

ide goes back into solution, releasing heat. A pump circulates the solution between the generator and absorber.

Carbon dioxide can be an excellent refrigerant fluid for automobiles because its critical temperature is only about 88 °F (31 °C). Therefore, precooling prior to expansion can take place over a relatively wide supercritical temperature range; in contrast, the common refrigerant 134a must be condensed at one specific temperature for a given pressure.

A research group in Norway has produced mechanically actuated carbon dioxide vapor-compression air conditioners for automobiles and has shown those air conditioners to be more efficient and potentially lighter than are comparable air conditioners based on a chlorofluorocarbon refrigerant fluid. The champagne heat pump goes beyond the Norwegian research by replacing mechanical actuation with heat actuation. Potential applications (other than automotive air conditioning) for the champagne heat pump include

home and industrial heating and cooling.

*This work was done by Jack A. Jones of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1)*

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## Controllable Sonar Lenses and Prisms Based on ERFs

Compact devices without moving parts would focus and steer acoustic beams.

NASA's Jet Propulsion Laboratory, Pasadena, California

Sonar-beam-steering devices of the proposed type would contain no moving parts and would be considerably smaller and less power-hungry, relative to conventional multiple-beam sonar arrays. The proposed devices are under consideration for installation on future small autonomous underwater vehicles because the sizes and power demands of conventional multiple-beam arrays are excessive, and motors used in single-beam mechanically scanned systems are also not reliable.

The proposed devices would include a variety of electrically controllable acoustic prisms, lenses, and prism/lens combinations – both simple and compound. These devices would contain electrorheo-

logical fluids (ERFs) between electrodes. An ERF typically consists of dielectric particles floating in a dielectric fluid. When an electric field is applied to the fluid, the particles become grouped into fibrils aligned in rows, with a consequent increase in the viscosity of the fluid and a corresponding increase in the speed of sound in the fluid. The change in the speed of sound increases with an increase in the applied electric field. By thus varying the speed of sound, one varies the acoustic index of refraction, analogously to varying the index of refraction of an optical lens or prism. In the proposed acoustic devices, this effect would be exploited to control the angles

of refraction of acoustic beams, thereby steering the beams and, in the case of lenses, controlling focal lengths.

Figure 1 schematically illustrates a sonar assembly according to the proposal. A planar array of acoustic transmitting/receiving transducers would both send out acoustic signals to irradiate targets and, in the acoustic analog of a retina, sense the spatial pattern of return acoustic signals. The transmitted and return signals would be collimated and focused, respectively, by use of two acoustic lenses. The front acoustic lens would be designed to contain an ERF in multiple compartments separated by electrodes, rather than one compartment between a single pair of outer electrodes, in

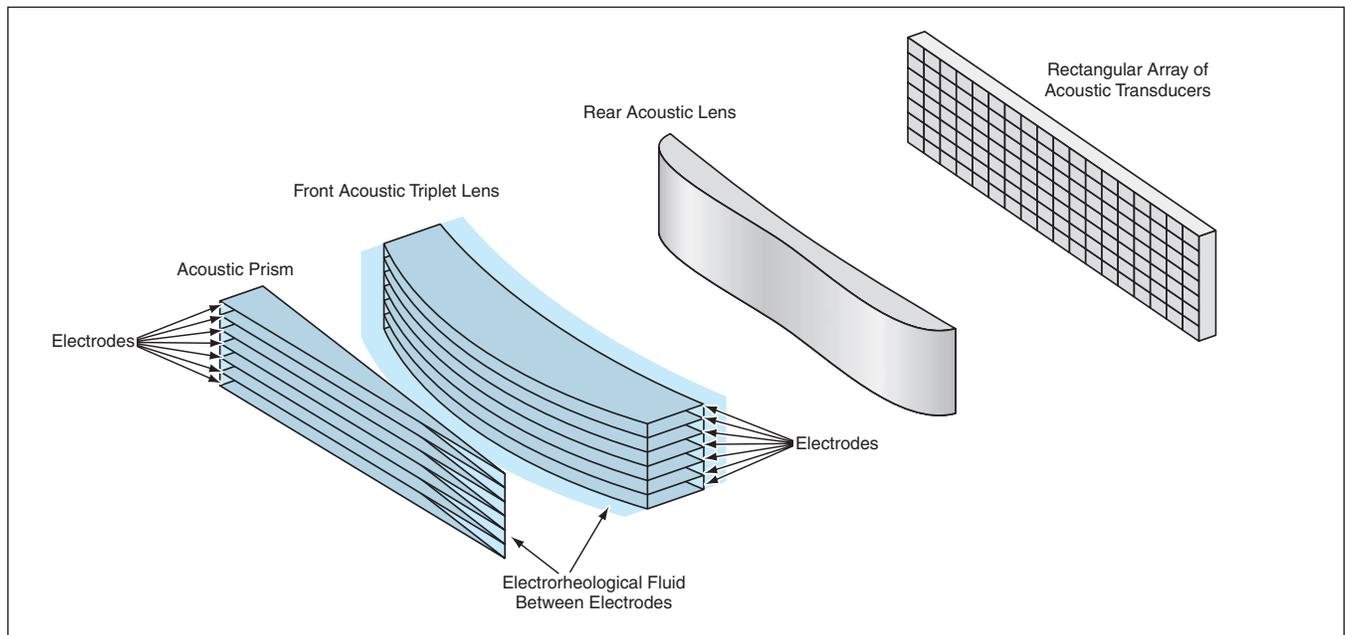


Figure 1. Electric Fields Would Be Applied to electrorheological fluids between electrodes to vary the indices of refraction of the acoustic prism and lens, thereby varying the beam direction and focal length, respectively.

order to reduce the magnitudes of the potentials needed to be applied to the electrodes to vary the focal length of the lens through the required range. A prism in

front of the front lens would also be constructed in layers, for the same reason. The index of refraction of the prism and, hence, the angle of refraction of the beam, would

be varied by modulating the potentials applied to the prism electrodes in order to steer the outgoing and incoming acoustic beams.

The concept of ERF-filled compartments separated by electrodes could be generalized and modified to that of a multicellular device comprising a rectangular array of ERF-filled cells (see Figure 2). Electrodes would be affixed to both the row and the column walls between cells, so that an electric field of controlled magnitude and direction could be applied to the ERF within each cell. Lens shape (convex, concave, etc.) can be varied by selectively activating individual cells.

*This work was done by Yoseph Bar-Cohen, Stewart Sherrit, Zensheu Chang, and Xiaoqi Bao of NASA's Jet Propulsion Laboratory; Iris Paustian and Joseph Lopes of NSWC Coastal Systems Station; and Donald Folds of Ultra-Acoustics, Inc. Further information is contained in a TSP (see page 1) NPO-30884*

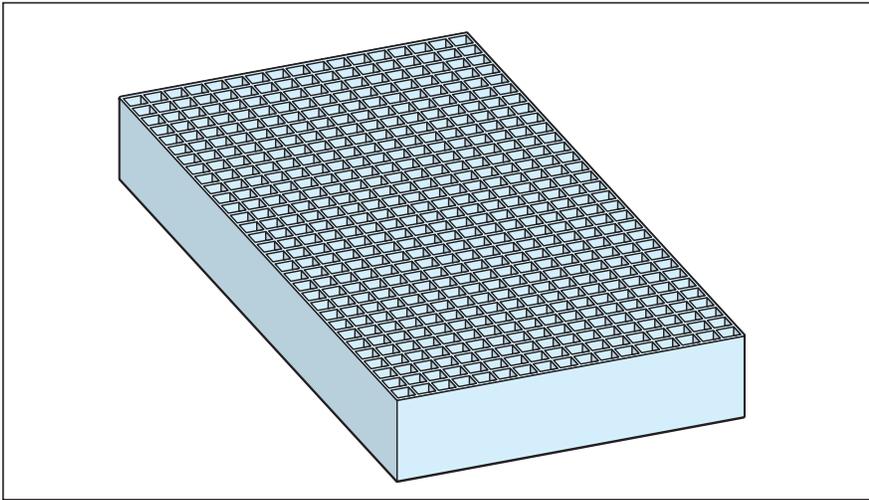


Figure 2. Cells in a Rectangular Array would be filled with an electrorheological fluid. Electrodes on the walls between the cells would make it possible to apply electric fields to individual cells along the row and column directions.

## Measuring Gravitation Using Polarization Spectroscopy

Numbers of cold atoms could also be measured.

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A proposed method of measuring gravitational acceleration would involve the application of polarization spectroscopy to an ultracold, vertically moving cloud of atoms (an atomic fountain). A related proposed method involving measurements of absorption of light pulses like those used in conventional atomic interferometry would yield an estimate of the number of atoms participating in the interferometric interaction.

The basis of the first-mentioned proposed method is that the rotation of polarization of light is affected by the acceleration of atoms along the path of propagation of the light. The rotation of polarization is associated with a phase shift: When an atom moving in a laboratory reference interacts with an electromagnetic wave, the energy levels of the atom are Doppler-shifted, relative to where they would be if the atom were stationary. The Doppler shift gives rise to changes in the detuning of the light from the corresponding atomic transitions. This detuning, in turn, causes the electromagnetic wave to undergo a phase shift that can be measured by conventional means. One would infer the gravitational acceleration and/or the gradient of the

gravitational acceleration from the phase measurements.

The figure depicts the optical layout of a version of an apparatus that would be used in the proposed method to measure the gravitational acceleration. (A slightly different version would be used to measure a gradient in the gravitational acceleration.) Also shown is a diagram of the relevant energy levels of atoms of an element suitable for use in these methods: The element must be one that has a  $\Lambda$ -shaped energy-level scheme as depicted here. A linearly polarized laser beam would impinge on a first polarizing beam splitter (PBS1), which would divide the beam into two beams of equal power. By use of quarter-wave plates, the two beams would be given opposite circular polarizations. One of the two beams would be steered to propagate upward, the other to propagate downward along a vertical tube containing an ultracold cloud of the atoms in question.

After propagating through the cloud, the beams would be converted back to linear polarizations by the same quarter-wave plates, then recombined in PBS1 to produce an output beam, which would

be steered through a quarter-wave plate oriented at  $45^\circ$  with respect to the original linear polarization. This quarter-wave plate would transform the beam into a linearly polarized beam, the polarization direction of which would differ from that of the original laser light by an angle,  $\phi$ , that would depend on the velocity of the atoms. A second polarizing beam splitter (PBS2), also oriented at  $45^\circ$  with respect to the original polarization, would split the beam into two parts that would go to two photodiodes (d1 and d2). The output currents of the two photodiodes would be proportional to

$$(1/2)[P_+ + P_- \pm 2(P_+P_-)^{1/2}\sin(2\phi)],$$

where  $P_+$  and  $P_-$  denote the powers of the two opposite circularly polarized beams. The sum of the two photocurrents would be proportional to the total output power, while the difference between them would give information on the polarization-rotation angle,  $\phi$ .

A lengthy mathematical derivation that must be omitted here for the sake of brevity leads to an equation for dependence of  $\phi$  on a number of variables that include time ( $t$ ) and the gravitational acceleration ( $g$ ). The equation could be used to infer  $g$  from the mea-