NUCLEAR ENGINEERING INTERNATIONAL

NOVEMBER 2007
www.neimagazine.com

NUCLEAR ENGINEERING INTERNATIONAL

Editor:
Stephen Tarlton
Deputy Editor:
Corrina Thomson
Editorial Assistants:
Tracey Honney
Elaine Sneath
Managing Editor:
James Varley
Group Advertisement Manager:
Scott Galvin
European Sales Executive:
Katrin Doughty
Journal Secretary:
Natasha Denney
Art Editor/Designer:
Karen Townsend
Technical Illustrator:
Nick Stenning
Production Controller:
David Glenister
Classified Production Controller:
Doug McManus
Sales Director:
Tim Price
Publishing Director:
David Wildman
Managing Director:
Colin Bailey-Wood

Editorial & Advertising Office:
Progressive Media Markets Ltd,
2 Maidstone Road, Foots Cray, Sidcup,
Kent DA14 5HZ, UK
Tel: +44 20 8269 7773 Fax: +44 20 8269 7804
email: starlton@wilmington.co.uk

Japan office:
Masayuki Harihara, Yukari Media Inc, 3-4 Uchihiranomachi,
3 Chome chuo-ku, Osaka 540-0037, Japan
Tel: +81 6 4790 2222 Fax: +81 6 4793 0800

Subscription office:
For subscription enquiries, single copies or back issues:
Nuclear Engineering International
PO Box 251, Southall, UB1 2DB, UK
Tel: +44 20 8606 7515 Fax: +44 20 8606 7301
email: wilmington@wdis.co.uk

Subscription rates:
(NB: Annual subscription now includes the *World Nuclear Industry Handbook*)
UK/Europe: £273/€420
USA/Canada: $505
Rest of World: £280

US Subscriptions:
Nuclear Engineering International (ISSN 0029-5507) is published monthly by Progressive Media Markets Ltd, 2 Maidstone Road, Foots Cray, Sidcup, Kent DA14 5HZ, UK. Periodicals Postage Paid at Rahway, NJ. POSTMASTER: send address changes to Nuclear Engineering International, c/o BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001. US Agent: BTB Mailflight Ltd, 365 Blair Rd, Avenel, NJ 07001

Printed by Williams Press, Berkshire, UK

ISSN 0029-5507

ABC
AUDIT BUREAU OF CIRCULATIONS

LEAD NEWS

COMPANY NEWS

COMMENT

INSTRUMENTATION & CONTROL

RADIATION MONITORING & ALARA

SECURITY

CONFERENCE REPORTS

POWER MARKET DEVELOPMENTS

DECONTAMINATION & DECOMMISSIONING

POWER PLANT PERFORMANCE

VIEWPOINT

Covert plant detection

A spectroscopy innovation developed at Argonne National Laboratory can covertly detect chemical plumes at great distances and may help thwart future chemical or nuclear terrorist attacks.

The passive millimetre-wave spectroscopy (PmmWS) technology developed at Argonne National Laboratory (ANL), in the USA, has a number of uses – from covert detection of chemical plumes, finding environmental pollution, to determining the extent of tissue damage in burn victims without physical contact. The technology has the capacity to identify chemical plumes at ranges of up to a few kilometres and at concentrations as low as 100-1000ppm.

PmmWS was developed by Argonne's Nuclear Engineering Division and was primarily created to monitor chemical signatures emitted by processing facilities suspected of unauthorised nuclear activity, such as enrichment or reprocessing, and their use in weapons production.

In terms of its advantages over other forms of chemical sensing, previous remote sensing instruments for terrestrial use had lower ranges of detection (from 10-100m), were susceptible to interference from clouds and other atmospheric phenomena, and cost much more than PmmWS. The Argonne PmmWS is also more selective and can identify a particular molecule instead of just a molecular functional group.

Spectroscopic methods at microwave and millimetre-wave (mmW) frequencies for detection and identification of polar molecules have been limited primarily to space applications and to laboratory environments at low vapour pressures.

DEVELOPMENT

A passive mmW sensor operating at a centre frequency of 150GHz with a bandwidth of 8GHz has been developed for selective detection and identification of target molecules released from a stack at large standoff distances. Results of field tests under realistic atmospheric conditions showed the capability of the mmW radiometer to selectively detect the release of a target chemical at a distance of more than 0.5km from the stack.

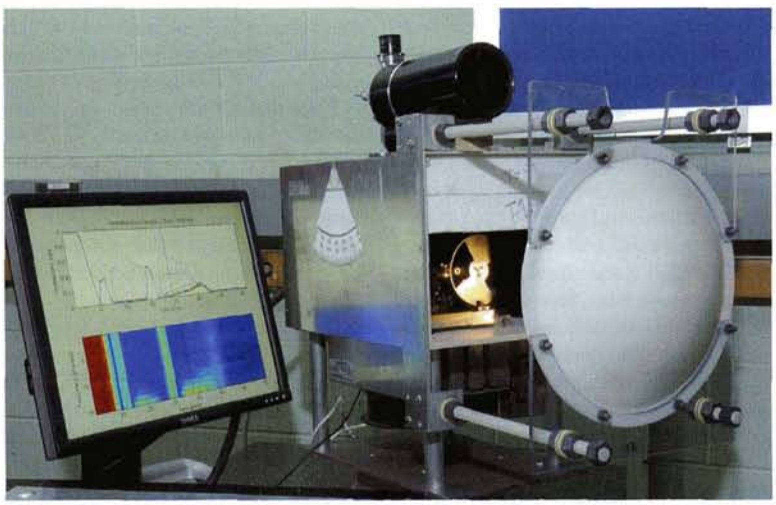
Radar techniques have been used extensively to monitor temporal variations of the earth's surface particularly for measuring backscattering characteristics of vegetation and sea ice. Active radar techniques at mmW frequencies have also been employed for remote sensing of the environment. Passive mmW techniques for the measurement of molecular emission/absorption spectra, however, have been used almost exclusively for space-borne remote-sensing applications and for laboratory measurements.

Although the strength of rotational and vibration energy transitions generally increases with frequency, the attenuation of electromagnetic radiation also goes up with frequency. This is because of stronger rotational absorptions by atmospheric constituents at higher frequencies. This trade-off sets an upper limit on frequency for ground-based remote sensors. As a direct consequence of operating at shorter electromagnetic wavelengths, mmW sensors are better suited for operation under adverse environmental conditions than their optical counterparts.

Analytical modelling was initially carried out to help quantify the detection limits of the proposed sensor under simulated test conditions. A multichannel bench-top system was then assembled to demonstrate the proof of principle by measuring the emission spectra of known polar molecules at various pressures inside a gas cell. The prototype system was built and tested.

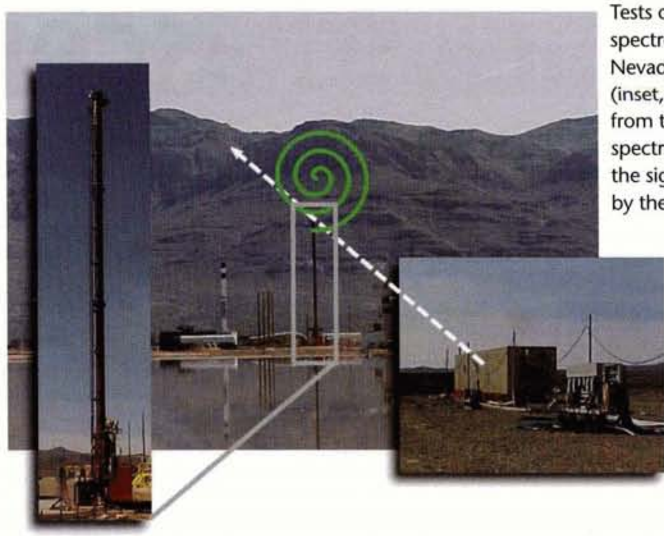
Feasibility studies for the proof of principle were carried out in two stages. Analytical modelling of a stratified atmosphere was performed by using radiative transfer formulation for the standard atmosphere and, in conjunction with molecular rotational absorption/emission spectra, acquired from an available database of spectral lines.

The atmosphere can practically be considered transparent at frequencies below X-band. The attenuation of microwave signals increases at shorter wavelengths and the atmosphere behaves as a lossy medium at millimetre wavelengths. Of the various gases in the atmosphere, oxygen and water vapour are the only constituents that exhibit significant absorption bands in the mmW spectrum. Oxygen has a permanent magnetic dipole moment with lines centred about 60GHz and 118.8GHz. Water vapour is a polar molecule possessing an electric dipole moment with lines at 22.2GHz and 183.3GHz and at several bands in the far-infrared region. Increase in line



A prototype of the passive millimetre wave spectroscope Photo: ANL width due to collision and interaction leads to broadening of the absorption lines. Pressure broadening is of particular importance for atmospheric absorption in mmW region of the spectrum.

The atmosphere was divided into three layers with the target cloud modelled as a spherical volume located in the middle layer. The emission and absorption by each layer were calculated separately and the contribution from all layers was traced downward to determine the apparent temperature at the radiometer position. Numerical integration was performed to obtain the absorption coefficient in each layer. A series of simulations were carried out next to examine various measurement scenarios, including the effect of sensor alignment and atmospheric conditions.



Tests of the millimetre wave spectroscope were conducted at the Nevada Test Site. Housed in a bunker (inset, right) several hundred metres from the test site (centre), the spectrometer was able to distinguish the signal of gas plumes (represented by the green spiral) from the background mountains. Photo: ANL

SIMULATIONS

A radiative transfer model was developed to simulate the expected signal levels for detection of a hot nitric oxide plume released from a stack against a mountain background. The simulation results show the feasibility of detecting the weak 150GHz spectral line of nitric oxide from a standoff distance of a few kilometres using a state-of-the-art radiometer. Several minutes of integration time was necessary to achieve the required sensitivity.

The results of simulations where the radiometer is pointed nearly toward the zenith and toward the horizon indicate that, although at short distances to the target, a stronger signal is expected from the absorption line at higher frequency, the opposite is true at long standoff distances that correspond to large observation angles for a ground-based sensor. This is because for observation angles approaching 90 degrees, the larger atmospheric attenuation at lower elevations can significantly reduce the differential radiometric temperature.

Based on the results of theoretical investigations, a 16-channel Dicke-switched radiometer, covering the frequency range of 146–154GHz, with 500MHz bandwidth per channel, was designed to detect the 150GHz transition of nitric oxide.

A multispectral radiometer system consisting of the mmW front end assembly, back end electronics, and data acquisition hardware and software was also assembled. A superheterodyne receiver at the front end converts the mmW input signal within the pass band (146–154GHz) of the filter down to the intermediate frequency (IF) of 10-18GHz, which subsequently goes through first stage amplification. The back end unit further amplifies the IF signal by passing it through another two stages of amplification. Cascaded power dividers split the signal into 16 channels, which then goes through a bank of bandpass filters each with a 500MHz bandwidth. The signal is finally down-converted to the video frequency range. To allow the radiometer to operate in Dicke-switched mode, an optical chopper was installed in front of the antenna unit that also provided the trigger signal for separating the scene from the reference signal.

The outputs of the radiometer and the synchronisation transistor-transistor logic signal from the optical chopper are all fed into an 18-bit data acquisition board for processing. Data collection and real time analysis of the signals were performed and specialised algorithms were developed for post-processing of multi-channel spectroscopic data.

TESTING TIMES

To test the proof of principle for passive mmW spectroscopy, several experiments were conducted by using chemicals with known transition lines. A laboratory setup was assembled for the measurement of absorption/emission spectra at millimetre wavelengths. The incoherent emission from a gas in a transparent cell was measured against a contrasting background. To simulate the expected thermal gradient in the field (that is, hot plume against ambient temperature), a cold background was placed behind the gas at ambient temperature. The measurements were made with a 30-second integration time and over an approximately 30-minute time span.

There is good agreement between the theory and measurement near the peak absorption frequency. With reduced power level away from the peak, variability among channels is more apparent at the upper end of the measurement spectrum. More frequent calibrations can help reduce the variability among channels.

A prototype system was subsequently built for field testing. Based on the feedback from laboratory experiments, a series of signal processing schemes were developed to mainly compensate for atmospheric fluctuations.

The temperature of the system's front end was maintained at a constant level by incorporating a thermoelectric cooler. The scalar feed horn of the mmW receiver was mounted with a 30.5cm (12-inch) lens antenna that provided the narrow beam width necessary to attain the small footprint requirement at large standoff distances.

A pointing telescope was mounted parallel to the lens axis for alignment purposes. A 150GHz source was initially used as a beacon to align the lens antenna and the telescope.

The entire assembly was mounted on a two-axis platform that allowed fine azimuth and elevation adjustments. The system was later tested in the field under realistic conditions. While the field tests were performed at a standoff distance of slightly more than 0.5km, the results showed the potential for significant increase in the standoff distance.

Based on the paper "A Millimeter-Wave Radiometer for Terrestrial Remote Sensing of Chemical Plumes" by Sasan Bakhtiari, Nachappa Gopalsami, Thomas W Elmer, and Apostolos C Raptis of the Nuclear Engineering Division, Argonne National Laboratory, 9700 South Cass Avenue, Building 308 Argonne, Illinois 60439-4825, USA