Magnetic levitator suspends small objects

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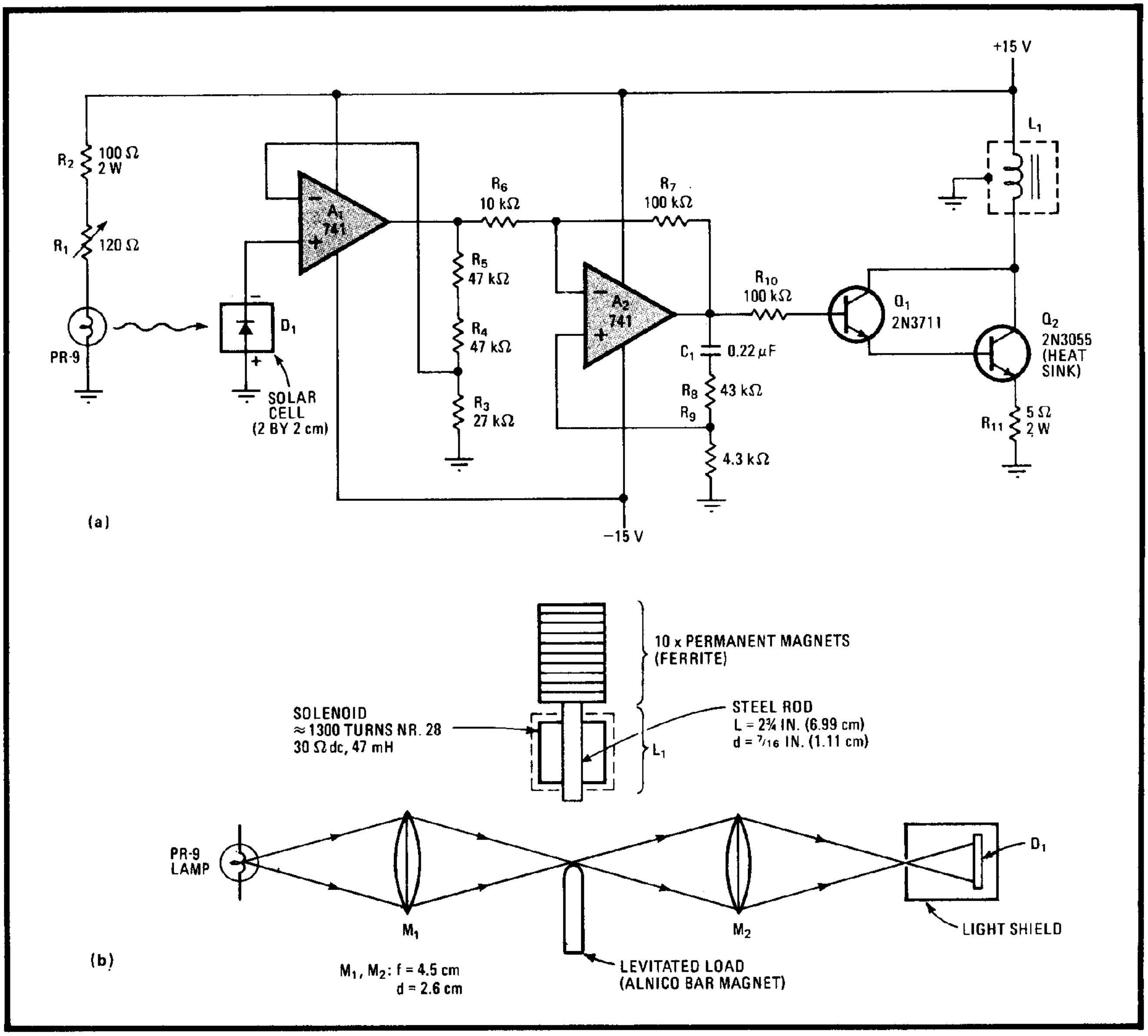
This circuit is a modern solution to the problem of securing frictionless bearings for small rotors and levitating small magnetic objects a few millimeters in space. Operational amplifiers replace the tubes used in earlier approaches, and an optical arrangement replaces the radio-frequency induction circuit originally used to position the object.

Potentiometer R_1 (a) sets the current through the PR9 lamp and thus its brightness and the gain of the position-sensing circuit. R_1 thus provides a fine adjustment of the position of the magnetic object that is suspended beneath the levitation coil L_1. The optical position-sensing circuitry (b), which should be mounted horizontally under L_1 if possible, includes two lenses to focus the beam via the levitated load to solar cell (photodetector) D_1. The light shield, with an aperture of approximately 3 millimeters, effectively eliminates background light. The suggested focal lengths and lens diameters are shown; as a check on the optics system, the beam should be aligned to yield a short-circuit current of 4 to 25 microamperes in D_1.

As for the basic circuitry, D_1's output is amplified by about 5 by operational amplifier A_1 and is then introduced to A_2, which is the all-important servo-loop stage. C_1, R_8, and R_9 provide positive feedback of the high-frequency components of the positioning signal. The stage thus generates the voltage derivative of the amp's output, preventing oscillations in the closed loop that would otherwise occur because of the lack of damping in



Rising rotors. Levitator circuit (a) suspends 1-in. steel spheres up to 2½ millimeters off reference surface. Optical arrangement (b) sets object distance. Details of levitation coil construction are outlined. Permanent magnets set ultimate levitation range.

the position servo portion of the circuit. Any closed-loop oscillation will be manifest as vibration of the levitated object.

Output stage Q_1 to Q_2 is a discrete darlington pair that drives L_1. The coil itself has 1,300 turns around a steel rod 2.75 inches long and 7/16 in. in diameter. A stack of 10 small permanent magnets atop the coil provides a bias field extending the range of levitation beyond that which would be normally attained. The coil is surrounded by a grounded shield to reduce the amount of stray coupling to the op amp inputs.

The most stable closed-loop condition is set by adjusting Q_2's collector voltage to about 7.5 volts by altering the levitation distance between the sensing optics and L_1. Levitation distances in this circuit range from about 20 millimeters for a small Alnico bar magnet to 2½ mm for a steel ball with a diameter of 1 in. □