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# Comparison of spinning centimetric resonant electric and magnetic dipoles with microwaves

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## Abstract

An experimental study of the rotation of two resonant systems is carried out using a microwave, to compare two mechanisms for transferring Angular Momentum from a wave to matter. The first is a Split Ring Resonator, a magnetic dipole driven by Laplace forces, the second is a Half Wave Dipole, an electric dipole driven by Coulomb forces. The result is, for the same mass, a higher initial acceleration for the former and a higher torque for the latter. The limits and perspectives of this work are discussed.

## I. INTRODUCTION

Electromagnetic wave carries a momentum, that can be divided into two [1, 2, 3] : *the linear momentum*, which corresponds to the wave's ability to exert a pressure on a surface to which it is exposed ; and the angular momentum (AM) of an electromagnetic wave, which corresponds to the wave's ability to rotate an object. With the paraxial approximation, the AM can be subdivided into two components: the spin angular momentum (SAM) associated with the circular polarization of light, and the orbital angular momentum (OAM) of the wave.

All these properties of the wave have been experimentally demonstrated [4]. The first measurements of linear momentum were carried out independently by Lebedew [5] and Nichols and Hull in 1901 [6, 7]. Beth [8, 9] and Holbourn [10] were the first to measure a SAM (in the optical field) and He [11] was the first to measure the OAM (also in the optical field). Experimental demonstrations have also been carried out in the microwave range [12, 13, 14].

The above-mentioned works describe the observed movements by a transfer of momentum from the wave to the matter set in motion. They do not describe the mechanisms of this transfer. In 2023, we carried out a theoretical and experimental study to describe and explain a mechanism of transfer through forces [15]. We use a Split Ring Resonator (SRR) and Laplace forces as an example.

This paper proposes an experimental study that involves two mechanisms of angular momentum transfer between waves and matter - Coulomb forces and Laplace forces - allowing a comparison between the two.

## II. EXPERIMENTAL SETUP

Two resonant centimetric objects, exposed to a circularly polarized wave, are being studied.

### A. Circularly polarized microwave

The circularly polarized wave, carrying a SAM, is obtained by superimposing two TE<sub>11</sub> modes perpendicularly and in phase quadrature in a cylindrical guide, as described in [15].

### B. Magnetic dipole - SRR

A Split Ring Resonator (SRR) is used as a magnetic dipole.

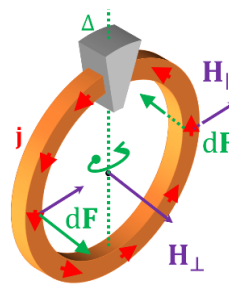


Figure 1 : Generation of a torque on a SRR using Laplace forces

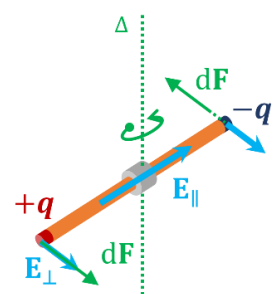


Figure 2: Generation of a torque on a half-wave electric dipole using Coulomb forces

The experimental SRR used is the same as the one described in [15], with a diameter of 15 mm, with a 1 mm<sup>2</sup> square cross-sectional area and a rotational inertia of the order of  $J_{\Delta,SRR} = 1,2 \cdot 10^{-8} \text{ kg} \cdot \text{m}^2$ .

As shown in Fig. 1, AM is transferred through Laplace forces. The incident wave induce an electric current  $\mathbf{J}$ , that interacts with the magnetic field  $\mathbf{H}$  according to (1).

$$\mathbf{F}_L = \mathbf{J} \times \mu_0 \mathbf{H} \quad (1)$$

By exploiting the SRR's first resonance mode, the resulting force is a torque along the  $\Delta$  axis. See [15] for further details.

### C. Electric dipole - Half-wave dipole

A Half-Wave dipole (HWD) is used as an electric dipole. The experimental HWD used is 5.9 mm long, with a 1.5 mm<sup>2</sup> circular cross-sectional area, and a rotational inertia of the order of  $J_{\Delta,HWD} = 2.4 \cdot 10^{-8} \text{ kg} \cdot \text{m}^2$ .

As shown in Fig. 2, AM is transferred through Coulomb forces. The incident wave generates electric charges  $q$  of opposite sign at the dipole's extremities. These charges interact with the electric field  $\mathbf{E}$  according to (2).

$$\mathbf{F}_C = q \cdot \mathbf{E} \quad (2)$$

The resulting force is a torque along the  $\Delta$  axis (which cannot be obtained from Laplace forces).

#### D. Method and measurements

The two dipoles are suspended from a spider's thread, and only the initial time average acceleration (from the first turn)  $\langle \alpha_{\Delta, res} \rangle$  is measured. The initial time average torque  $\langle \Gamma_{\Delta, res} \rangle$  is then deduced. See [15] for further explanations.

### III. EXPERIMENTAL RESULTS

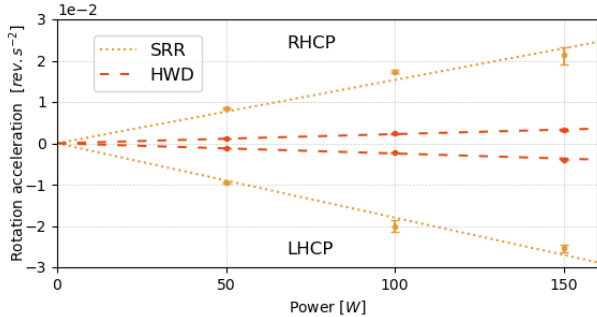


Figure 3 : SRR and HWD gross initial rotation acceleration as a function of the input power, at resonance frequency, for right and left hand circular polarization.

#### A. General observations

For both SRR and HWD, Fig. 3 shows an initial acceleration that is linearly dependent on power, and of opposite sign when the direction of polarization of the incident wave is reversed, as expected.

It may be noted that the results are quantitatively different (lower acceleration) than those we obtained in [15], probably mainly because the wire used is not the same. However, the aim of this article is not to achieve high performance, but to compare the forces and accelerations obtained for the two dipoles, and thus the two AM transfer mechanisms involved.

#### B. Comparison between the SRR and the HWD.

To compare the two dipoles, values are normalized by their mass. Table 1 summarizes them. Note that the normalized rotational inertia of the SRR is almost 10 times lower than the one of the HWD, as its mass is closer to its axis of rotation. The normalized acceleration obtained for SRR is higher than that of the HWD.

In contrast, the torque obtained with HWD is stronger. As the charges are concentrated at the ends of the dipole, the lever arm is greater.

Table I : MASS-NORMALIZED VALUES AT RESONANCE FREQUENCY FOR A GENERATOR POWER OF 150 W

Quantities	Units	SRR	HWD
$J_{\Delta, m}$	$[kg \cdot m^2 \cdot kg^{-1}]$	$2.8 \cdot 10^{-5}$	$2.9 \cdot 10^{-4}$
$\langle \alpha_{\Delta, res, m} \rangle$	$[rev \cdot s^{-2} \cdot kg^{-1}]$	$9.9 \cdot 10^{-6}$	$2.9 \cdot 10^{-6}$
$\langle \Gamma_{\Delta, res} \rangle$	$[nN \cdot m]$	1.8	5.3

#### C. Discussions on the experimental results

Both SRR and HWD are resonant dipoles. Measurements were taken at 2.47 GHz. However, given the experimental set-up, it is not possible to state that the resonant frequencies are exactly the same. The influence of a possible shift in their

resonant frequencies cannot be precisely quantified. The resonance quality factor is not known either.

No precise quantified study of these results should therefore be made. The results presented in this article are only first results for purposes of understanding and comparison.

### IV. CONCLUSION

This article focuses on two angular momentum transfer mechanisms between waves and matter, which are Coulomb and Laplace forces.

In order to enable a comparison between the two, the rotation of a magnetic dipole (a SRR) and an electric dipole (a HWD) by a circularly polarized wave is experimented. Our experimental setup described in [15] is used. As a result, the electric dipole used rotates more slowly than the magnetic dipole, but generates greater torque.

This is a first step towards understanding and appropriating these momentum transfer mechanisms, so that more complex systems can be envisaged, combining different dipoles for example. Resonant cavities could also be used to intensify the forces obtained.

### ACKNOWLEDGMENT

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