CANADIAN INITIATIVES IN SENSOR DEVELOPMENT

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ABSTRACT

Some new and sophisticated remote sensing devices are beginning to emerge from development programs in the Canadian government, industry and the universities. Supported by the Canada Centre for Remote Sensing of the Department of Energy, Mines and Resources, and in some instances by the Department of the Environment, the programs range from exploratory development to operational systems. They include instruments designed to operate at fixed positions on the ground as well as complete systems for mounting on aircraft and space platforms.

Specific Canadian sensing systems will be described including laser fluorometer devices for detecting oil slicks and effluents on water, ice thickness radar systems and special electro-optical remote sensors for detecting vegetation stresses, chlorophyll and ocean colour from aircraft and satellites. Probable future developments in remote sensing also will be explored.

1. INTRODUCTION

Canadian scientists and engineers have every reason to take pride in their contributions to the development of remote sensing systems now in use. Up until recently, most have been directed at military applications, but since 1970 the Canada Centre for Remote Sensing has sponsored a program to cultivate existing centres of excellence and develop new sensors to meet the needs of a rapidly expanding non-military remote sensing activity.

The modern era began during the second world war which spurred new developments in photogrammetry and related research and development conducted by the National Research Council. Immediately following the war, geophysical activities picked up in Canada and the late 1940's and early 1950's saw the development of a number of successful sensor systems. PSC Applied Research was one of the more active companies in the country at that time with an airborne magnetometer, the airborne profile recorder, automatic dodging equipment for image enhancement and several new devices in the airborne navigation field such as the Ground Speed Interception Computer and the Rho-Theta Computer for the Canadian military.

The military continued to provide the impetus for sensor development. The Doppler radar and associated navigation system is an example. Pioneered by the then Defense Research Telecommunications Establishment (now the Communications Research Centre) and developed by Canadian Marconi, it is in active military and civilian service in several countries. The late 1950's was a period when Canada got into more sophisticated weapons development - motivated by the CF-105 Arrow program, cancelled in 1959. During that period, advances in photoconductive infrared detectors of high detectivity led to developments in still-classified military surveillance, guidance, fuzing and countermeasures systems in Canada. More important, however, was that they laid the groundwork for Canada's entry into the space era of the 1960's and 1970's. Companies like RCA Limited and Spar Aerospace Products Limited (then the SPAR Division of the de Havilland Aircraft of Canada Limited) cut their teeth on these early military sensor programs and formed technical teams that made the major Canadian industrial contributions to the Alouette and ISIS satellite series, Anik and now CTS.

Following the recommendations contained in Science Council of Canada Report No. 1, A Space Program for Canada, in July 1967, wherein there was recognized a need to create an agency for coordinating and funding of a Canadian research program on resource satellites, an interdepartmental committee on Resource Satellites and Remote Airborne Sensing was formed in the fall of 1969. It recommended, among many other things, the creation of the Canada Centre for Remote Sensing (CCRS), that Canada participate in the ERTS program, establish an airborne sensing program and initiate a sensor R and D program. These recommendations were approved by cabinet, and a Sensor Working Group was established early in 1970.

The first action of the Group was to develop a "Request for Proposal" which would lead to initial study and development contracts on remote sensing devices and techniques. It was sent to 64 potential bidders, 53 of whom submitted proposals. Eleven contracts were placed in the year 1970-71. To date, the Working Group has supported a total of 17 programs with an annual budget of approximately $200,000 for the first three years, dropping to $100,000 for last year and the present. Initially, industry and university shared about equal portions of the budget, but more recently, the industrial component has dropped to approximately 30%. By March, 1974, the total expenditure from inception had been just under three quarters of a million dollars.

CCRS is not the only organization funding sensor programs in Canada. The Department of the Environment, Department of Communications and the Department of National Defense all have on-going programs of their own, as does industry - for example, Barringer Research.

The CCRS - funded programs have had to meet certain criteria. They must be:

1. Innovative and technologically sound,
2. Relevant to Canadian needs,
3. Undertaken by organizations capable of carrying the sensor to the field prototype stage,
4. Capable of achieving a market that would be attractive to industry, and
5. Capable of being developed within the financial resources of CCRS.

A number of programs funded initially did not survive these tests in subsequent years and therefore were dropped. The initial ones were selected on the basis of excellence, innovation and relevance.

The sensors to be described have not all been supported by CCRS, others have been included that are relevant to civilian remote sensing needs. The list is far from complete, and omits most geophysical instruments and meteorological sensors. For others that are relevant, and that have been omitted, the writer apologizes as either being unaware of their existence or equipped with insufficient details. The descriptions are directed at the user, and thus do not cover technical details of interest to the instrument developer.

The sensors fall under three main headings: Spectrometers and Multispectral Imaging Systems which are general sensors not necessarily directed at any specific application, Remote Probing with Lasers covering systems usually associated with air and water quality measurements and Special Purpose Sensors developed with very specific applications in mind. Finally, there is some speculation on future developments - the stimuli in Canada for new sensors, the opportunities to exploit them and an appeal to treat the sensor as a component of a remote sensing system, bearing in mind the requirements for data storage and processing, and the ultimate needs of the interpreter.

2. SPECTROMETERS AND MULTISPECTRAL IMAGING SYSTEMS

Detectivity, speed of response, spectral and spatial resolution are the four most important parameters in any general purpose instrument used to measure reflected and scattered radiation in the optical region of the electromagnetic spectrum. The four are not usually mutually exclusive in any particular instrument, but technology now is moving rapidly toward new instruments capable of maximizing all of them simultaneously, limited only by the information rate capacity or bandwidth of the associated electronics, detector noise limitations and the blur circles of the receiving optics. While certain aspects of the Canadian program are progressing in this direction, specific sensors have been developed which maximize or enhance one or two of the four parameters, in some cases at the expense of the others. Six such systems have emerged in Canada over the past few years.

2.1 Scanning Interference Filter Photometer

Developed by Shepherd, Miller and Koehler at York University, and supported by CCRS, the photometer is a rugged, compact instrument capable of studying four different spectral intervals simultaneously, each up to about 600 A in extent at a resolution of 15A. The photometer makes use of the passband shift of an interference filter with changes in incidence angle in 15 discrete steps created by stepping a mask between the filter and a photomultiplier detector. The patterns on the mask permit light to enter the detector successively from fifteen different angles of incidence resulting in a stepped spectral scan. The region of the spectrum is determined by the passband of the interference filter, and obviously must be within the spectral response band of the detector. The instrument has a 15° field-of-view, and a spectral scan requires 3 seconds.

The photometer also can operate in the multiplex mode. That is, it has the ability to observe all the relevant spectral elements simultaneously rather than one-at-a-time. The spectral mask is replaced by a multiplex mask and a Hadamard transform is applied to the 15-step output to retrieve the spectrum. Observing all spectral elements together improves the signal-to-noise ratio for detector-noise-limited cases.

The instrument has been flown in the CCRS DC-3 aircraft, and measurements were made over several lakes in southern Ontario. Figure 1 is a view showing the four-channel sensor on the right with a Lambert diffusing screen as a backdrop. The screen is used to measure incident solar radiation on the scene to be observed in order to determine the albedo. On the left are the power supply, control electronics and FM instrumentation tape recorder used in the aircraft installation.

Applications include the field of botany where the presence of chlorophyl can be detected because it is a good reflector in the near infrared, water quality measurements where the presence of algae and phytoplankton can be determined by changes in water colour, ocean depth measurements and water temperature mapping and where more detailed spectral information is required than that afforded by aerial cameras and line scanners. The relatively low spatial resolution of the instrument is advantageous in situations where total "biomass" measurements are wanted.

2.2 Multichannel Silicon Diode Spectrometer

This instrument, developed by Prof. G. A. H. Walker, University of British Columbia and supported by the DOE, Marine Sciences Directorate, Pacific Region, was developed particularly for the measurement of sea colour, but will have a number of other applications and so can be classified as a general purpose sensor. It makes use of a 256 silicon photodiode linear array illuminated by light reflected from a grating. The spectral response of the instrument covers 4000 to 8000A so that each diode corresponds to about 16A. The exact response depends on the gratings, but the diodes are sensitive over the range 3500 to 11,000A.

The diode outputs are scanned sequentially at a rate determined by an external clock. The output signal can be digitized and averaged over repeated scans of the array to give added sensitivity. The entrance optics consist of a standard Nikon 35 mm. camera lens, and the field-of-view is approximately 1 milliradian. Figure 2 is a view of the instrument with the cover removed. It is a rugged, compact sensor using no moving parts designed for aircraft installations.

While designed as a device to assess water productivity through chlorophyl content, it could be used in many other applications where rapid spectral measurements are wanted. Also, because of its narrow field-of-view, it could serve as a receiver in a laser induced fluorescence system of a type that will be described in a later section.

2.3 Wide Angle Michelson Interferometer

Supported by CCRS, this sensor is being developed by Shepherd and Gault at York University to measure reflection spectra from an aircraft or spacecraft platform. It produces a circular interference fringe pattern by means of a beamsplitter and two reflectors. The intensity of the central fringe is monitored photoelectronically as one reflector is scanned along the optic axis. The resulting intensity record is called an "interferogram" and can be Fourier transformed to yield the desired spectrum. The spectral resolution obtained is proportional to the length of the scan. Such an instrument collects far more light than a conventional slit spectrometer of comparable size and resolution, and therefore can measure spectra much more rapidly.

The special feature of this Michelson is the method of scanning by means of a gas cell which translates the reflector in one arm of the interferometer in accordance with the change in cell pressure. The motion of the reflector, and the change in refractive index of the gas through which the light beam passes, both cause the instrument to scan. The chief advantage of the gas scanning method is that the Michelson can be "field compensated" and accept a much larger solid angle than a conventional Michelson. The field-of-view with field compensation is 7° in diameter. With Freon - 115 as the scanning gas, a resolving power of about 1000 can be achieved at 5000A. The detector is sensitive to the spectral range 3000 to 10,800A.

Figure 3 is a photograph of the instrument which now has undergone successful flight tests. The cylindrical housing at the right rear is the main Michelson body. The detector housing projects vertically from the main body in front of which is a He-Ne laser reference source. On the left is the gas handling unit and electrical controls.

In its present state, the instrument has been fitted with a scanning mirror to compensate for aircraft motion during the scan period of 3 seconds (shown in Figure 3). The mirror "freezes" the image during the scan, permitting a spectrum to be obtained for a fixed area of the terrain the size of which is determined by the field-of-view and aircraft altitude. The next step is to take advantage of the wide field and place a two-dimensional array in place of the single-element detector. When the path difference is scanned, each detector in the array produces a separate interferogram. Thus, the image is dissected, and a separate spectrum can be computed for each section of the image. In this way, it is possible to combine good spatial and spectral resolution in a single instrument, but obviously a high-speed special purpose minicomputer is needed to handle the data rates required. As a first step, a 100 x 100 element solid-state self-scanned array will be tested in the laboratory.

2.4 Image Intensifier Scanning Spectrometer

The project, supported by CCRS, was motivated by the investigator's interest in using the Fraunhofer line depth technique for the detection of luminescence. The instrument, developed by Jeffers at York

University, is built around a grating spectrograph with a dispersion of 60A./mm. A single-stage electrostatically-focussed image intensifier (ITT Model F-4708) is mounted at the focus of the spectrograph. A transverse magnetic field is applied by two deflecting coils mounted around the image intensifier. With the centre of the appropriate absorption line coinciding with the exit slit pressed against the output fibre optic faceplate of the intensifier, a square wave modulated transverse magnetic field chops the spectrum between the absorption line and the adjacent continuum. The output of a photomultiplier tube placed at the exit slit then is a measure of line depth. An alternative scanning mode is achieved by applying a linear ramp voltage to the deflection coils and thus scanning the spectrum past the exit slit.

The instrument has been flown and used to detect the luminescence from Rhodamine B dye. In general, it can be used for the rapid recording of reflection spectra. Of considerable importance, however, is that this program has gained valuable Canadian experience in the use of image intensifiers and has led to the purchase and application of a 500-channel SSR optical multichannel analyser. The 500 silicon photodiodes are 25 microns wide on a 12.5 x 0.5 m.m. format, and an image intensifier stage is employed ahead of the diode array. Each photodiode is subdivided into two halves (top and bottom). The top half is generally reserved for viewing the background, the bottom half is used for the signal measurement.

The spectrum to be detected is focussed onto a fibre optic faceplate on which is deposited an S-20 photocathode.

The released photoelectrons are accelerated to a few KV and focussed on to the silicon diode array. The target is scanned in 33 msec. executing a closely-spaced sawtooth pattern of 500 cycles across the spectrum. The digital output is directed to either of two 500 word, 21 bit memories (memory A for the bottom half, B for the top half). These memories may be used to store the result of a single scan, or may be used to signal average over many scans, thus greatly improving the signal-to-noise ratio. The electronics provide for B-A subtraction so as to remove the background electronically before displaying the desired signal. Each channel may be read digitally on a panel display, directed to an auxilliary plotter, displayed on an oscilloscope or stored on a tape printer for further computer analyses. The laboratory setup containing these components of the system is shown in Figure 4.

The general advantages of the system are its very high sensitivity in the region 3500-8000A., simultaneous detection in 500 channels, and its ability to be gated for pulse durations in the range 10 nsec - 2msec. This capability permits it to be used in laser ranging applications. It can readily receive the short pulse, high repetition rate signal from a laser and its sensitivity will permit the recording of Raman scattering under this sort of illumination. This application will be described in a later section.

Before leaving the applications of the linear array, it should be mentioned that CCRS may be involved at some future time in the development of a multispectral scanner. Such arrays make it possible to construct one with no moving parts using pushbroom scanning. This is a term that describes the technique of using the forward motion of the vehicle (aircraft or spacecraft) to sweep a linear array of detectors oriented perpendicular to the ground track across a scene being imaged. The array must be sampled at the appropriate rate so that contiguous lines are produced. In this way, the photon flux from the scene is allowed to be integrated during the time required for the instantaneous field-of-view to advance the dimension of one resolution element on the ground. There is a considerable improvement in signal-to-noise ratio over mechanical scanners which permit only much shorter integration times for the same resolution. For comparable performance, size and weight can be reduced significantly. In future, silicon photodiode arrays will give way to charge-coupled devices with perhaps as many as 12,000 detectors per array or more. The data rates associated with such multispectral scanners will be prodigious, and a high degree of sophistication will be contained in the associated digital logic and storage systems. Canada needs to gain background and experience in such technology.

2.5 Multispectral Camera System

Supported by CCRS and developed by Spar Aerospace Products Limited, it uses an image dissector tube which is a type of photomultiplier where the optical image, focussed on a photocathode, can be scanned or sampled elementally. The image causes photoemission of electrons proportional to light intensity which are accelerated toward an aperture behind which is a photomultiplier. The size and shape of the aperture depends on the required resolution and the type of scan employed.

Used in a television mode, its aperture of 0.001 - inch diameter provides a resolution of 1000 TV lines per inch (20 lines/mm). The camera uses an ITT F-4052 tube with an S-20 response (3000-7000A). A wedge interference filter is placed in front of the system so that in one direction, y, the wavelength can be varied; and in the perpendicular direction, x, the camera can be line-scanned. When mounted in an aircraft, the line-scanning can be synchronized with the aircraft velocity so that a continuous strip of the terrain can be recorded similar to a conventional line-scanner. The wavelength then can be easily altered by varying "y" across the wedge interference filter. Thus, the multispectral camera can produce high resolution imagery at readily selected wavelengths within the range of the filter and the response of the tube. Figure 5 is a photograph of the system.

It is a general purpose instrument that can be used for a wide variety of applications where it is critical that it be rugged (no moving parts), have high spatial resolution - up to 40 lines/mm. with 0.0005" aperture, have a large number of spectral channels that can be selected and programmed remotely, have a small spectral bandpass (100-350A.) and/or have a wide dynamic range (10^4). The system has been flight tested and has produced imagery of correct quality using the Daedalus tape recorder in the CCRS DC-3 aircraft. It is available for operational use.

2.6 Semiconductor Infrared Photography (SCIRP)

Supported by CCRS and the Forest Fire Research Institute, DOE, the SCIRP program has been conducted by Dr. W. Pinson at McMaster University. The objective is to develop a simple and inexpensive method of infrared photography. At infrared wavelengths, ordinary film will fog because of natural ambient thermal radiation. Fogging times (and thus storage life) depend on wavelength sensitivity and ambient temperature which become shorter at longer wavelengths and at higher temperatures. SCIRP overcomes the problem by introducing the image-forming substance only at the time of exposure.

Two types of processes are being investigated - contact sensitized and electrically controlled. In the contact-sensitized technique, two separate parts of the photographic process, each incapable of recording an image separately, are brought into contact during exposure (typically a semiconductor and an electrolyte). However, because a separate semiconductor film must be used for each exposure, it is more expensive than the electrically-controlled technique. In this type of process, the capability of recording an image exists only during the time an electric field is applied to the system and current flows through it. The photoelectric gain can be several tens for this process, thus making it more sensitive than the contact-sensitized processes where the gain is less than unity.

Both methods are based on electrode reactions which transform the distribution of radiation intensity on the semiconductor surface into a current density or potential distribution, and as a final stage, into a distribution of a substance which is precipitated from an electrolyte solution to form a photographic image.

A lead sulphide film camera, electrically sensitized, has been used to record controlled fires. Current efforts are being devoted to increasing the speed of the PbS film and improve its thermal resolution using a charge injection method. Applications include forest fire detection, the steel industry, forensic science and situations where thermal photographs are needed. The related technology can be applied to the flotation process where semiconductor minerals are involved, and even to the extraction of oil from tar sands.

3. REMOTE PROBING WITH LASERS

Two major classes of remote sensing devices utilize the laser as a source of radiation to stimulate a response from the target. The first group induces fluorescence, and thus they are call fluorosensers; the second generates back scattering in the medium through which the laser beam passes, and operates much like a conventional radar but at optical frequencies - called a LIDAR (Light Detection and Ranging).

3.1 Fluorosensors

Two types of fluorosensors have been developed in Canada - one using a continuous wave (CW) laser sponsored and developed by the Inland Waters Directorate, DOE, and the other using a pulsed laser supported by CCRS, and developed at the University of Toronto Institute for Aerospace Studies. Both operate on the principle that various substances fluoresce when excited by radiation of a suitable wavelength. Of particular interest are crude oil or bunker C, fluorescent dyes such as rhodamine, chlorophyl in algae and seaweed, and effluent from pulp mills and chemical plants.

3.1.1 CW Fluorosensor - Developed by Kruus, Davis and Gross of DOE, this instrument uses a He-Cd CW laser with a 15 mw. output at 4416A. The receiver is an 8" Schmidt Cassegrain focussing the return radiation through optical filters onto a photomultiplier. The filters block laser light and background, passing only in the fluorescence band of interest. Figure 6 is a photograph of the system. The instrument has been flown on several occasions and has successfully detected oil slicks, rhodamine dye and lignon sulphonates from pulp mills. Because of the relatively low power of the CW laser, it can only be operated at night at relatively low altitude (in the order of 500 feet). For this reason, its most likely application would be as a fixed monitor viewing a lake or a stream, suspended perhaps from a bridge or embankment where it could creat an alarm when pollutant concentrations exceed some preset value. It is compact, rugged and cheap - the cost of components is less than $10,000.

3.1.2 Pulsed Fluorosensor - Developed by Measures, UTIAS, and Bristow, CCRS, the system uses a pulsed nitrogen laser operating in the ultraviolet at 3371 A. It emits short, powerful pulses of 100 kw. for a duration of 10 nsecs. with a maximum pulse rate of 100 per sec. The receiver is an 8" Newtonian telescope - photomultiplier system. The fluorosensor, weighing about 450 lbs., has been installed in a CCRS DC-3 aircraft and has completed flight tests successfully. Figure 7 is a photograph of the system set up at a field site.

Laboratory studies on such materials as crude oils, refined petroleum products, fish oils, rock and mineral samples have shown that their fluorescence spectra have limited use as a means of identification and discrimination because of spectral overlap and the difficulties associated with measuring and calibrating the relative magnitude of fluorescence return signals. An alternative procedure for improving the identification potential has been investigated using the fluorescence decay characteristics. It was discovered that each of the materials investigated had a more or less unique fluorescence lifetime - emission wavelength characteristic. Such fluorescence decay spectra are far less susceptible to uncertainties than is the amplitude of the signal. The program on decay spectra now is entering an intensive investigation stage.

3.2 Lidar

Back-scattered radiation from a high-power laser can reveal a lot about the properties and species of the medium through which the laser beam passes. The information is based on Rayleigh scattering of light by molecules and very small particles, Mie scattering by aerosols and Raman scattering by certain molecular components in the medium. Carswell at York University has developed an atmospheric and marine lidar system in a program supported by CCRS.

3.2.1. Atmospheric Lidar - The instrument shown in Figure 8, consists of a Q-switched ruby laser capable of providing up to 150 megawatts at the fundamental wavelength of 6943 A. in an 18 nsec. pulse. The system is water-cooled and provides pulse repetition rates of 10 per minute. The system also contains a second harmonic generator to provide radiation at 3472 A. The receiver includes four channels to permit simultaneous analysis of four backscatter signals capable of providing complete polarization measurements; the data can be recorded in digital form on magnetic tape. The unit is installed in its own mobile truck laboratory and incorporates precise motor-driven horizontal and vertical steering controls for aerosol and plume tracking. It is being used by air pollution agencies and utilities concerned with air quality management.

3.2.2 Marine Lidar - Figure 9 is a view of the marine lidar developed by Carswell and Sizgoric. The argon laser shown on the right works in the cavity-dumped mode. The output pulse is controlled by means of an intra-cavity acousto-optic diffraction cell that operates to switch out very short pulses. This unit at 4880 and 5140 A. delivers peak powers of up to 75 watts and pulse repetition frequencies variable from CW to 10 MHz, with pulse widths variable from 10 nsecs. to 1 msec. Average power in the cavity-dumped mode of up to about 1 watt at these wavelengths is available. The unit will operate on seven other Argon lines in the blue-green spectral range at lower power outputs.

The receiver is a 25 cm diameter Newtonian telescope with variable field stop and processing optics which include a 10 A. bandpass filter and a quarter-wave plate and linear polarizer for analysis of the scattered signal. A very high speed 5-stage photomultiplier is used as the detector. The output is fed through a preamplifier to a scope or to a "boxcar" signal averager and recording system.

Seen in Figure 9 are the 45 degree mounted mirrors for downward direction of the transmitter and receiver beams. These are mounted on an extendable member which protrudes over the side of the tank (for lab use) or the vessel (for shipborne measurements). The system has been tested in indoor-tanks and on board a ship in Lake Erie to check out the instrument, and to determine its useful operating range. When combined with the optical multichannel analyzer described in Section 2.4, it will be used to measure Raman scattering and thus identify certain molecular species in the water. For this reason, the marine lidar could become an important water quality sensor.

3.2.3 Bathymetric Lidar - In relatively clear and shallow waters such as are found over some parts of the Arctic north slope, an aircraft - mounted lidar, operating as a visible light radar, might be capable of performing bathymetric measurements of sufficient quality to be used for hydrographic survey purposes. It would be a logical extension of the aerial hydrography program now being planned by the Marine Sciences Directorate, Pacific Region, DOE. The most appropriate laser should emit in the blue-green window, and a likely candidate would be a frequency-doubled neodynium laser operating at 5300 A. We may expect to see such a development within the next year or two.

4. SPECIAL PURPOSE SENSORS

There are a number of Canadian sensor development programs that have been directed at very specific applications, some supported by CCRS, others by various government agencies and private industry. Four such applications will be described: ice and snow, soil moisture determination, forestry and atmospheric analysis.

4.1 Ice and Snow

A number of sensor developments have been directed at problems associated with Canada's arctic. There still does not exist an operational sensor that can measure the thickness of sea ice from an aircraft - this problem has been the subject of several developments. Other ice and snow sensors will be described in what is to follow.

4.1.1 Holographic Ice Surveying System (HISS) - The HISS radar, developed by Iizuka, University of Toronto and supported by CCRS, is designed to measure ice thicknesses up to four metres. Shown in Figure 10 it consists of three major parts - transmitter and receiving antenna arrays seen slung under the helicopter on the beam assembly, a receiver-transmitter unit and a special-purpose computer both located inside the vehicle. In contrast with conventional radars, HISS measures the spatial distribution of the scattered waves from the top and bottom sides of the ice, and from this determines the ice thickness.

Earlier tests in 1972 off the arctic coast near Tuktoyaktuk will be repeated in the near future at an arctic location where the salinity is more predictable. Meanwhile, the equipment has been tested successfully on fresh water ice in Lake Ontario and in an experimental setup at the the University of Toronto.

4.1.2 Wideband Radar - Under development by Page and Chudobiak at the Communications Research Centre, DOC, a new wideband radar technique is being explored for measuring ice thickness, initially fresh water ice. Figure 11 shows an experimental version of a very high resolution radar undergoing final checkout on a sled on the Ottawa River in February, 1974. It uses a small horn suspended at the side of the sled. In March, this radar was tested extensively in airborne trials over Lake Ontario and the St. Lawrence and Ottawa Rivers. It operated reliably and showed itself capable of producing continuous profiles of ice thickness to an accuracy in the order of 1 cm. A modified version will be fabricated for use over sea ice.

4.1.3 Microwave Radiometer - The radiometer is a very sensitive passive receiver which takes advantage of the fact that all bodies radiate electromagnetic energy, the intensity of which depends on the frequency, the absolute temperature, the electrical properties of the materials contained in the body, and the nature of the boundaries or surfaces. Water is a medium-strength radiator, metallic structures such as ships are weak radiators, while pack ice, icebergs, wakes and land are strong radiators.

Adey et al of the Communications Research Centre has developed a UHF radiometer that can be operated in four bands in the range 400-2300 MHz. It uses two antennas - a log-periodic and a horn with beamwidths of 50° and 40° respectively. The equipment has been flown on a number of occasions in an aircraft and in a helicopter.

Flight tests carried out in 1971 near Resolute, N.W.T. showed that the radiometer can give a qualitative statement about ice thickness and ice condition. Flights the following year over the Strait of Belle Isle and over Hudson Strait recorded signatures of ships, icebergs, pack ice, rocky and lichen-covered areas and fresh water lakes and streams. They revealed that there is a clear distinction between icebergs and ships, icebergs can be detected against a water background, the radiometer signal from open pack ice in a given area correlates with the fractional ice cover and the intensity of the radiation from water at the lower UHF frequencies is sensitive to the degree of salinity. Because of its abilities to operate in darkness, microwave radiometry is highly relevant to the arctic. For this reason, further work should be carried out to learn how such techniques can be fully exploited in operational surveillance systems.

4.1.4 Gamma Ray Spectrometer - Developed by Gasty and Holman of the Geological Survey of Canada, this instrument was developed to measure the water equivalent of snow pack.

Natural gamma radiation emitted by potassium, uranium and thorium is attenvated by the water content in snow layers over top of such elements. The sensor consists of twelve 9" x 4" sodium iodide crystals held at a constant temperature. When gamma rays impinge, the crystals put out pulses which are fed via an amplifier to a 128-channel analyzer. Appropriate portions of the gamma ray spectrum can be selected. Background calibration flights with no snow cover are necessary for comparison with flights in the presence of snow.

4.2 Soil Moisture Determination

In response to requests from the CCRS Working Group on Agriculture, a study was initiated with Barringer Research on the potential of electromagnetic techniques for the remote sensing of soil moisture. The quantity of interest is the amount of free water in the upper few feet of the earth's crust not held under tension, so that it is available for vegetation. The first phase of the study concluded that within the frequency range from 100 MHz to 20 GHz there is a relaxation phenomenon directly related to water content, although the nature of this relaxation and the bonding are not well understood. Subsequently, it was concluded that the spectral region from 100 MHz to 2 GHz was the most suitable for the remote sensing of soil moisture. The next phase involves laboratory measurements of various soil types in this frequency range, followed by in situ measurements which, if successful, could lead to the design and development of a multifrequency airborne radar system. Communications Research Centre and the Geological Survey of Canada are collaborating with CCRS on this project.

4.3 Forestry Radar Altimeter

At the request of the Forest Management Institute, DOE, Westby at the Radio and Electrical Engineering Division of NRC has developed a special type of radar altimeter for use in large-scale (low altitude) photography for forest inventory work. Photography at lower altitudes, however, presents a special problem of accurately determining the flying height of the aircraft above the ground. This is required before useful photo measurements can be made.

The forestry radar altimeter operates at a frequency that penetrates foliage and so is not affected by intervening vegetation between the aircraft and the terrain. The instrument error is ±1% of flying height, and this accuracy is maintained when flying over slopes up to 30°. The minimum height over forests is 200 feet, and the effective beam width is approximately 1.7°. Further work on the equipment will extend the range to 10,000 feet altitude, and reduce the maximum error to 1/3 of 1%.

4.4 Correlation Gas Analyzer (GASPEC)

Developed by Barringer Research and supported by CCRS, this instrument is designed to detect the presence of combustion gases associated with forest fires - the gas selected was carbon monoxide. A non-dispersive gas analyzer, it is designed to detect the decrease in energy in the incoming radiation due to the presence of an absorbing target gas. The instrument uses a reference call containing nitrogen or a non-absorbing gas in the region of interest, and a sample gas cell containing carbon monoxide. Ground chopping is used based on the work of an earlier CCRS contract. The incoming 4600 A. radiation is so chopped and passes, via a beam splitter, through both arms of the instrument to a double-element detector. When no target gas is present, the instrument is balanced and no signal is observed. When target gas drifts into the path of the instrument, a signal is observed proportional to the amount of gas present. A reference lamp is used to balance any variations in the respective gains of the two channels. A photograph of GASPEC appears in Figure 12.

The instrument has been fully laboratory and environmentally tested, and meets its intended specifications. Also, it has had an initial flight test under extreme atmospheric conditions and has been field operated from a truck. Further field testing as a CO detector is desirable, and there is interest by users to apply the instrument to other gases such as HCl, SO_2, NO_2, etc.

Barringer Research has developed a number of proprietary instruments for atmospheric analysis including the COSPEC correlation spectrometer for detecting SO_2, NO_2 and other gases, and the CO Pollution Experiment (COPE), a Michelson correlation interferometer which CCRS is flying in their Falcon aircraft over US and Canadian cities for NASA. The company also has developed a wide range of its own geophysical instruments.

5. FUTURE DEVELOPMENTS

Without doubt, future developments in Canadian sensors will be determined by government policy, plans and programs - mainly at the federal level, but also by an increasing extent at the provincial level. Policy and plans will create the stimuli, programs the opportunities.

The greatest stimuli of all has been the formation and on-going presence of the Canada Centre for Remote Sensing and its Working Group on Sensors. The Oceans policy announced by the Minister of State for Science and Technology, the energy crisis and the resulting focus on Canada's arctic and the accelerating need for conducting environmental baseline studies before developing remote Canada will all provide further stimulus for new and better sensors.

At the provincial level, there is increasing emphasis on land use planning - particularly as major energy projects get launched. Environmental and resource management techniques will grow in sophistication as the provinces begin to flex their technological muscle and new provincial remote sensing interpretation centres gain in strength and stature. Such changes can be anticipated as a result of a recent and growing interest on the part of the provinces in developing individual provincial science policies.

As policies and plans merge into programs, it becomes possible to foresee very specific applications for new sensors. Such an opportunity could develop from the long range patrol aircraft program (LRPA) now being pursued by the Department of National Defence. There could be a major civilian role for such an aircraft, and with it an opportunity for new sensor developments. Other programs will merge from the implementation of the Oceans policy, and there could well be a resource satellite in Canada's future.

Sooner or later, however, the true benefits from remote sensing must be forthcoming. Increased investment in this field, including new sensors, can only result from anticipated adequate rate of return. Thus it is critically important to monitor and document present remote sensing programs if we are to collect the necessary evidence for future investment.

Finally, for the sake of future remote sensorists, the sensor must increasingly be thought of as being part of a complete system, and not as a separate entity in its own right. The requirements for data storage and processing have become the main thrust of most new remote sensing systems, particularly those utilizing large detector arrays. The most important entity in the system, however, is the interpreter. He is the hub around which the entire system rotates. Let us in future, therefore, not stray from him as we have occasionally in the past, but become part of the system so that we may pursue the needs of the user as he perceives them.

6. ACKNOWLEDGEMENTS

The writer acknowledges the support received from the Canada Centre for Remote Sensing and many of the persons responsible for the sensor developments described in this paper. Their help in providing background material, photographs and slides is deeply appreciated.

7. REFERENCES

The descriptive material contained in this paper was derived from one or more of the following references:

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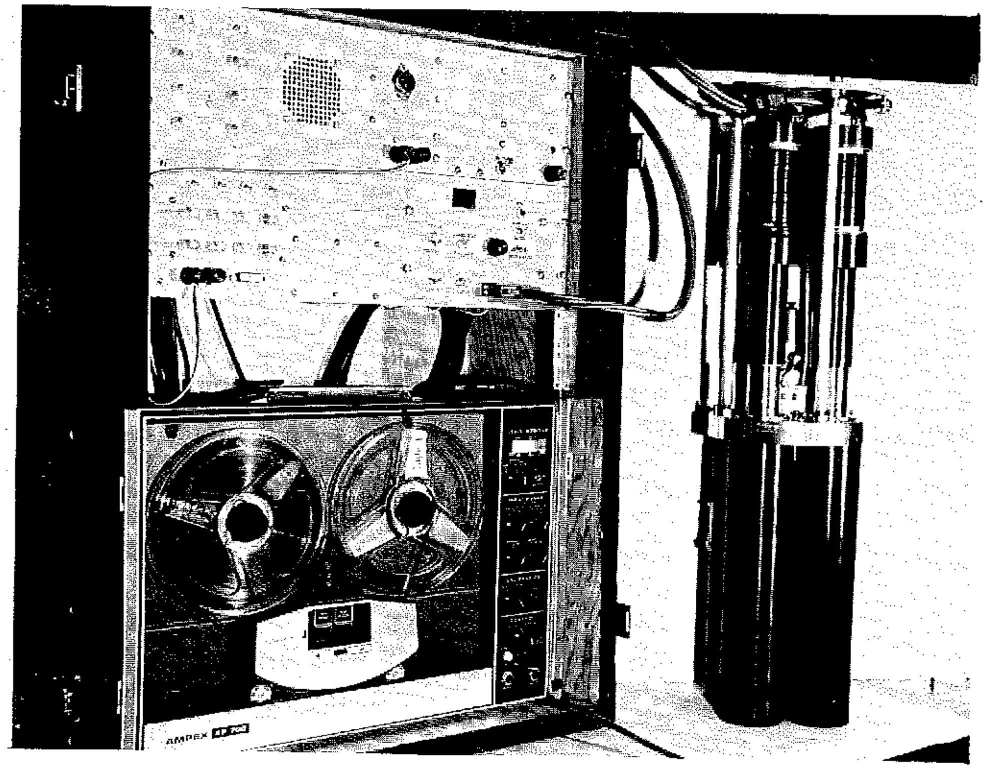

Figure 1 Scanning Interference Filter Photometer

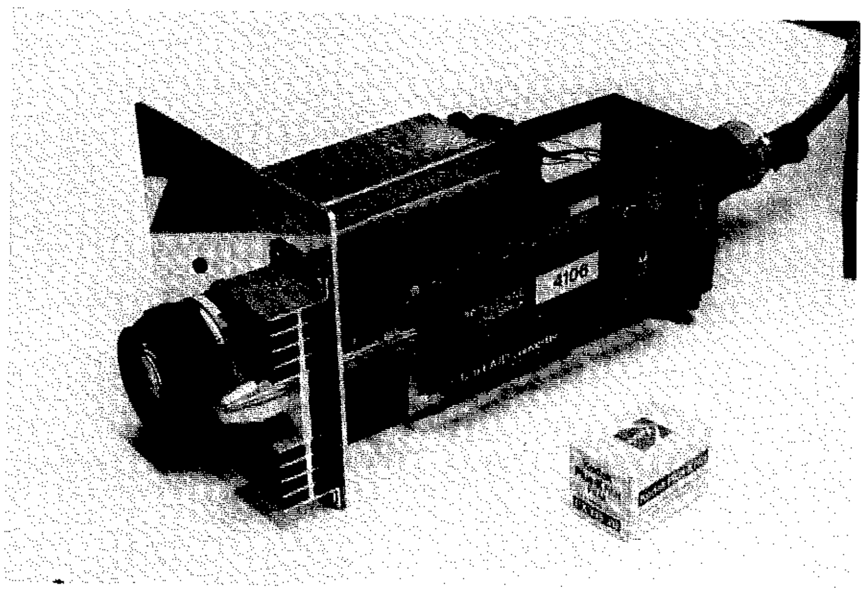

Figure 2 Multichannel Silicon Diode Spectrometer

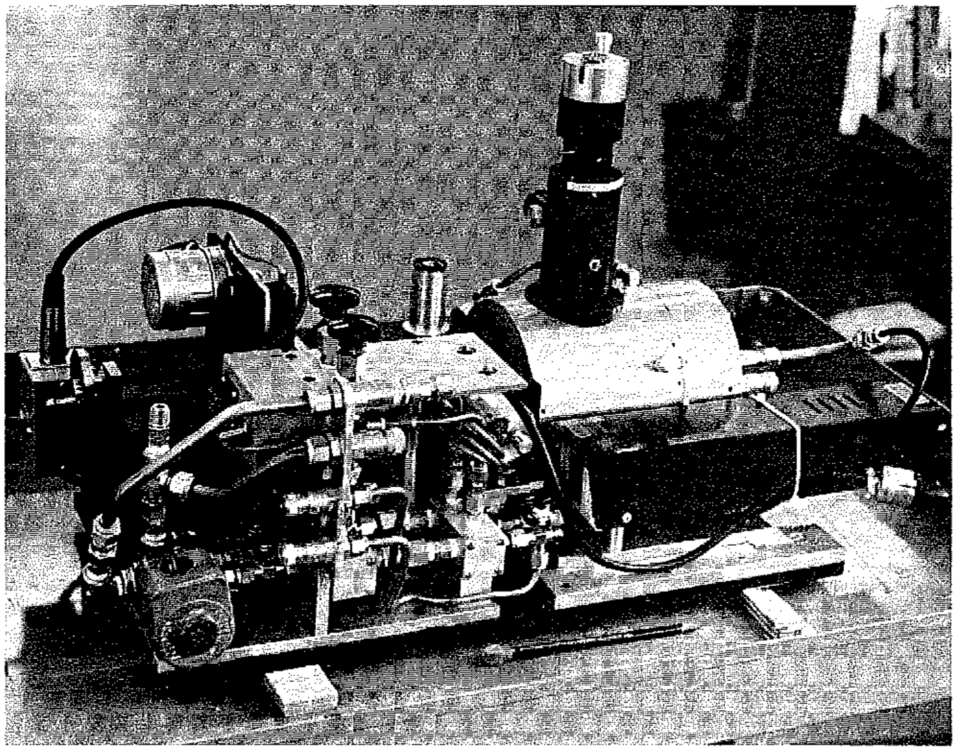

Figure 3 Wide Angle Michelson Interferometer

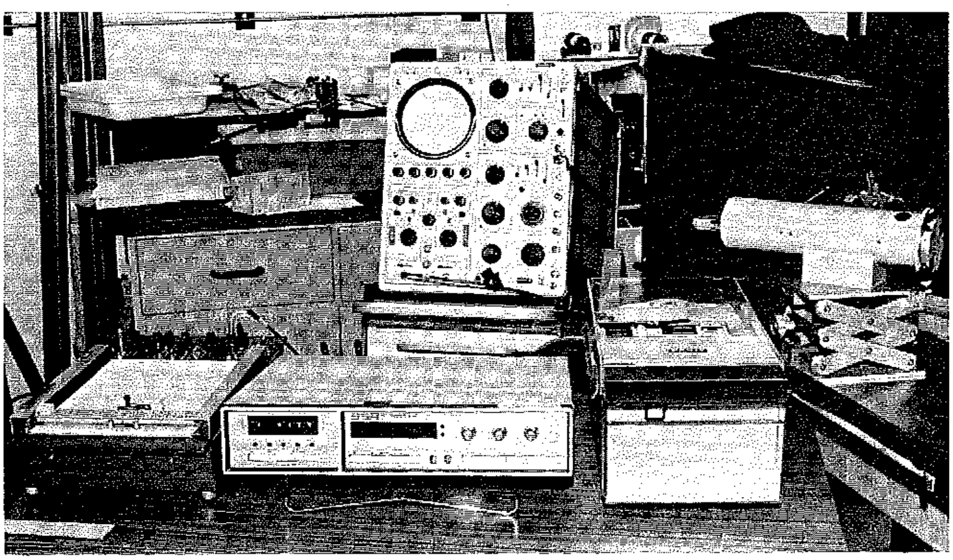

Figure 4 Optical Multichannel Analyser System

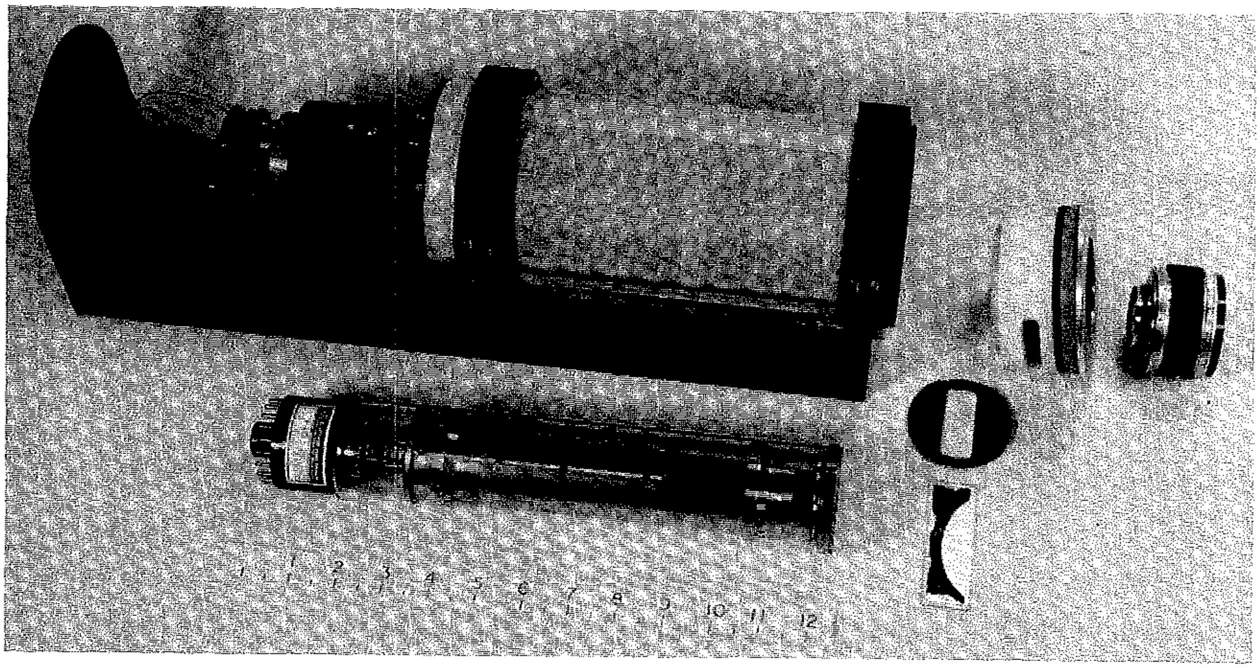

Figure 5 Spar Multispectral Camera System

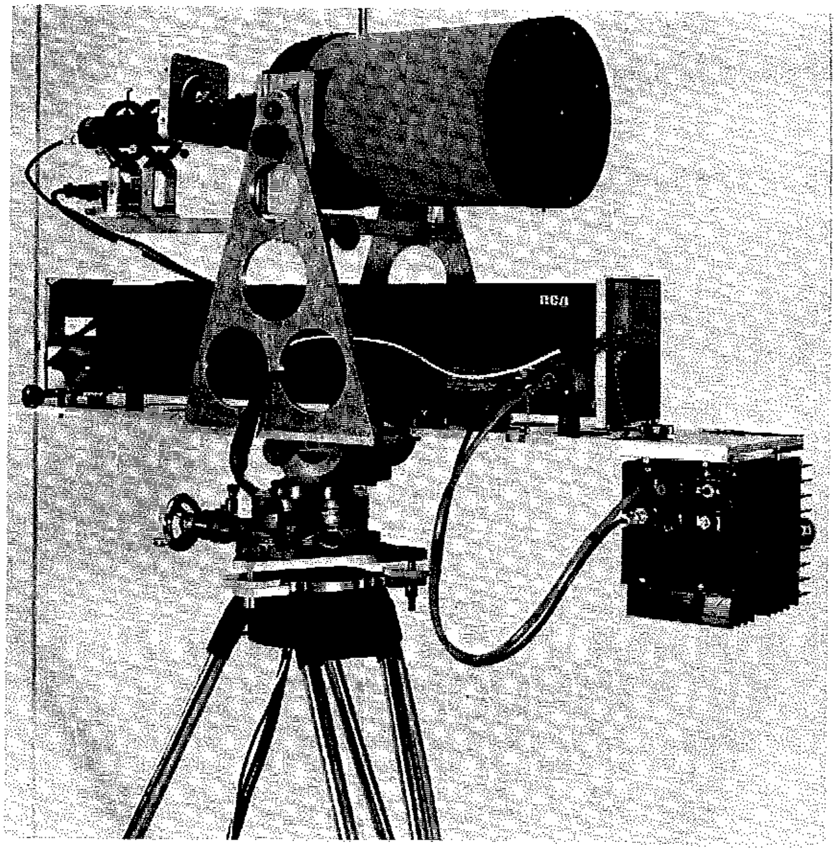

Figure 6 CW Laser Fluorosensor

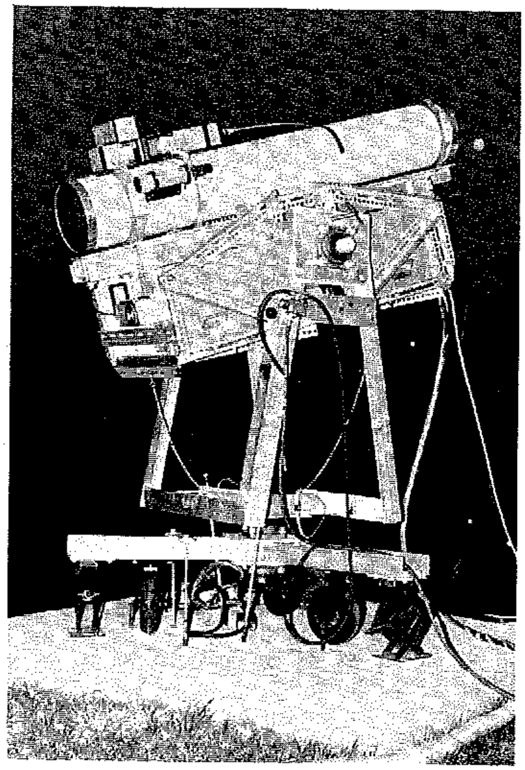

Figure 7 Utias Pulsed Laser Fluorosensor System

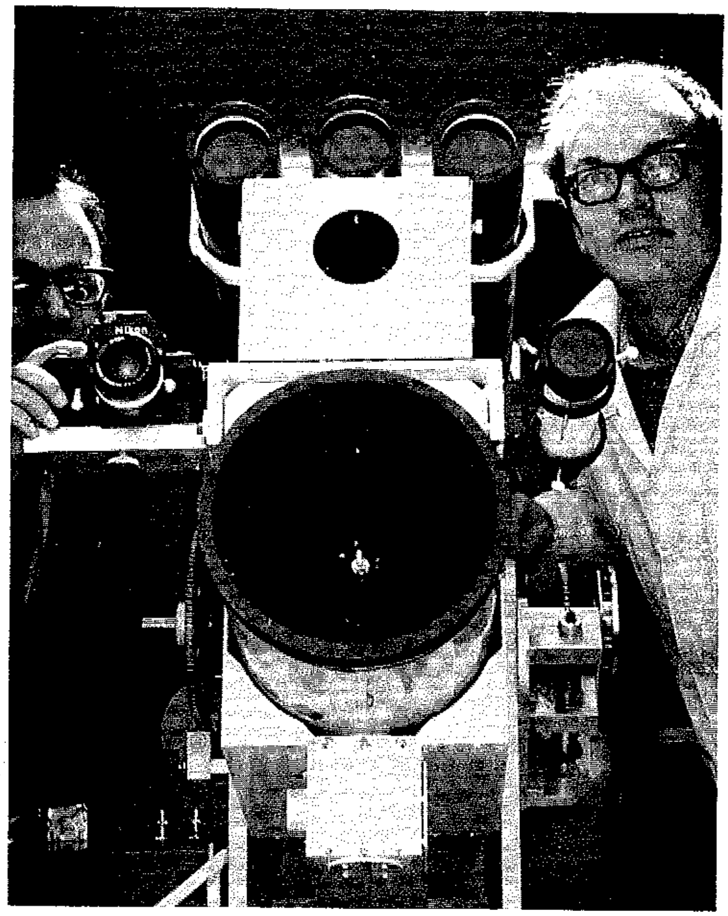

Figure 8 York University Mobile Atmospheric Lidar

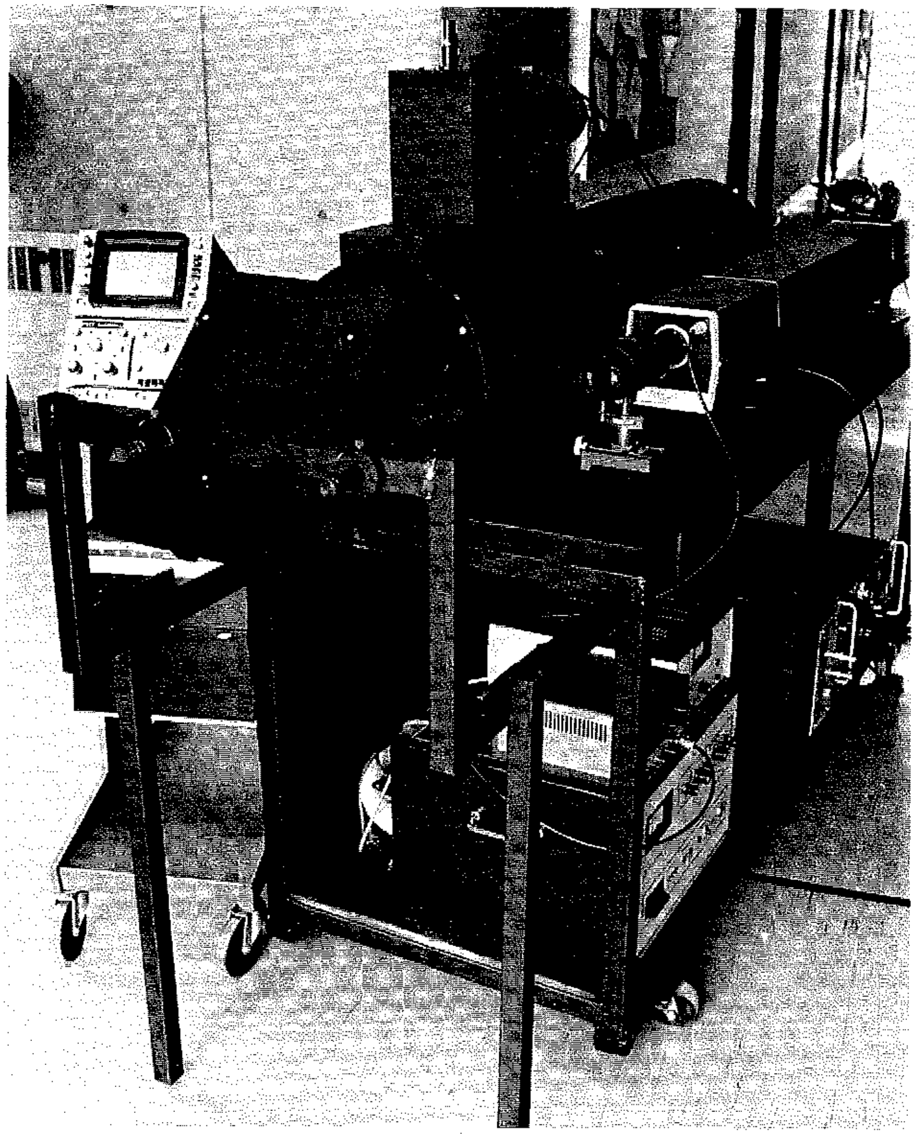

Figure 9   York University Marine Lidar

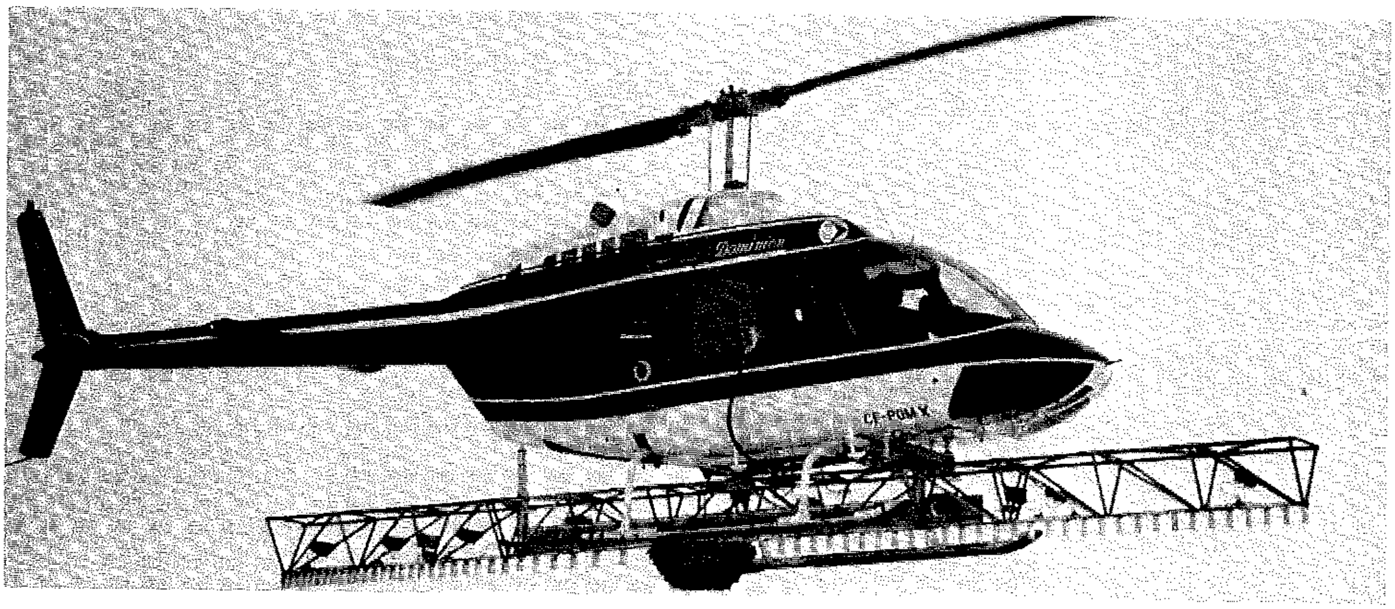

Figure 10   Holographic Ice Surveying System

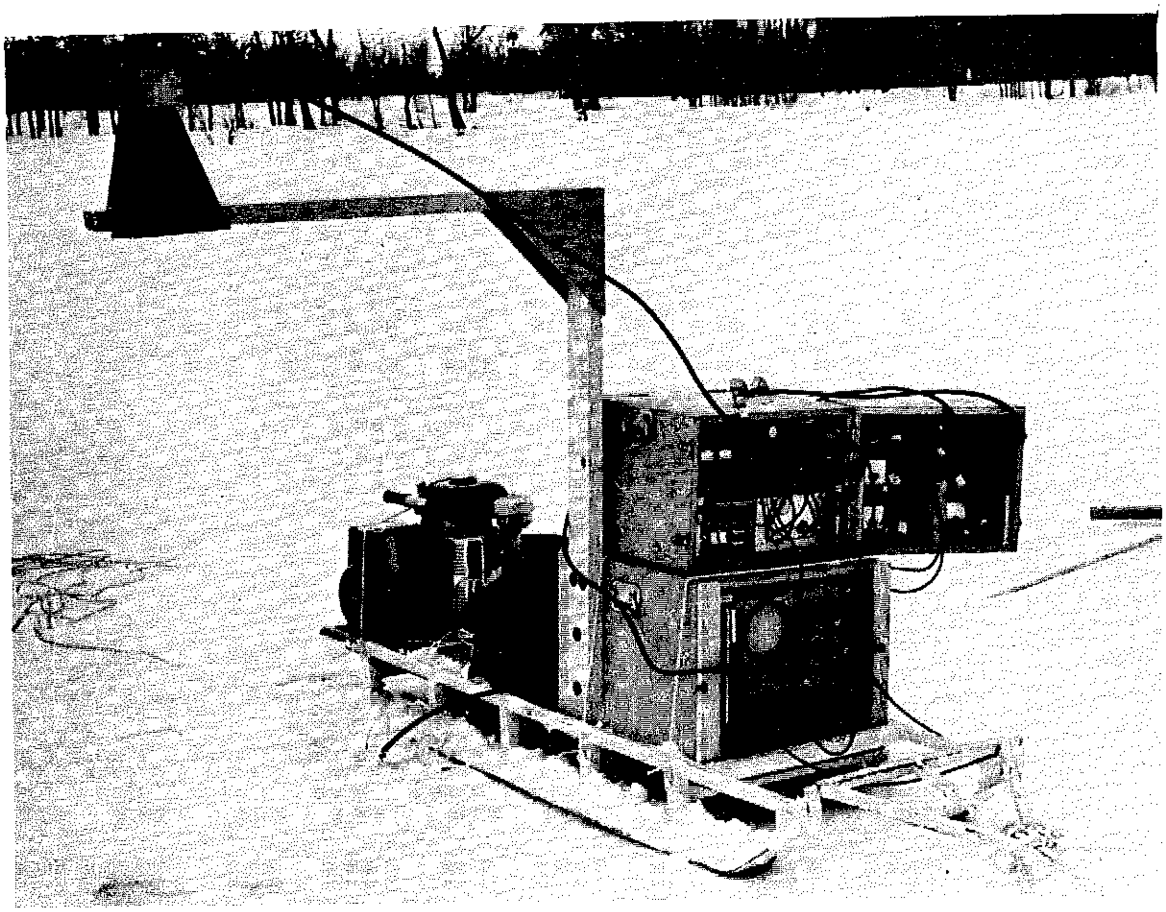

Figure 11 Wideband Ice Thickness Radar

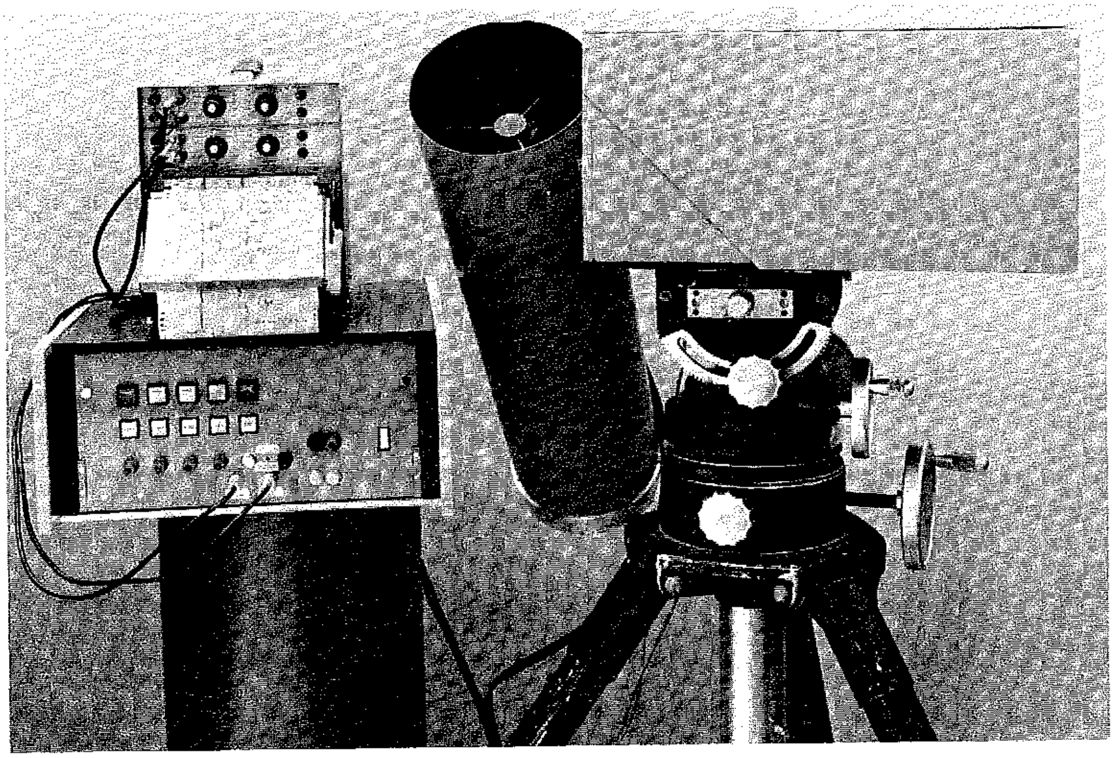

Figure 12 Barringer Correlation Gas Analyzer (Gaspec)