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A COST EFFECTIVE CONCEALED WEAPONS DETECTOR

by

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Summary. In this paper an experimental active weapons detector developed for the remote examination of boarding airline passengers is described in some detail. The design and operational philosophy, its physical realization, and its unique features are reviewed.

The system consists of a novel, yet simple, coil configuration combined with solid state transmitter and receiver circuitry which provides two modes of operation, corresponding to low and high security requirements. This permits the mode of operation to be changed on a person-to-person basis resulting in a lower false alarm rate than could be otherwise obtained. Operational tests of this unit are reviewed indicating the effectiveness of this device. Finally, the possible dangers to humans from active detectors is discussed and recent studies in this area are reviewed.

Introduction

The need for techniques for screening boarding air travelers for concealed weapons became apparent approximately 10 years ago when hijacking aircraft to Cuba become a popular American sport. Between 1930 and 1960 some 33 airline hijackings were attempted world-wide. By the end of 1970 this number had risen to 115. During 1971, 11 successful hijackings occurred in the United States and a new incentive was added to the sport with ransom becoming the desired reward. The response of commercial aviation over the past five years has varied from deep concern and action to partial apathy; weapons detectors are used sporadically at most airports, depending on the airline involved, a condition which is likely to continue until it becomes economically profitable to provide security or security precautions become mandatory.

During the intervening years technology has provided several approaches to the detection of concealed weapons at costs ranging from $500 to $10,000, per installation. The devices produced to date fall into two general classes, active and passive, depending on whether they generate their own electromagnetic field or sense disturbances in the earth's magnetic field. The former are capable of detecting all types of metal while the latter are limited to ferrous materials. All are capable of detecting weapons within different levels of confidence; all are subject to false alarms and finally, none of them provide a complete solution to the security problem; they are simply technical aides. The problem faced by technologists is thus to provide the cost-effective device, a unit which the airlines can and will use as part of their security precautions without overly inconveniencing passengers.

We consider in this paper the design philosophy of such a cost-effective unit, its realization in an experimental model, its performance characteristics in operational tests, and several safety factors of general concern to users of weapons detectors. This experimental unit has been tested under various operational conditions including actual airline use, and is the basis of a low cost weapons detector presently being marketed by the Sperry Rand Sensor Group, Gainesville, Florida.

Design Philosophy

The electromagnetic principles from which weapon detector designs emanate have been known for at least two decades. They have found application in many industrial processes, where one must eliminate undesirable metallic particles from a variety of background materials, and have been used in penal institutions (with varying degrees of success) for the screening of personnel. However, the problems of designing a weapons detector for use by airlines to screen boarding passengers and to a lesser extent for use in court rooms for screening spectators requires a much more sophisticated philosophy. The sophistication is required because the people being examined are almost all law abiding travelers or visitors. Furthermore, in the airline case, the user of this device is not a law enforcement agent. His main concern is to board passengers in an orderly, efficient, inoffensive manner without causing excessive delays in schedule. On the other hand, because of the expense and dangers involved, hijacking can certainly not be condoned. In light of these contradictory requirements, the following guidelines seem essential to a usable weapons detection system.

The System Must Detect Weapons

First consideration might indicate that this is a self-evident requirement, but weapons can be purchased or made from a variety of metals including aluminum, magnesium and stainless steel. Most weapons are made with iron or steel barrels, which are presumably magnetized during the course of their manufacture, but the degree of magnetization varies considerably from one gun to another. A device which detects all metals, both ferrous and nonferrous, seems preferable if the above guidelines are to be taken seriously. Knives, another potential weapon, are usually iron or steel and must be detected as well. They present a more difficult target because of the wide range of sizes available and because they are a common object carried by many travelers.

There are many other weapons which have been used in hijack attempts including razors and bombs. Indeed, the question of what constitutes a weapon is debatable; in the end analysis, the only sensible answer seems to be that it depends on the person carrying it.

The weapons detector developed by Sperry Rand is intended to detect mainly guns and knives, without regard to their metallic substance. The device responds equally well to aluminum and magnesium frames, as it does to steel frame weapons.

False Alarms Should Be Kept to a Tolerable Level

There are two distinct classes of false alarms to be considered. False alarms can be caused either by metallic objects which travelers commonly carry or by extraneous interference. Extraneous alarms can be minimized by proper and judicious electronic design. The choice of operating frequency, bandwidth and possible shielding sets a lower limit to the extraneous alarms that can be expected. For example, a narrow band active weapons detector is susceptible to sources within the receiver bandwidth or transients which electrically simulate the transient signal that can be expected by passing a weapon through the device. On the other hand, passive weapons detectors are prone to extraneous alarms caused by low frequency magnetic disturbances such as might be created by elevator motors turning on and off. To the extent that the device must be operated in the neighborhood of a metallic environment, one can expect moving metal doors, baggage carts, etc. to unbalance weapons detectors. These extraneous signals can be minimized in general, by localizing the field of influence of the weapons detector to a fixed area.

False alarms caused by common harmless objects carried by travelers present a different problem in the operational use of a weapons detector. The amount and variety of metallic material carried by most travelers precludes a "hands off" operation; that is, a procedure by which passengers and carry-on baggage can be screened simultaneously. It is reasonable to anticipate that most males will travel with at least a spray can of shaving cream and most females to carry key cases and metal rimmed purses in their handbags. Thus to allow carry-on baggage through a weapons detector is to invite an alarm rate in excess of 80% (if a meaningful attempt at detecting weapons is intended)(1). This alarm rate would cause excessive delay in boarding passengers since an attempt to identify the cause of the alarm must be made, if a credible security system is desired. Alternately, sophisticated discriminating techniques can and have been attempted at the expense of high additional cost.

The System Must Be Reliable, Maintainable and Should Require a Minimum of Operator Experience

The current state-of-the-art dictates the use of modular solid state integrated circuitry to achieve reliability and intelligent layout to ease maintainability. The need for a unit that can be used with little or no operator experience is mandatory from an economic viewpoint. Manpower is expensive! In addition, a unit that requires constant attention inhibits the flow rate of passengers and causes delays.

Flexibility

A weapons detector unit designed to be optimum for prison use is hardly usable in an airline terminal. Similarly, a unit designed for airline use alone is not optimum for courtroom or prison use. Flexibility of design is necessary from both the manufacturing and user point of view to keep the cost of the unit compatible with the economics of its use. As we shall show, the operational philosophy differs for prison, courtroom and airline situations and a unit which can be adapted to all three requirements is highly desirable.

Low Cost

The cost of the weapons detector should be compatible with the economics of its use. In general, a cost-effective unit is desirable. Below some level of performance the weapons detector becomes merely a deterrent. Although the deterrent effect should not be minimized, viable security systems can be built at reasonable costs.

Operational Philosophy

The Sperry Rand Weapons Detector operates on the simplest of discriminating features. Its circuits respond whenever a ferrous or nonferrous object is passed through the detector. The transmitted power of the device is preset to a level which will enable the detection of small weapons and yet be harmless to magnetic tapes and human beings. The alarm circuitry threshold is chosen by the operator in preset steps, determined by laboratory tests prior to manufacture, and gives both an audible and visual alarm if the output level is above the threshold. Where one sets the threshold is a complicated function of the response expected from common metallic objects as opposed to weapons. Depending on the operational use different thresholds are required. To understand the basis for this, one relies on hypothesis testing theory to describe the operational rationale of current weapons detector systems (2).

Assume that a traveler carrying no weapons walks through a weapons detector. Because of the common metal objects most people carry (such as keys, wristwatches, coins, cigarette lighter, etc.) the expected voltage level at the output of the weapons detector can be considered a random variable. In Fig. 1, curve A shows a typical probability density for the average passenger. In general, the density function shows a peak at some level V_1. Assume for the moment that this typical traveler is carrying a weapon in addition to common harmless metallic objects; the probability density for this hijacker is depicted by curve B. In general, the peak has shifted by an amount which depends on the size of the weapons, its placement on the body and possibly its orientation. The job of the designer of the security system is to establish a threshold, that is a signal level V_M above which he would want an alarm signalled and below which he will allow the

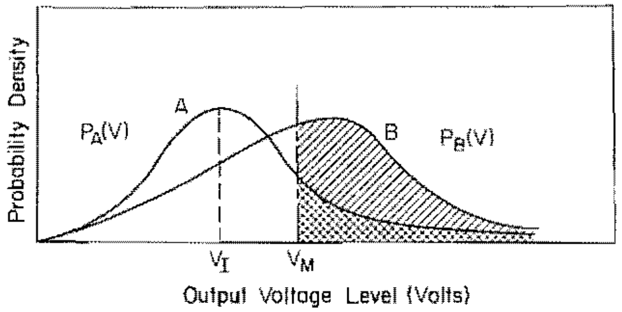

FIGURE 1. *Typical probability density functions for a traveler (curve A); and a hijacker (curve B).*

traveler to proceed. There is a basic dilemma, if the threshold level is set too high, there is a high probability that a man with a weapon will get through. If the threshold level is set too low, the false alarm rate (the rate at which harmless objects cause alarms) will become excessive and the plane's departure will be delayed. In general, the false alarm rate can be computed as proportional to the area under curve A above the threshold V_M. Thus, the probability of a false alarm P_{fa} is

$$P_{fa} = \int_{V_M}^{\infty} P_A(v)\ dv \quad . \qquad (1)$$

Similarly, the probability of detecting a weapon P_D is the area under curve B above V_M, thus

$$P_D = \int_{V_M}^{\infty} P_B(v)\ dv \quad . \qquad (2)$$

Figure 1 summarizes the basic information that is available to the designer for establishing his threshold. If one is searching for a large weapon, say a .45 cal. revolver, then the probability density functions shown in Fig. 1 are almost disjoint and it is a relatively simple matter to pick a threshold which yields high security performance and a low false alarm rate simultaneously. For smaller weapons, say a .22 cal. revolver, the probability density functions overlap considerably; current security procedures consist of a strategy which, in effect, makes these probability densities disjoint. A typical strategy might consist of the following procedures. With the threshold preset at a level corresponding to .22 caliber revolver, passengers who cause alarms are asked if they have anything metallic on them. The metallic objects are then temporarily removed and the passenger is asked to go through the weapons detector again. This procedure is repeated, theoretically until the false alarm is eliminated. Thus, as metallic material is removed, the probability that the person is a bona fide traveler changes. Depending on the size and type of material removed, the density function asymptotically approaches a limiting density function $P_{LA}(v)$ corresponding to a person carrying a minimum of metal as shown in Fig. 2. At the same time the probability density that the person is a hijacker asymptotically approaches the limiting density function $P_{LB}(v)$ corresponding to the passenger carrying a weapon alone (see Fig. 2). These two probability distributions are essentially disjointed. It is important to note that the threshold V_M must be lowered as this recursive testing procedure continues (if a constant probability of detection is to be maintained).

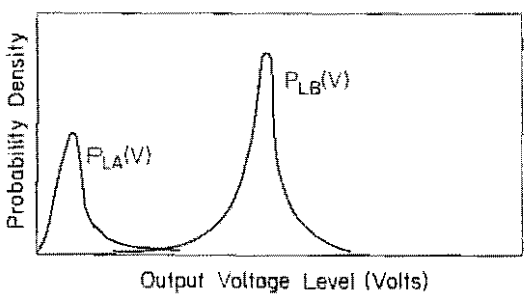

FIGURE 2. Limiting probability density functions of a traveler with minimal metal and a hijacker with a weapon alone.

If a fixed threshold test is to be used then this threshold must be chosen on the basis of the density function of a traveler ($P(A)$ in Fig. 1) as compared to a hijacker carrying a weapon alone ($P_{LB}(V)$ in Fig. 2)). Fixed threshold testing thus results in a higher false alarm initial rate.

The procedure described above is currently being used on many international flights where U. S. Custom's is able to provide the necessary manpower to examine carry-on baggage. Domestic flights generally follow a different strategy. Here the passengers to be stopped are preselected on the basis of a behavior profile developed by the FAA. Although all passengers pass through the weapons detector only preselected candidates are stopped, independent of the results obtained using the weapons detector.

In effect, the behaviorial profile can be viewed as providing an a priori estimate that the preselected candidate is a hijacker. Rather than ignoring results obtained from weapons detector devices, a strategy which uses both behavior profiles and an actual hypothesis test (using a reliable weapons detector) would yield a more effective overall system. In addition, it should be clear that a trade off exists between the number of preselected candidates and the level of security one can anticipate. Clearly, by modifying the behavioral profile to include more travelers and using a weapons detector to test the hypothesis, more travelers can be checked in the same time.

System Configuration

A sketch of the Sperry Rand weapons detector is shown in Figure 3. The system consists of a walkway assembly containing excitation and detection coils and a remotely situated operator's control unit housing the electronics (3).

The walkway assembly provides a rigid fixed aperture for the detection of metallic objects. Each side panel of the walkway contains an exci-

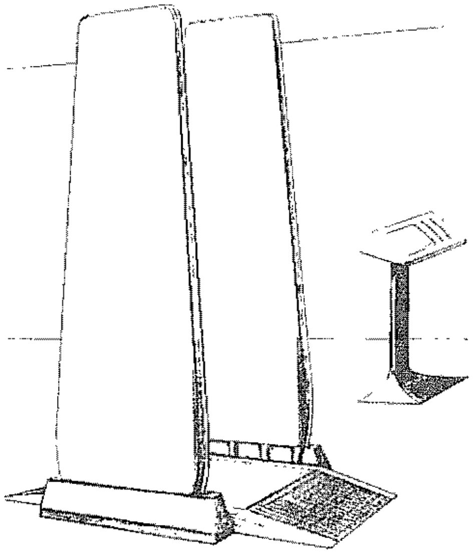

FIGURE 3. Artist rendering of the Sperry Rand Weapons Detector.

tation coil and a detection coil which are physically positioned to minimize mutual coupling. The panels are formed into a 2 x 7 foot frame (approximately rectangular). The introduction of metal between the panels causes an imbalance (between excitation and detection coils) which is amplified and detected. The detection coils are electrically isolated, providing two independent sensing channels. All coils have common ground center taps for electrical safety and to achieve balanced line drive and output interface. Faraday shields are included on each coil to minimize electrostatic interference. In addition to the various operating controls and indicators, the control unit contains the frequency drive source for the excitation coils, detection and alarm circuits, and power supplies.

The frequency drive source consists of a crystal controlled oscillator, a divider chain and a solid state power amplifier as shown in the block diagram of Figure 4. A stable frequency of 8 KHz (nominal) is generated by the crystal oscillator. Logical division by 8000 reduces this frequency to the desired value. Push-pull Class C Darlington power transistors feed the drive taps of one excitation coil with a symmetrical square wave, while corresponding taps on the other excitation coil provide a reference signal for the control circuitry.

Two identical detection channels are provided for the two detection coils. Each channel includes independent passive nulling circuits; bandpass amplifiers, filters, and comparators for detection thresholds. Separate in-phase and quadrature nulling adjustments are located on the front control panel to enable the operator to cancel static imbalances resulting from nearby metal objects. These adjustments are normally accomplished at the time of installation to adapt the detector to the particular environment in which it is to be operated. Electrical signals from the detection coil are summed with the nulling signal and applied to a high gain bandpass amplifier whose center frequency coincides with the excitation. The output from the bandpass amplifier is applied to an envelope detector through a third harmonic notch filter. The envelope detector translates the amplified detection signal to a dc level. Clearly, the dc output of the envelope detector is directly related to field imbalance in the walkway. If the nulling adjustments have been properly made and no metallic objects are in the walkway aperture, the envelope detector output will be minimal.

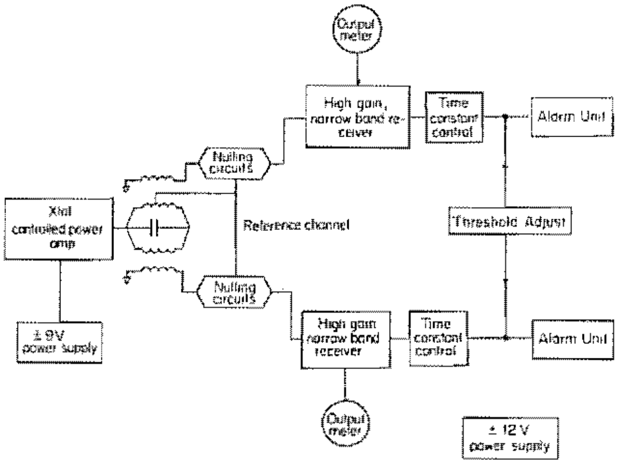

FIGURE 4. Overall functional block diagram.

Alarm detection can be performed by comparing the envelope detector output to a fixed threshold. However, experience has shown that the residual envelope detector level (after proper nulling and with no metal in the aperture) varies with location, i.e., some environments are noisier than others. To minimize this effect, a low-pass filter and difference amplifier is used to subtract the "long term" average residual level from the envelope detector output. Alarm detections are then made by comparing this difference with fixed thresholds. A front panel meter monitoring the averaged residual level serves to alert the operator of gross changes in the environment (i.e., movement of large metallic objects in the area), as well as aiding in performing initial null adjustment.

Two modes of operation are provided. In the first, the threshold is set to detect relatively large weapons, while causing few alarms on commonly carried objects. This mode is intended for fixed threshold testing at airports. An alternate mode, using a lower threshold, detects small weapons but in general may also alarm on certain types of key rings, cigarette cases, wrist watches, etc. Although providing higher levels of security, its use at airports requires a coordinated procedure to eliminate obvious sources of alarms. For convenience, we designate these modes as normal and high-security. The mode of operation is controlled by a switch on the front face of the console and can be changed from passenger to passenger. In the present model, independent alarm thresholds are provided for the two detection channels. Thus, the operator is given an indication of the placement of a weapon, i.e., right side or left side. The alarm may be either visual, audible or both.

Operational Tests

The Sperry Rand Weapons Detector has undergone several levels of testing to evaluate its effectiveness. The initial testing was conducted at the Sperry Rand Research Center where 200 employees were asked to pass through the device to establish its false alarm rate. With the threshold set to detect a .22 caliber weapon, a false alarm rate of 35% was found. Employees were not permitted to carry attache cases or handbags through the detector. Each of these alarms was resolved and a careful analysis of them indicated that the major causes were due to keys and key cases, cigarette lighters and wrist watches. Testing was continued and it was found that by eliminating keys alone, the alarm rate could be reduced to 8%.

There were several reasons to suspect that the alarm rate obtained at the research laboratory is not typical. First, the electromagnetic environment is quite different from that found at an airport. There are all sorts of high power devices and electrically controlled ovens within the building being turned on and off. Secondly, a collection of employees arriving for work in general carry a different assortment of metallic objects than air travelers.

The experimental unit was delivered to the Department of Transportation, Transportation Systems Center in Cambridge, Massachusetts for testing by DOT personnel. Here the effectiveness as a weapons detector was established. A variety of weapons of different size and shape were used and comparative data between the Sperry Rand experimental unit and other weapons detectors was obtained. With DOT's encouragement and cooperation, additional tests were arranged through the FAA resulting in the installation of the experimental unit at Logan Airport in Boston. Here U. S. Custom agents and TWA used the unit nightly, passing approximately 600 passengers per week through the device, on international flights. It was found that after one night's experience with the active unit, the operational procedures used by TWA agents yielded a 10% alarm rate. On the average, the passengers were boarded at a rate of 3 to 4 per minute, at a security level substantially higher than they had previously achieved. In addition, the constructive comments of U. S. Customs and TWA personnel has resulted in the introduction of several operational features and the elimination of several others in the preproduction unit.

The experimental unit has also been tested by the National Bureau of Standards, Law Enforcement Standards Laboratory, a new agency whose primary function is to establish testing procedures. No official report has been authorized, however. In addition, the experimental unit will be used for court room security applications at the Suffolk County Superior Court, Boston, Massachusetts, in the near future.

Safety Factors

With the advent of active weapons detectors has come some concern on the part of users as to the safety of these devices on persons being tested. In particular, the danger to persons with cardiac pacemakers has been singled out as an area requiring investigation. Indeed, persons equipped with cardiac pacemakers are subjected to potential hazards from a wide range of sources. Medical journals report cases of potential danger from radio stations, motorcycles and gasoline ignition systems, radar sites, electric shavers, television receivers as well as electric mixers (4). In addition, hospital environments present particular dangers because of diathermy equipment.

Medical research has been sponsored by the FAA to define the dangers of active weapons detectors on passengers. Actual cardiac patients were used with real weapons detectors and it was concluded that no clinical effects resulted in the proper use of these devices.

It is felt that the Sperry Rand device is particularly safe because of the frequency of operation and power level chosen. The actual magnetic field strength in the aperture of this device varies from .5 to 1.5 oersteds, depending on the distance from the plane of the coils. This should be compared with a static magnetic background of .5 oersteds due to the earth's magnetic field.

In addition, it should be noted that at these low levels of magnetic field it is virtually impossible to alter information of magnetic tapes. Finally, it should be pointed out that a passenger wearing a hearing aid may actually hear a tone as he passes through the device. This is caused by direct pickup of the audio signal into the transducer in the earpiece that is commonly worn. This, too, has been found to be nonoffensive.

Conclusions

The Sperry Rand Weapons Detector, an experimental device, has been designed to meet the security needs of the airlines in coping with attempted hijackers. The main features of the system, its simplicity of operation, the dual channel alarm circuitry, the multilevel threshold concepts and its low cost, provide considerable flexibility in operational use. In addition, the effectiveness of this unit has been demonstrated by laboratory tests at DOT, and operational tests by U. S. Customs and TWA. A preproduction prototype, incorporating many of the suggestions of those who have tested this unit, has been designed and will be marketed by the Sperry Rand Sensor Group.

Acknowledgment

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LAW ENFORCEMENT APPLICATIONS OF MAGNETIC SENSORS

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Introduction. Recent advances in magnetic sensor technology stimulated by unique intelligence, surveillance and security requirements of the Vietnam war have increased the capability to detect ordnance, personnel and vehicles. The problem of finding contraband weapons hidden in junks and sampans is similar to that of detecting weapons carried by skyjackers.

Military surveillance sensors to remotely detect intruding personnel and vehicles may be helpful for certain law enforcement applications. As an example, monitoring vehicle border crossings (land and water) with low cost unattended magnetic sensors.

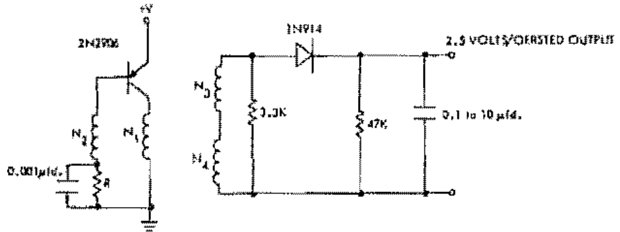
The purpose of this paper is to introduce the law enforcement community to magnetic sensors and some Navy device concepts and hardware. It is felt that recent military magnetic surveillance sensor research is applicable to certain unique law enforcement problems.

Magnetic Sensors

A magnetic sensor is a device which detects a magnetic field or changes in the field. Among the simplest sensor is the magnetic compass which senses the earth's magnetic field. Others include reed switches, which are activated by large fields produced by permanent magnets. Magnetically activated switches are used in some security and burglar alarm systems.

An alternating magnetic field may be detected by a search coil consisting of thousands of turns of wire on a core of ferrite or soft magnetic material. The search coil was used initially in most simple low power magnetic sensors until the advent of the Brown magnetometer. The Brown magnetometer is similar to but different from the standard ring core fluxgate sensor as described at last year's conference (1), and has significant advantages of low cost, small size, low power consumption, low internal noise and can operate in any ambient temperature and most environments. Background information on magnetometers and magnetometry may be found in references 2 and 3.

The Brown magnetometer (4), developed especially for surveillance systems is of the fluxgate type employing a small permalloy tape bobbin core purchased commercially. The simple magnetically-coupled drive oscillator and detection circuit are shown in Figure 1. The transistor acts as a switch to apply the battery voltage periodically (about 40 KHz drive frequency) to the drive winding. Thus, the magnetic material is driven into saturation periodically without reversal of the induction. This minimizes drive power. Power consumption is about 4 milliwatts.



N_1 = 600 OR 1500 TURNS (V=1.35 OR 4.05 VOLTS).
N_2 = 100 TURNS.
N_3 = N_4 = 400 TURNS.
R IS SELECTED TO PROVIDE PEAK DRIVING FIELD OF 2 TO 3 OERSTEDS.

FIGURE 1. Brown Magnetometer, schematic diagram.

The split magnetic field sensing winding is wound on two opposite 180° segments of the core in such a way that the drive signal is canceled out in this winding and only the ambient field dependent signal remains. Following saturation of the core, the transistor turns off, the induction returns rapidly to an equilibrium point, and a large fly-back voltage spike appears on all windings. It is during this fly-back interval that the diode in the detection circuit conducts and samples the ambient field signal on the sense winding. The fly-back path of the circuit is controlled largely by passive circuit elements. It is believed that the low intrinsic noise observed in the magnetometer is due to detecting during the fly-back interval when the drive circuit is relatively quiescent. To ensure detection during this interval with the simple half-wave detector shown, the sensor must be biased with a small permanent magnet so that the ambient field dependent signal is always of the correct polarity for any orientation in earth's field. We have also used successfully (and prefer) another detector of only slightly greater complexity that does not require the bias magnet. The intrinsic noise of the magnetometer in the passband 0.01 to 1 Hz is less then 0.3 gamma for a temperature range 130°F to -20°F. The output of the detection circuit is 2.5 volts/oersted ±about 5% for ± 0.6 oersted applied fields. The magnetometer is quite rugged with respect to rough handling.

One of the magnetometers is shown in Figure 2. A bobbin core is shown before and after winding. The circuit board contains the fluxgate sensor together with the drive and detection circuit of Figure 1. Figure 3 is a photograph of the DC magnetometer output characteristics. Linearity over ± .6 gauss dynamic range is about 5 percent and the noise in this range is typical of that shown in Figure 4.