Experimental characterization of a 6.7 GHz coaxial Bragg reflector

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A coaxial line periodically loaded by circular disks on the inner conductor is designed and constructed to act as Bragg reflector in the 4.0–9.5 GHz frequency range. This is achieved by placing 10 disks (0.35 cm thick and 6.22 cm in diameter) equally spaced by the periodic distance of 1.8 cm on a coaxial waveguide with inner and outer diameters of 6.90 and 4.22 cm. Experiments on a periodic structure made from stainless steel demonstrate a band gap of 5.6 GHz centered at the 6.7 GHz design frequency in close agreement with 3D microwave computer simulations. © *2007 American Institute of Physics.* [DOI: 10.1063/1.2782761]

Bragg reflectors are highly reflective mirrors consisting of repeated periodic structures, either in the form of a periodically loaded metallic waveguide, a multilayer film, or an arrayed dielectric. These structures exhibit so-called stopband phenomena leading to frequency-selective reflection, with applications in Gunn oscillators for integrated circuits,[1] tunable lasers,[2] high-power microwave masers,[3] and conductivity measurements in pulsed magnetic fields.[4] A stopband appears at a chosen frequency when the periodic length of the structure, i.e., the spacing between discontinuities, is one-half wavelength in the unloaded guide or in the dielectric without grating. The reflected waves interfere so strongly that no direct wave at all can be propagated through a lossless and infinitely long guide of this sort. This is the phenomenon which, in x-ray diffraction, becomes Bragg reflection. At a wavelength outside the band gap the reflected waves are out of phase and cancel one another out, thus allowing the incident wave to propagate through the structure.

In this report, the filtering and electrodynamic properties of a coaxial Bragg reflector[5] are experimentally investigated by measuring its band gap and determining the spatial characteristics of the $\pi+$ mode, of cosine-like character inside the unit cell and associated with a voltage standing wave with nodes coming at the disks. All made from stainless steel, the reflector consists (Fig. 1) of 10 disks 0.35 cm thick and 6.22 cm in diameter, equally spaced by the periodic distance of 1.8 cm on a coaxial waveguide with outer and inner diameters of 6.90 and 4.22 cm, respectively. Required by a TM_{020}-mode 6.7 GHz monotron under development,[5] the reflector is specifically designed to provide a wide band gap centered at 6.7 GHz center frequency.

The stopband characteristics of the Bragg reflector were experimentally investigated by determining the transmission coefficient S_{21} in the 1–15 GHz frequency range by using the experimental setup shown in Fig. 2. In measuring the resonant frequencies, the periodic structure was excited by means of a magnetic loop inserted into the left open end of the guide with the loop surface perpendicular to the cylindrical outer surface of the coaxial waveguide to ensure it operated in the transmission electron microscopy (TEM) mode. Attached to a waveguide-coaxial adapter, a broadband pyramidal horn antenna positioned at the end of the resonator was used as a receiving detector to measure the power radiated by the reflector.

The experimentally measured transmission coefficient S_{21} (continuous line) is shown in Fig. 3, along with the simulated spectrum (dashed line) obtained by using the 3D electromagnetic software CST MICROWAVE STUDIO.[6] Comparing the two plots, we see a very good agreement regarding both the stopband range (3.73–9.58 GHz) and the presence of two groups of resonant modes clustered around 10 and 12 GHz.

Another experiment consisted of determining the $\pi+$ mode electric-field longitudinal distribution by using a perturbation technique. The principle of the measurement relies on the fact that introducing a perturbing object inside the cavity causes a shift in the resonant frequency. This shift from the unperturbed resonant frequency yields a measure of the electric field intensity at the corresponding longitudinal position, according to the Slater theorem[7,8] $(f_0-f)/f_0=(\Delta W_E-\Delta W_H)/4U$, where f_0 and f are the unperturbed and perturbed resonant frequencies, respectively, U the average energy stored in the reflector cells, with ΔW_E and ΔW_H denoting the magnetic and electrical energies in the perturbing volume, respectively. This formula states that a small object placed inside a waveguide resonator produces a frequency shift directly related to the difference of the magnetic and electric energies in the volume of the perturbing object. In the case of a small dielectric sphere or cylinder of radius a and relative dielectric constant ε introduced into the cavity at the longitudinal position z, the corresponding frequency shift $\Delta f=f-f_0$, according to,[7,8] follows:

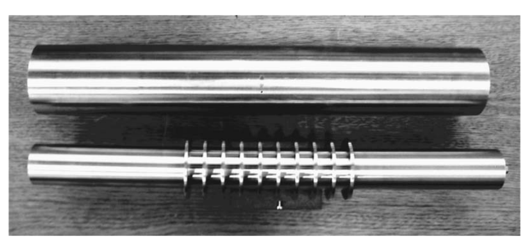

FIG. 1. Coaxial Bragg reflector disassembled showing its parts: inner structure periodically corrugated and outer cylinder.

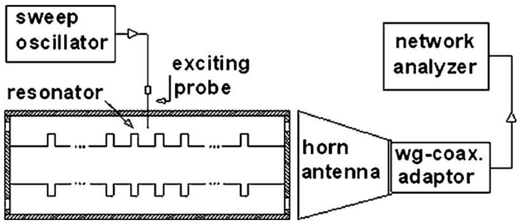

FIG. 2. Experimental setup for measuring the transmission coefficient S_{21}.

$$\frac{\Delta f}{f_0}(a,\varepsilon) \propto E^2(z). \quad (1)$$

If the perturbing object is small enough in comparison with the guided wavelength, we can assume that the electric field is nearly constant inside the volume of the loading object, and so the measured frequency shift of a given resonant mode is proportional to the square of the electric field at the perturbation position.

In the experiments to measure the π+ mode electric-field longitudinal profile, we used a cylindrical alumina bead, 3.5 mm in diameter and 1.5 mm long, suspended in the cavity by a thin nylon thread passing through its center axis, shown in Fig. 4. The motion of the nylon thread and therefore the position of the bead was adjusted by four pulleys and a spring to render the thread stretched. In the measurements, the π+ mode was excited and also detected by a pair of electric probes inserted into 1.0 mm diameter holes symmetrically drilled halfway through the outer waveguide and located midway on the length of the center cell, where the maximum peak electric field is concentrated. The signal coming from the resonator was detected by an electric probe instead of a horn antenna, for easy handling in moving the probe in and out of the coaxial structure so as to adjust the degree of coupling once the π+ mode had already been excited.

In Fig. 5, experimental measurement of the π+ mode electric-field axial distribution is compared with that calculated by using the code SUPERFISH.[9] In this case, agreement between experiments and theory is good, considering that the interaction of the perturbing bead with the electric and magnetic fields has become weaker for distances of two periodic lengths ($2d$) far from the center cell. Nevertheless, locations of the central peaks coincide with those predicted by simulation. In this experiment the π+ mode was initially tuned at 9.6975 GHz (without frequency perturbation).

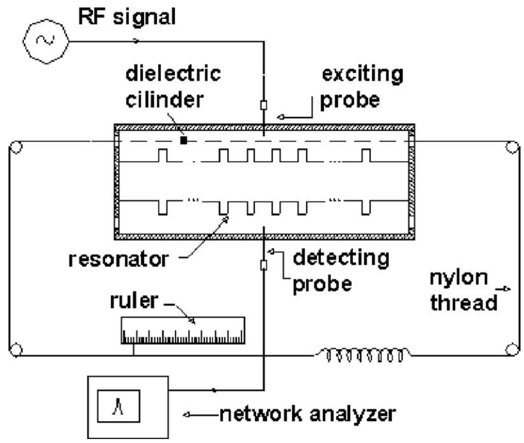

FIG. 4. Experimental setup for measuring the π+ mode electric-field longitudinal distribution.

It has been discussed that a periodic modification of the geometry of a transmission line produces Bragg reflection in some frequency bands, leading to passbands-stopbands in the frequency response, thus endowing the perturbed structure with filtering properties. Loading a uniform coaxial waveguide periodically, the perturbing element considered here is a reactive circular disk which can be represented by a normalized susceptance.[5] We have seen that loading the coaxial line with ten disks produces a band gap with a breadth of 5.6 GHz and depth of −50 dB centered at the 6.7 GHz design frequency. Featuring a corrugated inner conductor (instead of the outer one) for ease of machining and assembling, the selected geometry is easy to implement at millimeter dimensions. Manufactured from stainless steel, a coaxial Bragg reflector containing a corrugated inner conductor with ten disks equally spaced was experimentally studied. Experiments were implemented to verify the filtering properties of the periodic structure, for which the measured band gap centered at around 6.7 GHz appears to be in close agreement with that calculated by CST code. Using a perturbation technique, the electric-field longitudinal distribution was determined to characterize the π+ mode, which is resonant at the measured frequency of 9.6975 GHz. Concerning resonance properties of the coaxial Bragg reflector, the experiments confirmed the expected behavior of the designed device.

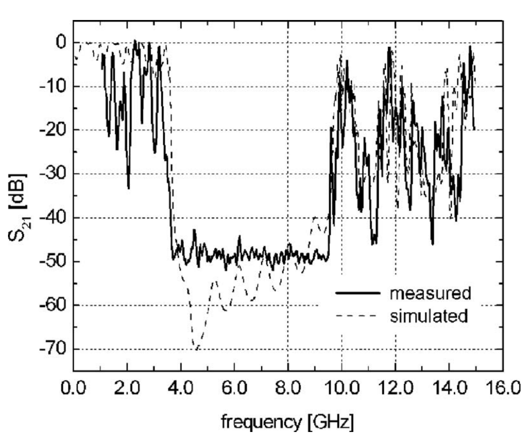

FIG. 3. Measured (continuous line) and simulated (dashed line) transmission coefficients S_{21}.

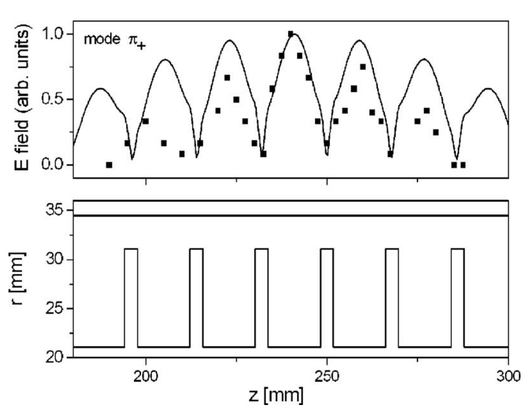

FIG. 5. Simulated π+ mode electric-field longitudinal distribution (continuous line) and measured (square data points) electric field strength.

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