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FLUERICS 30. THE MATCHED ACOUSTIC GENERATOR

by

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December 1971

U.S. ARMY MATERIEL COMMAND

HARRY DIAMOND LABORATORIES

WASHINGTON, D.C. 20438

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13. ABSTRACT

A swept-frequency, matched acoustic generator for quickly measuring the insertion power gain and bandwidth of flueric components was developed and tested. The generator produces and measures the signal incident on flueric elements unaffected by their reflections. The components are connected to the generator by transmission lines. The output of the flueric unit is measured in a line of the same diameter as the input line and long enough to attenuate reflections from the far end of the line to negligible levels.

The generator produces an acoustic signal of 17.7 x 10^{-3} kilopascal (2.6 x 10^{-3} psi) in a 1/8-inch (0.32-cm) line over the frequency range of 200 to 5000 Hz. The maximum error in measuring the incident signal pressure is approximately 5 percent. More precise construction of the generator could reduce the measurement error, but the accuracy presently obtained is sufficient for many engineering purposes. The swept-frequency responses and carrier pulse responses of several flueric amplifiers are illustrated. The frequency response of certain proportional amplifiers has been shown to extend to 4000 Hz.

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A swept-frequency, matched acoustic generator for quickly measuring the insertion power gain and bandwidth of flueric components was developed and tested. The generator produces and measures the signal incident on flueric elements unaffected by their reflections. The components are connected to the generator by transmission lines. The output of the flueric unit is measured in a line of the same diameter as the input line and long enough to attenuate reflections from the far end of the line to negligible levels.

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1. INTRODUCTION

The development of flueric proportional amplifiers has called for streamlined techniques to measure the power gain and bandwidth of these units. Brown[1] made some dynamic measurements on a proportional amplifier in 1966. He used two methods: in one the admittance matrix of the amplifier ports was obtained by measuring pressure and volume flow using piezoelectric transducers and hotwire anemomentry; in the other, the wave scattering matrix (using acoustic signals) was measured with a tunable standing-wave tube and piezoelectric transducers. Either of these methods provides data which enables the fluidic circuit designer to compute power gain of the unit, but the procedure is time consuming. The device described here quickly and simply measures the insertion gain of proportional flueric elements.

2. DESCRIPTION

A matched acoustic generator for frequency-sweep testing of the insertion power gain of flueric proportional amplifiers and passive components has been designed. The hardware is dimensioned for proper operation over a frequency range of 200 Hz to 5000 Hz. The most important feature of the device is that it enables the rapid measurement of insertion power gain by pressure measurement only, eliminating the necessity for simultaneous flow measurements, which are generally laborious and require constant current or constant temperature anemometer bridges and calibration.

Insertion pow : gain is usually defined with reference to a transmission line. Figure 1a shows a transmission line matched at both the sending end and receiving end, with a reference point P along the line. Figure 1b shows the same line cut at P with an amplifier inserted at P. The ratio of the sinusoidal power measured at P in figure 1b to that measured at P in figure 1a is the insertion power gain of the amplifier or of any passive device under test. Should the amplifier have an input impedance matched to the input line and an output impedance matched to the output line, the measurement yields the true power gain of the device. In the unmatched situation the gain is referred to as insertion power gain and is, of course, a lower gound for the true power gain. The matched acoustic generator is directly analogous to the matched generators used in the measurement of microwave amplifiers.

A functional diagram of the matched acoustic generator is shown in figure 2. The "infinite" transmission lines are 100-foot (30-m) coils of hollow tubing, open or closed at the far end as is convenient. The signal attenuation in this length is sufficiently great that pressure at the input end is independent of the termination over the frequency range of interest. A moderately large acoustic signal is delivered directly to the center transmission line (driving line) by an acoustic driver. Two small matched orifices couple small but equal fractions of the energy of the center line into the upper and lower doubly

[1] F.T. Brown, "Stability and Response of Fluid Amplifiers and Fluidic Systems," MIT Eng. Projects Lab., Cambridge, Mass., Oct. 1, 1967. (for NASA, Contract NAS 3-5203)

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infinite transmission lines. The microphone at P monitors the pressure that would exist at P´ if there were no amplifier inserted in the lower line. The microphone at P´ monitors the output of the amplifier; the microphone at P´´ monitors reflections from the amplifier. The rectified output of the upper microphone is compared with a preset dc voltage and the difference is amplified and used to set the level of output of the sweep frequency generator. This feedback maintains the pressure at P constant as the frequency is swept from 200 to 5000 Hz. The squared ratio of the pressure readings of the microphone at P´ to the one at P is the insertion power gain of the amplifier under test.

An additional feature of this device is that the pressure difference between P and P´´ is the signal reflected from the amplifier input. Viewing the difference in pressures at P and P´´ on a swept-frequency display gives an immediate evaluation of the degree of mismatch between the input impedance of the component and the generator, over the frequency range. The accuracy of this measurement depends on the distances of P and P´´ from the orifices being equal and sufficiently short so that the line attenuation may be neglected. The signals in the upper and lower lines must also be equal in phase as well as magnitude. Preliminary tests show that the signals in the upper and lower lines although nearly equal in magnitude are different in phase, especially at the higher test frequencies. This makes the measurement of the reflected signal inaccurate.

If the device is to work properly:

(1) The coupling orifices to the upper and lower lines must be identical so that readings obtained at P and P´ without an amplifier are identical.

(2) The area ratios A/α and a/α, defined in figure 2, must be sufficiently large so that the orifices represent a negligible shunting impedance across any of the transmission lines.

(3) Acoustic power from the driver must be sufficient to provide useful signal-to-noise ratios given the necessarily large orifice attenuations.

(4) Attachment of the monitoring microphones must not produce any significant discontinuity in the transmission lines.

The degree to which objective (1) was attained in tests is illustrated in figure 3. The upper trace shows the pressure at P (fig. 2) in the upper or "leveling" line, which is maintained constant by the negative feedback to the generator. The lower trace is the pressure at P´ in the "signal" line without a component. The two pressures are, in general, within 4 percent of each other.

Figure 4 is a drawing of the microphone holder used for the pressure measurements and designed to minimize discontinuities in the lines. The microphones measure the pressure in a cavity connected to the line through a small hole. Modeling the inductance of the hole and the capacitance of the volume as a Helmholtz resonator, the resonant frequency is 24,500 Hz. This frequency is far above the highest frequency used in our tests.

Figure 5 is an exploded view of the coupling unit and figure 6 shows the actual hardware. The decoupling between the leveling line and the driving line as a function of frequency is shown in figure 7. At 200 Hz the ratio of the driving line pressure (lower trace) to the leveling line pressure is 33:1. This ratio rises to about 66:1 at 5000 Hz. The corresponding power ratios of the driving line to leveling line are:

$$(33)^2 \times (A/a) \approx 9000:1 \text{ at } 200 \text{ Hz},$$

and

$$(66)^2 \times (A/a) \approx 36000:1 \text{ at } 5000 \text{ Hz}$$

The leveling line pressure in figure 3, of about .018 kilopascal (kP), was the maximum pressure that could be attained with a harmonic distortion (attributed to the orifice[2]) of less that 10 percent.

3. TESTS WITH THE GENERATOR

Insertion gain measurements of five-, three-, and one-stage differential amplifiers are described. Figure 6 shows an amplifier being tested. The amplifier connectors were enlarged with Teflon sleeves to fit the transmission lines. One input port and one output port were used; the others were left open. Loading these ports could improve gain, but the close spacing of the ports made it infeasible to connect transmission lines to all of them. The multistage amplifiers were operated at signal levels just below saturation to provide a good signal-to-noise ratio.

Figure 8 shows the frequency response of a five-stage amplifier with a 50-kP power-jet pressure. The top trace is the amplitude envelope of the input signal, and the bottom trace is the output signal swept from 200 to 5000 Hz. Amplifier noise level can be seen just before and after the input signal is applied. The insertion pressure gain is approximately 65 at 200 Hz. Since the characteristic impedance of both the input and output lines are identical, the power gain is the square of the pressure gain and is approximately 4200. The frequency response is good, exhibiting gain to about 4000 Hz.

Figure 9 shows the frequency response of a three-stage amplifier with a power-jet pressure of 75 kP. The pressure gain at 200 Hz is approximately eight. The frequency response extends to about 4000 Hz.

Figure 10 shows the frequency response of a single-stage amplifier with a power-jet pressure of 3.5 kP. The insertion pressure gain is approximately 2.5 at 200 Hz. Figure 11 shows the response of the small amplifier with a power-jet pressure of 10 kP. The frequency response at higher pressures is better, but the output noise is also higher.

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[2]Uno Ingrad and Hartmut Ising, "Acoustic Nonlinearity of an Orifice," Journal of the Acoustic Society of America, Vol. 42, No. 1, 1967.

The pressure gain of the single-stage amplifier is larger than the gain per stage of the multistage amplifiers. The single-stage amplifier was larger and may have been a better impedance match to the transmission lines.

The audio oscillator was replaced by a signal generator that produced a pulse-modulated carrier signal. This type of signal is useful for studying the transient response of amplifiers and for testing pulse carrier systems.

Figure 12 shows the pulse carrier response of the single-stage amplifier with a power-jet pressure of 3.5 kP. The upper trace is the signal produced by the generator in the leveling line. The generator does not produce a perfect pulse-modulated signal and some ringing is evident. The response of the amplifier to the input signal is quite good.

4. CONCLUSIONS

An acoustic matched-impedance generator was designed and built to measure the high-frequency insertion power gain of flueric proportional amplifiers. The error in the measurement is estimated as less than 5 percent. The maximum signal amplitude with the accuracy stated above is 1.77×10^{-2} kP (approximately 120 dB). A frequency response scan can be made in minutes.

The speed and convenience of this measurement system makes it a strong candidate for a universal standard for testing high-frequency response of proportional flueric amplifiers. Amplifiers used as repeaters in transmission lines should have their input and output port diameters equal to each other and equal to the diameter of the transmission line. This is similar to the approach used in wide-band microwave amplifier design.

5. LITERATURE CITED

[1] F.T. Brown, "Stability and Response of Fluid Amplifiers and Fluidic Systems," MIT Eng. Projects Lab., Cambridge, Mass., Oct. 1, 1967. (for NASA, Contract NAS 3-5203)

[2] Uno Ingard and Hartmut Ising, "Acoustic Nonlinearity of an Orifice," Journal of the Acoustic Society of America, Vol. 42, No. 1, 1967.

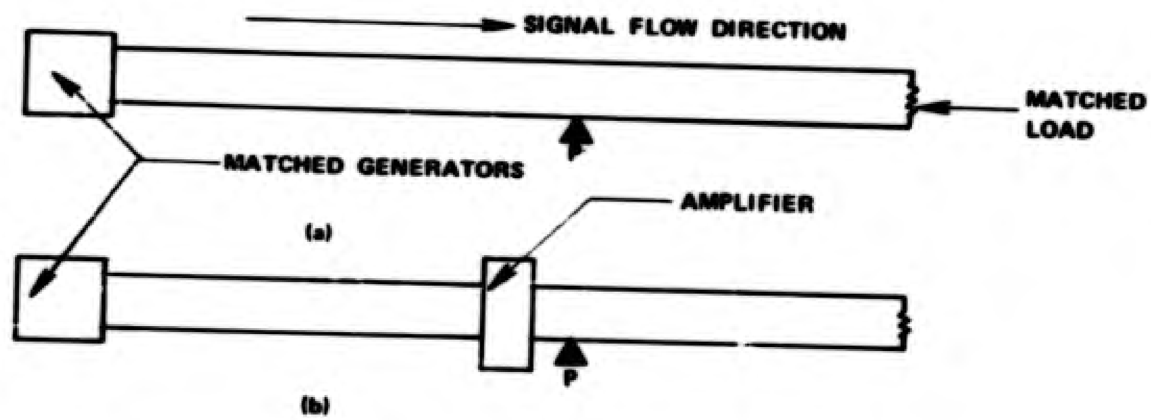

Figure 1. Diagram for defining insertion power gain.

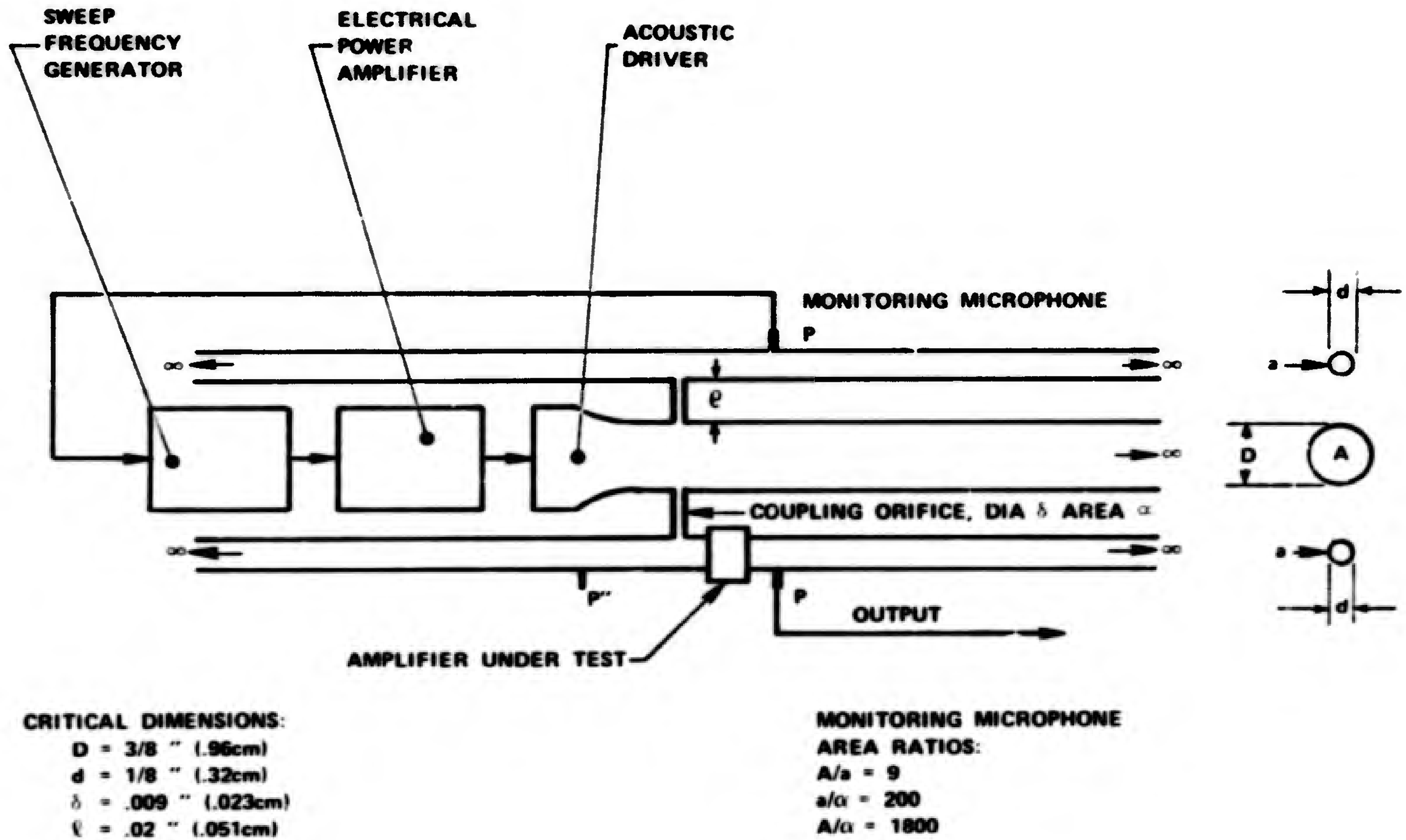

Figure 2. Matched acoustic generator functional schematic.

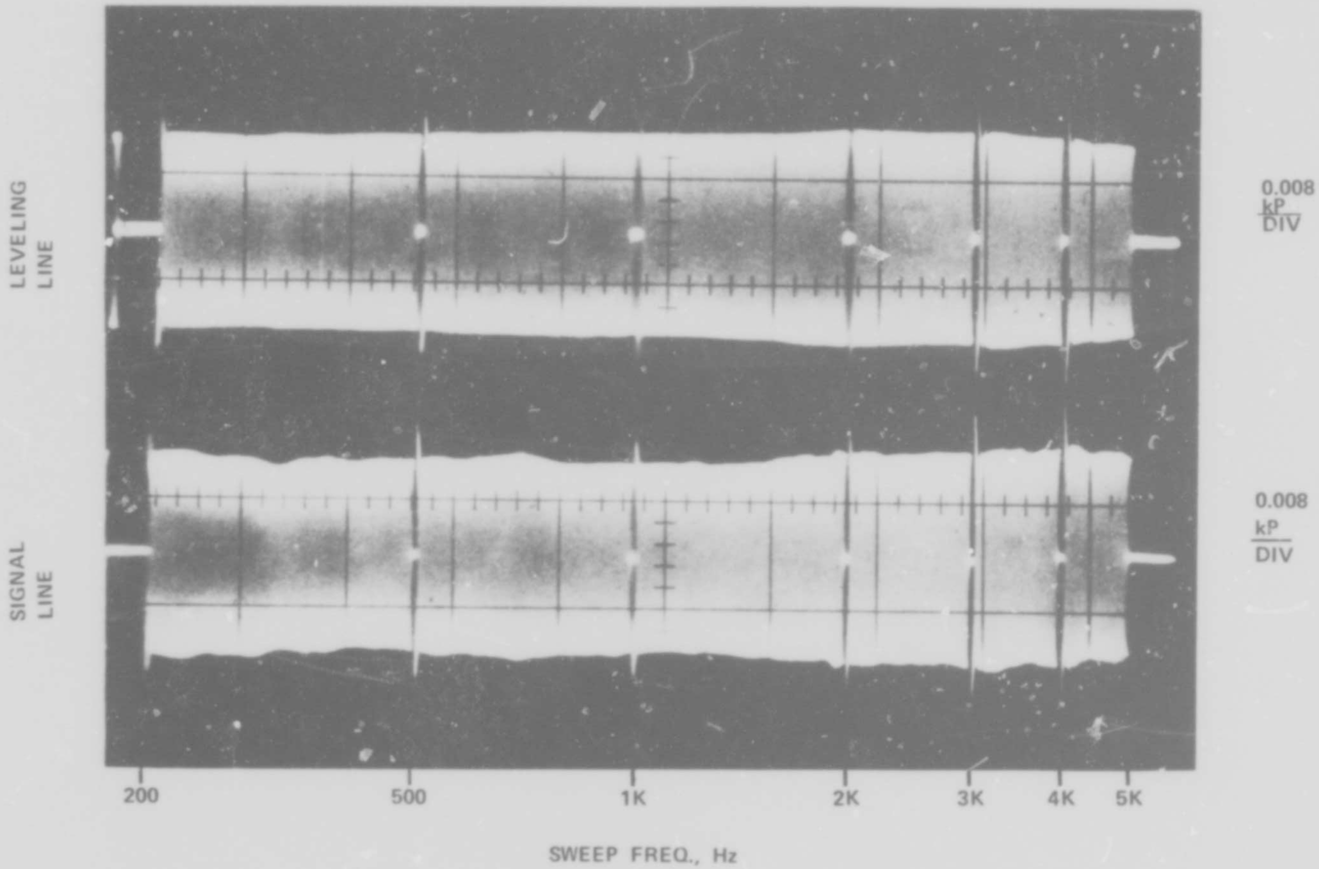

Figure 3. Match between leveling line and signal line.

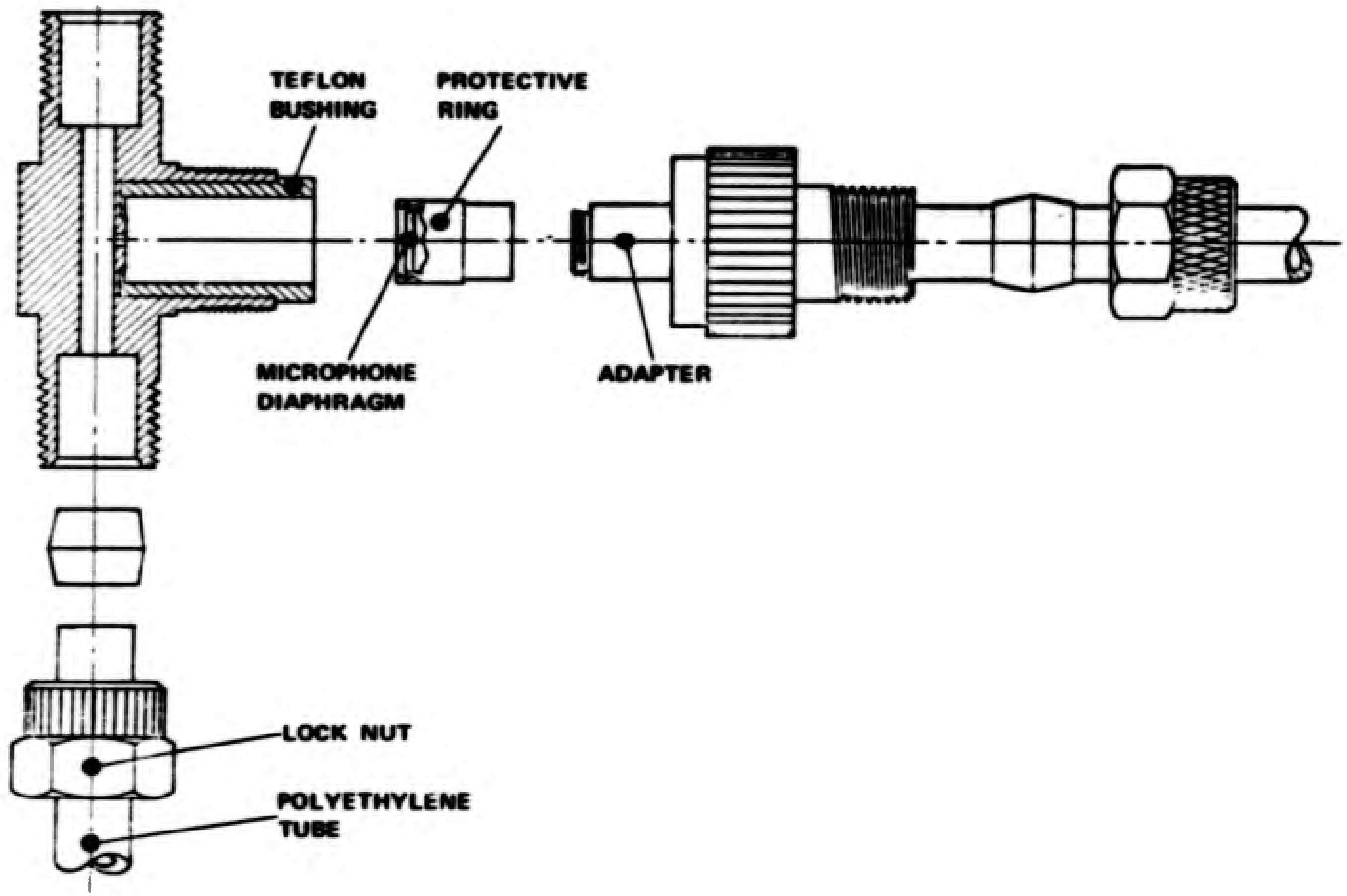

Figure 4. Microphone holder.

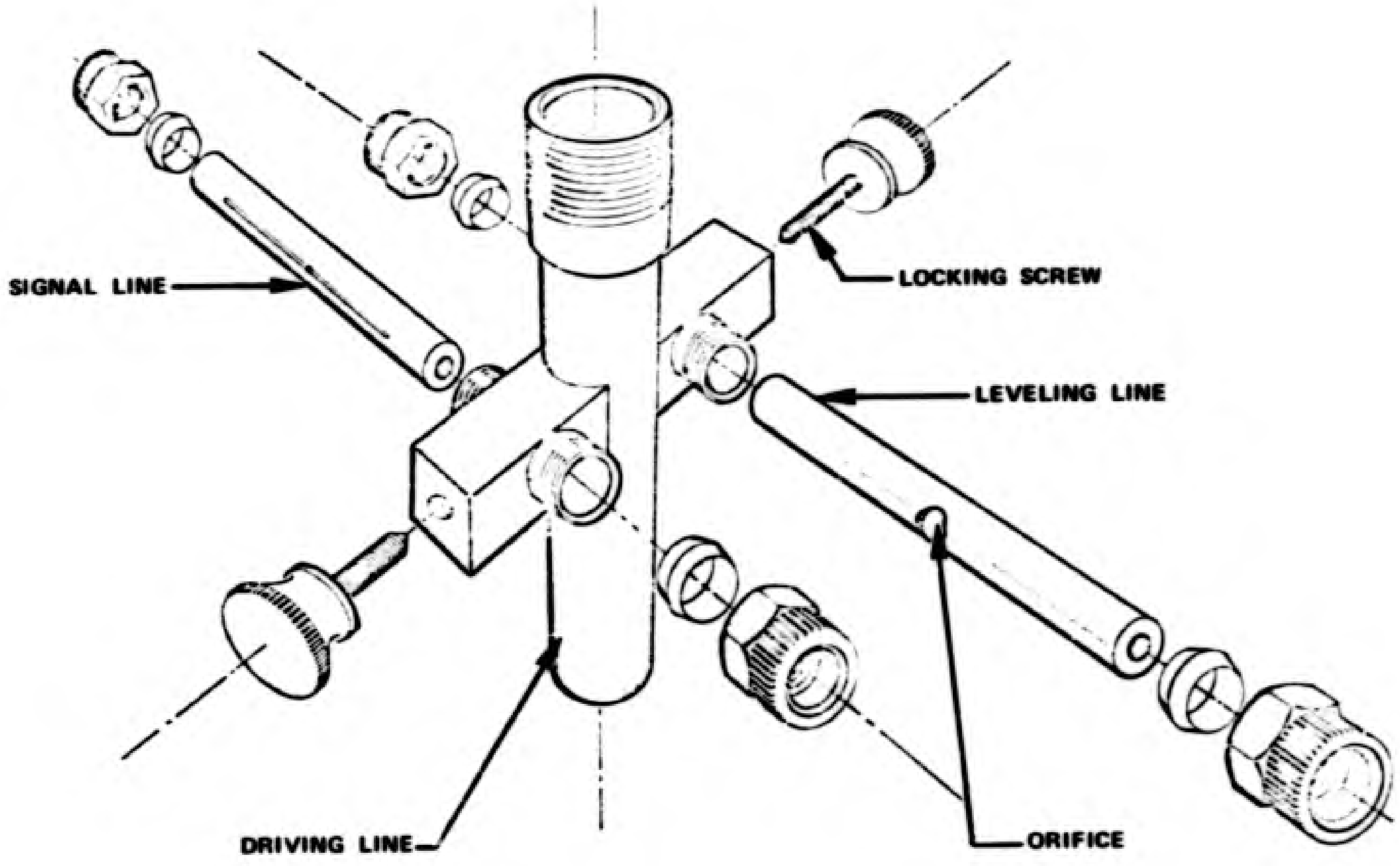

Figure 5. Coupling unit, exploded view

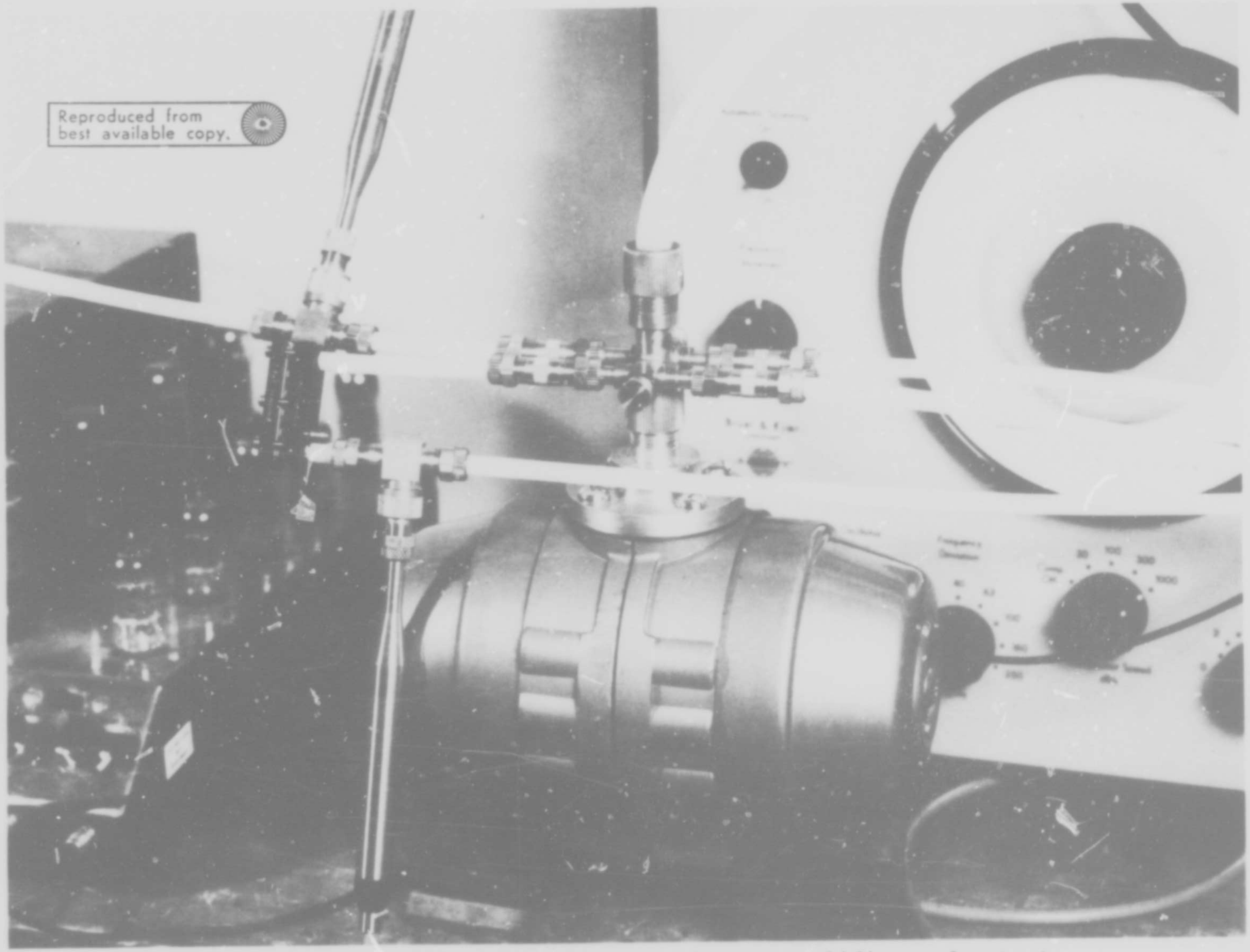

Figure 6. Matched generator, showing an amplifier under test.

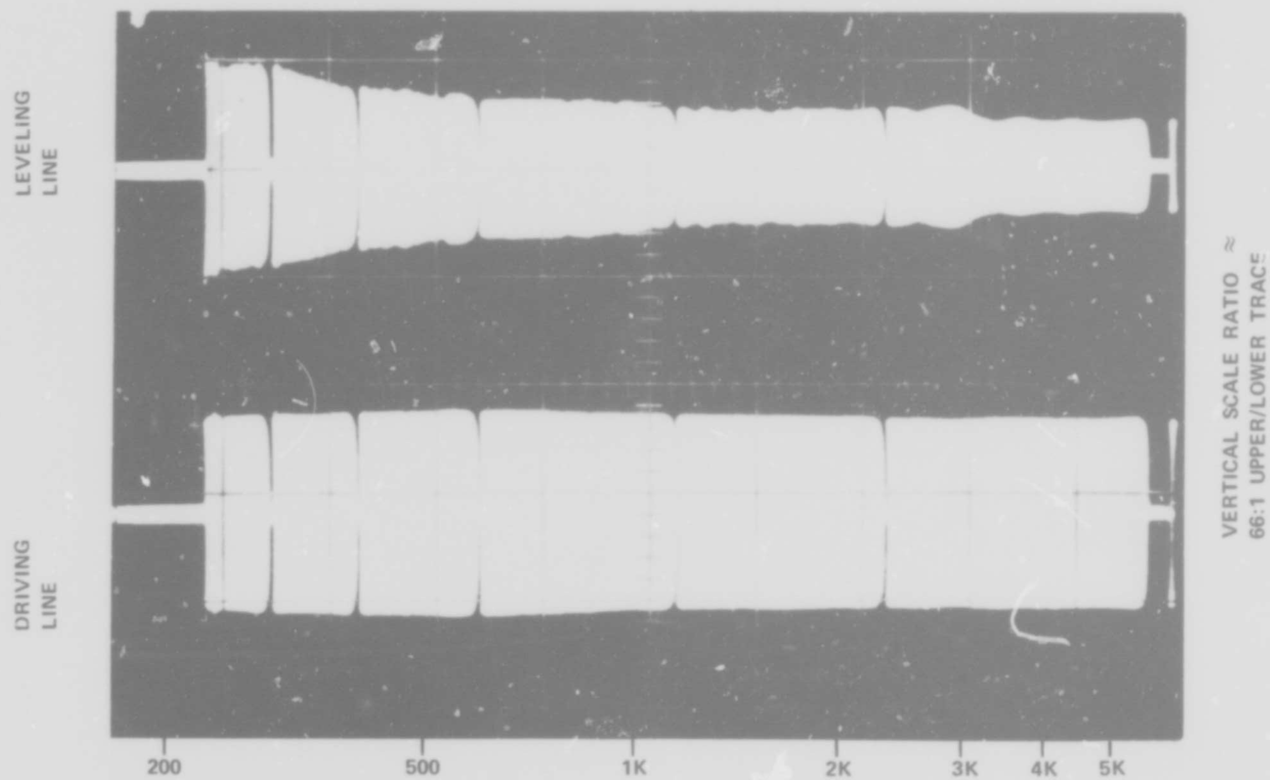

Figure 7. Leveling line/driving line decoupling versus frequency.

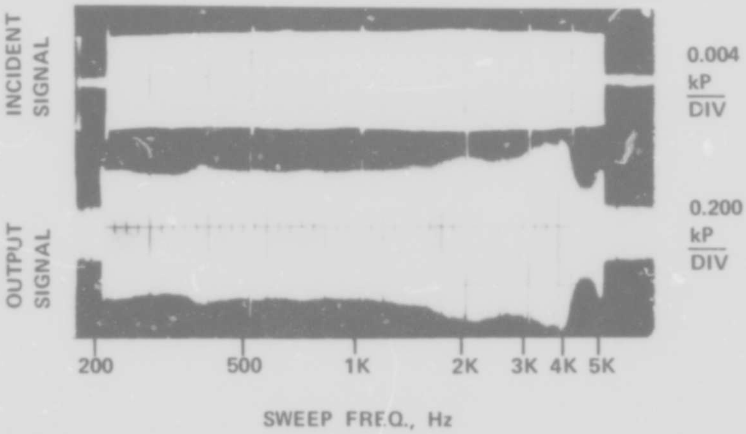

Figure 8. Frequency response of five-stage amplifier with power-jet pressure of 50 kP.

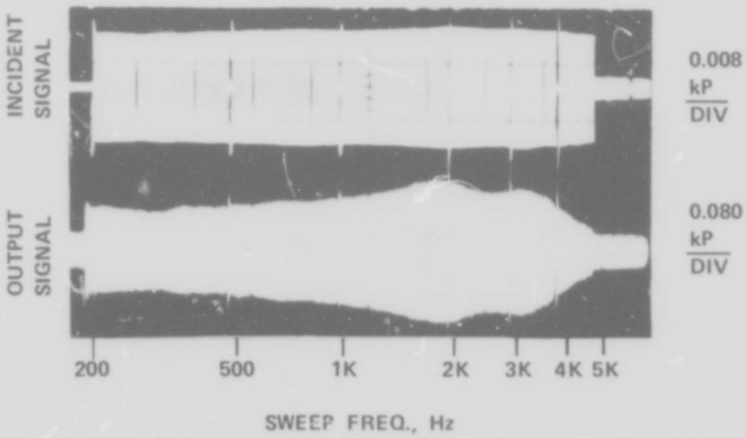

Figure 9. Frequency response of three-stage amplifier with power-jet pressure of 75 kP.

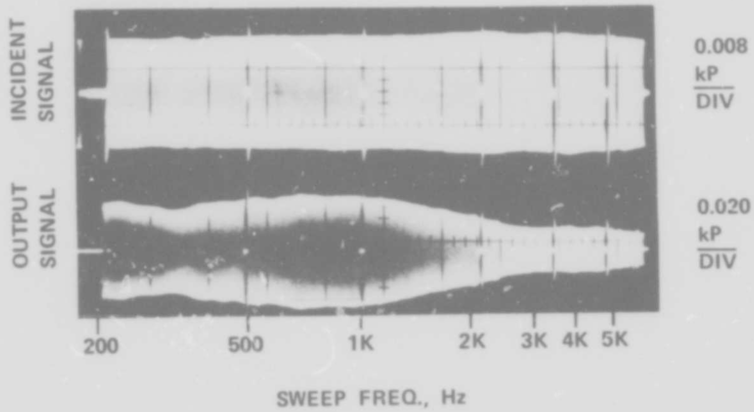

Figure 10. Frequency response of one-stage amplifier with power-jet pressure 3.5 kP.

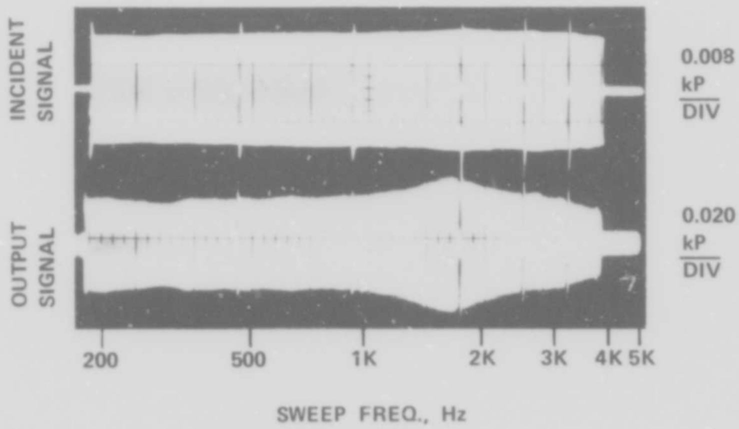

Figure 11. Frequency response of one-stage amplifier with power-jet pressure of 10 kP.

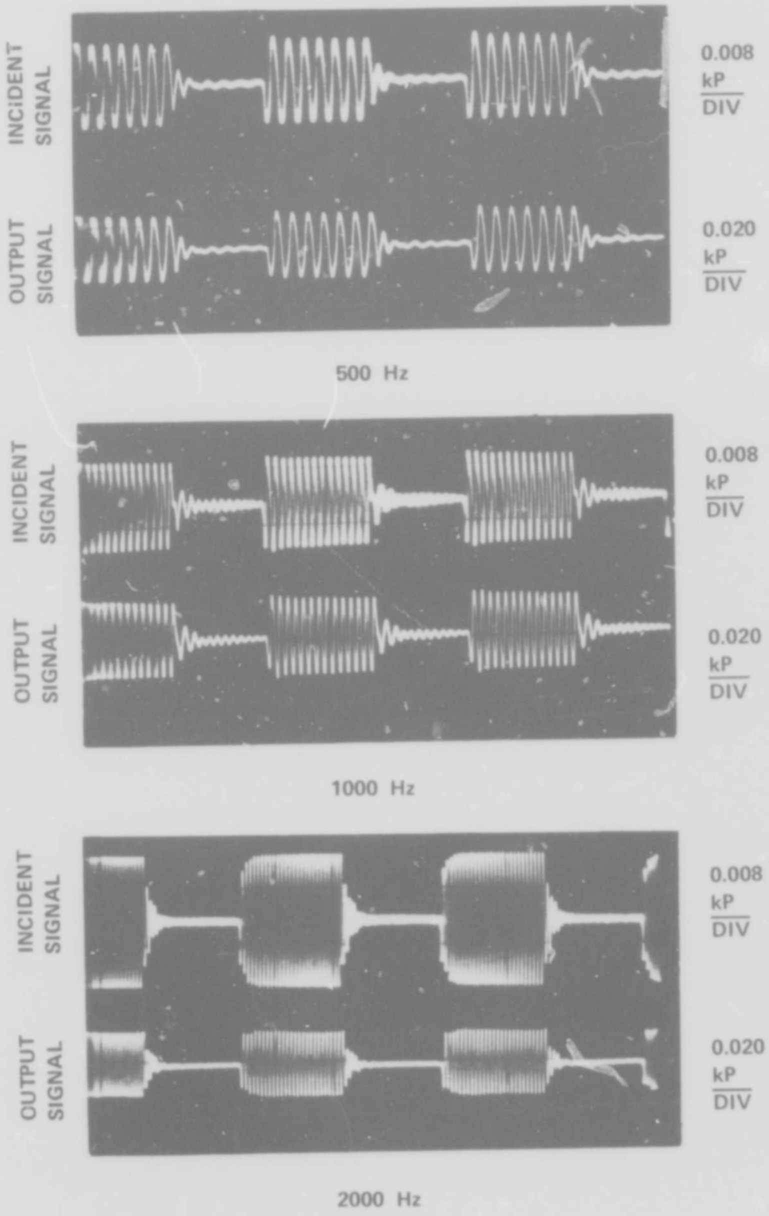

Figure 12. Pulsed frequency response of one-stage amplifier with power-jet pressure of 3.5 kP.