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MICROWAVE LINK FOR DATA TRANSMISSION

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Introduction

The success of any long baseline interferometer observations in radio astronomy depends upon the solution of two technical aspects, namely, provision of coherent local oscillator signals at the observing stations and the method of bringing the IF signals, without affecting their phase relationship, to a central location for real time correlation. By the very nature of baseline lengths involved (10 km to 50 km), cable transmission is not a very attractive solution because of the signal losses and dispersion in the cable. Microwave link is a feasible solution to achieve the above objectives and the present report describes such a system for transmission of data from a remote station to the control station in which the phase fluctuations due to atmospheric variations are largely eliminated.

1.0 Design Considerations

The NRAO 3-element interferometer is a double sideband interferometer and has a maximum baseline of 2.7 km and it was felt necessary to extend the baseline to 35 km by locating a smaller dish (45 ft. dia.) at the remote station so that it can be made very effective for the study of small diameter sources such as quasars and nuclei of some external galaxies. The interferometer operates either in dual frequency mode (11 cm and 3.7 cm) or in dual polarization mode at one of the above wavelengths. It can also be operated as a line interferometer at 21 cm wavelength. Hence, the microwave link should be capable of transmitting the above data to the control station and the design specifications are as follows:

1. The carrier frequency of the link should be high so that it (including its harmonics) will not interfere with the existing radio astronomy frequencies that are being used on the site at Green Bank.

2. Two IF channels, each 30 MHz wide (5-35 MHz) should be brought back to the control station and the isolation between the two bands should be at least 40 dB.

3. Digital data giving the information of telescope position and other parameters such as temperature inside the front-end box and total power outputs from the front-end box, etc., should be carried on the link.

4. A 100 kHz signal should be sent back to the control station for use in the phase lock loop of the phase coherent local oscillator system.

5. Voice channel should be provided for communication between the two stations.

Based on the above criteria, it is decided that:

1. The main carrier frequency of the link will be 17. 5 GHz.

2. The two IF bands will be carried as double sideband (AM) signals on the main carrier.

3. Digital data will be carried as FM on a sub-carrier at 87 MHz which, in turn, is transmitted as DSB signal on the main carrier.

4. The 100 kHz and voice signals will be carried as FM on another sub-carrier at 90 MHz which, in turn, is carried as DSB signal on the main carrier.

As the NRAO 3-element interferometer is a double sideband type, the requirements on the stability of IF phases and delay time are not so stringent when compared to a SSB type. However, these variations should be much less than the minimum delay steps introduced in the system for delay tracking. Measurements of path length variations at 9. 6 and 34. 5 GHz over a path length of 64. 25 km (ref. 1) shows that one could expect short-term (20 min. duration) variations of about 0. 2 ns, whereas the long-term (24 hr. duration) variations could be about 1 ns. These variations are quite acceptable in the case of NRAO interfereometer.

1. 1 Transmitter Power Requirements

Maximum baseline	32 km
Minimum signal/noise at the receiver	20 dB
Transmitting and receiving antennae	6 ft. paraboloids
Receiver system noise temperature	1400 °K

Receiver bandwidth	200 MHz
Free space path loss	149 dB
Loss due to multipath fading .... (ref. 2) 99% reliability	20 dB
Loss due to rainfall (ref. 2) .... (rate 10 mm/hr)	30 dB
∴ Total (maximum) path loss	199 dB
Net path loss (after subtracting .... transmitting and receiving antenna gains)	199 - 96 = 103 dB
Receiver input noise power	$k\,T_{sys}\,\Delta F$ = -84 dBm
Signal power required (20 dB S/N)	-64 dBm
Signal power required with synchronous detection	-64 - 3 = -67 dBm
∴ Transmitted power	-67 + 103 = + 36 dBm = 4 watts

A traveling wave tube amplifier operating at 17.5 GHz can be used immediately following the double sideband modulator and will be able to supply the required power.

2.0 General Description of the System

A block diagram of the microwave link system is shown in Figure 1. CH 2 IF is converted up by means of 42 MHz local oscillator signal to occupy the band 47-77 MHz. In addition, part of the 42 MHz signal is also added to the spectrum so that it can be used to convert down the CH 2 IF to its original spectrum (5-35 MHz) at the receiving end. FM sub-carriers carrying the other data are also added to the combined IF spectrum and then used to modulate the 17.5 GHz main carrier in a double balanced mixer. The resulting spectrum is shown in Figure 2a. The output from the DSB modulator goes through a current-controlled ferrite attenuator and then amplified in a TWT amplifier to the required power level. On the receiving end, the received power is first amplified in a low-noise tunnel diode amplifier and then mixed with a 17.4 GHz local oscillator signal to obtain the spectrum as shown in Figure 2b. The resulting spectrum is symmetrical with respect to the 100 MHz signal which is the difference between the link carrier frequency and the local oscillator signal of the first converter. Assuming that these two oscillators (17. 5 GHz and 17. 4 GHz) are stable oscillators, one can see that the resulting 100 MHz signal contains the information regarding phase and amplitude variations caused by the atmospheric variations in the link path. Hence, this 100 MHz signal is used to control the amplitude of the signal spectrum (AGC action) and also generate a second local oscillator (VCXO) signal whose phase is the same as that of the 100 MHz signal in a phase lock loop. After mixing the IF spectrum with the phase locked oscillator (100 MHz) signal, we get back the spectrum with which we originally modulated the 17. 5 GHz carrier. The received spectrum, after second conversion, is shown in Figure 2c. CH 1 IF is separated out by means of a low pass filter and CH 2 IF is converted down to its original spectrum by means of the 42 MHz carrier. FM sub-carriers are separated out and detected in the FM receiver.

One technique which is employed and found very useful in obtaining good isolation between the two IF bands to introduce a certain amount of delay (60 ns in the present case) in one of the IF bands before modulation on the main carrier and then introduce the same amount of delay in the other IF band after they are separated in the receiver.

2. 1 Double Sideband Modulator and Transmitter

Block diagram of the DSB modulator and transmitter is shown in Figure 3. The carrier oscillator (17. 5 GHz) is a phase locked Gunn oscillator manufactured by Micromega. The primary reference is a crystal controlled oscillator around 100 MHz. The quoted stability of the phase locked oscillator is 1 p. p. m. over a 24-hour period and puts out 25 mW of power. The Gunn oscillator can also be locked to an external oscillator of better stability and about the same frequency as that of the crystal oscillator. A current-controlled ferrite attenuator is introduced between the DSB modulator and TWT amplifier so that the transmitter power could be controlled (remote operation) in case of severe fading due to bad atmospheric conditions. The TWT amplifier is capable of putting out 10 watts (saturated) power and has a maximum gain of 48 dB. Output power from the TWT amplifier is monitored by means of a 20 dB directional coupler and displayed on the front panel meter. A photograph of the front panel and the component layout inside the chassis of the DSB modulator is shown in Figure 4.

2.2 FM Modulator

A block diagram of the FM modulator is shown in Figure 5a. Detailed circuit diagrams are given in Figure 5b. A photograph of the front panel view and the component layout is shown in Figure 6. Voltage-controlled transistor oscillators are used as FM modulators at both the frequencies, 87 and 90 MHz. In order to improve the center frequency stability of the VCO, a portion of the output is fed to an accurately tuned frequency discriminator which is included in a feedback loop containing the FM driver and VCO. FSK modulation is employed in the case of the digital data which is at a rate of 2.5 kHz. Modulation index can be adjusted by means of a front panel control and is usually set at 3 or more. It is also displayed on the front panel meter. In the case of 100 kHz signal, modulation index cannot be increased beyond 1 because of limitations on the maximum rate of VCO tune. Audio modulation index is generally set by listening to the voice quality coming down the link.

3.0 Receiver — Front-End Box

This box is mounted at the back of the 6-ft dish and is temperature controlled. The power received by the antenna is first amplified in a low noise (NF = 5.5 dB) tunnel diode amplifier of medium gain (G = 15.5 dB) operating at 17.5 GHz and then mixed with a local oscillator signal at 17.4 GHz in a waveguide balanced mixer. The local oscillator signal is obtained from a phase locked Gunn oscillator, similar to the one used in the transmitter. The converted spectrum (0-200 MHz) is then amplified in a low noise (2.8 dB) wideband IF amplifier and sent down the tower to the control building. A block diagram of the electronics contained in the front-end box is shown in Figure 7.

3.1 Receiver

Block diagrams of the main receiver are shown in Figures 8a and 8b and the individual circuits are shown in Figure 8c. A photograph of the front panel, top and bottom views of the receiver chassis, is shown in Figure 9. The incoming signal spectrum (0-200 MHz) is first amplified and then passed through a MIC amp-attenuator whose AGC terminal is controlled by the amplitude of the 100 MHz signal. The bias to the control terminal is also displayed on the front panel meter marked receiver gain and the mean level can be set at any desired gain level by means of a 10-turn potentiometer (marked gain) accessible on the front panel. When set at the mid-position on the meter, AGC action is effective for approximately 25 dB variation of RF input signal to the attenuator. If the input signal varies beyond the above range (due to increased path losses because of heavy rain, etc.), transmitted power may be controlled by means of the current-controlled ferrite attenuator inserted before the TWT amplifier. Table 1 gives the total RF power (as measured by means of a power meter) at the 100 MHz mixer for different settings of gain potentiometer, assuming AGC action is effective.

TABLE 1

Gain Potentiometer Setting	Power Input to 100 MHz Mixer (dBm)
0	-16.7
5	-14.4
10	-12.5
15	-11.0
20	-9.9
25	-9.0
30	-8.1
35	-7.4
40	-6.7
50	-5.6

Apart from generating the AGC voltage, the 100 MHz signal is also used to generate a phase-coherent local oscillator signal (100 MHz) in a phase lock loop as shown in the block diagram. Phase of the 100 MHz RF input to the mixer can be made exactly equal to the local oscillator signal derived from PLL by means of the phase trimmer provided in the PLL branch. When this happens, the amplitude of the converted signals will be maximum. The loop filter in the phase lock system is a passive second order loop followed by a DC amplifier of gain of 100. The loop bandwidth is

5 kHz. The phase lock loop has a pull-in range of ± 30 kHz and a lock-in range of ± 300 kHz. VCXO has harmonics separated every 2 MHz and so we have to use a band pass filter in order to reduce the harmonics. They are about 50 dB down after the filter. Cosine output from the phase comparator is used for display on the front panel meter to indicate the condition of lock. 100 MHz PLL MONITOR output on the front panel can be connected to a scope while obtaining lock by means of bias knob on the front panel. This bias effectively increases the pull-in range to ± 80 kHz.

After the second conversion in the 100 MHz mixer, the whole input spectrum gets folded and occupies from 0-90 MHz. FM side bands are routed to the FM receiver while IF sidebands are separated in the IF Processor. CH 1 IF is separated by means of a low pass filter and amplified to the required level. CH 2 IF is separated by means of a high pass filter and down conversion with the help of the 42 MHz sub-carrier present in the spectrum. Total power present in the two IF bands can be monitored by means of the front panel meter. They are also present at the back connectors for computer sensing. LOCK indicator voltage (approximately 7 V) is also available at the back panel connector for display at the console.

3.2 FM Receiver

87 MHz and 90 MHz FM sub-carriers are first separated by means of band pass filters and then passed through limiters before they are fed to frequency discriminators. Block diagram of the FM receiver is shown in Figure 10a while Figure 10b shows the individual circuits. A photograph of the front panel and component layout inside the chassis is shown in Figure 11. Digital data and 100 kHz signals coming out of the FM receiver are monitored by means of the front panel meter.

4.0 Operation and Maintenance

Dual frequency or dual polarization operation: Connect the two IF outputs from the 45-ft front-end box to CH 1 and CH 2 IF inputs at the back panel of the DSB modulator chassis. All the signal levels in the modulator are adjusted for -3 dBm inputs of IF bands. Connect digital data, 100 kHz and voice signals to the input connectors provided at the back panel of the FM modulator chassis. With the front panel switch in DIG-DATA position, adjust the modulation index (screw driver adjustment) to approximately mid-scale (10 V scale) on the front panel meter. Next switch to 100 kHz and adjust the modulation index to full scale (10 V scale). Remove the 100 kHz input, keep the switch in AUDIO and adjust the AUDIO ADJ. so that the meter reads approximately half scale (1 V scale). Connect back the 100 kHz input. For switching on the TWT amplifier, follow the instructions given in the instruction manual. The front panel meter on the DSB modulator is calibrated such that it reads mid-scale for 1 watt power at the TWT amplifier output.

At the receiver end of the control station, one may have to turn the PLL bias knob to obtain the lock. Turn the knob to mid-position after obtaining the lock. Lock indicator reading should be around 0. 7 on the front panel meter. If the gain meter reads full scale, front panel attenuator may have to be decreased because the input signal level is low. The gain meter reading will also be affected by the gain pot setting. Adjust the gain pot so that the total power outputs of CH 1 and CH 2 read approximately 0. 3 on the front panel meter. This will correspond to -3 dBm IF outputs. Whenever the gain pot is adjusted, care has to be taken to retune the phase trimmer for maximum IF outputs. The front panel attenuator may be adjusted so that the gain meter reads approximately 0. 4. In this position, AGC action is effective for 25 dB variation of signal input.

For line frequency (21 cm) operation, terminate CH 2 at the power combiner as shown in Figure 3. Feed the line IF to CH 1. On the receiver end, by-pass the low pass filter in CH 1 as shown in Figure 8b so that the whole spectrum (22 MHz — 82 MHz) is available at CH 1 IF out. One may have to introduce a sharp cut-off low pass filter (0-82 MHz) if the FM sub-carriers (87 and 90 MHz) give trouble.

Maintenance of the equipment is relatively simple. On the transmitter side, one may have to retune the frequency discriminators located in the FM modulator chassis if the center frequency drift is excessive. Zero crossing frequency of the frequency discriminator determines the center frequency of that particular VCO. It can be adjusted either by retuning the detectors or by adjusting zero adj. potentiometers. The latter adjustment may introduce a slight non-linearity. It can also be adjusted by the CENTER FREQ. adjust potentiometer in the FM driver and feedback control box in the FM modulator chassis. TWT amplifier tube may have to be replaced after 10,000 hours of operation. The instruction manual may be referred to for that information.

On the receiver end, we do not expect major maintenance. Frequency discriminators in the FM receiver chassis may have to be retuned if any similar changes are made in the transmitter side. Most of the performance checks are monitored on the front panel meters and hence trouble-shooting is relatively easy. If it becomes difficult to obtain lock, check the input (IF input) to the receiver on a spectrum analyzer. 100 MHz signal should be at least -50 dBm for satisfactory operation.

The microwave link system has been field tested on a shorter baseline (approximately 2.5 km) with a horn as the transmitting antenna and the 6-ft dish as the receiving antenna. With a transmitting power of 1 watt, it gave reasonably good performance even though signal strengths are about 16 dB less than the predicted values. It is believed that this is attributable to the obstruction caused by trees along the transmission path.

Acknowledgements

I am very grateful to Dr. S. Weinreb for his continued encouragement and advice during the progress of this project and also for making this visit to NRAO possible by offering me a visiting appointment. I have had many helpful discussions with J. Coe during the course of this project and received a great deal of help during the testing stage. R. Ervine assisted in construction of this equipment.

References

1 H. B. Janes, M. C. Thompson, Jr., D. Smith and A. W. Kirkpatrick, "Comparison of Simultaneous Line-of-Sight Signals at 9.6 and 34.5 GHz", IEEE Trans. Antennas and Propagation, AP-18, pp. 447-451, July 1970.

2. Reference Data for Radio Engineers, 5th Edition, ITT.

<u>List of Figures</u>

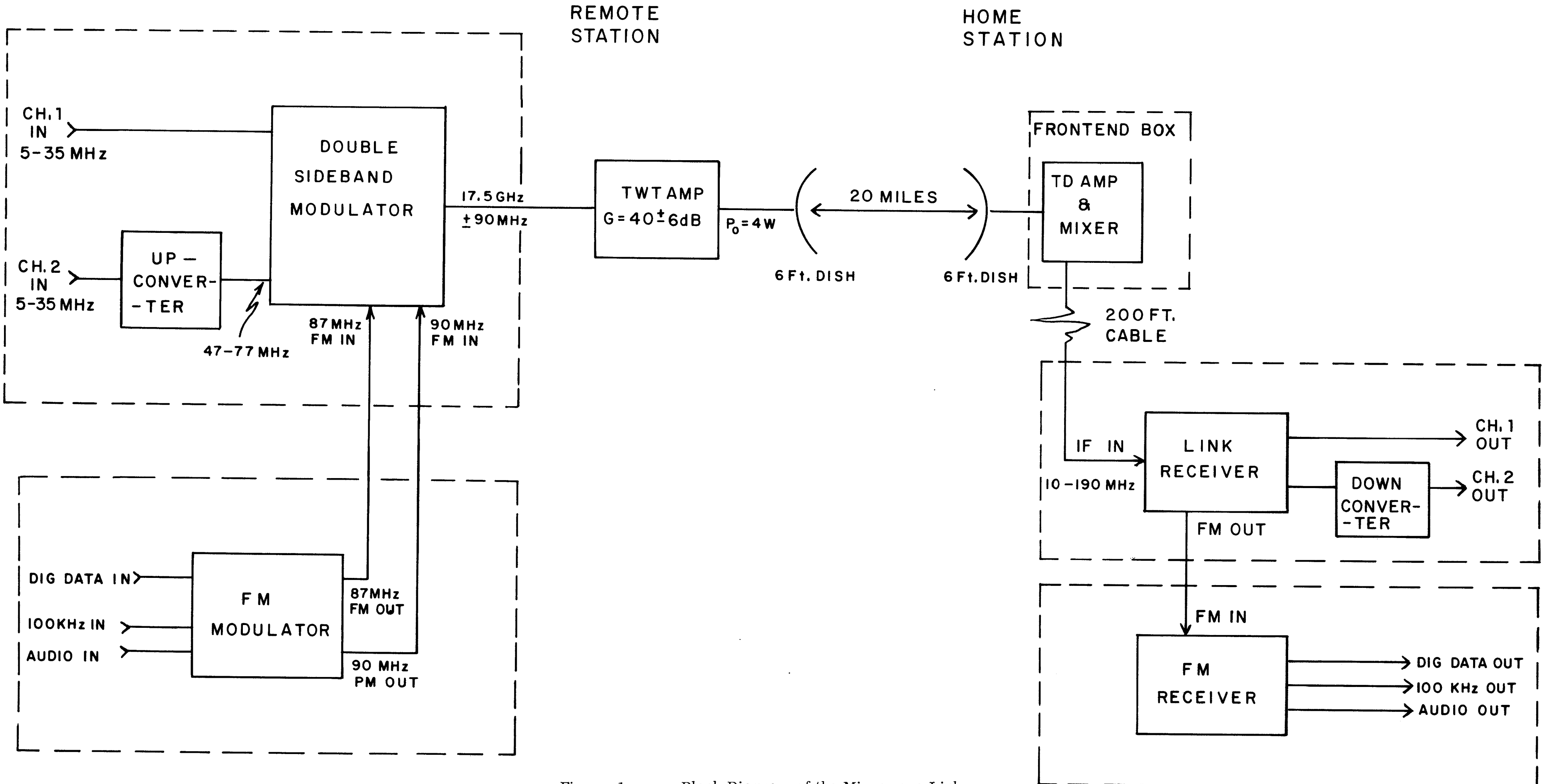


Figure 1 — Block Diagram of the Microwave Link

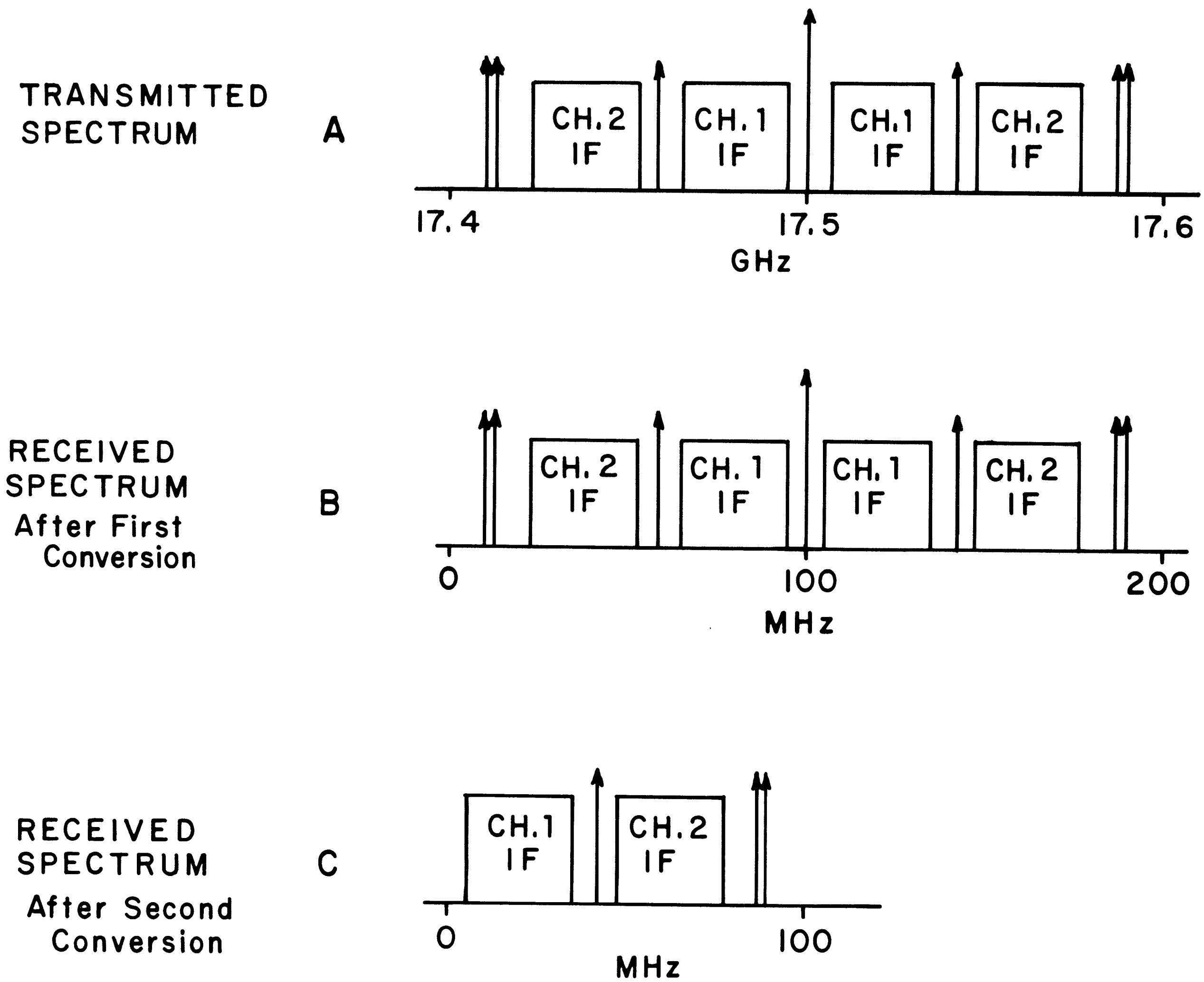


Figure 2 — Sideband Locations in the Spectrum

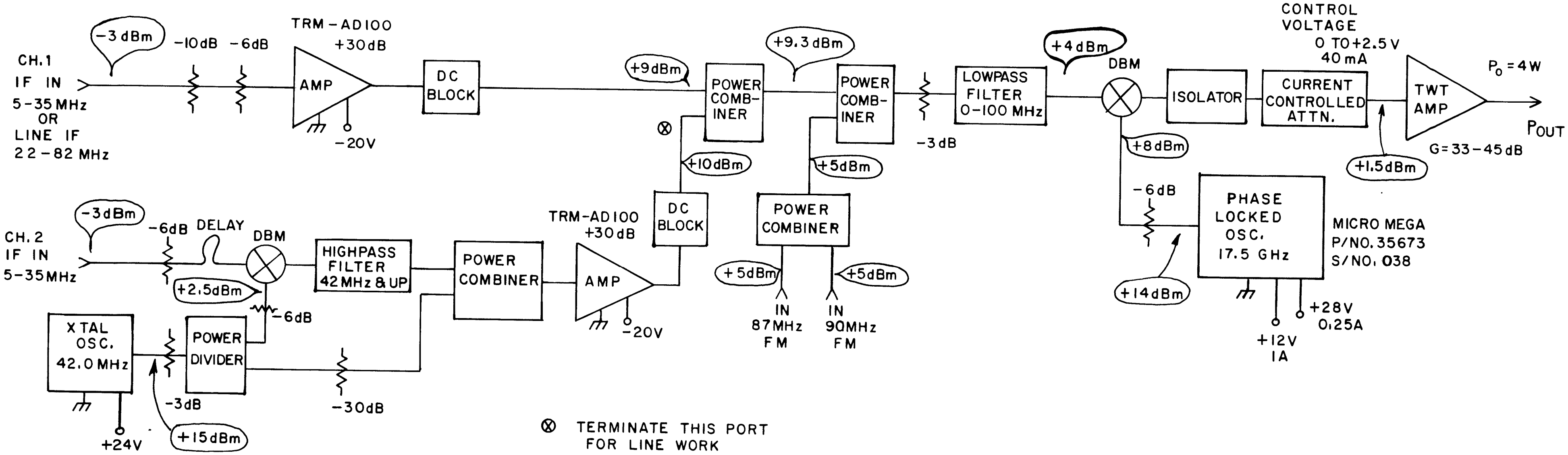


Figure 3 — Double Sideband Modulator and Transmitter — Block Diagram

ID

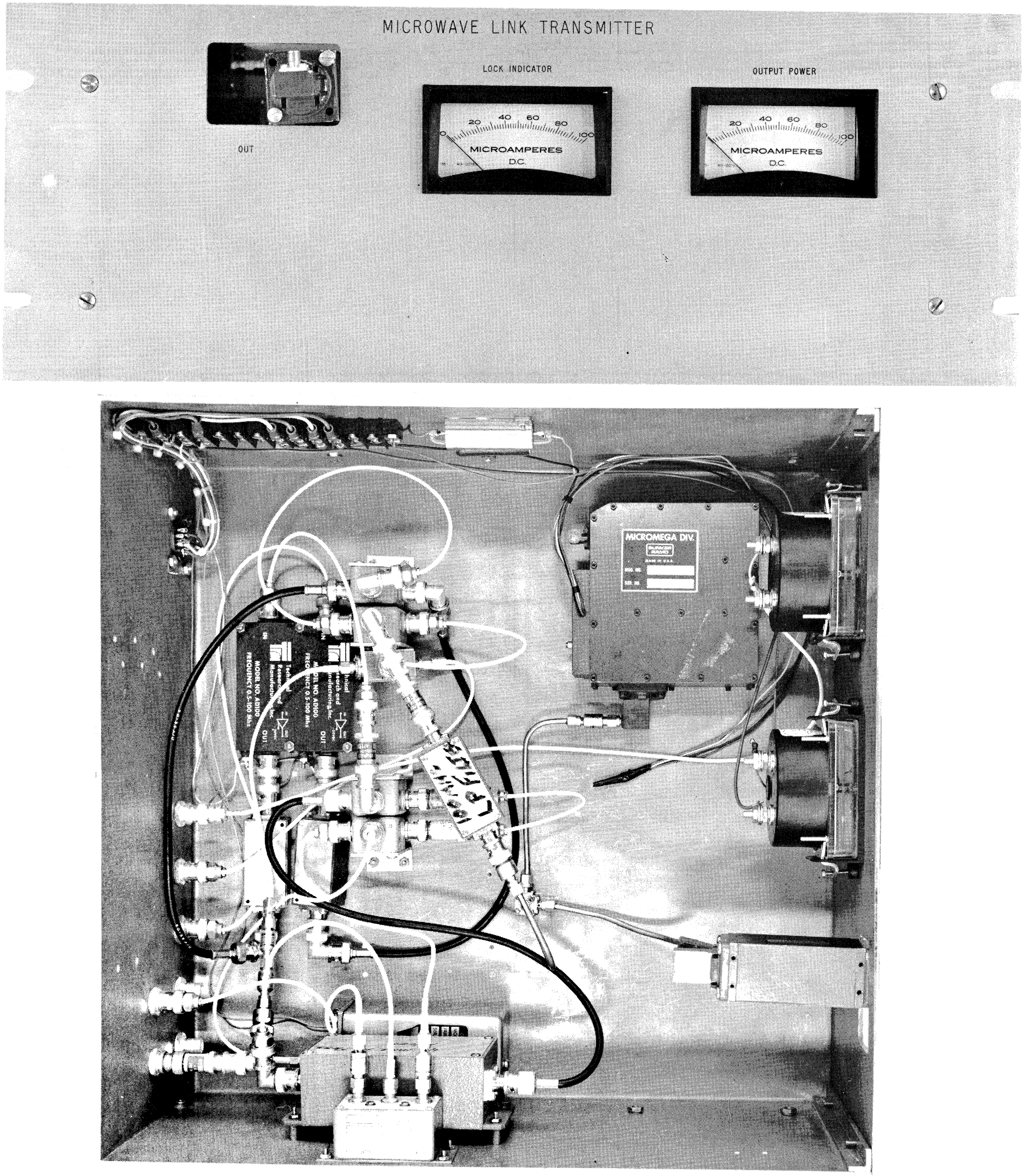


Figure 4 — Front Panel and Top View of the DSB Modulator

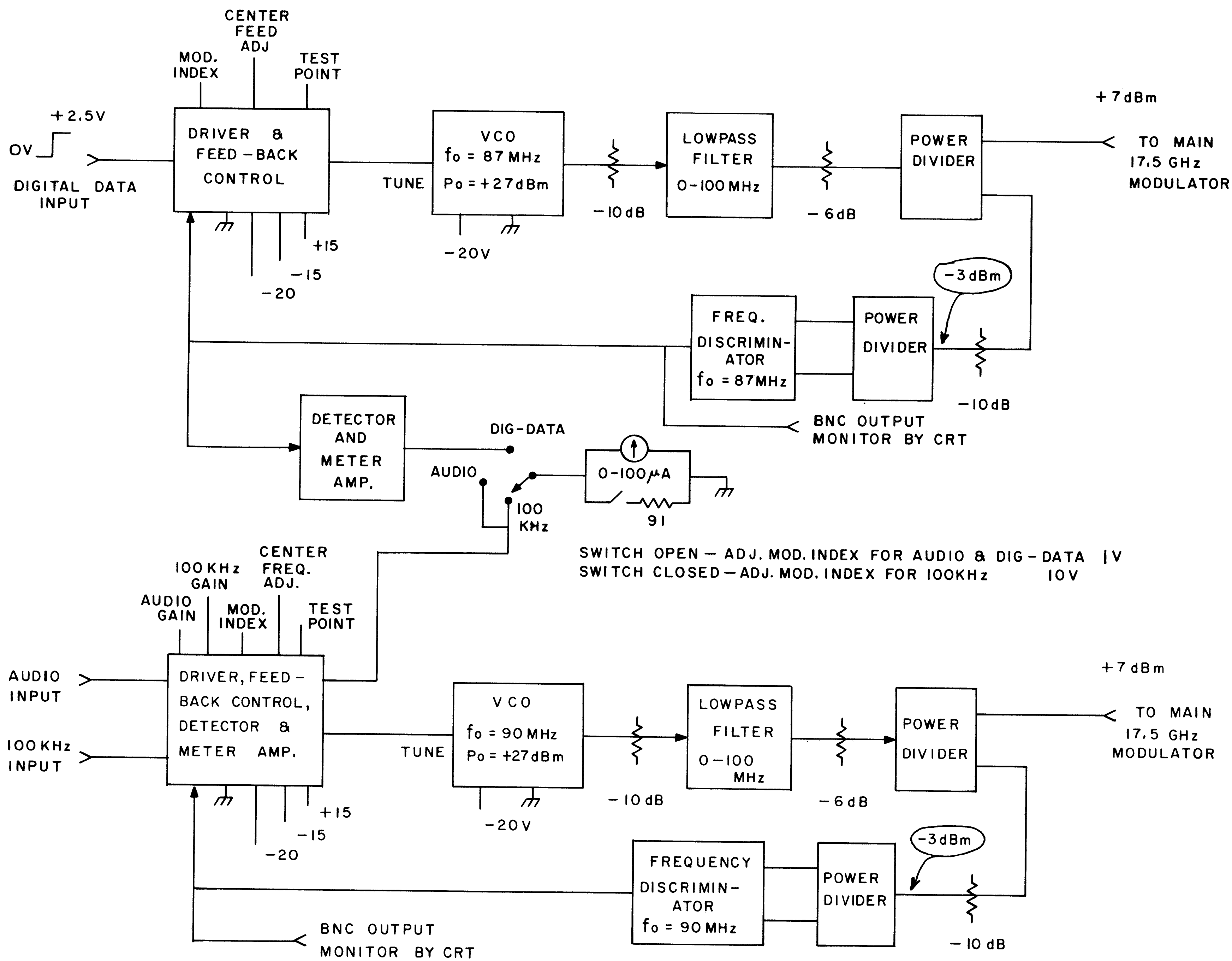


Figure 5a — FM Modulator — Block Diagram

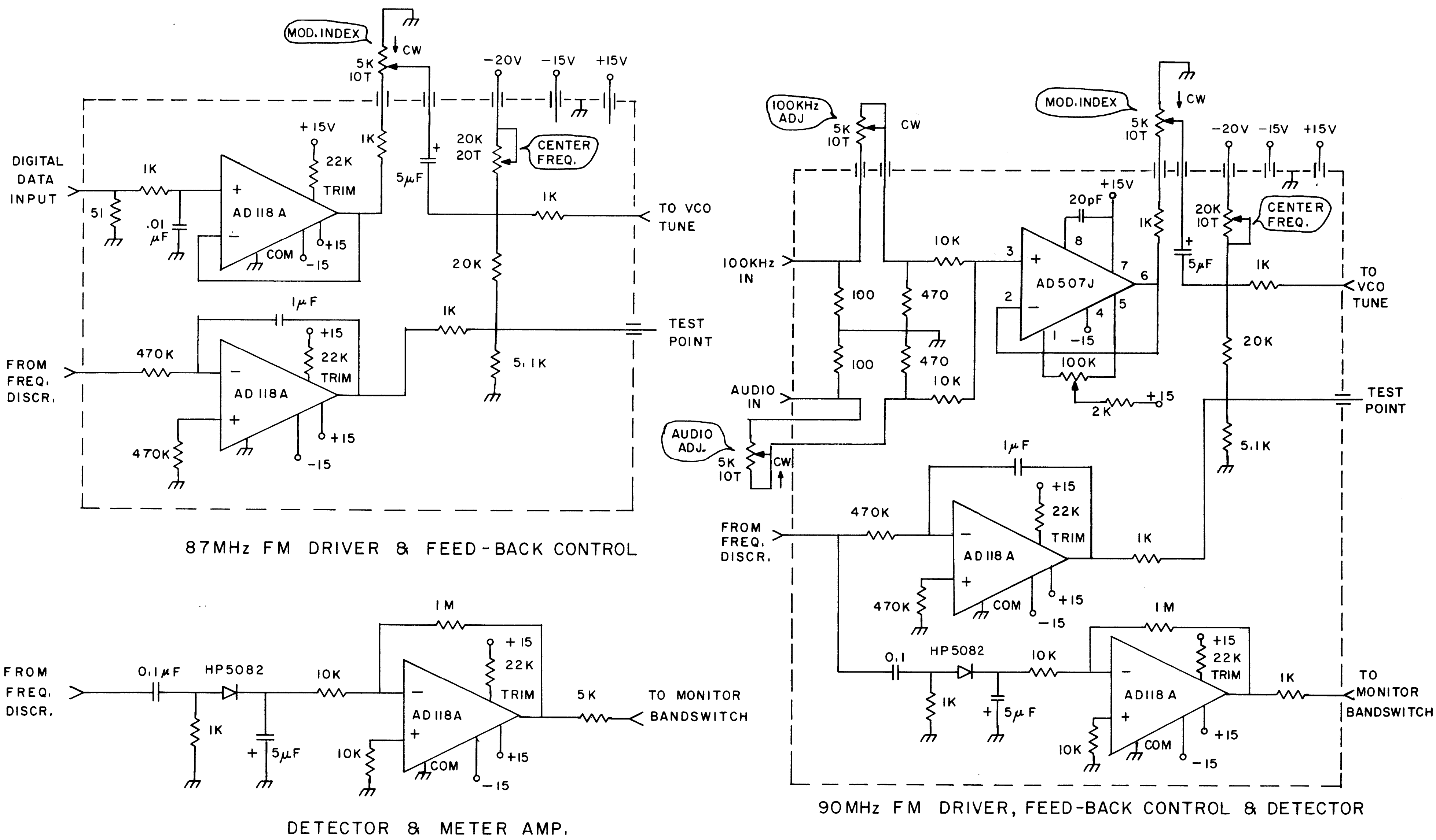


Figure 5b FM Modulator — Individual Circuits

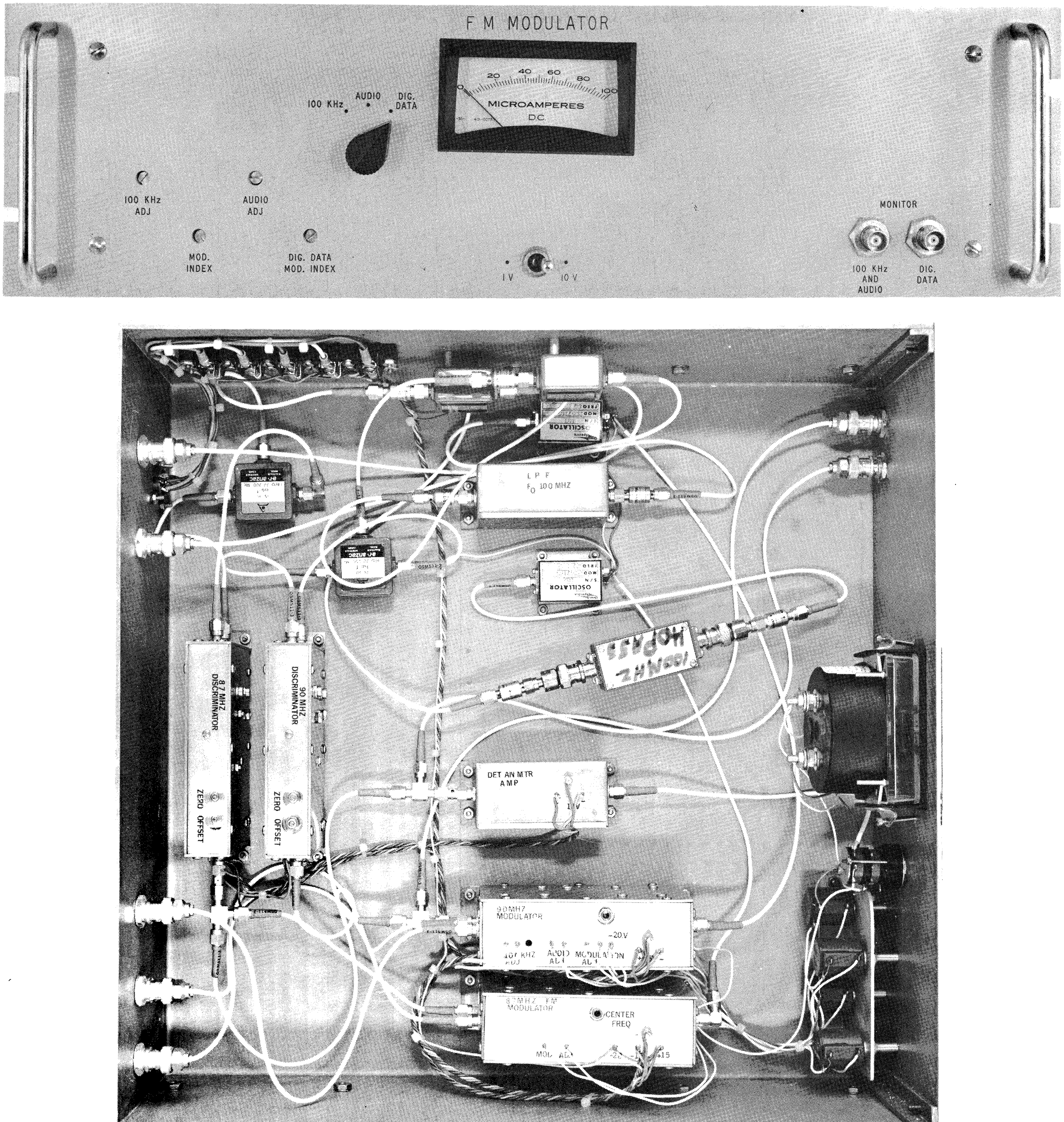


Figure 6 — Front Panel and Top View of the FM Modulator

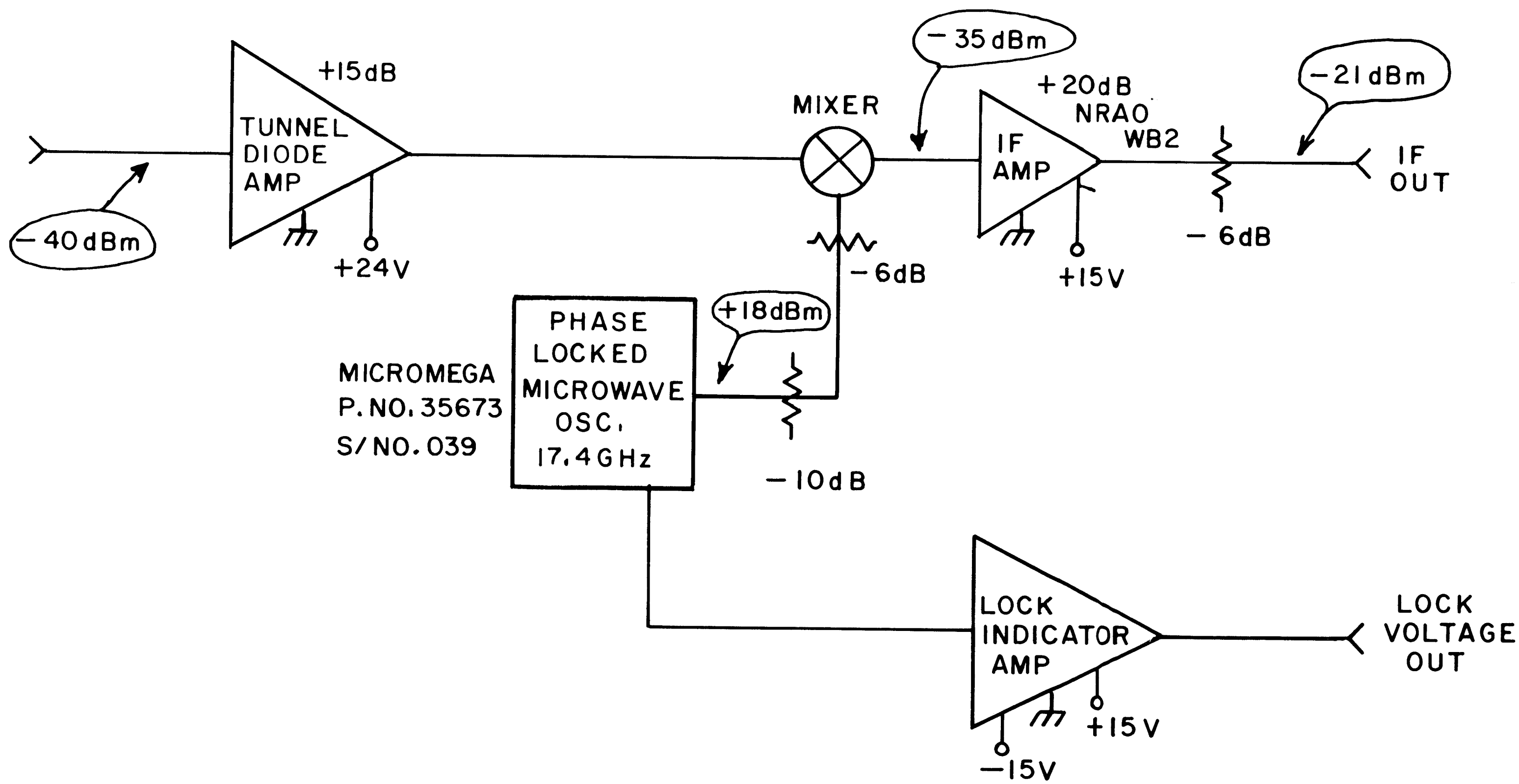


Figure 7 — Link Receiver Front-End Box — Block Diagram

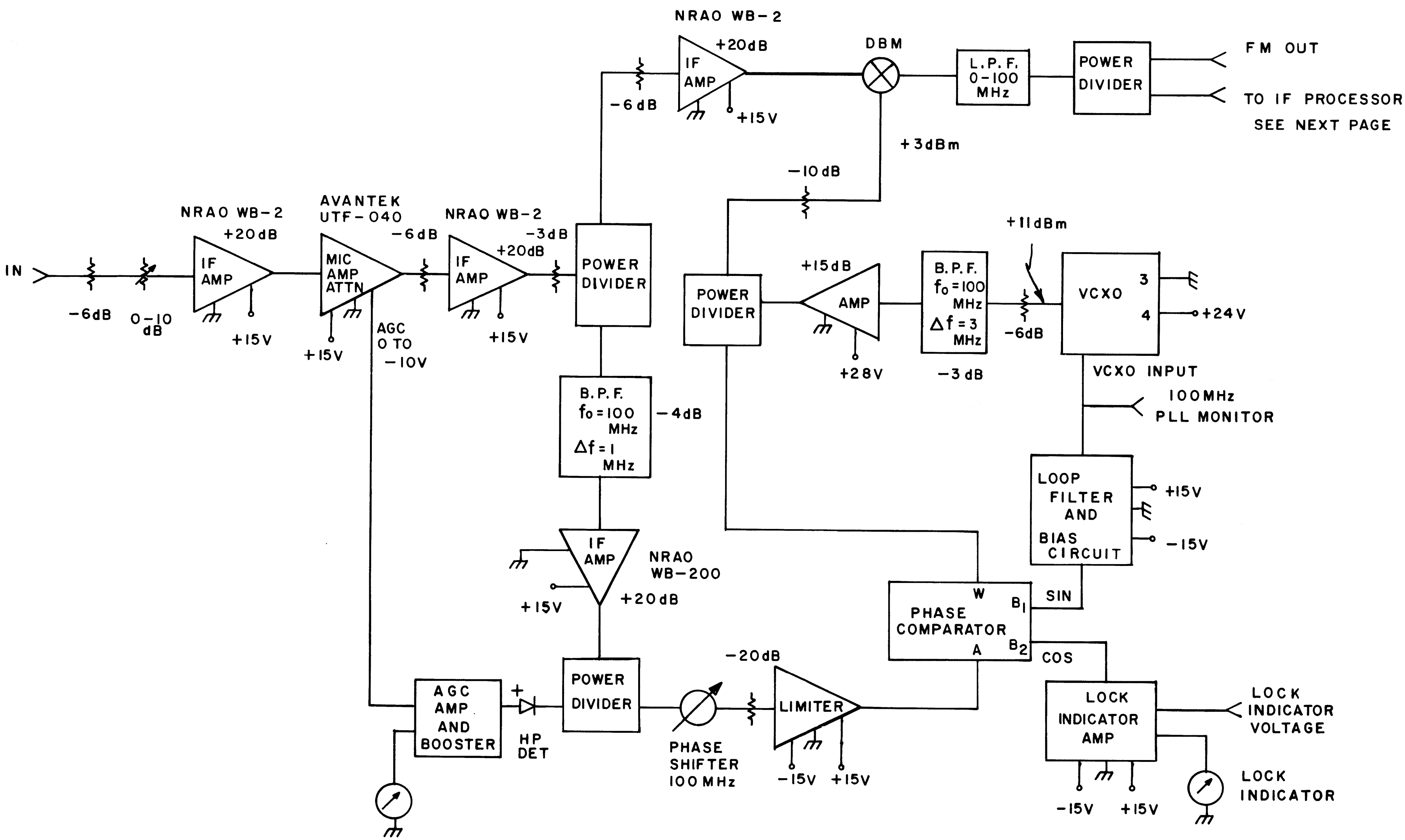


Figure 8a — Line Receiver — Block Diagram

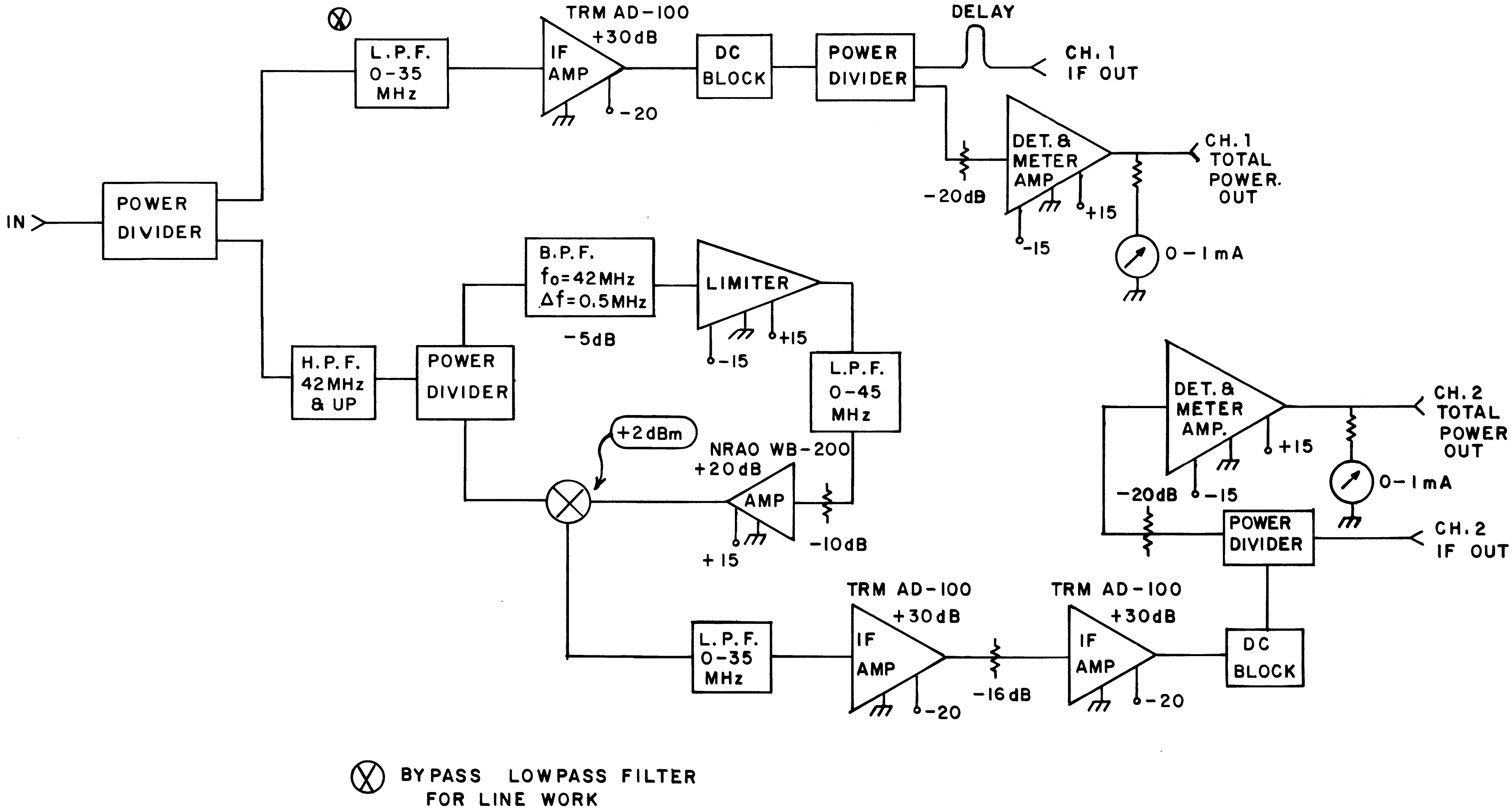
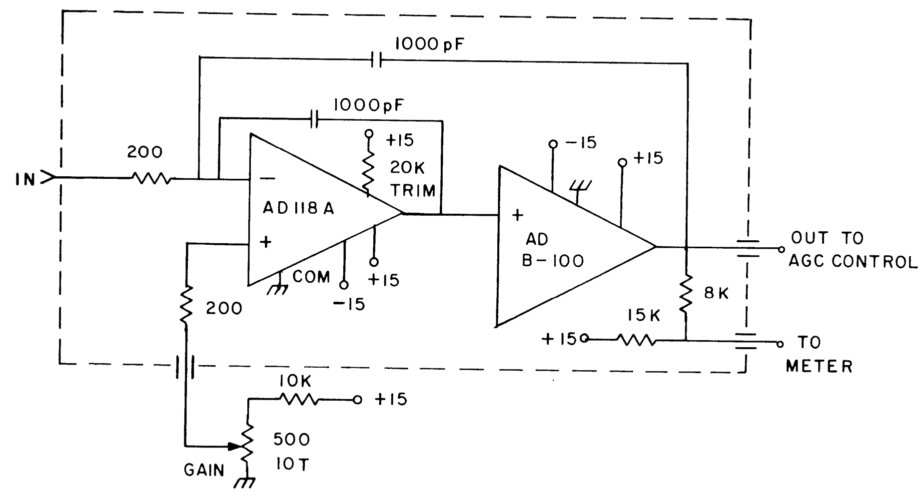
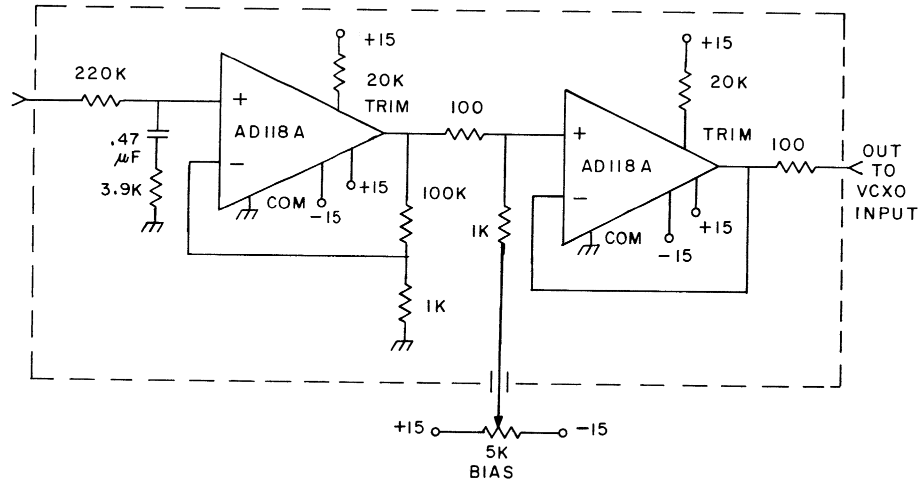


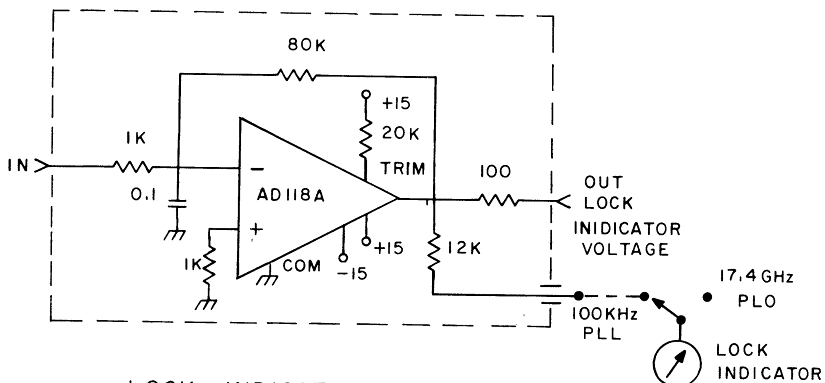
Figure 8b — Link Receiver — IF Processor — Block Diagram



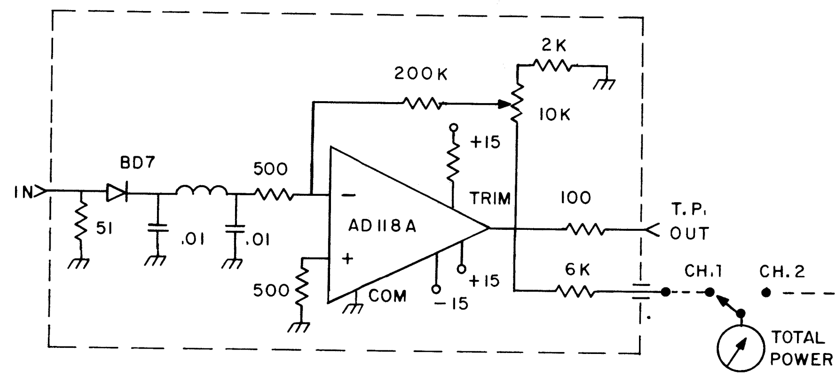
AGC AMPLIFIER & BOOSTER



LOOP FILTER & BIAS CIRCUIT



LOCK INDICATOR AMPLIFIER



SQUARE-LAW DETECTOR & METER AMPLIFIER

Figure 8c — Link Receiver — Individual Circuits

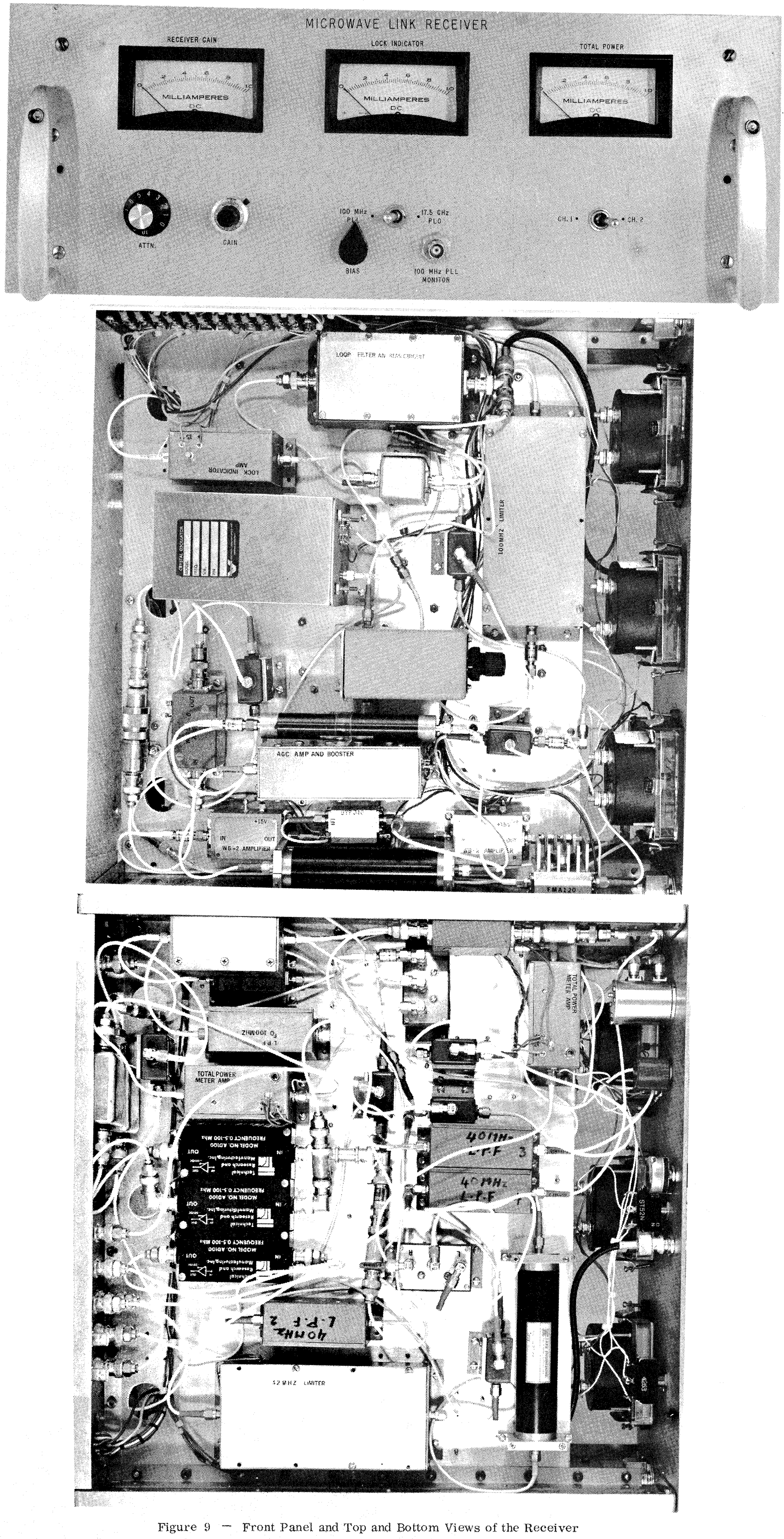


Figure 9 — Front Panel and Top and Bottom Views of the Receiver

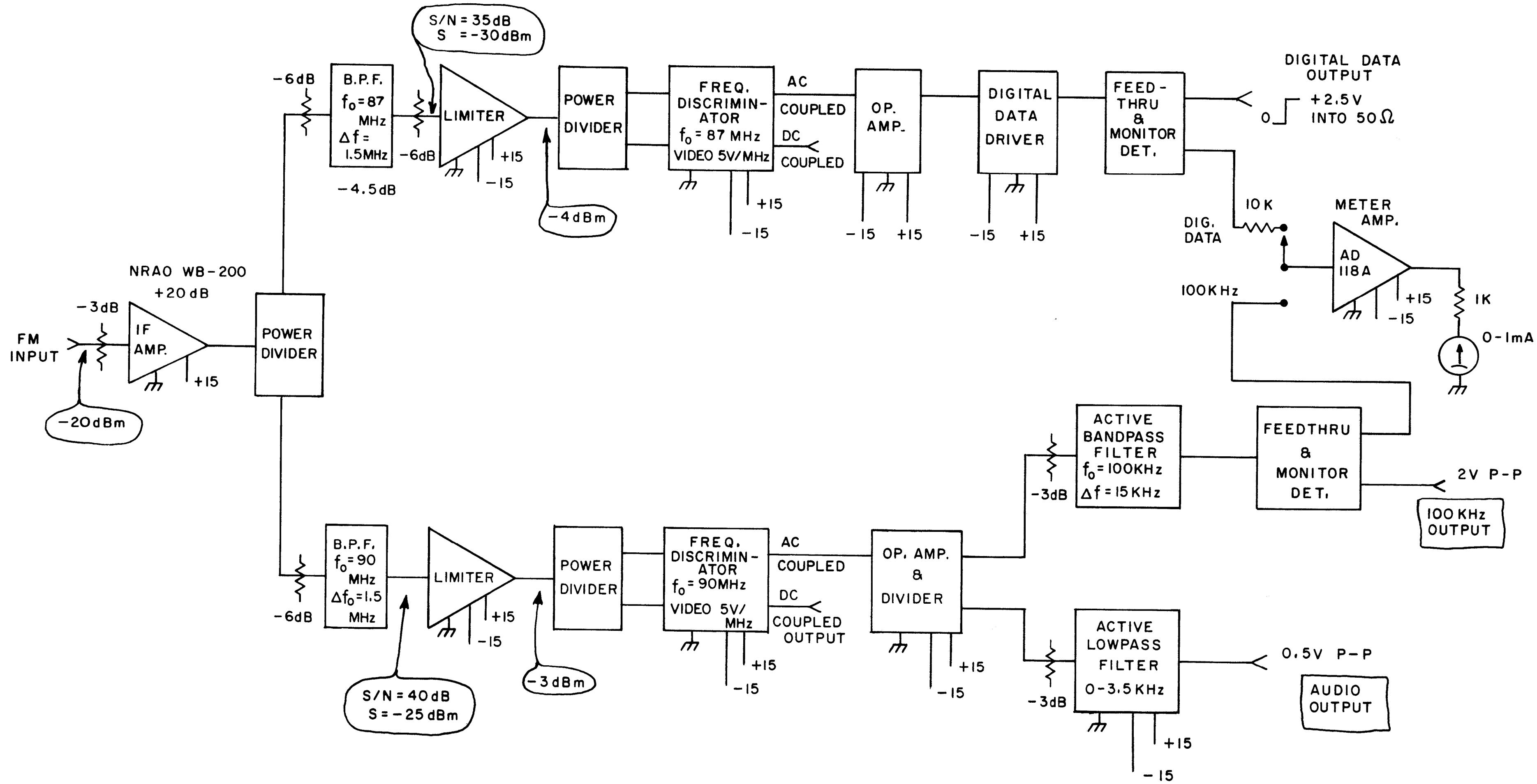


Figure 10a — FM Receiver — Block Diagram

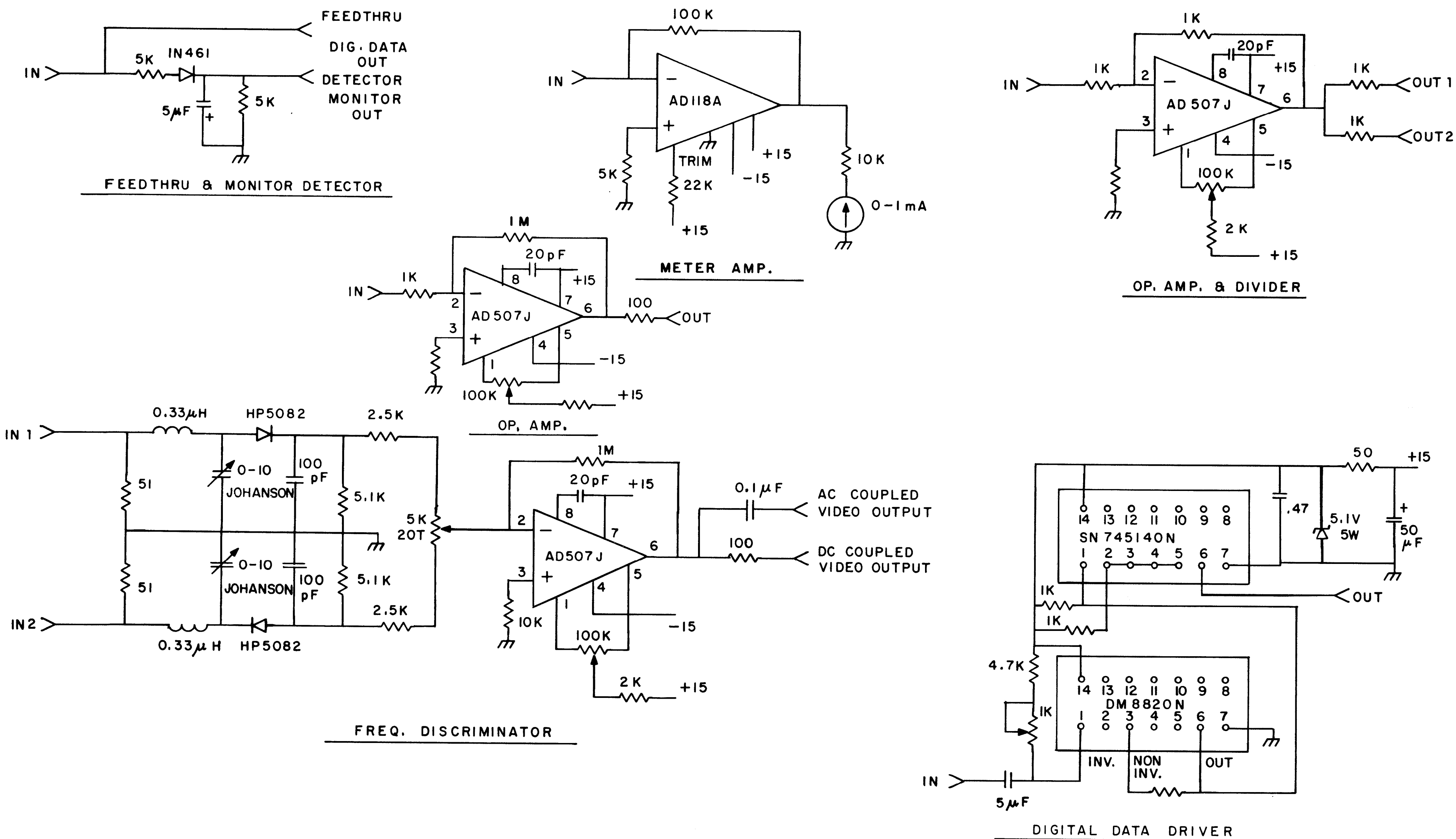


Figure 10b — FM Receiver — Individual Circuits

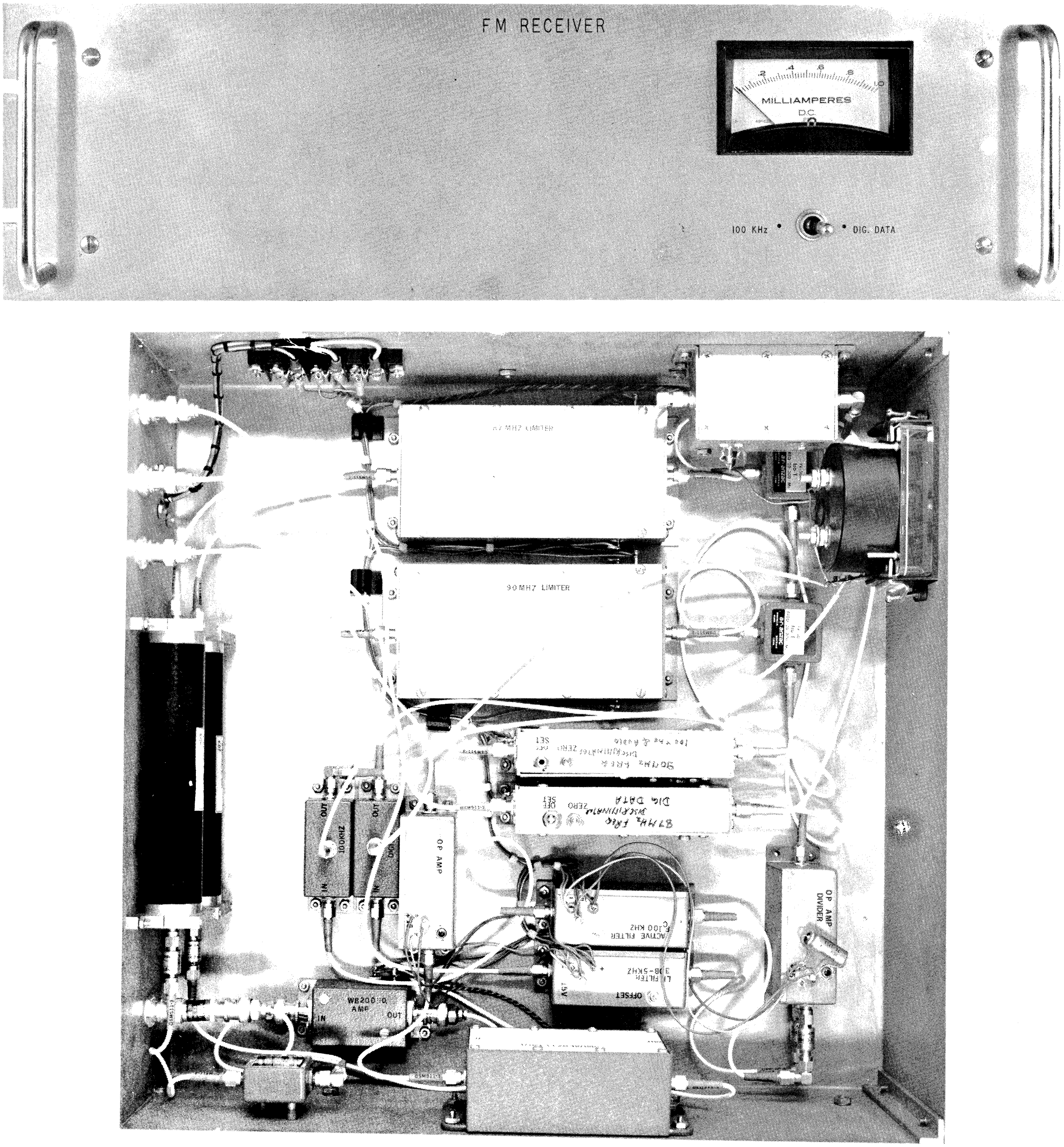


Figure 11 — Front Panel and Top View of the FM Receiver