ELTECdata # 104

ELTEC INSTRUMENTS, INC.

Achieving High Reliability in Passive Infrared Intruder Alarms with Lithium Tantalate Pyroelectric Detectors

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Abstract

The problem of false alarms is defined showing the demanding nature of the application. Detector dependencies are discussed relative to reliability, such as: pyroelectric material, possible depolarization, long term stability, use of separate load resistors to achieve predictable time constants, response to temperature changes, soft error rate, potential microphonics, and the need for EMI protection. Highest reliability of the circuit design involves consideration of the internal JFET of the detector as well as careful selection of coupling capacitors, resistors and the power supply. The detector signal's dependence on optical design is identified and the relationship of signal-to-noise specified. User handling precautions of the detector are also given. Appendices show 1) the relationship of S/N ratio to false alarm rate in Gaussian terms, 2) failure rates of alarm components, 3) evaluation of approaches to testing, and 4) a brief discussion of soft error mechanisms.

Contents

1. Introduction

Pyroelectric detectors or sensors for passive infrared intruder alarms were commercially introduced in 1975, and have become the leading technology used today in intruder detection.

In this application pyroelectric detectors are operated near the theoretical limits of their operation and a false alarm with its consequences (police alarm, etc.) is more than just a defect or an annoying glitch.

a. The attendant consequences of a false alarm including loss of credibility for the system places an ever-increasing responsibility for product quality and reliability on the sensor manufacturer. And one must be careful in comparing sensors that are designed for other less critical applications, with sensors that are designed for security systems that must exhibit an extremely good long-term stability and reliability.

b. One must also make a careful examination of the interdependencies of the detector and the system in which it will be used.

With this paper, we would like to help facilitate use of the sensors in the best possible way in order to really profit from the very high reliability achievable with today's technology.

2. Failure Modes

There are different failure modes in security systems:

1. Component failures that render the system inoperable.

2. Spontaneous false alarms. The reason for these can very often not be discerned. They can occur only once or repeatedly throughout time.

3. Alterations of component parameters that do not cause a change in system operation.

Failures of the type 1 and 2 will be regarded in this paper as one type of failure or false alarm. We can do this because the consequences of both failures are very similar. It means the installation has to be serviced or the instrument repaired.

Failures of type 3 are, thus far, meaningless. Nevertheless, they are used here because the easiest way to achieve high reliablility is to convert failures of the type 1 and type 2 to failures of the type 3. This means that any malfunction of a component should not cause a false alarm. This and a careful selection and testing of the components used are the only ways to achieve reliability figures usually found only in military equipment.

2.1 Definition of the False Alarm Rate

Different figures are used to define the false alarm rate; for example, the average percentage of failures per 1,000 hours. In this article, we will use the instantaneous false alarm probability (P). P is the momentary probability of a false alarm right in this moment. As the time constant of the system is approximately one second, the output state of the intruder alarm can only change once in a second. Therefore, P is, in the case of the intruder alarm, equivalent to the average number of false alarms per second and can easily be converted to false alarms per year, etc.

Another practical figure is the inverse of P, the mean time between failures or "MTBF" as abbreviated.

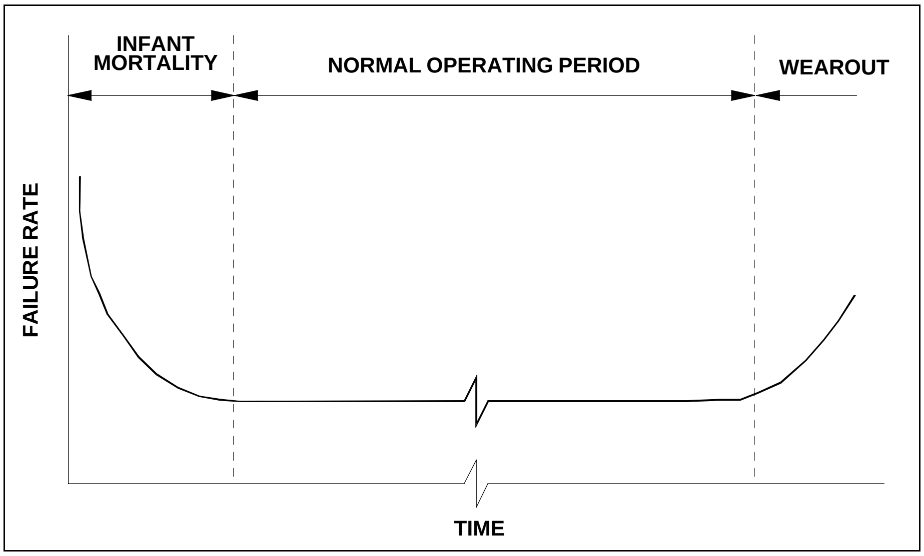

Figure 1. Traditional "bathtub" curve used to describe failure rates through time.

For example, $P = 10^{-10}$ is equivalent with 10^{-10} false alarms per instrument per second, or about .003 false alarms per instrument per year. This means that, in an installation with 300 intruder alarms, one out of these will produce a false every year, statistically.

The mean time between failures (MTBF), in this example, would be about 300 years. Please note that this figure can be used to predict the average number of false alarms to be expected per year, but cannot be used for any prediction of overall system lifetime.

2.2 Failure Mechanisms

Like all system hardware — mechanical, electrical or electronic — the reliability of passive infrared intruder alarms conforms to the well known "bathtub" curve, which plots failure rate against time. As shown in Figure 1, the three vital statistics associated with this curve are: infant mortality, failure rate at useful life and wearout.

Infant mortality means that the initial failure rate is rather high, but decreases rapidly. False alarms in this period are usually caused by damaged or potentially defective components. It can be reduced by careful selection and testing of the components used. However, infant mortality is rather an economic than reliability factor as long as a burn-in test is used in production and infant mortality occurs during this time.

The succeeding period is the useful lifetime or the flat portion of the curve. Here, the false alarm rate is mainly given by the two factors: system design and type of installation.

The next period is characterized by an increase of false alarms that reflects the onset of wearout. The main reason for wearout is corrosion. General figures for the useful lifetime are between five and twenty years and depend strongly on operating conditions such as temperature and humidity.

3. Reliability Dependencies on the Sensor

The pyroelectric sensor is the heart and the most critical component in a passive infrared intruder alarm and, therefore, a major factor in system reliability. As in other technologies, sensor related problems have served as the impetus to advance sensor technology.

3.1 Lithium Tantalate

The pyroelectric detector (Figure 2), using monocrystalline lithium tantalate is established today as the leading technology, and other principles such as thermistors or thermopiles are rarely employed in intruder alarms.

3.2 Depolarization

Monocrystalline lithium tantalate is a stable and non-soluble material that invites comparison with quartz. Depolarizations and, therefore, loss of sensitivity, (as they can occur in other materials as ceramics, TGS or PVF) have never been observed in lithium tantalate nor been described in literature and can only be expected at temperatures near the Curie point of 610^{o}C. Also, the monocrystalline structure does not exhibit phase transitions, locally depolarizing domains or other changes in structure as are known for ceramic or polycrystalline materials. Such changes can produce sudden and unpredictable output signals of the sensor and therefore, cause unpredictable false alarms.

3.3 Long Term Stability

Crystal dislocation and stresses are avoided by proprietary crystal processing techniques. A residual, slow aging process in the first year of operation can still be observed in some Eltec detectors, as it is known also of quartz resonators. Controlled pre-aging can limit that effect to a minimum, but in many applications a slight reduction of the noise signal over weeks and months can be observed (positive aging). Note that the sensitivity is not affected by this aging process.

3.4 Discrete Load Resistors

Sensors using lithium tantalate exhibit extremely good quality and long-term stability, but have the highest electrical impedance among all other pyroelectric materials, such as ceramics or plastics. This is a severe complication in making lithium tantalate sensors. As a consequence, a special hybrid impedance converter must be employed with lithium tantalate detectors. This impedance converter circuit uses a discrete high megohm thick film resistor (made by Eltec) together with a field effect transistor (FET). These resistors are manufactured in a proprietary process that results in extremely good stability and a noise figure of 0.5dB relative to the ratio of the resistor noise to the Johnson (thermal) noise; in short, near the theoretical limits. Together with specially selected FETs, the resulting impedance converters are routinely produced in quantity with good noise performance over temperature and time, even at impedance levels up to 10^{11} ohms. A detailed illustration is given in Figure 3.

3.5 Variations in Sensitivity

A result of using a discrete, stable load resistor and a pyroelectric material operated far below its Curie point is that the sensor exhibits almost no variations in sensitivity over temperature. This is not true for other materials and especially not for those detectors that do not use a discrete resistor for loading the element. Such detectors that use a doping of the pyroelectric material to make it conductive (to eliminate need for load resistor), as well as the sensors using any kind of diode for loading the crystal, show a sensitivity that is affected by temperature; i.e., their electrical breakpoint changes more or less predictably at increased temperature. This effect, the lowering of the sensitivity at high temperatures, can reduce it to 50 percent at about 45^{o}C, and yields units that "seem" to have a very good noise in temperature, but few people are aware of or can test the decrease in sensitivity that comes together with it. Some alarm manufacturers have found that they had to add a thermistor to lower the gain of their circuits at high temperature when using lithium tantalate sensors to match the characteristics of aforementioned ceramic sensors.

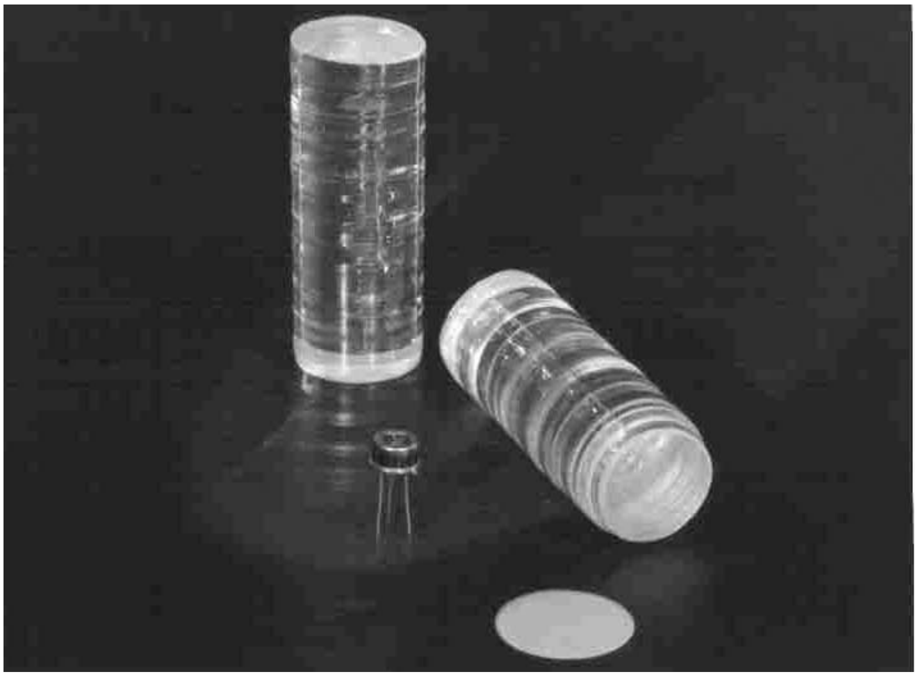

Figure 2. Boules of single-crystal lithium tantalate with cut wafer and detector (TO-5 can) to show size. Wafer is 0.23mm (0.009 inch) thick before lapping, polishing, electroding, and dicing.

3.6 Electrical Time Constant

Another consequence of using a discrete resistor is that the electrical time constant is well defined, to a tight tolerance. In sensors designed for intruder alarms with good sensitivity at low frequencies, the low frequency cutoff is usually determined by the electrical time constant (load resistance times detector capacitance, as given in ELTECdata # 102).

The resulting sensor has a controlled cutoff frequency near 0.1 or 0.2Hz (depending on Model), compared to cutoffs of ceramic element sensors without resistor varying from 0.001 to 0.1Hz. Although frequencies below 0.1Hz are seldom used in intruder alarms, the sensitivity at very low frequencies is of extreme importance since it determines behavior of the sensor during and after temperature changes.

3.7 Temperature Changes

A change in ambient temperature of 1C^o creates approximately 1 volt over the pyroelectric crystal. Consequently, a high output voltage can be created if this voltage is not discharged as quickly as possible through the resistor. Ceramic detectors with an unspecified and large electrical time constant easily saturate and become inoperative at temperature changes as low as 1C^o per minute. Also, after exposure to a temperature change, e.g., when taken from a hot car standing in the sun, such detectors may need up to half an hour to discharge and become operational, whereas resistor-loaded sensors settle within seconds.

3.8 Soft Error Rate

Another advantage of the impedance converter is that it can solve the problem of the so called "soft error rate." This effect is well known in high density semiconductor memories and

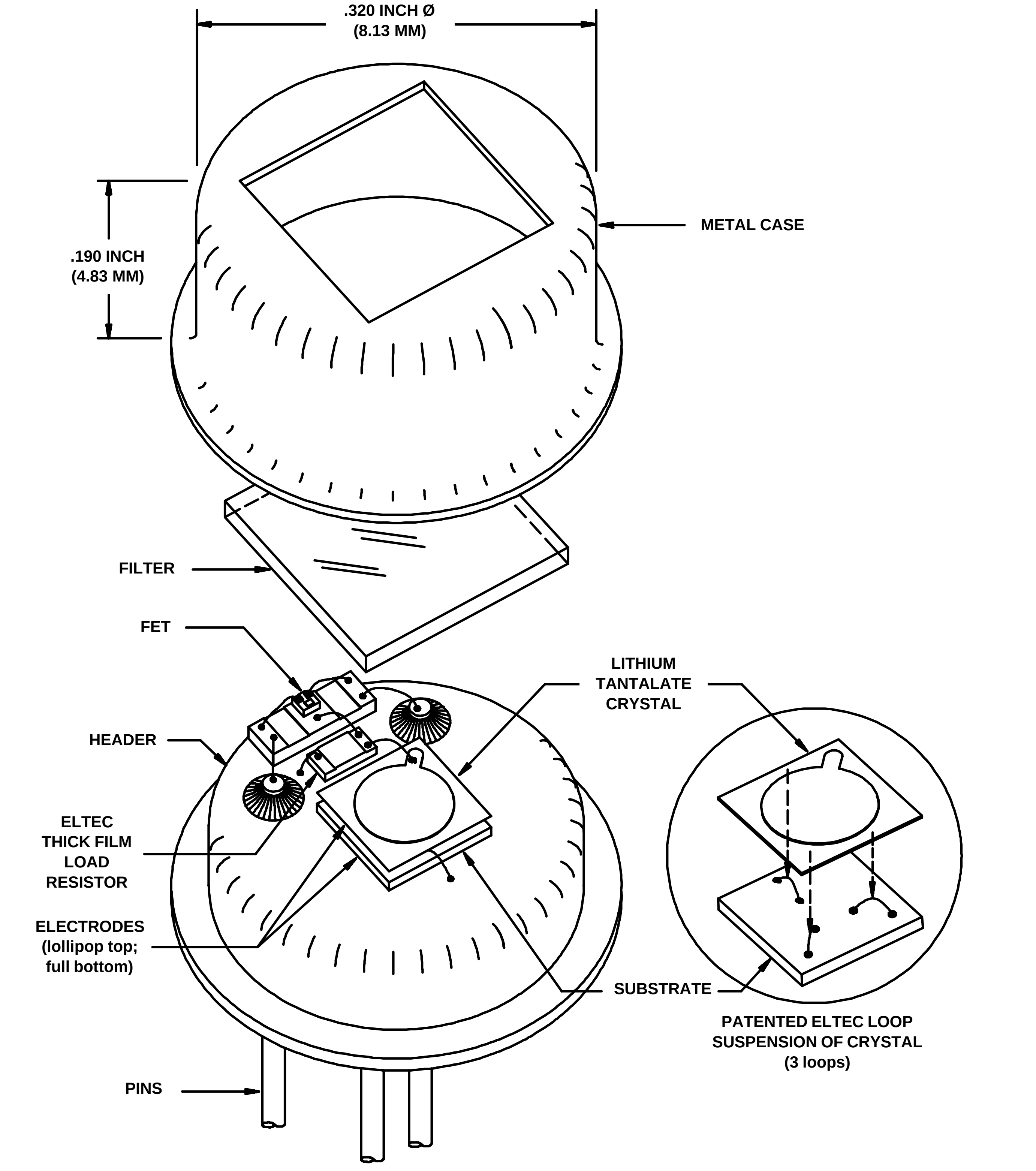

Figure 3. Single-element lithium tantalate detector with detail of crystal suspension.

is caused by alpha particles emanating from the natural content of radioactive elements in the surrounding materials. A transistor hit by such an alpha particle can charge the state of a memory cell, or, in the case of an intruder alarm, creates a signal of 10 to 100 millivolts at the output of the sensor and in most systems, causing a false alarm. By using standard, low-noise FETs and uranium doped ceramic materials as is done in some pyroelectric sensors, this soft error rate can produce several unpredictable false alarms per year and there is almost no possiblity for testing or predicting it. Careful selection of hyperpure materials inside the detector and the use of lithium tantalate permit use of a FET with minimal gate geometry thereby reducing the chance of being hit by an alpha particle dramatically. The probability of a false alarm is reduced to an expected MTBF of 400 years.

3.9 Microphonics

All pyroelectrics are electrets, which means materials with an inherent polarization in their structure. Therefore, they all are, to some extent, piezoelectric, and thus they act as microphones. Pyroelectric plastic film (fluorocarbon) detectors often encounter microphonic problems partially due to their being stretched in place, similar to the diaphragm of a microphone. Problems have been reported with ceramic detectors, but it is difficult to separate sensitivity attributable to materials from that of element mounting configurations and resulting capacitative changes which translate into noise. Fortunately, lithium tantalate detectors have not shown microphonic sensitivity to any extent that is not well within the basic electrical noise envelope. Unique mounting schemes have allowed lithium tantalate detectors to be used in shock and vibration environments several orders of magnitude beyond those found in commercial intruder alarm environments.

3.10 RFI Protection

Still another feature of the described impedance converter is its superior performance in electromagnetic fields. Intruder alarms need reliable operation under RF fields up to 10 volts/meter or more. A critical point is RF energy that is picked up by the circuitry and fed to the sensor, where it is rectified in the FET gate diode and creates shifts in the output DC level (step functions) that usually cause false alarms.

It is a consequence of the low stray and transfer capacitance of the lithium tantalate sensor that it has a much better RF rejection than many other devices.

Note: Of the pyroelectric detectors available today only Eltec's use a coated silicon or germanium optical filter window that is electrically joined to the case or housing. The resulting electrical shield over the sensing element is important for RFI protection and should be specified when using any pyroelectric detector for intruder alarm applications.

The only tradeoff of the lithium tantalate technology is limitation of FET choices which in turn limits adaptability to some alarm manufacturer requirements. This means that operating conditions such as drain current and load impedance must be adapted to the specific characteristics of the Eltec FET used in order to obtain optimum results. Sometimes, circuits designed for other sensors with high drain currents must be altered when lithium tantalate sensors are substituted.

4. What the User Must Do to Eliminate False Alarms

Intruder alarm reliability is determined by four factors: circuit design, system design, handling and field (or installation) problems.

Field problems are not discussed here, but obviously they can be influenced by the system design.

The objective of an optimum design should be to bring all factors affecting reliability to the same confidence level with concomitant recognition that the neglect of one single factor can be disastrous.

4.1 Circuit Design

The circuit design starts with the correct operation of the detector. Recommended circuits are available from detector manufacturers. In the past, pyroelectric sensors were very often operated at currents up to 1mA, but that accrues only disadvantages:

a. The gain (and therefore the sensitivity) can be reduced up to a factor of two to three when operating sensors at high drain currents and low impedance loads (See Figure 4.)

b. The pyroelectric crystal is a very sensitive temperature sensor and can pick up temperature changes as small as $10^{-4}C^{o}$. Any power dissipation inside or even near the detector housing should be reduced to a minimum, as this creates additional noise, instabilities or even microphonic effects (vibrations induce heat convection mechanisms) due to warm air drafts inside the detector.

c. Overall detector performance is the best when the FET is operated at a voltage of less than six volts and at drain currents in the range of 0.1 to 10µA, as FET noise figures are better at low current and voltage. Not all FETs may exhibit that relationship, but statistical data on thousands of detectors used in various circuits confirmed this data. Also, the low current FETs preferred by Eltec for the above reasons are a first step to low current, battery operated self-contained systems, an approach not feasible with active systems such as ultrasonic, microwave, etc.

Once the detector operating conditions are fixed, the other components of the input stage must be carefully selected. Coupling capacitors should be either film type or low leakage electrolytics. Avoid high E or multilayer ceramics. (E = dielectric constant.)

Low leakage dipped tantalum capacitors are good, but can become noise generators when humidity intrudes because the sealing is not good or broken during insertion or soldering. Also, they need a long recovery time to quiet down once they become polarized the wrong way, e.g., in the initial period when the instrument is switched on.

Good and relatively inexpensive aluminum electrolytics are less prone to the referenced problems than tantalums. Always orient such that there will be the correct polarization under worst case conditions!

Resistors are usually not a problem. Metal films are the best choice, but, carbon film types are a good second choice.

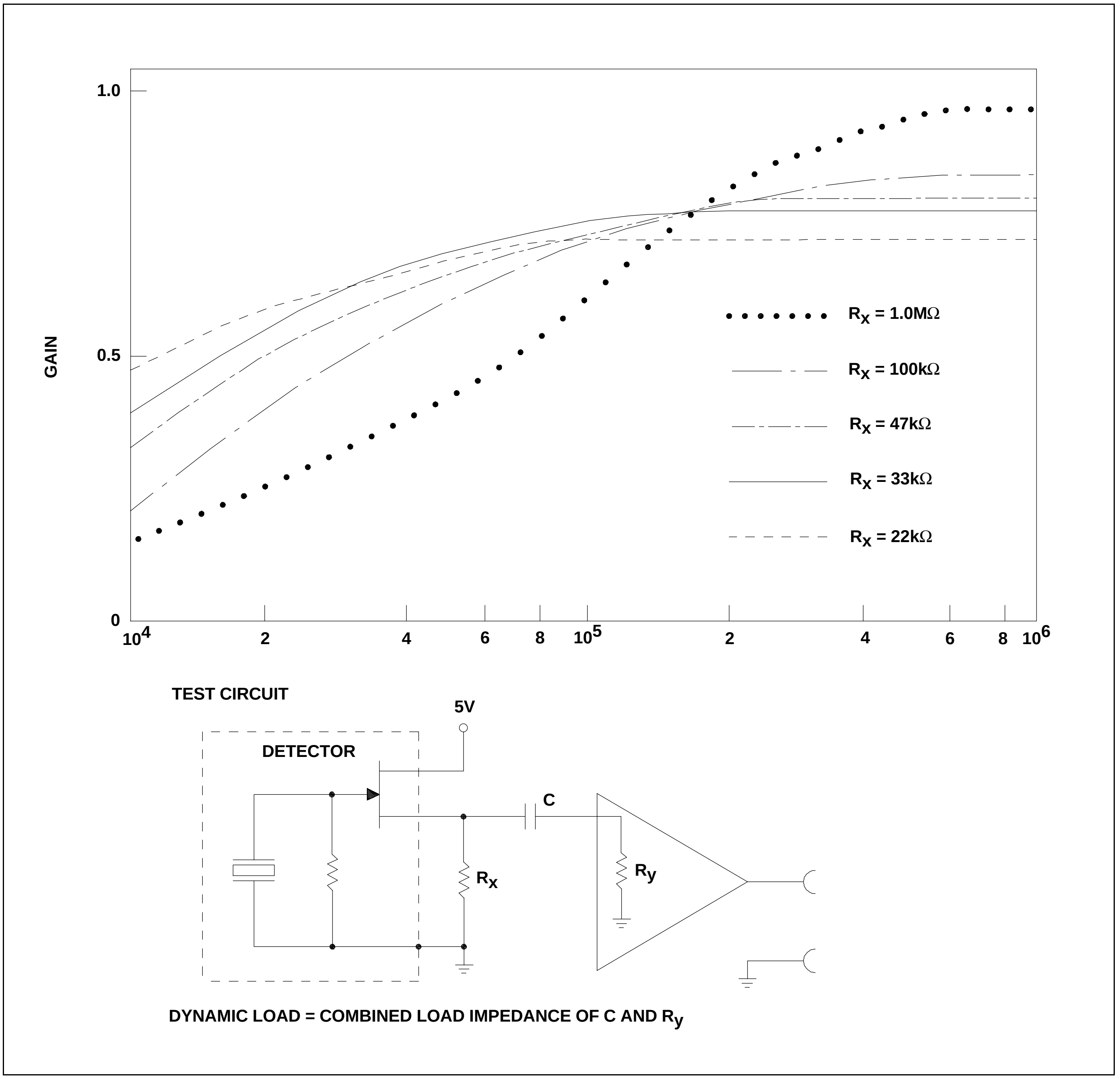

Figure 4. Impedance converter FET gain versus load (or "source") resistor and dynamic load.

As amplifiers, discrete FETs or transistors as well as BIFET op amps are recommended. Bipolar op amps need careful considerations for an adequate high input impedance (either low gain or non-inverting configuration for the first stage).

CMOS analog amplifiers are ideal for low current applications such as battery operated systems. They are readily available on the market, but can also be formed by unbuffered inverter CMOS digital devices with an appropriate resistor in the power supply to lower current drain.

The power supply needs careful consideration because there is no power supply rejection of a detector in the standard voltage follower configuration. There is no need for an absolute stabilization, but power line transients have to be smoothed down to one millivolt/sec or even less at the drain of the detector. This can be accomplished with a combination of integrated regulators, zener diodes and R-C combinations. (See Fig 5.)

4.2 System Design

The key factors for system performance and reliability are the signal-to-noise ratio and the discrimination principle.

The signal-to-noise ratio (S/N) is the quotient of the infrared signal available at the detector and the sum of all noise signals. The resulting S/N cannot be further improved by subsequent electronics.

1. Large signal is obtained when:

   The focal length (F) of the optics is large enough so that the diameter of the sensitive zone (Y) in not much larger than the person to be detected (X). (See Figure 6.) To achieve this with a 1 x 2mm sensitive area, the minimum focal length has to be approximately 1/500 of the desired range (D), e.g., 50mm for a 25m range.

Under this condition, the aperture (A), the area of the lens or mirror for each sensitive zone, directly determines the available signal. Approximately 2cm^2 area is the minimum for the required S/N ratio, 5 or 10cm^2 is better.

The quality of the optical lens or mirror has to be adequate to achieve the necessary image quality for the desired range. A dual sensor can only operate successfully when only one sensor element is irradiated at a time, i.e., when image blur is smaller than the detector geometry. This can easily be checked with a spotlight placed at the end of the anticipated range and a paper screen in the detector plane. The spot size obtained this way will determine the optimum sensor geometry. Care should be taken to minimize any additional optical losses from front windows, shrinkage of molded lenses or mirrors, oxidized mirror surfaces, obstructions in the field of view, etc. Thick and rigid front windows may be desirable from a designer's standpoint, but to compensate for the additional signal losses may become very expensive, if not impossible.

2. The noise at the sensor can be regarded as the sum of three components:

a. Electrical noise of the sensor and the circuit;

b. Electromagnetic interference from the environment; and

c. Optical background noise.

The electrical noise of the circuit can easily be reduced by the described precautions so that the most sensitive amplifier stage, the one inside the sensor, becomes dominant. There is a choice of sensors with different noise levels, but with a strong impact on price.

Electromagnetic interference (EMI) or radio frequency interference (RFI), is a factor of primary importance in infrared systems, as they respond to small shifts in DC levels from RF energy rectified in the semiconductor devices of the input stage. Complete shielding of the system and feed through filters for the external connections are usually required. Appropriate shielding can always be accomplished, but can become a major cost factor.

Optical background noise includes any thermal or infrared interference impinging on the detector. These are temperature changes in the field of view such as from sunlight, heaters and air conditioning systems. Such background noise is an absolute limiting factor for infrared systems.

Other thermal noise sources, also considered here as background noise, are the effects of thermal fluctuations of the IR system, itself, mainly of its front window, caused by air drafts and sunlight.

Improvement here is possible: the first "window" of the system (usually a polyethylene film) should absorb or reflect as much sunlight as possible. Although the integral optical filter of the detector has perfect blocking characteristics, its effectiveness is limited as any absorbed energy will heat up the filter and cause thermal fluctuations and noise. Also, the plastic front window should be protected from air drafts by an appropriate grid, recess mounted window, etc. In short, any object in the field of view of the sensor crystal that is heated up by light, air drafts or internal heat dissipation may reradiate infrared radiation that cannot be distinguished from a real signal.

Proper care for optical background noise and reduction of such secondary radiation effects may eliminate the need for a dual sensor. Another related problem is thermal radiation or air drafts (convection) onto the sensor

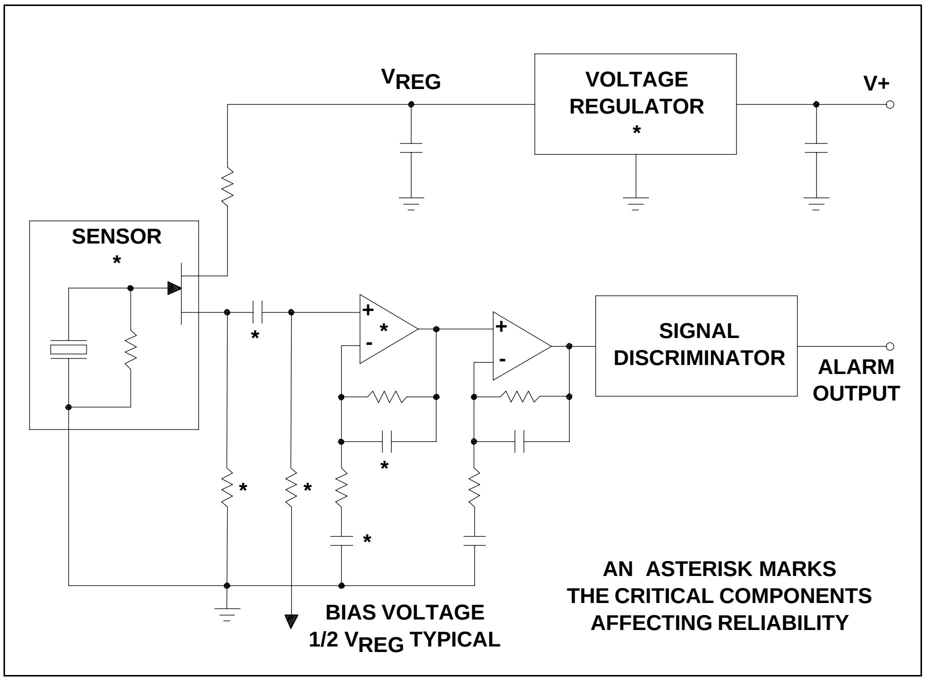

Figure 5. Typical intruder alarm circuit.

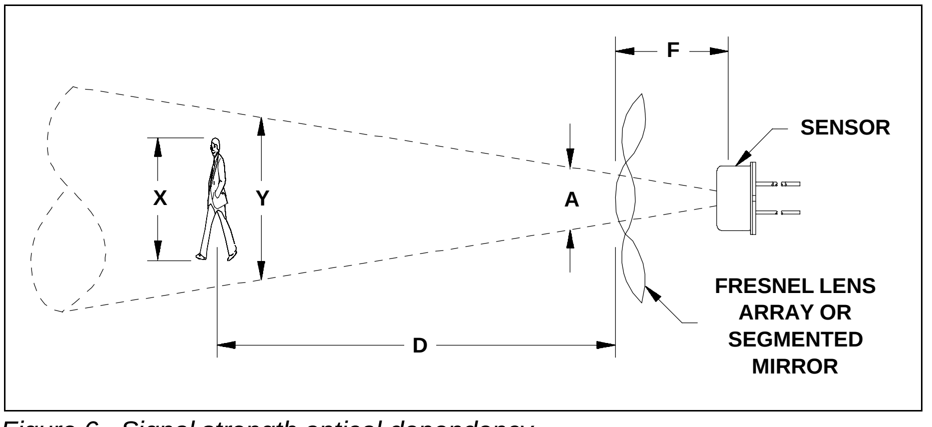

Figure 6. Signal strength optical dependency.

case itself. A temperature change of the case is transferred either by reradiation or by internal air convection to the crystal. Although less sensitive than the window, the case has a large surface and can pick up unwanted signals. It is a common practice to protect the sensor with a plastic sleeve or a molded plastic housing, with an opening only for the required field of view. Such a protection also improves the behavior of the system in response to ambient temperature changes.

4.3 Handling

One should always be aware that the pyroelectric sensor produces a voltage upon a temperature change. It does this from temperature changes induced by radiation as well as from ambient temperature changes. As mentioned previously, the sensitivity is approximately 1 volt per C° temperature change on the crystal. Consequently, a temperature increase of 100C° during soldering near the case results in a signal voltage of 100 volts that could well destroy the internal FET.

To avoid this, temperature changes must be kept to a minimum and should be as slow as possible so generated charge can discharge through the internal load resistor.

Overvoltage Protection: Although junction FETs are used, it is recommended that in production assembly the detectors be treated "as though they were MOS devices" and protected from electrostatic charges. With current mode detectors with integral amplifiers, it is important to see that the devices are not subjected to reversal of supply voltage polarity.

Thermal Shock: Most infrared filters are susceptible to damage from thermal shock. So, although the storage temperature range is -55°C to +125°C, the rate of temperature change should be kept below 50C°/minute. Whenever possible, the detectors should be stored in covered containers in a cool environment.

Mounting: Avoid mechanical stresses on case and leads.

Soldering: Detectors must be hand soldered to minimize the chance of destroying the internal components. Avoid machine or hot air soldering. Leave a minimum lead length of .250 inch (6.35mm). When soldering to detector leads, use a heat sink between the case and leads. Beware that the new RoHS compliant solders require a higher soldering temperature making heat sinking the detector extremely important.

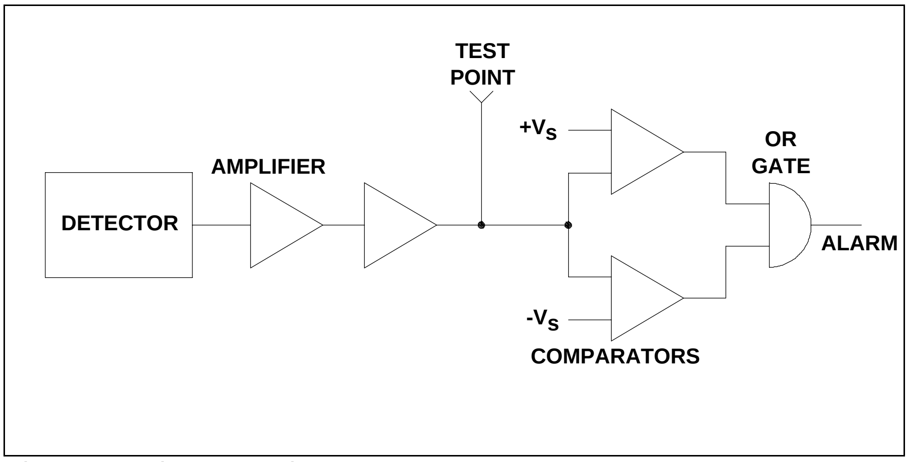

Figure 7. Noise measuring test setup.

Filters: Advise production workers not to touch filters. Lint, dust or fingerprints can usually be removed simply by rubbing with a cotton swab. If a cleaning solvent is needed, alcohol will suffice.

Solder Joints: They can be noise sources with their spectrum right in the target bandwidth. Careful inspection for weak joints is necessary and, depending on environmental conditions, a conformal coating should be applied to prevent crystallization or corrosion.

Appendix 1

Signal-To-Noise Ratio vs. False Alarm Rate

1. Gaussian Statistics

An absolute limitation to system false alarm rate is given by the assumption that there is only electrical noise and that this noise behaves according to gaussian statistics.

The probability (P) that the amplitude of the noise signal reaches a certain value V_s is

$$P(G) = e^{-(V_s^2/V_r^2)} \qquad (1)$$

if v_r^2 is the mean square noise signal.

Examine the signals at the output of the amplifier, where we have the total system noise and where the signal is fed to the comparator, triggering on positive and/or negative pulses (See Figure 7).

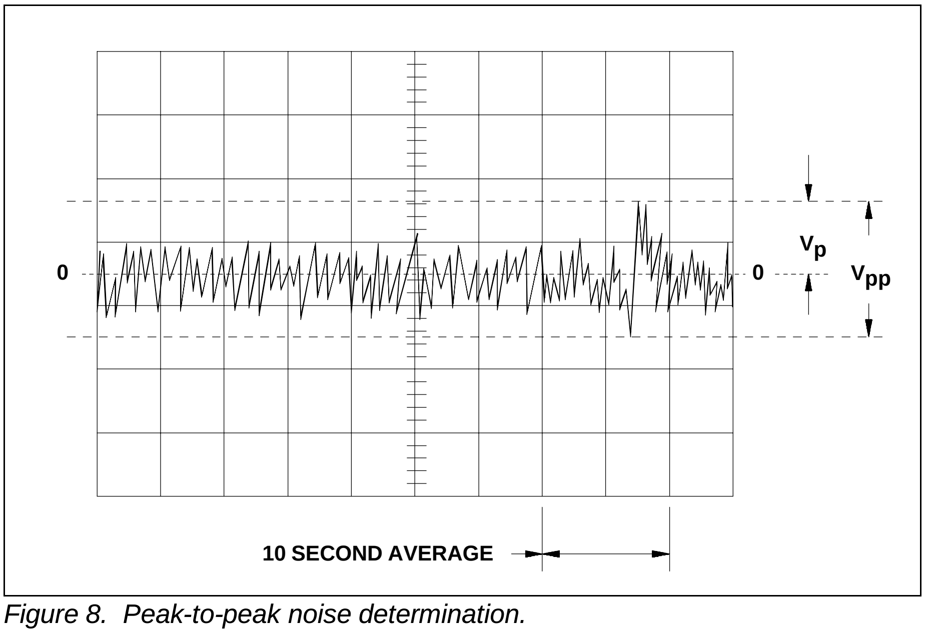

Figure 8. Peak-to-peak noise determination.

If v_s is the trigger level on each side, equation (1) is also the false alarm rate of the system when v_r^2 is the mean square noise signal at the test point.

In practical tests, infrared sensors are not tested to mean square or RMS $(v_r^2)^{1/2}$ noise signals, but rather to peak-to- peak amplitudes over a time of a minute or so. Such a peak-to-peak amplitude (v_{pp}) can be considered as the sum of the maximum positive and negative amplitudes reached about evey ten seconds (See Figure 8).

The exact time of observation is not of importance, it is only a matter of the order of magnitude.

Per the formula (1) or the graph in Figure 9, the amplitude reached every 10 seconds is about 1.5 x $(v_r^2)^{1/2}$ or 1.5 x v_{RMS} with either polarity. With that relationship, there is no need to know the RMS noise and we can directly use the oscilloscope reading of the noise signal.

For convenience, we use the single side noise signal $v_p = 1/2V_{pp}$, as we defined the trigger level also as single sided, i.e., +/- v_s.

From the graph P(G) in Figure 9, we can directly read the expected false alarm rate as a function of S/N (v_p), the ratio of the trigger level v_s to the single side peak noise signal v_p.

For example, a S/N (v_p) of 2 corresponds to a P(G) of approximately 1.2 x 10^{-4}/sec or a false alarm (MTBF) every two hours, whereas a S/N (v_p) of 3 increases the MTBF to 20 years.

In the previous considerations, we have seen that even in an ideal system, it is very dangerous to operate it near the S/N (v_p) of 3, as the slightest reduction of it increases the false alarm rate to unacceptable levels. For inevitable circuit tolerances, we add a safety margin of 30%, i.e., a minimum S/N (v_p) of 3 + 30% = 4.

2. Other False Alarm Mechanisms

The effect of optical background noise cannot be described in a generally applicable formula as it depends on operating environment and specific system design. However, Eltec is in a position to give an averaged figure over many hundred thousand sensors used in various systems.

This false alarm probability P(B) is the sum of all non-gaussian noise mechanisms and includes also non-gaussian electrical noise, weak solder joints, etc. As derived from field data, it is impossible to state the relative contribution of each noise source; however, it is commonly noticed that optical background noise is dominant.

P(B) is obviously a rather linear function. There is a slight false alarm probability even in the best system, e.g., from reflected sunlight, an extreme RF interference, etc. The S/N (v_p) of 4 required by the gaussian statistics is inadequate for alarm systems and results in MTBF figures of weeks or months.

S/N (v_p) 8:1 is the minimum for MTBF figures over one year and S/N (v_p) 16:1 to 20:1 should be the minimum design goal for high reliability systems with MTBF over ten years. (Note that MTBF = 10 years means still one false alarm per year in an installation with 10 detectors!)

3. Temperature

There are many temperature dependent noise mechanisms, but the

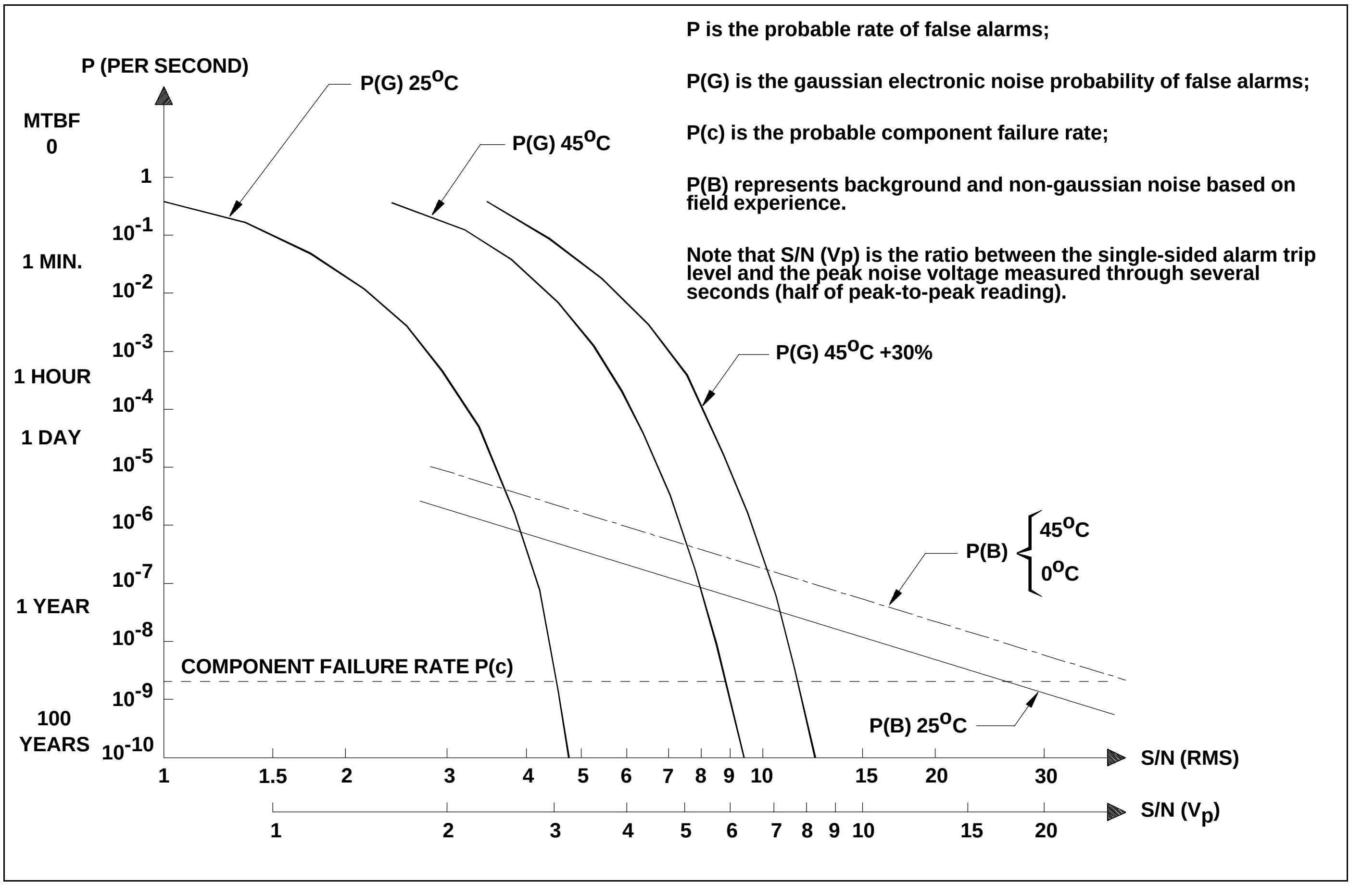

Figure 9. False alarm rate versus signal-to-noise ratio (single pulse discrimination).

signal (sensor responsivity and amplifier gain) can be considered as more or less stable.

As the dominant gaussian noise can be current noise (this need not be so in all sensors), it will approximately double for a temperature increase of 20C^o. Consequently, the P(B) plot shifts upwards by a factor of 2 (See Figure 9).

No system can be operated or tested at 45^{o}C having a S/N (v_p) of less than 8 at room temperature, without a predictable percentage of false alarms in short periods!

For the same temperature interval, optical background noise P(B) will be approximately five times higher. As such high temperatures exist usually only for a relatively short time period, the impact of a higher P(B) can be tolerated for S/N (v_p) figures around 20.

If a S/N (v_p) of about 20 (at room temperature) cannot be provided, the system must be improved by temperature compensation or a more sophisticated discrimination principle.

Care should be taken that some sensors using conductive ceramics or other non-linear devices for loading the crystals sometimes already have such a temperature behavior and apparently show good temperature stability, but have reduced sensitivity (as mentioned earlier).

The rate of change of the temperature should be kept to less than 1C^o/min. to avoid additional noise due to thermal fluctuations. This can be done by proper thermal isolation of the sensor.

4. Signal Discrimination and Redundancy

Up to this point, we only considered single channel systems that trigger an alarm on the first signal pulse exceeding v_s. Although simple and sensitive, sometimes false alarms cannot be reduced far enough under particular background noise conditions or instances where the optical system cannot be further improved.

Several alternative signal discrimination principles have been used or proposed:

4.1 Counting several signal pulses or sequences. Such systems are very effective, but need an optical system with an adequate number of zones.

4.2 The simplest 2-channel system is obtained with a dual sensor, providing an analog addition of the signals of the two sensors with opposed signs. Although somewhat less sensitive than single sensor systems, they have proven to be the most practical compromise. A representative sensor (without cover) is shown in Figure 10. A lack of sensitivity in the near range can be compensated with an asymmetric field of view of the sensor.

4.3 Other 2-channel systems can be made with real 2-channel sensors, providing two output signals. There is a wide range of possibilities for separate processing and correlating the two signals.

If the two signals are multiplied, they form a redundant system. An alarm is only produced when both channels have a signal simultaneously. The overall false alarm probability is P^2, reducing the reliability requirement for each channel drastically. However, such a system does not overcome background noise.

Other, but more expensive, combinations can be made with an infrared system and a microwave or ultrasonic system.

4.4 Adaptive threshold decoding is a common practice in communication systems and can be helpful in infrared alarms. The gain is automatically adjusted for a constant noise output of the amplifier, thus maintaining a constant signal- to-noise ratio.

4.5 Many more possibilities can be realized with a wide band amplifier and analog and/or digital signal processing, for example with a microprocessor.

All these methods can help to improve a given system with an inadequate signal-to-noise ratio.

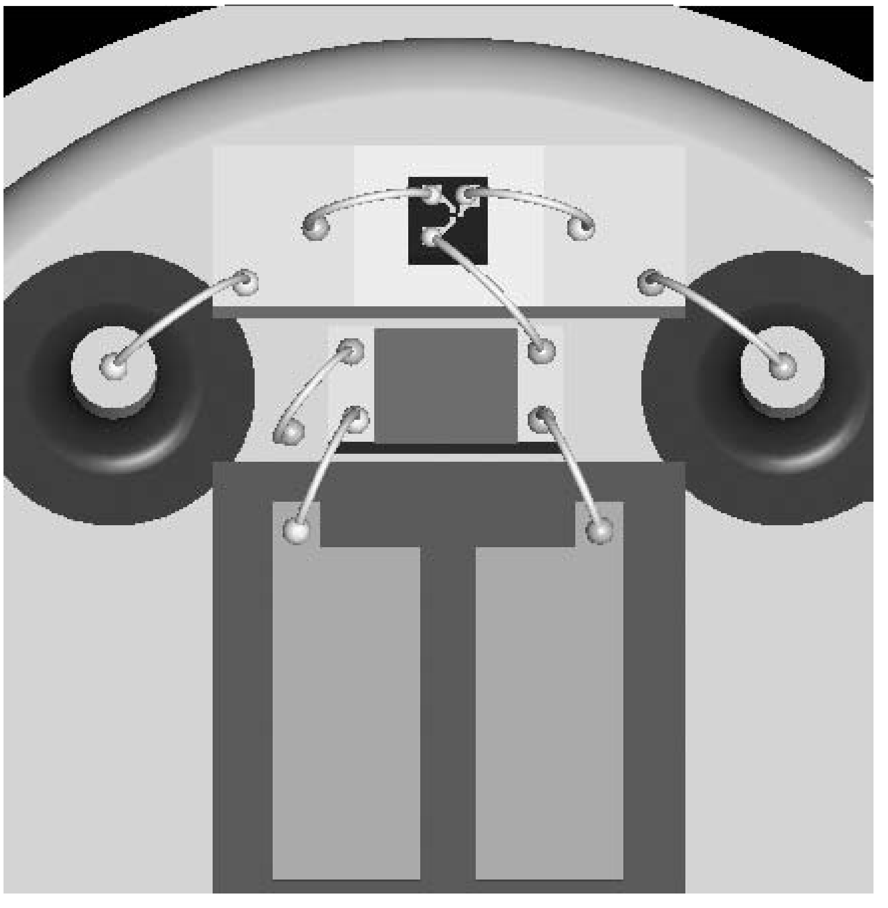

Figure 10. Header of dual element, series opposed lithium tantalate detector with load resistor and FET. Bottom electrode unconnected (floating). Wire from resistor to header makes case ground. Graphic enhanced to make 0.025mm (1 mil) gold wire visible.

	COMPONENT	COMPONENT FAILURE RATE $P(S^{-1})$	NUMBER OF COMPONENTS IN SYSTEM n	FAILURE RATE Pn (S^{-1})	RELATIVE PROBABILITY (%)
NORMAL OPERATION[1]	SOLDER JOINTS	3×10^{-13}	200	6×10^{-11}	2.8
	RESISTORS	1×10^{-12}	30	3×10^{-11}	1.4
	CAPACITORS, DIODES	3×10^{-12}	10	3×10^{-11}	1.4
	ELECTROLYTIC CAPACITORS	1×10^{-11}	8	8×10^{-11}	3.7
	POTENTIOMETERS, RELAYS, TRANSISTORS, ZENER DIODES	3×10^{-11}	5	1.5×10^{-10}	7.0
	IC'S	8×10^{-11}	2	1.6×10^{-10}	7.4
CRITICAL PARTS (SEE FIGURE 5)	RESISTORS (INPUT STAGE)	1×10^{-11}	4	4×10^{-11}	1.9
	ELECTROLYTIC CAPACITORS (INPUT STAGE)	2.5×10^{-10}	2	5×10^{-10}	23.2
	VOLTAGE REGULATOR	5×10^{-10}	1	5×10^{-10}	23.2
	INPUT AMPLIFIER (IC)	1×10^{-10}	1	1×10^{-10}	4.7
	ELTEC SENSOR	5×10^{-10}	1	5×10^{-10}	23.2
	TOTAL		264	2.15×10^{-9}	100
	TOTAL MTBF APPROXIMATELY 15 YEARS				

Table 1. Failure rates of intruder alarm components.

Appendix 2

Typical Failure Rate of Passive Infrared Intruder Alarms and Their Components

The effect of signal-to-noise ratio has been described in Appendix 1, but there is another noise-independent false alarm probability, indicated in Figure 9 as a horizontal baseline, the component failure rate P(C).

Component problems as described in Section 4, e.g., tantalum capacitors, can well increase failure rates by many orders of magnitude.

The figures in Table 1 are calculated for an average intruder alarm with 64 components and 200 solder joints, operated indoors at 20°C to 30°C.

[1]The data for normal operation is derived from statistics taken from a communication system. They apply for standard industrial components operated well within the specification and after a proper burn-in test, i.e., they apply for the horizontal part of the "bathtub" curve.

The total failure probability of P(tot) = $2.15 \times 10^{-9} s^{-1}$ corresponds to an MTBF or average system life time of approximately 15 years (See Table 1).

It is typical for such a system with critical components operated near the limitations in the input stage, that 70% of the failures are caused by only four components: the two electrolytic capacitors, the voltage regulator and the pyroelectric sensor with a similar contribution each. Individual circuits MTBF can be calculated using MIL-HDBK- 217.

Appendix 3

Testing Sensors and Systems

1. Purpose of Testing

Sensors and systems are tested to ensure operation and the required signal-to-noise ratio with an adequate safety margin.

Noise measurements at the low frequencies used (0.1 to 10Hz) require test times of about one minute and cannot be tested initially like other parameters. Significant investigations here have been made to find quicker test methods, e.g., at higher frequencies, higher temperatures, higher voltages, etc., to simulate operation conditions, but with no definitive results to date.

This is due to the fact that many different noise mechanisms can be dominant, with each mechanism dependent on different parameters. There is no other way than to test under realistic operating conditions.

An additional burn-in test should be made, especially in single pulse discriminating systems that give a false alarm on most component failures or parameter changes, to ensure that the required signal-to-noise ratio is maintained over a specified period and to eliminate potentially defective components.

2. Initial Tests

Although Eltec sensors are tested 100% to all relevant parameters, an incoming inspection may be justified, especially when there is little safety margin in the application and when the frequency range used differs significantly from the one tested at Eltec, i.e., when different noise mechanisms may be dominant.

Care should be taken that contact noise from the test sockets and RF interference do not spoil the test results. It is therefore recommended to retest the rejects. Such tests should be made to the same or somewhat extended specifications as those of the manufacturer. If tested over longer time periods, e.g., with sample and hold circuits, the statistically expected larger noise signals per the gaussian statistics (Figure 9) must be considered.

A final test of the system is usually made after assembly. The sensors having undergone the stresses of handling and soldering, reject rate (up to this point) of a fraction of a percent (0.8%) is normal. Some failures such as weak contacts and erroneously accepted units cannot economically be eliminated in sensor production.

If the failure rate is higher, it is very likely that the sensors were either destroyed in handling and assembly or that the system will not meet the required specification under worst case conditions. In most such latter cases, there is no other way than to use a sensor model with a better performance if the circuit or range cannot be further altered.

3. Burn-In Test

Over years of experience with high reliability systems, we found that a burn-in test is unavoidable for intruder alarms.

The components with the highest field failure rate, electrolytic capacitors, voltage regulator and the sensor, also have the highest infant mortality.

Noise generators, especially tantalum capacitors in the input stage, reach their final performance only after hours or days. Noise can either increase or decrease from its initial value.

Care should be taken that switching-on the system does not invert the voltage on the capacitors and destroy the insulating barriers, thus altering the capacitor noise performance.

The following tests are recommended:

a. The minimum burn-in is to operate the system for a day and then to retest for operation and minimum S/N.

b. Same as (a.), but with continuous supervision on false alarms, e.g., with an alarm memory. If done over a week and checked daily for alarms, a reliability prediction is possible.

c. Same as (b.), but with reduced alarm trigger level or increased gain. The statistically expected false alarm rate per Figure 9 must be considered.

d. Operation at higher temperature (e.g., 45°C) or temperature cycling. This is especially effective to eliminate any potentially defective components. Care should be taken when noise measurements are made that they are done after complete stabilization of the sensor and that they consider the predictable increase in noise.

Most thermostatically controlled temperature chambers have too high fluctuations and air drafts for such noise tests and require careful shielding and isolation of the sensors.

4. Accelerated Life Tests

Such tests are made to gather information on field failure rate and expected lifetime.

They are not burn-in tests as they are usually destructive and do not improve the quality of the systems tested and selected. Common tests for semiconductors are high temperature and high humidity. They assume migration of contaminants and package sealing as the major failure mechanisms (Figures 11 and 12).

They have proven to give useful results for common failures such as leaking capacitors (humidity) and temperature dependent semiconductor failures; however, they do not cover all false alarm mechanisms in

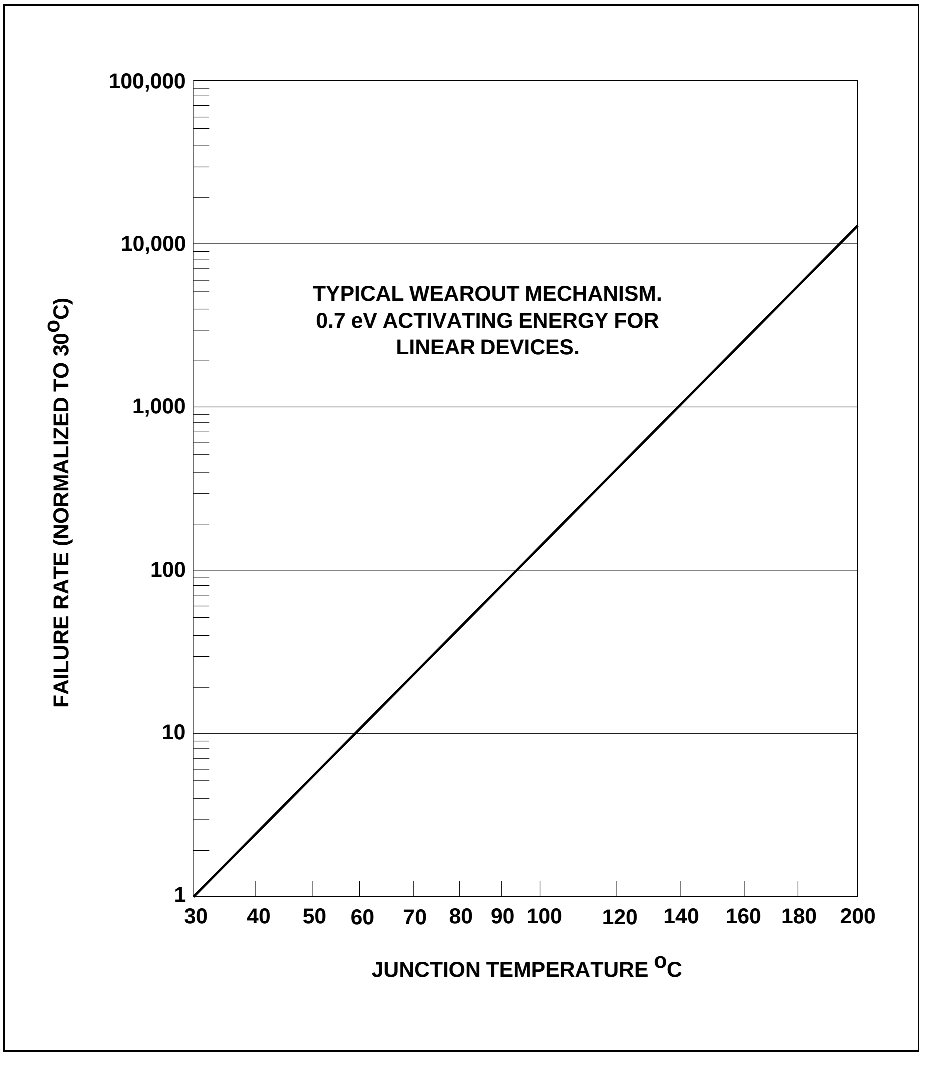

Figure 11. Failure rate as a function of junction temperature.

intruder alarms and cannot eliminate the need for a proper burn-in test.

Other applied stresses such as overvoltage and vibration have not yet given results correlated to the system false alarm rate.

Appendix 4

Soft Error Mechanisms in Pyroelectric Detectors

(False alarms due to radioactive alpha radiation)

Alpha particles emanating from radioactive contaminants are found in all materials and have a detrimental effect when they hit the field effect transistor of a pyroelectric sensor in an intruder alarm system.

The mechanism is the following:

An alpha particle absorbed in any material will produce about 10^6 ions which is a charge in the order of 10^{-13} Coulombs (C). Even stronger signals may result if these ions makes a channel through the gate diode barrier of the field effect transistor and an additional current flows until the ions recombine.

Charges of 10^{-13} C obviously do not harm standard intruder alarm circuits with either kilohm impedances or nanofarad capacitances. But on the gate of the input FET with an input capacitance of say 10pF (crystal capacitance), the signal will be 10mV or more with a signal duration of the electrical time constant of the sensor, 1 second or so. This is a pulse of 100 to 1000 times stronger than average sensor noise and with a pulse shape that cannot be distinguished from an intruder signal.

The actual magnitude of such pulses can easily be verified when a sensor is opened and the FET chip directly exposed to a weak radioactive source, e.g., within a distance of a few millimeters from an Americium source taken from a smoke detector or by using an incandescent mantle from a gas lamp which has a few milligrams of Thorium.

For reliability calculations in actual sensors, alpha radiation can be calculated from the natural content of Uranium or Thorium in the package materials, normally in the ppm range. Actual semiconductor package emissions are reported* to be up to 1 particle per hour and cm^2. In such an extreme situation, assuming a FET geometry of 10^{-3} cm^2, the false alarm probability will be 10^{-3} per hour or 9 false alarms per year.

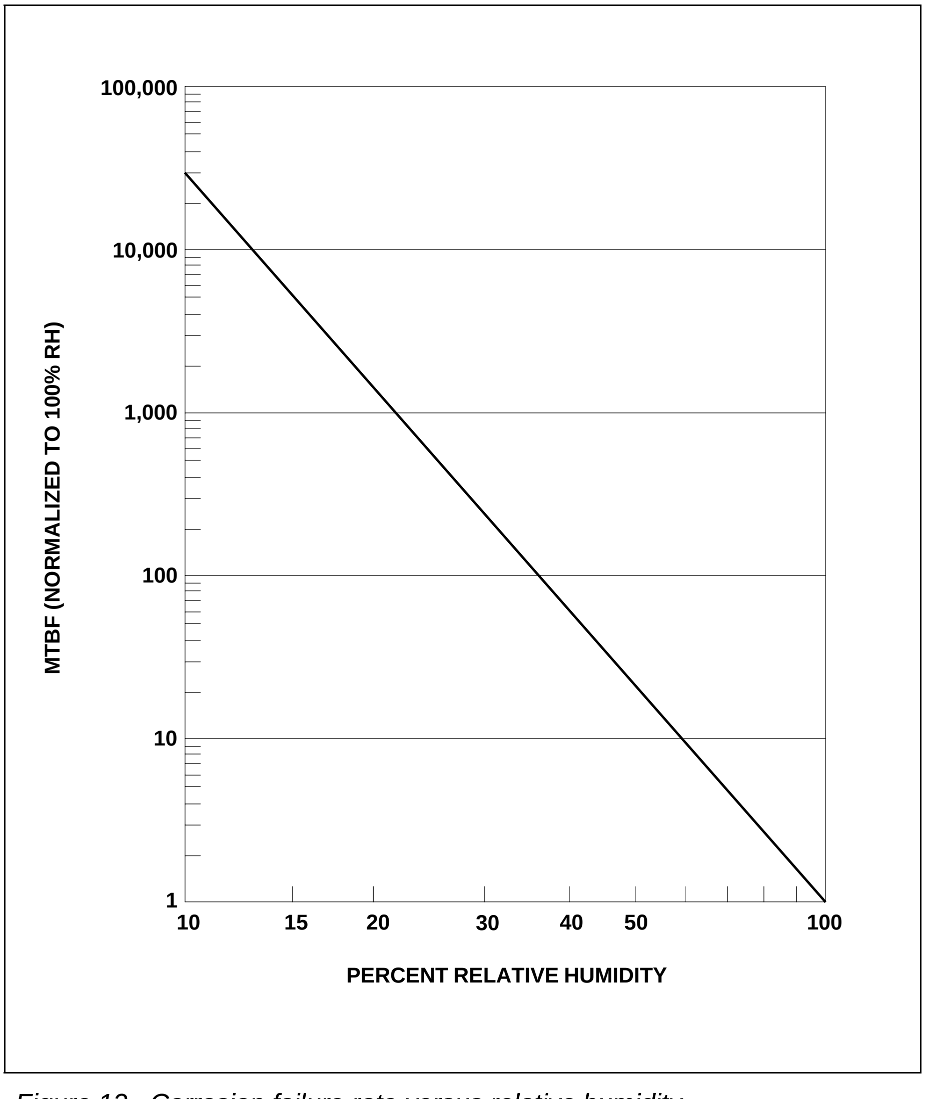

Figure 12. Corrosion failure rate versus relative humidity (at constant temperature).

*"Hardening RAMs against soft errors" *Electronics,* pp 117-122, April 24, 1980. Also, "Alphas cause rift at ECC", *Electronic Engineering Times,* May 28, 1979.

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