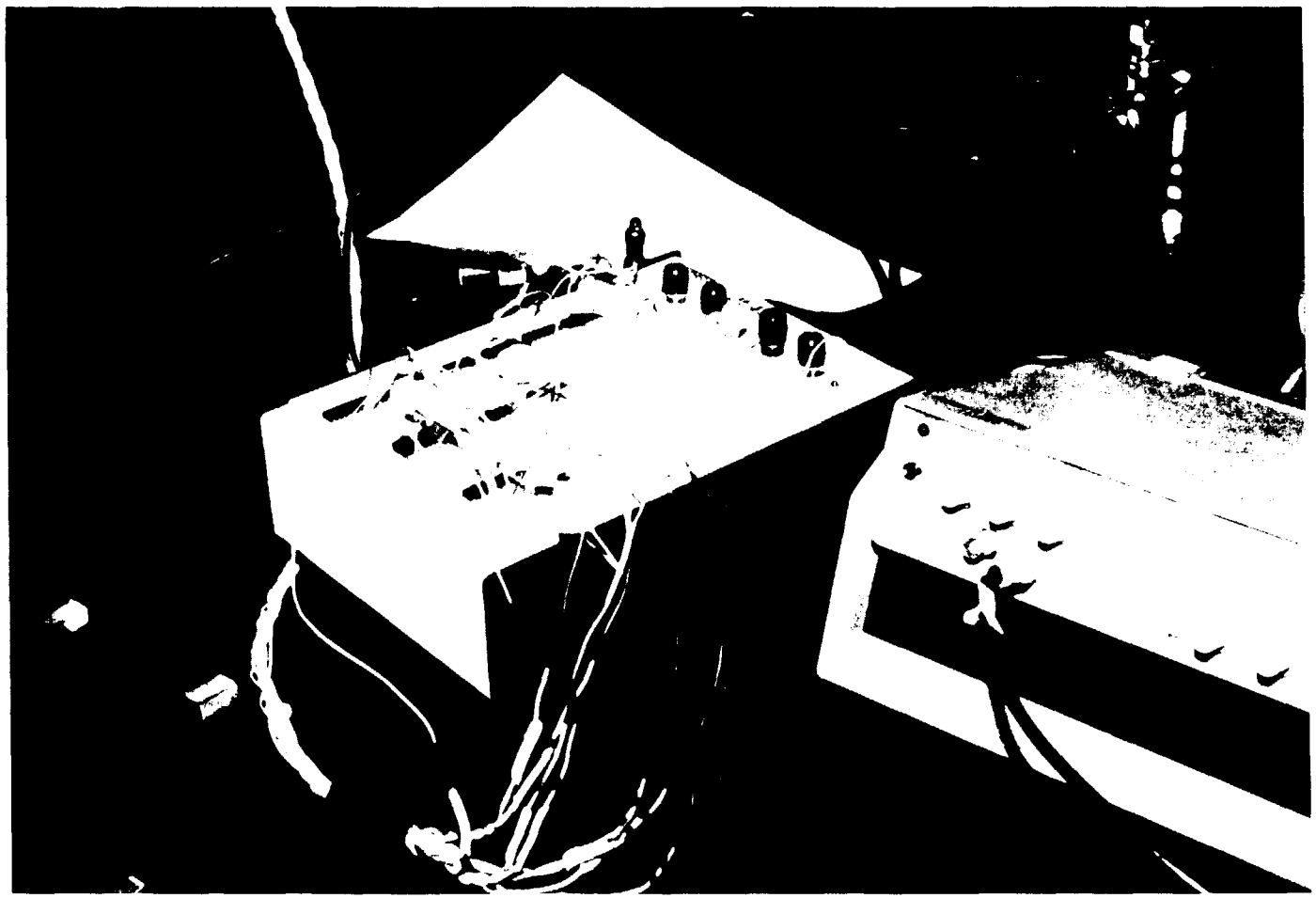

Figure 4

DATA GENERATOR USED TO CONTROL THE COMPOSITE TRANSMITTERS

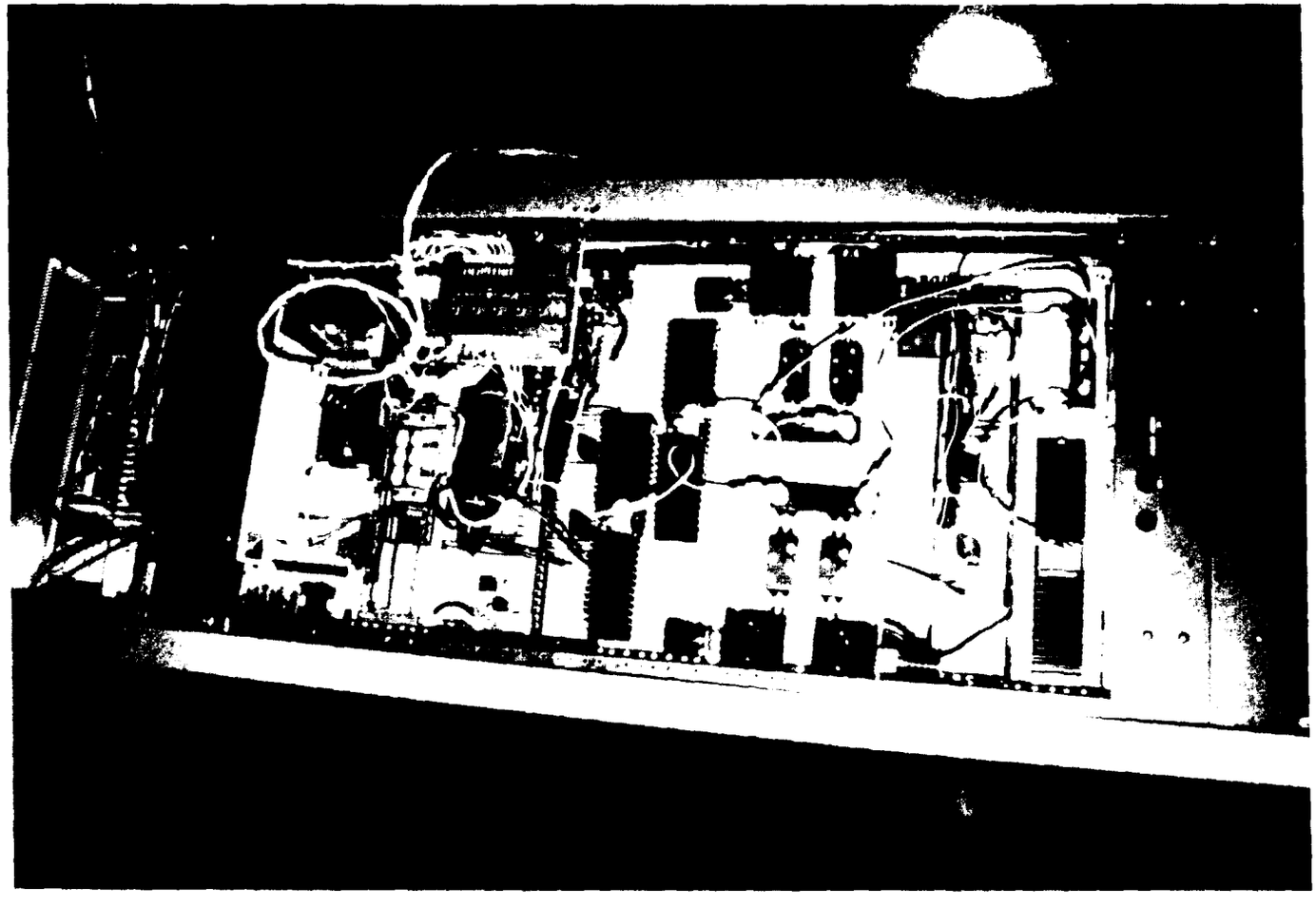

Figure 5

REAR OF COMPOSITE TRANSMITTER SHOWING
COMBINER AND CONTROL LINE INTERFACE

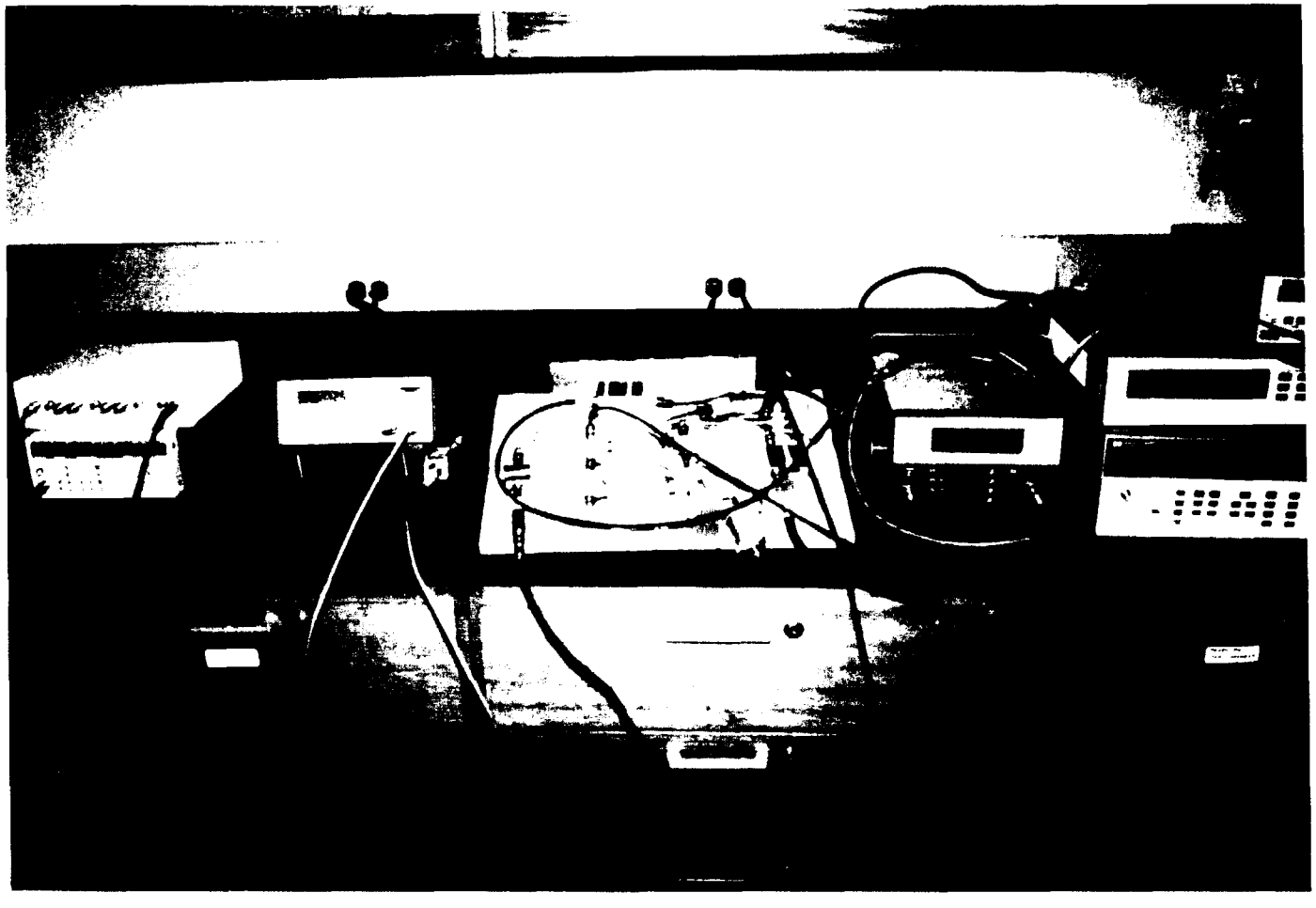

Figure 6

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

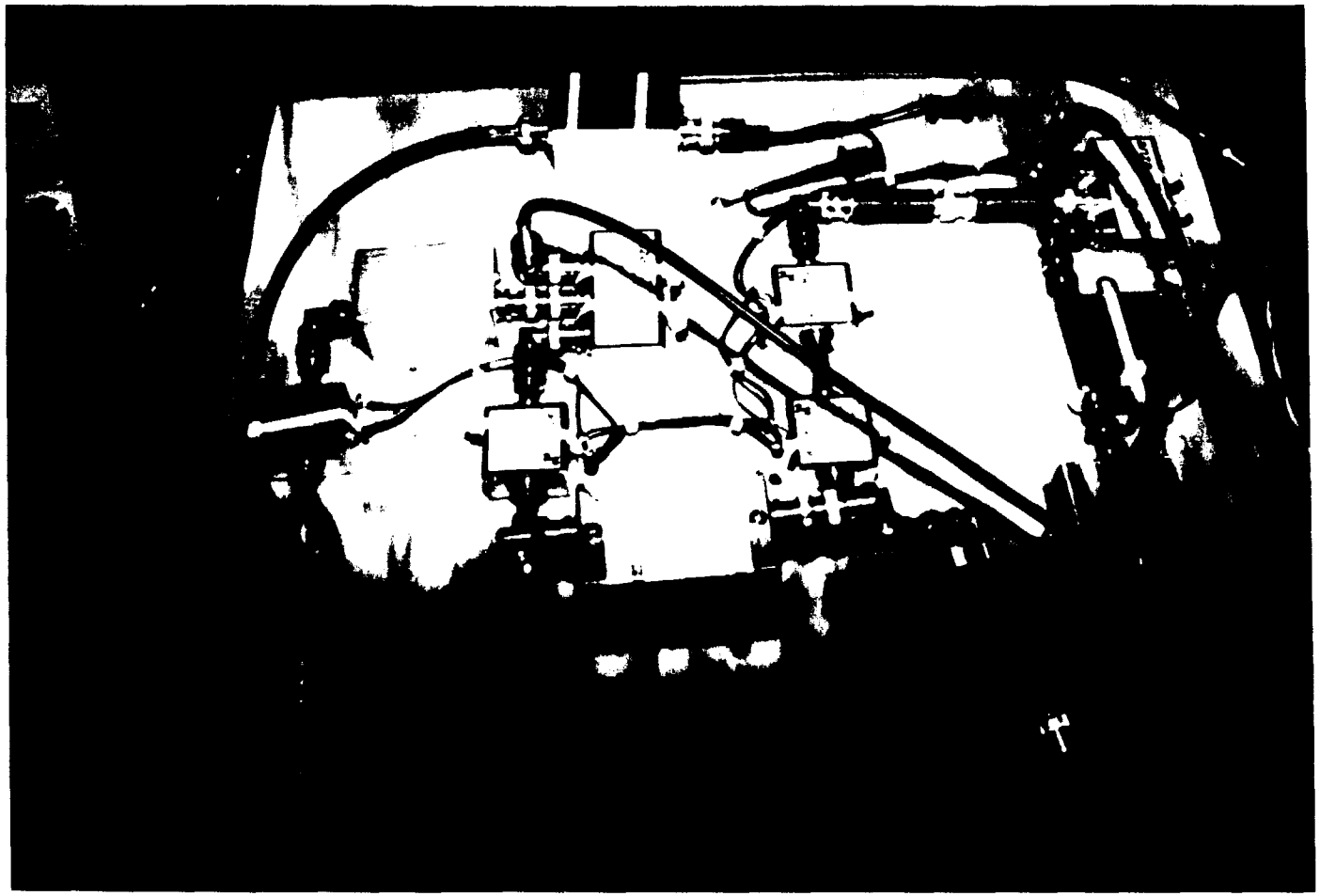

Figure 7

RF FRONT END OF NWN INSTRUMENTATION RECEIVER

Figure 8

MOBILE TEST LABORATORY SIDE VIEW

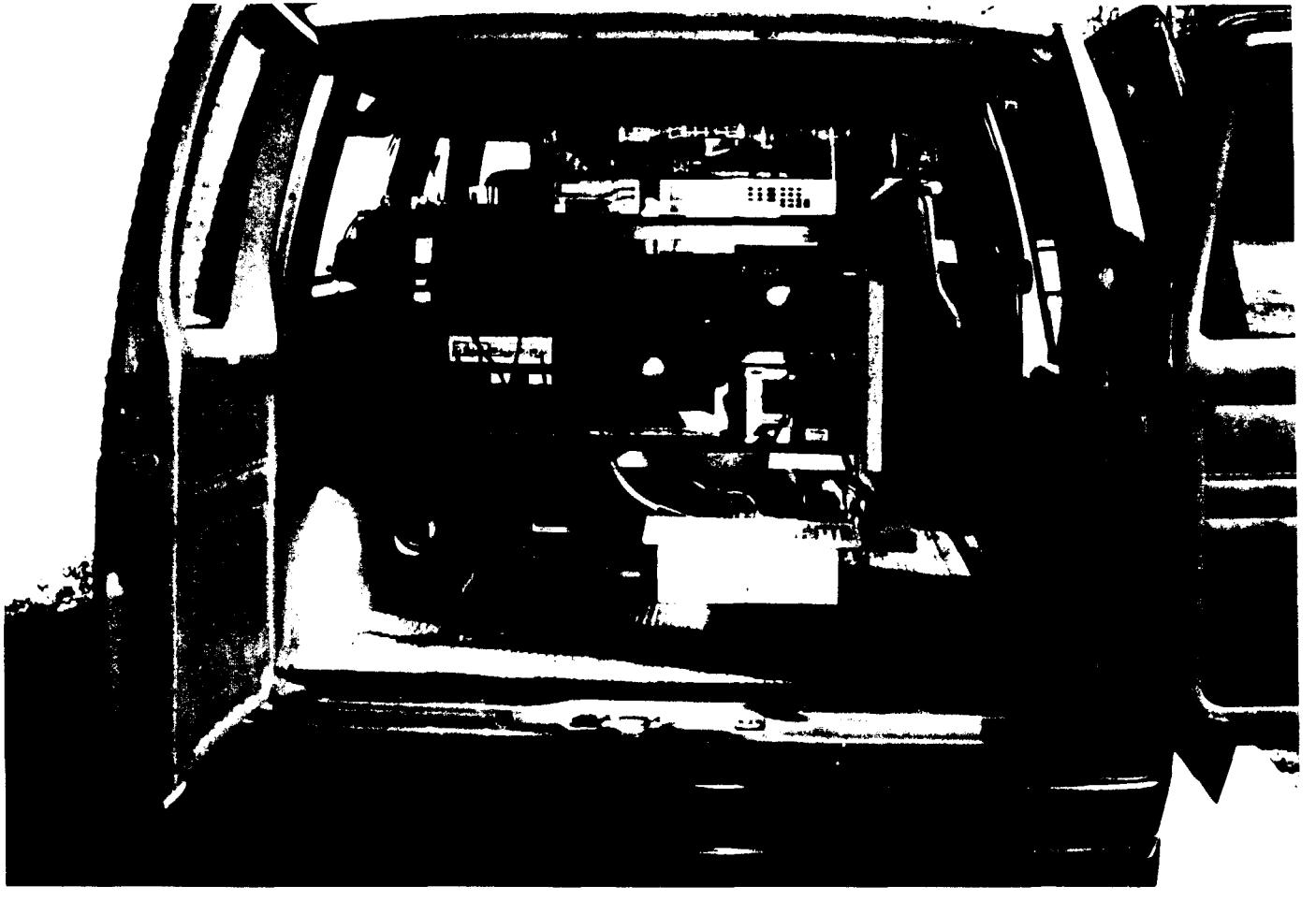

Figure 9

MOBILE TEST LABORATORY REAR VIEW

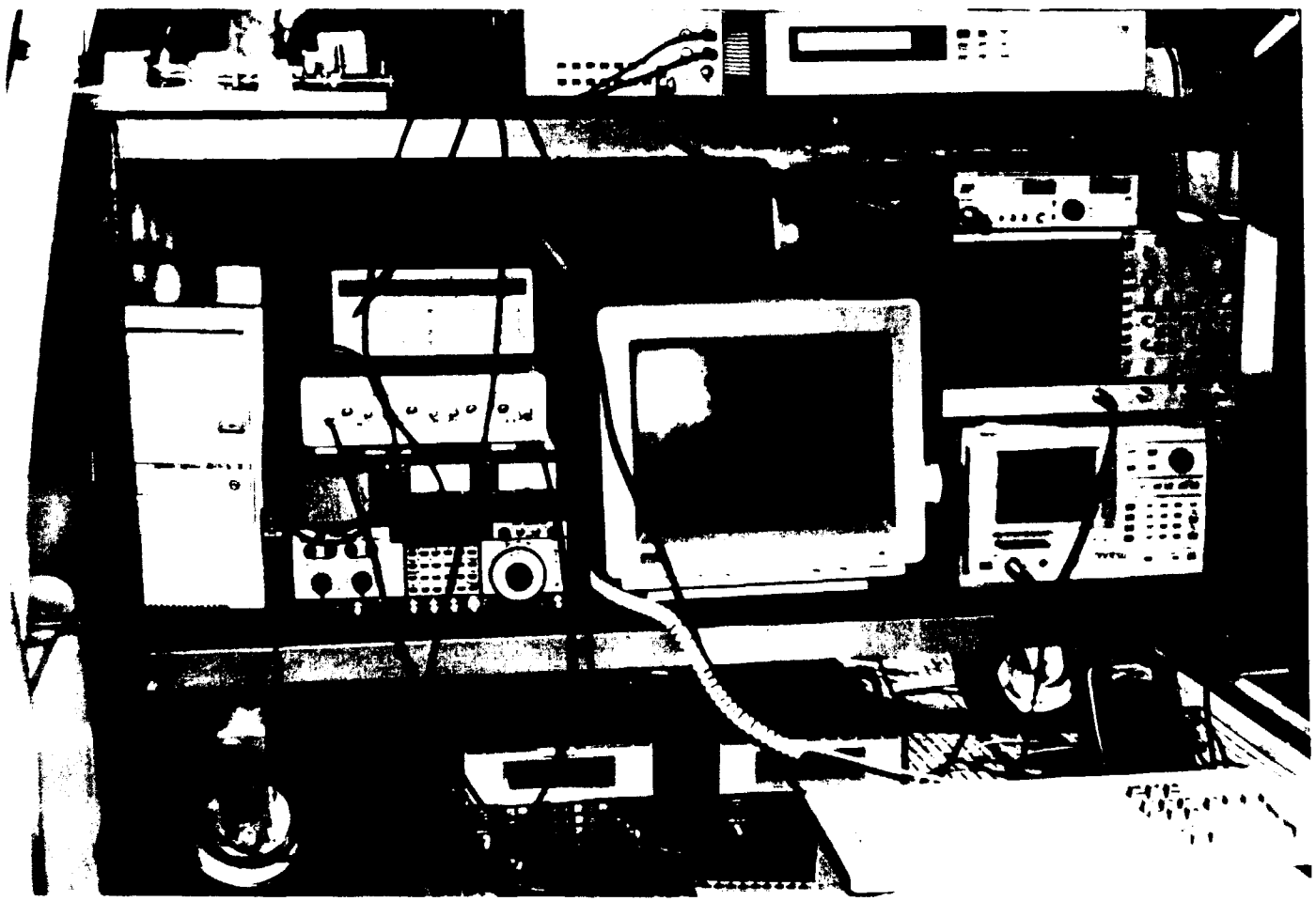

Figure 10

MOBILE TEST LABORATORY
DETAIL OF EQUIPMENT RACK

TAB A

Appendix A

MOOK and PFSK as Variants of MCM

In the Petition for Rulemaking filed in November 1991, Mtel recognized that various forms of multi-carrier modulation ("MCM") might prove suitable for use in its proposed Nationwide Wireless Network ("NWN") system. Two of these possible modulations noted originally included multi-tone on-off keying ("MOOK") and permutation frequency shift keying ("PFSK"). While related, each has distinct attributes that make one or the other modulations more suitable in certain situations. Both forms, however, can provide for a 24,000 bps data rate as proposed for the NWN.

In MOOK schemes each of the carriers is used as an independent binary channel. This leads to the highest bit rate, for a given number of carriers and symbol rate. Therefore, MOOK was the first variant investigated and reported in the June 1992 FCC filings. Those experiments proved that an MCM signal could be detected using digital signal processing technology. One of the unanticipated results of those investigations was the low levels of transmitter intermodulation that could be achieved. Those low levels make a more aggressive use of the available bandwidth (wider spacing of the subcarriers; increased symbol rate) viable. With that more aggressive deployment, PFSK becomes a pragmatic means of attaining 24 kilobits per second in a simulcast environment. Therefore, this round of experimentation focused on PFSK implementations.

In the NWN environment the primary channel constraints are the characteristics of the simulcast environment -- delay dispersion on the order of 50 microseconds and

rapidly changing phase due to the combination of multipath and multiple transmitters. Therefore, Mtel's experimental attention has focused on multi-carrier modulation techniques that are compatible with non-coherent (power or envelope based) demodulation.

MOOK has the advantage of maximizing the throughput for a set of N sub-carrier slots and a fixed symbol rate. However, MOOK also has some disadvantages. There are transmitter complexity implications in the fact that a symbol might require simultaneous presence all of N sub-carriers. If a shared power amplifier is used, the peak power requirement is set by the "all carriers ON" symbol; if each sub-carrier is generated by a separate sub-transmitter (a "composite" transmitter) there must be N sub-transmitters. There are also demodulation task implications. The receiver must decide, on a sub-carrier by sub-carrier basis, the presence or absence of power. Accurately making that decision, in a fading environment, is a non-trivial task.

PFSK constrains each symbol to have exactly M (a fixed number) of active sub-carriers in the N possible sub-carrier slots. There are certain implementation benefits. Only M sub-transmitters are needed in a composite transmitter; with a shared power amplifier the peak power demands are reduced. The demodulation rule is also simple and robust -- since the number of active sub-carriers per symbol is known, the receiver need only rank-order the sub-carrier slots by power and pick the M-strongest slots to determine the detected symbol.

These advantages caused Mtel to pursue a PFSK form of MCM that provides 24 kilobits per second in a 50 kiloHertz channel in this phase of the experimental efforts. The almost complete lack of intermodulation products in well-designed composite transmitters facilitated this arrangement. The signal used for the bulk of the experiments reported on here is a 4-out-of-8 PFSK scheme with the sub-carrier slots on a 5 kiloHertz spacing. The symbol rate is 4 kilobaud. Using a sub-carrier slot spacing that is larger than the symbol rate provides a guard space, or in the time-domain where the Digital Signal Processing (DSP) detection is performed, a guard time: only 200 microseconds out of each 250 microsecond symbol is sampled. The 50 microsecond guard space allows for transmitted signal transitions and the delay spread (intersymbol interference) within the simulcast overlap areas. The 6 bits per PFSK symbol and the 4 kilobaud signaling rate results in a gross bit rate of 24 kilobits per second. This was the scheme that was successfully tested during this reporting period.

For these latest experiments the signals were generated by a composite transmitter consisting of four sub-transmitters. Each sub-transmitter output a 4-ary FSK signal and the composite transmitter generated 66 of the 70 possible 4-of-8 PFSK signals.[1]

A portable receiver that is capable of detecting the power at each of 8 sub-carrier slots can successfully demodulate a variety of forward channel modulation

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[1] Since the current encoding plans for the NWN are to use just 64 of the PFSK symbols to carry 6 bits of user information, the loss of 4 PFSK symbols was not considered significant.

waveforms. In an NWN system these differing modulation schemes could co-exist in adjacent zones, with the zonal forward channel format identified in the overhead portions of the cycle. The portable is informed of the decision rule it should use within that zone by information included in the overhead portions of the cycle header. The use of two different forms of MCM could facilitate more widespread implementation of the NWN. PFSK may prove to be the best choice initially for all service areas and in the long term for less densely populated areas. It is these low density areas that are likely to require the highest power transmitters -- the low density equates to large areas to be covered. Conversely, high density areas, such as lower Manhattan, are relatively compact. In these areas, migration to MOOK with the prospect for data rates greater than 24,000 bps may be appropriate. Thus, a set of low power multi-carrier transmitters that can economically provide the higher throughput could prove advantageous.

In summary, the deployment of the NWN may afford opportunities to tailor the service through the use of various forms of MCM including MOOK, PFSK, or other variations. Refinement of the NWN technology through additionally experimental work should provide a basis for the selection of the initial modulation to be employed commercially. The work to date not only underscores the feasibility of the modulations tested thus far, it points out the desirability of fielding a system that is robust enough to offer the high level of service envisioned but flexible enough to evolve as demands change to impose new requirements driven by the usage of the service.

TAB B

Appendix B

NWN TEST TRANSMITTERS IN OXFORD

November - December 1992

The NWN Composite Transmitter consists of four sub-transmitters operating into a WACOM 4 port Hybrid Coupled Transmitter Combiner.[1] This arrangement provides the 4 carriers required for the PFSK modulation scheme (see fig. B-1).

Each sub-transmitter consists of a QT-5995, 45 Watt, 4-level FSK transmitter which was modified to increase its maximum deviation from 5 kHz to 20 kHz. This was accomplished by increasing the range of the FSK adjustment controls and increasing the gain of the VCO modulation port. Glenayre's standard 10 pole, 3.9 kHz Bessel filter was used to control the slew rate between FSK levels. This filter provides a rise time of about 88 microseconds between FSK levels and keeps all spurious emissions well within the proposed FCC criteria for this service. Future tests will use a rise time of approximately 50 microseconds to make full use of the allowed spectrum.

Interface to Transmitter

Each sub-transmitter has two control lines that determine which of the four FSK levels (sub-carrier frequencies) will be transmitted. Figure B-2 shows the sub-carrier frequencies

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[1] The instruction manual for the combiner is Attachment 1 to this Appendix.

produced by each sub-transmitter (QT-5995) and the control line states required to obtain these frequencies. The data generator insures that only allowable combinations that contain 4 discrete frequencies per baud interval.

As can be seen from the above and Figure B-2, each FSK frequency is covered by two different sub-transmitters. It is up to the data generator never to allow two transmitters on the same frequency at the same time. Therefore, each baud will consist of 4 discrete frequencies. Note that there are cross dependencies between the carriers -- while any one sub-transmitter can be driven to any of its 4 frequencies, that sub-transmitter being on, say frequency 3, constrains the acceptable patterns to the other sub-transmitters -- it is not allowed that those patterns cause any other sub-transmitter to be set to frequency 3. There are only 66 acceptable patterns or symbols that can be generated by four 4-level sub-transmitters.

The data generator was connected through a switch arrangement that allowed each sub-transmitter to be individually turned off while the others transmitted data from the data generator. This made it easy to determine the overlap areas very accurately by leaving one sub-transmitter off at one site and another one off at the second site. Then, going to an area where the carriers of the singly transmitted frequencies were equal, both simulcast and single-site frequencies could be

observed simultaneously, giving an accurate determination of the equal signal overlap areas.

Referenced to the channel frequency, sub-transmitter A had its FSK resting points set to -17.5 kHz, -12.5 kHz, -7.5 kHz and -2.5 kHz for control line inputs of 00, 01, 10, and 11 respectively. Sub-transmitter B FSK points were set to -17.5, -12.5, +2.5 and +7.5 kHz for control line inputs of 00, 01, 10, and 11 respectively. Sub-transmitter C FSK points were set to -7.5, -2.5, +12.5, and +17.5 kHz for control line inputs of 00, 01, 10, and 11 respectively. Finally, sub-transmitter D had its FSK points set to +2.5, +7.5, +12.5, and +17.5 kHz for control line inputs of 00, 01, 10, and 11 respectively.

Performance

Intermodulation products caused by the simultaneous presence of four unmodulated carriers are better than -70 dBc and the average level of these products drops even lower when the composite transmitter is modulated with random data. Figure B-3 shows the spectrum of the NWN test transmitter operating with four unmodulated carriers. This configuration is used for the "Unmodulated carrier level" calibration.

Figure B-4 displays a comb of spectral components that result when the composite transmitter alternatively sends the symbol composed of the "even" frequencies (f_2, f_4, f_6, f_8) and the symbol compound of the "odd" frequencies (f_1, f_3, f_5, f_7). It is

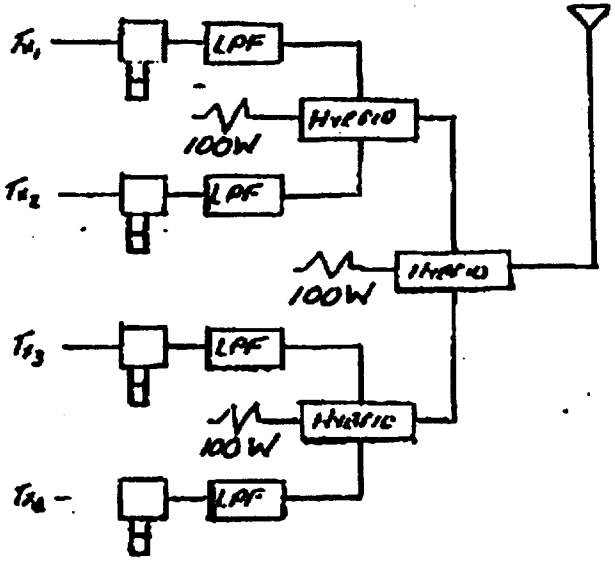
expected that these two symbols may be used for synchronization functions.

In Fig. B-5 random data at 4 kilobaud modulated the composite transmitter. It shows the transmitter to be well within the proposed FCC specifications for this service. The rise time of the data transitions can be increased to further improve the bit-error-rate of the system and remain within proposed FCC spectrum constraints.

Attachment B1

INSTRUCTION MANUAL

WACOM PRODUCTS



NOTES:

1. FREQUENCY RANGE : 806-960MHz
2. ISOLATION, T_x-T_x : 70dB
   ANT-T_x : 38dB
3. INSERTION LOSS : 8.0dB
4. ATTENUATION, HAR, IMPROD : 65dB
5. INPUT POWER, EACH, MAX : 100 WATTS
6. INPUT VSWR : 1.25:1
7. FREQ SEP., T_x-T_x MAX : 1MHz
8. TEMPERATURE RANGE : -30 TO +60°C
9. CONNECTOR TYPE : N-FEMALE

DATE	APPROVED BY	REVISION	ITEM NO.	NO. REQ'D	PART NO.	DESCRIPTION

WP-996-4 FOUR CHANNEL HYBRID COMBINER

TOLERANCES EXCEPT AS NOTED: (DECIMAL) ± .010; (FRACTIONAL) ± 1/32; (ANGULAR) ± 1°

NOTICE: The information contained herein is considered to be confidential material and proprietary to WACOM PRODUCTS, INC.

WACOM PRODUCTS, INC.

SCALE: —

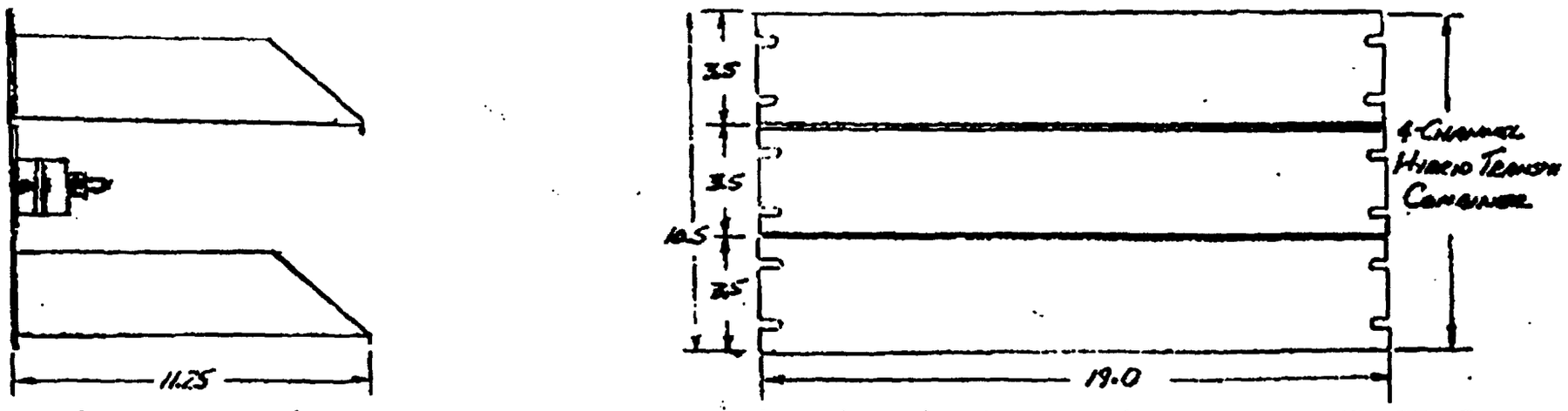
DATE: 9/16/92

DRAWN BY: EWlodarek

APPROVED BY:

DRAWING NO. 920916 RE 21581-E

REV.



DATE	APPROVED BY	REVISION	ITEM NO.	NO. REQ'D	PART NO.	DESCRIPTION

4-Channel Hybrid Transmitter Combiner
WP-996-4-SP353B MTEL Technologies

WACOM PRODUCTS, INC.

TOLERANCES EXCEPT AS NOTED
(DECIMAL) ± .010
(FRACTIONAL) ± 1/32
(ANGULAR) ± 1°

NOTICE: The information contai[illegible] herein is considered to be confider[illegible] material and proprietary to WAC[illegible] PRODUCTS, INC.

SCALE: —
DATE:
DRAWN BY: EWLodovik
APPROVED BY:
DRAWING NO. RE21581-A 921029

HYBRID TRANSMITTER COMBINER TEST SHEET

Customer: MTEL TECHNOLOGIES

JACKSON, MS.

Model No. WP-996-4-SP3538 Serial No. 21581-19

Tx Frequency (MHz)	Loss dB	Isolation Tx-Tx	Isolation Ant-Tx
930.900 BOTTOM LEFT	7.6	90+	57
930.900 BOTTOM RIGHT	7.9	90+	53
930.900 TOP LEFT	7.7	90+	57
930.900 TOP RIGHT	7.9	90+	58

Inspector BWD Date 10/29/92

WACOM PRODUCTS, INC.

P.O. BOX 21145 • WEST HWY 6 AT SPUR 412 • WACO, TEXAS 76702 • (817) 848-4435

INSTALLATION AND OPERATING INSTRUCTIONS FOR WACOM PRODUCTS, INC. HYBRID COUPLED TRANSMITTER COMBINER SYSTEMS AND ACCESSORIES.

GENERAL

The Wacom Products, Inc. series of hybrid coupled transmitter combiner assemblies were designed for application in VHF and UHF two-way radio communications systems in which from two to eight transmitters are combined for operation on one or more antenna systems. The distinguishing performance characteristic of this combiner series is that the combined transmitters may operate on frequencies spaced as closely as 25 KHz apart.

COMBINER OPERATING THEORY

Figure 1, below, shows a schematic representation of the basic two transmitter to one antenna combiner.

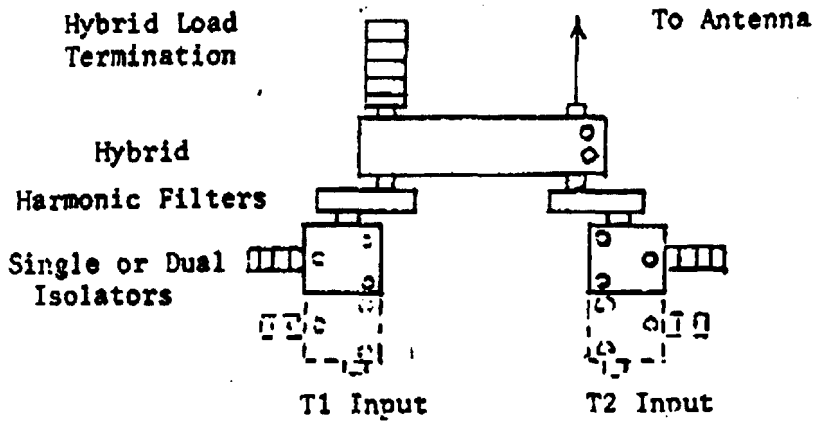


FIGURE 1

Note that each transmitter feeds the input of a single or dual ferrite isolator, followed by a harmonic filter. Filter outputs are connected to an input of a hybrid coupler, which has a load termination connected to a third port and the remaining port feeds the antenna system.

The appendix of this manual includes more detailed descriptions of the operation of each of the components shown in Figure 1 should the reader need an understanding of these devices.

The hybrid coupler, when tuned to match the antenna system impedance, will provide at least 45 dB of isolation between its two input ports. Single stage isolators will provide 35 dB of isolation and dual stage isolators will provide 70 dB or more of isolation. Power loss through the hybrid is 3 dB (half of the power of each transmitter being split

between the antenna and the hybrid load termination), and insertion loss of single stage isolators is under 0.3 dB and loss is 0.5 dB or lower for dual stage isolators. The various losses in connectors and cables will account for an additional 0.2 to 0.4 dB of loss.

Referring again to Figure 1, the sum of the losses will be in the order of 3.7 dB with single stage isolators and 4.1 dB or under for combiners using dual stage isolators. Isolation between transmitters will be equal to the sum of that provided by the hybrid, one isolator plus distributed connector and cable losses. Thus, with single stage isolators Tx-Tx isolation will exceed 80 dB and with dual stage isolators, will be well in excess of 100 dB. Isolation from the antenna to each transmitter will be equal to the sum of hybrid loss, distributed connector and cable loss plus the reverse signal attenuation of the isolator used in the channel, or nominally 38+ dB with a single stage isolator and 78+ dB with a dual stage isolator.

COMBINER INSTALLATION

Our practice is to secure the customer's transmitter frequencies and to completely tune and test each combiner prior to shipment from the Wacom Products factory. Since we cannot predict the characteristics of your antenna system, we test each hybrid coupler to ensure that it will match antenna system VSWR's from 1:1 to 1.3:1, however, we final tune the combiner with a 1:1 termination at the antenna port. The only adjustment required at time of installation is to adjust the hybrid to match your antenna characteristics. This procedure will be found under "Hybrid Adjustment".

Unless specially designed, all Wacom Products hybrid combiners are provided for installation in standard 19" relay rack panels. We also use Type N connectors as standard due to their superior characteristics over "UHF Series" connectors above 100 MHz. If you must interface with UHF fittings, the necessary UHF to N adaptors must be secured.

Locate the combiner such that a minimum run of cables will be required from the transmitters to the combiner and from the combiner to the antenna feed line. If you use rigid or simi-rigid line to the antenna, make up a suitable jumper to run from the combiner to the heavy line. This will prevent placing undue stress on the hybrid coupler and facilitate the insertion of a portable watt-meter for system test purposes.

Before applying power to the combiner, the hybrid tuning sequence must be accomplished.

HYBRID TUNING PROCEDURE

Test Equipment Required: To successfully adjust the hybrid, the following test equipment is required:

A. A stable signal generator, accurate to ± .005% of frequency setting, and providing signal level output of at least 100 K microvolts. An output level of 1 milliwatt is most desirable.

B. An R.F. signal measuring device having a dynamic range of at least 60 dB below the maximum signal output level of your signal generator. A spectrum analyzer, wave analyzer or a sensitive R.F. voltmeter are among the instruments suitable for this requirement.

Arrange the test equipment as indicated in Figure 2, below.

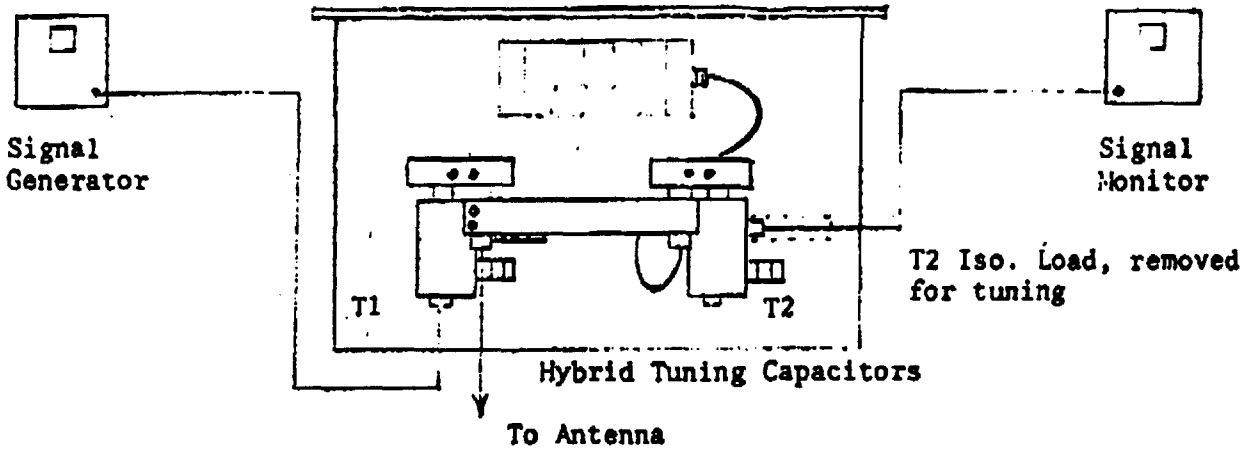


Figure 2

Calculate the mid-point frequency between the two transmitter frequencies being combined (Example: T1=153.500 MHz., T2=153.600 MHz. Test frequency will be 153.550 MHz.)

Proceed as follows:

1. Remove the cover plugs from the hybrid tuning capacitors and unscrew the load termination from the isolator port nearest the hybrid of T2 channel. Connect antenna line to combiner output.

2. Drive the T1 port at test frequency and monitor at the open isolator load port.

3. Alternately adjust the two hybrid tuning capacitors for MINIMUM signal indication. You should secure hybrid isolation of at least 45 dB if the antenna system VSWR is under 1.3:1: Up to 80 dB can be secured with an acceptable antenna system and careful hybrid adjustment.

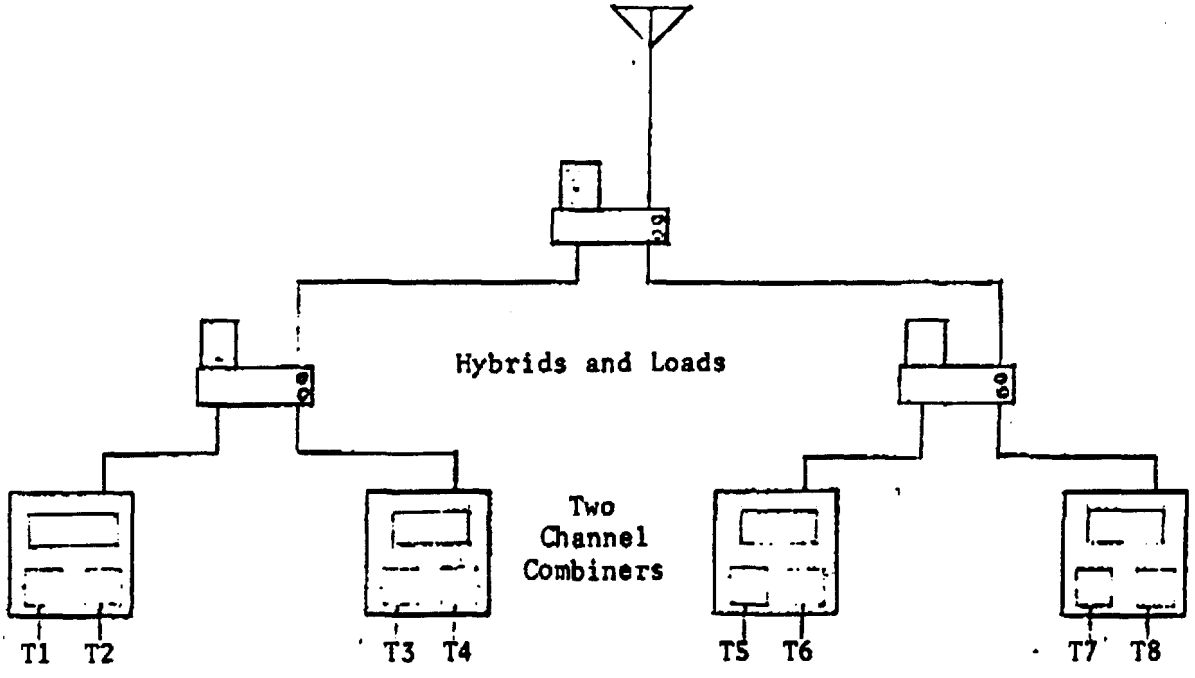


FIGURE 3

In general, these combining arrangements evolve from 2 channel combiners feeding additional hybrids in a "Christmas tree" configuration. When ordered according to requirement, Wacom Products, provides all of the assemblies along with tested cable kits of the proper length and type. Figure 5 shows the racking arrangement for the various combinations of assemblies to combine up to eight transmitters.

Tuning procedure is essentially the same, except that the hybrid nearest the antenna is tuned first, then working back toward the isolators-each adjustment made at a test frequency centered on the mean of the frequencies feeding the hybrid.