**GEORGIA INSTITUTE OF TECHNOLOGY**
Engineering Experiment Station

**PROJECT INITIATION**

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<tr>
<th>Project Title</th>
<th>Tower Mounted Fire Detector Development - Phase I</th>
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<td>Project No.</td>
<td>A-1528</td>
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<tr>
<td>Project Director</td>
<td>Mr. J. L. Birchfield</td>
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<tr>
<td>Sponsor</td>
<td>Georgia Forestry Commission, Macon, Georgia</td>
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<tr>
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<td>5/23/73</td>
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**REPORTS REQUIRED**
Final Report - Phase I

**SPONSOR CONTACT PERSON**
Mr. James E. Turner, Jr.
Georgia Forestry Commission
Box 619
Macon, Georgia 31202

**Assigned to**
Communications Division

**COPIES TO**
- Project Director
- Assistant Director
- STR
- Division Chief(s)
- Service Groups
- Project Coordinator
- Photographic Laboratory
- Security, Property, Reports Coordinator
- EES Accounting
- EES Supply Services
- Library
- High Electronic Computer Center
- Project File
- Other
PROJECT TERMINATION

Date 7-17-74

PROJECT TITLE: Tower Mounted Fire Detector Development—Phase I

PROJECT NO. A-1334

PROJECT DIRECTOR: Mr. J. L. Birchfield

SPONSOR: Georgia Forestry Commission; Macon, Ga.

TERMINATION EFFECTIVE: 6-30-74 (Contract Expiration)

CHARGES SHOULD CLEAR ACCOUNTING BY: M/A—All authorized funds have been expended.

Georgia Forestry Commission  
P. O. Box 819  
5156 Riggins Mill Road  
Macon, Georgia 31202  

Attn: Mr. James C. Turner, Jr.

Subj: Monthly Status Report No. 1, covering period  
March 23, 1973 to April 23, 1973, Project A-1528,  
"Tower Mounted Fire Detector Development - Phase I"  

Gentlemen:

The objective of Project A-1528 is to investigate techniques using  
tower mounted sensors for remotely sensing forest fires.

The first period of this program has been devoted to (1) the design  
of a telescope for collecting infrared energy emitted by hot carbon dioxide  
above forest fires, and (2) specification of optical components for use  
in the telescope and in a breadboard sensor unit.

The preliminary design of a telescope-sensor unit has been completed  
and major component parts have been ordered. A four-inch diameter, con-  
cave main mirror and a two-inch diameter concave, sub-reflecting mirror  
were selected for use. Infrared energy, emitted by hot carbon dioxide,  
in the 4-5 μm band will be passed by this filter to a thermoelectrically  
cooled lead-selenide detector element. Energy with wavelengths outside  
the 4-5 μm range will be attenuated. These major components were selected  
from the available stock of optical component manufacturers and have been  
ordered.

During the next period, design of a mechanical assembly to house the  
telescope, optical filter and detector element will be initiated. After  
the design is completed and after the major components have been received,  
fabrication of the breadboard unit will begin. Also during the next  
period, planning for the field test program will be initiated.

Respectfully submitted:

Jerry L. Birchfield  
Project Director  

Approved:  

D. W. Robertson, Chief  
Communications Division
Georgia Forestry Commission  
P.O. Box 819  
5156 Riggins Mill Road  
Macon, Georgia 31202

Attn: Mr. James C. Turner, Jr.


Gentlemen:

The objective of Project A-1528 is to investigate techniques, using tower mounted sensors, for remotely sensing forest fires.

The second period of the program has been devoted to (1) fabrication of a breadboard telescope, detector, and associated electronic subassemblies, and (2) design of experiments to be performed in the field to evaluate the detection concept.

During this period, the final telescope design was completed and the breadboard was begun. All components have been received and assembled except for the chopper wheel motor and the finder scope assembly. Delivery of these items is expected during the week of June 4. Final assembly will be completed when these items are received.

Also during this period, the design of field experiments to yield data to evaluate the detection concept was begun. It is anticipated that three basic experiments will be conducted. The first will be directed to yield data for determining relative emission from hot CO$_2$ as a function of height above fires of a given size. The second will be directed to yield data to show the relative emissions from fires of given sizes at known range. The third will be directed to yield data for determining typical background emission levels that may be incident on the detector.

In the first two experiments, the assistance of Forestry Commission personnel will be needed to set and control test fires. For these experiments, and at the suggestion of your Mr. Turner, the Five Points tower and the Round Oak tower have been considered thus far as candidate base stations.
June 7, 1973

During the next period, the fabrication of the breadboard unit will be completed. Also, detailed plans for the three experiments will be developed and communicated to you. In addition, it is suggested that EES personnel survey the candidate test sites at and around the towers mentioned above and meet with your Mr. Turner to coordinate the test program.

Respectfully submitted,

J. L. Birchfield  
Project Director

Approved:

D. W. Robertson, Chief  
Communications Division
3 August 1973

Georgia Forestry Commission
P. O. Box 819
5156 Riggins Mill Road
Macon, Georgia 31202

Attn: Mr. James C. Turner, Jr.

Subj: Monthly Status Report Number 3, covering period
July 1, 1973 to August 1, 1973, Project A-1528
"Tower Mounted Fire Detector Development - Phase I"

Gentlemen:

The objective of Project A-1528 is to investigate techniques using
tower mounted sensors for remotely sensing forest fires.

This period of the effort has been directed to laboratory and prelimi-
nary field tests of the complete breadboard telescope and electronic
signal processing equipment. Initial tests of the breadboard system
showed that interference from 60 Hz power line signals obscured the
detector output. It was thus necessary to design and construct a synchro-
nous detector to process the output signal from the infrared detector
element. Subsequent tests showed that the 60 Hz interference could be
successfully eliminated by synchronous detection processing. Preliminary
field tests of the breadboard system were also conducted during this
period at the Stonewall fire tower in Fulton County. During these tests
significant variations in detector output were noted while the telescope
was trained on a forest background. Changes in the detector element
temperature caused by wind induced air motion are thought to be the source
of these variations. Also during this period, conversations with your
Mr. Curtis Barnes confirmed that a test site approximately 1.5 miles west
of the Round Oak tower would be available as a site for a controlled forest
fire. Tests at this site will be conducted as soon as the forest is dry
enough to burn.
During the next period investigations will be conducted to eliminate the variations in detector output noted in field tests. Also the tests at Round Oak will be performed during the next period if suitable weather and forest conditions occur.

Respectfully Submitted:

J. L. Birchfield
Project Director

Approved:

D. W. Robertson, Chief
Communications Division

JLB:sw
INVESTIGATION OF TOWER-MOUNTED REMOTE FIRE DETECTION TECHNIQUES

By

J. L. Birchfield and J. B. Langley, II

30 June 1974

SYSTEMS AND TECHNIQUES DEPARTMENT
FINAL REPORT
Project A-1528

Prepared for
THE GEORGIA FORESTRY COMMISSION
FOREWORD

This report was prepared by the Engineering Experiment Station at Georgia Tech for the Georgia Forestry Commission. The work described was performed in the Systems and Techniques Department under the supervision of Mr. D. W. Robertson, Chief of the Communications Division. This report summarizes the objectives, activities and results of a 15-month program to investigate the feasibility of tower mounted remote forest fire detection techniques.

The contributions of Messrs. Turner, Lundy, McMichaels, and Barnes of the Georgia Forestry Commission and Mr. Bill Grant of Georgia Tech are acknowledged.
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ABSTRACT

This report summarizes investigations conducted during a 15-month program to determine the feasibility of a specific tower mounted remote forest fire detection technique. The feasibility of detecting infrared radiation in the 4.0 to 5.0 micron range that might be given off by warm carbon dioxide in smoke columns above forest fires was studied to determine if sufficient signals might be present to indicate the presence of forest fires.

During the program a breadboard infrared detector was designed and fabricated. A lead selenide, cooled, infrared sensor was used with an optical telescope to sense the infrared radiation intensity generated by materials in the telescope field-of-view and to convert the intensity to a voltage. Also field tests were conducted with the breadboard detector in order to measure: (1) the characteristics of background infrared radiation that may be incident on a tower mounted sensor, (2) the intensity of radiation that may be generated in a smoke column at various heights above a forest fire, and (3) the infrared radiation that may be sensed by a tower mounted detector while viewing smoke columns above test forest fires.

The data collected during this study indicate that direct remote sensing of radiation in the 4.0-5.0 micron range will probably not provide adequate information to identify wildfires typical for the southeastern U.S. Time varying background radiation effects (noise) were noted to mask radiation from smoke columns and to cause insufficient signal-to-noise ratio. With the resulting low signal-to-noise ratio positive identification of fire signals were not obtained in tests conducted from tower locations.
1. Introduction

1.1 Purpose and Objectives

This report describes a feasibility study conducted at the Engineering Experiment Station under Research Project A-1528 for the Georgia Forestry Commission. The purpose of the study was to investigate the feasibility of using tower-mounted, infrared detectors for forest fire detection.

Objectives of the project were to:

(1) measure the characteristics of background infrared radiation that may be incident on a tower-mounted sensor;

(2) measure the intensity of infrared radiation that may be generated in a smoke column at various heights above a forest fire; and

(3) measure the intensity of infrared radiation that may be sensed by a tower-mounted detector while viewing smoke columns above test fires.

During the program, a breadboard infrared telescope having a narrow field of view was designed and fabricated. An optical filter - sensor assembly, sensitive in the 4.0 - 5.0 micron wavelength range, was developed for use with the optical telescope for sensing radiation at 4.3 microns from warm CO₂ above forest fires. The breadboard system was then used to gather data on fire and background characteristics in several field tests conducted in conjunction with the Georgia Forestry Commission.

1.2 Background

Conventionally, forest fire detection is performed by trained observers manning forest towers located throughout the state. During the fire season these towers are manned during most of the daylight hours with the observers continually scanning the surrounding countryside for early signs of forest fires. Generally these operators, trained for their duties, perform the fire detection function well. Unfortunately, current high labor costs and the
difficulty of obtaining satisfactory personnel makes continued use of a conventional manned tower system unattractive. Consequently, efforts have been undertaken by the Georgia Forestry Commission to investigate remote sensing techniques for possible replacement of manned tower systems.

Remote sensing of forest fires has been performed with satisfactory results under a federally funded program "Project Firescan." In this program infrared sensors are used in a detection system that is flown over the forest. The sensors scan (looking downward onto the forest) the surface of the forest and produce indications of the surface temperatures. The output of the sensor is recorded on a film. Fires are detected by study of the developed film to locate hot spots. Such a system concept, although workable, suffers from the disadvantage that significant time lags are introduced by use of film. The film must be retrieved from the aircraft and then processed and studied - a process that may require several hours. During this period, the fire may have become a major conflagration or have changed characteristics. In addition, airborne systems suffer the disadvantages of the high cost of the aircraft platform, maintenance, etc. These considerations have prompted investigations into other remote sensing techniques for forest fire detection.

An alternate approach to the airborne sensing of forest fires is use of tower mounted detector systems. Fortunately, continued use of the manned tower concept over many years has resulted in construction of an extensive tower system that could be used as platforms for tower mounted sensors. Sensors that might be used in the towers would be required to sense the presence of fire by scanning the tops of the forest tree crowns for indications of fire activity. One possible indicator of fire activity is infrared radiation from the hot gases in the smoke column above the fire. Signals
indicative of fire may be separable from the background radiation by signal processing to provide a positive indication of a fire.

In order to establish the feasibility of a tower mounted detector system, the characteristics of the smoke column above the fire were investigated as were the characteristics of background infrared radiation that might be sensed by a tower mounted detector. A breadboard detector system consisting of a telescope, an infrared sensitive detector, and electronic signal processing equipment was developed for use in field tests to study the characteristics of fire smoke columns and background infrared radiation. Data collected with the breadboard detector were used to assess the feasibility of tower mounted detector systems.

2. Factual Data

2.1 General Design Considerations

To detect fires with remote sensing equipment some unique separable indicator or signature must be present for sensing. Since forest fires burn in an oxygen rich atmosphere and consume hydrocarbon fuels it may be assumed that carbon dioxide (CO₂) will be present in the smoke column above a fire. The CO₂ will normally be warmer than the surrounding air and thus rise above the fire. Heated CO₂ emits infrared radiation at a wavelength of 4.3 microns. The amount of energy radiated will depend upon two factors; fire size and CO₂ temperature. If sufficient radiation is emitted by the CO₂ then it may be a useful indicator of fire activity.

The amount of radiation produced will be dependent on the amount of CO₂ in the smoke column and on the temperature of the gases. An estimate of the energy available for detection can be obtained by assuming probable values for the amount or extent of the gas, the temperature of the gas, and the
propagation characteristics of the atmosphere at the wavelength of interest. The radiance at a temperature of 2400°F and a wavelength of 4.3 microns has been measured to be 0.8 watts/cm²-μ-steradian [1]. Assuming a gas temperature of 500°F this value is reduced to 1.4 x 10⁻² wat/cm²-μ-steradian. Assuming a column having an area of about 10 square meters the equivalent radiation intensity is 5.8 x 10³ watts/steradian. At a range of 10 miles this corresponds to a power density of 2.2 x 10⁻⁵ watts/m². Absorption by atmospheric CO₂ further reduces this figure to about 1.3 x 10⁻⁵ watts/m² [2]. This power density may be available for use for sensing the presence of a fire. The amount of energy that can be captured is dependent on the aperture of the optical system used to focus the energy onto a detector.

Since a tower mounted infrared sensor used to sense radiation from gases in fire smoke columns will be required to scan horizontally through the atmosphere it will be susceptible to radiation from sources other than forest fires. To reduce the amount of undesired radiation both spatial filtering and spectral filtering can be used. The field of view of the optical system can be established by the telescope design. It should be narrow to make the scanned area at the maximum useable range satisfactorily small. It should be wide enough, however, to eliminate the need for nodding movements in the scanning motion since mechanical nodding scanning systems are more costly than are systems without nodding capability.


In addition to spatial discrimination, optical filters can be used to limit the range of wavelengths passed to the detector. Since warm CO$_2$ may be a dominant emitter of energy with an emission line at 4.3 microns, an optical filter with a pass band centered at 4.3 microns and passing the range of wavelengths immediately adjacent to this wavelength would pass the energy emitted by the CO$_2$ to the detector. Energy at wavelengths outside the passband would be rejected. The width of the passband will determine the amount of undesired radiation that reaches the detector. The bandwidth should thus be narrow. However, other warm combustion products present in the column may also radiate at wavelengths close to the CO$_2$ wavelength and may provide additional signal energy. Additionally the cost of custom narrowband optical filters may be a controlling factor.

To detect radiant energy several detector elements are available. Typical detectivities of these are $10^{-8}$ to $10^{-9}$ watts. Generally the elements have sufficient bandwidth to cover the infrared region around 4.3 microns. The output of the detector element must be amplified, processed, and filtered in order for it to be useful as an indicator.

2.2 Sensor Development

The general design considerations described above were used to guide the design and development of a breadboard tower mounted sensor. Included in the sensor was an optical section and signal processing equipment. Figure 1 shows a cross section sketch of the sensor system, and its component parts, that were designed and fabricated.

The general operation of the sensor can be understood by considering Figure 1. In the system, incident radiation enters the telescope tube and is reflected by a 4.25 inch diameter spherical main reflecting mirror to an
Figure 1. Cross Section View of Detector Telescope.
elliptical planar diagonal mirror mounted 62.4 cm in front of the main mirror. The radiation striking the diagonal mirror is reflected through a chopper that converts the continuous radiation into an alternating signal to eliminate dc drift. The chopper chops the signal at a 300 HZ rate. It consists of a five vaned blade driven by an electric motor. Energy passing through the chopper is next reflected by a spherical secondary mirror through an optical filter and onto a lead selenide element. The filter passes radiation in the 4.0 to 5.0 micron wavelength range and attenuates energy outside this band. The detector element is a lead-selenide unit mounted in a TO-5 header. The unit is cooled to about -10°C by a integral thermoelectric cooler. Signals from the detector are coupled out of the detector housing to a preamplifier. A reference source consisting of a light emitting diode (LED) and a photo transistor are mounted in an assembly connected to the chopper housing. The chopper chops the LED signal and provides a coherent reference for use with the signal processing equipment.

Signals from the pyroelectric element and the LED references are carried to external electronic equipment and processed for display. The signal from the detector element is amplified and then multiplied by the reference signal in a synchronous detector. The synchronous detector output is amplified and filtered for display on a strip chart recorder and a front panel meter. The output from the system consists of a voltage whose level is proportional to the temperature of the area viewed by the optical system.

2.2.1 Mechanical Design and Optics

The breadboard sensor as shown in Figure 1 was designed initially to have an approximate field of view of one degree. This field of view was selected since it provides acceptable viewing areas at expected test
ranges. For example at one mile range the area viewed is about 100 feet across. (Test ranges on the order of one mile were anticipated with the results to be extrapolated to show the results at other ranges.) Also, since commercially available components were to be used wherever possible and since it is desirable to use the largest diameter optics available to yield a large effective aperture, a 4.25 inch diameter spherical mirror was selected for use as the main reflector. The mirror has a 45 inch focal length. With this mirror and the one degree beamwidth the image size will be approximately 20 mm in diameter at the image plane. This image must then be focused onto a heat sensing element. The heat sensing element selected for use is a lead-selenide element made by Optoelectronics, Inc. (Model OTC-12) and has an active area approximately 2mm x 2mm. Thus the 20 mm diameter image must be reduced to about 2mm diameter and a magnification of about 0.1 is needed. With a 52 mm diameter secondary mirror having a 38 mm focal length the necessary image size reduction can be accomplished. Location of the secondary reflector on axis with the primary mirror would block an excessive amount of incident energy so it was decided to use an elliptical planar diagonal mirror to bend the beam perpendicular to the telescope axis. Use of a diagonal mirror also eased design requirements on the chopper housing and detector housing assembly. Both the main reflector mirror and the diagonal mirror are mounted in a 5 inch (ID) tube as shown in Figure 1.

Radiation is reflected from the main reflector and the diagonal mirror into the chopper housing and detector housing assembly and is chopped by a mechanical chopper at 300 HZ rate. An electric motor, running at 3600 rpm turns a blade with five vanes which interrupt the beam. The chopped radiation is then reflected from the subreflecting mirror through an optical filter.
having a passband from 4.0 to 5.0 microns onto the detector element which is mounted on three thin supporting arms attached to the detector housing assembly.

From Figure 1 it can be seen that energy is blocked by the diagonal mirror and the pyroelectric element and holder assembly. In addition, energy losses occur at each reflecting surface and in the optical filter. These losses combine to reduce the effective aperture of the system from about 4.25 inches (the main reflector diameter) to about 2.25 inches. The resulting aperture area is thus

\[ A = 97.3 \text{ cm}^2. \]

With the estimated power density given in section 2.1 and this effective aperture the received power should be approximately $1.3 \times 10^{-7}$ watts. With this received power level and the $10^{-8} - 10^{-9}$ watt detectivity of the cooled lead-selenide detector a 10dB signal-to-noise ratio should result. This theoretical signal-to-noise ratio will be reduced, however, by background radiation (noise signals caused by radiation from the area viewed by the telescope).

Signals from the pyroelectric element and the LED reference source are coupled into the electronic equipment shown schematically in Figure 2. The signal from the detector element is first amplified by OP1. This is a low noise operational amplifier selected to set a low system noise figure. Typical noise figures of 5dB are obtained with this type amplifier. The amplified signal is next fed to a twin T filter to eliminate interference and then to amplifier circuits OP2 and OP3. These units further amplify the signal. The gain of the detector is adjustable by varying potentiometer Pl. The nominal
Figure 2. Schematics of Electronic Circuits Used with Breadboard Detector.
2.2.2 Electronics and Signal Processing Equipment

A reference signal coherent with the chopping signal is obtained from a LED and photo transistor mounted in a housing attached to the chopper housing assembly. In this assembly, light is passed across a gap which is alternately blocked by the chopper vanes as the chopper motor turns. The reference input from the LED - phototransistor mounted on the chopper assembly is amplified in OP4 and OP5. The phase of the reference signal is shifted with these circuits to make the reference coherent with the chopped signal from the pyroelectric element. The two signals from the detector element and the reference are then multiplied in multiplier M1. The low frequency component of this product is proportional to the amplitude of the signal from the pyroelectric element. The multiplier output is amplified in OP6 and filtered with a 1 Hz bandwidth low pass filter. The output of OP6 is then fed to a front panel meter and to a recorder output as the detector output.

The electronic equipment requires several power supply voltages, and schematics of these are shown in Figure 2. The multiplier and operational amplifiers require ±12 volts. The LED-phototransistor reference circuit requires +6 volts. The lead selenide detector requires +100 volts bias a 1 volt at 750 ma for operation of the thermoelectric cooler.

The temperature of the pyroelectric cooler is maintained at -10°C by a proportional control circuit. In the controller circuit a thermistor (T1), integral with the detector cooler assembly, is used as the temperature sensing element. The temperature controller circuitry shown in Figure 2 senses change
in Tl and adjusts the current to the thermoelectric cooler to maintain constant detector element temperature.

2.3 Field Test Program

To evaluate the feasibility of the tower mounted detector concept described above, several field tests were conducted with the breadboard detector. These tests were conducted (1) to define the characteristics of background radiation that might be received by a tower mounted detector operative in the infrared range from 4.0 to 5.0 microns, (2) to establish the relative temperature of gases (principally CO₂) present above forest fires, and (3) to determine if test fires could be detected by sensing infrared radiation from warm gases in the smoke column above forest fires. Tests were conducted at the Electronics Research Building at Georgia Tech, at the Fulton County Office and Tower, the Jones County Office and Tower and the Waycross State Forest of the Georgia Forestry Commission.

2.3.1 Test Configurations and Results

Background Radiation Tests

In order to measure the characteristics of background radiation that might be received in the 4.0 to 5.0 micron ranges, tests were conducted at the Electronics Research Building and at the Fulton County Tower of the Georgia Forestry Commission. In these tests the infrared detector described in Section 2.2 was used to scan the terrain surrounding the test sites. In the tests conducted at the Electronics Research Building, data were collected with the detector located on the roof of the building and pointed at several sites around the building. These tests were conducted to ensure proper operation of the equipment and to make preliminary controlled measurements of typical backgrounds.
Data collected in the tests conducted at the Fulton County Tower are shown in Figure 3. In Figure 3(a) data collected when the detector was directed at a hill approximately one mile away from the tower are shown. In the figure a voltage proportional to the intensity of radiation in the 4.0 to 5.0 micron range is plotted versus time. In these data a significant short term fluctuation, and a much longer term but equally strong fluctuation can be seen. Initially, drifts in the instrumentation were suspected as the source of these variations. Consequently, the input to the preamplifier was connected to circuit ground and the recording in Figure 3(b) was made. This record shows that very little drift is produced by the instrumentation. Attempts to correlate variations such as are shown in Figure 3 with changes in cloud cover and other effects did not prove successful. Subsequently it was decided to shield the detector housing assembly to keep external radiation from entering the system through the slit provided for the chopper blade and also to reduce airflow over and around the detector housing and hence minimize temperature variations experienced by the detector element. When a shield was added the recording shown in Figure 3(c) resulted. Notice that the short term variations have been reduced significantly although the longer term variations are still present. These data show that the short term variations were probably caused by either undesired radiation entering the system through the slit provided for the chopper blade or from air motion. Subsequent experiments in which the detector assembly was unshielded but in which varying amounts of shading (from sunlight and other external radiation) was provided indicated that the short term variations were still present. Thus the short term variations in the data were probably due to temperature variations caused by air motion around the detector element.
Figure 3. Background Radiation Data Collected at Fulton County Fire Tower.
The long term variations present in the data shown in Figure 3(a) were not affected by addition of a wind shield nor by selective shading of the detector housing. Consequently, it is assumed that these variations are sensed in the area viewed by the detector. The source of these variations is not presently known; time varying thermal columns in the atmosphere caused by uneven surface heating may be present in the field of view of the detector and could cause the variations.

The data shown in Figure 3(c) illustrate the magnitude and characteristics of typical ambient background radiation. The long term drifts or variations in background evident in Figure 3(c) will complicate identification of unique fire generated radiation. From the data in Figure 3(c) the magnitude of the background variations are seen to exceed 500 millivolts. These variations would probably overshadow signals from fire generated radiation except for instances of fires at very close ranges if the detector were used to measure absolute radiation levels. The characteristics and magnitude of the background radiation suggest that differential temperature measurements may be required instead of absolute temperature measurements.

Other tests were also conducted at the Fulton County Tower. In these tests data were taken with the detector directed at other selected fixed sites and also with it scanning over the terrain visible from the tower. Two recordings of the data collected are shown in Figure 4. Figure 4(a) shows data recorded while the detector was aimed at a forested hillside located approximately 1 mile from the tower. Figure 4(b) shows data collected with the detector aimed at the horizon. In both of these recordings the long term variations in background radiation can be seen to be very similar to those
Figure 4. Background Radiation versus Time for Two Different Scenes - Fulton County Tower.
noted in data taken at the first site shown in Figure 3, and are probably caused by thermal activity in the atmosphere.

Figure 5 shows data collected as the detector was scanned through a 30 degree sector (between 70° and 100° azimuth) and directed at the terrain about 1 mile from the tower. These scans were repeated several times to determine if a repetitive background pattern was evident. These repeated scans are shown in Figure 5(a), 5(b), and 5(c). Since the detector was scanned manually the individual records cannot be overlaid exactly. However, a pattern can be seen by comparing the three recordings to each other. Again large variations (from scan to scan) in the received background radiation can be seen in these data.

In these tests a significant time varying background radiation level was noted. This radiation, which is coupled into the detector, will appear as a noise component and will result in a signal-to-noise ratio reduction. From these data it can be seen that the long term background radiation variations can be expected to exceed 500 mv (peak-to-peak in Figure 3(c) ) and may obscure fire generated signals.

2.3.2 Temperature Versus Height Above Test Fires

In these tests radiation from the region above test fires was measured with the broadband detector described in Section 2.2. The test configuration is illustrated in Figure 6. In these tests the detector was set up across an open field about 500 feet from a test forest fire. As the fire burned, scans were made at various elevations across the fire front.

In these tests a fire was started in the underbrush in the edge of a pine forested area. Since the fire was set in late August and the underbrush was green, the fire was not intense. Forestry Commission personnel present at the
Figure 5. Data Collected in Scans made from Fulton Co. Fire Tower.
Figure 6. Test Configuration - Detector Output vs. Scan Height Above Fire.
tests indicated that the fire did not have the intensity of a typical wildfire. Thus, since the test fire may not have been typical, the data shown in this section should be interpreted with caution.

The recording shown in Figure 7(a) was made with the detector set at 0 degrees elevation. Thus, as it was scanned across the fire front through a $\pm 10^\circ$ sector, it was directed at the active flame area of the fire. As can be seen from the recording, the received radiation saturated the detector when the instrument was aimed directly at the fire flame area. Figure 7(b) shows a recording made with the detector aimed at a position about 15 to 20 feet above the active flame area and scanned through a $\pm 10^\circ$ sector. Again it can be seen that the detector was saturated by the radiation from gases above the active fire area as it was scanned. Figure 7(c) shows a recording made with the detector aimed at a position about 40 feet above the fire area and again scanned through a $\pm 10^\circ$ sector. This position corresponded to the tops of the trees under which the fire was burning. From the data it can be seen that the radiation did not saturate the detector as the detector was scanned across the fire front at the elevation. Rather, the radiation caused about a 1.5 volt variation in detector output signal level as it is scanned across the fire front. These data indicate that the radiation from the smoke column above the test fire is strong at locations immediately above the active flame but are much weaker at tree top heights and above.

Since the test fire used to obtain these data was not intense, these data should only be interpreted to show approximate amounts of radiation that might be given off from the warm gases above a fire. From Figure 9(c) with the detector aimed at tree-top elevation the gases were seen to emit radiation sufficient to cause a 1.5 volt variation in detector output. If these data are
NOTE: These data recordings show inverted signal intensity, i.e., a negative going signal indicates an increasing temperature.

Figure 7. Detector Output for Several Heights Above a Test Forest Fire.
extrapolated to indicate results at a range of 50,000 feet (~10 miles) a variation of about 0.015 volts would be expected.

Another field test was conducted in November 1973 at the Waycross State Forest. Conditions in these tests were more representative of wildfire conditions although all fires were set in the backfire mode. Terrain features at the test site were such that the fire could be viewed from a range of about 0.5 miles across an open field. The fire was set in the edge of a pine forest to the palmetto-underbrush ground cover. The area had been burned about 3-4 years previously and the underbrush height ranged from one to three feet.

Data were collected by scanning the telescope assembly through sectors in azimuth at ground level, mid-tree, and tree-top elevations (tree-top height was about 60 feet). Scans were made over a ±90° sector to determine signals received in a wide range of backgrounds adjacent to the fire site. The fire front was approximately 100 feet wide. Figure 8(a) shows the data collected in this field test. The figure illustrates the signals received from the base of the fire in a 30° sector with the fire at the sector's center. No unexplained signals were received from outside the 30° sector. From the data, the signal received from the fire is clearly recognized and the peak signal received is seen to be 4.2 volts. Figure 8(b) shows data collected in a scan at the mid-tree level (~25 feet above ground level). The peak signal received from the fire is reduced to approximately 1.5 volts. Figure 8(c) shows data collected in a scan at the tree-top level (~50-60 feet). These data show that the signal received while viewing the fire is opposite in sense to the signals received in the ground-level and mid-tree scans. This indicates that the apparent temperature of the column is below that of the background which is in this case the sky. The minimum signal relative to the background level is about 300 mV.
a) Scan Across Base of Fire Front

b) Scan Across Fire Front 30 feet (mid-tree height) Above Base of Fire

c) Scan Across Fire Front 60 feet (tree-top height) Above Base of Fire

Figure 8. Signal Intensity Recorded From Several Scans Across Fire Front at 0.5 Mile Range-Waycross State Forest, November 1973.
Data collected in this November 1973 field test indicated that the received signal decreased rapidly with height above the fire-base and that the column temperature was greater than the temperature of the forest background but less than the background temperature of the sky.

The background variations which were noted in earlier tests do not appear to be present in the data presented in Figure 8. This is due to the scale factor used to make the recordings. The recorder scale factor was set to record the maximum signal excursions and these were such that the background variations were not apparent. Data collected with the instrument located in a fire tower scanning over the tree crowns with the recorder scale set for higher resolution showed background fluctuations similar to those recorded during the previous field tests.

2.3.3 Detectivity versus Fire Size

In addition to the tests described in Sections 2.3.1 and 2.3.2 experiments were conducted to determine if test fires could be detected from towers with the breadboard detector. These experiments were conducted in late August 1973 at the Jones County Office of the Forestry Commission. At the tests conducted in August a test fire was set by Forestry Commission personnel at a location about 1.7 miles from the Jones County Office and Tower. The fire was first set to be 60 feet across. It was then enlarged to about 120 feet across and finally increased to cover an area of about 1 acre. The breadboard detector was set up in the tower and was used to scan the area including the fire to determine if radiation from the smoke column could be sensed. Since the vegetation in the fire area was green the test fire was not intense. Forestry Commission personnel present at the test indicated that the test fire was probably not representative of a typical wildfire. Consequently,
the data collected may not be representative of signals that might be
generated by wildfires.

Figure 9(a) shows data collected as the detector was scanned through a
20 degree sector at an elevation such that it passed through the base of the
smoke column at tree top level. The fire had a 60 foot front for this test.
Figure 9(b) shows similarly scanned data with the detector set at an
elevation such that it passed through a point about 50 feet above the tree
tops where the smoke column originated. The location on the scan occupied
by the smoke column is indicated on the figures. As can be seen no signal
indicative of the fire is evident.

After the data for the 60 foot front fire was collected the fire size
was increased to have a front of about 120 feet. Similar data to that
collected for the 60 foot front fire are shown in Figure 10(a). Again, no
indication of the fire location can be inferred from analysis of these data.

The test fire size was next increased to cover an area of about one acre.
Data were collected at the two elevations described for the 60 and 120 foot
front size fire. These are shown in Figure 11(a) and 11(b). No indication is
present in these data to show the location of the fire.

2.3.4 Tests with 0.1° Field-of-View Telescope

Since the unexplained background variations (illustrated by the
data recordings of Figure 4) were thought great enough to obscure signals
that might be received while observing fires from tower locations, it was
decided to modify the telescope to reduce its field-of-view. It was hypoth-
esized that by reducing the field-of-view, the received heat from random
sources making up the background would be reduced since the viewing area
would be reduced. Conversely, the heat from a smoke column would not be reduced since
Figure 9. Scans Across Smoke Column Above 60 Foot Front Test Fire.

Figure 10. Scans Across Smoke Column above 120 Foot Front Test Fire.
Figure 11. Scans Across Smoke Column Above 300 Foot Front Test Fire.
the column would be within the field-of-view. Such a modification should, if sufficient signals were present from the smoke column, increase the effective signal-to-noise ratio of the detector system. Any signals received from the smoke column should therefore be more likely to be discernible from data collected with the instrument. To test this hypothesis, it was decided to reduce the field of view to 0.1°. This represents an order-of-magnitude reduction and was considered sufficient to test the hypothesis.

The telescope was modified to incorporate a planar subreflecting mirror and to utilize a longer optical path within the instrument to give a 0.1° field of view. The changes were performed and another field test was conducted at the Waycross State Forest in May 1973.

In these field tests, a test fire was set in a cleared area of a large field. The underbrush that had remained after clearing, although piled together, was thought similar enough to that which had been burned in the November tests to yield valid data for comparative purposes. The test fire was viewed at a range of about 200 yards across the open field. Scans were made across the sector including the fire at several heights above the base of the fire by manually moving the instrument.

Figure 12 shows the data collected at approximately 200 yards range from the test fire. Figure 12(a) shows the signals recorded as the instrument was directed at the flame area of the fire front. The signals appear erratic and indicate that several areas of flame were viewed interspersed with cooler areas. The field of view is narrow enough to respond to each of these "hot spots" in this test whereas the instrument responded to signals from the total fire front in the November 1973 tests (Figure 8). The maximum signal excursion (peak-to-minimum) recorded in these data is approximately 7.5 volts.
Figure 12. Signal Intensity at Several Heights Above a Test Fire -- Waycross State Forest, May 1974.
Figure 12(b) shows data collected at 200 yards range with the instrument scanned at approximately 15 feet above the base of the fire and across the fire front. In these data the background signal level had increased to approximately midscale (5 volts) on the record as is seen in the figure. As the instrument was scanned across the fire front individual "hot spots" can still be recognized but the maximum signal variation is reduced to 2.5 volts (note that the instrument was saturated by the signal and could not respond to the peak excursion). Figure 12(c) shows data collected as the instrument was scanned across the fire front while pointed about 30 feet above the base of the fire. Again the background signal had level shifted (downward (cooler) by about 5 volts). The maximum signal variation recorded at this elevation was about 3.5 volts. Figure 12(d) shows data collected with the instrument pointed approximately 60 feet above the base of the fire (pointed at tree-top level). The background signal excursion was about 1.75 volts. Figure 12(c) shows data collected with the telescope pointed at about 90 feet above the base of the fire. The background level had increased again by about 3 volts. No signals indicative of the fire were noted in these data.

From the data shown in Figure 12, it can be seen that the previously described background signal fluctuations are present even with the telescope modified with a narrowed field of view. This indicates that the source of the signal fluctuations is probably thermal activity in the atmosphere through which the telescope is directed rather than surface temperature variation effects. Also from the signals recorded a strong dependence of temperature with height above the fire base is to be noted. At heights of approximately
90 feet no discernible fire signal is present while at mid-tree heights (30 feet) strong signals were received.

2.3.5 Feasibility of Remote Detection of Fires Using Radiation in the 4.0-5.0 Micron Range

In each of the tests directed to observing signals from the smoke column above the forest canopy, strong, fluctuating background signals were noted. These signals are thought to be caused by time varying thermal activity in the atmosphere resulting from differential surface heating. In addition to these strong background signals, a rapid decrease in smoke column temperature at heights above the surrounding tree tops was noted. These two factors combine to reduce the ratio of fire signal intensity to background noise intensity and result in a low effective signal-to-noise ratio. This low signal-to-noise ratio condition, in which the background radiation level obscures radiation from the column, makes separate identification of the fire signal difficult and no clearly identifiable indication of fire activity was obtained in the tests that were conducted. Thus direct detection of radiation from warm gases in the smoke column is not thought to be a feasible technique for detection of small wildfires that may be encountered in the southeastern U.S.

2.4 Summary, Conclusions, and Recommendations

During this effort the feasibility of tower mounted detection techniques based on sensing radiation in the 4.0 to 5.0 micron infrared range were investigated. A breadboard detector was designed and fabricated and used in field tests to: (1) measure the characteristics of background radiation that might be sensed by a detector operating in this infrared range, (2) to investigate the radiation from various heights in the smoke column above forest
fires, (3) to determine if test fires could be detected by the tower mounted detector.

Background variation measurements were performed at four field sites:

1) The roof of the Electronics Research Building on the Georgia Tech campus,
2) at a Forestry Commission Fire tower in south Fulton County,
3) at a Forestry Commission Fire tower in Round Oak, and
4) at the Waycross State Forest.

In each of these tests signal variations similar to those shown in Figure 5 were observed. These fluctuations are thought to be sufficient to obscure signals that might be observed from a smoke column above a forest fire. Although the source of these fluctuating signals was not identified it is thought that they are possibly due to thermal columns in the atmosphere arising from uneven heating of the forest cover. Since the instrument was being used to "look" horizontally through the atmosphere in these tests signals were being received from a sector including a large area of forest cover as well as a considerable depth of atmospheric gases. The heat from these sources will vary with time as cloud cover conditions change and as atmospheric thermal air columns change. Without further research the exact source of these variations cannot be more clearly defined.

Other field tests were conducted to give data to show how radiation from a smoke column varied with elevation above the base of a test fire. These tests showed that significant radiation is given off by gases in the smoke column but that the intensity decreases rapidly with height above the active flame area of the fire. At heights greater than tree-top level, the intensity may not be sufficient to indicate fire conditions especially in the presence of the strong background signals that were observed.
Tests were also conducted to give further data to determine if fires could be detected by observing the column above the fire from fire towers. In tests at both Round Oak and the Waycross State Forest, these efforts were unsuccessful. Background signals were sufficient to obscure any signals that might have been received from the test fires.

In addition to data from these tests discussions were held with Mr. Al Hauck of the Southeastern Forest Fire Laboratory late in the program concerning data that he had collected on temperatures that might be present in the smoke columns above forest fires. His preliminary data (unpublished) showed that temperatures in smoke columns at approximate tree-top levels were only 1.8° higher than the temperature of the surrounding atmosphere.

The data collected with the breadboard telescope and furnished by Mr. Hauck indicate that radiation from warm gases above forest fires coupled with strong background radiation levels result in signal-to-noise ratios that are probably not sufficient to allow direct detection of small fires by automatic means.

Automatic detection of small forest fires may be possible if some other identifiable fire signature could be isolated. Studies should be continued with the purposes of (1) identifying fire signatures and (2) characterizing background (noise) radiation. These studies should include tests to determine the radiation characteristics of smoke columns at wavelengths other than in the 4.0 to 5.0 micron range. Also studies of radiation in a narrow band around the 4.3 micron CO₂ emission line should be conducted. The infrared telescope and ancillary electronic equipment could be utilized in these studies. In addition, studies of test fires conducted under controlled conditions in the Southeastern Forest Fire Laboratory should be undertaken with the infrared
telescope to further define the radiation characteristics of smoke columns. In each of these tests background radiation (noise) data should be collected to define the probable signal-to-noise ratio that could be achieved in an operational system.