

RUBIDIUM-VAPOR MAGNETOMETER

by Thomas L. SKILLMAN
Fredericksburg Magnetic Observatory and Laboratory
Coast and Geodetic Survey
Corbin, Virginia

A new type of magnetometer is under development, with promise of measuring the earth's magnetic field more accurately than other types. Absolute measurements of the total field are made by observing radio-frequency absorption lines in the vapor of an alkali metal, currently that of rubidium. This work is being carried out by Varian Associates of Palo Alto, California, for commercial application and by the U. S. Coast and Geodetic Survey for possible observatory use. It is anticipated that further progress will lead to an improved vector airborne magnetometer, for use in mapping the earth's field.

A. KASTLER (1950) suggested the technique of optical pumping for orienting nuclei and for detecting nuclear magnetic resonance signals in gases at low pressures. Successful experiments along these lines were carried out in 1953 both in Paris and at Princeton University. Further development of this technique was made in 1956 by H. G. DEHMELT (1957) of the University of Washington, and in the following year by BELL and BLOOM (1957) of Varian Associates.

In September 1957, the National Bureau of Standards brought to the Fredericksburg Magnetic Observatory of the Coast and Geodetic Survey their apparatus for redetermining the constant known as the gyromagnetic ratio of the proton. This move led to collaboration between personnel of the two organizations in developing a rubidium-vapor magnetometer for use at Fredericksburg (SKILLMAN and BENDER, 1958). In January 1958, a trial apparatus was completed and tested, and by March, comparison observations with observatory standards were carried out with satisfactory results. Measurements were made with Cesium, Rubidium 85, and Rubidium 87.

In the rubidium-vapor magnetometer (fig. 1), light from a rubidium lamp is first passed through an interference filter which transmits only the strong rubidium optical line at 7 947 angstroms. The light is then circularly polarized by a polaroid sheet and quarter-wave plate, and is passed through an absorption cell containing rubidium vapor and an inert buffer gas. The magnetometer is oriented so that the light beam is roughly parallel to the magnetic field. The amount of transmitted light is monitored by a photocell. Not shown on fig. 1 is a square Helmholtz coil that is used to modulate the earth's magnetic field by a few gammas. This modulation is accomplished by energizing the coil at 10 cycles per second with alternating

current generated by an oscillator, thereby superimposing on the earth's field an alternating magnetic field in the same general direction.

Circularly polarized light causes the magnetic moments of the rubidium atoms to orient themselves along the direction of the magnetic field. With the atoms so oriented, the amount of transmitted light will be greater than if the atoms were randomly oriented (DEHMELT, 1957). If a radio-frequency

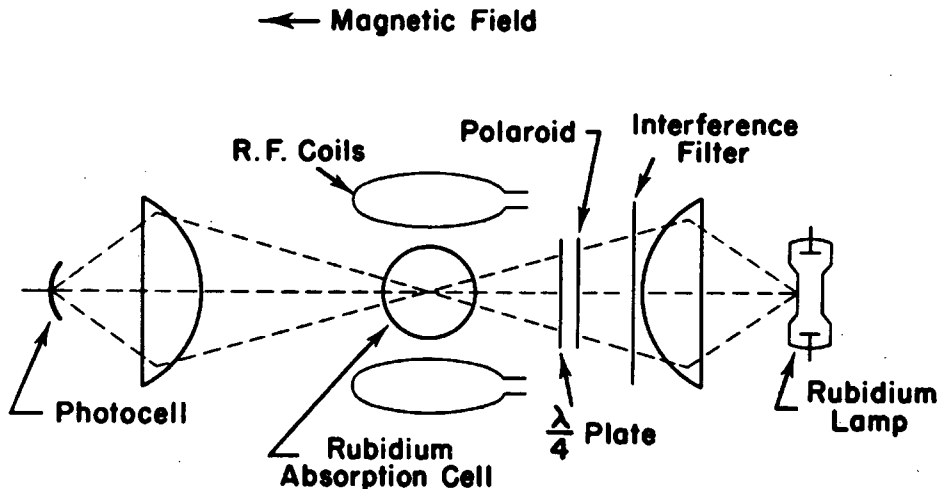


FIG. 1. — Rubidium Vapor Magnetometer (Schematic diagram).

magnetic field is then applied at right angles to the earth's field at a frequency corresponding to the Zeeman transitions, the atoms will change their orientation, and the amount of transmitted light will also change. At Fredericksburg, this phenomenon occurred at about 395 kilocycles per sec for Rubidium 87, in the earth's field of about 56500 gammas (0.565 oersted).

As already mentioned, the light path is roughly parallel to the magnetic field. The light path has been tilted by as much as 20° with a signal reduction by only one half. Line widths of 15-20 cycles are obtained. This is equivalent to 2 or 3 gammas for the absorption-line width. It is, of course, possible to read the centre of the dip in output with greater accuracy.

With the atoms oriented by the optical pumping, the output from the photocell is constant. If the magnetic field is slowly swept through the resonance curve while a small 10-cycle modulation is applied, the 10-cycle output becomes a maximum when the rate of change is greatest on the side of the curve, a minimum at the centre, and again a maximum on the other side of the resonance curve. Fig. 2 shows a resonance curve. The total line width is approximately 3.5 gammas. The 10-cycle outputs at the two maxima are out of phase by 180°, making it possible to *lock-in* the radio frequency generator to the centre of the resonance curve. As the field tries to move off resonance, the increase in 10-cycle output is used to drive the radio frequency generator back to the centre, using a servo-mechanism. This locking-in has been accomplished to an accuracy of about .05 gamma. Fig. 3 shows the block diagram of the electronic components. For lighting the lamp, radio frequency power is advantageous because of low lamp noise

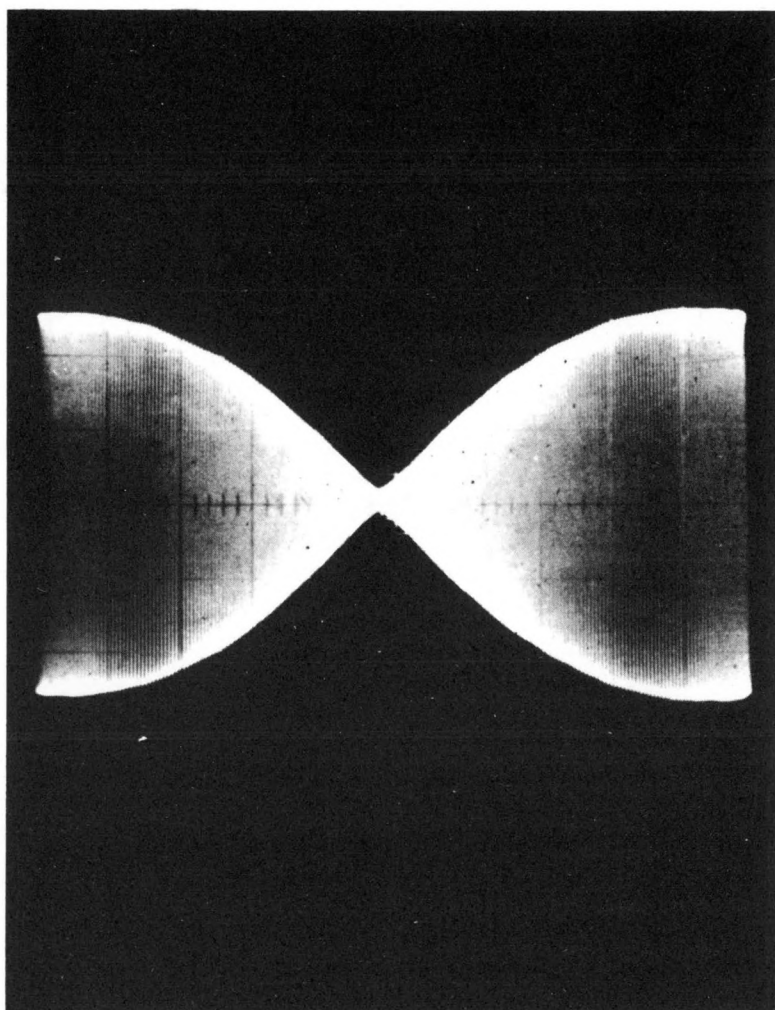


FIG. 2. — Photograph of Resonance Signal on Oscilloscope.
(Horizontal Scale 2.3 Cycles/cm or approximately
3-1/2 gammas from maximum to maximum.)

and because no electrodes are needed in the lamp. The 10-cycle oscillator used to sweep the magnetic field is also used as the reference signal for the phase discriminator.

Some of the advantages of a magnetometer of this type are :

- (a) It is an absolute instrument, requiring no comparison with a standard magnetometer for calibration.
- (b) It facilitates continuous digital recording.
- (c) It is not subject to drift and has no temperature coefficient.
- (d) It can be miniaturized.

In this application of nuclear resonance, there is no feedback from the instrument to the field under study. The photocell output shows when resonance is obtained, but the signal strength is not dependent on the field intensity.

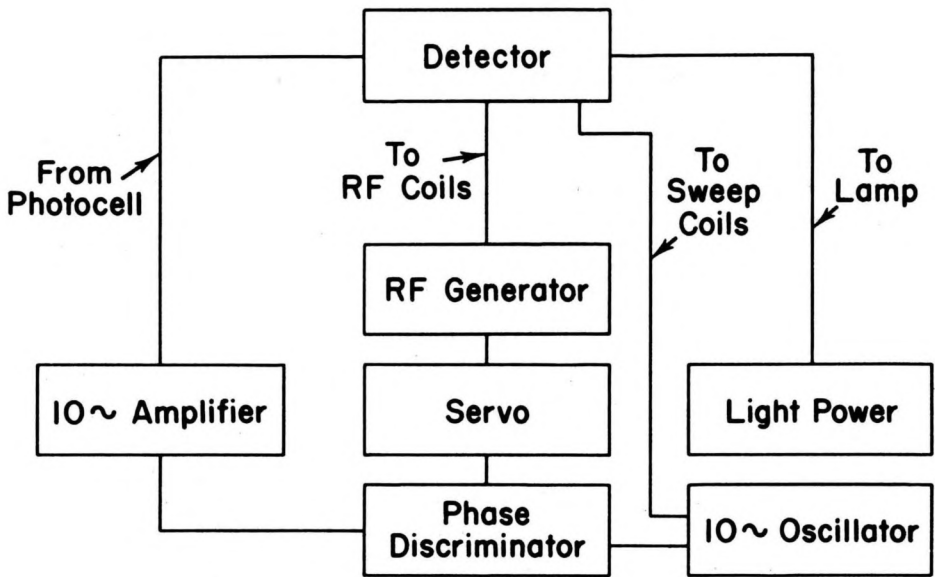


Fig. 3. — Block Diagram of Electronic Components.

REFERENCES

- W. E. BELL and A. L. BLOOM : Optical detection of magnetic resonance in alkali metal vapor; *Phys. Rev.*, v. 107, pp. 1559-1565, 1957.
- H. G. DEHMELT : Slow spin relaxation of optically polarized sodium atoms. *Phys. Rev.*, v. 105, pp. 1487-1489, 1957.
- A. KASTLER : Quelques suggestions concernant la production optique et la détection optique d'une inégalité de population des niveaux de qualification spatiale des atomes. Application à l'expérience de Stern et Gerlach et à la résonance magnétique, *J. Phys. Radium*, v. 11, pp. 255-263, 1950.
- T. L. SKILLMAN et P. L. BENDER : Measurement of the earth's magnetic field with a rubidium vapor magnetometer, *J. Geophys. Res.*, v. 63, pp. 513-515, 1958.