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thermal analysis
low-temperature plasmas

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looking at the world through

an infrared eye

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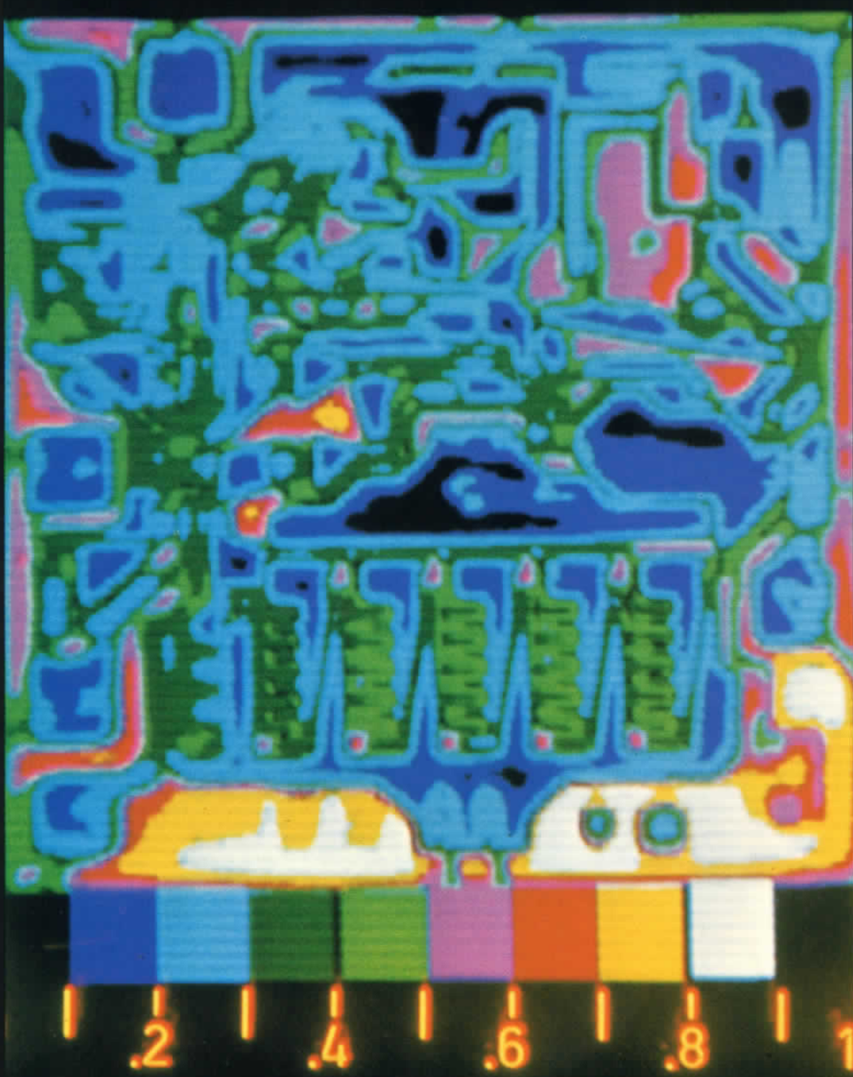


Thermogram of a regulator circuit with associated resistors, transistors, etc. The energized circuit, potential failure areas appear as very hot parts, shown in white, yellow, and red. Each color represents a temperature differential of 5 C.

IN THE WORLD in which man exists, humans are relatively insensitive creatures. They relate to the outside environment only through the limited perception of their five known senses. And among these senses, only the ability to hear, to smell, and to see allows mankind to perceive phenomena outside the immediate contact with the physical body.

Speaking somewhat more scientifically, our senses recognize only a small portion of an incredibly broad and varied spectrum of communications. Such signals pervade our immediate environment and the whole macrocosmos.

Nature failed to equip us to receive this multitude of communication and signal transmission which goes on around us all the time. Therefore, we focus our attention on those things which most stimulate our senses—mainly on what we see in terms of colors, distance, movement, etc., and on what we hear within a rather narrow band of frequencies to which our ear is sensitive.

Aside from sound and light, we are also capable of recognizing one part of the world of invisible signals—namely, heat, infrared radiation. But our sensitivity in this frequency band is crude, at best. It is limited to an appreciation of hot, warm, cold—and maybe too hot and too cold—just enough to keep us out of trouble.

Nevertheless, this infrared radiation has probably more influence than anything else on our condition. We are not constantly aware of it. Yet nearly everything we experience or do is, in some form, temperature-dependent or -related.

When we think of it, this fact is so obvious that citing examples is superfluous.

Recently it has become possible to translate thermal radiation into visible signals which we can measure and quantify with remarkable accuracy. This is one of the more important achievements in man's attempt to extend his sensitivity beyond the natural limitation of his senses.

Infrared energy was discovered as a part of light when the various colors were separated from sunlight with the help of a prism. We now know what the electromagnetic spectrum is. We know that the spectrum covers a range from x-ray particle emission through the ultraviolet into the infrared (heat) range and on to the radio waves.

Sensing infrared energy

The development of highly-sensitive infrared detectors, capable of registering temperature variations to fractions of a degree within microseconds, is at the heart of the present state-of-the-art infrared imaging system.

The technology of remote sensing of heat radiation has been considerably stimulated by military needs for night vision.

The infrared imaging system is essentially a closed-circuit TV, producing a CRT picture displaying a heat pattern. Differences in the infrared emissions from the surface of an object appear as brightness or color variations in the image.

Now it may be rather interesting to view the world with heat-sensitive eyes, so to speak. But the application of this technology to the most diverse ranges of our human, scientific, and industrial endeavors has rendered remarkable results, opening the door to yet undetermined opportunities.

IR imaging instrumentation

In 1965, AGA Aktiebolag, an international Swedish concern, introduced to the U.S. its Thermovision® System. This represented the first high-resolution infrared scanner with real-time image presentation. The frame rate was 16 per sec, and the thermal resolution was 0.2 C at 30 C object temperature.

The CRT image displayed differences in infrared radiation from an object in terms of variations in the brightness level. With the use of an isotherm circuit, the intensity of infrared radiation levels could be accurately measured.

A state-of-the-art thermal imaging system will provide high scanning efficiency, because it employs a completely refractive scanning system, using prisms for both the vertical and the horizontal sweeps. Interchangeable bayonet-mounted lenses offer various fields of view, ranging from a wide angle of 45 deg to a supertelephoto lens of 2 deg.

The color-display monitor presents 10 temperature levels within a heat picture, displaying them as 10 different colors. This makes it possible to perform instantaneous quantitative measurements of temperature differentials between various areas of the object. Photographic records of both the black-and-white and the color images may be obtained through a camera attachment.

Interface equipment also is available for the storage of thermal data on magnetic tape through a recorder or on compatible computers. This makes it easy to play back recorded events for later analysis and interpretation.

When the observation of rapid thermal transients demands stop-action recording, a magnetic disc recorder can be used. It can accumulate 45 frames in the sequential loading state, or it can store one frame at a time at the operator's command.

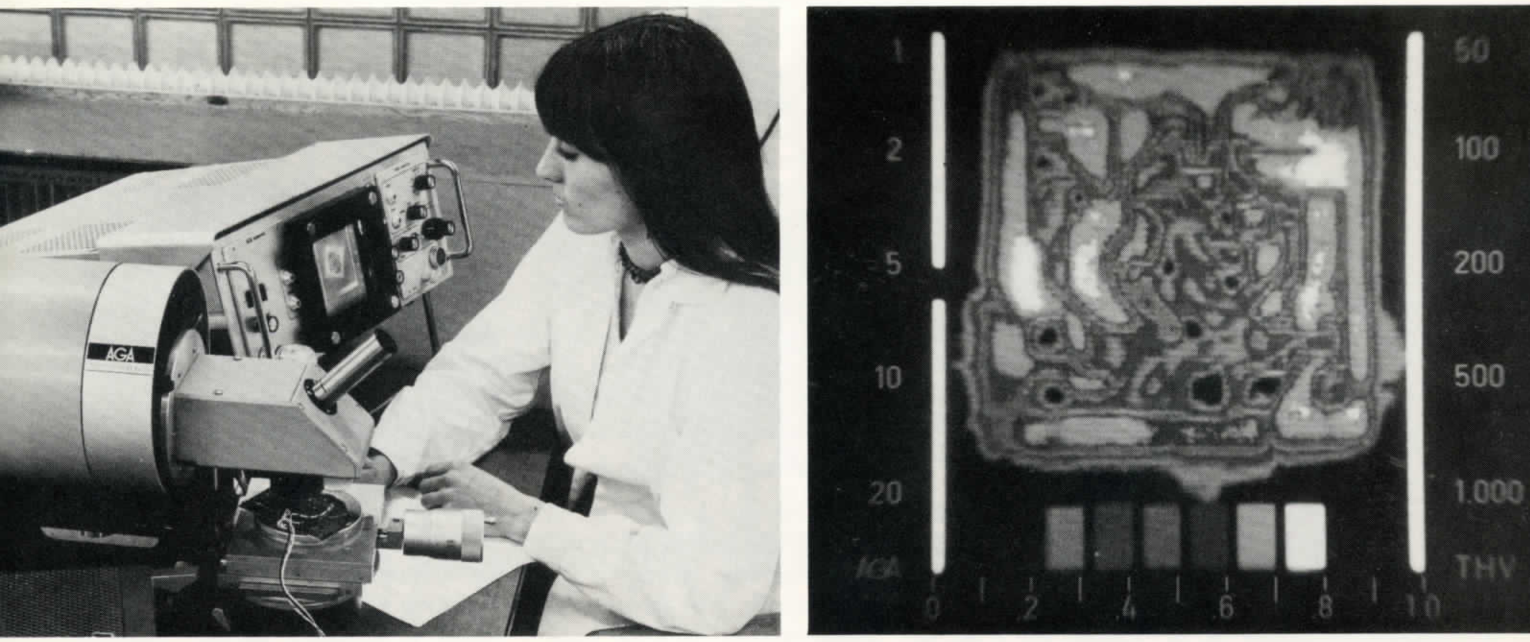
Any of the 45 frames may be selectively viewed for an unlimited time. In other words, playback presents a frozen picture consisting of one frame per track. The use of the isotherm function or the color monitor permits later quantitative analysis of recorded data.

At least one current infrared imaging system is easily converted into an infrared microscope by replacing the normal lens with a microscope attachment. Three interchangeable sets of microscope optics provide 15X, 50X, or 125X magnification.

The 50X optics, for example, cover an area of 1.6 x 1.6 mm, resolving approximately 0.025 mm per picture element. A visual channel makes for quick target positioning and focusing before switching to infrared imaging.

One such unit, the AGA Thermovision® infrared microscope received an *I•R 100* Award in 1972.

Introduced in 1973, a miniaturized version



***Operation** of the Thermovision IR microscope (left), in observing a power transistor chip (right). The chip has been energized to show clearly the base emittor and collector parts in thermal image.*

expanded the field of infrared technology. The system uses the same type of refractive scanning and offers in addition interchangeable lenses with a 20-deg and a 7-deg field of view.

The total package weighs 6.2 kg, and the instrument can be operated easily by one man in a portable mode. It works on any 8 to 15 V dc source, or through a power supply, on regular 115 V ac current. Power consumption is of the order of 20 W.

All related systems are regularly equipped with a liquid nitrogen-cooled, photovoltaic, indium antimonide detector in the spectral range of 2 to 5.6 μm. A mercury/cadmium telluride detector is used in the long-wavelength version, covering a spectral band of 8 to 12.5 μm.

Special infrared imaging systems have been designed for use in medical diagnosis—primarily for the early detection of breast cancer and the study of vascular and inflammatory processes in the human body.

Applications of IR imaging

In order to discover the information to which thermal imaging gives us access, we need to make a habit of viewing materials and processes for their thermal characteristics. To anyone not in that habit, the study of thermal behavior rarely is an obvious approach to solving a problem. But considering the thermal properties of materials and processes might well provide a solution.

Testing solar cell arrays is an example for the research of hot spots. All of the solar cells in an array must have the same current/voltage delivery and internal resistance. But there are differences in cells. This will affect the chain of cells and may cause destruction of some by overheating. NASA has used thermal imaging for the quality control of solar cell panels.

The semiconductor industry has similar problems. For example, the effectiveness of heat-sinking in power transistors is clearly displayed in a thermal image. This is, of course, particularly important when the semiconductor is permitted to work at peak performance.

The safety of an automobile tire is substantially a function of its construction. Ply separation of the tire is a frequent cause of tire failure. Ideally it should be corrected before the tire reaches the market.

In a steady state, a condition such as a ply separation is virtually undetectable. But when the tire is exercised, excessive heat resulting from friction between the separated plies becomes clearly visible as a thermal signal.

Today, major tire manufacturers around the world use thermal imaging techniques in their research and for control of quality. The fact that tire wear is substantially related to the thermal behavior of a tire on the road makes obvious the value of research through thermal imaging.

Fatigue testing is important when it comes to the design and quality control of materials used in aviation. Structural failure is almost always preceded by heat build-up in the area in which failure will eventually occur.

A typical research example is the fatigue testing of boron fiber structures. When a test specimen is subjected to vibration at varying frequencies, the small temperature differentials which become visible in the thermal image clearly map out the progress of destruction which leads to the eventual failure of the specimen.

Thermal imaging is the only technique which will provide this kind of information. Procedures for detecting defects in materials depend on the creation of heat flow situations in an object which is otherwise in a steady state.

To illustrate the process, take a 2.5 cm dia aluminum rod about 30 cm long. Make a quick-focused heat-input at the midpoint of it. The ball of heat which forms there will quickly divide and propagate to the ends of the rod. If there is an interruption in the consistency of the material (e.g., a crack or void), the reduced thermal conductivity would become distinctly apparent in the heat pattern, thereby revealing the defect.

The principle of observing heat flow is used in the nondestructive testing of certain bonded and laminated structures. If a poorly-bonded multilayer structure is uniformly heated or cooled on one side, the heat flow may be expected to create a uniform thermal pattern on each side. If a disbond or other structural defect sufficiently impairs the uniformity of heat flow, it will create a relatively warmer or cooler area on either side.

The blockage of a cooling channel in a ventilated turbine blade, for instance, can be made visible on the surface of the blade, because of the interruption of heat flow it causes. This effect is achieved by injecting into the blade "Freon" or another cooling agent substantially below ambient temperature. The injection will temporarily reduce the surface temperature over the unblocked channel, so that the blockage becomes visible in the thermal image.

***A remote infrared sensor** used to obtain a thermal image of stand-off-insulators on a power transmission line. Points of potential failure appear as hot spots on the thermogram.*

The Navy has successfully used thermal imaging in the nondestructive testing of fuel coalescers. During the test, hot air is injected into the coalescer. The air escapes through the filter wall, generating a heat pattern which reveals defects, such as end-cap leaks, split seams, areas of improper repair, or inadequate material density.

Nondestructive testing of these coalescers is important, because undetected defects may cause water contamination of jet fuel, possibly stopping the engines.

Smelting operations

The vast amount of heat used in iron- and steel-making often creates conditions which invite and suggest inspection by infrared imaging. The quality and condition of the refractory lining of certain vessels is crucial to the safety and productivity of many processes.

By correlating the outside shell temperature with the inside temperature of a basic oxygen furnace, a blast furnace, or a ladle car, the actual thickness of the refractory brick may be computed.

Infrared imagery lends itself well to the remote measurement of shell temperatures and identifies immediate problem areas. The ability to evaluate the refractory is desirable, in order to prevent unscheduled shutdowns. Since immediate problems can be detected and can be rectified by grouting, thermal examination may also extend the life of vessel linings by reducing the frequency of routine relinings. The usefulness of such inspection is recognized by the steel industry throughout the world.

The recent concern with fuel conservation has brought about an acute awareness of the importance of building insulation. Large amounts of energy currently are wasted as a result of inadequate insulation.

The thermographic evaluation of buildings provides an ideal method for the detection of insulation faults, such as faulty installation, the presence of wet insulation, and the infiltration of cool air through openings or cracks. The technique is used in several northern European countries. On a contract service basis, it is promoted in the U.S.

The ingenuity of people involved in a large variety of projects in many different industries has generated the useful application of infrared technology. The examples which we have briefly discussed in this article are representative of the creativity of those accustomed to using infrared imaging systems. No doubt, the potential benefit which comes from increasing understanding of thermal processes will continue to stimulate innovative minds. ■

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