Chapter 9

VALVES AS AMPLITUDE LIMITERS

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Sect.

CHAPTER 9

VALVES AS AMPLITUDE LIMITERS

1. GENERAL PRINCIPLES

In the normal operation of a pulse amplifier, described in Chap. 7, Secs. 9-13, care is taken that the valve works on the linear portion of its dynamic characteristic, otherwise amplitude distortion occurs. As an extreme case of this distortion, Amplitude Limitation arises when the amplifier is operated over one or both of the flattened portions of the dynamic characteristic (Fig.472).

Common applications of amplitude limitation are:-

(i) The production of a rectangular output of voltage from a sinusoidal input.

(ii) The elimination from the output of irregularities which occur at the extreme values of the input voltage.

(iii) Discrimination between wanted and unwanted pulses.

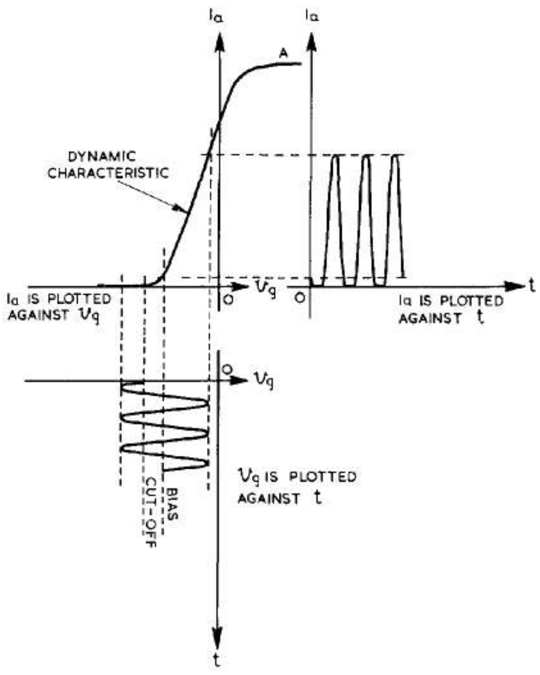


Fig.472 - Limiting at cut-off

Either diodes or amplifying valves may be used for amplitude limitation. In the case of the diode circuit of Fig.473 the maximum value of the output voltage is approximately zero, so that the positive portions of the input voltage are ineffective. By a suitable biasing arrangement this limiting action can be made to take place at any desired voltage level.

Two diodes are necessary if both upper and lower excursions of the output voltage variations are to be limited.

With a single amplifying valve both positive and negative excursions of the output voltage may be limited if the valve is operated over both of the flat regions of the dynamic characteristic. Alternatively, the grid-cathode portion of the valve may be used as a diode, and the positive part of the input limited when grid current flows by the inclusion of sufficient series resistance, as in Fig.473. This takes the place of limiting at the upper bend of the dynamic characteristic, and limits the negative-going portions of the output voltage. In all cases the limiting action is independent of the nature of the input voltage variation; for simplicity, in discussing the action of the elementary circuits we shall assume that this is sinusoidal.

2. DIODE LIMITING CIRCUITS

A diode circuit is considered first, as it provides the simplest case of the use of a valve as an amplitude limiter. Suppose that a sinusoidal voltage is applied to an unbiased diode in series with a resistor R_s (Fig. 473). The diode conducts during the positive half-cycles of the input voltage and does not conduct during the negative half-cycles. If R_s is large compared with the resistance of the diode when this valve is conducting, the fraction of input voltage developed across the diode during the positive half-cycles is small. If R_s is small compared with the impedance of the diode when this valve is not conducting, a large fraction of the input voltage is developed across the diode during the negative half-cycles. The diode may have a resistance of between 1000 and 2000 ohms when conducting, this resistance being the ratio of the anode-cathode voltage to the current through the valve, and not the slop resistance. The impedance of a diode, if it is not conducting, is entirely due to the anode-cathode interelectrode capacitance, and this capacitance may be about 10 pF. Fig. 473 shows the limiting of the positive half-cycles in the voltage developed across the diode, and also the limiting of the negative half-cycles in the voltage developed across the resistor R_s.

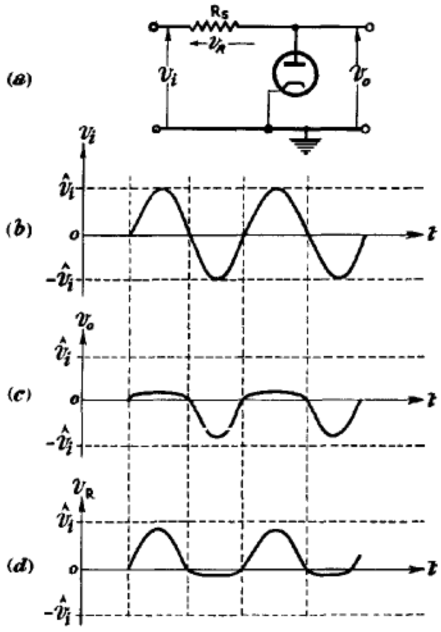


Fig. 473 - Positive peak limiting; output across diode.

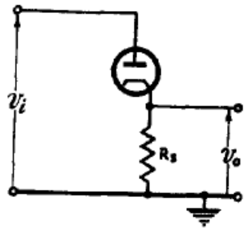


Fig. 474 - Negative peak limiting; output across resistor.

Fig. 473a shows the diode limiting circuit arranged so as to obtain the output in the form of negative pulses (Fig. 473c), while Fig. 474 shows a circuit suitable for producing positive pulses (Fig. 473d). If the diode is reversed as in Fig. 475, the positive half-cycles appear mainly across the diode whilst the negative half-cycles are developed mainly across the resistor.

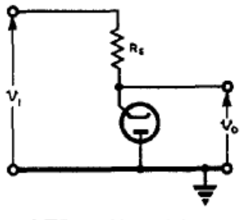


Fig. 475 - Negative peak limiting; output across diode.

So far the limiting of either the positive or the negative portions of the input has been considered as beginning when the input voltage passes through zero. If, however, the cathode of the diode is held at a fixed positive voltage, as shown in Fig. 476a, the diode does not conduct until the input reaches this level, and limiting of the voltage across the diode thus occurs at a fixed positive voltage. The voltage across R_s in Fig. 476a consists of the peaks of the positive half-cycles of the input, shown dotted in Fig. 476b. Fig. 477 shows the limiting circuit in a form suitable for obtaining this voltage as an output. In this circuit R_1 and R_2, which are effectively in parallel, take the place of R_s in the previous circuits. Fig. 478 shows circuit arrangements in which the negative peaks are limited and the output voltage is developed across the diode. In Fig. 478b C is a blocking condenser necessitated by the change in voltage level. In both circuits the voltage across R_s consists of the peaks of the negative half-cycles of the input voltage. Figs. 479a and b show the corresponding circuits in a form suitable for obtaining this voltage across R_s as an output.

In any limiting circuit using a coupling condenser, as for example in Figs. 478b, 479b the time-constant of the input circuit must normally be chosen so that no appreciable slide-back occurs. (See Chap. 7, Sec. 4).

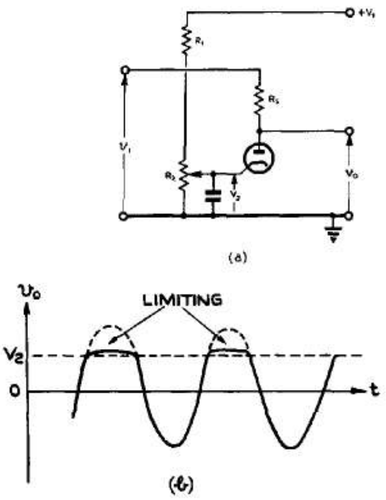


Fig. 476 - Positive peak limiting with bias; output across diode.

If a suitable choice of condenser and resistor values is made slide-back biasing circuits may be used to provide bias in some cases.

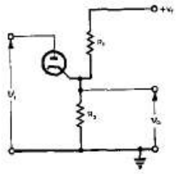


Fig. 477 - Negative peak limiting; output across resistor.

By using a pair of diodes arranged as in Fig. 480 , both upper and lower excursions of the input voltage can be limited. In this circuit diode 2 is conducting if there is no input voltage, so that the common cathode voltage is

$$V_K = \frac{V\,R_2}{R_1 + R_2}$$ (neglecting the resistance of the diode compared with R_1 and R_2)

When the input voltage reaches this value diode 1 conducts, and the

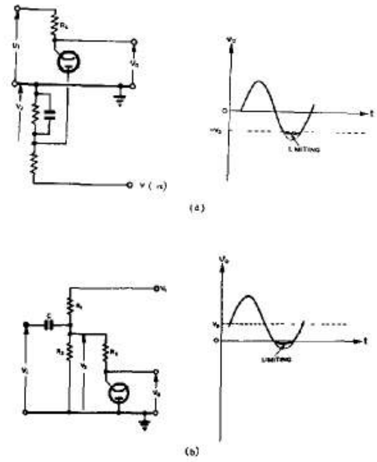


Fig. 478 - Negative peak limiting; output across diode.
With no voltage shift (a) and with voltage shift (b).

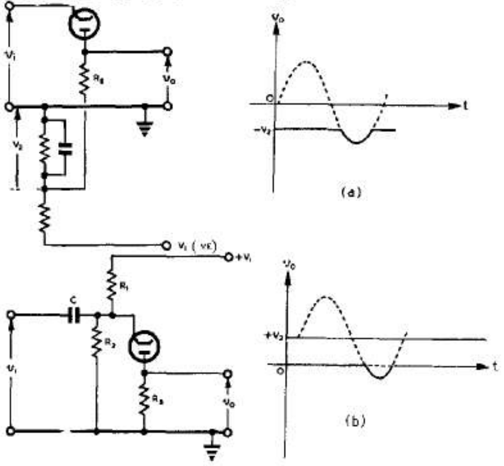


Fig. 479 - Positive peak limiting; output across resistor. With no voltage shift (a) and with voltage shift (b).

voltage developed across R_2 rises. As long as diode 2 is conducting the voltage at its anode is practically equal to the common cathode voltage. Therefore, as the voltage across R_2 rises from

$$\frac{V R_2}{R_1 + R_2}$$

the output voltage rises with it.

As soon as the voltage across R_2 rises above V, diode 2 ceases to conduct and the output voltage remains at the value V. It follows that the portion of the input lying between the values V and $\frac{VR_2}{R_1 + R_2}$ is the only portion which contributes to the output. In this and similar cases we shall call this portion of the input the Effective Input Voltage.

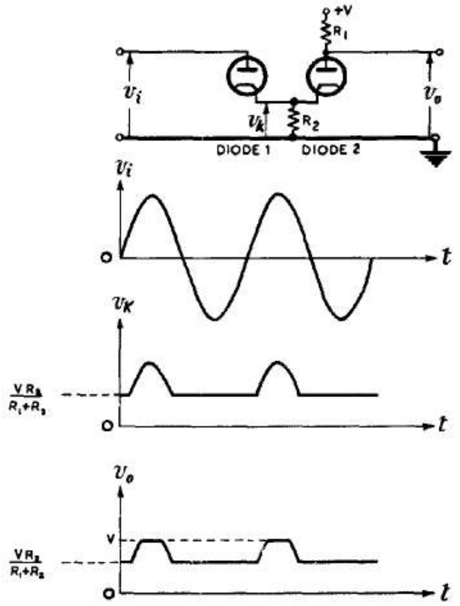


Fig. 480 - Positive and negative peak limiting using twin diodes.

LIMITING CIRCUITS EMPLOYING TRIODES OR PENTODES

3. Limiting Amplifiers.

Since there is no fundamental difference between the action of a triode and that of a pentode used as an amplitude limiter, unless otherwise stated the discussion of triode circuits may be taken as applying equally well to those containing pentodes.

Consider a sinusoidal voltage applied to the control grid of a resistance-loaded amplifier. The cut-off voltage is determined by the HT supply V_B, and for values of the input voltage below cut-off the anode voltage remains constant at its maximum value V_B. By adjustment of the bias, the lower level of the input at which limiting takes place may be fixed at any desired value.

The upper level of the input at which limiting occurs depends on the position of the flat portion of the dynamic characteristic (A in Fig. 472). This in turn is determined by V_B and the anode load resistor. If a sufficiently large load resistance is used the anode current reaches its maximum for a correspondingly low grid voltage. This is usually advisable because of the undesirable effects of driving the grid voltage far beyond the region at which grid current begins to flow.

Since it is not usually advisable to employ a very large anode load this method of limiting is normally confined to pentodes, which do not require the large load resistances needed by triodes (see Sec. 4).

An alternative method of achieving the limiting action for the positive portions of the input, is to use the grid-cathode portion of the valve as a diode. The circuit arrangement is shown in Fig. 481. The mode of operation is almost identical with that already described for the diode circuit of Fig. 473. In the circuit of Fig. 481 as long as the input voltage does not exceed the cathode voltage almost the whole value of the input voltage is developed between grid and cathode. However, as this voltage reaches the cathode voltage grid current flows and the resistance of the grid-cathode path drops to a low value, of the order of 1000 ohms. If the limiting resistor R_s is large compared with 1000 ohms, e.g. 50 kΩ, only a very small fraction of the applied voltage appears between the grid and cathode when grid current flows. The greater the value of the grid resistor the greater the limiting action. There are, however, reasons why R_s should not be too large. R_s and the input capacitance of the valve form a series circuit across the input, and it is the voltage developed across the capacitance which is actually applied to valve. The allowable maximum value of R_s is determined by the frequency f of the input voltage, since the reactance of the input capacitance of the valve must be large compared with R_s if a large fraction of the applied voltage is to appear between grid and cathode. This condition may be written $C_iR_s << \frac{1}{2\ f}$, so that a short time-constant circuit is required. If the voltage appearing between grid and cathode is not a large fraction of the input voltage it may not raise or lower the grid potential sufficiently to cause either grid-current or cut-off limiting.

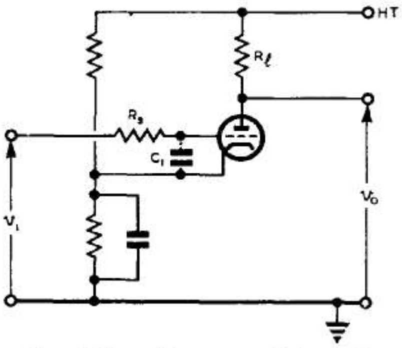


Fig. 481 - Circuit of triode amplitude limiter (grid current limiting).

If instead of a sinusoidal voltage a rapid change of voltage is applied to the circuit, the rapidity with which the grid voltage follows the input is determined by the time-constant C_iR_s. If this is too large the action of the amplifier in producing a rapid change in output voltage is largely nullified.

In the foregoing discussion the resistor R_s has been included for the specific purpose of limiting the output voltage. A similar effect is obtained if the output resistance of the generator is large. In this case the effective limiting resistance is the sum of this output resistance and any additional resistance R_s included to ensure the limiting action.

It should be noted that in the grid-current method, limiting occurs actually at the grid and is reproduced in the anode circuit. In the two other methods the grid voltage is substantially the same as the input voltage.

Almost any resistance-loaded amplifier circuit may be adapted for use as an amplitude limiter by arranging for the input voltage to operate over one or both of the flat portions of the dynamic characteristic, or by the use of a grid limiting resistor. This normally entails a suitable choice of grid base and bias. Possible arrangements for providing either positive or negative bias are described in Chap. 7, Sec. 4.

4. Relative Merits of Triodes and Pentodes

A pentode has the following advantages over a triode for use as a limiting amplifier:-

(i) The input capacitance of a pentode is normally smaller than that of a triode owing to the diminished Miller effect. This enables a larger limiting resistance to be used. (See Sec. 3).

(ii) Because a higher gain can be obtained from a pentode the fall in anode voltage as the grid voltage rises through cut-off is much sharper than for a triode, so that the limiting effect at cut-off is more definite.

(iii) The grid-base of a pentode is usually smaller than that of a triode under similar operating conditions. This makes it more suitable for the production of rectangular pulses from a sinusoidal input voltage (see Sec. 6) and for similar pulse-shaping requirements.

(iv) Good limiting action at the flat portion of the dynamic characteristic (A in Fig. 472) is practicable with a pentode but not normally with a triode. This enables the limiting resistor to be dispensed with. Fig. 482 shows typical dynamic characteristics for a triode and a pentode. For the pentode (Fig. 482a) using a 30 kΩ anode load the limiting action occurs for grid voltages greater than that about -1·5 volts. In the case of the triode such limiting action would not occur until much higher grid voltages were reached, even with a much larger anode load and reduced HT voltage (Fig. 482b).

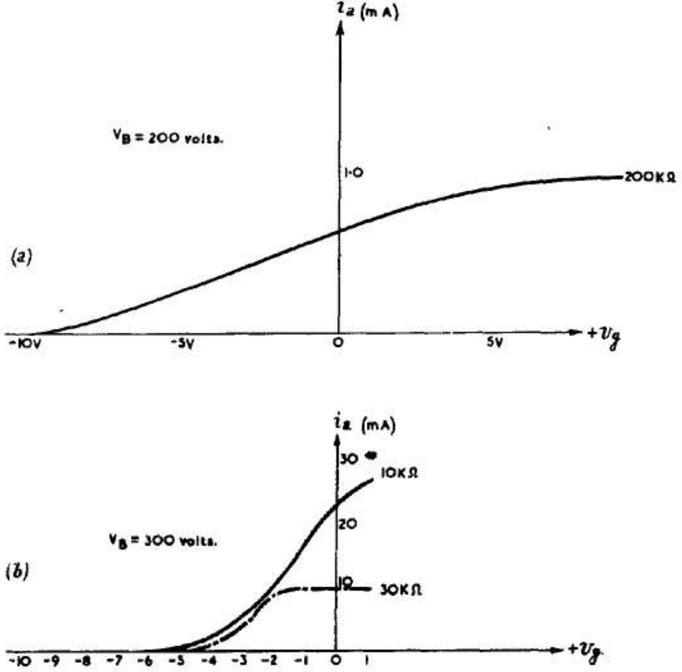


Fig. 482 - Dynamic characteristic, (a) triode, (b) pentode.

APPLICATIONS OF AMPLITUDE LIMITERS

5. The Production of Rectangular Pulses

Fig. 483 shows how an approximately rectangular output may be produced from a sinusoidal input by limiting action at suitably chosen levels AA' and BB'. Figs. (a)-(d) show how, by varying the bias in relation to these levels, the relative durations of the effective positive-going and negative-going portions of the input (Mark-To-Space ratio) may be controlled. If diode limiters are employed the output voltage is approximately identical with the effective input, whereas with limiting amplifiers the output voltage is an inverted and amplified version of the effective input.

The greater is the ratio of the amplitude of the sinusoidal voltage to that of the effective input the more closely does the output

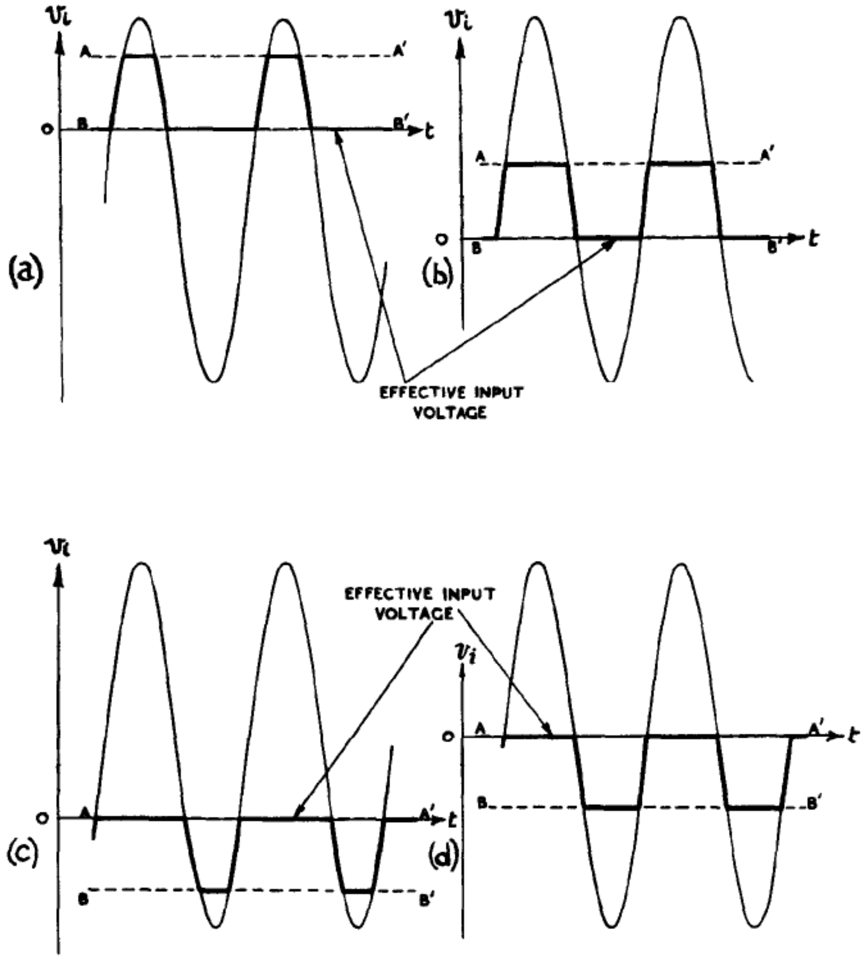


Fig.483 - Production of "rectangular" pulses from sinusoidal input.

conform to a rectangular shape. Further, the rate of change of the sinusoidal input voltage is greatest at the points where this voltage passes through its mean value; accordingly, the more closely the effective input voltage approaches to this mean value the more nearly rectangular is the output. For example, in Fig. 483 the output voltage is more nearly rectangular in cases (b) and (d) than in cases (a) and (c).

We deduce also that as the inequality between the positive-going and negative-going portions of the output becomes more marked the output pulses deviate further from a rectangular shape.

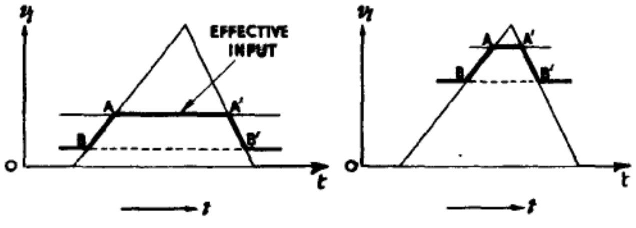


Fig.484 - Production of "rectangular" pulses from triangular input voltage.

Fig. 484 illustrates the production of output pulses which are approximately rectangular from a triangular input. The duration of the output pulses depends upon which portions of the triangular pulses are limited.

We have assumed so far that the amplitude limiter produces an undistorted version of the effective input voltage. This is true in the case of a resistive-loaded valve, but in practice the presence of capacitance in parallel with the load may introduce considerable distortion. The effect of this on limiting amplifiers is considered in Sec. 8.

6. Elimination of Irregularities

In general the pulses encountered in practice rarely possess the perfect shape shown in Fig.485a ; typical irregularities are illustrated at (b), (c), (d) and (e). If any of these pulses is applied to an amplitude limiter so that the effective input voltage lies between the limits AA' and BB', the irregularities are not present in the output.

In a similar manner, if a succession of pulses of varying amplitude (Fig.486) is applied to a limiter, the upper limiting level AA' can be fixed so that the output consists of a succession of pulses of uniform amplitude.

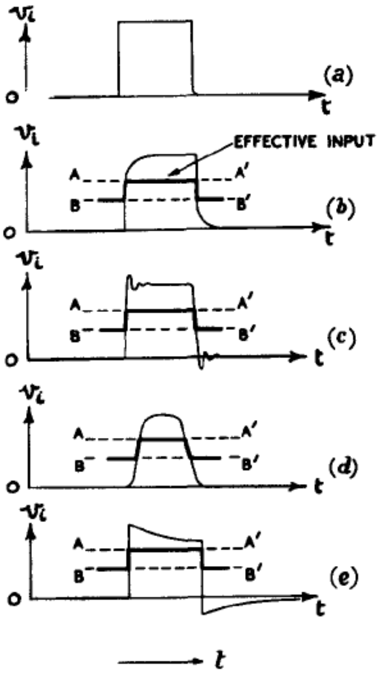


Fig.485 - Elimination of irregularities.

7. Pulse Selection

As an extreme case of the elimination of irregularities, consider the waveform of Fig.487 . By a suitable choice of the upper limiting level AA' positive-going peaks of the input can be made ineffective.

In the particular example shown in Fig. 487, in which a limiting amplifier is used, not only the positive-going portions of the input voltage, but also the peaks of the negative-going portions are made ineffective.

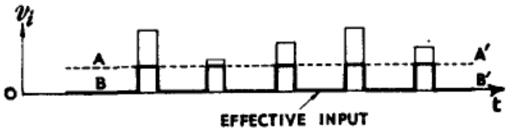


Fig.486 - Limiting the amplitude of a succession of pulses.

Further examples of discrimination between wanted and unwanted pulses are shown in Figs. 488 and 489.

8. TIME-CONSTANT CONSIDERATIONS AFFECTING THE OUTPUT CIRCUIT OF A LIMITING AMPLIFIER.

It has been shown in Chap. 7 Sec. 11 that capacitance in parallel with the anode load of a resistance-loaded amplifier may considerably modify the output voltage. This particularly applies to limiting amplifiers used for the production of rectangular pulses.

The circuit diagram of Fig. 490 with its simple equivalent circuit (b) shows that the time-constant of the output circuit is

$$C \cdot \frac{R_a R_\ell}{R_a + R_\ell}$$

where R_a is the slope resistance of the valve. For a linear amplifier R_a is constant; but for a limiting amplifier which works over the curved portions of the dynamic characteristic R_a is by no means constant, and when the valve is cut off R_a is infinite. It follows that as the input rises through cut-off the time constant of the output becomes:-

$$\frac{C \cdot R_a R_\ell}{R_a + R_\ell}$$

whilst, as the input voltage falls through cut-off, the time-constant becomes

$$C\ R_\ell \text{ (Since } R_a = \infty)$$

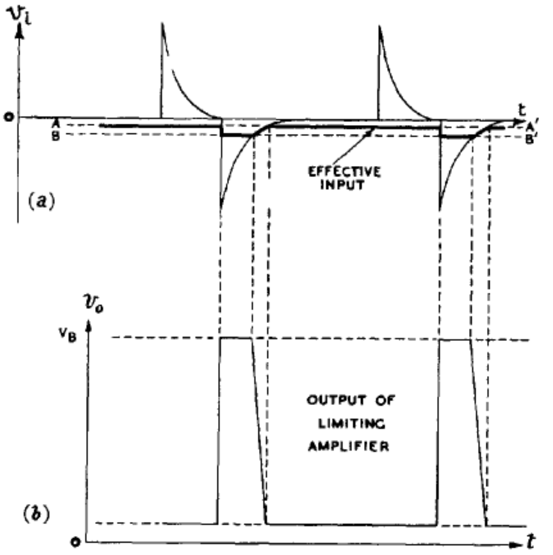
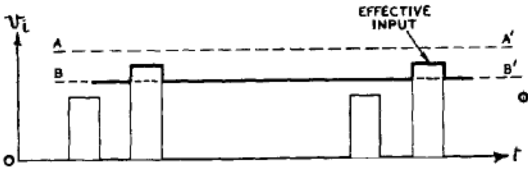


Fig.487 - Pulse selection; positive input pulses ineffective.



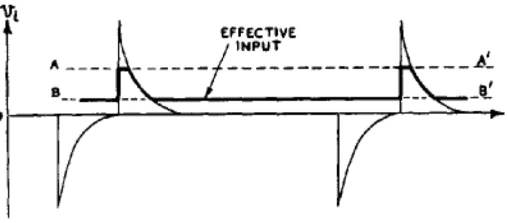


Fig.488 - Pulse selection; pulses ineffective below given amplitude

Fig.489 - Pulse selection; negative-going pulses ineffective.

Consider the response of an amplifier to a rectangular input pulse

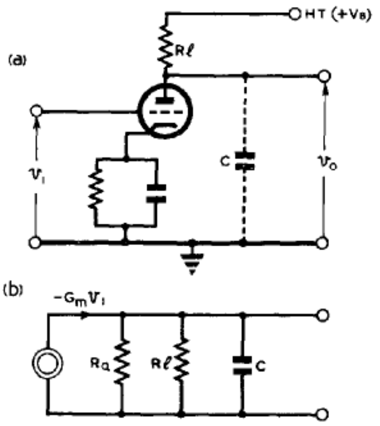


Fig.490 - Limiting amplifier circuit; time-constant considerations.

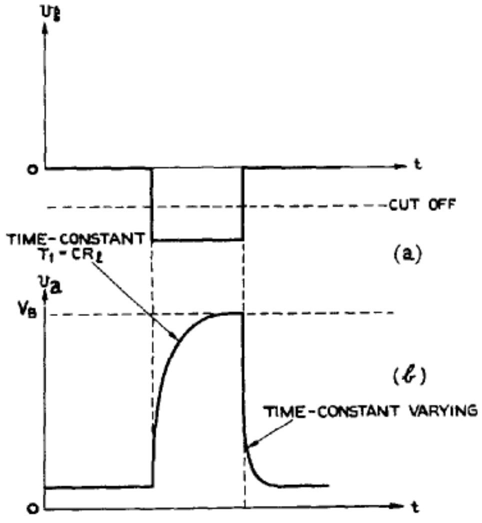


Fig.491 - Limiting amplifier; time-constant considerations.

which cuts off the valve (Fig. 491). The initial rise of anode voltage follows an exponential law with time-constant $T_1 = CR_\ell$.

After the input voltage has risen through cut-off at the end of the pulse and acquired its steady value, the time constant for the fall in anode voltage is

$$T = \frac{C\,R_a\,R_\ell}{R_a + R_\ell}$$

Since R_a is not constant this time-constant is continually changing so that the fall in voltage is not exponential. However, the time-constant is always smaller than CR_ℓ so that the fall in anode voltage takes place in a shorter time than the initial rise (Fig.491).