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SENSOR-BASED MATERIAL TAGGING SYSTEM (U)

by

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SENSOR-BASED MATERIAL TAGGING SYSTEM

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ABSTRACT

Electronic identification tags are being developed for tracking material and personnel. In applying electronic identification tags to radioactive materials safeguards, it is important to measure attributes of the material to ensure that the tag remains with the material. The addition of a microcontroller with an on-board analog-to-digital converter to an electronic identification tag application-specific integrated-circuit has been demonstrated as means to provide the tag with sensor data. Each tag is assembled into a housing, which serves as a scale for measuring the weight of a paint-can-sized container and its contents. Temperature rise of the can above ambient is also measured, and a piezoelectric detector detects disturbances and immediately puts the tag into its alarm or beacon mode. Radiation measurement was also considered, but the background from nearby containers was found to be excessive. The sensor-based tagging system allows tracking of the material in cans as it is stored in vaults or is moved through the manufacturing process. The paper presents details of the sensor-based material tagging system and describes a demonstration system.

1.0 INTRODUCTION

The safeguarding of Special Nuclear Material is a demanding task. The need is to monitor material at various stages of the manufacturing cycle as well as supervise its continuing presence in inventory. Manual methods of inventory monitoring require the exposure of personnel to nuclear radiation. In a study program on the "Analysis of a Container Safeguards System" new radio frequency (RF) electronic identification tag approaches were explored to determine their applicability to the Special Nuclear Material safeguards problem. During the course of the study, it became apparent that not only is the tagging of containers important, but also validation is necessary that the material put in the container is still present. In looking at the problem of container safeguards a number of alternative electronic monitoring methods were considered. An approach using a sensor-based system was proposed that meets the requirements of rapid installation, minimal personnel exposure, and the ability to provide unattended monitoring of the Special Nuclear Material. This paper describes the decision process that led to design of a Container Surveillance Unit for a feasibility demonstration.

2.0 BACKGROUND

Very large-scale integrated-circuit (VLSI) technology now makes possible electronic solutions that were formerly prohibited because of concerns related to reliability, cost and size. The continuing evolution of this technology allows new approaches to safeguarding based on distributed processing, sensing and communication. Particularly impressive are the strides made in complete microcontrollers contained on a single chip featuring analog-to-digital conversion, intelligent input/output subsystems, and non-volatile memory. Another remarkable achievement is the development of single-chip modems that can provide communications interfaces for distributed microcontrollers. The silicon processing that has made this possible is silicon-gate complementary-symmetry metal-oxide semiconductor (CMOS). An important attribute of this technology is its extremely low power drain. As a first approximation the CMOS circuitry exhibits current drain of the same magnitude as a back-biased diode until logic elements are switched. The power drain for low frequency or low duty-cycle operation can be kept very small indeed. This extremely low power supply drain capability has led to long-life applications using batteries. The batteries themselves have evolved to match the long-life capabilities of the CMOS circuitry. Shelf-life of 15 years is now available with lithium carbon mono-fluoride batteries. The combination of CMOS circuitry and long-life lithium primary cell batteries has given rise to a host of consumer products such as watches, calculators, and hand-held equipment as well as commercial grade products such as the zero-power random access memory used in personal computers and controllers.

These successful technologies are now being exploited in the development of RF Identification Tags for tracking material and personnel. The developments use low-power-drain CMOS circuitry for providing identification of badge numbers and other stored information at portals or read-heads. The CMOS circuitry is either powered from the read-head or from batteries. The range of reading depends on the read-head power. In order to extend the range and keep the read-head power within allowable limits, batteries are used. The life of the batteries is limited by the circuit design and the duty for use of the tag. In summary, both battery powered and read-head powered tags are possible. The use of such tags in safeguards applications is attractive from the viewpoint that a variety of data can be stored and interchanged with the tag. Also, through-the-air communications can eliminate the need for wiring to each container.

3.0 SENSOR ISSUES

While electronic tagging is attractive for storing data, it is insufficient to protect the nuclear material in the container. The problem is that tracking the tag does not guarantee that the material is still present. Accordingly the challenge is to identify the presence of the materials by monitoring attributes of the material.

Some common attributes are weight, temperature-rise above ambient, and radiation level. Additionally, the physical disturbance of the container can be monitored as well as its location. Each of these attributes have difficulties associated with them such as complexity of the electronics, location of the sensor, accuracy, and ease of deception. The choice of attributes may be different depending on whether containers are large or small, and whether containers are placed within other containers. For small containers the selection of attributes was weight, temperature rise above ambient, disturbance, and location. Radiation was ruled out because of its sensitivity to adjacent containers and the overall background levels found in storage vaults. The complexity issue then drove the selection of approaches for sensing the chosen attributes. The weight measurement required a sensor with relatively high-level output signal, low power and freedom from problems of offset, hysteresis or friction. A force transducer or strain-gauge bridge meets most of the requirements; however, the structure for concentrating the force in the transducer can introduce mechanical bearing points that affect the consistency of the readings. Accordingly a method was selected using a bellows with known spring constant to directly convert force into deflection. The deflection was then measured using a linear-variable-differential-transformer (LVDT). The LVDT senses a rod connected to a pan on which the container is seated. The LVDT does not contact the rod, and the magnetic field forces are negligible. Hence there is no stiction or friction associated with the LVDT. Other effects such as linearity, offset, and temperature can be calibrated.

To obtain the temperature reading high-level semiconductor junction temperature sensors were chosen. The semiconductor junction is on a chip that produces a linear current to temperature relationship. Two chips are used: one measures the can temperature and the other measures ambient temperature. The ambient temperature is used to correct for mechanical temperature coefficient in the weight measurement. The temperature rise of the container above ambient is the most important parameter. The difference temperature between the container and the ambient is computed in an operational amplifier to maximize the resolution of the analog-to-digital converter measurement.

The disturbance sensor is essentially a motion detector. An inertia attached to or part of the sensor prevents immediate movement of the inertia and results in a displacement until the inertia again reaches a rest state. Mercury switches perform this function, but the introduction of mercury into the vault may be undesirable with regard to clean up after accidental breakage of the encapsulation. Another approach using a piezoelectric crystal was chosen. An inertia is attached to a metal beam which holds the crystal and the crystal produces a voltage in response to the beam flexure. A benefit of the piezoelectric crystal is that it produces its own voltage at high level, which can be easily detected by a low-power-drain field-effect transistor.

Radiation detection requires more complex electronics including high-voltage power supplies. The least complex and most economical radiation sensor appears to be the Geiger-Mueller (GM) tube. The GM tube contains a gas that ionizes in the presence of radioactivity. The ionization is detectable as an event, and the number of events per unit time determines the radiation level. The tube is sensitive to alpha, beta, gamma, and neutron radiation. Thin metal shielding can effectively eliminate alpha and beta events. The design of a practical detector system using the GM tube appears feasible. The use of such a detector for safeguarding small containers, however, is impractical because of the proximity of containers and the high background level.

In summary, the sensors chosen for weight, temperature rise, and disturbance appear to be useful set when used in combination. The correlation of diverse sensor measurements should reduce the number of nuisance alarms.

4.0 COMMUNICATIONS

The safeguarding of special nuclear materials would be best served by continuous communications with the container. The direct wiring of the sensors to an interrogation unit satisfies the requirement as does the establishment of serial data link over hard wires. The hardwire methods present the most secure communications. In considering the needs for monitoring during the movement of materials, through-the-air communications have an advantage. Through-the-air communications are either optical or electromagnetic e.g. either infra-red (IR) or radio-frequency (RF). The through-the-air communications are preferably serial in nature to allow a relatively large amount of information to be sent. RF has an advantage over IR in terms of the amount of power required. IR has advantages where RF spectrum is not available or when concerns exist relative to activation of NIM devices. A selection of RF was made to allow more flexibility in orientation and less criticality relative to line of sight. The choice of frequency depends on convenient antennae, desired range, and allowed radiated power. The UHF band assists in keeping antenna size small. A quarter-wavelength monopole is only 3 inches at a frequency of 915 MHz. Communications in free space requires only 0.5 mW effective radiated power to establish reliable communications at 150 ft. The low transmitter power and small antenna made 915 MHz an ideal frequency for transmissions from an RF tag. The interrogation or receive direction of the tag has limits on the current drain of the receiver in the RF tag. The use of an RF frequency of approximately 33 MHz allows a simple, low current drain receiver circuit for the tag. The receiver antenna can be a small ferrite loopstick which still has useful permeability at 33 MHz. Again low radiated power from the interrogating antenna can be achieved. Thus an RF communications system can be used.

5.0 A PROPOSED APPROACH

A Container Surveillance Unit (CSU) based on a sensor-based RF identification tag is proposed. The sensor-based tag features a microprocessor with on-board analog-to-digital conversion and a custom integrated-circuit that implements the RF tag memory management and serial-to-communication functions. A block diagram of the CSU is shown in Figure 1. The circuitry is designed for low power drain to allow operation of of a pair of 3-volt lithium carbon monofluoride primary cells. The circuitry power requirements are further reduced by duty-cycling the power supply voltage to selected circuit elements. The CSU is constructed as a base on which the container sits. A diagram of the CSU mechanical assembly is shown in Figure 2. The top surface of the CSU rests on a metal bellows. The bellows has a known spring constant that converts the weight of the container and its contents to a displacement. The container can be permanently mounted to the pan using an adhesive or held in place with a permanent magnet. The bellows in turn sits on a plastic cylinder that houses the electronics. The plastic cylinder is notched and extends below the metal spacer ring so that the UHF antenna is not shielded. The electronics, sensors, and batteries are all contained in the CSU. A jack is provided on the side to carry 6.3 Vac rms or 9 Vdc to the unit to extend the battery life. The ambient temperature sensor extends through the plastic below the spacer ring so that it is thermally isolated from the can temperature. A light-emitting diode also protrudes through the plastic so that an infra-red scanner can locate the specific CSU during interrogation. The electronics are packaged on 2 circuit boards inside the plastic base. The linear-variable-differential-transformer is on the top board and is centered to receive the bellows displacement rod. A second temperature sensing chip is in contact with top plate or pan on which the container sits. Up to three disturbance sensors are mounted in different orientations to sense motion.

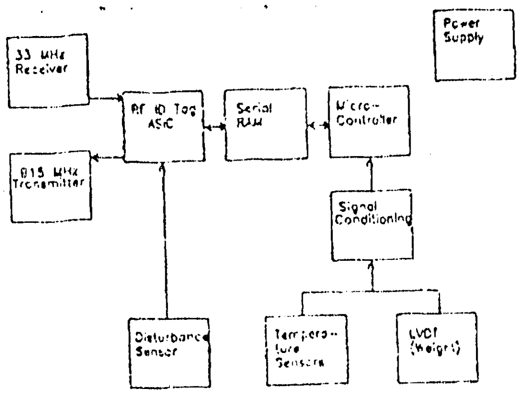


Figure 1. Block Diagram of Container Surveillance Unit

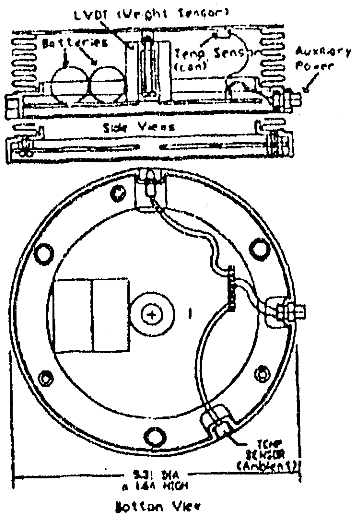


Figure 2. Mechanical Layout of Container Surveillance Unit

The principal function of the CSU is to respond to interrogations concerning its status. The Interrogation Unit (IU) polls specific CSU addresses and the appropriate CSU replies. These polls and replies are RF communications. At the end of the polling sequence, a "who are you" command is sent. If any units have not been addressed in the previous poll, they will respond. If one CSU replies, it will be interrogated with its specific address and added to the poll sequence. If more than one CSU replies, a collision occurs and the Interrogation begins a sequence of "How are you" commands. The logic for this is built into the CSU as well as contained in the sorting algorithms executed by the IU. As each CSU is identified, it is added to the poll. In order to speed up the poll, only change of status is sent by the CSU. If change of status is noted, the Interrogation Unit asks for more specific data. The tolerance bands for charge of status indication are downloaded from the IU to the CSU.

While a delay exists in identifying a change in status due to the polling sequence, the CSU has a beacon mode in which it can immediately send a message if one of the disturbance sensors produces a signal. The beacon messages may collide with the polled replies or with other beacon messages, but this is taken care of by making the CSU replies and beacon messages short, at high data rate, and at low duty cycle. Additionally the beacon messages are randomized. The data rate from the Interrogation Unit is 9600 baud and from the CSU is 100k baud. The CSU design allows up to 2000 CSU's to be polled in a minute.

6.0 RADIATION EFFECTS

The use of electronics in a radioactive environment leads to concerns relative to the life of the electronics. The radiation level is typically 300 mR/hour maximum. Ionizing gamma radiation predominates with neutrons accounting for 1/2 to 1/3 measured levels. Shielding is not practical, and, therefore, the electronics must survive the environment. Over 10 years the accumulated dose would be 26,280 rads. Bulk polysilicon CMOS integrated circuits can be hardened for 100,000 rads. The 10 year period would be a reasonable life given the limitations on other components such as the batteries. The duty cycling of bias voltage makes possible longer life in the presence of radiation. When the circuit is unbiased, the effects of radiation are small since there is no charge buildup or formation of degrading electron pairs. The absence of bias for a large percentage of the time makes possible sufficient radiation tolerance for the use of commercial semiconductor components.

7.0 RELIABILITY

The reduction in exposure of personnel is the primary goal of electronic safeguarding methods. It is important that the reliability of the electronics be sufficiently high that safeguarding of the material is not compromised and the exposure of personnel is in fact reduced. The CSU *mean-time-before-failure* (MTBF) is calculated to be 1.5 million hours. This number is based on failure rates of discrete components from Mil Handbook 217D and failure rates of integrated circuits from manufacturers. The MTBF will be reduced to 750 hours for a 2000 unit vault. The goal will be to more highly integrate the electronics to reduce the number of discrete devices and obtain a higher MTBF number.

8.0 THE DEMONSTRATION SYSTEM

A five-CSU demonstration system was constructed. The demonstration had as its objective the validation of the sensor, circuit and firmware approach. The CSU design used a stainless-steel bellows as a distributed spring to convert weight to displacement and an LVDT to measure displacement. Semiconductor temperature sensors measured ambient and can temperature. A disturbance detector based on a piezoelectric crystal and a spring and mass assembly was employed. The electronics employed an MC68HC805B6 microcontroller, which has on board an 8-bit A/D converter, 172 bytes of RAM and 5k bytes of EEPROM. The microcontroller performed the sensor measurements and interchanged data with a serial RAM. The RF Identification Tag ASIC also interchanged data with the serial RAM, which acted as a mail box. Communications was established in a full-duplex mode using RF at 3[illegible] MHz from the Interrogation Unit to the CSUs and 915 MHz from the CSU's to the Interrogation Unit. The Interrogation Unit employed a personal computer with a customized interface board for message encoding and decoding as well as transceiver circuitry. A photograph of a CSU is shown in Figure 3. Figure 4 shows the CSU electronics module with the LVDT held in the center of the top circuit board. Figure 5 shows a typical screen displayed by the personal computer.

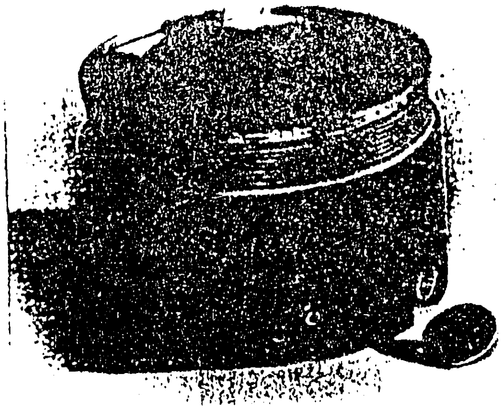


Figure 3. Photograph of Container Surveillance Unit

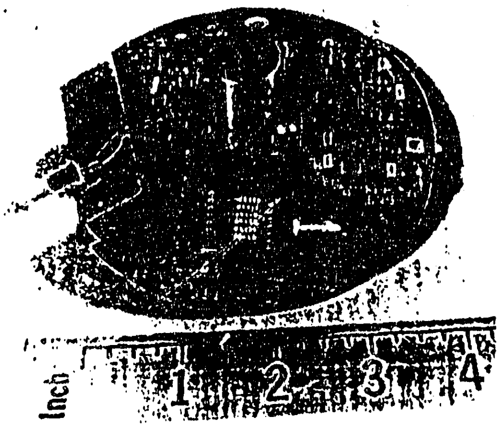
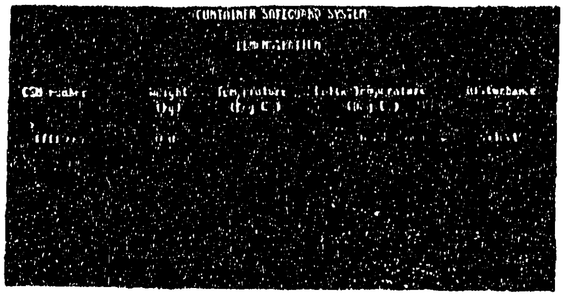


Figure 4. Container Surveillance Unit Electronics Module



CONTAINER SAFEGUARD SYSTEM

Figure 5. An Interrogation Unit Display Screen

9.0 SUMMARY AND CONCLUSIONS

A Container Surveillance Unit for safeguarding Special Nuclear Material has been described. The unit based on RF communications allows tracking of the material both in transit and in storage. Alternate arrangements and designs have been considered. The evolution of a serial data communications interface is an important step to reducing the cost, time, and exposure of personnel to do wiring. The use of RF is valuable for materials that are to be tracked during movement. Vault systems can use hardwired links, and this may be a better option if thereby batteries are eliminated. The eventual very-large-scale integration of these circuits will enhance the mean-time-before failure. The use of sophisticated sensors and processing will make materials secure and reduce the time persons are required to be in the vaults.

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