2.3.2 Field Links

The field transmitter/receiver link is composed of antennas and propagation losses. At Oxford, the transmitter antennas were located atop the Engineering building at the University of Mississippi and on an existing tower approximately 7 miles North of the University. These sites were selected based on "Okamura-rural-open" computer modeling to provide a variety of propagation conditions and significant areas of coverage overlap (simulcast areas) and non-overlap (single transmitter areas). The transmit antennas have omnidirectional horizontal coverage with approximately 6 dB of gain. The receive antennas were 860-930 MHz "pig-tails" with an omnidirectional horizontal coverage pattern and approximately 3 dB of gain. These receive antennas were mounted along the center-line of the mobile laboratory van.

2.4 Spectral Occupancy Measurements

Classical scanning spectrum analyzers (either an HP 8567A or an Anritsu 2601B) were used to determine the magnitude of the intermodulation products and spread of power. The analyzer also provided a simple means of monitoring signal levels, particularly when locating equi-signal points in the overlap areas. This was accomplished by silencing different carriers in each of the transmitters and searching for equality of the non-simulcast carriers (see Fig. 19). The only special arrangement needed was the addition of a low noise pre-amplifier during the field trials, to compensate for the relatively small signals received at the edges of the coverage area.

2.5 Frequency Domain Analysis

Spectrum analysis of single baud intervals is required to determine the detectability of an MCM signal. While the scanning spectrum analyzer, described above, gives excellent accuracy in measuring the long-term average frequency components of the signal, it can not provide the spectral "snapshot" of a single symbol needed to determine if detection is possible -- the sweep speed is too slow. The Fast Fourier Transform (FFT) capability, provided by high end digital oscilloscopes, supplies this capability. In the experiments at hand, a LeCroy 9400A oscilloscope was used to provide FFT and Frequency Domain Eye Diagrams ("FDED") of received symbols. The details of this use of the FFT are provided in Appendices B and C. A modified 930 MHz receiver (normally used for monitoring or control links) was used to provide the amplification needed to interface the weak antenna signals to the FFT analyzer. The second local oscillator was externally supplied by a high stability signal generator and the output of the second mixer was sent directly to the analyzer. This "second IF" was set to a relatively low frequency (10's of kilohertz for most of the measurements) although some experimental runs were made with higher 2nd IF frequencies in order to obtain experience with sub-Nyquist sampling (which worked very well).

An eye diagram for a typical serial communication system consists of a plot of the output of the demodulator versus time, accumulated over a number of symbols. An FDED is the accumulation of the output of the FFT algorithm over a number of symbols. Since each MCM symbol consists of a number of individual subchannels, displaced in frequency, a FDED presents amplitude versus frequency (rather than time), accumulated over a number of multicarrier symbols. For these tests the FDED were the principal result -- they are the basis for concluding that successful demodulation of the MCM signals could be accomplished.

Ongoing research will determine whether an analog demodulator (a band of filters followed by detectors) or a digital demodulator (a computer based implementation of a frequency domain analysis) is the ultimate implementation of the MCM receiver. Cost and power requirements will be the ultimate determinants in this decision. What has been established is that the task is possible.

2.6 Synchronization Equipment

It was necessary to provide for the synchronization of the data streams at the two transmitter sites and a synchronized baud rate clock at the mobile laboratory. A separate control link transmitter, operating at 930.1 MHz, was used for this purpose. One of the control signals, provided by the simulcast controller associated with the control link, operated a reset line on the data generator. The data link capability of the controller carried a square wave with transitions occurring at the baud rate. Edge detection and a one shot multi-vibrator (as a pulse generator) provided a sufficient length clock pulse for clocking the data generators at the transmitter sites and the trigger circuit of the FFT analyzer in the mobile laboratory.

2.7 Equipment Interconnection

All of the components described in this section were brought together to perform the Oxford field tests. Figure 20 shows the overall arrangement, with the Control Point at

UMCT broadcasting both control and data signals to the Mobile Laboratory and just control signals to the Remote Site. Figure 21 portrays the details of the equipment at the Control Point. The Function Generator provides a square wave to clock symbol transitions. Since the data generator circuits responded to both negative and positive going transitions, the cyclic rate of the Function Generator was set to half the desired baud rate. The Anti-Glitch and SYC circuitry, which are part of a standard simulcast control link arrangement, took responsibility for reliably distributing this clock signal. The SYC unit allows a PC console to control remote transmitters. In these tests the main use made of this capability was the initialization of the data generator circuits. The Link Transmitter (TX) translated the control signals to 930.1 MHz and boosted the power to the levels needed to reliably work with the low gain Mobile Lab link receiver antenna.

The same SYC output that controlled the Remote Site and the Mobile Laboratory also was patched, at baseband, to the Transmitter Controller (TXC) circuits associated with the Control Point Data Generator. The F0 control lead from the TXC (normally used for changing frequencies in an operational system) was used to initialize the Data Generator. The Data Generator produced four parallel streams of pseudo-random data to modulate the four Transmitters (TXs). All four TXs were connected, via circulators (indicated by the small circles) to the combiner, and thus to the antenna. (The circulators and the combiner can also be seen in Figure 3).

The Remote Site, as shown in Figure 22, had the same TXC, Data Generator, TX, Circulator/Combiner and antenna arrangement. The only difference was the use of a Link Receiver (RX) to drive the TXC.

The Mobile Laboratory, shown in Figure 23, had three independent receive antennae. The upper antenna fed a typical paging monitor receiver to act as a front-end for the FFT Analyzer by translating the signal level and signal frequency to ranges that were compatible with the LeCroy 9400A. A real-world NWN portable terminal would contain circuitry to recover the baud clock from the data stream. For these tests it was expeditious to simply add a Link Receiver and Transmitter Controller (TXC) to deliver the clock signal to the FFT Analyzer. The lower-most antenna in Figure 23 fed the Low Noise Block (LNB) to drive the Spectrum Analyzer.

3.0 TEST PROCEDURES

Mtel's experimental testing was designed to evaluate two items:

- The ability to generate Multi-Carrier Modulation signals conforming to the proposed spectral occupancy mask.
- The feasibility of successfully detecting Multi-Carrier Modulation signals in a simulcast environment.

These test procedures were designed to facilitate that evaluation.

3.1 Spectral Occupancy

Obtaining the required accuracy in measuring the average spectral occupancy is best accomplished with a classic swept filter spectrum analyzer. The bandwidth of the filter is set to 300 Hertz, the figure commonly accepted by the FCC for measurements close to the nominal carrier frequency. Attenuators were used to reduce the transmitter output to levels compatible with the spectrum analyzer.

Two measurements were made. In the first, all of the carriers are keyed "ON," adjusted for approximately equal amplitude, and the level of the carrier peaks are noted. When N carriers are present, the effective level of the "unmodulated carrier" is 10 log(N) dB above the level of the individual carriers. The second measurement has all of the carriers modulated with a pseudo-random sequence generated at the proposed baud rate (*i.e.*, 3000 baud for NWN). The level of the sidebands are noted and compared with the mask limits.

3.2 Simulcast Detectability

The essence of detectability for Multi-Carrier Modulation techniques, whether Multicarrier On Off Keying ("MOOK") or Permutation Frequency Shift Keying (PFSK), is the ease with which energy radiated for one baud interval, at one of the carrier frequencies, can be reliably detected. For these tests, the Fast Fourier Transform (FFT) capabilities of a high performance digital oscilloscope, adjusted to sample one baud interval, were used to measure the energy at each of the carrier frequencies. By repeating this measurement for a number of random symbols, instances of carrier ON and carrier OFF for each carrier frequency will be captured. Carrier OFF instances give a measure of the noise, interference, and intermodulation energy present at a carrier location. Carrier ON instances add the energy of the carrier. The comparison of carrier "ON" and carrier "OFF" instances gives the energy contrast, and a measure of the detectability of the signal. These comparisons are most easily made if the plots of energy versus frequency for a number of random symbols are superimposed, giving a Frequency Domain Eye Diagram ("FDED"). A successful test yields an FDED with "eyes" that are open, indicating adequate energy contrast for successful detection.

4.0 CURRENT RESULTS

The measurements were positive beyond Mtel's original expectations. Intermodulation poroducts were not a problem. The proposed emission mask requirements were satisfied and MOOK symbols were successfully received.

4.1 Spectrum Analysis Results

Mtel's prototype MCM transmitter, assembled from components not designed for this purpose, completely satisfied the proposed mask. The sidebands were more than 70 dB down at the edges of the 50 kHz band. Figure 24 shows the spectral occupancy of the unmodulated carriers. The "hole" in the center of the constellation is a space left for a possible pilot carrier. The discrete peaks seen in the sidebands are residual intermodulation products of the unmodulated carriers. When the carriers were modulated the discrete line spectra disappeared and the sideband energy decreased to the levels seen in Figure 25.

4.2 Simulcast Detectability Results

The Frequency Domain Eye Diagrams ("FDEDs") show that there is sufficient energy contrast to allow successful demodulation. Figures 26, 27, and 28, taken at various points around the test site in Oxford, show distinctly open "eyes." These eyes indicate that a receiver that was custom built for this purpose (rather than a general purpose oscilloscope with an FFT capability) should have no problem properly detecting the signals.

5.0 CONCLUSIONS

This initial experiment has proven the following points:

- MCM is a commercially viable modulation scheme.
- MCM can be used to implement either permutation modulation or multitone on-off keying modulation.
- Baud rates as high as 4.8 kbaud are theoretically possible in a simulcast environment.
- Baud rates up to 3 kbaud are definitely practical in a simulcast environment.
- Data rates up to 24 kbps are practical and higher data rates are possible using MCM in a simulcast environment.
- There is an alternative to the use of class A amplifiers in transmitter design -- combined class C amplifiers.
- At least one approach to receiver design can be implemented. DSP is technically feasible for receiving and decoding MCM (other receiver methods continue to be investigated).

Based on the above conclusions, Mtel has proven that NWN is technically feasible and practical. Additional experimentation will further refine NWN.

6.0 MTEL'S ONGOING TEST PROGRAM

As part of its continuing comprehensive validation program, Mtel will return to its seven stage testing sequence to characterize and evaluate the various aspects of the NWN environment. Mtel's research and modeling to date have validated the NWN MCM techniques, demonstrating that there are no insurmountable obstacles to implementing Mtel's NWN system as originally envisioned. Mtel's field experimentation under its recently granted experimental license, in conjunction with supplemental laboratory development work on the modulation schemes and the portable devices, includes:

- ***Stage 1 - Transmitter Installation.*** Install and optimize three transmitters in and around Oxford, MS.
- ***Stage 2 - Coverage Testing.*** Characterize coverage from each transmitter individually and determine signal strength of each to approximately 5 μv/m using unmodulated CW.
- ***Stage 3 - Determination of Simulcast Characteristics.*** Using unmodulated CW, determine characteristics of overlap areas for transmitters in pairs and as a group.
- ***Stage 4 - Modulation Testing.*** Using modulated carriers, repeat stage 3 tests to test for distortion and SINAD at edges of coverage and in overlap areas.
- ***Stage 5 - Multitone Modulation Testing.*** Using multiple tones, repeat stage 3 tests to further refine characteristics of simulcast signal in a manner more closely related to actual system modulation.
- ***Stage 6 - Return Path Verification.*** Using a single receiver and a 1-2 watt portable transmitter, determine the capability of the return path, including absolute range and building penetration.
- ***Stage 7 - Return Path Verification for Multiple Receivers.*** Using multiple receivers, multiple 1-2 watt transmitters, and a prototype subcontroller, ascertain the ability to receive several signals at one time and determine capture effects.

Because Mtel had to deviate from its originally planned schedule, Mtel believes that testing through stage 2 will be completed within 45 days, testing through stage 4 in 75 days, testing through stage 5 in 105 days, testing through stage 6 in 135 days, and final testing through the end of stage 7 in 165 days. Additional experimentation will involve further applications of the MCM modulation schemes under consideration for NWN. Mtel intends to submit experimental progress reports to keep the FCC accurately apprised of its ongoing progress as it reaches appropriate benchmarks.

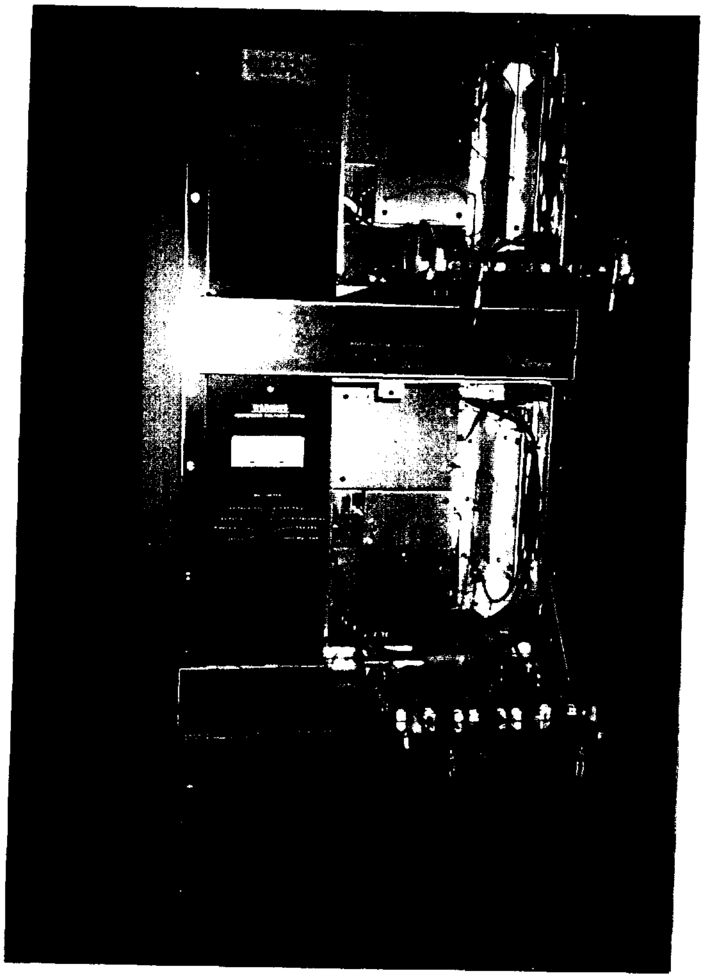

FIG. 1 FRONT OF MCM TRANSMITTER

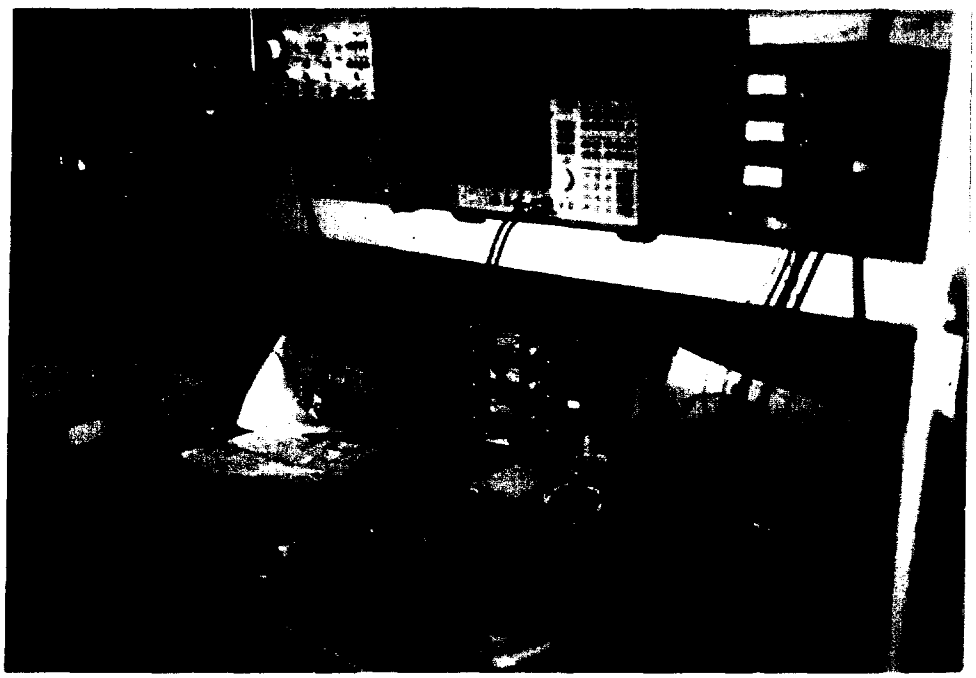

FIG. 2 TRANSMITTER CONTROL (QUINCY, IL)

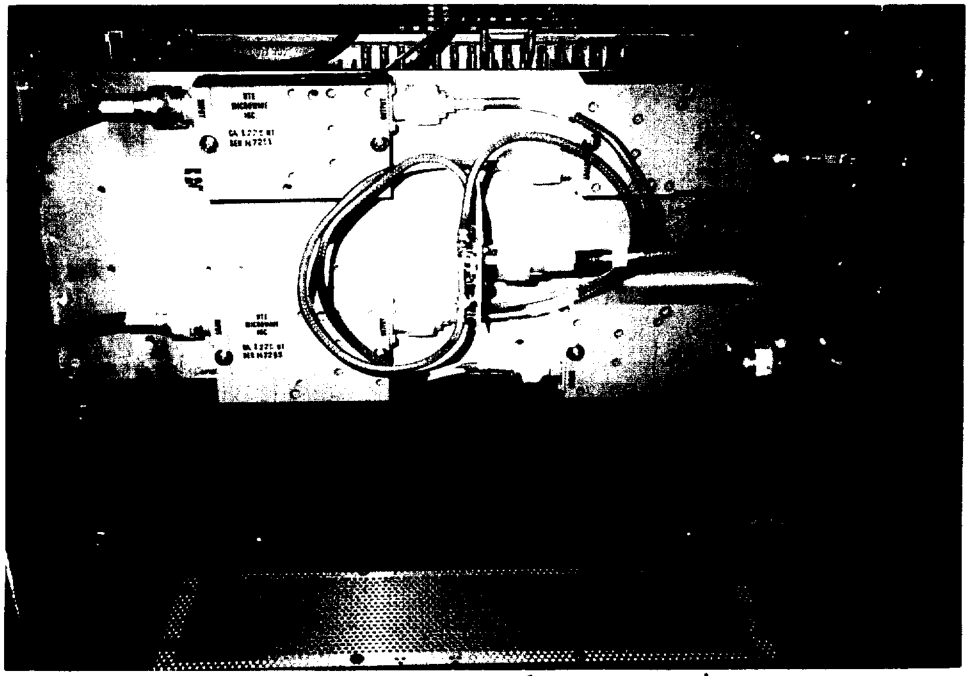

FIG. 3 DETAIL OF COMBINER (QUINCY, IL)

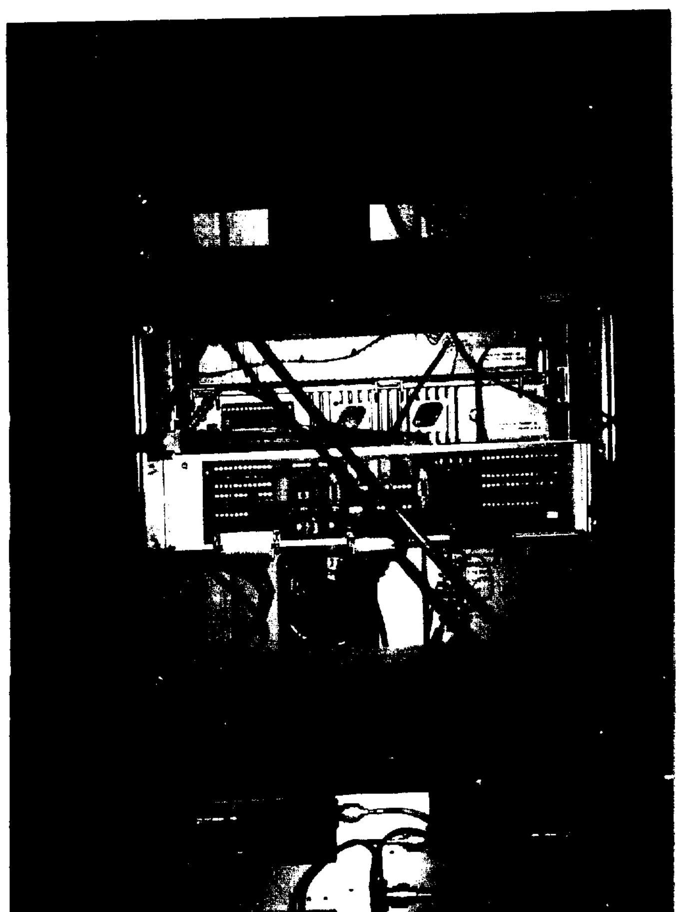

FIG. 4 REAR OF MCM TRANSMITTER (QUINCY, IL)

FIG. 5 LABORATORY SET UP (QUINCY, IL)

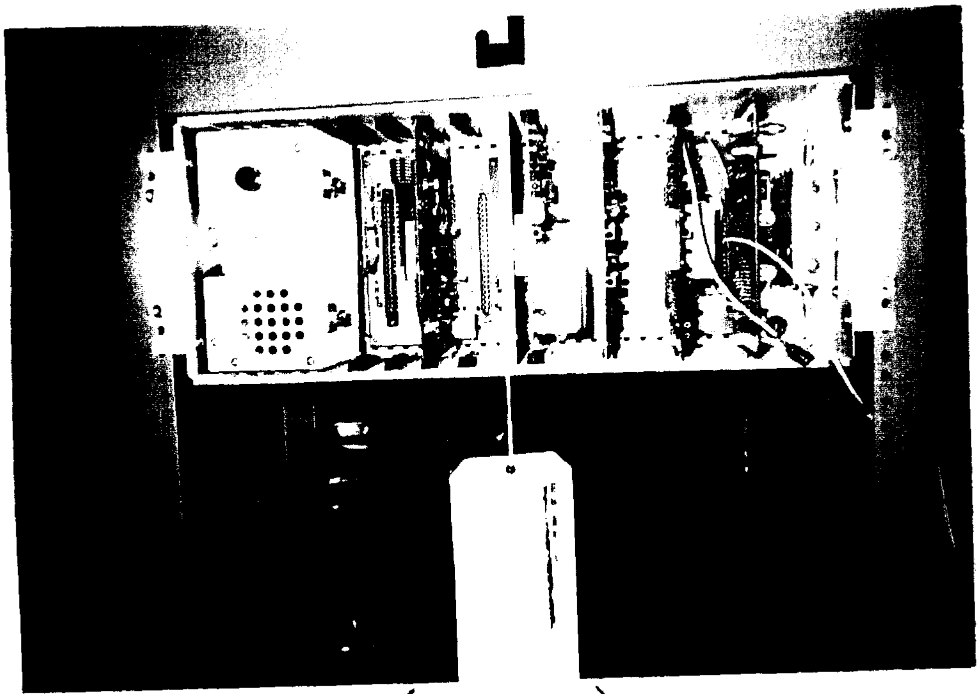

FIG. 6 RECEIVER (QUINCY, IL)

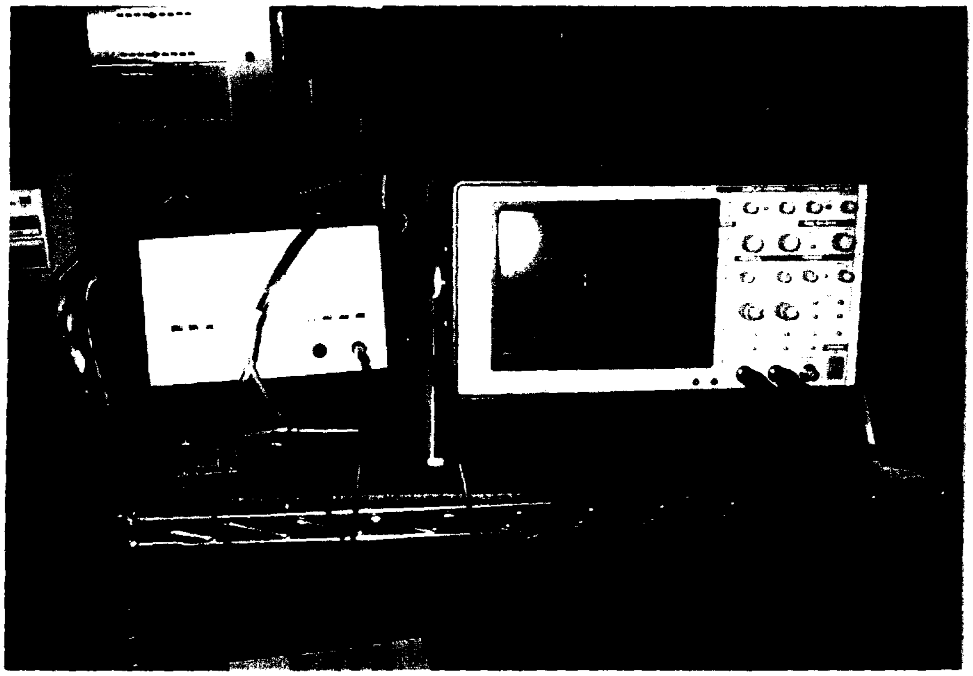

FIG. 7 FFT ANALYZER (QUINCY, IL)

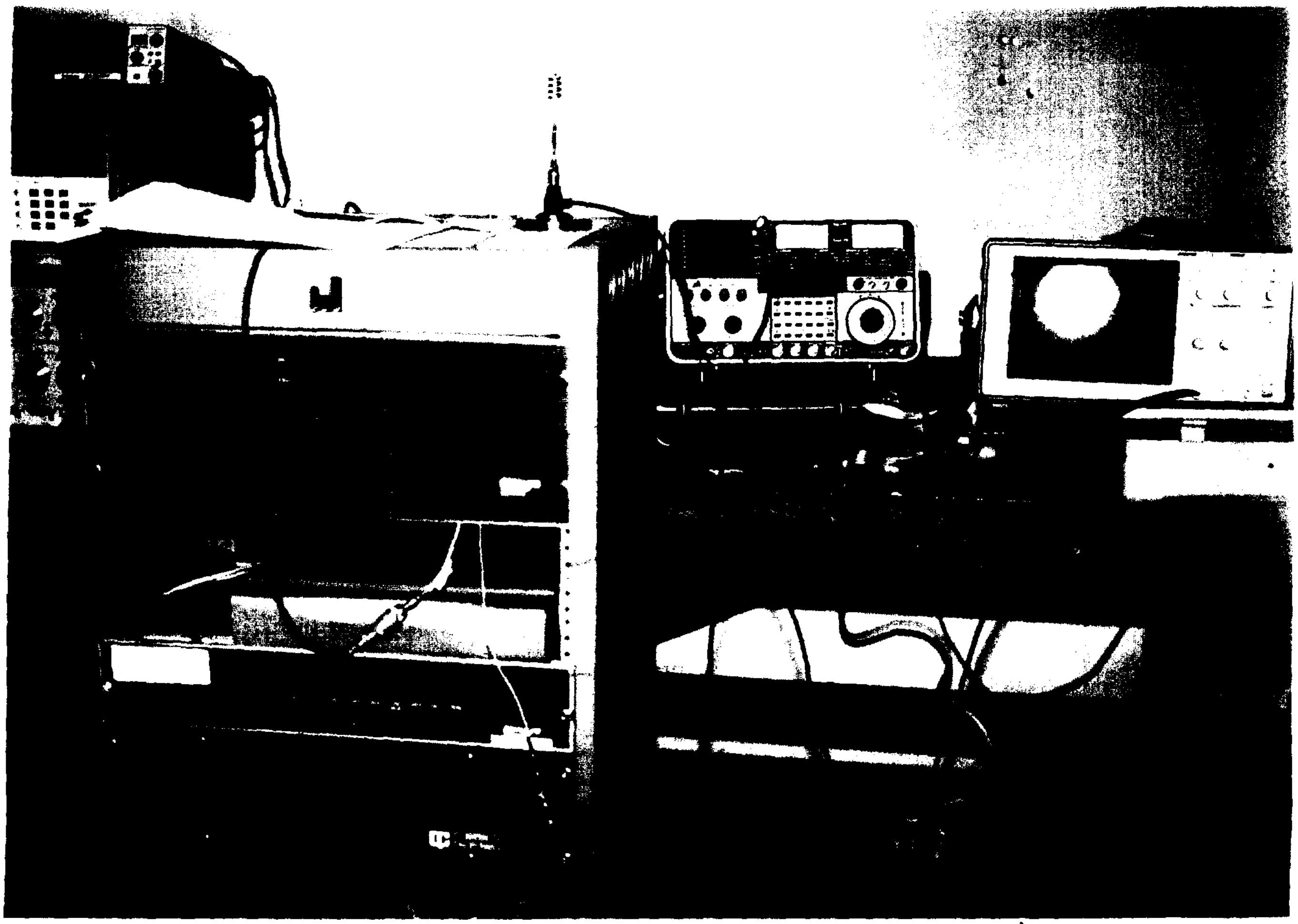

FIG. 8 LABORATORY RECEIVER SET UP (OXFORD, MS)

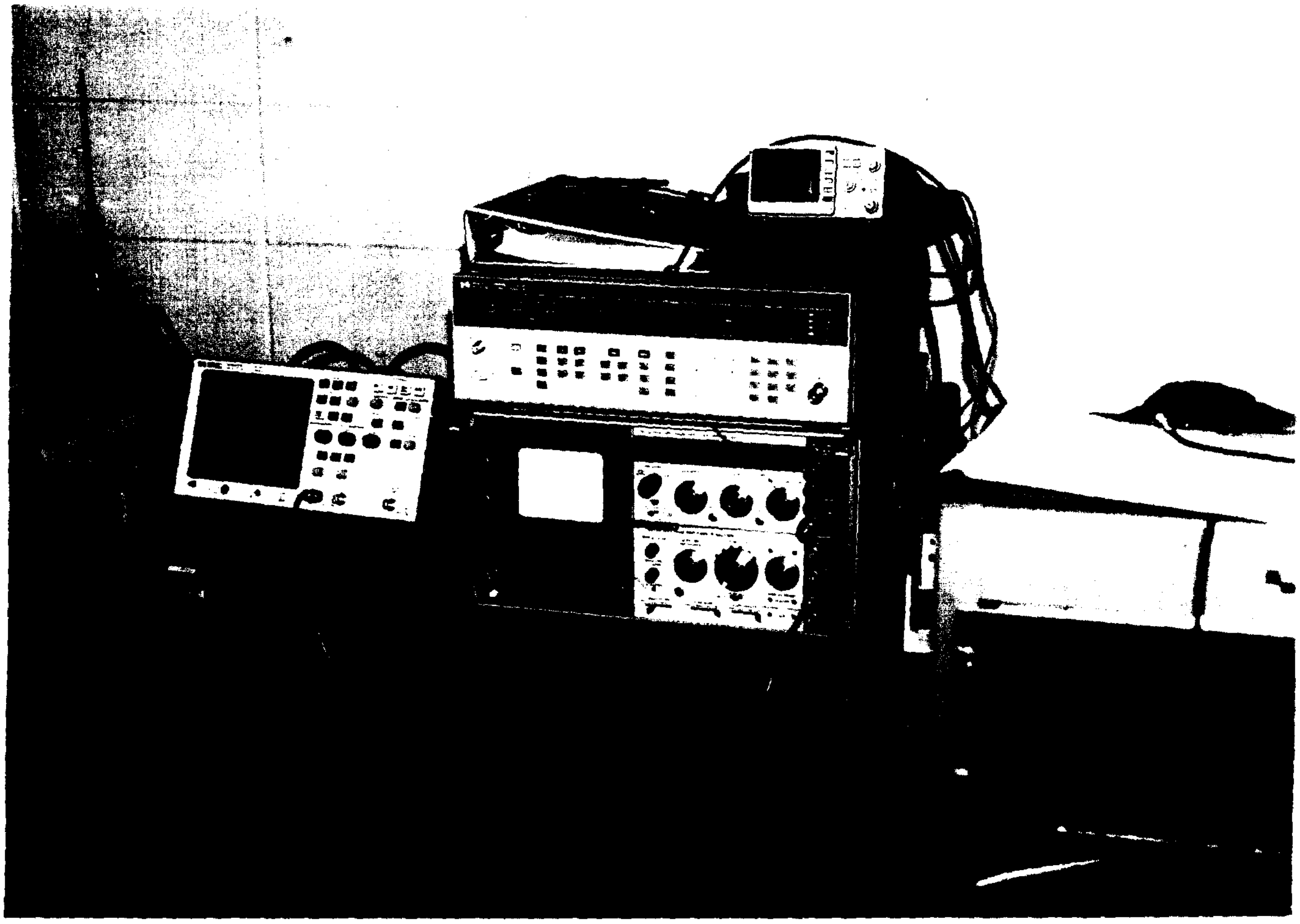

FIG. 9 LABORATORY RECEIVER SET UP (OXFORD, MS)

FIG. 10 MOBILE RECEIVER (OXFORD, MS)

FIG. 11 MOBILE RECEIVER DETAIL (OXFORD, MS)

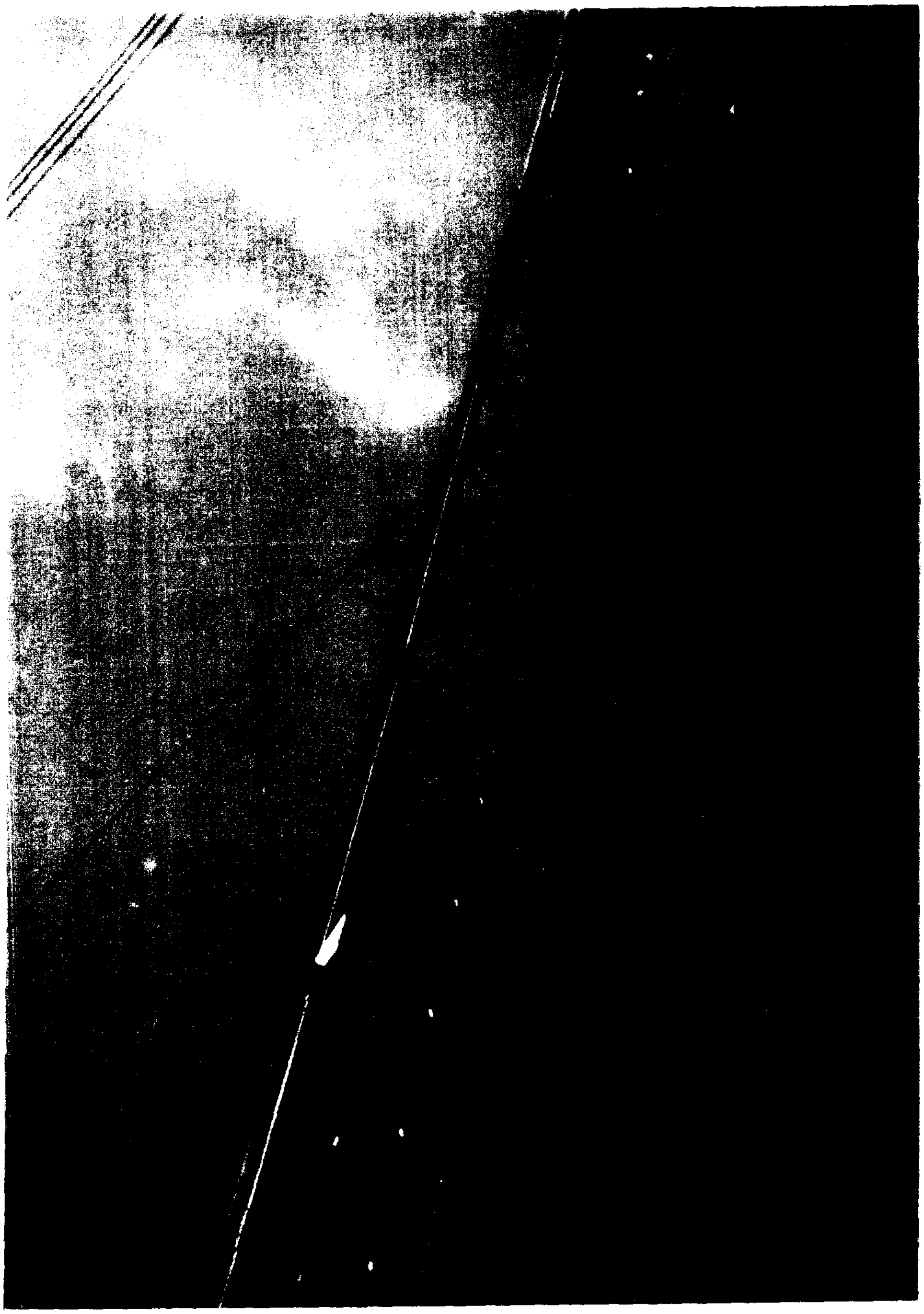

FIG. 12 ABBEVILLE ANTENNA (OXFORD, MS)

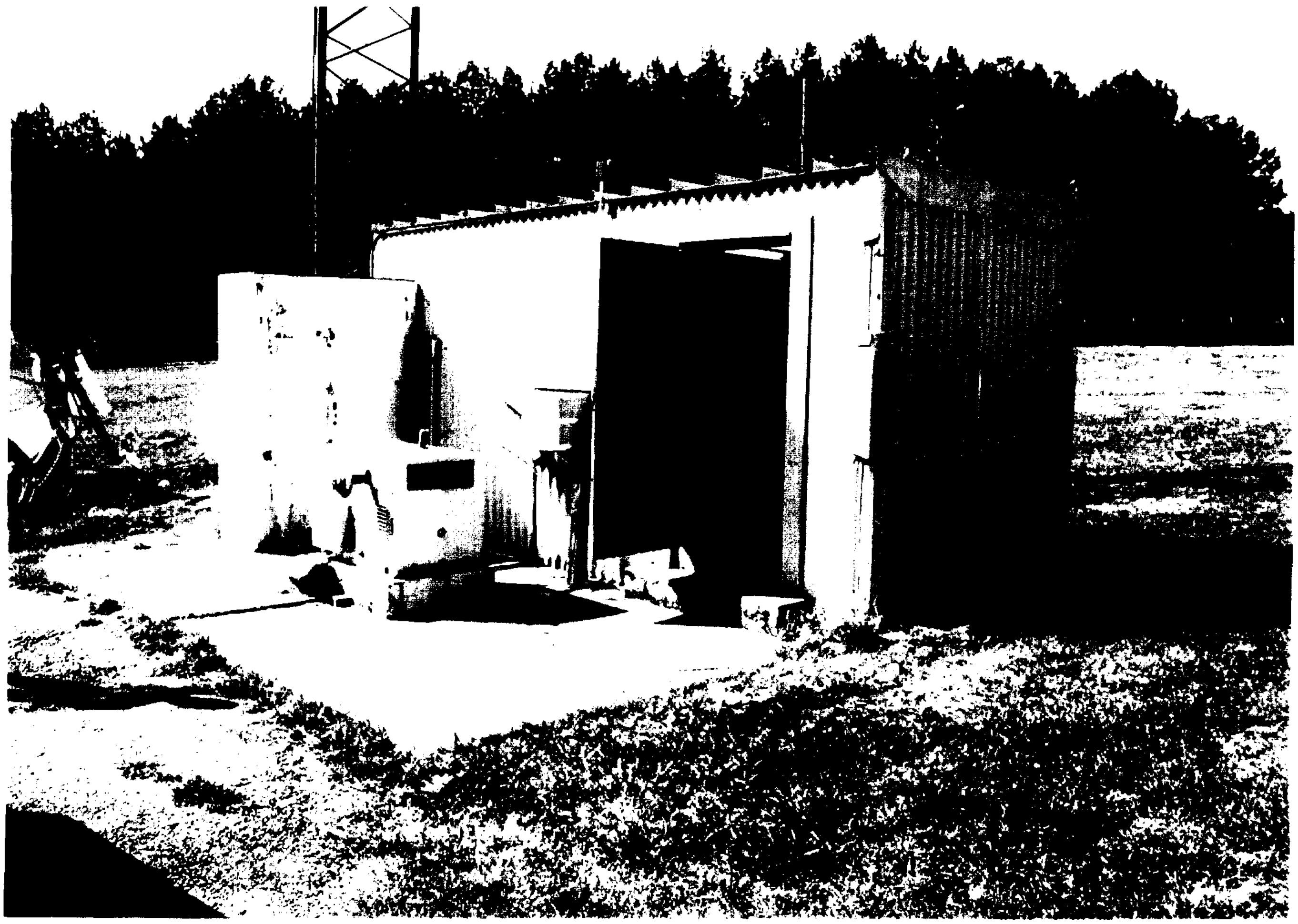

FIG. 13 ABBEVILLE TRANSMITTER CONTROL (OXFORD, MS)

FIG. 14 ABBEVILLE TRANSMITTER (FRONT) (OXFORD, MS)

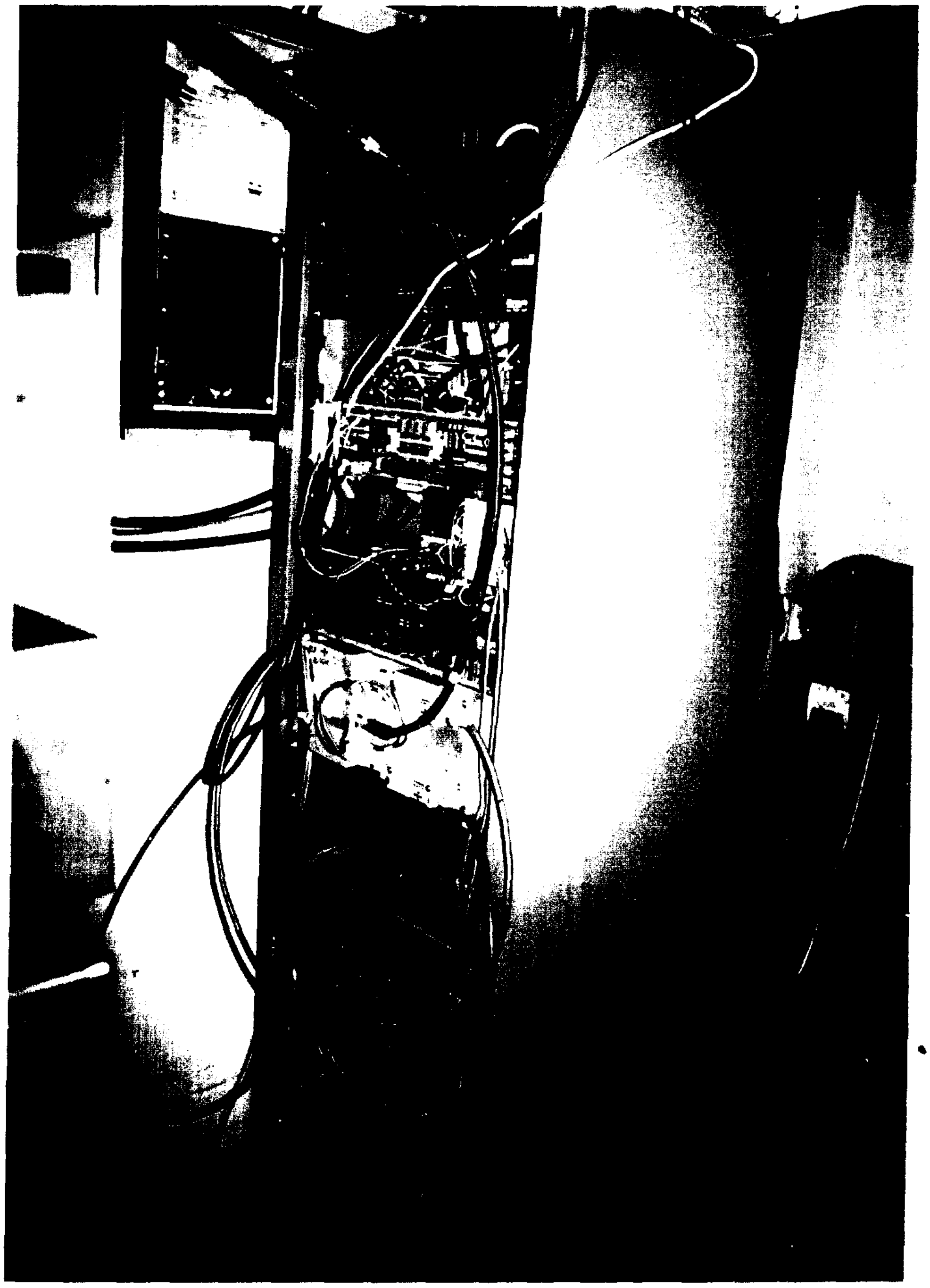

FIG. 15 ABBEVILLE TRANSMITTER (BACK) (OXFORD, MS)

FIG. 16 UM TRANSMITTER ANTENNA (OXFORD, MS)

FIG. 17 UM TRANSMITTER (OXFORD, MS)

FIG. 18 UM TRANSMITTER AND CONTROL EQUIPMENT (OXFORD, MS)