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Under the DoD/AFOSR's Defense University Research Instrumentation Program (DURIP) grant to MIT, we have acquired the Ionospheric Radar Integrated System (IRIS) which includes a portable HF/VHF radar operating in the frequency range of 10 - 60 MHz, a digital ionosonde operating from 1 to 10 MHz, and two student-built VLF wave receiving systems. These instruments provide powerful plasma diagnostics in both laboratory and field experiments, supported by the Air Force office of Scientific Research grant F49620-98-1-0389. We have recently received two site licenses, authorized by the DoD US Air Force Frequency Management Agency (AFFMA). One allowed us to transmit radar signals at 24.26 MHz, 41.45 MHz, and 46.8 MHz at Millstone Hill, Massachusetts from June 12 to July 21, 2000. The other pennited transmission of 11.92 MHz, 24 MHz, and 46.8 MHz signals at Gakona, Alaska during July 15 - Sept. 1, 2000. The testing campaign of the portable HF/VHF radar in Massachusetts was very successful (see attached two pictures of the experimental setup). Applications have been submitted to AFFMA for frequency licenses to conduct extensive experiments in Massachusetts, California, and Puerto Rico. A brief description of the IRIS is given below.

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Final Report on MIT's Defense University Research Instrumentation Program (DURIP) Grant (F49620-98-1-0253)

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Sponsored by Air Force Office of Scientific Research
Program Manager: Maj. Paul J. Bellaire, Ph.D.
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1. Introduction:

Under the DoD/AFOSR's Defense University Research Instrumentation Program (DURIP) grant to MIT, we have acquired the Ionospheric Radar Integrated System (IRIS) which includes a portable HF/VHF radar operating in the frequency range of 10 – 60 MHz, a digital ionosonde operating from 1 to 10 MHz, and two student-built VLF wave receiving systems. These instruments provide powerful plasma diagnostics in both laboratory and field experiments, supported by the Air Force office of Scientific Research grant F49620-98-1-0389. We have recently received two site licenses, authorized by the DoD US Air Force Frequency Management Agency (AFFMA). One allowed us to transmit radar signals at 24.26 MHz, 41.45 MHz, and 46.8 MHz at Millstone Hill, Massachusetts from June 12 to July 21, 2000. The other permited transmission of 11.92 MHz, 24 MHz, and 46.8 MHz signals at Gakona, Alaska during July 15 - Sept. 1, 2000. The testing campaign of the portable HF/VHF radar in Massachusetts was very successful (see attached two pictures of the experimental setup). Applications have been submitted to AFFMA for frequency licenses to conduct extensive experiments in Massachusetts, California, and Puerto Rico. A brief description of the IRIS is given below.

2. Portable HF/VHF Radar

The HF/VHF portable radar consists of 4 transmitters, 4 receivers, 4 transmit/receive (T/R) switches, 7 power combiners, 3 sets of antennas and a controlling computer. The transmitters are wideband MOSFET amplifiers. The nominal operating frequency range is 10-60 MHz. Each of the four amplifiers puts out 8 kW PEP at up to 15% duty cycle. Each 8 kW amplifier is composed of four 2 kW modules. The output of each 2 kW module is accessible at the back of the transmitter. These outputs can be independently phased for purposes of beam steering. In turn, the four transmitters may be independently phased. Thus in principle, 16 antennas can be used as a phased array in either a linear or square matrix. However, currently the radar has four Yagi antennas for use at 48 MHz, four Yagis at 24.5 MHz and one Yagi at 12 MHz. For operation at 48 MHz and 24.5 MHz, there are four 8 kW combiners which are used to combine the sixteen 2 kW outputs into four 8 kW outputs. For operation at 12 MHz, there are two additional combiners to combine the four 8 kW outputs into two 16 kW outputs and one further combiner to combine the two 16 kW outputs into a single 32 kW output. Breaking the 8 kW to 32 kW combination into two steps allows one to also run with two antennas if that is preferred.

The radar is intended to run monostatic, so that the antennas will receive as well as transmit. In the case of four antennas, each antenna, receiver and transmitter is interfaced with a transmit/receive (T/R) switch. This is a passive device which senses RF voltage on the line and switches the antennas between the transmitters and the receivers. In the case of one antenna, the switches are placed between the outputs of the four 2 kW-to-8 kW combiners and the inputs of the two 8 kW-to-16 kW combiners. Pulse shapes can be programmed into the computer. The temporal resolution is limited only by the 350 nS rise/fall time of the amplifiers, and the amplitude resolution is 8 bits. Multiple pulses can be combined to make coded sequences. The maximum length of any sequence is 2 mS at 4% droop. The pulse repetition frequency can be varied anywhere from 0 to 1 kHz, maximum duty cycle permitting.

In addition to single-frequency operation, the carrier frequency may be swept over a sequence of up to 16 frequencies to conduct FDI (frequency domain interferometry) observations. These frequencies can be stepped on a pulse-to-pulse basis if necessary. The echo signals are switched into four receivers and translated to baseband in one stage (direct conversion). The local oscillator frequency of the receivers may be set independently of transmitter carrier frequency in order to observe echoes that have been Doppler-shifted by large values. Up to 124 dB of receiver gain is available, adjustable over a 60 dB range in 1 dB steps. The outputs of the mixers are sent through 4th-order Bessel filters and sampled with 12-bit resolution at up to 500 kS. Faster sampling rates may be obtained by using less receivers. Up to 200 range gates can be recorded for a single pulse transmission, with the delay to the first gate being arbitrarily long. Samples are coherently averaged up to 65536 times.

The computer can process the data in two ways. Either raw baseband data can be streamed to hard disk, or data can be sent through an analysis module before being recorded. The analysis module is a flexible entity which can be inserted and removed as desired. The radar user can write analysis modules in the C programming language. The vendor provides a default analysis module which converts the data to three output displays: range-time-intensity, Doppler-time-intensity, and range-Doppler-intensity. The method of analysis is the so-called two-frequency correlation function. Calculating the two-frequency correlation function involves performing the cross-correlation of the received echo and a frequency/time-shifted version of the transmitted pulse. A frequency/time-shifted pulse would consist of a time-delayed pulse multiplied by a complex exponential corresponding to a shift in frequency in the frequency domain. The magnitude squared value of the two-frequency correlation function is an indication of the amount of power at a given range and Doppler. A reasonable interval of frequency and time shifts are used in order to sweep out the Doppler-range search plane. Values of the magnitude-squared two-frequency correlation function can be (incoherently) averaged over many periods before recording them to storage.

The data are written to disk in either raw or processed (analyzed) form. The data records are time stamped with GPS time. At any point, the data may be backed up to recordable compact disk for economical archiving. The computer runs the FreeBSD operating system and is fully operable from the internet. In principle, the radar may be run unattended for months. The system is broadly configurable over the internet and diagnostics can be run from afar when visual cues to the instrument's state are not available. The entire system occupies a total of six 20-RU standard 19" racks. Currently, shock-mounted rack containers are being used. The entire system consumes about 13 kW at full duty cycle. Power is provided by means of four 5-kW diesel generators. The extra generation capacity may be used to power other components, such as lights and air conditioning/heating for the radar shelter building (currently a 16' [4.9 m] utility trailer).

3. Digital Ionosonde

The digital ionosonde is a simple HF radar. It consists of a transmitter, a receiver, a controlling computer and three antennas. All electronics (everything except the antennas) fits in a standard 19" rack-mount chassis, and is approximately 10.5" (26.7 cm) high. The controlling computer uses the method of direct digital synthesis (DDS) to create the carrier frequency. The output frequency is in the range 1-20 MHz, arranged in up to 400 linear or logarithmic steps per sweep. The pulse shape is either a single rectangular pulse of 40 uS length or a 13-bit Barker code of 520 uS length. The output power is 600 W PEP. Pulse repetition rate is either 20 pps or 40 pps. The slower rate will allow a higher maximum observable range. The pulses can be triggered by the internal timer or by external GPS timing.

A single delta antenna is used for transmission. It consists of a 50' (15.2 m)-tall equilateral triangle. During transmission, the wires forming the base of the triangle are excited and in turn excite traveling current waves in the two upper sides of the triangle. As the current waves propagate upwards along the two upper sides of the antenna, they radiate their energy into the surrounding space. The upper sides of the triangle are angled such that the radiation from the traveling waves interfere constructively in the vertical direction. Any remaining non-radiated energy in the current waves is dissipated in load resistors at the top of the antenna.

The signal is reflected from the ionosphere and the return signal is detected by two orthogonal deltas. The receiver mixes the signals to baseband in two stages and the in-phase and quadrature-phase signals are sampled. The signals are correlated with the Barker code if the Barker code is being used and then recorded on the hard drive of the computer. Multiple pulses can be averaged coherently in order to improve the signal to noise ratio.

The ionosonde software allows the operation of the system to be automated. The system can be programmed with a series of operational modes to be cycled through each day. One operational mode may consist of pulse type, amount of coherent averaging, type of data display, detection threshold, height range, gain control, and table of frequencies to be transmitted. This automated daily scheduling is useful for meeting the time and frequency restrictions inherent in one's frequency license. The data can be automatically backed up to tape drive on a daily basis, allowing the system to run unattended for months at a time.

4. VLF Receiving System

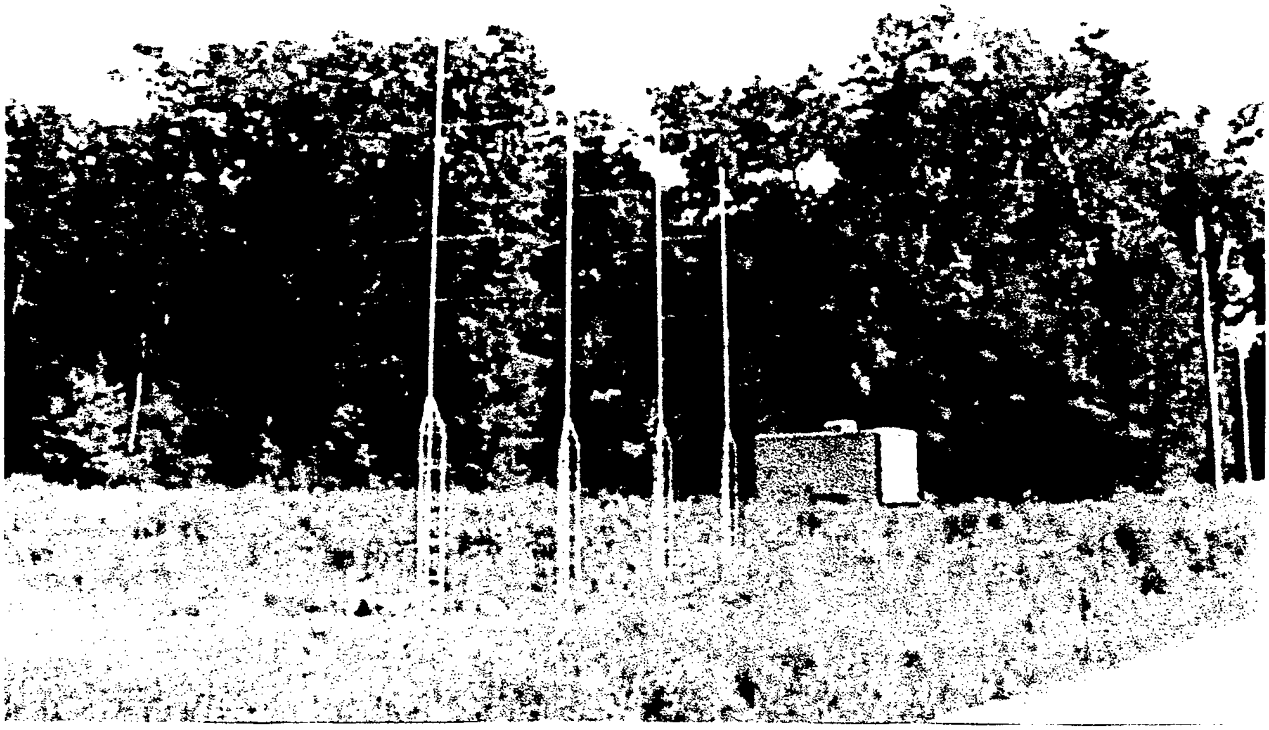
The VLF receiver system performs passive observations of VLF emissions. It consists of an antenna, a receiver and a data acquisition system. The antenna is a loop antenna of 6 turns. It is an equilateral triangle 20' feet in height. The antenna can be hung from existing structures, or a collapsible radio tower mast can be used as a support. A second antenna can be hung at right angles to the first in order to provide measurement of the orthogonal component of the fields. The lossy resistance of the antenna is 1 ohm. The antenna receiver is matched to the lossy resistance of the antenna for maximum power transfer for given excitation field.

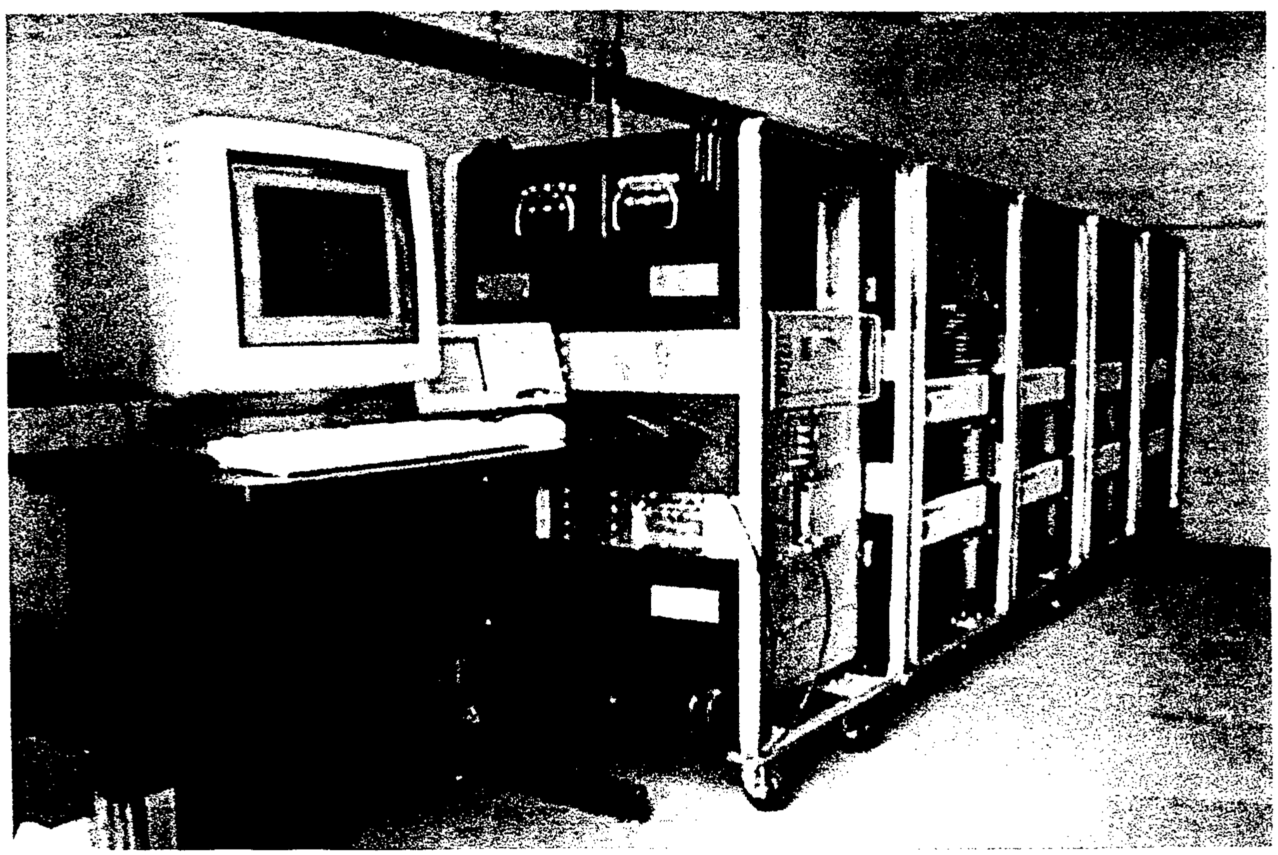
The receiver consists of a differential common-base input stage. The amplifier is biased so that the input impedance is 520 ohms. A ferrite pot core transformer is used to reduce the input impedance to 1 ohm. The second stage is a differential common-emitter. The output of the differential common-emitter is fed into an active filter. The active filter removes frequency content below 1 kHz and provides 20 dB of gain in addition to the two amplifier stages. The output of the active filter can be viewed on an oscilloscope. Alternatively, a second filter stage may be added to provide anit-aliasing filtering for sampling purposes and up to another 20 dB of gain.

The digitizer is a PCMCIA card provided by National Instruments. C Language routines have been written to stream digitized raw time signals to the hard disk at continuous rates of up to 100 kHz. Given the finite transition width of the anti-aliasing filter, 35 kHz is a typical useful upper frequency for observations. If one wishes to sample for long periods of time, the signals can be saved to Jaz media. The sampling needs to be interrupted for a few seconds every 90 minutes while the Jaz cartridge is replaced. Time signals can be parsed and processed in MATLAB for subsequent analysis. Currently the data acquisition is only designed for one channel. Two channels can be recorded by slowing the sampling rate and possibly translating the desired frequencies of interest into a lower frequency band.

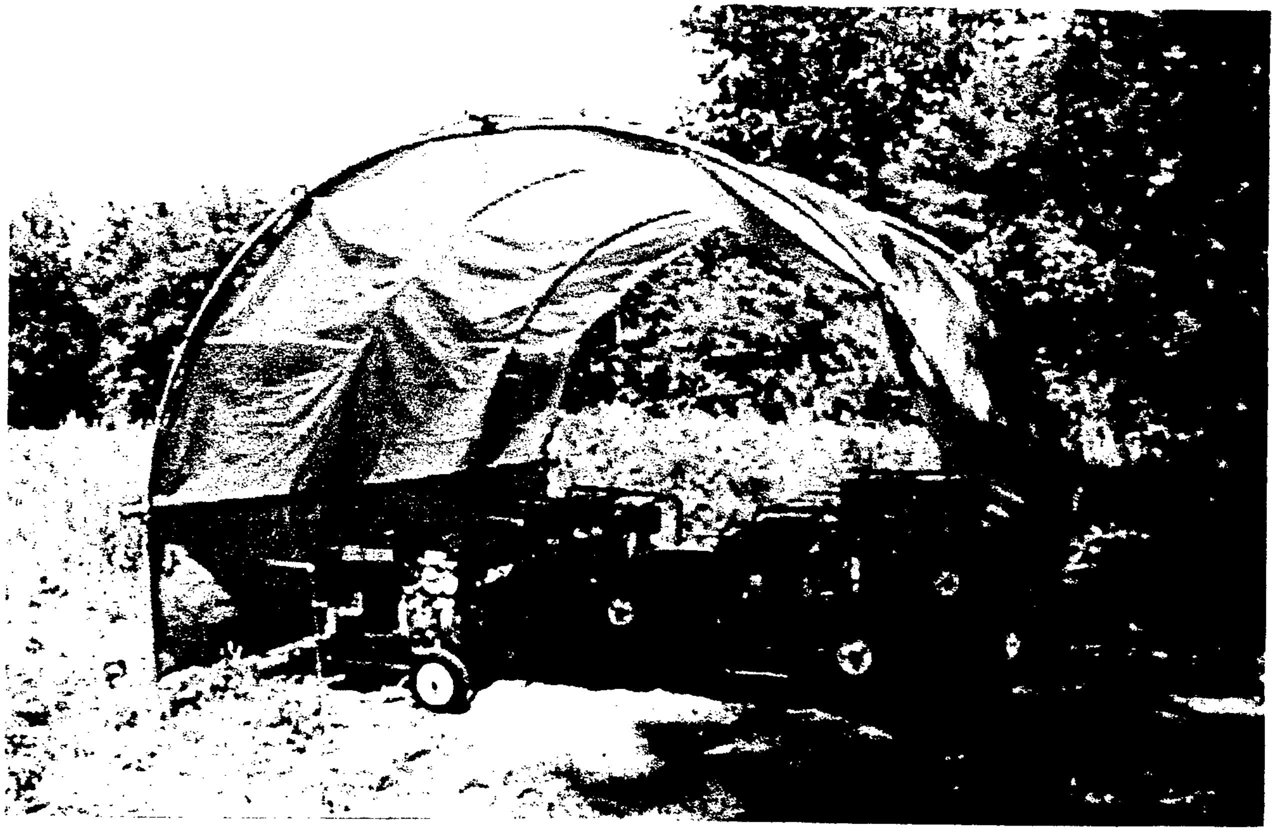
5. IRIS Lab

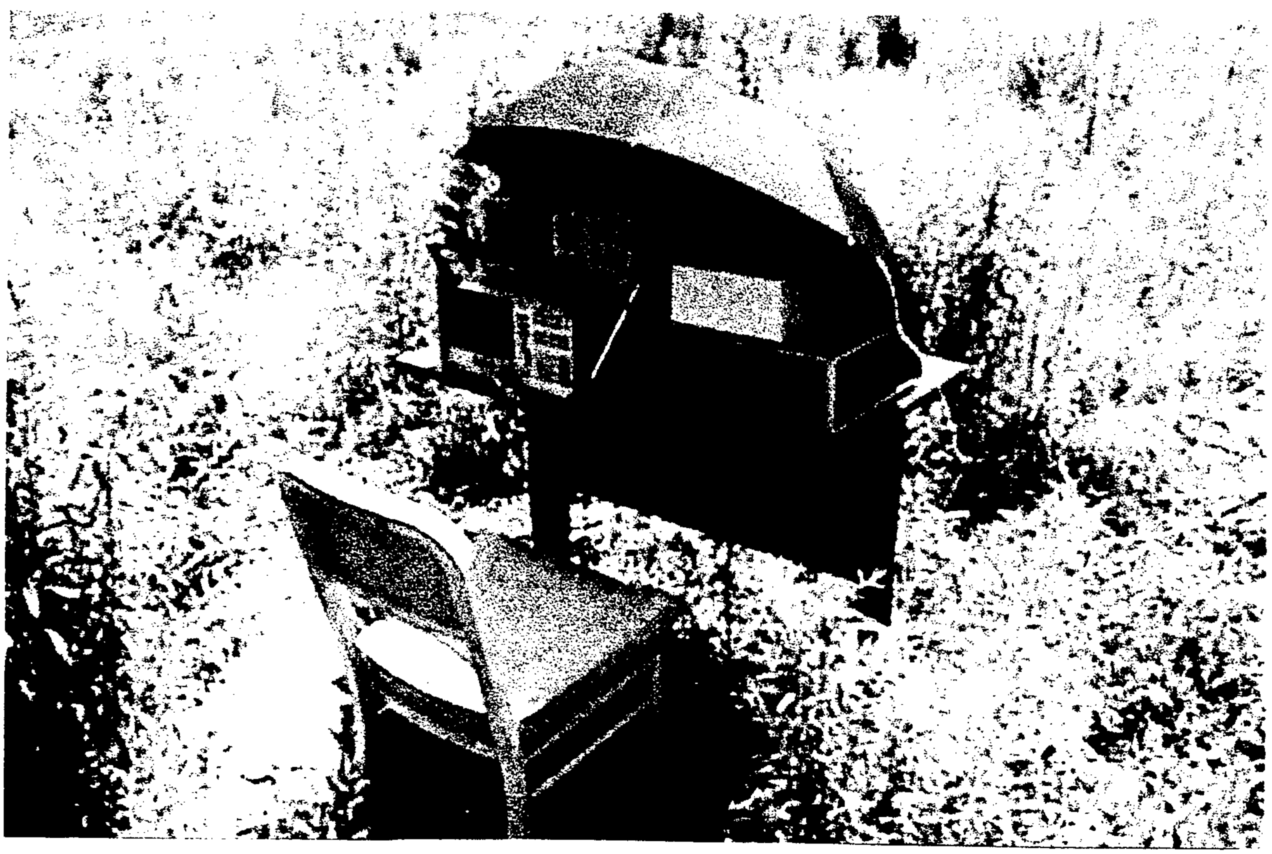
Ionospheric Radar Integrated System (IRIS) Lab is located at NW 14-255 of the headquarters of the Plasma Science and Fusion Center on campus. IRIS has been electrically tested and assembled at the lab (see attached picture). The radar transmitters can be used as new RF (radio-frequency) sources for our laboratory experiments at our Versatile Toroidal Facility (VTF) Lab at NW 21-122.



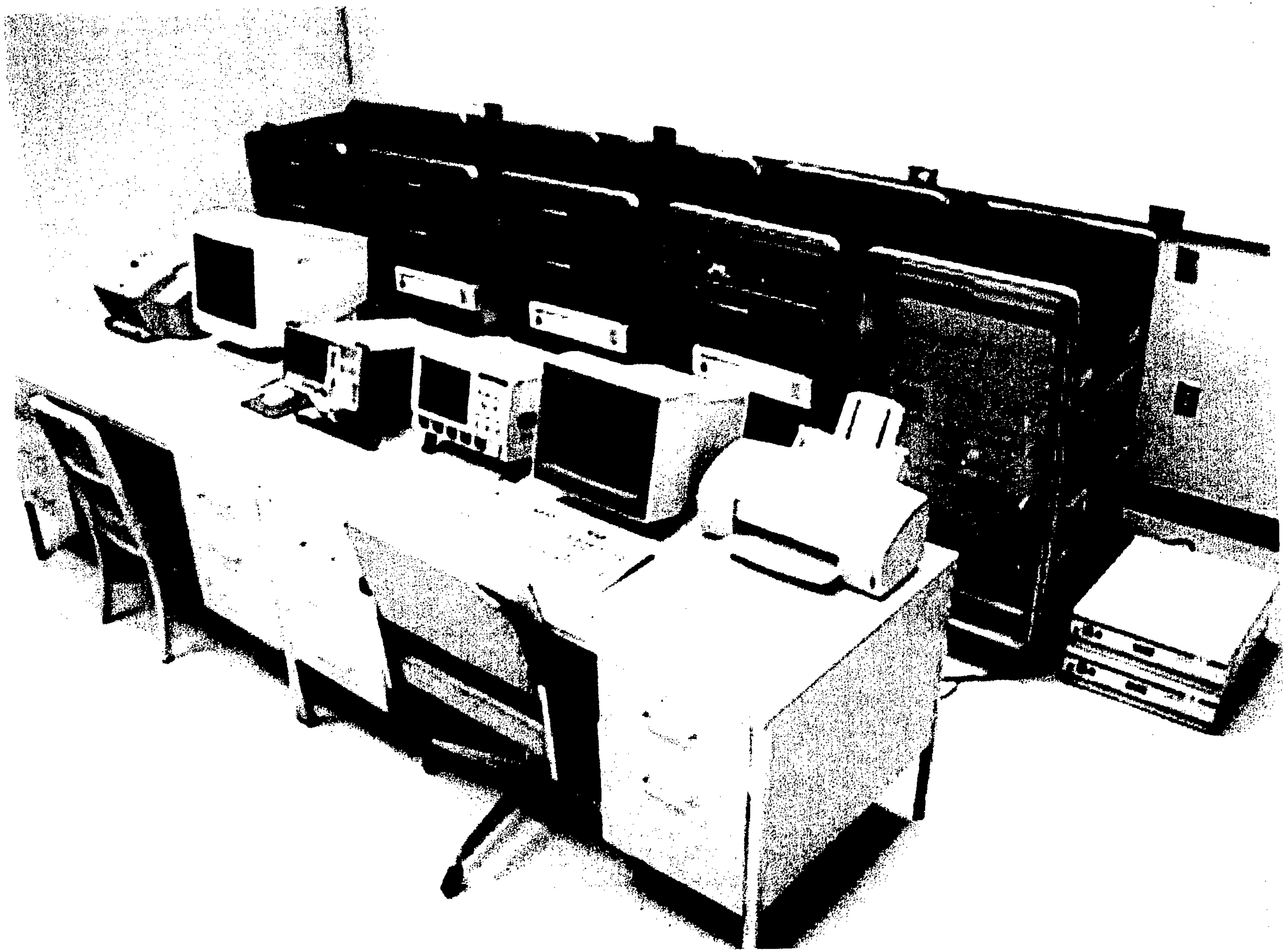


(Above): A linear array of four 4-element Yagi antennas was set up at Millstone Hill, Massachusetts to test IRIS's portable HF/VHF radar during June 12-July 21, 2000. The utility trailer carried the radar transmitters and the data acquisition systems. (Bottom): The four radar transmitters and the data acquisition system were operated inside the trailer.





(Above): Four diesel generators were used to power the radar transmitters.
(Bottom): The VLF receiving system was also tested at Millstone Hill together with the portable HF/VHF radar in July, 2000.



Testing of portable radar system in IRIS Lab (NW16-255).