Experimental Extraction of the Effective Properties of Metamaterials from Measured S-parameters

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This talk overviews experimental work related to metamaterials and chiral materials at microwave frequencies and address some of the controversies surrounding effective property extraction for metamaterials. A focused plane wave beam is used to illuminate planar samples in a free space set-up. TRL calibration in conjunction with a vector network analyzer leads to the establishment of two phase and amplitude reference planes for homogenization and effective medium modeling and subsequent extraction of complex permittivity, permeability and magneto-electric coupling if any from S-parameter measurements [1, 2]. Experimental results showing negative permittivity, permeability and refractive index are presented for ordered and random metamaterials that exhibit plasmonic resonances at the frequency range of interest. Several different types of scattering elements were used to make the samples, such as C left, right and racemic mixtures of small metallic springs, metallic Omega shaped elements, combinations of split ring resonators and wire elements. It is shown that it is possible for all such scatterers to exhibit negative refraction. Good agreement is obtained with numerically simulated data for effective properties. It is shown that disordered structures can also lead to NIM behavior thus periodicity is not required. There is current controversy regarding the allowed sign of the imaginary parts of the permittivity and permeability. Experimental data confirming loss in such materials from plots of power absorption, resistive part of the complex impedance and attenuation constant is shown for those cases where one of the material properties exhibits a negative imaginary part. Homogenization methods are used by experimentalists and theorists alike to derive effective medium properties and this is discussed with reference to the experimental study. A new method for extracting the effective properties of Omega media is presented in order to obtain a third material property, the magneto-electric coupling coefficient. Omega media are non-symmetric ($S11 \neq S22$). This however does not resolve the question of negative imaginary parts of the complex properties as had been suggested by some researchers.

REFERENCES

1. *IEEE I&M*, Vol. 39, 387, 1990.
2. *Radio Science*, Vol. 29, 9, 1994.