{E}$$

has been solved by imposing a uniform excitation at the feeding and coupling microstrip lines, via “lumped” ports.

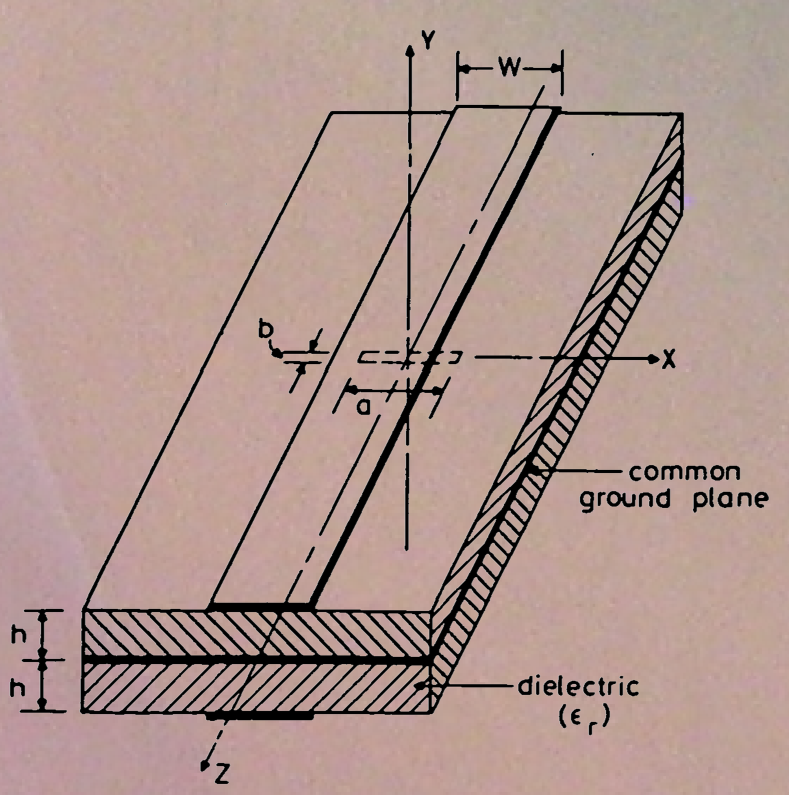

Fig. 5 – A schematic representation of the coupling problem between two microstrips through a rectangular slot in the common ground-plane.

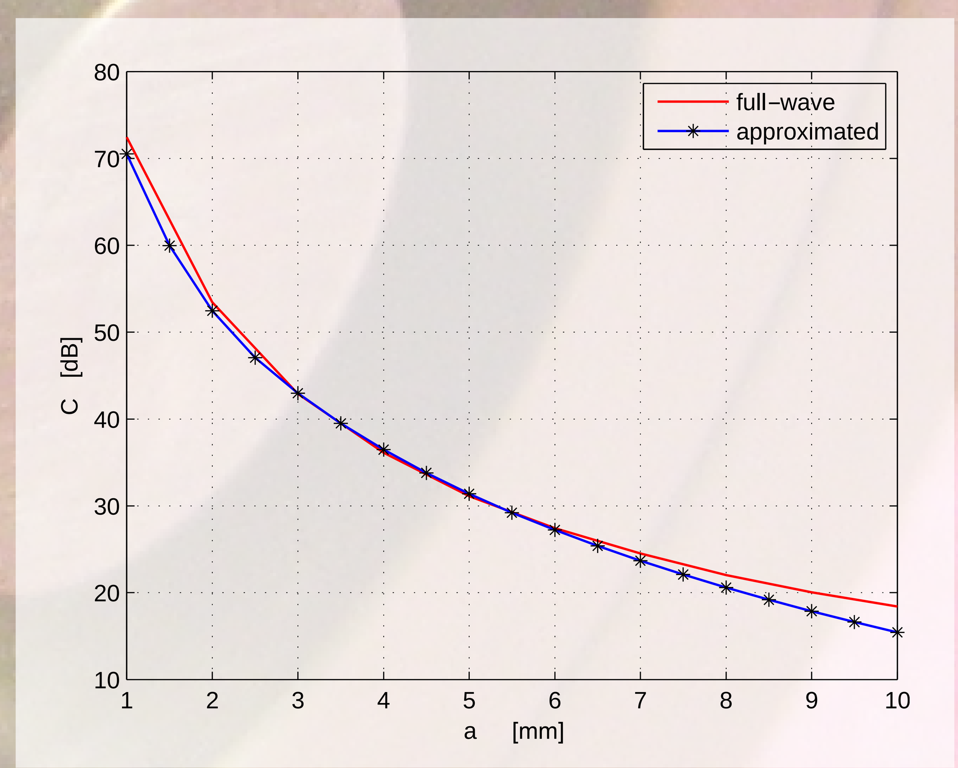

Fig. 6 – A comparison between the coupling factor obtained with a fullwave simulation and the approximate formula between two identical microstrips with w=4,3 mm, h=1,6 mm, εr=2,54 at f=3 GHz.

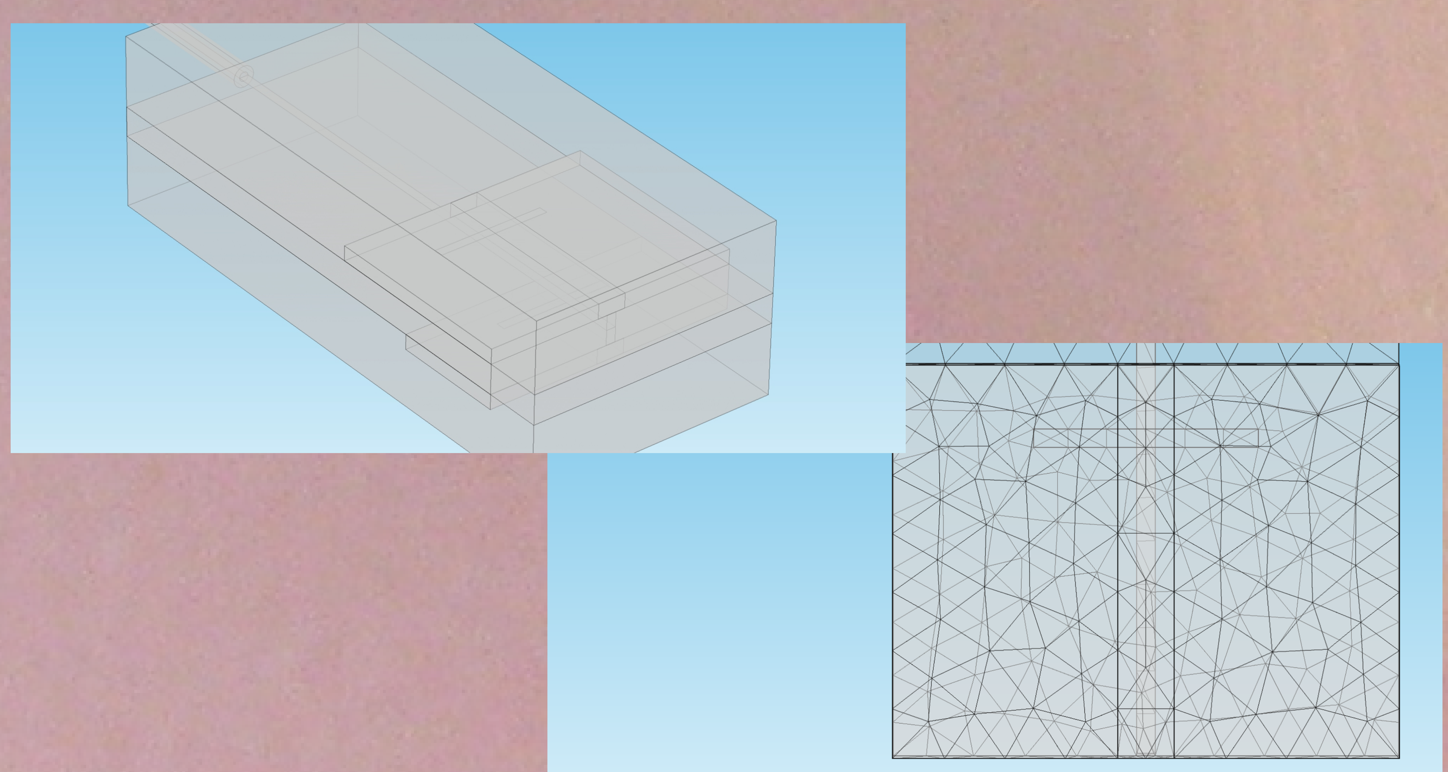

Fig. 7 – The model used for the full-wave simulation of the new sensor with slot coupling. The multilayer structure on the left and a particular of the coupling slot between the feed and the resonant lines meshed on the right.

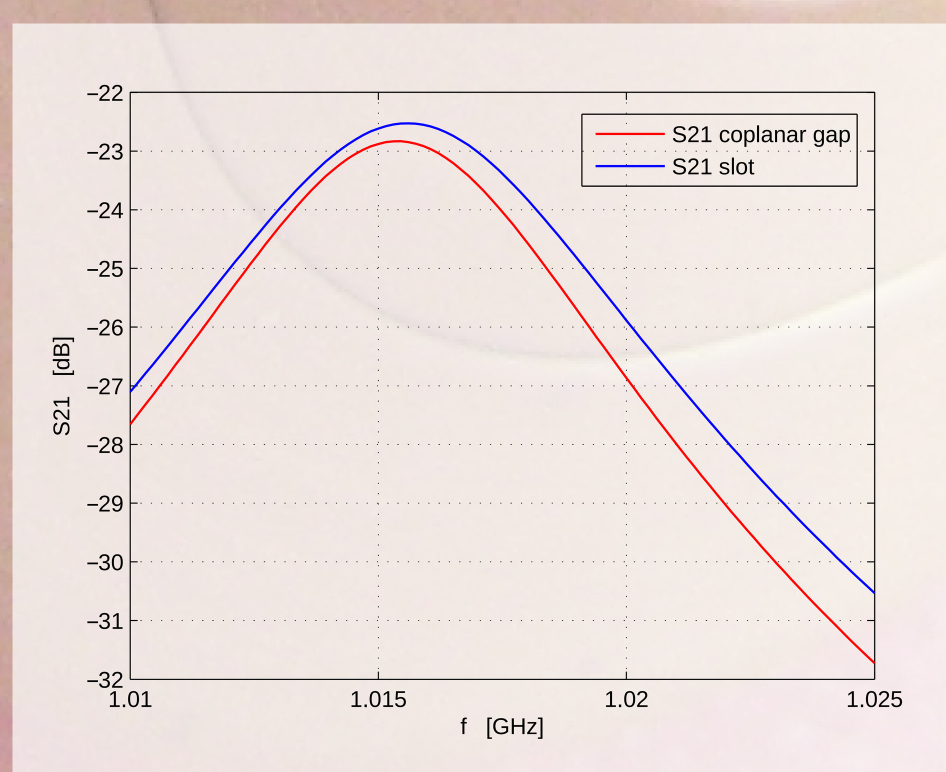

Fig. 8 – A comparison of the sensor transmission coefficient (S21) near the resonance on vacuum-condition measurement between the model of the coplanar-gap sensor and the model of the slot one.

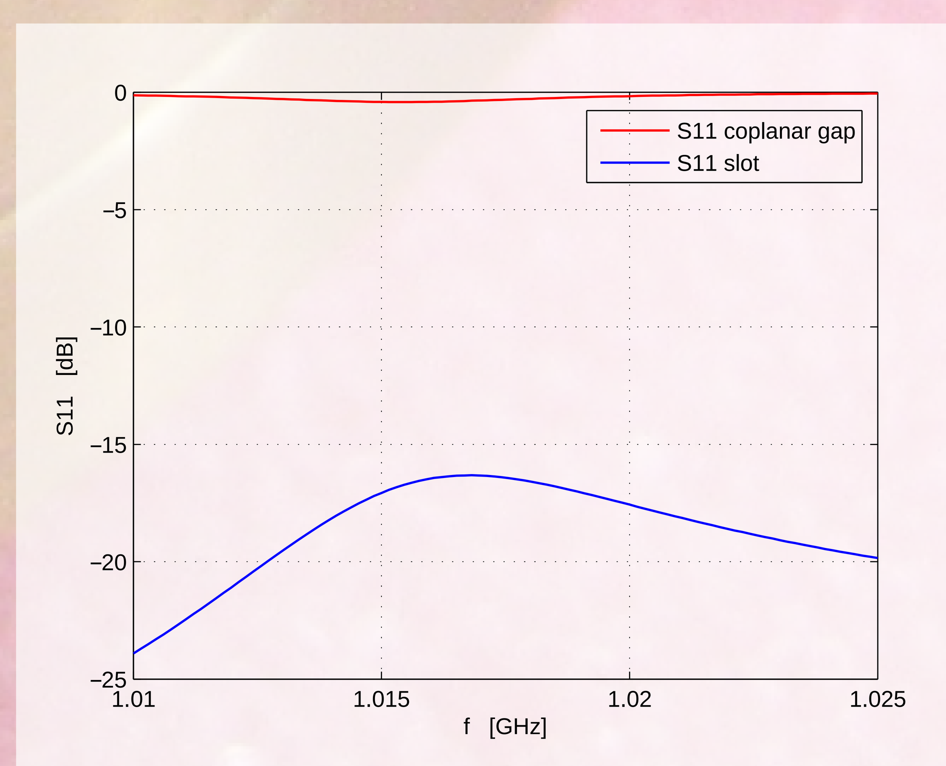

Fig. 9 – A comparison of the sensor reflection coefficient (S11) near the resonance on vacuum-condition measurement between the model of the coplanar-gap sensor and the model of the slot one.

References:

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