CONCLUSION

For the reasons set forth above, Mtel respectfully requests that the Commission promptly ratify its Tentative Decision and grant Mtel a final Pioneer's Preference with respect to its Nationwide Wireless Network Service.

Respectfully Submitted,

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January 8, 1993

CERTIFICATE OF SERVICE

I hereby certify that on this 8th day of January, 1993, I caused copies of the foregoing "Reply of Mtel to 900 MHz Narrowband PCS Pioneer's Preference Comments" to be mailed via first-class postage prepaid mail to the following:

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TAB A

Progress Report On Development of the Nationwide Wireless Network Service

Mobile Telecommunication Technologies Corporation

January 8, 1993

EXECUTIVE SUMMARY

In recognition of Mtel's efforts to develop the Nationwide Wireless Network ("NWN") Service, the Commission tentatively awarded Mtel a Pioneer's Preference in an order released on August 14, 1992.[1] In this *Tentative Decision*, the Commission concluded that Mtel "merits a preference for its having developed and demonstrated significantly improved bit transmission rates, submitted an innovative proposal based upon these improved rates that will result in new service functionalities being available to consumers, and developed the technology necessary to implement its proposal."[2] The FCC also noted that "Mtel has developed and preliminarily demonstrated what it has named "Multi-Carrier Modulation" (MCM) technology . . . that provides the foundation for Mtel's proposal to provide a wireless network offering a broad range of two-way data communications services, acknowledgment paging, encryption, error correction, and general determination of subscriber location."[3]

The Commission's tentative award did not interupt Mtel's continued pursuit of the implementation of NWN. This *Second Report on Field Tests of the Nationwide Wireless Network Service* details Mtel's progress since its June 29, 1992, experimental report, on a number of fronts, towards commercial deployment of NWN. As discussed below, the report describes further field tests of the NWN multicarrier modulation techniques, additional

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[1] *Amendment of the Commission's Rules to Establish New Personal Communications Services*, 7 FCC Rcd 5676 (1992) ["*Tentative Decision*"].

[2] *Tentative Decision*, 7 FCC Rcd at 5735.

[3] *Id.*

demand research provided by Arthur D. Little ("ADL"), and describes Mtel's continuing plans for ensuring the successful commercial deployment of NWN.

Attachment 1 to this report details Mtel's simulcast transmission of messages at a data transmission rate of *24,000 bits per second with a commercially acceptable error rate without forward error correction.* Specifically, Mtel's most recent tests utilized:

- ***4-out-of-8 Permutation Frequency Shift Keying.*** Using a multi-carrier modulation technique known as permutation frequency shift keying ("PFSK"), Mtel was able to achieve sustained, commercially acceptable service at 6 bits per symbol.

- ***Experimental Receiver.*** Mtel's field trials utilized an NWN receiver based on a custom programmed Digital Signal Processor and readily available off-the-shelf materials.

Mtel's tests have thus shown that a sustained NWN transmission rate of 24,000 bits per second (4000 baud x 6 bits/baud) with commercially acceptable bit error rates can be rapidly deployed upon finalization of Mtel's tentative preference.[4]

Attachment 1 also discusses Mtel's continuing plans for ensuring the successful commercial deployment of NWN. In particular, Mtel describes the role of its continuing radio experimentation in Oxford, Mississippi; a planned demonstration of a NWN system in Dallas, Texas, to be implemented in conjunction with Motorola; and progress and plans on developing the network components necessary to implement NWN. Based upon Mtel's existing work and estimated schedule for developmental activities, Mtel will be able to begin commercial deployment of NWN upon grant of a 900 MHz narrowband PCS license.

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[4] Efforts are now underway to write manufacturing specifications for the first generation of commercially deployable transceivers known as "personal messaging units" ("PMUs").

As a final matter, Attachment 2 to this report describes further demand and market information provided by ADL. ADL conducted a comprehensive series of market research activities to assess the size of the market for NWN, the attractiveness of nationwide and regional messaging services, and anticipated message lengths both by individuals purchasing NWN systems for business needs and by corporate MIS bulk purchasers. As discussed below, ADL's research confirms a market for NWN exceeding 10 million subscribers within 10 years, establishes a significant preference among prospective users for nationwide services, and shows that Mtel's original research on NWN traffic characteristics correlate closely to measured needs.

TAB 1

Mtel Nationwide Wireless Network

Field Trial Operations - November and December 1992

1.0 INTRODUCTION

Mtel continues to make progress bringing the Nationwide Wireless Network ("NWN") to fruition using multi-carrier modulation ("MCM") operating at 24,000 bps. In the six months since Mtel's last report an improved transmitter and receiver have been constructed and successfully field tested. Work is progressing on the modulation, the hardware, and the overall system architecture. Recently completed simulcast over-the-air testing in Oxford, Mississippi, has afforded additional insight into the practicality of employing permutation frequency shift keying ("PFSK") - one of the forms of MCM identified early on by Mtel as a possible candidate for field implementation of the NWN.

The latest testing with PFSK complements the work conducted during the spring and summer of 1992 involving the field demonstration of multi-carrier on-off keying ("MOOK"). Both forms of MCM hold great promise. Each affords a means for transmitting at 24,000 bps in a 50 kHz channel and each may play a key role in the commercial implementation of NWN.[1] This report summarizes the work over the last six months and notes the effort that Mtel expects to complete over the next few months as work progresses on the refinement of many components of the NWN system.

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[1] For a discussion of PFSK as contrasted with MOOK and the possible role for both in the NWN system, see Appendix A to this report.

1.1 Summary of the Work

The latest series of tests proved that PFSK should afford a robust and readily implementable form of MCM that will support 24,000 bps data rates in a simulcast environment. The latest experimental work also provided valuable insight into the problems associated with demodulating MCM signals and the implications for receiver design. In short, the experiment underscored the validity of the concepts tested and pointed the way for further testing as envisioned by Mtel in its last report on experimental operations filed June 29, 1992.

As described below, the experiment necessitated the improvement of MCM transmitters using experience gained from the June 1992 over-the-air MCM tests and construction of a new receiver designed to demodulate PFSK.[2] Actual text was transmitted in a simulcast mode over transmitters operating in the 930 MHz band. In order to evaluate the robustness of the system and to identify potential areas for further refinement, no error correction was employed in the transmissions. This experiment also provided the opportunity to characterize very precisely the propagation involvement. For the latter task, a mobile data gathering van was equipped with a geopositioning navigation system receiver to determine its location at any point and an Anritsu signal strength

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[2] Details concerning the transmitter used in this experiment are supplied in Appendix B to this report. The PFSK receiver is discussed in Appendix C to this report.

receiver.[3] Both positioning information and the data received from the experimental transmission system were recorded on a personal computer so as to facilitate analysis. This work sets the stage for the next set of experimental tests in the spring of this year.

1.2 Next Step - Two Way Tests

Mtel is now planning an over-the-air two-way test of NWN technology in an urban environment. Tests are to be conducted this spring in Dallas, Texas. This work will involve field testing of not only MCM as transmitted from simulcasting base transmitters, but also the transmission of the low powered return signal. Thus, a "closed loop" will be established in which a signal simulcast from base transmitters will be received, decoded and an acknowledgement sent from a portable station. While the feasibility of such low power signalling has long been established in a variety of communications systems involving land mobile technology[4], the integration of these components will mark an important milestone in the development of NWN as a "system." The future tests will also afford an opportunity to study further improvements in transmitters and receivers for MCM. At the same

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[3] As an efficient data gathering tool, this system was most valuable. Its design is described in Appendix D to this report. Details of the experimental test set-up are set forth in Appendix E.

[4] Examples include portable cellular operations, amateur QRP (i.e. low power) packet data systems, and conventional low power voice and data radios used for commercial operations.

time, experimental work will continue in Oxford as will Mtel's system planning.

2.0 FIELD TRIAL RESULTS

During November and December Mtel successfully performed field trials of its new transmitters and receiver in and near the Center for Telecommunications (See Figures 1 and 2) in Oxford, Mississippi. These trials proved that it was possible to successfully demodulate a continuous stream of PFSK symbols carrying 24 kilobits per second of data using a digital signal processor ("DSP") based receiver.

2.1 Physical Arrangements for the Experiments

The major difference in the physical arrangements for these tests, compared to the tests reported upon in June 1992, is the transmitter and receiver used. These tests continued to have transmitters installed at Anderson Hall on the University of Mississippi campus (See Figure 3) and at the Abbeville tower, approximately 7 miles north of Anderson Hall. A separate control link, also operating in the 930 MHz band, was used to broadcast symbol clock to data generators, Figure 4, located at each transmitter. The reasons for using the control link to provide clocking for these tests were the same as the June 1992 tests:

centralized broadcast of the clocking signal facilitates experimental changes in symbol rate; and

using the broadcast clock avoids diverting efforts to building

and testing symbol clock circuits in the experimental receivers.

In commercial systems the clock signal to the base transmitters will be multiplexed into the data coming over the satellite control link to each transmitter. Commercial Personal Messaging Units will derive the symbol clock from the MCM signal.

2.2 Transmitters

"Composite" transmitters were used for these tests -- each transmitter consists of four sub-transmitters, as shown in Figure 5, that are summed to produce the transmitted signal. This arrangement was very similar to the June 1992 configuration with two important differences:

high performance commercial combiners were used for the summing, thus increasing the efficiency and eliminating the leakage that caused selective fading in the June 1992 tests;[5]

4-ary Frequency Shift Keyed sub-transmitters were used for these tests, which allowed the composite transmitter to generate 4-out-of-8 PFSK signals.[6]

2.3 Receiver

The DSP based receiver (shown in Figure 6) constructed for these tests is capable of error free demodulation of continuous PFSK signals in the face of a broad range of degradations. The

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[5] See Appendix F pertaining to Selective Fading for more details.

[6] Only 66 of the 70 possible PFSK symbols could be generated, but since only 64 of the symbols are needed to carry 6 bits of information this was not a significant limitation.

receiver has a conventional (analog) front end (RF amplification, 1st IF, 2nd IF); a sample and hold and analog/digital convertor operating at 160 kilosamples per second; a digital signal processing board running a Fast Fourier Transform (FFT) algorithm; and a commercial personal computer for Input/Output functions.[7]

2.3.1 Receiver Laboratory Tests

The laboratory tests established that (1) the "breadboard" experimental receiver seen in Figure 7 worked and (2) the amount of signal degradation the receiver could tolerate and still deliver error-free data. In the lab an HP 5245A Waveform Synthesizer was used as the signal source. While this source was limited to generating just 16 symbols, it did have the advantage of having little uncontrolled impairments.[8] The receiver has a 49 dB dynamic range -- error free detection with signals between -63 dBm and -112 dBm. While a commercial receiver would have a greater dynamic range this range was entirely adequate for these tests. This receiver is not a commercial prototype but it gives assurance that a commercially deployable PFSK receiver with adequate performance can be constructed. Timing errors (jitter and/or misalignment) of at least +/- 33.15 microseconds were observed and were tolerated without causing errors. Similarly, frequency errors of +/- 1100 Hz

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[7] Details of the receiver's composition are contained in Appendix B and its testing are contained in Appendix D.

[8] In contrast, the transmitters were found to have significant levels of jitter and frequency error.

were tolerated.

2.3.2 Field Trials

Combined testing of the experimental transmitters and receiver provided results that are similar to the lab tests described above. The inclusion of the transmitter implementation imperfections in the test setup did cause measurable decreases in the additional degradation that could be added before errors started to appear.[9] However, the bounds on the error free performance region were within Mtel's target numbers. For error free performance, a minimum signal level of -95 dBm was required; jitter of up to +/- 28.1 microseconds, and frequency offsets of up to 600 Hz were also tolerated.

The receiver complex was then moved into a van, as shown in Figures 8, 9, and 10, and signals were sampled at a number of uni-signal and equi-signal points. A fixed message was repeatedly transmitted. One sample of this message was captured every second and displayed on the PC screen to provide a qualitative assessment of the detected signal quality. Selected screens have been captured to a portable printer to provide a record of the performance observed. Note that:

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[9] The transmitters have both a static deviation adjustment and a dynamic deviation adjustment. Toward the end of this experimental period it was determined that the dynamic deviation was significantly misadjusted, resulting in errors of up to 2 kHz in some of the sub-carriers. Re-tuning significantly improved the performance.

(1) this was a "canned" message -- at this point in the experimental program such a prerecorded message is advantageous as a means of quickly comparing results

(2) since physical link characterization is the main interest no error control capabilities are included -- all link errors are fully visible;

(3) for these displays a simple mapping of PFSK symbols to 64 printable characters was used -- in a commercial PMU each PFSK symbol will be mapped to 6 bits of binary information and that binary stream will be mapped to whatever format is appropriate (e.g., full 7 bit, 128 character ASCII; 32 bit computer words; 1 bit ON/OFF telemetry messages); and

(4) the only formatting or manipulation of the received stream was insertion of a carriage return after the first "+" (the sync character) -- word wrap, which insures that carriage returns are only inserted at spaces between words, was not used.

All these caveats aside, the results are still encouraging -- a "real" message has been passed, using PFSK, through an over-the-air simulcast environment.

3.0 CONCLUSIONS AND FUTURE WORK

The latest phase of the on-going experiments accomplished several tasks that will assist in the refinement of the various systems that will make up NWN. In particular, the following were accomplished:

1. Selective fading was analyzed and a solution devised;

2. Permutation frequency shift keying modulation at 24 kbps was evaluated under simulcast conditions in the field;

3. Automated signal strength measurements for determining coverage contours and simulcast overlap areas were made compared to a computer propagation prediction model;

4. Composite transmitters for use in evaluating MCM modulation and as development tools for the NWN transmitters were refined; and

5. An experimental receiver for PFSK MCM capable of functioning as a development tool was developed.

As a result of this work, large amounts of data have been collected and will be analyzed thoroughly to guide and focus upcoming testing and experimentation. Examples of the data and analyses are included with this report.

The latest round of experimental efforts has yielded the following conclusions:

1. Permutation modulation ("PFSK") operating at 24 kbps performs well in various field environments;

2. PFSK in a strong signal environment gives error free data;

3. PFSK in weak signal areas works well enough to be corrected easily by the use of forward error correction;

4. PFSK works as well or better in simulcast areas as in weak signal areas; and

5. Digital signal processing using Fast Fourier Transforms is a viable method of decoding MCM.

The most recent work also helps to set the stage for progress. Based on the data collected at Oxford, Mtel expects that the robustness of MCM will prove out in a major metropolitan area. Mtel is also sufficiently confident with DSP to move to the next stage of development for portable terminals. To that end, an experimental system is to be constructed in Dallas during the second quarter of 1993 consisting of three base transmitters and

seven base receivers. Motorola will supply equipment custom built to Mtel's specifications. The transmitters will be capable of sending various forms of MCM and will be capable of operating independently or in simulcast. They will be used to verify further the robustness of MCM under a wider set of conditions including dense urban areas. In addition, a series of portable to base receiver tests will be run in order to help to establish a model for more accurately calculating the number of receivers necessary for a given market.

In sum, the experimental work thus far has further confirmed MCM as a means for conducting simulcast messaging at 24,000 kbps. This work has laid the foundation for the further refinement of the many systems that will be integrated into NWN. Mtel looks forward to continuing along the path to the eventual deployment of NWN on a commercial basis.

Figure 1

NATIONAL CENTER FOR PHYSICAL ACOUSTICS WHERE
THE CENTER FOR TELECOMMUNICATIONS IS LOCATED

Figure 2

CENTER FOR TELECOMMUNICATION LABORATORY
UNIVERSITY OF MISSISSIPPI

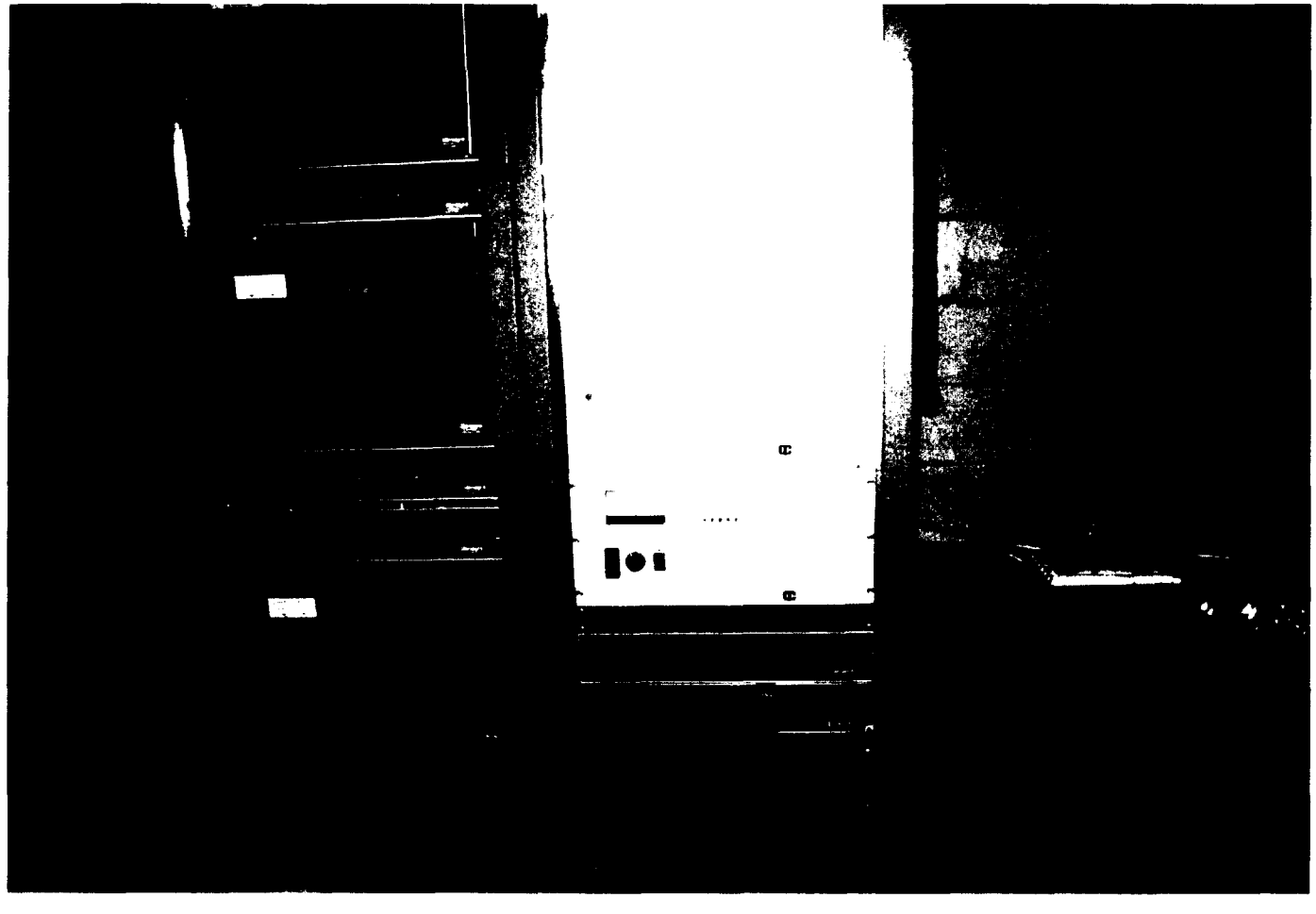

Figure 3

ANDERSON HALL SITE SHOWING COMPOSITE
TRANSMITTER AND DATA GENERATOR/SYNC GENERATOR

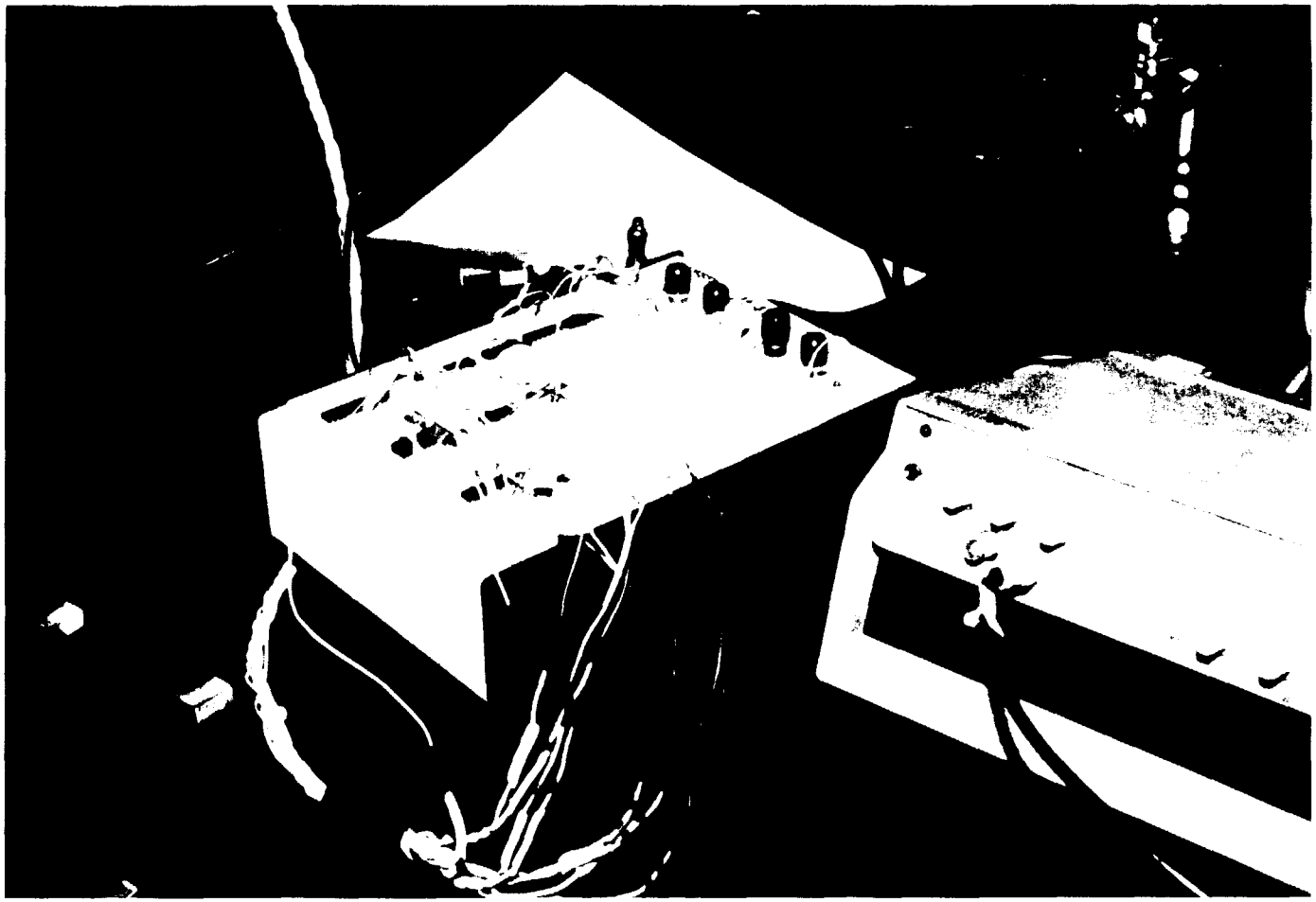

Figure 4

DATA GENERATOR USED TO CONTROL THE COMPOSITE TRANSMITTERS

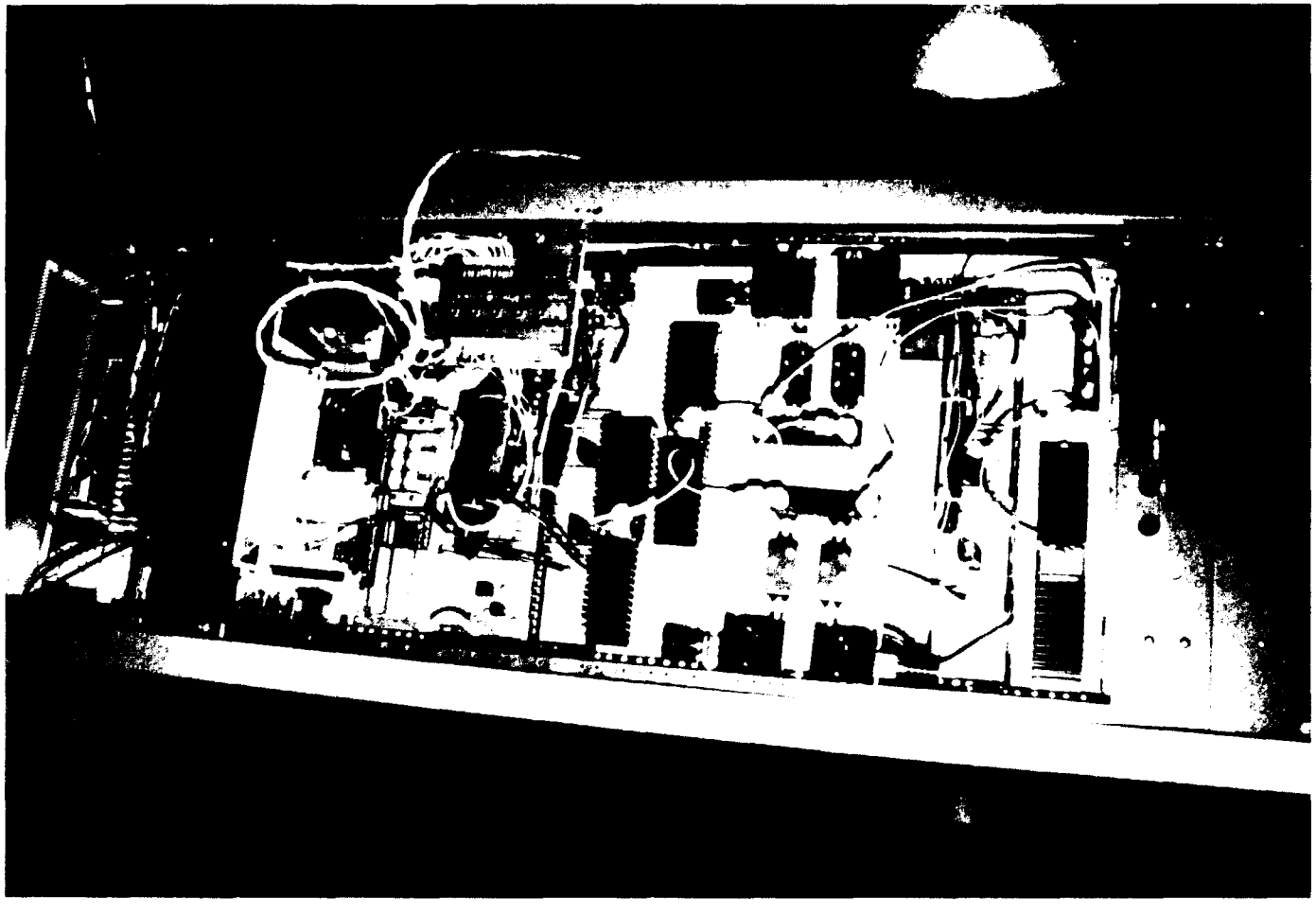

Figure 5

REAR OF COMPOSITE TRANSMITTER SHOWING
COMBINER AND CONTROL LINE INTERFACE

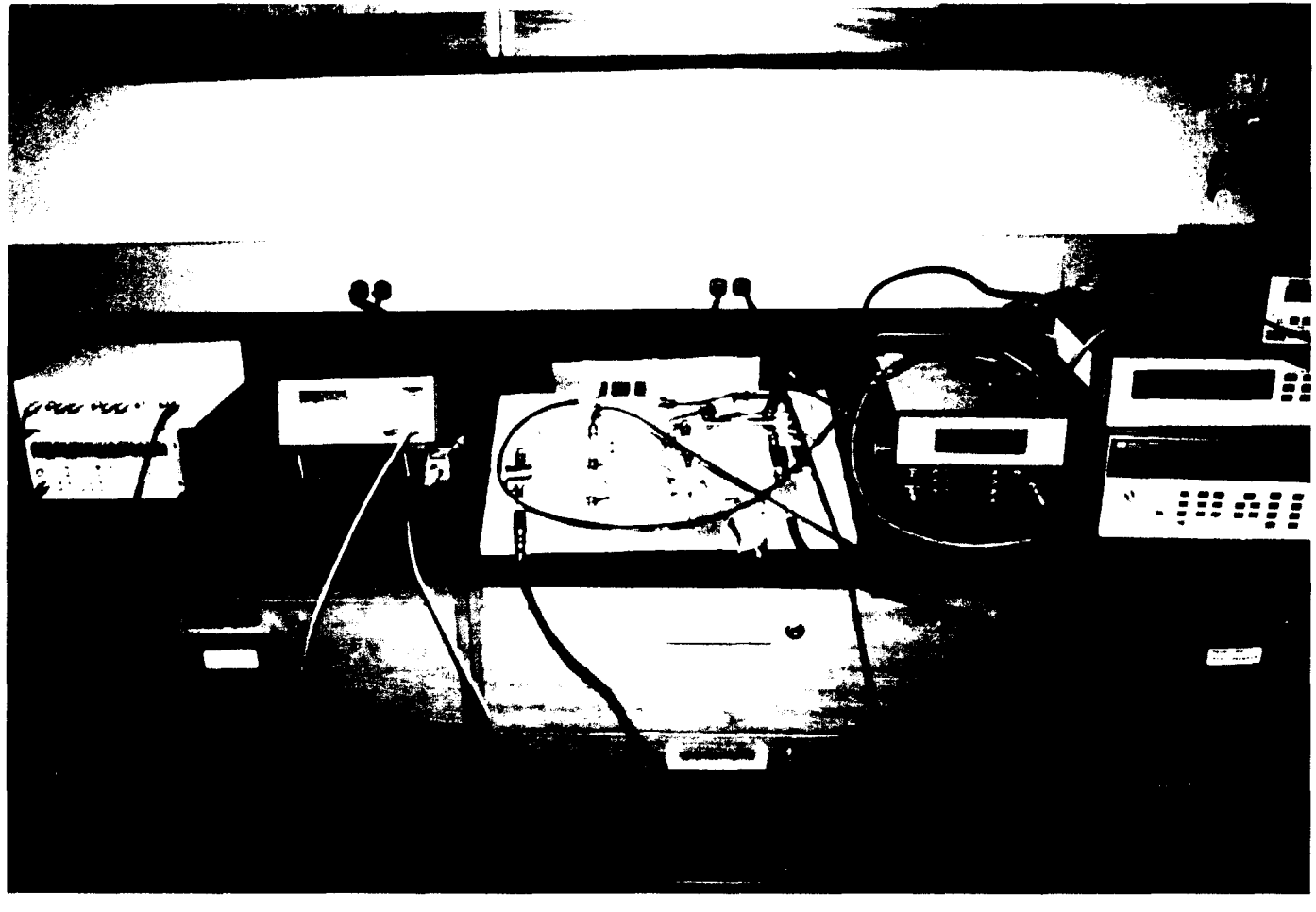

Figure 6

RF FRONT END WITH LOCAL OSCILLATORS,
A/D CONVERTER AND POWER SUPPLY

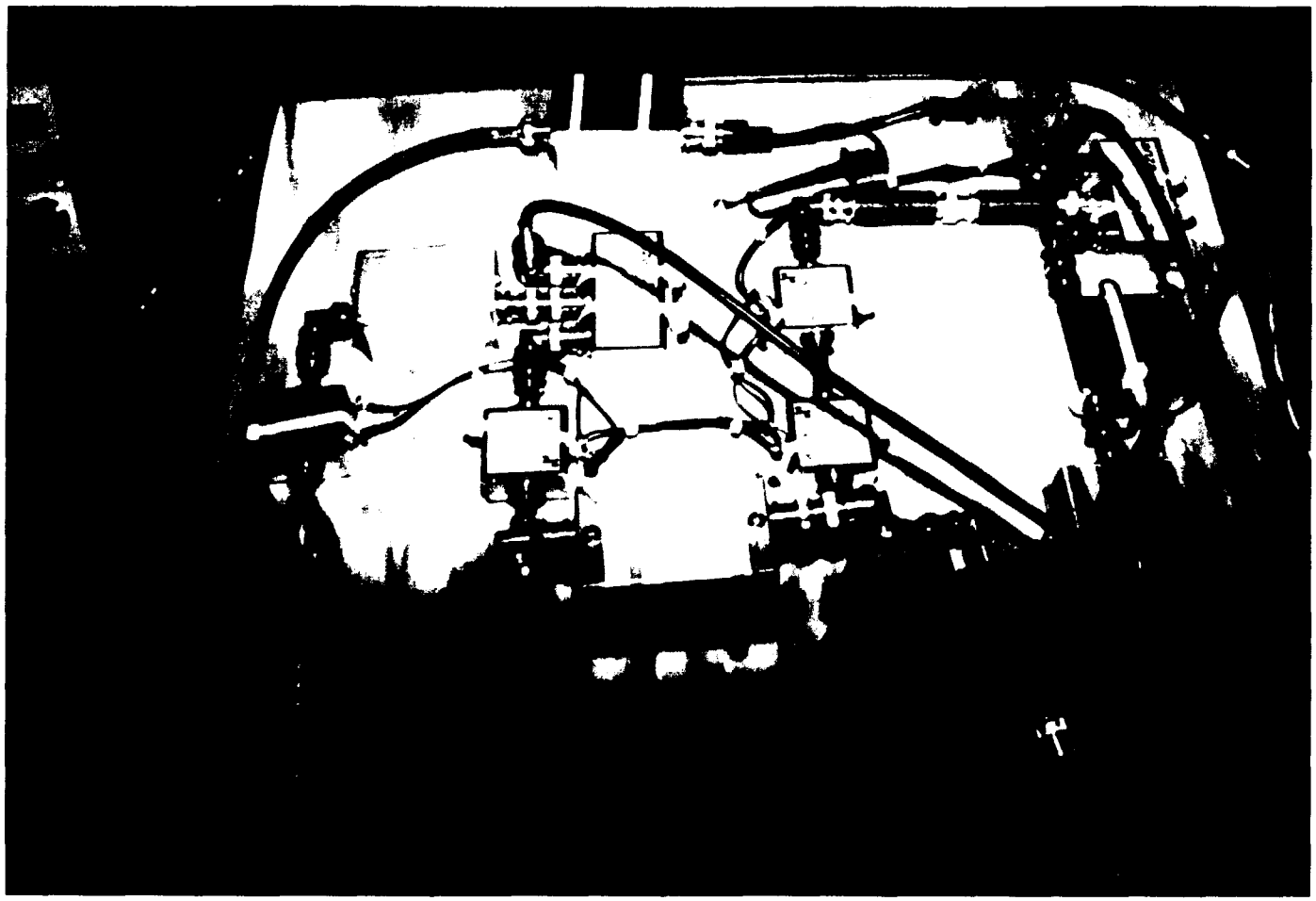

Figure 7

RF FRONT END OF NWN INSTRUMENTATION RECEIVER