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COUSTIC BACKGROUND
T THE EARTH'S SURFACE

Final Report

JOHN W. WESCOTT
S. STEVEN KUSHNER

ACOUSTICS AND SEISMICS LABORATORY
Institute of Science and Technology
THE UNIVERSITY OF MICHIGAN

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ACOUSTIC BACKGROUND AT THE EARTH'S SURFACE
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ABSTRACT

Acoustic background noise at the earth's surface for frequencies from 0.2 to 100 cps was monitored outdoors with two low-frequency condenser microphones placed 1500 feet apart. The wind speed at each microphone was monitored with cup anemometers. Data were transmitted by microwave links to a central receiving station and recorded on magnetic tape. The acoustic data were preemphasized 6 db/octave before transmission to improve signal-to-noise ratios.

Oscillograms of the multichannel acoustic data show cross-correlations by visual inspection for the sounds radiated from upper-air turbulence and aircraft. Oscillograms of noise generated locally by surface winds show no apparent cross-correlation.

Details of instrumentation are presented. These include a block diagram of the detection, data-link, and recording system and circuit diagrams of components developed for it. A pistonphone calibrator with pushbutton frequencies from 0.125 to 30 cps is described, and its use for amplitude and phase calibration of microphones is explained.

1
INTRODUCTION

The object of this project was to investigate the nature and sources of acoustic background noise at the earth's surface. The results relate to the problem of acoustic detection and location of target sound sources at long ranges. The detection system is arbitrarily specified as a four-element array of low-frequency microphones placed at the corners of a 1500-foot square. For this report, however, only two microphones were used. The sources of background noise against which desired signals are detected fall into two categories — natural and man-made. Both types were investigated and, in the frequency range of interest (0.2 to 100 cps), were found to have consistent spectrum shapes. Because of this an equalizing or spectrum-shaping network with a transfer function approximating the inverse of background noise was developed for the microphone amplifiers in order to improve overall s/n.

Wind speed was monitored at each microphone station and then compared with acoustic background levels. The comparison confirmed reports from other investigators that local surface winds are the principal source of natural background noise and that the pressure level of this noise is roughly proportional to the square of wind speed. When surface winds were zero it was possible to detect the sound radiated from upper-air turbulent winds. This was confirmed by visually cross-correlating the outputs of two microphones.

Man-made noise from nearby aircraft and motor vehicles was often found to be at levels of 1 dyne/cm^2 peak-to-peak in the infrasonic data range from 0.2 to 1.5 cps. Much higher noise levels at frequencies above 20 cps were removed by the aforementioned equalizing networks. This prevented amplifier overloading from aircraft noise that was often present since the detecting array was unavoidably located at a commercial airport.

Highway restrictions, buildings, and other factors made it impractical to run wire lines from microphone stations to the data-collection center. Accordingly, a microwave data-link system was developed as a substitute for wire lines. This should be of more than passing interest because its use will permit expanding the dimensions of the array to several miles. This in turn should result in improved low-frequency resolution and azimuth determination of target sound sources. Details of the data-link system are presented in the event that it should prove practical for use in other arrays.

Data processing for this report included visual comparison of oscillograms. By this method it was possible to determine significant cross-correlation of signals from two microphones at frequencies of 0.2 to 0.5 cps for sounds radiated from aircraft and for sound radiated from upper-air turbulence. The same technique was tried without much success for the next higher frequency range, 0.5 to 1.5 cps. There may well be significant cross-correlation for the same sound sources in this range; however, verification would require the use of a cross-multiplying and integrating process to obtain the actual correlation function.

2
CONCLUSIONS

Evidence to support the conclusions which follow consists of calculations, graphs, oscillograms, and text which appear later in this report.

(1) Sound radiated from upper-air turbulence produces acoustic pressures of 0.1 to 3 dynes/cm^2 peak-to-peak in the frequency band from 0.5 to 1.5 cps at the earth's surface in still air.

(2) Piston and jet-engined aircraft produce acoustic pressures of about 1 dyne/cm^2 peak-to-peak at frequencies from 0.5 to 1.5 cps at microphones on the earth's surface when the aircraft are several miles distant. Aircraft landing and taking off near these microphones produce acoustic overload unless frequencies above 20 cps are severely attenuated.

(3) Significant cross-correlation of signals from two microphones occurs in the infrasonic data range of 0.2 to 0.5 cps for sound radiated from upper-air turbulence. This correlation may also be present in the 0.5- to 1.5-cps range, but simple visual comparison of oscillograms does not reveal it.

(4) Local surface winds do not produce cross-correlations among the microphones in a widely spaced array.

(5) Local surface winds produce pressure fluctuations proportional to the square of wind speed at a microphone diaphragm placed four inches above the ground. A 5.5-mph wind produces 1 dyne/cm^2 peak-to-peak fluctuations at frequencies from 0.5 to 1.5 cps.

(6) Flow noise alone, generated by moving a microphone at constant speed through still air, produces pressure fluctuations proportional to the square of air speed and about 91% as great as those produced outdoors by wind. Thus, most of the pressure fluctuations associated with local surface winds are due to flow noise generated at the microphone housing.

(7) The pressure spectrum of acoustic background noise from natural sources falls off with frequency at rates of 6 to 10 db/octave in the infrasonic data range.

(8) The pressure spectrum of man-made background noise generally increases with frequency in the region from 20 to 100 cps.

(9) An equalizing network inserted in the microphone amplifier improved s/n in the infrasonic data range and prevented overloading in the audible range. From conclusions 7 and 8 the network was designed to preemphasize at 6 db/octave to about 20 cps and to de-emphasize rapidly (12 db/octave) at higher frequencies.

(10) Substituting microwave data links for wire lines suggests that microphone array dimensions might be increased to several miles to improve low-frequency resolution and azimuthal accuracy. The data links employ corner-reflector antennae, Signal Corps Radiosonde Transmitters Type AN/AMT-4A, Rawin Receivers Type R-301D/GMD-1, and auxiliary PFM demodulators accommodating both the infrasonic data range and a subcarrier modulated by wind-speed data.

(11) Monitoring of wind speed at each microphone station aids in determining whether an increase in infrasonic signal level is due to propagating sound or increasing local winds.

3
DISCUSSION OF RESULTS

The chief concerns of the research on which this report is based were: (1) to study the major and most persistent sources of acoustic background noise from frequencies of 0.2 to 100 cps at the earth's surface, (2) to devise schemes for minimizing the effects of this noise on ground-based microphone or microbarograph arrays, and (3) to improve the array system in any way possible. The discussion which follows deals with the results of work done to satisfy the above three research objectives. In addition, the eleven conclusions listed in the preceding section present in capsule form the results of this research project.

3.1. WIND NOISE

As anticipated, the principal source of natural acoustic background noise at the earth's surface was found to be the hydrodynamic or flow noise caused by local surface winds. Many tape recordings were made of this noise obtained with Schellenger Research Laboratory (SRL) condenser microphones standing about four inches above the ground and unprotected by wind screens or other shielding devices. Wind speed was measured with rotating-cup anemometers and simultaneously recorded on the same tape. Thus, it was possible to compare microphone output levels with wind speeds. The result is shown in Figure 1 for frequencies from 0.5 to 1.5 cps. It is a confirmation of Bernoulli's principle that pressure fluctuations are proportional to the square of velocity fluctuations for, in this case, wind blowing past a microphone diaphragm. A parabola which best fits the experimental data is drawn in Figure 1. Departures of the experimental data from this curve are probably due to the inherently sluggish response of the cup anemometer used to measure wind speed. A tacit assumption of the curve is that the velocity fluctuations, which constitute hydrodynamic noise at the surface of the microphone diaphragm, are directly proportional in magnitude to wind speed. It is also assumed that the flow of wind past the microphone is laminar and time-steady.

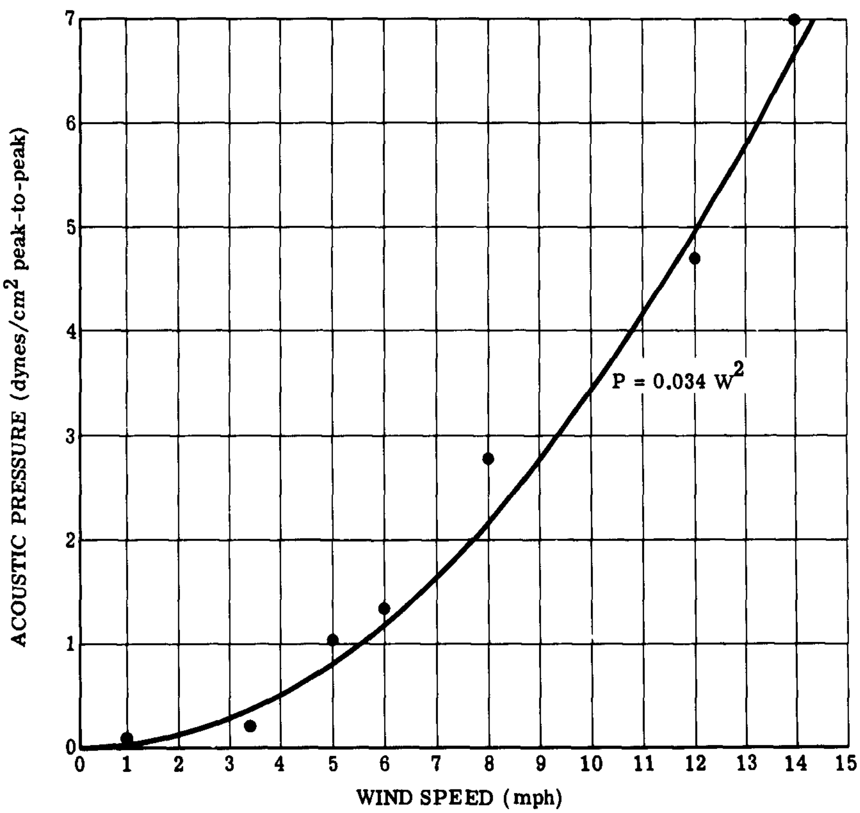


FIGURE 1. WIND NOISE 4 IN. ABOVE EARTH

To test these assumptions an experiment was conducted in still air inside a large aircraft hangar. An SRL condenser microphone was suspended by a 15-foot cord from one end of a 15-foot counterbalanced horizontal boom supported at its center by a vertical axis. The boom was then swung horizontally about the axis by a quiet motor and gear train. In this manner the microphone was pulled through still air at various rates while readings were taken of microphone output signal and peripheral air speed. The results of this experiment are shown in Figure 2. Again in accordance with Bernoulli's principle, a parabolic curve has been drawn which best fits the experimental data. The curve of Figure 2 is in close agreement with the curve of Figure 1 and indicates that for a given flow rate, wind noise at a microphone diaphragm four inches above the ground outdoors is about 10% greater than for laminar flow indoors. The 10% difference is probably due to the proximity of the outdoor microphone to boundary-layer turbulence at the earth's surface. Thus, the assumptions made in drawing the curve of Figure 1 seem to be valid.

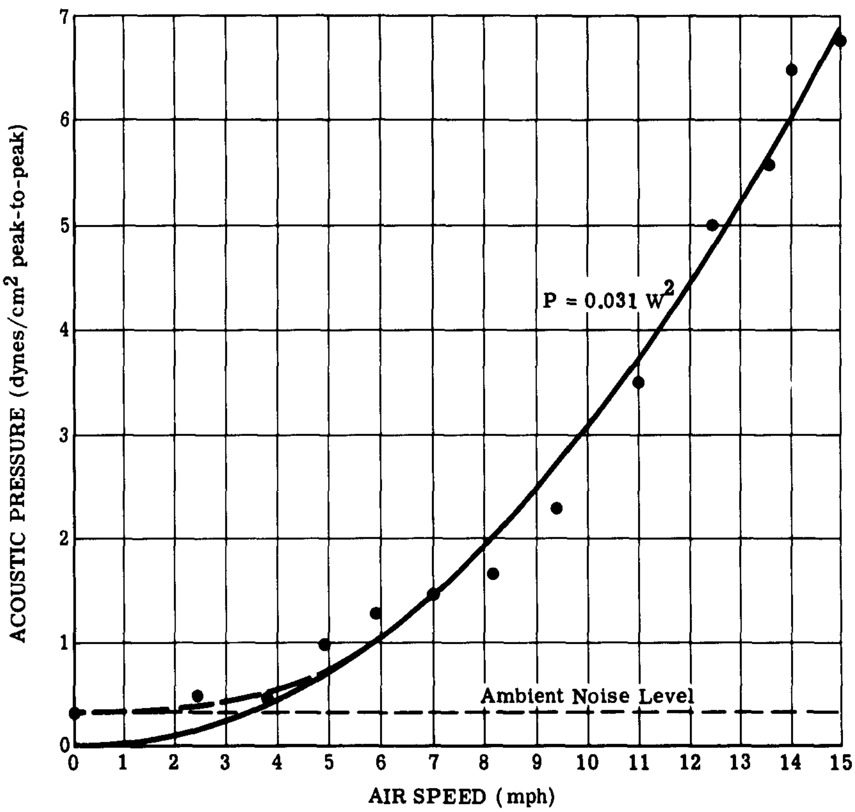


FIGURE 2. LAMINAR FLOW NOISE

There is usually some wind outdoors, and Figure 1 indicates that a mere 5.5-mph wind causes 1 dyne/cm^2 peak-to-peak pressure fluctuations in the 0.5- to 1.5-cps frequency region. At 11 mph the peak-to-peak pressure is 4 dynes/cm^2. Although these pressure fluctuations are not those of a propagating sound wave, it is nonetheless conceivable that the pattern of winds which cause them might produce misleading cross-correlations from an acoustic array. This possibility was investigated by visually comparing wind-noise oscillograms from two microphones spaced 1500 feet apart. Fortunately, as can be seen in Figures 3 and 4, there are no apparent cross-correlations in either the 0.2- to 0.5-cps or the 0.5- to 1.5-cps range. Figure 3 shows the oscillograms produced by a fairly steady 3.5-mph wind. The oscillograms of Figure 4 were produced by a moderately gusty 3- to 7-mph wind. By cross-correlating it should be possible to detect and recognize a 0.1 dyne/cm^2 propagating acoustic signal masked by a 10-mph wind, even though the noncorrelating wind noise would be about 30 db above the desired signal. In spite of this possibility, background noise levels 30 db larger than the desired signal should be avoided because amplifier overloading will occur if the background increases very much (strong winds and wind gusts will cause this), and weak signals will be lost if the correlation process is pushed to its limit for average signal levels. Wind screens, tapered pipes with ports, and flush mounting of microphones in the earth are techniques that have already been used successfully to reduce hydrodynamic noise caused by wind.

3.2. NOISE RADIATED BY TURBULENCE

Noise is produced by and radiated from turbulence in the atmosphere. Some of this turbulence is at the earth's surface. If there were a localized area of strong turbulence at a point on earth not far from a microphone array, noise would propagate from this turbulence to the array and be detected as a correlating signal. This problem should be investigated. It could not be investigated for this report because a cross-correlator was not available to recover this type of turbulence signal from local wind noise.

It was possible, however, to detect and identify the noise radiated from high-altitude turbulence. This was done when there was virtually no wind at the ground-based microphone array and no local, man-made background noise. Figure 5 shows the oscillograms from two SRL microphones under the above conditions. The microphones were 1500 feet apart. The oscillograms are of two frequency ranges, 0.2 to 0.5 and 0.5 to 1.5 cps. There is probably a significant degree of cross-correlation in the 0.5- to 1.5-cps range, but it is not apparent by simple visual inspection. In the 0.2- to 0.5-cps range, however, correlation between the two microphone signals is very evident. To make it even more obvious, the corresponding peaks in the 0.2- to 0.5-cps oscillograms have been numbered. The cross-correlations of Figure 5 are very strong evidence of propagating sound. The negligible time delay between the signals indicates that most of the energy comes from directly above the array. To confirm that the received sound has propagated from high-altitude turbulence, its acoustic pressure spectrum was compared with

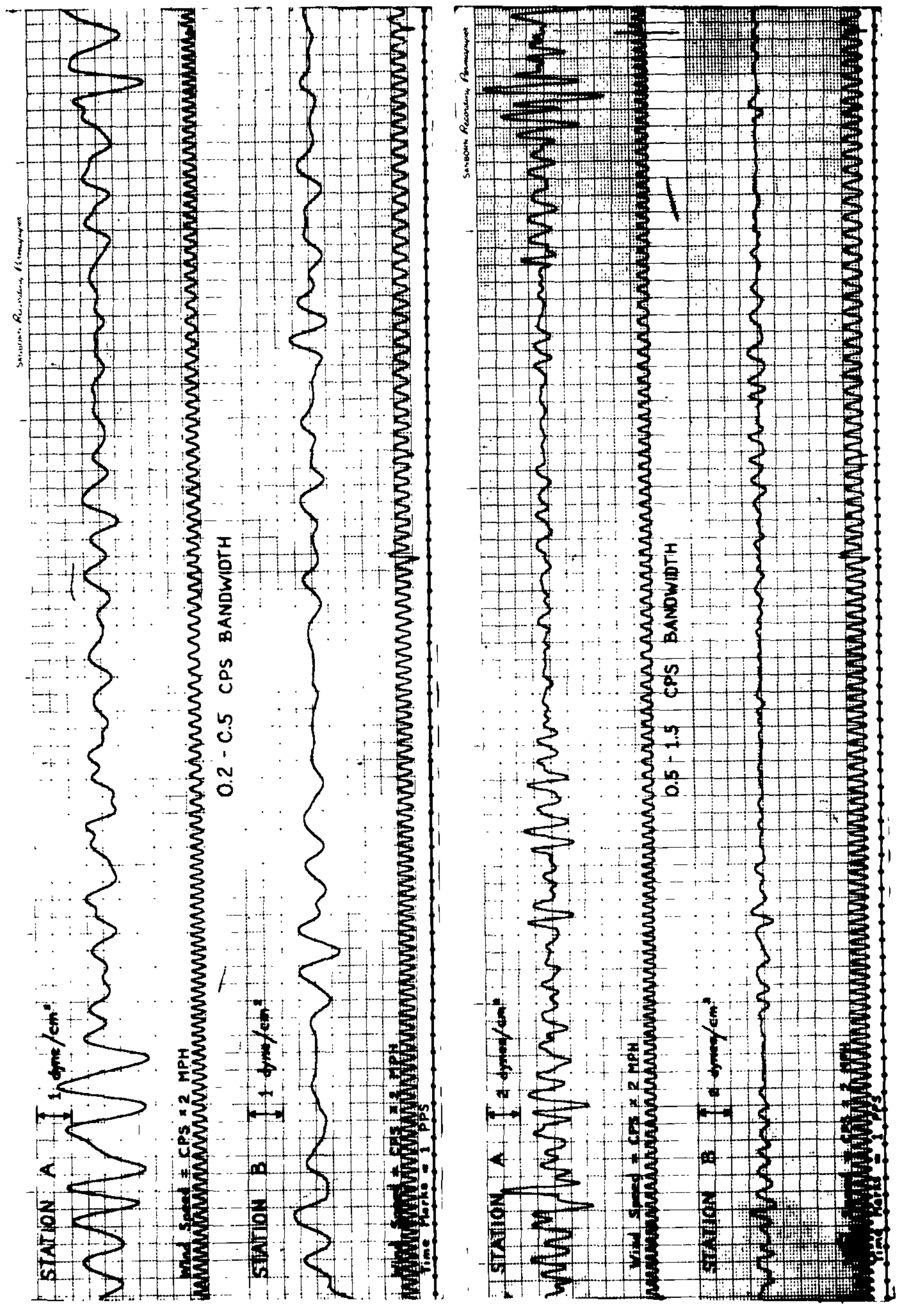


FIGURE 3. OSCILLOGRAMS OF 3.5-MPH SURFACE WIND

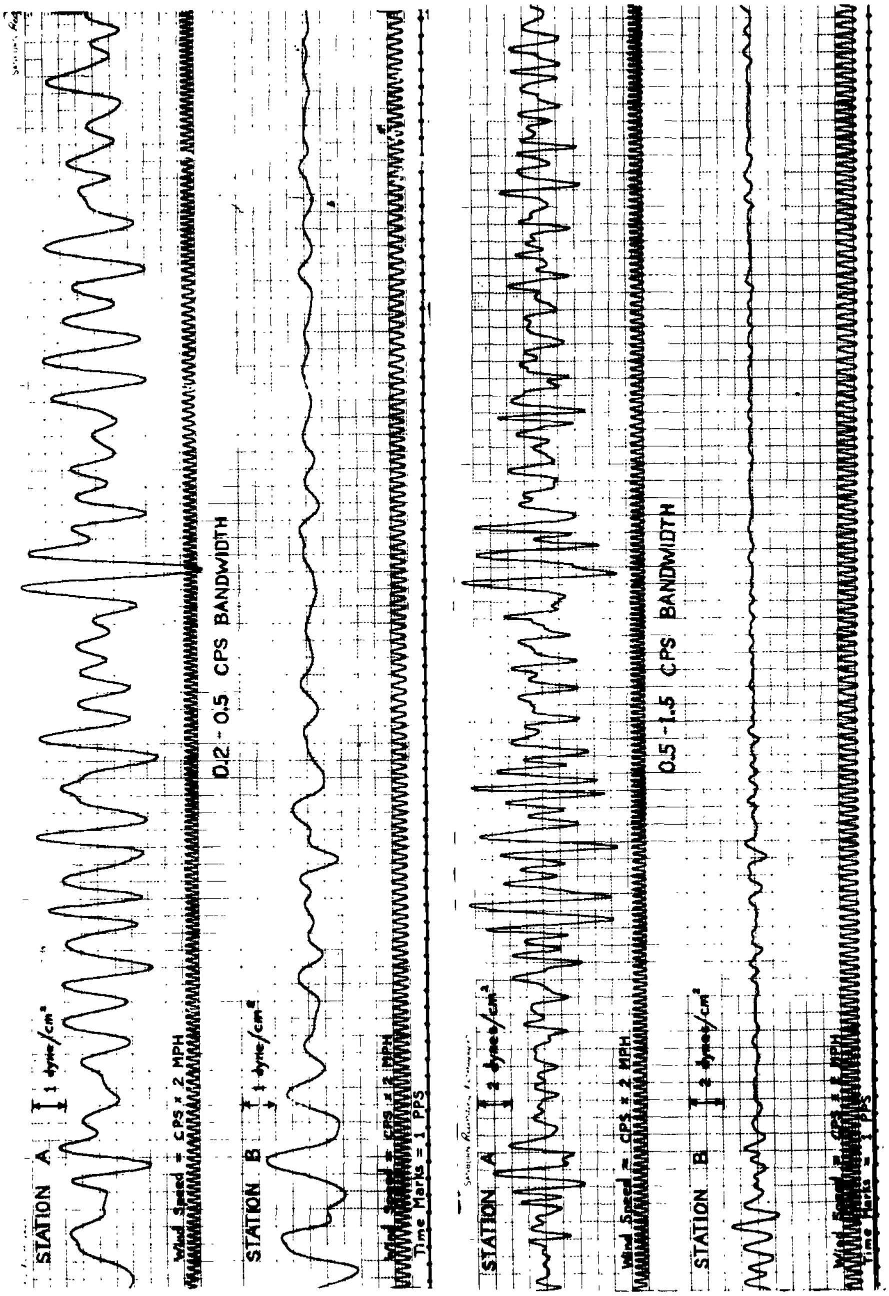


FIGURE 4. OSCILLOGRAMS OF VARIABLE 3- TO 7-MPH WIND

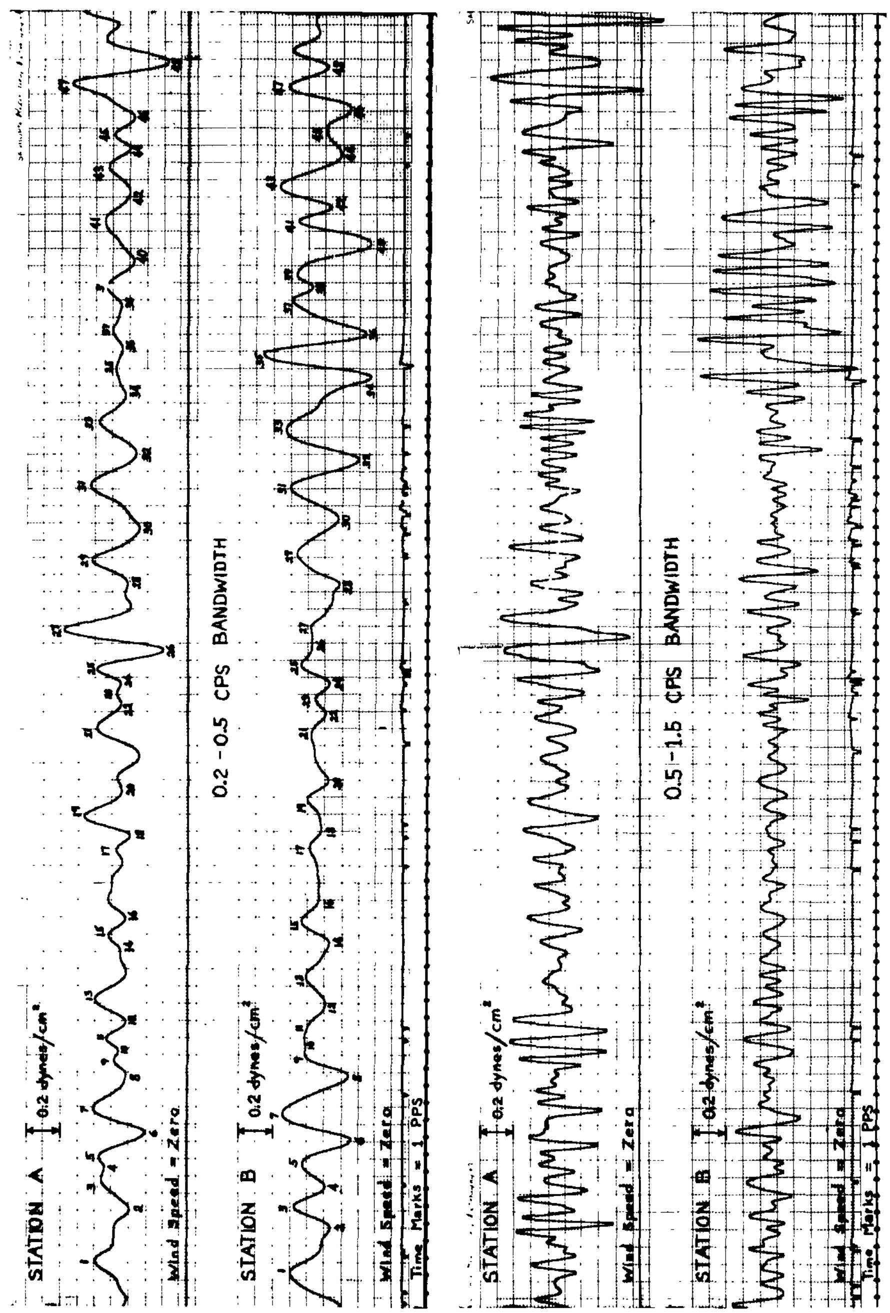


FIGURE 5. HIGH-ALTITUDE TURBULENCE NOISE SAMPLED AT EARTH

that of a sample known to be sound from high-altitude turbulence. In both cases the spectrum from 0.2 to 100 cps falls off with frequency at rates of 6 to 10 db/octave for various analyzed segments of each sample.

As further proof that turbulent air does radiate detectable amounts of acoustic energy, oscillograms of the sample known to be sound from high-altitude turbulence are shown in Figure 6. This sample was recorded from two microphones, 150 feet apart, suspended from a free-floating balloon 60,000 feet above the earth. The microphones were at least 10,000 feet above jet-stream and maximum-turbulence altitudes, and so were floating in relatively calm air. Local background noise was therefore at a minimum. Figure 6 shows almost 100% cross-correlation of the two microphone signals for not only the 0.2- to 0.5-cps frequency range, but also the 0.5- to 1.5-cps range. The slight time delay between the two signals indicates that the sound detected was propagated from below the microphones. The spectrum of the sound, as indicated earlier, is characteristic of atmospheric turbulence.

In earlier work many tape recordings of the noise radiated from high-altitude atmospheric turbulence were made through the use of balloon-borne microphones and a microwave data-link system. The results of analyzing those recordings show that there is a diurnal variation of about 30 db in the level of sound detected. At 60,000 feet the sound pressure in the 0.5- to 1.5-cps region varies from about 0.2 to 6 dynes/cm^2 peak-to-peak. At the earth's surface the variation was found to be from about 0.1 to 3 dynes/cm^2 peak-to-peak or about 6 db lower, on the average, than was measured at high altitudes. These findings indicate that on some days the noise radiated from turbulence is large enough to interfere with the detection of desired signals by an acoustic array. It should be remembered that this type of turbulence noise is propagating sound and therefore cannot be reduced by using wind screens or pipes. In a multi-element array the sound from turbulence will cross-correlate as well as any other propagating sound wave.

3.3. PISTON-ENGINE NOISE

There was ample opportunity to study the effects of aircraft engine noise, since the acoustic array was of necessity located at The University of Michigan's Institute of Science and Technology, which faces upon Willow Run Airport, a commercial airlines terminal. Indeed, it could be stated conclusively after the first day of operation that when any aircraft passes within 100 feet of a microphone, amplifier overloading occurs at all frequencies down to 0.2 cps. Normally, however, aircraft passed only within a mile or two of the array. This made it possible to determine that even at ranges of several miles piston-engined aircraft radiate significant levels of acoustic energy in the 0.2- to 0.5- and the 0.5- to 1.5-cps frequency ranges. Sound pressures of 1 dyne/cm^2 peak-to-peak are typical for piston-engined aircraft several miles from the detecting array. This can be seen in the 0.5- to 1.5-cps oscillograms of Figure 7. One of these oscillograms is from a microphone in still air. But 1500 feet away at the second microphone station a slight breeze is evident. The anemometer record just under the second oscillogram indicates that the breeze is a variable 3-mph wind. Note how this produces pressure fluctuations that exceed the aircraft signal. The

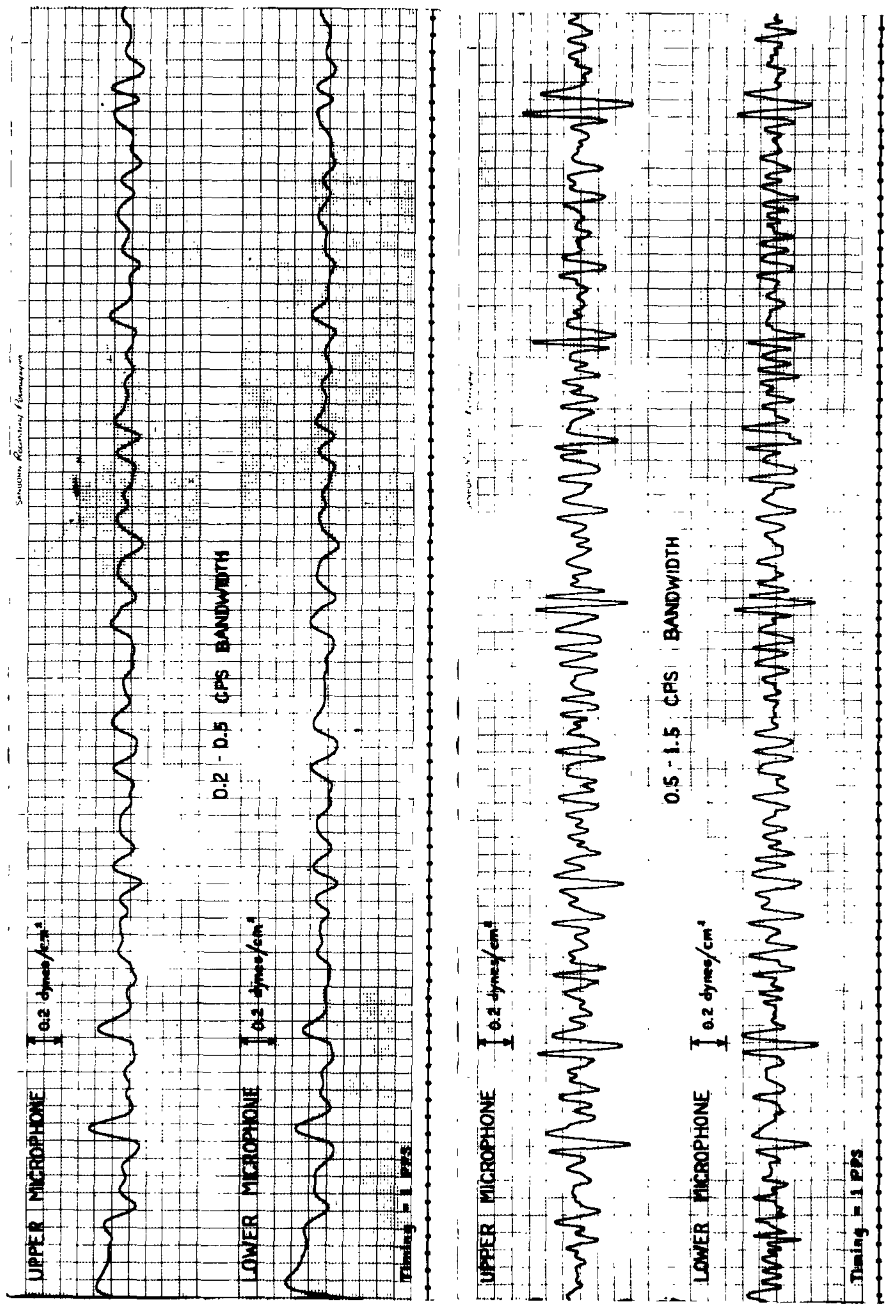


FIGURE 6. HIGH-ALTITUDE TURBULENCE NOISE SAMPLED AT 60,000 FT

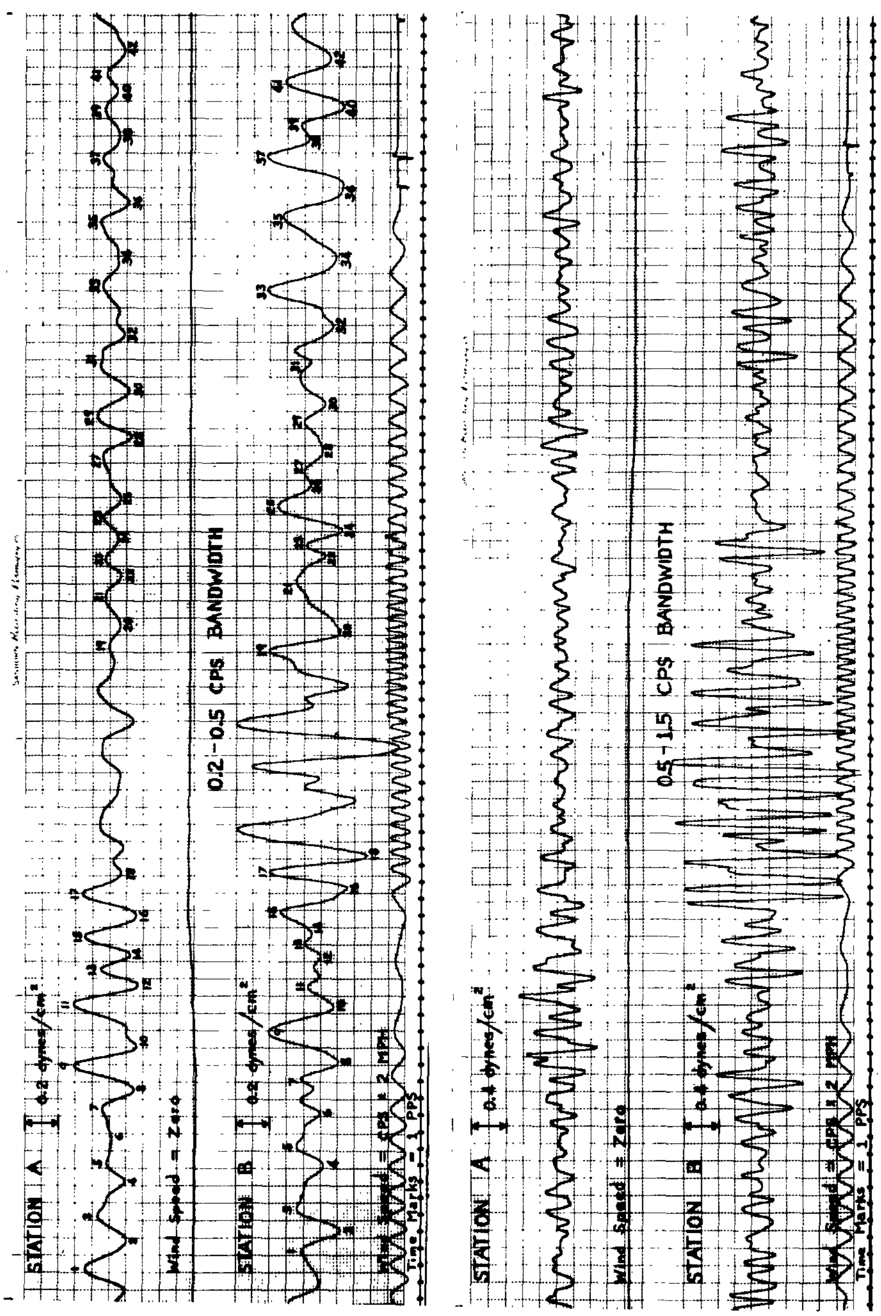


FIGURE 7. CORRELATING OSCILLOGRAMS OF AIRCRAFT AT 3 MILES

wind was gustier than the anemometer record indicates, since pressure fluctuations of 3 dynes/cm^2 peak-to-peak are shown. This demonstrates that the moving mass of a rotating-cup anemometer is too great to respond to gustiness.

Figure 7 also shows the cross-correlation of aircraft noise received at two microphones. This can be seen best in the 0.2- to 0.5-cps oscillograms, in which corresponding pressure peaks have been numbered for greater clarity. Bear in mind that the aircraft is flying by the array so that the delay time between channels changes accordingly. The variable breeze just described obscures the correlation during part of the record, thus demonstrating the limitation of cross-correlation by simple visual inspection of oscillograms. It seems that the visual method begins to fail when noncorrelating noise levels exceed correlating signal levels.

3.4. EQUALIZING NETWORKS

As the preceding paragraphs explain, there are both natural and man-made background-noise sources that generate propagating acoustic waves of detectable amplitudes in the frequency range of 0.2 to 100 cps. A study of the pressure spectra of these unwanted signals led to the design of simple RC equalizing networks with transfer functions approximating the inverse of the unwanted signal spectra. Thus it was found that a three-stage RC network with 6 db/octave preemphasis to about 20 cps and 12 db/octave de-emphasis at all higher frequencies permitted data-link transmission and recording of desired signals at levels about 6 to 12 db higher, relative to instrument noise, than was possible without equalization. The amount of increase in s/n varied with diurnal changes in the spectrum of background noise. In general, the lower part of the background noise spectrum (0.2 to 10 cps) was found to consist mostly of turbulence and wind noise, which falls off with frequency at rates of 6 to 10 db/octave. The preemphasis network was used to compensate for this. Man-made noise, especially from engines, is very strong from 20 cps to beyond 100 cps. The de-emphasis networks were used to prevent amplifier overloading from man-made noise. Figure 8 shows the amplitude and phase responses of the complete three-stage equalizing network. The buffer stages shown between network sections in Figure 8 are actually stages in the microphone amplifier into which the network is incorporated.

It was necessary to phase-match all three-stage networks to avoid azimuth errors when using them in a multi-element array. The matching was done with a low-frequency laboratory oscillator and oscilloscope by padding one or more elements of each network to bring its output voltage into phase with that of the others throughout the 0.2- to 100-cps passband.

3.5. MICROWAVE DATA LINKS

Four microwave data links were constructed to eliminate the need for running long multi-conductor wire lines from microphone stations to the data-processing center. Two of these stations have been opera-

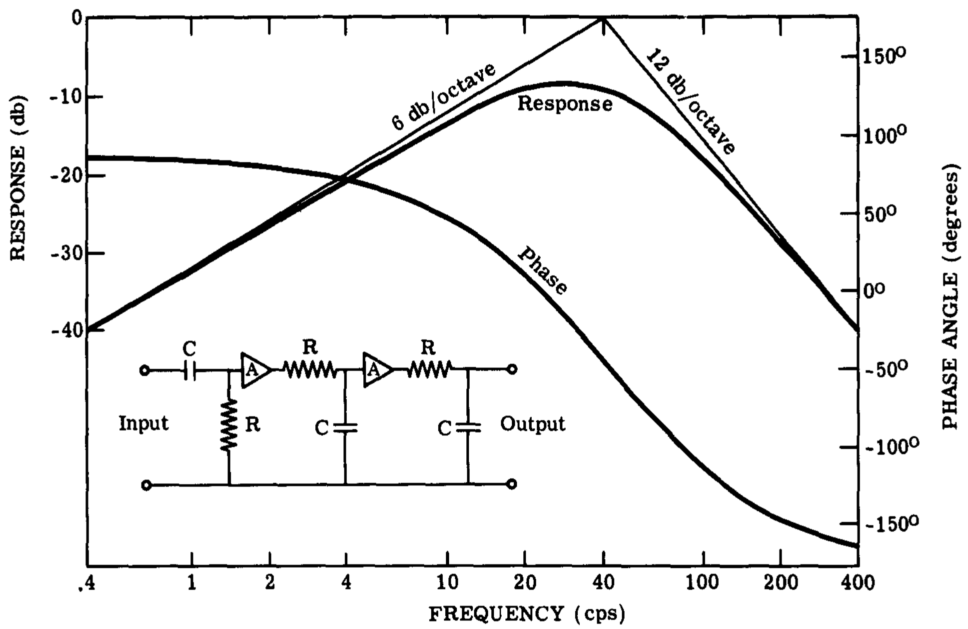


FIGURE 8. EQUALIZATION NETWORK RESPONSE

tional for over six months and have supplied data for this report. The other two stations have been assembled and tested, but not in time for this report to include any four-channel acoustic data. The high rf signal strength and excellent quality of acoustic data obtained with the microwave system suggest an extension of array dimensions from the present 1500 feet out to several miles between microphones. A 1-cps acoustic signal has a wavelength of roughly 1000 feet. Array dimensions of at least several thousand feet (several wavelengths) will permit sharper focusing and more accurate azimuth determination of 1-cps signals than is possible with a 1500-foot array.

The data-link system was assembled principally from standard Signal Corps components for two reasons: (1) to get the job done faster and (2) to make it easier for others to assemble the same system if it should prove feasible. The system utilizes four Rawin Receivers R-301D/GMD-1, including mixer assemblies, and four Radiosonde Transmitters T-304/AMT-4A. Pulse-frequency-modulating and -demodulating components for each data link were built on the premises. Simple 45°-angle corner reflectors were fabricated and used with all transmitting and receiving antennas. This not only increased the s/n of the data link but also prevented the system from interfering with Radiosonde balloon flights made from nearby weather stations. All of these components are presented in more detail in Section 4 together with photographs, block diagrams, and circuit diagrams (Figures 9 through 17).

The microwave data links not only delivered acoustic signals from two microphone stations to a central processing center, but also delivered anemometer wind-speed data from each station in the form of a frequency-modulated 1000-cps subcarrier. The Radiosonde Transmitters, T-304/AMT-4A, used at the microphone stations were surprisingly dependable. These units are normally used as meteorological-balloon transmitters to supply data for only a few hours. As employed in the ground-based array, however, the same transmitters have been operated during work days for over six months without a tube failure. The transmitter stations are inefficient in their consumption of battery power. Each station is supplied by a 100-amp-hr, 12-volt storage battery that currently provides about twenty-four hours of operating time between rechargings. Through improved circuit design, especially in the power-converter components, it should be possible to extend the duty cycle to about one week with the same battery.

4
DESCRIPTION OF EQUIPMENT

Circuit diagrams and/or photographs of equipment which was designed and constructed for this project are included in this section. A diagram of an SRL condenser microphone and amplifier as modified for the project is also included. A block diagram of the entire detection, data-link, and data-processing system is included for explanatory purposes. Complete details of Rawin Receiver R-301 D/GMD-1 are available in Department of the Army Technical Manual TM 11-271A. Similarly, complete details of Radiosonde Transmitter AN/AMT-4A are in TM 11-2432A.

4.1. DETECTION, DATA-LINK, AND RECORDING SYSTEM

Figure 9 shows the arrangement of components for one complete channel of the four-channel array developed during this project. A description of this figure begins with consideration of the group of blocks labeled "Microphone Station." The output of an SRL condenser microphone drives a modified SRL microphone amplifier which contains the equalization network of Figure 8. A circuit diagram of the microphone-equalizing amplifier is shown in Figure 10. The output of the equalizing amplifier, shown in Figure 9, is mixed with a 1-kc subcarrier that is frequency modulated by the a-c output signal of a rotating-cup anemometer. The mixed signals are applied to a 10-kc PFM multivibrator and control the repetition rate of its output pulses. These pulses are applied to the control grid of the Radiosonde-transmitter tube, where they modulate both the frequency and amplitude of its rf output. The FM mode is used in this system since it has been found to be more noise-free than the AM mode. The Radiosonde-transmitter antenna nominally radiates between 1 and 2 watts of rf power at 1680 Mc. Circuits of the 1-kc, frequency-modulated subcarrier oscillator, the mixing network, and the 10-kc PFM multivibrator are shown in Figure 11.

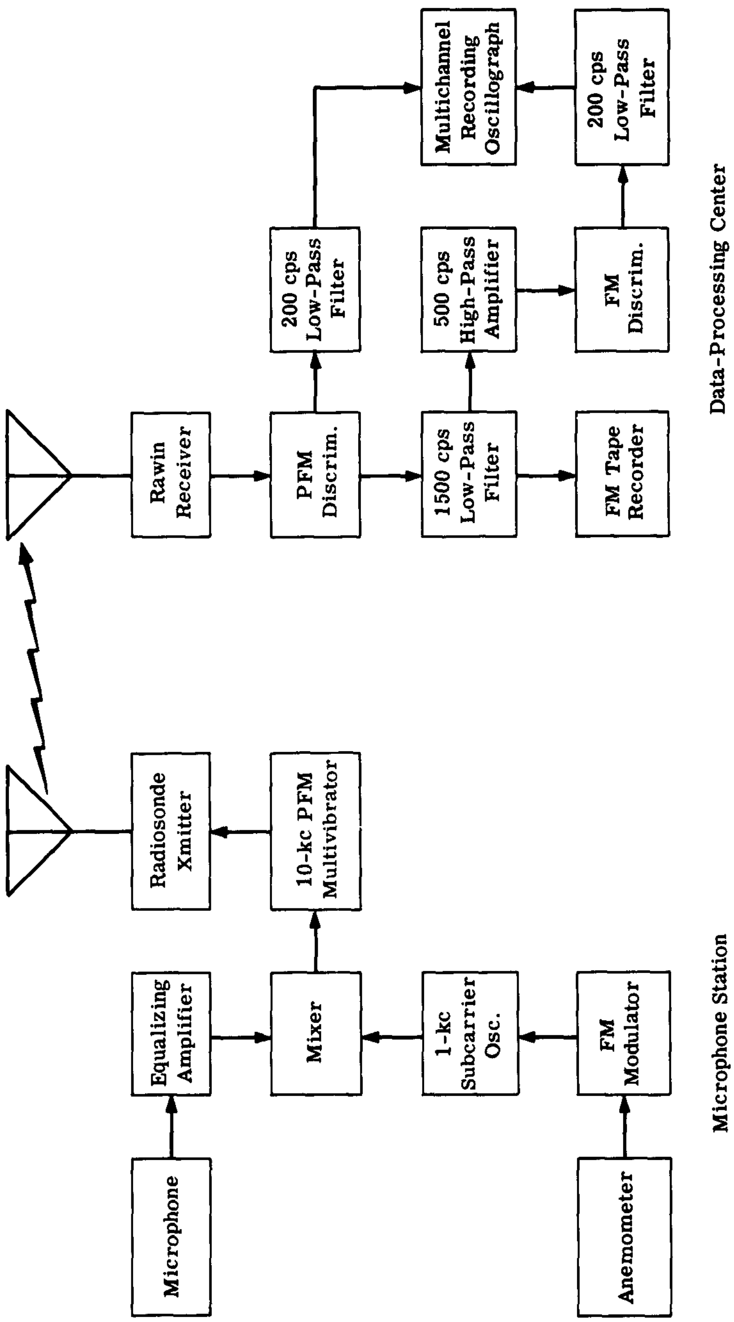


FIGURE 9. DETECTION, DATA-LINK, AND RECORDING SYSTEM

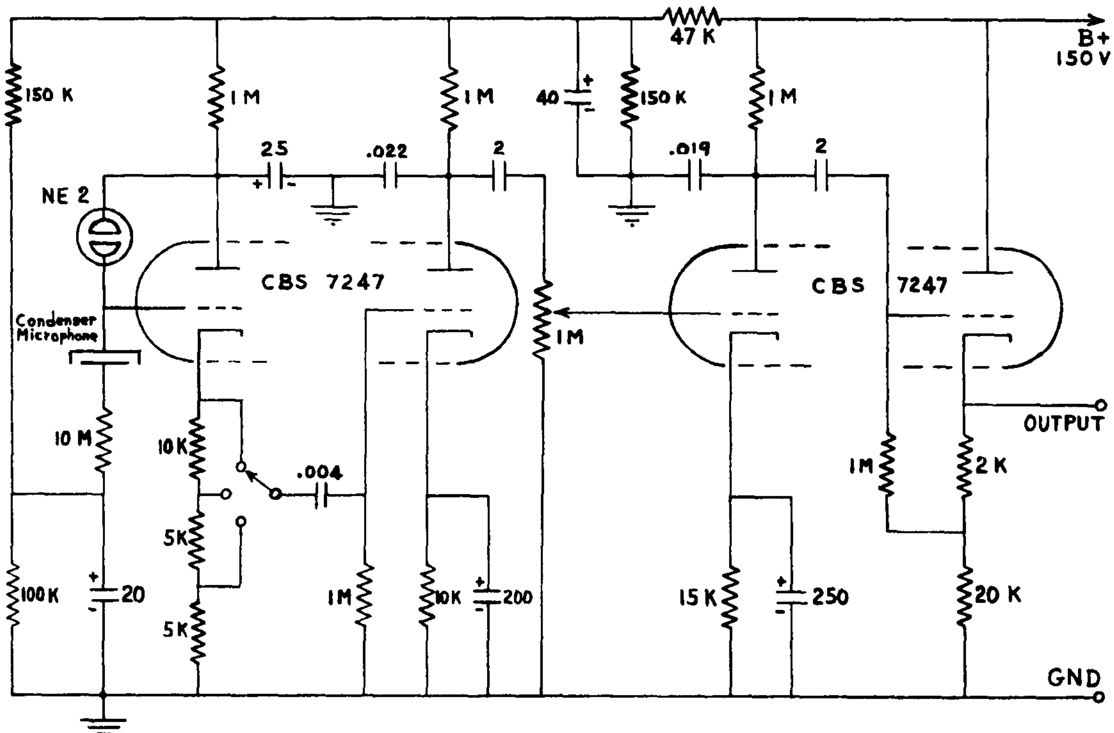


FIGURE 10. MICROPHONE AMPLIFIER CIRCUIT WITH EQUALIZATION

Now, return to Figure 9 and consider the group of blocks labeled "Data-Processing Center." The 1680-Mc signal from a microphone station is sampled by the receiving antenna and fed to the Rawin receiver which is switched for FM reception. The output of the receiver is a continuous train of pulses having a variable repetition rate in the neighborhood of 10 kc. The variation in repetition rate of these pulses is the modulation which contains combined acoustic and wind-speed data. The receiver output pulses are used to drive the PFM discriminator. This component generates pulses of fixed width and height at whatever rate it is triggered. These pulses then pass through an integrating network or low-pass filter so that the output signal becomes a function of the variation in input triggering rate. The circuit diagram for a dual-channel PFM discriminator is shown in Figure 12.

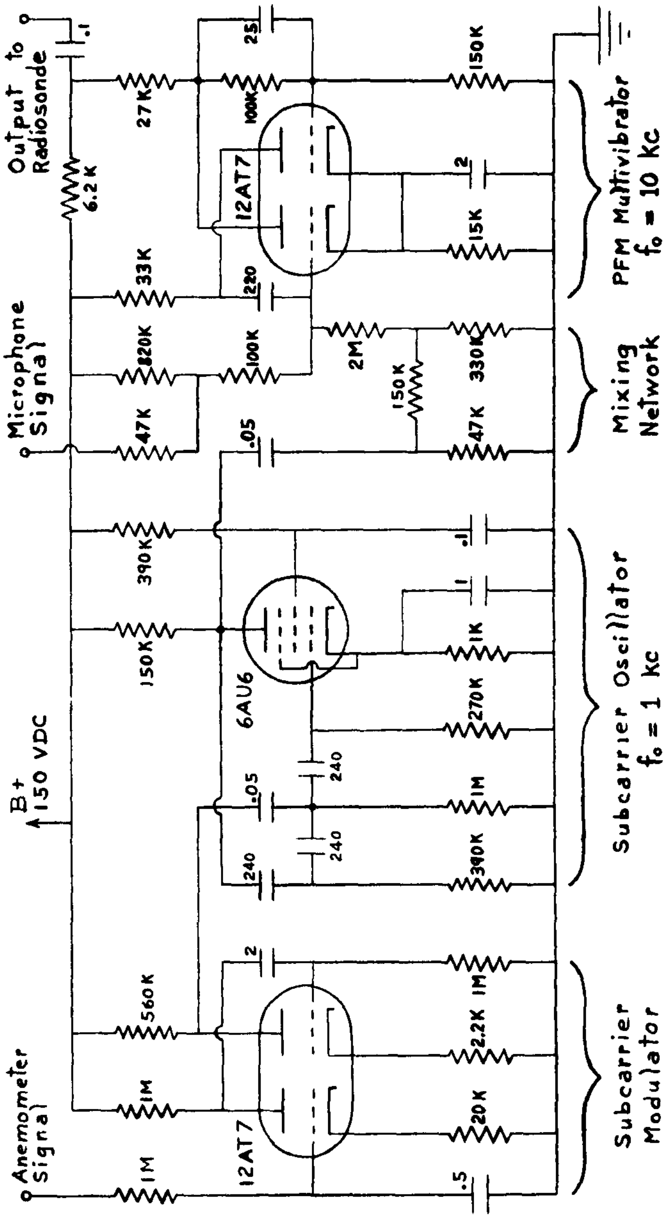


FIGURE 11. CIRCUITS OF PFM AND ANEMOMETER SUBCARRIER OSCILLATORS

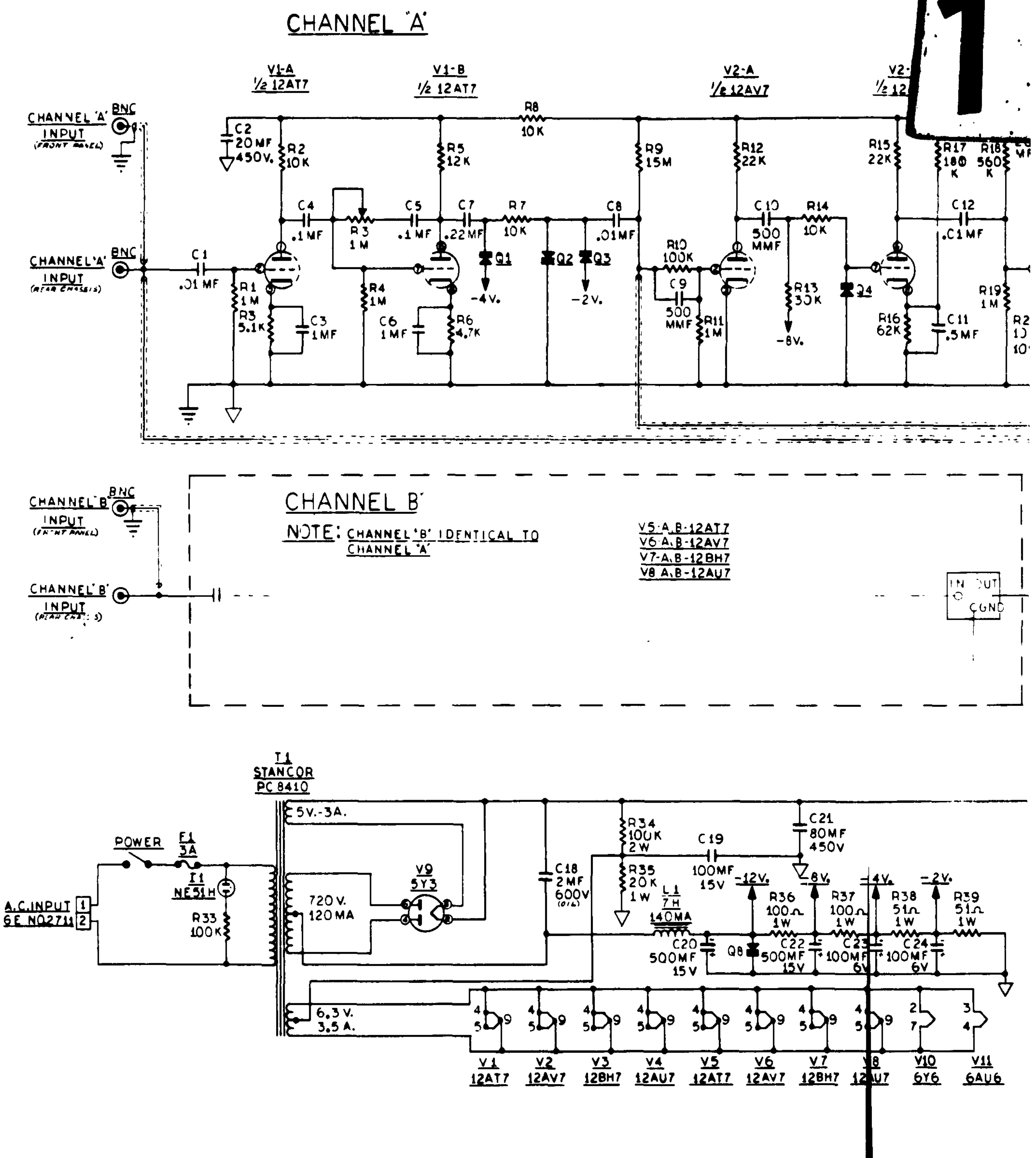
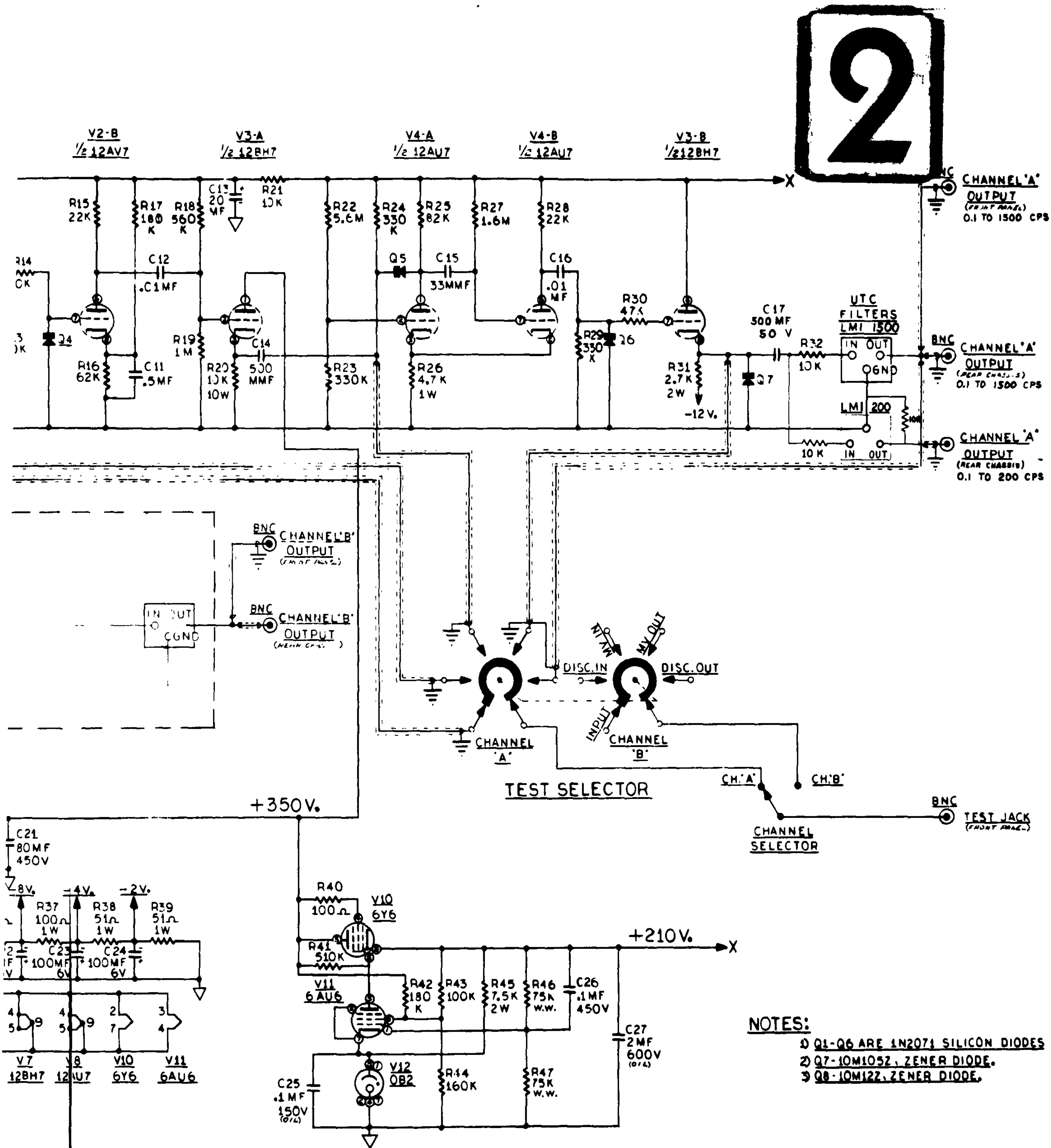


FIGURE 12. CIRCU[illegible]S OF PFM DUA


2
V2-B
1/2 12AV7
V3-A
1/2 12BH7
V4-A
1/2 12AU7
V4-B
1/2 12AU7
V3-B
1/2 12BH7
R15 22K
R17 180 K
R18 560 K
C13 20 MF
R21 10K
R22 5.6M
R24 330 K
R25 82K
R27 1.6M
R28 22K
C12 .C1MF
Q5
C15 33MMF
C16 .01 MF
R30 47K
C17 500 MF 50 V
R32 10K
UTC FILTERS LMI 1500
IN OUT GND
R19 1M
R16 62K
C11 .5MF
R20 10K 10W
C14 500 MMF
R23 330K
R26 4.7K 1W
R29 330 K
Q6
R31 2.7K 2W
-12 V.
Q7
LMI 200
10 K
IN OUT
BNC
CHANNEL 'A' OUTPUT
0.1 TO 1500 CPS
CHANNEL 'A' OUTPUT
0.1 TO 1500 CPS
CHANNEL 'A' OUTPUT
0.1 TO 200 CPS
BNC
CHANNEL 'B' OUTPUT
BNC
CHANNEL 'B' OUTPUT
IN OUT
GND
DISC. IN
DISC. OUT
MX IN
MX OUT
INPUT
CHANNEL 'A'
CHANNEL 'B'
TEST SELECTOR
CH. 'A'
CH. 'B'
CHANNEL SELECTOR
BNC
TEST JACK
+350 V.
C21 80MF 450V
8V.
-4V.
-2V.
R37 100Ω 1W
R38 51Ω 1W
R39 51Ω 1W
C23 100MF 6V
C24 100MF 6V
V7 12BH7
V8 12AU7
V10 6Y6
V11 6AU6
R40 100Ω
V10 6Y6
R41 510K
+210 V.
V11 6AU6
R42 180 K
R43 100K
R45 7.5K 2W
R46 75K W.W.
C26 .1MF 450V
C27 2MF 600V
V12 OB2
C25 .1MF 150V
R44 160K
R47 75K W.W.
NOTES:
1) Q1-Q6 ARE 1N2071 SILICON DIODES
2) Q7-10M105Z, ZENER DIODE.
3) Q8-10M12Z, ZENER DIODE.

By referring to Figure 9 again, it can be seen that the PFM-discriminator output is applied to two filters. The 200-cps, low-pass filter blocks out the 1-kc anemometer subcarrier but passes the acoustic data to a multichannel recording oscillograph. The 1500-cps, low-pass filter output is a mixture of acoustic data and the 1-kc subcarrier. This is simultaneously recorded on magnetic tape and applied to a 500-cps, high-pass amplifier. The high-pass amplifier blocks out the acoustic data but passes the frequency-modulated subcarrier. The high-pass amplifier circuit is shown in Figure 13. Finally, Figure 9 shows the anemometer subcarrier signal from the high-pass amplifier applied to an FM discriminator. The latter component is actually a duplicate of the PFM discriminator described earlier. This component demodulates the 1-kc subcarrier and passes the original anemometer signal through a 200-cps, low-pass filter to the multichannel recording oscillograph.

There are four microphone stations and data links in the complete system. To avoid interchannel interference, the rf carriers were set at 7-Mc intervals in the 1680-Mc range. The likelihood of interchannel effects was further reduced by the use of corner reflectors at the receiving antennas. Self-explanatory photographs of various system components are presented in Figures 14 through 17.

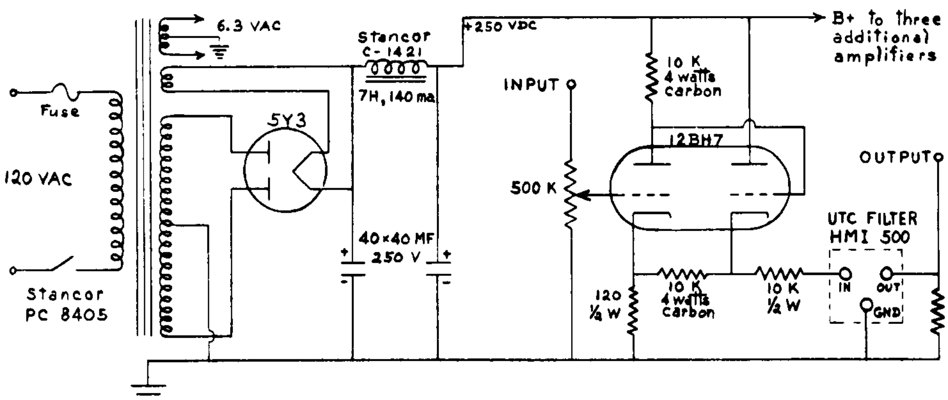


FIGURE 13. CIRCUIT OF 500-CPS, HIGH-PASS AMPLIFIERS

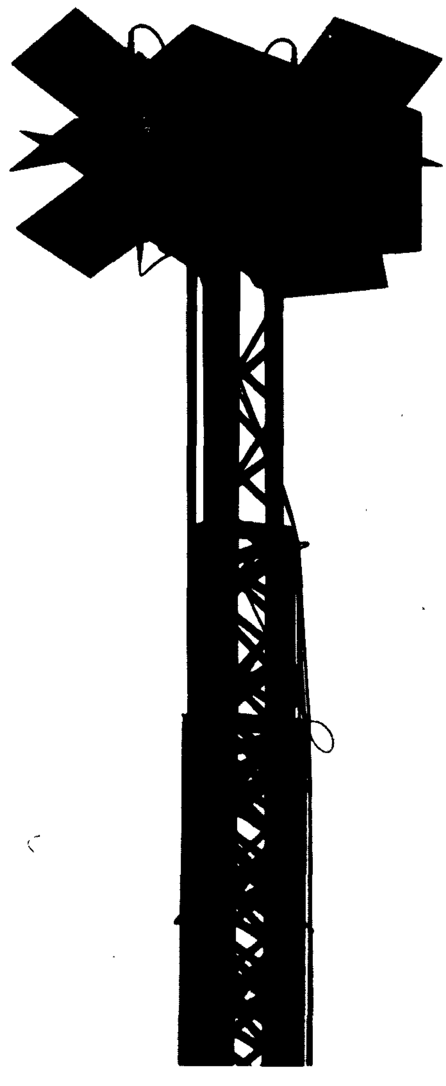


FIGURE 14. COMPLETE MICROPHONE STATION

FIGURE 15. TRANSMITTER POWER-SUPPLY AND MODULATOR COMPONENTS

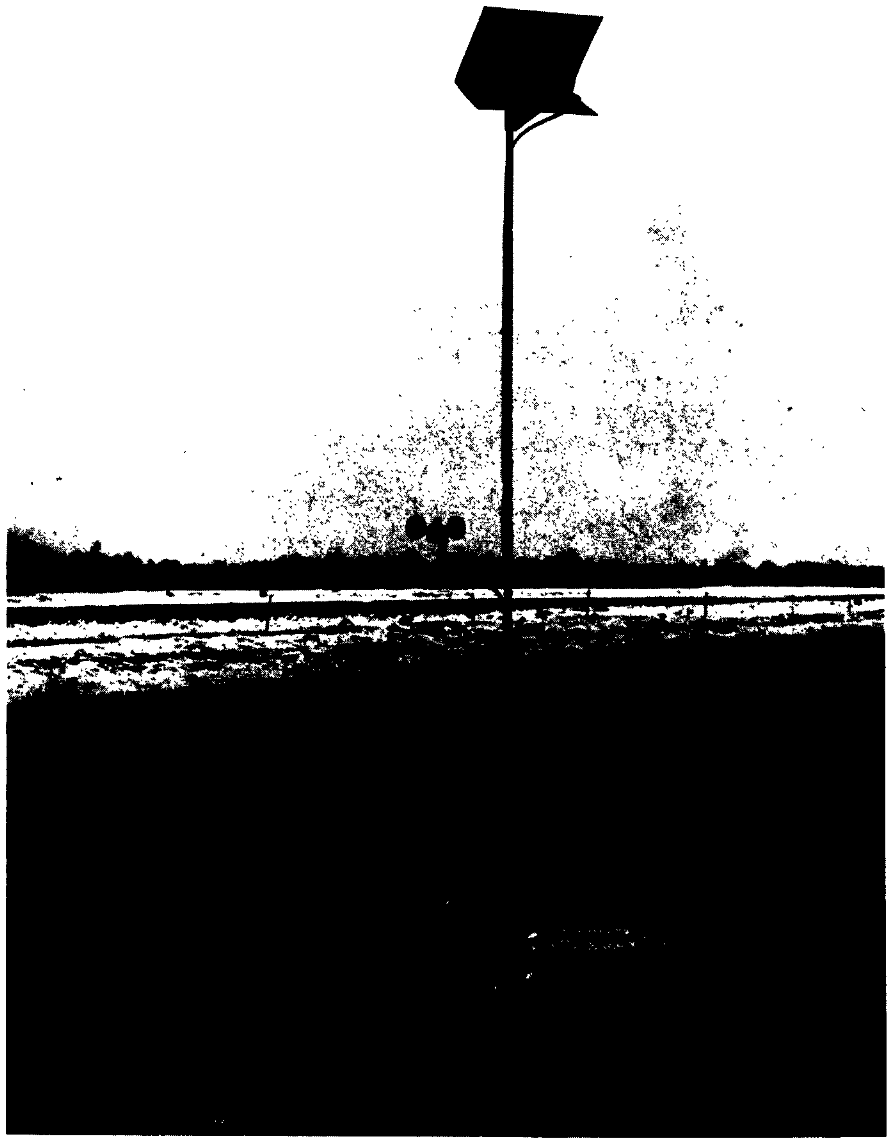


FIGURE 16. 4-CHANNEL RECEIVING ANTENNA

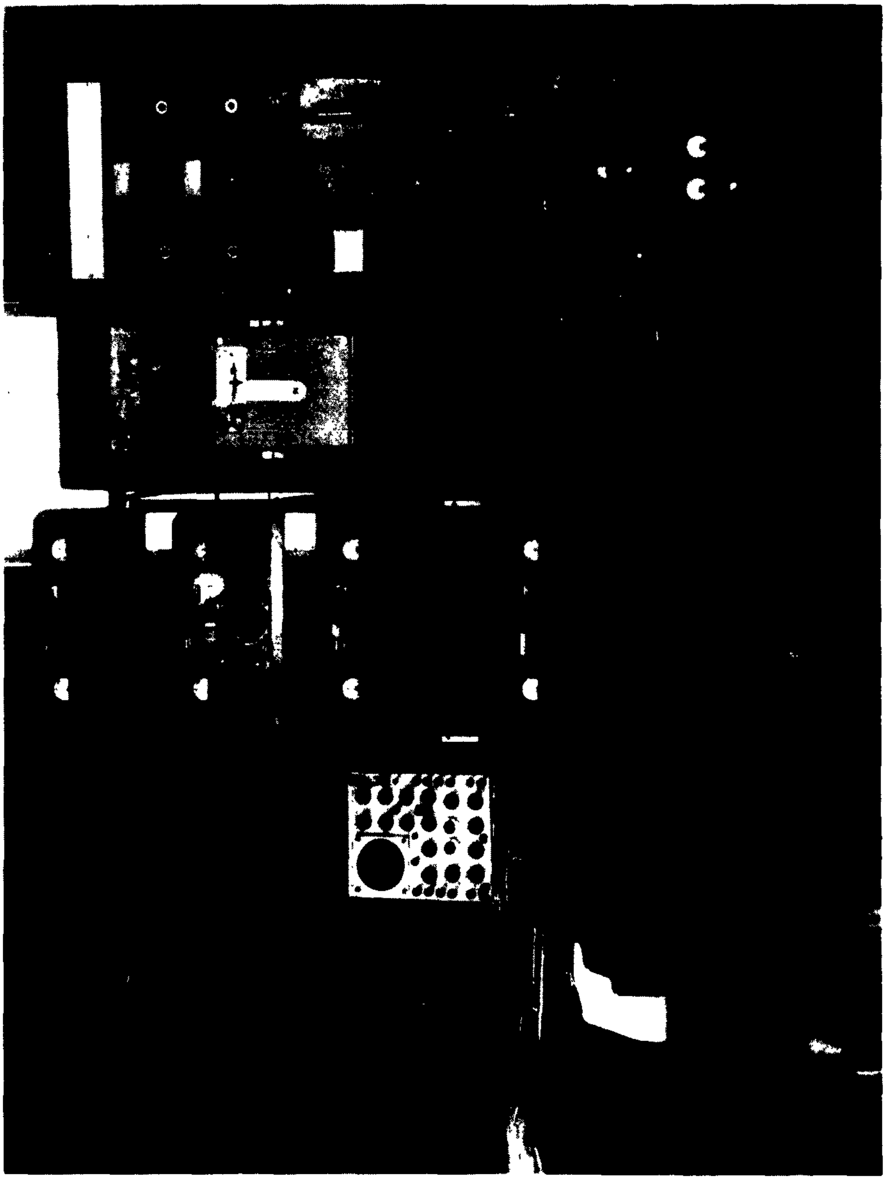


FIGURE 17. DATA-PROCESSING CENTER

4.2. PISTONPHONE CALIBRATOR

A pistonphone for calibrating microphones or microbarographs at frequencies from 0.125 to 30 cps was developed and constructed in connection with earlier work on balloon-borne "Pulsonde" acoustic detectors. It was later used for calibrating modified SRL microphone and amplifier units of the type described in this report. A description and photographs of the pistonphone calibrator are therefore presented here.

In the interests of simplicity and portability the pistonphone chamber consists of nothing more than a large bell jar lying on its side with a 1/2-inch thick aluminum plate clamped across its mouth. A hole in the plate is sealed with a flexible diaphragm that is deflected in and out by a rod that connects to an eccentric drive. The eccentric drive operates from a gearbox equipped with pushbutton gear selectors. The gearbox and synchronous motor are shock mounted on the 1/2-inch thick aluminum plate. The bell jar is about 18 inches in diameter and 30 inches long. The incremental volume change caused by the flexing diaphragm was calculated to produce a pressure fluctuation of 10 dynes/cm^2 rms inside the sealed bell jar under standard atmospheric conditions.

Figure 18 is a photograph showing the pistonphone pushbutton frequency selector. Note that frequencies are available at one-octave intervals from 0.125 to 30 cps. The synchronous motor is shown mounted directly beneath the frequency-selector panel. An SRL condenser microphone being calibrated is visible inside the bell jar. Figure 19 is another view of the pistonphone and shows the flexible diaphragm, connecting rod, and eccentric drive, isolated from gearbox and motor vibrations by two flexible couplings.

Also shown in Figure 19 are a vacuum pump and mercury manometer used to simulate high-altitude air pressures by pumping part of the air out of the bell jar. When microphones are calibrated under these conditions the pressure fluctuation caused by the flexing diaphragm must be calculated for each specified air pressure. The pump and manometer were also used to check the pistonphone chamber for air leaks. The leak rate for a high vacuum was a few millimeters of mercury in twenty-four hours. This is negligible for microphone calibration applications. Figure 20 is a detail view of the flexible diaphragm, connecting rod, and eccentric drive. The diaphragm was cut from a sheet of 0.010-inch thick Teflon and sealed over a hole in the 1/2-inch thick aluminum plate with a clamping ring and eight bolts as shown. The diaphragm is clamped at the center between two large, round washers tightened together with hexagonal nuts on the threaded end of the connecting rod. As Figure 20 shows, the large, round washers cover most of the diaphragm area so that its motion closely approaches that of a true piston.

Nine electrical leads are brought out through a sealed connector in the 1/2-inch thick aluminum plate to provide for operating two microphones simultaneously in the bell jar. This makes it possible not only to obtain a calibrated frequency response of each microphone but also to make a phase comparison between microphone outputs at each pushbutton frequency. This is particularly important with low-frequency arrays because at low frequencies a few degrees of phase shift between microphone responses is equivalent to a significant difference in arrival times of an acoustic wavefront. Therefore, all microphones are both phase and amplitude calibrated before use in the field. In practice, for a complete system calibration, the pistonphone signal is channeled through the microphones, their data links, and the data-processing center. The output voltage at the data-processing center is set to 1 volt rms at 1 cps for a microphone sound pressure of 10 dynes/cm^2 rms.

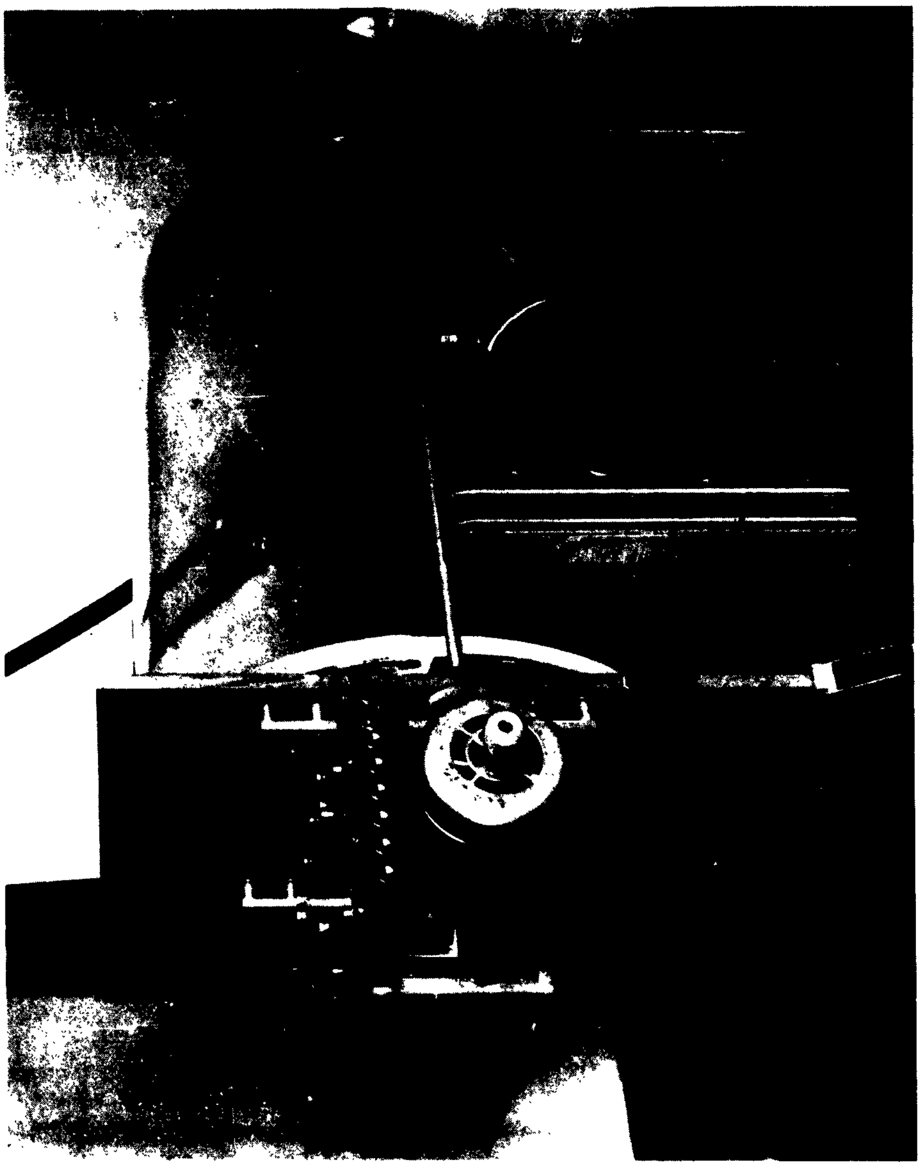


FIGURE 18. PISTONPHONE PUSHBUTTON FREQUENCY SELECTOR

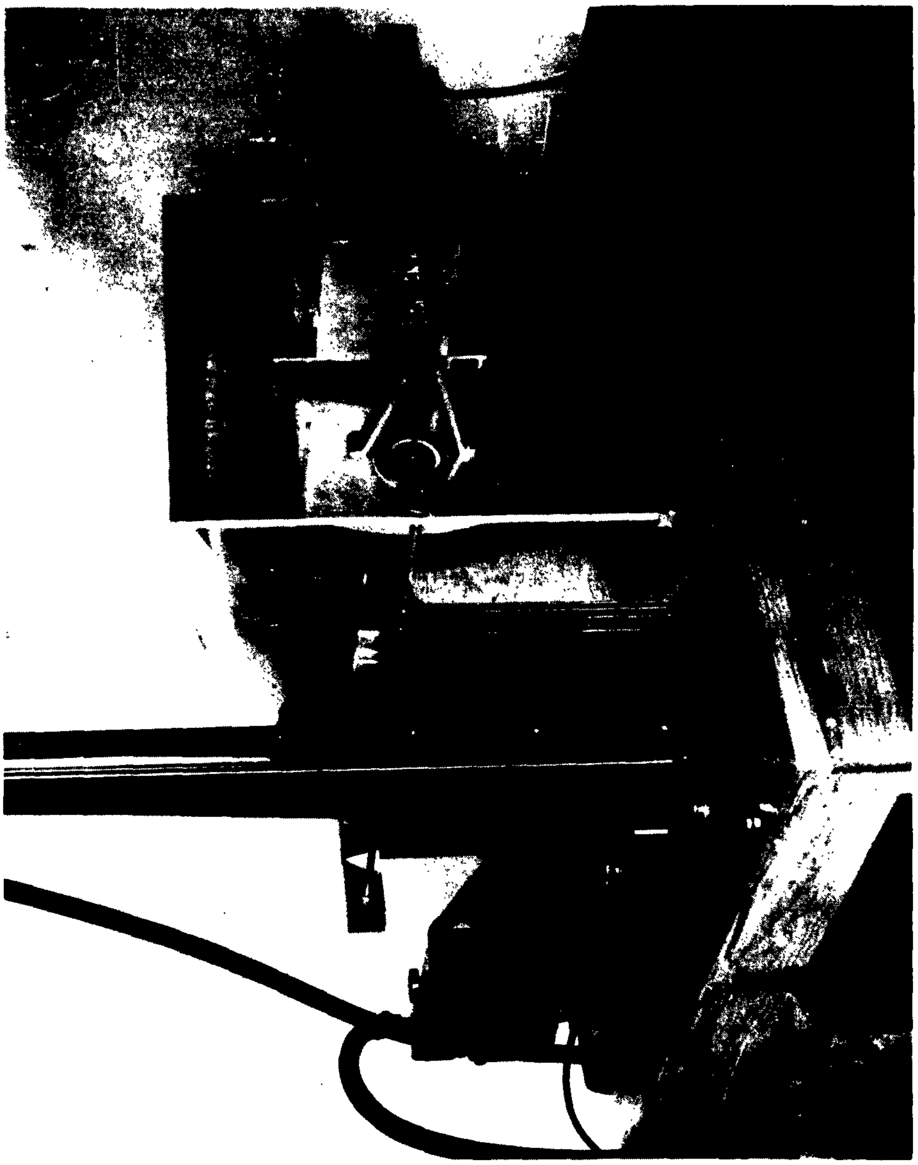


FIGURE 19. PISTONPHONE SEALED DIAPHRAGM AND GEARBOX

FIGURE 20. DETAIL OF SEALED DIAPHRAGM AND ECCENTRIC DRIVE

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Details of instrumentation are presented. These include a block diagram of the detection, data-link, and recording system and circuit diagrams of components developed for it. A pistonphone calibrator with pushbutton frequencies from 0.125 to 30 cps is described, and its use for amplitude and phase calibration of microphones is explained.

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