hp JOURNAL

TECHNICAL INFORMATION FROM THE HEWLETT-PACKARD LABORATORIES

VOL. 1 No. 1

PUBLISHED BY THE HEWLETT-PACKARD COMPANY, 395 PAGE MILL ROAD, PALO ALTO, CALIFORNIA SEPTEMBER, 1949

A New Amplifier For Milli-Microsecond Pulses

RECENT developments in nuclear radiation measurements have created a need for amplifiers having extremely wide bandwidth or speed compared to conventional video amplifiers. For example, certain photomultiplier type radiation detectors have output pulses as short as 0.01 microsecond.

The new Model 460A amplifier shown in Figure 1 will amplify such pulses with very little distortion and provide suitable output for operating scalers, coincidence devices, or for direct viewing on a cathode ray tube. Although this amplifier was developed primarily to meet these requirements, other more general applications suggest themselves for amplifying signals anywhere in the range from audio frequencies to 200 megacycles. The amplifier can readily be used for extending by tenfold the sensitivity of a peak-reading diode voltmeter or for amplifying the output of a low-level signal generator.

The distributed amplifier[1] circuit provides a means for connecting conventional amplifier tubes in parallel so that their plate currents add but their capacities do not. Thus, the bandwidth can be increased beyond the point where the individual tubes have a gain of one, which is the limiting point in conventional cascaded stages.

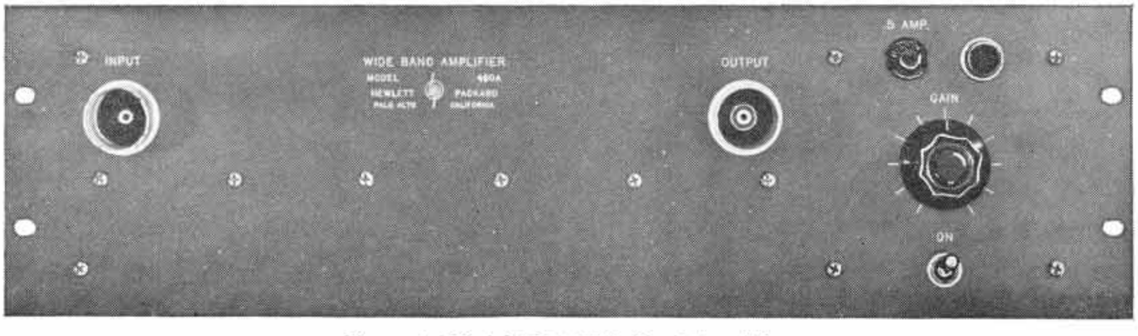


Figure 1. *Model 460A Wide Band Amplifier*

PRINTED IN U.S.A.

---

[1] Ginzton, Hewlett, et al, "Distributed Amplification," Proc. I.R.E., Vol. 36, pp. 956-969; August, 1948.

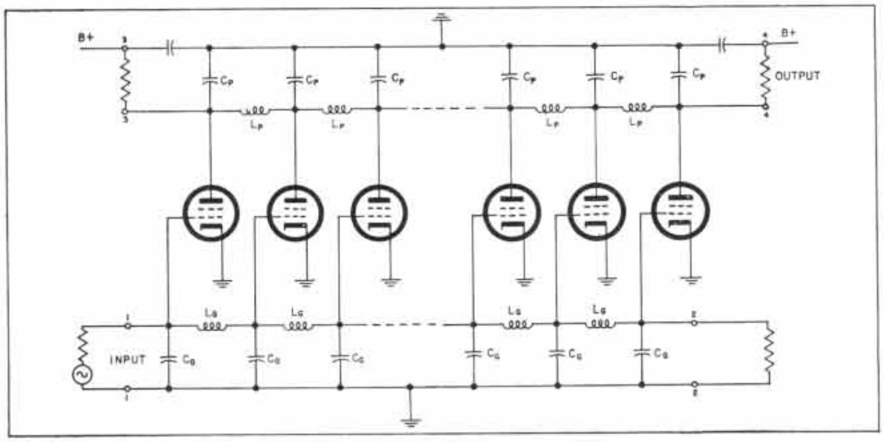


Figure 2. *Basic Circuit of Distributed Amplifier*

Figure 2 shows a basic circuit for the distributed amplifier.

The tube capacities are used for the shunt capacities of simple low-pass filters or artificial transmission lines. A signal applied at the input terminals 1-1 will travel along the grid line and be absorbed in the terminating resistor at 2-2. As the signal reaches the grids of successive amplifier tubes, it causes plate currents to flow. Half the current from each tube will flow to the output terminals 4-4 and half to the reverse terminating resistor at 3-3. By making the grid and plate lines with equal velocities of propagation or cut-off frequencies, the currents from all tubes will arrive in phase at the output terminals 4-4. The currents arriving at the reverse terminals 3-3 will not be in phase and will be absorbed in the terminating resistor without providing useful output at this point.

It is apparent that the gain of the amplifier will be $nG_mZ_0/2$, where n is the number of tubes, G_m their mutual conductance, and Z_0 the characteristic impedance of the plate line. The characteristic impedances of the lines are fixed by the tube capacities and the desired bandwidth, according to conventional filter theory. From the standpoint of tube usage, it is most economical to build stages[2] with just enough tubes to give a gain of 2.72 (ε) and to cascade such stages to obtain the required total gain. The 460A amplifier consists of two five-tube stages in cascade, each having a gain of approximately three.

Figure 2 shows the use of simple filters, known as constant K filters, as the line sections. Other more complex lines have been found to have more desirable frequency response and delay characteristics, however, and the structure known as the bridged-T has been selected for use in the amplifier. The basic amplifier circuit using the bridged-T sections is shown in Figure 3.

The bridged-T is formed by using negative mutual inductive coupling between adjacent coils together with a bridging capacity across each coil. This circuit can be shown to be an all-pass network when the elements are chosen in proper relationship. Thus, the lines themselves have no cutoff frequency, only a delay variation with frequency. The bridged-T lines offer the greatest choice in amplifier frequency response, and it is possible to obtain a response as shown by the "Gain" curve of Figure 4.

PULSE AMPLIFICATION AND THE GAUSSIAN RESPONSE

The quality of an amplifier for use with pulses can best be rated by the smallness of the rise time and overshoot when tested with a pulse or step having an infinitely fast leading edge. Although a physically realizable pulse must always have a finite rise time, it will generally be somewhat less than the rise time of any economical amplifier designed to amplify it. Hence, the pulse is capable of exciting overshoot within the amplifier. Overshoot alters the pulse shape and makes its peak value dependent upon the steepness of the leading edge of the signal pulse. Also, overshoot in the form of a slowly dying oscillation can cause false indications in pulse counting circuits.

It has been found that pulses are not distorted with overshoot in an amplifier if the amplifier high frequency response drops in accordance with the normal probability curve known as the Gaussian curve. Applied to an amplifier, the curve is shown in Figure 4 and is given by

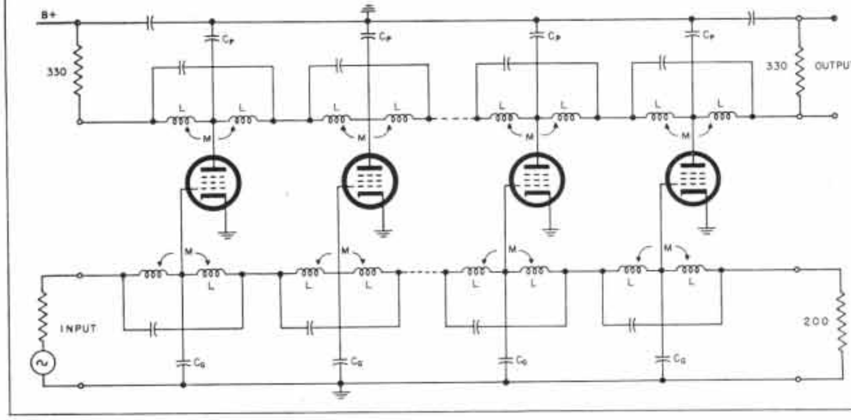


Figure 3. *Basic Amplifier Circuit Using Bridged-T Lines*

---

[2] A stage in the distributed amplifier consists of a group of tubes connected so that their plate currents add together.

the relation:

$$\text{Gain} = \epsilon^{-.346\left(\frac{f}{f_o}\right)^2}$$

where f_o is the 3-db point. In contrast a low-pass filter with a sharp cutoff will produce slowly decaying overshoot oscillations when excited with a pulse or square wave. The relationship of high frequency response to the Gaussian curve is reasonable in the light of known transient behavior of familiar circuits. For example, experience with RC and simple video amplifiers shows that zero overshoot is associated with a gradual high-frequency cutoff.

The response of the bridged-T amplifier section can be made to approximate the Gaussian curve quite closely, as shown in Figure 4, and for this reason is used in the 460A amplifier.

An amplifier having an overshoot of less than a few percent has been found to have a rise time between the 10 and 90 percent points of approximately $.35/f_o$, where f_o is the high-frequency 3-db point.[3] This can be verified in a simple RC amplifier, which has an f_o of $1/2\pi RC$, and hence a rise time of $.35(2\pi RC)$ or 2.2RC. Reference to the familiar exponential RC curve will show this to be equal to the time between the 10 and 90 percent points.

An amplifier consisting of a number of stages in cascade, each with a Gaussian frequency response, has an overall response that is also Gaussian, as can be shown by multiplying the expressions for the individual stage gains. For example, an amplifier consisting of three stages with low frequency gains of A_a, A_b, and A_c, and high-frequency 3-db points of f_a, f_b, and f_c, has a total gain

$$A = A_a A_b A_c \, \epsilon^{-.346\left[\left(\frac{f}{f_a}\right)^2+\left(\frac{f}{f_b}\right)^2+\left(\frac{f}{f_c}\right)^2\right]}$$

or

$$A = A_a A_b A_c \, \epsilon^{-.346\left[\frac{f}{\frac{1}{\sqrt{\frac{1}{f_a^2}+\frac{1}{f_b^2}+\frac{1}{f_c^2}}}}\right]^2}$$

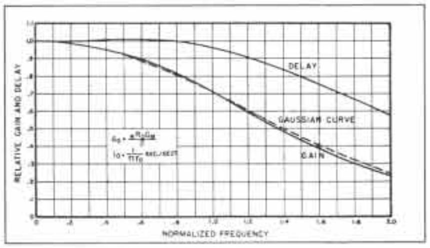


Figure 4. *Calculated Gain and Delay Characteristics Using Bridged-T Lines*

Thus the response is still Gaussian, and the f_o of the entire amplifier is given by the relationship

$$\frac{1}{f_o^2} = \frac{1}{f_a^2} + \frac{1}{f_b^2} + \frac{1}{f_c^2} \cdots + \frac{1}{f_n^2}$$

Since the rise time has been defined as $.35/f_o$, for amplifiers free from overshoot, the important expression for total rise time in an amplifier made up of a number of individual stages is obtained:

$$T_o = \sqrt{T_a^2 + T_b^2 + T_c^2 \cdots + T_n^2}$$

This expression that the total rise, time of an amplifier is equal to the square root of the sum of the squares of the individual stages rise times can be simplified if the stage rise times are identical, resulting in

$$T_o = \sqrt{n}\, T_a$$

Here, T_o, the total amplifier rise time is equal to the square root of the number of stages multiplied by the individual stage rise time. Thus, a pulse having a rise time T_p applied to an amplifier free of overshoot and having a rise time T_a will result in an output pulse having a rise time again equal to the square root of the sum of the squares of the individual rise times:

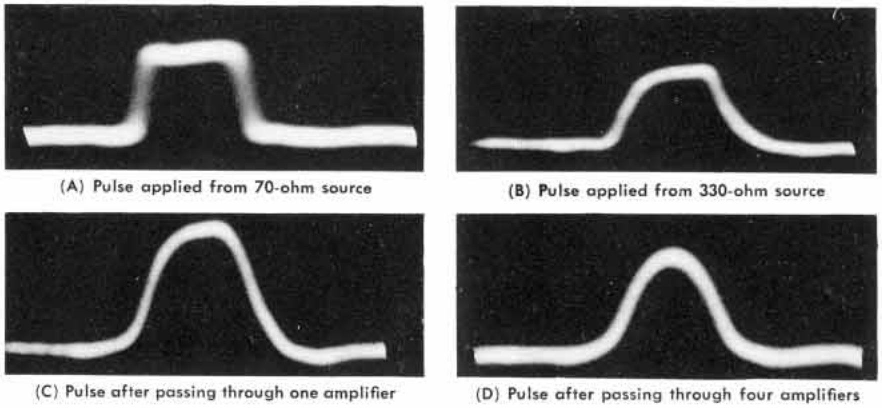
$$\sqrt{T_p^2 + T_a^2}$$

Using the above relationships, the 460A amplifier was designed to have a high-frequency 3-db point of 140 megacycles, corresponding to a theoretical rise time of 2.5 milli-microseconds (0.0025 μsec).

AMPLIFIER RISE-TIME MEASUREMENTS

In order to verify experimentally the calculated rise time of the amplifier, a special pulse generator was developed in order to obtain short pulses having extremely fast rise times. The pulse generator used generated 0.010-microsecond pulses with a rise time of less than 0.001 microsecond. This pulse generator in combination with a 5XP11 cathode-ray tube was used to measure the amplifiers' rise time.

Because of the time constant of the capacity of the deflecting-plates and the output impedance of the 460A amplifier, the use of approximately five amplifiers in cascade is necessary in order to find the amplifiers' rise-time accurately. The output resistance of the amplifiers is 330-ohms and the capacity of the deflecting circuit is approximately 4 mmf, giving a rise time of 2.9 x 10-9 seconds for this part of the circuit alone (t=2.2-RC). This response is shown in the photograph in Figure 5(b).



(A) Pulse applied from 70-ohm source

(B) Pulse applied from 330-ohm source

(C) Pulse after passing through one amplifier

(D) Pulse after passing through four amplifiers

Figure 5. *Pulses of 10 Milli-Microsecond Duration Viewed on 5XP11 Cathode Ray Tube*

---

[3] This and the following rules are due to G. E. Valley, Jr., and Henry Wallman, "Vacuum Tube Amplifiers," Vol. 18, Radiation Laboratory Series, McGraw-Hill Co. Inc., New York, N. Y., 1948, Chap. 2.

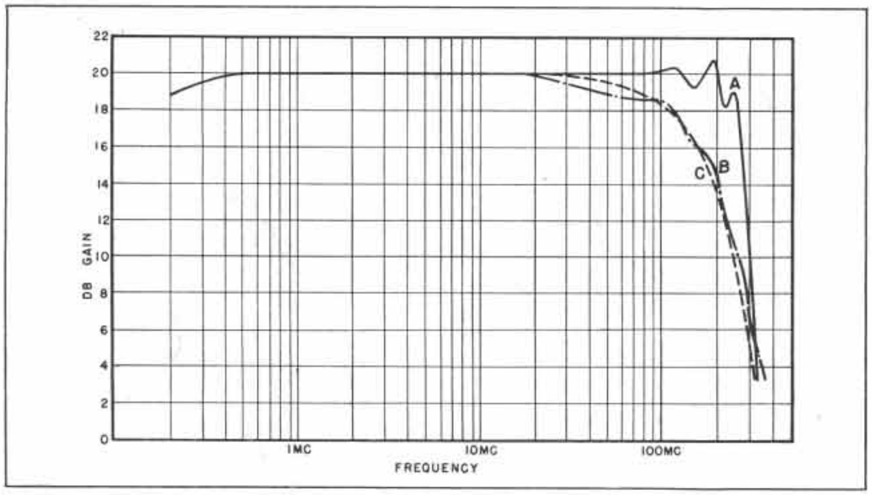


Figure 6. (A) *Typical Response of Amplifier Working Into Resistive Load,* (B) *Using 410A Voltmeter Adapter,* (C) *Gaussian Curve.*

The rise time for five of the 460A amplifiers in cascade (approximately 100-db total gain) was measured as 6.5 x 10-9 seconds. Using this value the rise time of the individual amplifiers can be computed with good accuracy from the previously given rules:

$$6.5 = \sqrt{5T^2 + 2.9^2}$$
$$T = 2.6 \times 10^{-9} \text{ seconds}$$

where T is the rise time of a single 460A amplifier. This measured value of rise time checks closely with the design data.

LOW FREQUENCY RESPONSE

Most of the anticipated applications for the 460A amplifier do not require an extended low frequency response. The low frequency response is dependent upon the interstage coupling capacitors and upon the values of the resistors used to terminate the grid and plate lines. The response of the 460A is substantially constant down to 100KC. Where necessary, the low frequency response can be made constant down to audio frequencies.

APPLICATION DATA

Although the grid lines of the 460A have been designed for 200 ohms and the plate lines for 330 ohms, both the input and output connectors for the amplifier are designed for 200 ohm coaxial cable. This arrangement is possible because the characteristic impedance of the bridged-T lines is nominally a constant pure resistance at all frequencies. The reflection from the output connector is absorbed in the reverse plate line termination and causes no undesirable effect or change in frequency response. A substantial gain improvement is obtained in this case over the case where the plates are loaded with additional capacity to make the impedance the same as the grid line.

VOLTMETER ADAPTER

One of the uses of the 460A is as a multiplier for a diode volt-meter such as the 410A. In this application it is desirable that the high frequency response of the amplifier be flat instead of the gradual drop of the Gaussian curve.

An approximately flat response can be obtained up to 200 megacycles by adding series inductance in the voltmeter connection so that a resonant rise across the voltmeter input compensates for the decreasing high frequency gain in the amplifier. An adapter has been designed to have the proper characteristics and the response curve of the combination of the 460A amplifier, adapter, and 410A voltmeter is shown in Figure 6.

—N. B. Schrock

SPECIFICATIONS FOR MODEL 460A AMPLIFIER

FREQUENCY RESPONSE: High frequency response closely matches Gaussian curve to obtain optimum pulse transmission. High frequency 3 db point is approximately 140 mc. When operating from a 200-ohm source in series with a .01 condenser, and into an open circuit or another 460A amplifier, low frequency response is constant within approximately 3 db down to 3 kc; when operating into 200-ohm load, response is down approximately 3 db at 100 kc.

GAIN: Approximately 20 db with 200-ohm load. Gain varies with Gm of tubes used (6AK5) and is approximately 20 db with 5000-micromho tubes and 18 db with 4500-micromho tubes.

GAIN CONTROL: A panel control allows gain to be adjusted downward approximately 6 db from maximum gain.

MAXIMUM OUTPUT VOLTAGE: Approximately 8 volts peak open circuit. If 200-ohm load used, maximum output voltage is approximately 4.75 volts peak (internal impedance of output system is approximately 330 ohms).

RISE TIME: Approximately .0026 micro-second with no overshoot.

DELAY: Approximately .012 micro-second.

MOUNTING: For relay rack mounting; 5¼" high x 19" wide x 6" deep.

WEIGHT: Approximately 10 pounds.

POWER SOURCE: Self-contained power supply; operates from nominal 115-volt, 50/60 cycle power source. Requires approximately 35 watts.

PRICE: $185.00 f.o.b. Palo Alto, California.

ACCESSORIES

No. 46A-16A *PATCH CORD:* Special 200-ohm cable two feet in length, complete with two No. 46A-95B Cable Plugs; for interconnection of two amplifiers in cascade $18.50

No. 46A-16B *PATCH CORD:* Same as No. 46A-16A except six feet in length...... $25.50

No. 46A-95A *PANEL JACK:* Special low capacitance panel jack designed for 200-ohm cable. Mates with Nos. 46A-16A and 46A-16B Patch Cords or No. 46A-95B Cable Plug. Requires 1⅛ inch diameter mounting hole $7.50

No. 46A-95B *CABLE PLUG:* Low Capacitance plug designed for use with 200-ohm cable. Mates with No. 46A-95A Panel Jack and with No. 46A-95E Connector Sleeve. $7.50

No. 812-52 *CABLE:* Special 200-ohm cable available in lengths to meet customer requirements .... foot $1.75

No. 46A-95C *50 OHM ADAPTOR:* Provides a type N connection for coupling a 50-ohm transmission line to the input of a Model 460A amplifier. Includes a terminating resistor $15.00

No. 46A-95D *ADAPTOR FOR MODEL 410A VOLTMETER PROBE:* Consists of a bayonet type sleeve with which a Model 410A Probe may be directly connected to the output of a Model 460A Amplifier. Includes the proper compensating LC components $15.00

No. 46A-95E *CONNECTOR SLEEVE:* Provides for joining two No. 46A-95B Cable Plugs in order to interconnect two lengths of 200-ohm cable $7.50

DATA SUBJECT TO CHANGE
WITHOUT NOTICE