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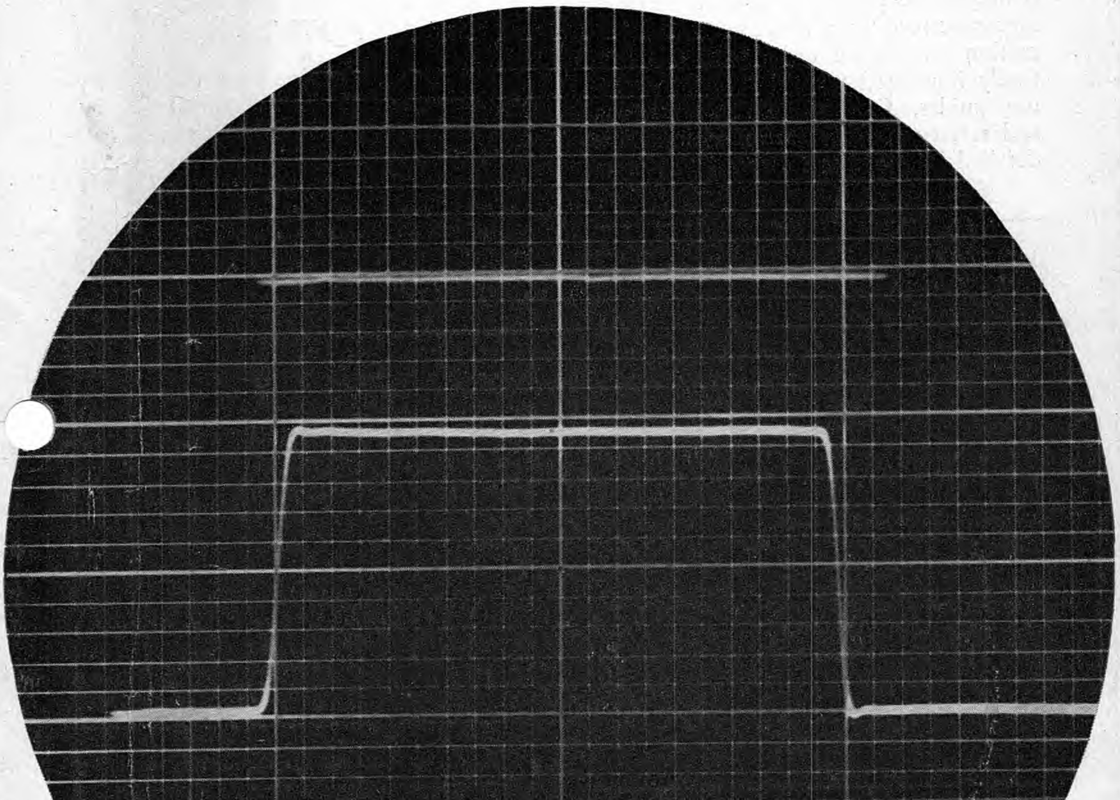

PULSE MEASUREMENT

SEE PAGE 2

Techniques of Photo Recording – 3rd Edition

The Instrument Division announces publication of the Third Edition of TECHNIQUES OF PHOTO-RECORDING. This popular book outlines in detail the problems encountered in photographing cathode-ray patterns, and the means for overcoming them. The Third Edition, completely revised and reset, includes considerable new material, with the inclusion of a section of the Polaroid-Land photographic process as applied to oscillographic recording. In addition to information on general techniques, this profusely illustrated manual contains exposure guides, film-emulsion comparisons, and references for readers desiring more detailed information on specific subjects.

Complete descriptions of commercially available equipment for photo-recording are also included.

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THE
OSCILLOGRAPHER

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ON THE COVER

The subject of the feature article of this issue, Techniques of Pulse Measurement (See page 3), is symbolized by this oscillogram of a pulse approximately 1μ second in width, photographed from the screen of a Du Mont Type 303-AH Cathode-ray Oscillograph, with a Du Mont Type 295 Oscillograph-record Camera. A sinusoidal wavetrain for time calibration and amplitude calibrating waveform, both internally supplied, have been double exposed on the oscillogram to facilitate quantitative measurement.

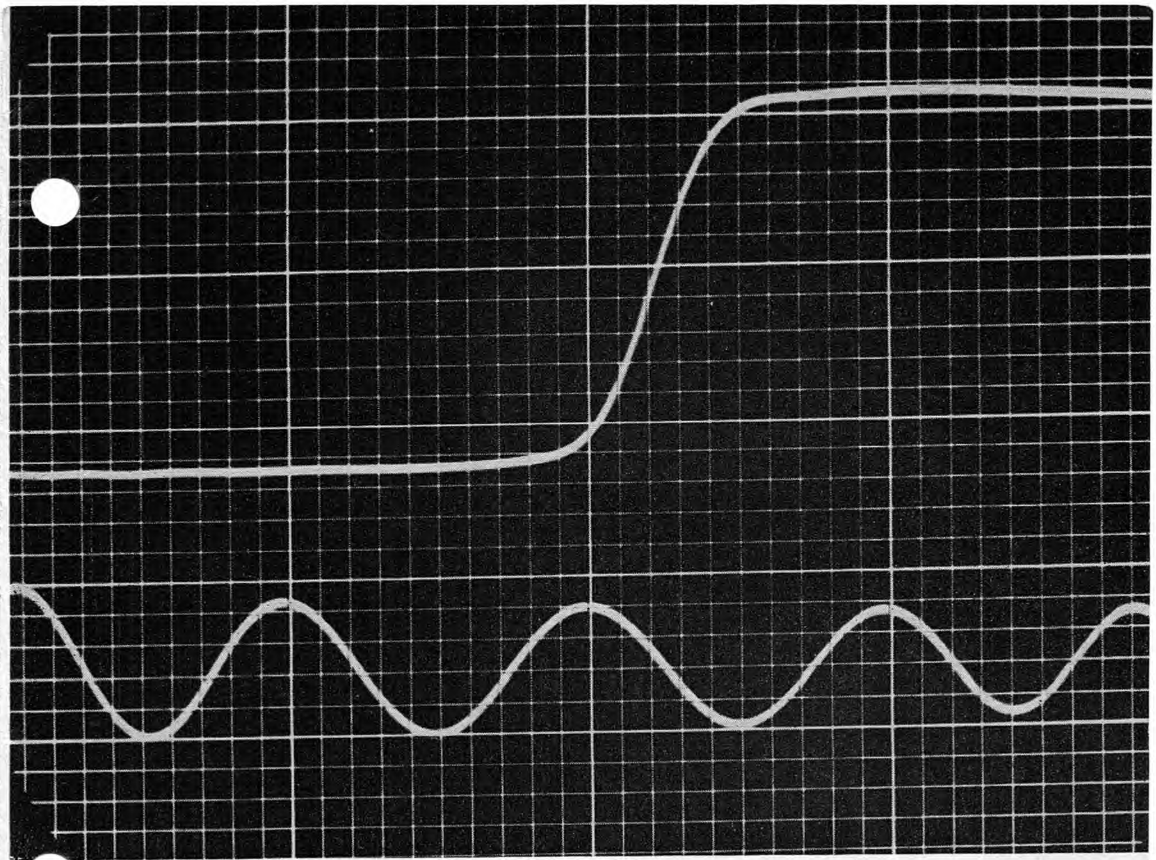
NOTICE

We wish to remind our readers that the Instrument Division has moved to its new and greatly enlarged quarters at 760 Bloomfield Avenue, Clifton, New Jersey. All communications to the Instrument Division should be sent to this new address. Phone numbers for the Instrument Division are: GRegory 2-2000 or MUlberry 4-7400.

OSCILLOGRAPHER BINDERS

The Instrument Division of Allen B. Du Mont Laboratories, Inc., make available to *Oscillographer* readers a sturdy three-ring binder for those who wish to make a permanent file of this publication. The binder is finished in attractive green leatherette with gold lettering. To obtain your binder send $1.25 to the Instrument Division, 760 Bloomfield Ave., Clifton, N. J.

TABLE OF CONTENTS



Techniques in Pulse Measurements

by

Melvin B. Kline

Assistant Engineering Manager, Instrument Division

PART 1

Introduction

Not many years ago it was thought that the best way to make a good amplifier was to make its frequency response as flat as possible out to as wide a frequency as one was interested in and to pay little attention to what happened after that. Besides being wasteful of bandwidth and power, it was soon found that such an amplifier was not a faithful reproducer of non-sinusoidal wave shapes such as fast transients. Whereas, for a vacuum-tube voltmeter in which one is reading sinusoidal voltages, such a flat characteristic is preferable so that the accuracy of measurement on the meter may be held to as high a frequency as possible, such a characteristic is far from the ideal in the transient domain and it is preferable to allow the response to start dropping off much sooner but to drop off gradually. It has since been noted that the shape of the fall-off characteristic is of even greater importance in the faithful reproduction of transients than is the portion during which the amplitude remains flat. Figure 1 indicates two such response characteristics and the type of output responses often obtained from such characteristics when a transient is applied. Note that although Curve B starts falling sooner than Curve A, its more gradual rate of fall produces a more desirable pulse response.

The relationships between frequency and time domains have been well established in the literature and may be rigorously obtained mathematically through the use of such devices as the Fourier Series for periodic phenomena or the Fourier Integral or LaPlace Transform theory for non-recurrent transients. It is not my intention in this discussion to dwell on these points other than to note that such an equivalence does exist. Indeed, such an equivalence allows one to take any type of electrical network, whether passive or active or a combination thereof, which may be analyzed, and to predict the shape of the responses. It also provides a very useful tool for synthesizing circuits so that they will have desired responses.

Not much more than a decade ago the use of non-sinusoidal or non-steady-state techniques began to be applied to the testing of amplifiers and other circuits, particularly as the bandwidth of such circuits increased where steady-state or point-by-point measurements became rather difficult or time-consuming. One of the earliest of such techniques is that of the use of square-waves which are, in effect, series of pulses occuring periodically. Application of square waves to circuits and the observation of their output soon became a useful tool for the circuit designer. It not only showed him how faithful his circuit was likely to be in reproducing complex waveshapes, but provided a very useful tool for adjusting this circuit while watching its response until the optimum adjustment was achieved.

As we started to go up higher and higher in bandwidth, we required higher and higher frequency square waves until the problem became one of generating high frequency recurrent square waves, and the next logical step was to reduce the repetition frequency and convert the square waves into series of pulses. Today, test equipment is available so that the user may, in general, use for most applications either square waves or pulses for obtaining his information. For ultra-high speed measurements, present-day square wave generators are not adequate and only very few pulse generators are available. Even as recently as five to seven years ago, square wave generators having repetition frequencies higher than a hundred kilocycles and pulse generators having rise times better than 0.02 to 0.03 μs were not generally available, but today one finds square wave generators operating at frequencies of a megacycle or more and pulse generators generating pulses as narrow as 0.01 μs with rise times of the order of 0.001 μs (1 millimicrosecond).

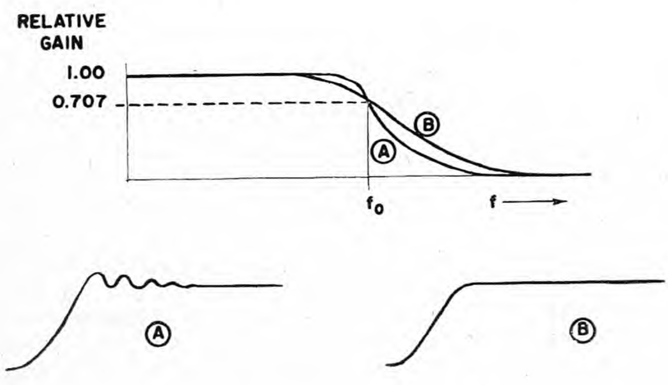


Figure 1. Effect of shape of amplitude vs. frequency response characteristic on pulse shape. Wave Form A corresponds to pulse shape A and wave form B corresponds to pulse shape B.

It can be appreciated that, as we progress along the frequency scale from kilocycles to megacycles, hundreds of megacycles and kilomegacycles, techniques in measurement become more and more critical and more and more of the order physically of the dimensions of the components themselves. We can appreciate that, in a similar manner as our pulses have narrowed and rise times have decreased, our techniques become equally critical. While it is a relatively simple matter to test a 100 kilocycle amplifier with any commercial square wave generator or one, for that matter, which can be made up very simply in one's own laboratory, when dealing with pulses of less than a microsecond in width with rise times in the hundredths of microseconds or even thousandths of microseconds one must be extremely critical as to all these matters.

The rest of this paper will indicate first of all a set of definitions to use as a measuring standard in discussing pulses, and to indicate some of the rules of thumb that have been evolved about information we may obtain by pulse testing and its equivalence to frequency testing. Next it will describe briefly some of the important characteristics to look for in test equipment for making pulse measurements and in how to set up for such measurements; and, finally, it will illustrate both correct and incorrect techniques and the types of troubles one may get into by a series of examples. Obviously, it is not possible to cover all types of measurements on pulses, nor is it the intention to discuss techniques or measurements that may readily be found in the literature, but rather to give some examples from experience of some of the newer techniques as well as some of the common errors that well-trained engineers and technicians make every day.

It has very often been found that test equipment believed by the user to be faulty or to be giving incorrect information, or even to be inadequate for the test being performed is actually extremely useful, if properly used. Sometimes a relatively simple modification in a test set-up has made the difference between a measurement which was previously useless and one which gave all the pertinent information and perhaps somewhat more.

Pulse Definitions

Let us first, then, define the test pulse. It is necessary to define both the effective high-frequency and low-frequency portions of the pulse, i.e., what happens in the transition region, and what happens immediately after the transition region as the system tries to return to a steady-state condition. It will be found that the transition region or the so-called rise time region contains the high-frequency information and the flat top or the steady-state level seeking region contains the low-frequency information providing the pulse is wide enough.

A pulse may be thought of as nothing more than the result of a closing of a switch or a sudden change in a d.c. voltage. Suppose that, at what we will call time $t = 0$, a switch is closed allowing a voltage to suddenly change from 0 to 100 volts. This amounts to the application of a transient step to the circuit to which the switch and voltage source is connected. Ideally, we would like the switch to close instantaneously and the voltage to change from 0 to 100 instantaneously, but we know, of course, that this is not possible and that it does take some appreciable time for such an event to occur even though it may be only hundredths of a microsecond. Of course, if we are dealing with a system where the time it takes for the system to react is measured in seconds or miliseconds, we may treat such a sudden closing as instantaneous. If, on the other hand, we are dealing with a system which can respond almost as quickly as the time it takes for the pulse to appear, we must be careful in evaluating our results.

So it becomes necessary to note the characteristics of our equipment, what its limitations are, and what meaningful results we may get from it. The first thing that we will find is that we will try to measure the rise time of the pulse between the 0 and 100% levels and that we will have extreme difficulty in trying to locate where the pulse departs from such

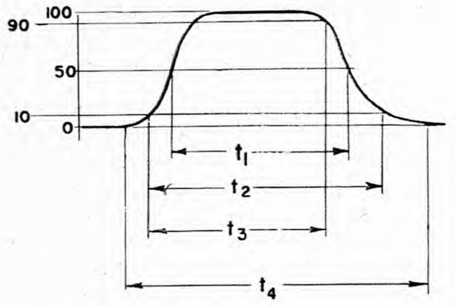


Figure 2. Various definitions of pulse width.

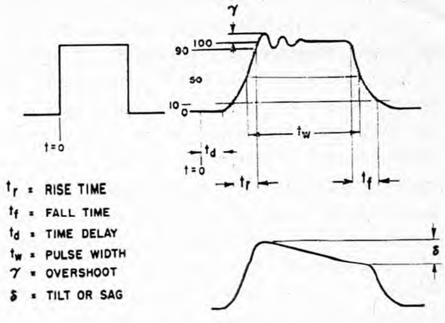


Figure 3. "Standard" definitions of pulse characteristics.

levels. We generally do not have sharply defined square corners. By the same token, suppose we were to define our pulse as having a certain width. Knowing that it has a certain specific time to rise and certain specific time to fall, we must decide whether we shall measure its width at the base, at the top, or someplace in between. Many definitions have been used in making pulse measurements and there is no prescribed set of standards, although, just as the half-power point (3db down in voltage) has been used for many years as a standard measure of bandwidth, so we will find that there are certain of these various pulse definitions that have tended to become what we shall term "standard" definitions.

For example, Figure 2 shows a pulse as it actually might appear, and shows several definitions that have been and are still being used for pulse width. One may note here measures of width made at the base, wherever the base may be thought to be, measures made at 10% and 50% amplitude points, and even one in which the measurement is made at a point at which the pulse is 10% up on the rise towards its maximum value and a point at which it is 10% down on its fall. For a pulse that is very long with respect to its rise and fall times, it is obvious that all three of these tend to give the same answer with very little error. In a specific case known to the writer, where, due to the nature of the circuitry involved the circuit to which the pulses were applied tended to make a very long gradual return time, the 10% up-10% down type of pulse width measurement actually turned out to be a much more practical definition than the one to be described as a standard.

Let us now look at our "standard" pulse definitions. Figure 3 shows an ideal pulse and what may appear as the output of a circuit to which such a pulse is applied. A number of items are shown and defined in this figure. First, we see that we have established a time $t = 0$, which time we shall call the beginning of time for these measurements. On the ideal pulse this is the time at which the pulse suddenly jumps from one level to the other. On our output pulse, however, we find that this time $t = 0$ appears somewhat to the left of where the pulse begins to actually show up. This is due to the fact that in all practical systems some appreciable time delay does occur between the application of the stimulating pulse to the circuit and the resultant reaction. In some cases the time delay is insignificant and the portion marked t_d may be neglected. In many cases, however, this cannot be neglected, and knowledge of this delay time is of value. For the purposes of our discussion we shall define delay time as the time from $t = 0$ (that is the application of the input pulse) to the time at which the output pulse begins to break away from the base line.. Other definitions, avoiding the ambiguity of the break-point have been proposed such as to the 10% point or to a line arbitrarily drawn tangent to the 50% amplitude on the rise time and to the point at which this crosses the base line or to the 50% amplitude point on the rise. These are probably more tenable for measurement purposes. We shall define our "standard" pulse width as the width between the 50% amplitude points on the rise and fall.

We shall define our rise and fall times, as shown, as the 10 to 90% transition points. Others have defined rise time by again drawing the tangent line through the 50% amplitude point and measuring the time from 0 to 100% or 10 to 90% on such a tangent. One must be aware that in making direct measurements, such as on cathode-ray oscillographs for example, it is not always possible and very often extremely difficult to try to draw such a tangent line and one must be able to use the calibrated scale on the oscilligraph to be able to measure between a 10 and 90% level. This is one of the reasons why we define rise time as being between the actual 10 and 90% level of the pulse.

We also notice in this figure some overshoot or "ringing" on the top of the pulse and we define gamma, γ, as the overshoot. Here again many definitions have been proposed for gamma and one that seems to be popular and with considerable merit is that gamma shall be the measure of the laregst overshoot whether it is positive or negative, i.e., whether it is above or below the 100% amplitude level. Most usually, it will be found that gamma will be the first major overshoot.

Also illustrated in this figure is the case where a long pulse has been applied and one is able to see what is often called tilt, sag, droop, or sawtooth on top of the pulse. This is a measure of the low-frequency response, and tilt, or sag, delta (δ), is measured as indicated in the figure. The percentage does, of course, depend upon the pulse width, but when testing with pulses of prescribed width, one can specify that tilt or sag shall be no more than a certain percentage and have a very good indication of the low frequency response of the circuit.

Rise Time — Bandwidth Relationships

We may now spend a few minutes on some mathematical relationships between the bandwidth of an amplifier and its pulse performance, notably rise-time. Certain simple relationships are readily derived for the simple R-C amplifier configurations and it may be shown that these relationships are pretty good rules of thumb even for complicated configurations which are rather difficult, and in some cases almost impossible, to calculate, providing certain precautions are observed. A good reference on this is the book "Vacuum-Tube Amplifiers", Volume 18 of the MIT Radiation Laboratory Series.

It is well-known that the bandwidth of an R-C coupled amplifier is given by the following expression:

$$\beta = \frac{1}{2\pi RC} \qquad (1)$$

where β is the frequency where the amplitude has dropped 3 db, R is the output resistance, and C the output capacitance of the amplifier.

It may also be easily shown that the 10 to 90% rise time of an R-C amplifier is given as follows:

$$t_r = 2.2RC \qquad (2)$$

It thus follows that the bandwidth-rise time product is a constant as shown in equation 3.

$$\beta t_r = \frac{2.2RC}{2\pi RC} = 0.35 \qquad (3)$$

While this is strictly true only for R-C coupled amplifiers, it has been found to be approximately correct for many types of amplifier combinations including cascaded amplifiers as well as amplifiers in which peaking exists. The following general rules have been formulated:

1. β t_r will usually be found to lie between the values of 0.30 and 0.45. If the overshoot, γ, is less than 5%, 0.35 is a good figure to use.

2. The above presupposes that the amplifier cutoff characteristic is such that the cutoff is gradual.

3. The above also presupposes that the phase shift is essentially linear in the pass band.

It can therefore be seen that this handy rule may be quickly applied to amplifiers and rise time closely estimated from known bandwidth or vice-versa.

We may now ask ourselves the question, "Suppose I cascade a number of stages and know only the individual stage rise times, how can I know what the overall rise time will be?" Again it can be proved rigorously that for n cascaded R-C stages (less than 2% overshoot), the resultant rise time may be calculated knowing the individual stage rise times by means of equation (4).

$$t_r \approx \sqrt{t_1^2 + t_2^2 + \cdots t_n^2} \qquad (4)$$

If all stages are alike, this may be simplified as shown in equation (5).

$$t_r \approx t_1 \sqrt{n} \qquad (5)$$

Although this is only an approximate formula, it is an extremely handy one. It may be stated that errors in actual rise time for up to ten identical stages may range from about 6 to 16% when applying this formula. However, this is usually considered a fair degree of accuracy according to the present status of most pulse measurement techniques. More precise information may be had by plotting carefully the output response such as shown in Figure 1.25, Page 66, Volume 18 of the Radiation Laboratory Series.

We may now ask ourselves, "Suppose I know what the rise time of the pulse is that I am going to apply to a circuit I want to test, and suppose I can measure its resultant rise time, what is the rise time of the circuit I am testing?" From equation (4) above it can be simply shown that the rise time of a system under test is given as shown in equation (6).

$$t_r\ (\text{syst}) = \sqrt{t_r^2\ (\text{result}) - t_r^2\ (\text{pulse})} \qquad (6)$$

Since the most common setup for making pulse measurements will include a pulse generator of known characteristics as a source of pulses and a cathode-ray oscillograph of known characteristics as an indicator of the output response, we naturally next ask ourselves the question, "How good must my test equipment be in order to get useful results?" Very quickly we find that, for many cases, a pulse generator and an oscillograph having rise times only three to five times better than that of the system which we want to test may be treated as contributing little error to the measurements. Even more astonishing, we find that we may make measurements of rise times using test equipment having the same rise time as what we are testing simply by applying the above formulas.

Let us illustrate this with some examples. Suppose we want to measure an amplifier that has a 10 mc bandwidth, then according to equation (3)

$$t_r \approx \frac{0.35}{10} = 0.035\ \mu s$$

If now we let

t_{rp} = pulse generator rise time,

t_{rx} = rise time of device being tested,

t_{ri} = indicated rise time, and

t_{rc} = cathode-ray oscillograph rise time

then, referring to equation (4), we may write the following expression:

$$t_{ri} = \sqrt{t^2_{rp} + t^2_{rx} + t^2_{rc}} \qquad (7)$$

Let us further suppose that

$t_{rc} = 0.003\ \mu s = 3 \times 10^{-3}$

$t_{rp} = 0.003\ \mu s = 3 \times 10^{-3}$

$t_{rx} = 0.035\ \mu s = 35 \times 10^{-3}$

What then is t_{ri} and how does it affect the measurement? Substituting in equation (7).

$$t_{ri} = \sqrt{3^2 + 35^2 + 3^2}$$
$$= \sqrt{9 + 1225 + 9}$$
$$= \sqrt{1243}$$

or $t_{ri} = 0.0352\ \mu s$

We thus see that our error in the indicated rise time is very small and we can consider the test equipment as introducing negligible error.

But suppose now we want to measure the indicated rise time and the pulse generator has a rise time of say 0.01 μs and the oscillograph a rise time of 0.035 μs.

Substituting in the formula once more we obtain the following:

$$t_{ri} = \sqrt{100 + 1225 + 1225}$$
$$= \sqrt{2550}$$
$$= 0.051\ \mu s$$

We note that we have now a 73% error. This cannot be neglected.

Suppose we wanted to find t_{rx} knowing the characteristics of the pulse generator and the oscillograph. The procedure then is to measure t_{ri} the indicated rise time. Suppose, for example, the indicated rise time comes out to be 0.04 μs and that the oscillograph and pulse generator rise times are 0.035 and 0.01 μs, respectively, then revising equation (7) properly as shown in equation (8)

$$t_{rx} = \sqrt{t^2_{ri} - t^2_{rp} - t^2_{rc}} \qquad (8)$$

and putting in the numbers we arrive at the following measure of t_{rx}.

$$t_{rx} = \sqrt{1600 - 100 - 1225}$$
$$= \sqrt{275} = 0.017\ \mu s$$

We find now that with a CRO having a bandwidth of 10 mc. (0.035 μs t_r) we can actually measure an amplifier having a bandwidth of 20 mc. (0.017 μs t_r) by applying the formula. It is perhaps well to mention a word of caution at this point since a 10 mc amplifier may not be expected to faithfully reproduce all parts of a waveshape having higher frequency components. There are times when undesirable overshoots or ringing or other phenomena will exist in the circuit under test but will not show up in the observed pattern due to the limitations of the oscillograph amplifier's bandwidth. In such cases, where enough deflection voltage is available, it is possible to view the output directly on the oscillograph deflection plates if proper precautions are observed as will be discussed later. In any event the oscillograph will give a fairly accurate idea of the order of rise time or bandwidth of the circuit under test.

Now let us find out how good a rise time we need in our pulse generator and oscillograph to avoid calculation. Let us say that we want to measure a circuit having a rise time of 0.035 μs and t_{rp} and t_{rc} are both equal to 0.01 μs. We find that t_{ri} is as follows.

$$t_{ri} = \sqrt{100 + 1225 + 100}$$
$$= \sqrt{1425}$$
$$= 0.038\ \mu s$$

and the error is less than 10%.

More generally, in terms of t_{rx}, if

$t_{rp} = 0.1\ t_{rx}$ and

$t_{rc} = 0.1\ t_{rx}$

$$t_{ri} = \sqrt{1 + 0.01 + 0.01}$$
$$t_{rx} = \sqrt{1.02}\ t_{rx}$$
$$= 1.01\ t_{rx}$$

Thus if the rise times of the pulse generator and oscillograph are ten times better than the rise time of the circuit being measured, the error in the indicated measurement will be 1% and may usually be considered negligible. Table I indicates the order of error that will occur with various other combinations of t_{rp} and t_{rc} in terms of t_{rx}.

TABLE I

Error in indicated rise time due to rise times of Test Equipment.

t_{rp}/t_{rx}	t_{rc}/t_{rx}	t_{ri}/t_{rx}	% error
0.1	0.1	1.01	1
0.2	0.2	1.04	4
0.3	0.3	1.09	9
0.4	0.4	1.15	15
0.5	0.5	1.225	22.5
1.0	1.0	1.73	73
0.1	0.2	1.025	2.5
0.1	0.3	1.05	5
0.1	0.5	1.13	13
0.1	1.0	1.42	42

It should be noted that even with t_{rp} and t_{rx} only three times better than the unknown, the error is approximately 9%, and at the present state of the art, this is not considered to be unreasonable. For many measurements we may, therefore, neglect making any corrections. If anything, when neglecting such errors, the indicated rise time will always be slightly worse than the actual one so that if we have a certain maximum limit that an amplifier should be no worse than 0.03 μs and we get readings that are no worse than this, we can be assured that the amplifier itself is somewhat better.

It is thus seen that there are certain general rules and a very simple formula that may be used to more accurately calculate and obtain rise times and that it is not necessary, in general, to obtain test equipment considerably better than what is being tested so long as we intelligently interpret our results or make simple corrections.

Characteristics Required Of Pulse Test Equipment

Let us now consider the test equipment, particularly the characteristics required of pulse test equipment. While not always considered in the sense of a technique, the selection of the equipment with which a measurement is to be carried out is an important phase in an investigation. We have frequently encountered people who have decided that their present equipment is incapable of providing desired information if the first setup has not proved satisfactory. Often, with improved techniques or minor modifications, the equipment will give excellent results. It is important to recognize the limitations of your test equipment and to take them into account. The importance of reading the operating instructions supplied with the equipment BEFORE attempting to operate it cannot be overemphasized. The manufacturer will usually indicate his limitations and how to work around them. Every effort should be made to assure that failure to obtain the desired result is not due to such limitations. One has only himself to blame if, through negligence on his part, he has not considered the various limitations of the equipment with which he has to work. So consult operating instructions of test equipment carefully for any points that may be of aid and benefit in your application of the equipment.

Before describing characteristics of the test equipment to be used, it is appropriate to show a typical setup for pulse measurement. This is shown in Figure 4. The

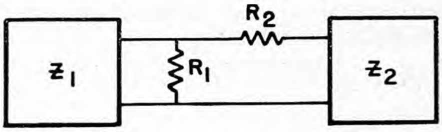


Figure 5. Resistor-matching network for low impedances.

matching networks are not always required, but when required are extremely important for optimum results or, in some cases, for any useful results. If the pulse generator works into a high impedance in the circuit under test, very often no matching may be required unless a long cable connects the pulse generator to the circuit under test, in which case proper termination at the end of the cable may avoid difficulty. A similar situation is true in the connection between the circuit being tested and the oscillograph. The oscillograph will generally have high enough input impedance that often matching networks will not be required. For those cases where such a network is required, it is very simple to calculate the component values.

Usually, a resistive L-pad will suffice to properly match both the pulse generator and the circuit being tested. A proper match means that when the pulse generator and circuit to be tested are connected together through this L-pad both the pulse generator and the circuit under test will see their proper terminating impedances. If these impedances should become high, it may be necessary to compensate parts of the matching network. For low impedances (of the order of several hundred ohms or less) ordinary composition resistors will do a good job of matching. (Needless to say, when dealing with sharp pulses, wirewound resistors are to be avoided.) A simple matching formula is shown in Figure 5 and equations (9) and

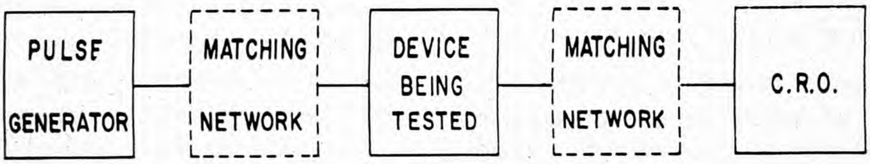


Figure 4. Block diagram of set up for typical pulse measurement.

(10) for cases where resistors only are necessary.

$$\frac{R_2}{R_1} = \frac{Z_2}{Z_1} - 1 \qquad (9)$$

$$R_1R_2 = Z_1Z_2 \qquad (10)$$

The difficulties one gets into with improper matching will be shown in later illustrations.

Let us then look into the characteristics desired in the pulse generator. First, the pulse generator should have a rather broad range of repetition rate and as high a duty cycle as possible, i.e., it should be possible to use pulses of all widths at the highest repetition rates without ill effects. This is not generally possible in most pulse generators available today. Typical repetition rate ranges are 0 to 5,000 or 10,000 pps. Zero means that the pulse may be initiated singly as for example by a single external trigger. One should be cautious in using most pulse generators to use the lowest repetition rate which will allow useful information to be obtained or which will allow pulses to be seen on the oscillograph. Also, using wide pulses, where duty cycles may tend to become larger than the pulse generator can tolerate, may actually result in either a breakdown of the pulse generator or deterioration of its waveshape.

Next, the range of pulse width should be adequate. Pulse widths varying from less than 0.1 μs to 20 or more are available in commercial pulse generators, and widths of 0.01 μs have been obtained in laboratory generators.

The rise time of the pulse generator should be known, should be measurable, should be free from extraneous excursions, and preferably should not change. Rise times of the order of 0.01 or 0.02 μs are common in commercially available pulse generators, and rise times of the order of 1 millimicrosecond have been achieved in laboratory pulse generators. It is important to know the waveshape of the pulse, particularly with regard to its stability, its rise time, its freedom from overshoot (preferably with no overshoot exceeding 2%), and its freedom from other extraneous waveshape distortions.

The output impedance, as in other types of signal generators, should be as low as possible. Unfortunately, in some pulse generator circuits it is not possible to achieve impedance as low as one would desire. In such cases, the effective capacitive loading on the pulse should be known since this may seriously deteriorate waveshape.

The useful output voltage when loaded is another important item to look for in a pulse generator. Pulse generator sales literature may indicate, for example, that the pulse generator will deliver 100 volts at an impedance of 50 ohms open circuited. It is seldom, however, that a pulse generator may be used with no loading. If terminated in its characteristic impedance, the output voltage immediately is halved, and it is therefore necessary to accurately note under what conditions the pulse generator is to be used and to know what output voltages will be available. In many cases, if impedance matching is required, further attenuation of the signal will occur. If working into high impedances shunt capacitance may not be neglected.

Other items which should be carefully looked into are the effect of the attenuators, both fixed and variable, on the waveshapes. This will be illustrated in a later section of this paper. It should not be assumed that attenuators will introduce no distortion, although it may generally be expected that any distortions introduced by attenuators will not change with time.

Provision for delay and trigger output is also desirable in a pulse generator. A built-in delay control which allows the output pulse to precede or follow the trigger is very handy. Provision for triggering the pulse generator from the circuit to be tested in cases where that is important is also desirable. The pulse generator should be looked at very critically as regards freedom from jitter. In some cases jitter will render any measurements meaningless. Some pulse generators will provide double pulses. This will help in making resolution measurements in some circuit configurations.

Let us examine next the characteristics

of the cathode-ray oscillograph that are of importance in pulse testing. Input impedance is important. Generally, the input impedance of the oscillograph is high, usually high enough so that little or no loading is imposed upon circuits being tested. It is usually equivalent to a resistance shunted by a capacitor; seldom are inductive input impedances encountered. The magnitude of the resistive impedance is particularly important when high impedance circuits are being measured to avoid loading the circuit under test. Where higher input impedance than the customary 1 or 2 megohms are required, one solution is the use of a high-resistance attenuating probe, usually capacitively compensated to preserve signal waveshape. Another possibility is the use of an adapting device consisting of a cathode-follower tube in a probe, in which case care must be exercised to avoid overloading the tube. The capacitive component of input impedance also is important when the source impedance is high since it can result in the reduction of high frequency performance. It too may be reduced by means of the probes described. If probes cannot be used, the loading of the input capacitance must be considered in interpreting results.

An adequate input sensitivity is also desirable so that measurements may be made of pulses at relatively low levels. In such cases an amplifier is usually used in order to achieve a reasonable deflection on the cathode-ray tube. It is therefore important to know what the characteristics of the amplifier are in terms of its pulse response. These specifications are usually conservatively rated by oscillograph manufacturers. It is a simple matter, however, to check them by just connecting the pulse generator to the oscillograph and measuring the indicated rise time on the cathode-ray tube itself. This will also indicate any overshoots or other distortions that may exist, For some applications where the response of the amplifier is not adequate for the circuits to be tested and where sufficient output amplitude is available, it is possible to use the deflection plates of the cathode-ray tube directly. In such cases, of course, care must be taken in making connections to the deflection plates so as not to introduce unwanted distortion.

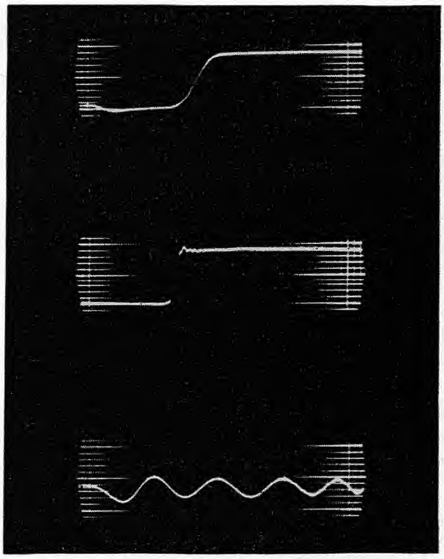


Figure 6. Oscillographic response to sharp pulse when going through amplifier (top trace) and applied directly to deflection plate terminals (center trace). Bottom trace shows 10 mc timing waveform.

Figure 6 shows the response of an oscillograph to a sharp pulse when going through the amplifier and directly to the deflection plate terminals. The timing wave is 10 mc giving an equivalent of 0.1 μs per inch. The lower pulse is a result of applying a fast pulse having a rise time of 0.01 μs directly to the deflection-plate terminals. Notice that there is some ringing evidenced on the top of the pulse. The reason for this will be discussed later on. The upper pulse shows the response through the 10 mc amplifier of the oscillograph. Noting the measured rise time as approximately 0.035 μs and the pulse generator rise time as 0.01 μs, by the use of equation (6) the amplifier rise time is computed to be 0.033 μs. The bandwidth-rise-time figure is therefore 10 x 0.033 or 0.33. It can be seen that this agrees pretty closely with the figure given in equation (3) for an R-C amplifier, even though this is a compensated amplifier of several cascaded stages.

Although it is not usually necessary to

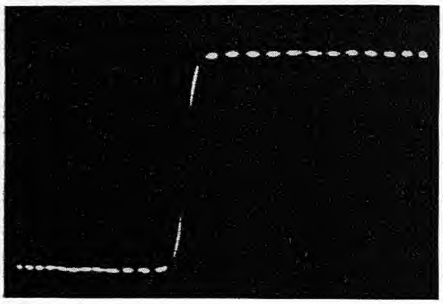


Figure 7. Pulse with intensity-modulation timing markers.

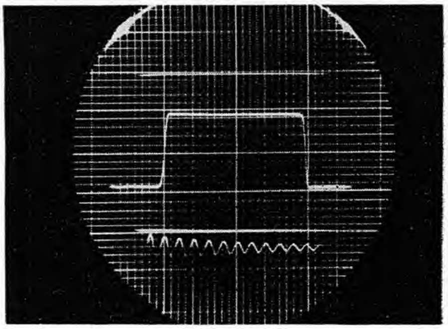


Figure 8. Pulse displayed with time-calibration wave train and amplitude-lines.

match impedances, there are occasions when such matching is indicated. It is usually a good idea when first using an oscillograph to check it out by applying pulses to it as shown in Figure 6 and noting the behavior of the oscillograph.

The fidelity of the fixed attenuator and variable amplitude control should also be noted, particularly with regard to any waveshape distortions which might be attributed to them. When using the amplifiers, the amount of undistorted deflection and the linearity of deflection may be of importance. The linearity of the sweep is also important. It may be noted in Figure 6, for example, that the timing wave for the middle two inches of the trace is quite linear and that there is some compression in the sweep towards the end. It has already been indicated that the rise time of the oscillograph may be corrected for so that an accurate indication of the rise time of the circuit under test may be obtained.

Means for calibration of amplitude and time are extremely beneficial in making measurements on cathode-ray tubes. Figure 7 shows a pulse with intensity markers in which the rise time may be measured. Figure 8 illustrates the use of both amplitude and time calibration. Timing markers are 10 mc or 0.1 μs between peaks. In this case, the indication shows a spacing of 0.5 μs per inch. The pulse width may be measured as 0.98 μs and the rise time as 0.05 μs. Amplitude calibration is set for one volt for two inches or 0.5 volt per inch. (In order to get a clear picture, not confused by the calibrated scale, it is actually set slightly less than two inches.) Pulse amplitude may therefore be measured as approximately 0.45 volts.

For fast pulse measurements, oscillographs are available having rise times of the order of 0.03 μs and sensitivities of the order of 0.1 volts peak per inch or better, Also available are oscillographs which are capable of measuring pulses having rise times in the millimicrosecond region.

The use of photographic recording has become much more prominent in recent years, and with fast development processes possible such as in the Polaroid-Land camera, it is possible to have a finished picture of the oscillogram one is interested in within a minute. It is possible to enlarge recorded oscillograms by projection or to study fine detail using a magnifier. Such techniques frequently are employed where it is necessary to obtain data accurate to the order of 1%. It is surprising to find how much information may be obtained from a suitably enlarged oscillogram compared to what can be seen on the original negative or on the face of the tube itself.

One must recognize also that all test equipment has limitations, and such limitations must be taken into account. When this is done, it is possible to obtain surprisingly good results.

Interconnection Of Pulse Test Equipment

Let us now discuss the interconnection of pulse test equipment and precautions that must be observed in order to obtain useful results. Having established the general nature of the measurements to be made and selected suitable equipment, it is timely to review the considerations often described as the "techniques of measurement." This broad term includes not only the basic considerations, but also some items that might be termed "tricks of the trade". Although most of the factors involved seem obvious after they have been mentioned, unfortunately they are all too frequently overlooked, even by those with long experience in laboratory methods.

In pulse measurements, the precautions generally necessary in r-f work may be required. These include attention to such matters as —

(a) Adequate shielding of measuring equipment leads to prevent undesired coupling to other parts of the circuits,

(b) Consideration of detuning or loading effects caused by measuring equipment input admittance,

(c) Lead lengths which may introduce resonance effects,

(d) Proper terminations where such are a factor in operation,

(e) Choice of components to function properly at the frequencies encountered (for example, the use of non-inductive resistors),

(f) Due regard to residual parameters in circuit elements (for example, inductance present in capacitors),

(g) Proper physical location of ground leads, and

(h) Due regard to possible non-linear behavior of circuit components due to appreciable voltage or temperature coefficients.

Frequently, it is important to shield both equipment and leads. This is particularly true when measuring signals having high source impedances, using equipment having high input impedances.

Since the oscillograph is used with other equipment close by, we may be concerned with radiation, and shielding and grounding assume even greater importance. Often, it is found helpful to operate all the equipment on a bench which has a ground plane, a large conductive sheet insulated from the bench top itself, to which a single ground connection may be made. If this ground plane is not insulated, it is possible to set up circulating ground currents through the equipment cases which causes further difficulty.

Occasionally, it is convenient to use external synchronizing and triggering signals rather than to operate the equipment from signals derived from the phenomena being studied. When this is done, attention must be paid, as in the case of signal leads, to the use of proper types of cables and their terminations. Grounding of such cables is also important to avoid spurious effects. The common impedance of ground leads for input terminals at different points on the panel sometimes can give trouble; signal cables should be grounded adjacent to their corresponding oscillograph input points. This has been found to be a frequent source of difficulty in the use of the oscillograph for observation of square wave or pulse signals, where generating equipment provides a triggering pulse as well as the signal pulse. Sometimes, through carelessness or thoughtlessness, open wire leads are used for the triggering signal relying upon the signal ground lead for the return path. Faulty operation usually can be corrected in such cases by providing a shielded cable with its own ground return for the triggering signal. This also applies to other external signals that may be connected to the oscillograph, including high-frequency timing signals used for intensity modulation. In many pulse applications it is customary to operate with low impedance coaxial cables used as signal conductors. Here impedance matching becomes extremely important and the length and types of leads must be given careful consideration. Even the connectors may have to be examined for proper impedance and for discontinuities that might be contributed at such points.

The conclusion of Mr. Kline's article will appear in Volume 14, Number 3, of the Oscillographer.

MODIFYING THE DU MONT TYPES 304 AND 304-H CATHODE-RAY OSCILLOGRAPHS TO ACCEPT THE NEW TYPE 5ADP-CATHODE-RAY TUBE

Du Mont's policy has always been to render the greatest service possible to its customers. To implement this policy Du Mont has offered many of the latest oscillographic features in kit form, or as low-cost accessory units. Examples of such modernizing equipment include the Du Mont Type 2562- Illuminated Calibrated Scale Kit, scales and filters for all Du Mont oscillographs, the Du Mont Type 2592 Terminal Adapter, and others.

Now, with the introduction of the Du Mont Type 304-A Cathode-ray Oscillograph, incorporating the new "Tight-tolerance" Du Mont Type 5ADP- Cathode-ray Tube, the Du Mont Service Department has issued Bulletin 58 which describes in detail how the Types 304, 304-H and 304-HR Oscillographs may be modified to use the new Type 5ADP-.

Among the important advantages of the Type 5ADP- are reductions by 50% in critical tolerances for deflection sensitivities and grid cutoff, improved perpendicularity between "X" and "Y" deflection plates by 300%, greatly improved sensitivity on both axes without a material reduction in useful scan, plus a flat face plate to reduce parallactic error. (For a detailed comparison of the Type 5ADP- with the Type 5CP-A, see Table 1 in the article, "A True Electronic Voltmeter — the Du Mont Type 304-A Cathode-ray Oscillograph" in The Oscillographer, Vol. 13, No. 3.) Since the Type 5ADP- is 6 and 7, when completed.

approximately twice as sensitive as the Type 5CP-A, it is necessary to change the X- and Y-Amplifier circuits slightly to reduce their gain. This reduction in amplification results in generally increased amplitude linaerity Also, the addition of an astigmatism control insures optimum focus.

A highly desirable addition to older instruments, which is recommended with the change over to the Type 5ADP-, is the Du Mont Type 2562- Illuminated Calibrated Scale Kit. The Type 2562- Kit greatly facilitates amplitude and time calibrations for both visual and photographic applications. This kit is especially useful under darkened room conditions, or inside a camera hood, where the markings on an unilluminated scale are difficult to discern. Calibrations on the plastic scale are engraved ten lines to the inch, both vertically and horizontally, with one-inch vertical lines and half-inch horizontal lines accentuated. In addition, the Type 2562- Kit includes a suitable filter to improve pattern contrast for visual observation. To select the proper kit to go with your present instrument, consult the information at the end of the article.

The step-by-step procedure for the proper conversion of the Types 304-H and 304-HR is detailed below. Since the Types 5CP-A and 5ADP- are quite similar externally, except that the latter has a flat face, it is unnecessary to replace or modify the mu-metal cathode-ray tube shield. The effect of the following changes is to reduce the overall gain of both the X and Y amplifiers without cutting down the internal sync sensitivity.

A. Y Amplifier

1. As shown in Figure 1, add a 100K ±5%, 2 watt resistor (Part No. 02036-960) between plates (pin 5) of V5 and V6, the final Y-amplifier stage.

B. X Amplifier

1. As shown in Figure 2, change plate load resistor R113 of VIIA (pin I) to 10K ±5%, ½ watt (Part No. 02030-720).

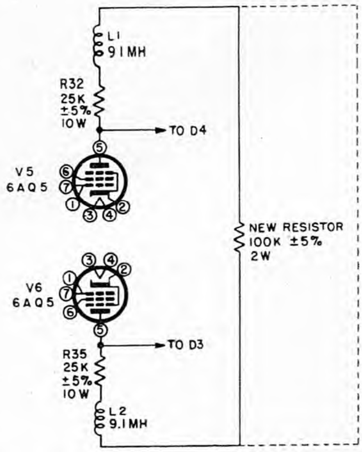


Figure 1. Schematic diagram of Y-amplifier change necessary to adapt Types 304-H and 304-HR to new "Tight-tolerance" Type 5ADP- Cathode-ray Tube

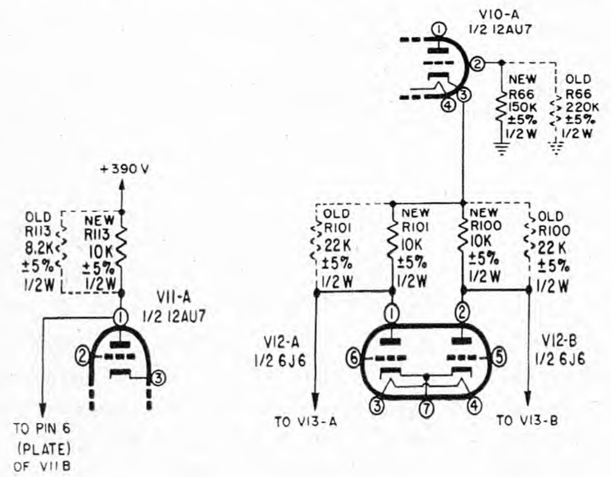


Figure 2. Schematic diagram of X-amplifier changes necessary to adapt Types 304-H and 304-HR to new "Tight-tolerance" Type 5ADP-Cathode-ray Tube

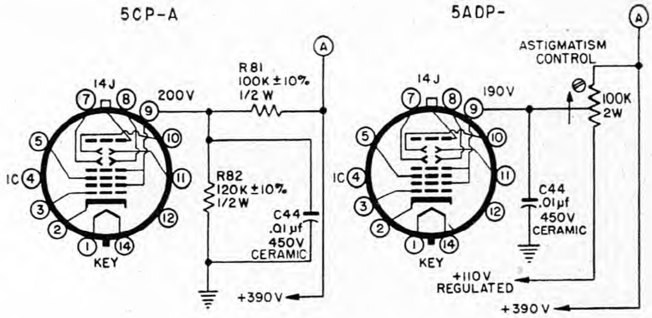


Figure 3. Schematic diagram of Cathode-ray Tube circuit necessary to adapt Types 304-H and 304-HR to new "Tight-tolerance" Type 5ADP- Cathode-ray Tube

KEY FOR BOTH CATHODE-RAY TUBES

PIN NO.	ELEMENT
1	HEATER
2	CATHODE
3	GRID NO. 1
4	INTERNAL CONNECTION
5	FOCUSING ELECTRODE
7	DEFLECTING ELECTRODE D_3
8	DEFLECTING ELECTRODE D_4
9	ACCELERATOR
10	DEFLECTING ELECTRODE D_2
11	DEFLECTING ELECTRODE D_1
14	HEATER

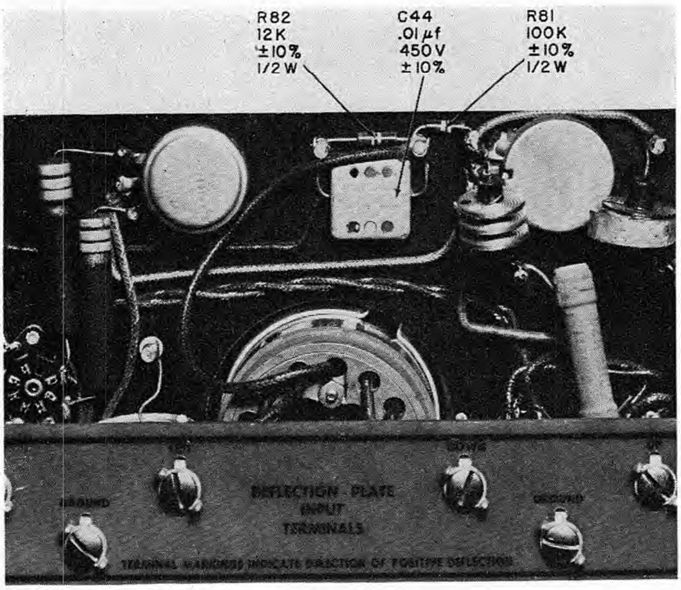


Figure 4. Rear chassis of Type 304-H before adaptation to Type 5ADP-. (Layout of components will vary slightly among Type 304-H's and 304-HR's. However, any Type 304-H or 304-HR can be adapted to the Type 5ADP- by the described method)

2. Change plate load resistors R101 and R100 of V12A and V12B (pins 1 and 2 respectively) to 10K ±5%, ½ watt (Part No. 02030720). (See Figure 2.)

3. Change grid bias resistor R66 of V10A (pin 2) to 150K ±5%, ½ watt (Part No. 02031000). (See Figure 2.)

C. Cathode-ray Tube Circuit

1. Remove voltage divider network R81 and R82 (pin 9 of 5CP-A), as shown in Figure 3.

2. Add astigmatism control between the +390 volts unregulated to the +110 volts regulated supplies. This control consists of a 100K, 2 watt potentiometer (Part No. 01014880). (See Figure 3.)

Figure 4 shows the rear chassis of a Type 304-H before the modification.

The astigmatism control is mounted in

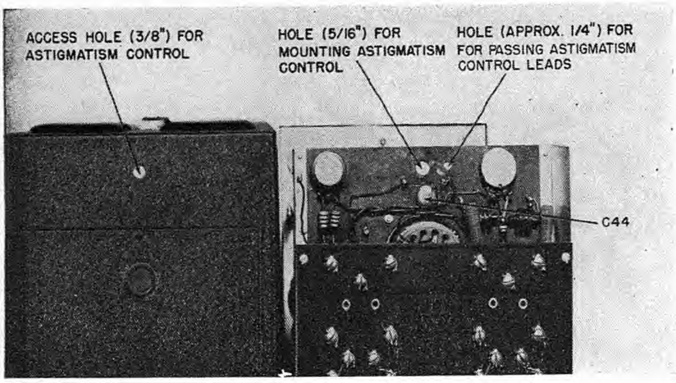


Figure 5. Rear chassis and cabinet rear of Type 304-H showing C44 relocated and necessary holes drilled to mount, wire, and adjust astigmatism control

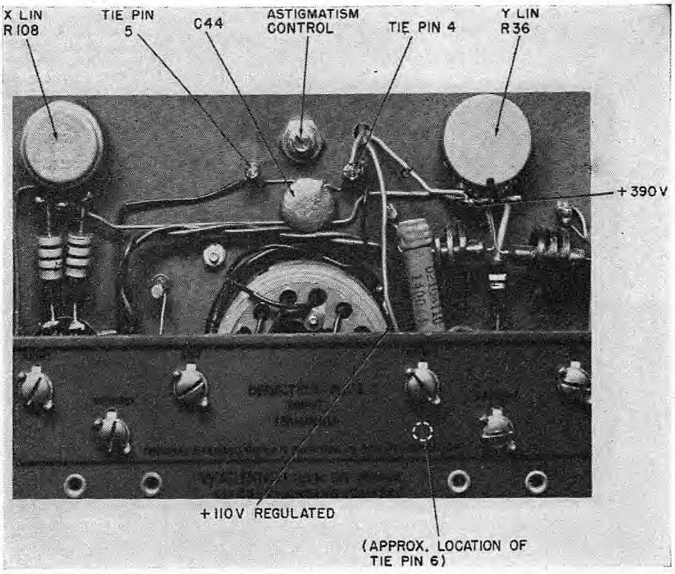


Figure 6. Astigmatism control mounted and wired into circuit (rear view)

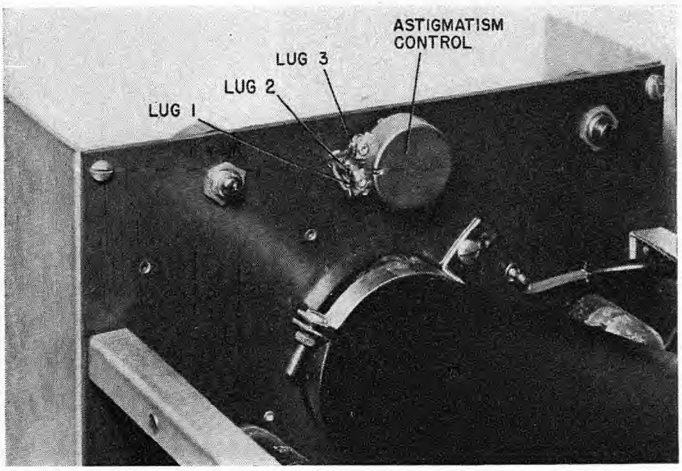


Figure 7. Astigmatism control mounted and wired into circuit (front view). Note how potentiometer lugs are bent to clear chassis ad prevent short circuits

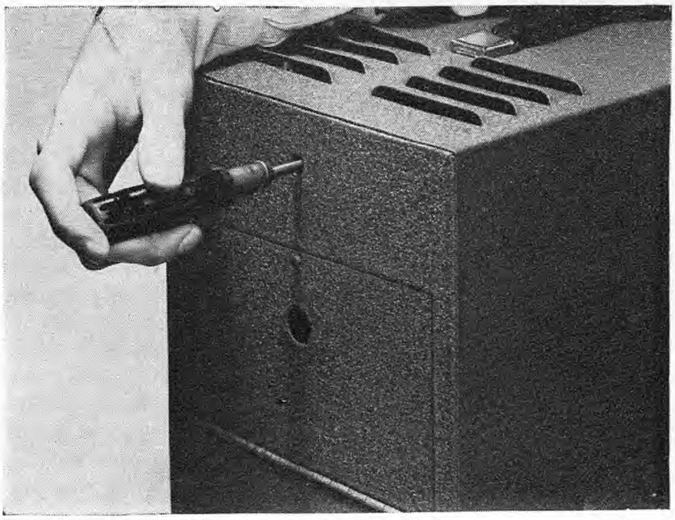


Figure 8. Astigmatism control must be adjusted to obtain optimum focus full length of trace after oscillograph is adapted to the Type 5ADP-

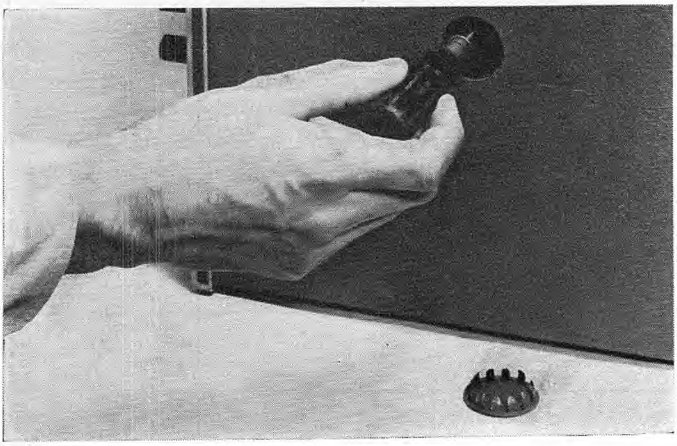


Figure 9. Y-sensitivity control (R24) should be rechecked, and reset if necessary, after adaptation to the Type 5ADP-. Control is accessible through hole in side panel of cabinet. Recommended standard for this test is the Du Mont Type 264-B Voltage Calibrator, or else a battery and d-c voltmeter may be used, since the amplifier response of the Type 304 series extends to d-c

position on the rear chassis of the Type 304-H and 304-HR in the following manner:

1. Remove R82 and R81 as described above and relocate C44, as shown in Figure 5.

2. Measure 4⅛″ from either side of the vertical bank, and ⅝″ from the top and drill a 5/16″ hole for the potentiometer shaft. (See Figure 5.)

Drill a smaller hole to pass the three potentiometer leads through the vertical bank, locating it ⅝″ from the top and approximately 3¼″ from the right side of the instrument as you face the rear.

Also, drill an access hole through the rear of the cabinet, 4½″ from either side and 1″ from the top of the cabinet.

3. Mount potentiometer in the 5/16″ hole as shown in Figures 6 and 7. Care should be taken that the clearance between tie pins 4 and 5 and the outer metal shell of the potentiometer is sufficient to prevent a short circuit. Bend the three potentiometer lugs slightly away from the mounting board, as shown.

4. Connect potentiometer arm (lug 2) to tie pin 4 and junction of C44.

5. Connect a lead from potentiometer lug 3 to the nearest lug of Y linearity control R36 to tap the +390-volt supply.

If the above changes have been made correctly, the rear of the Type 304-H, or 304-HR, will appear as shown in Figures

The astigmatism control, accessible through the newly cut hole in the rear of the cabinet, as shown in Figure 8, is adjusted by applying a 60-cycle sinewave test signal to the Y-input terminal. Synchronize one or two cycles of this signal on the screen, and expand the trace to full-screen diameter. Adjust the FOCUS control for sharpest trace from start to finish. It will probably be necessary to readjust the FOCUS control simultaneously with the astigmatism control to maintain best focus. Once properly adjusted the astigmatism control should require no further attention under normal conditions.

After the modifications have been completed and the astigmatism control adjusted properly, it is advisable to recheck, and reset if necessary, Y SENsitivity control R24. This potentiometer is the third from the front on the small vertical panel over the shock-mounted chassis. It is accessible through a hole on the right side of the cabinet, as shown in Figure 9. After a 10-minute warm-up period, the Y-SENsitivity control should be reset to give the amplifier a sensitivity of precisely 10 millivolts per inch rms or 28 millivolts per inch d-c at full gain. For standards, a d-c voltage of known amplitude or a Du Mont Type 264-B Voltage Calibrator may be used.

The Type 5ADP- can be adapted to the Type 304 Cathode-ray Oscillograph, but it is recommended that the instrument be modified to include the additional 2X2A rectifier and capacitor to provide a positive 1600-volt post-accelerator potential. This potential is already available in the Types 304-H and 304-HR. Information on this addition may be found in the Operating And Maintenance Manuals for these instruments, or can be obtained upon request from the Instrument Service Department, Allen B. Du Mont Laboratories, Inc., 760 Bloomfield Ave., Clifton, N. J.

Complete details of the parts necessary to adapt the Types 304-H and 304-HR, including the recommended Type 2562-Illuminated Calibrated Scale Kit, are included in the following table:

The total cost of the modification is between $50 and $60 depending on the cathode-ray tube screen type selected. This cost does not include adding the post-accelerator supply to the Type 304.

Quantity	*Item*	*Value*	*Du Mont Part No.*
	Resistor	100K±5%, ½W	02036960
	Resistor	150K±5%, ½W	02031000
	Resistor	10K±5%, ½W	02030720
	Potentiometer	100K, 2W	01014880
	Type 5ADP- Cathode-ray Tube	(P1 Screen Cat. No. 2381-E)	

1 TYPE 2562- ILLUMINATED CALIBRATED SCALE KIT

Type No.	*Cat. No.*	*For Use With Fluorescent Screen Type*
2562-A	1604-A	P1
2562-B	1605-A	P11
2562-C	1606-A	P7