Some Experiments on Pulse Compressor Using Tunnel Diodes

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The present paper describes some experimental results on pulse compressor using high speed switching action of tunnel diodes. The experiments were carried out to find the relation between the d-c bias voltages and the number of tunnel diode, connected in series, between the linearity of input-output characteristics and various values of output load resistance and to confirm the disturbance of output waveforms resulting from increase of the slope of input voltage which linearly uprise with time and from that of the amplitude of sine wave which is superimposed on that voltage.

1. Introduction

When a small signal is superimposed on a pulse, and if the range of variation of pulse amplitude is large, it is difficult to amplify this wide amplitude range by an ordinary linear amplifier. Especially, when only the small signal is wanted and the pulse itself is not so much in need, a linear amplifier which amplify to the extent of unnecessary pulse is not only unsuitable but also it will be brought to the overloading. In such a case, a pulse compressor using tunnel diodes is a useful equipment.

A point of the question of this equipment is linearity of input-output characteristics at small signals, and this linearity is influenced by the voltage-current characteristics of tunnel diode. A. A. Clark and W. H. Ko[1)] observed the output waveforms at the input which linearly increases with time and qualitatively described that the linearity of input-output characteristics is improved by increasing the output load resistance. The author[2)] previously carried out the quantative analysis on this linearity by expressing the voltage-current characteristics of tunnel diode by a suitable analytic function.

This paper describes some experiments made on the following matters together with the examination of the above fact and the important results obtained are shown by several photographs.

(1) Measurement of the relation of d-c bias voltage to the number of tunnel diode, connected in series, and to the value of output load resistances.

(2) Observation of the linearity of input-output characteristics by applying the input voltage which increases linearly with time.

(3) Observation of differentiated output waveforms by applying the same input voltage as (2).

(4) Observation of output waveforms at the small signal superimposed on the voltage

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which increases linearly with time.

(5) Observation of the difference of switching actions to the voltages which linearly increase and to those similarly decrease with time.

(6) Observation of the disturbance of output waveforms at various amplitudes of sine wave superimposed on the voltage which linearly increases with time.

(7) Observation of output waveforms immediately after the finish of the switching action at the various slopes of the voltage which linearly increases with time.

The tunnel diodes, used in these experiments, are 1T1101, 1T1103, 1T1104 and 1T1110 made by SONI CORP..

2. Principle and Circuit

A voltage-current characteristic of tunnel diode and a load resistance line are as shown in Fig. 1. A slope of this load resistance line is given by the following formula;

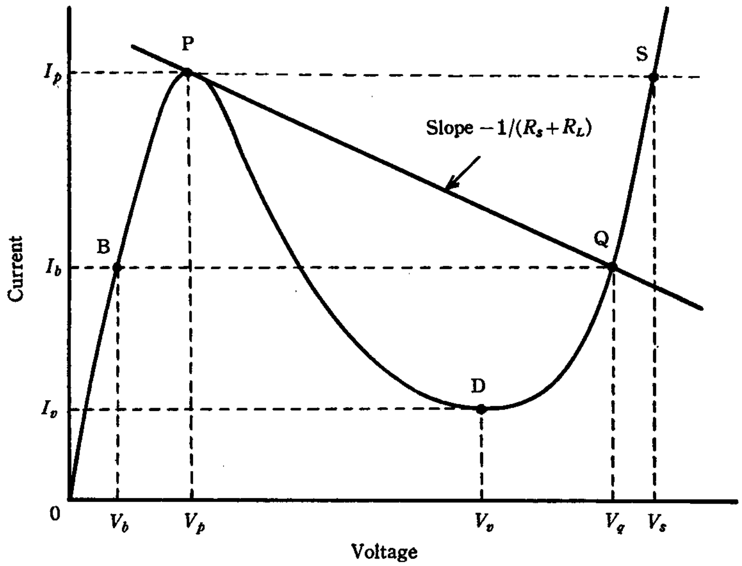


Fig. 1. Voltage-current characteristic of tunnel diode and a load resistance line.

$$-1/(R_s+R_L), \tag{1}$$

where R_s is the sum of the internal resistance of power source and the equivalent resistance of tunnel diodes, and R_L is output load resistance.

Now, it is assumed that input voltage V is situated between 0 and V_p. From this condition, V is assumed to increase and when the value of current became equal to the current I_p, the peak point value, the operating point of tunnel diode removes with very high speed to another safety point Q.

Fig. 2 shows a series circuit of n pieces of tunnel diode, the power source and the output load resistance. In this circuit, even if all tunnel diodes are of the same sort, the values of the peak current have a little difference among each other. Consequently, when

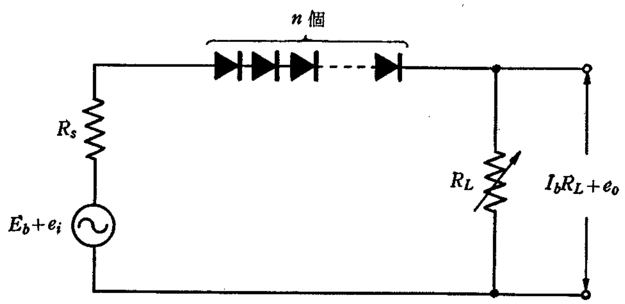


Fig. 2. Fundamental circuit.

input voltage is increasing, one of the tunnel diodes does the switching action at first and its across voltage rapidly increases. Under this condition, if input voltage continuously increases, the switching action is continued in turns from tunnel diode of the lower peak current to that of higher one, and finally, all of the tunnel diodes finish the switching action. After that, the output voltage increases according to increase of the input voltage. Thus, the relation between input and output voltages becomes as shown in Fig. 3. In

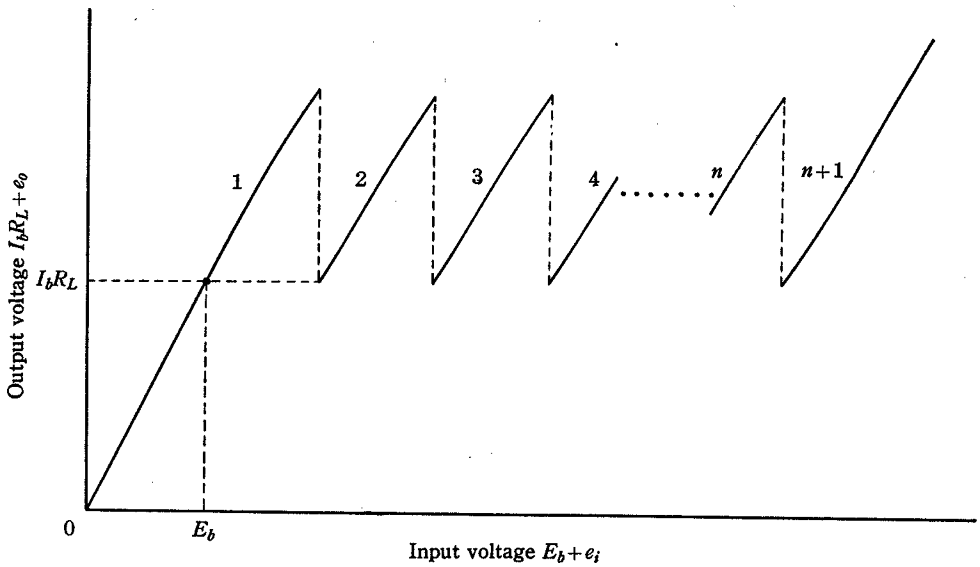


Fig. 3. Relation between input and output voltages in the circuit of Fig. 2.

this figure, part 1 shows a condition that all of the tunnel diodes have lower voltage than the voltage V_p, the peak point value, and part 2 shows a condition that one of the tunnel diodes which has finished the switching action has higher voltage than the voltage at the point Q of Fig. 1. According to increase of the number of tunnel diode which has finished the switching action, the influence of the part of the same characteristic as an ordinary diode becomes large, and when all of the tunnel diodes finished the switching action, input -output characteristic becomes as shown by part $n+1$ of Fig. 3. Further, E_b is the d-c bias voltage which give the first operating point and I_bR_L is the d-c output voltage corresponding to that E_b.

As only the region exclusive of the d-c voltage part of Fig. 3 is important, so the d-c part is omitted, and thus an idealized relation between e_i and e_0 for $n=3$ can be shown as given by Fig. 4. From this figure, if it is assumed that the maximum input voltage

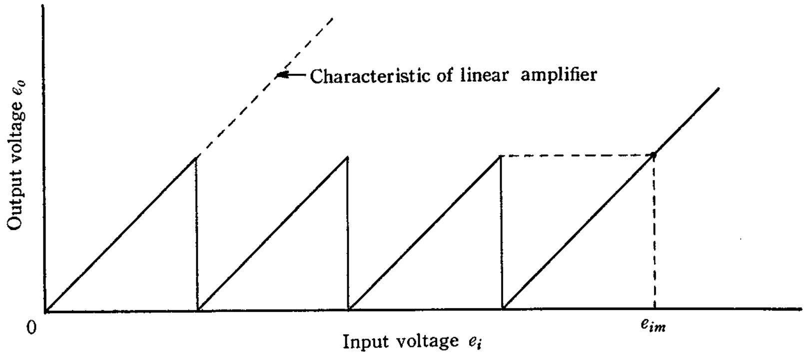


Fig. 4. Idealized relation between input voltage e_i and output voltage e_0 for $n=3$.

is e_{im}, the compressibility will approximately be given by the following formula;

$$20 \log (n+1) \qquad \text{dB}, \tag{2}$$

where n is the number of tunnel diode.

From Figs. 1 and 3, it is able to understand that the linearity of this compressor is improved by reducing the difference between the values of current at the peak point P and the safety point Q in Fig. 1. In other words, the larger the output load resistance is made and so the looser a slope of load resistance line becomes, the more the linearity between the voltages of input and output will be improved.

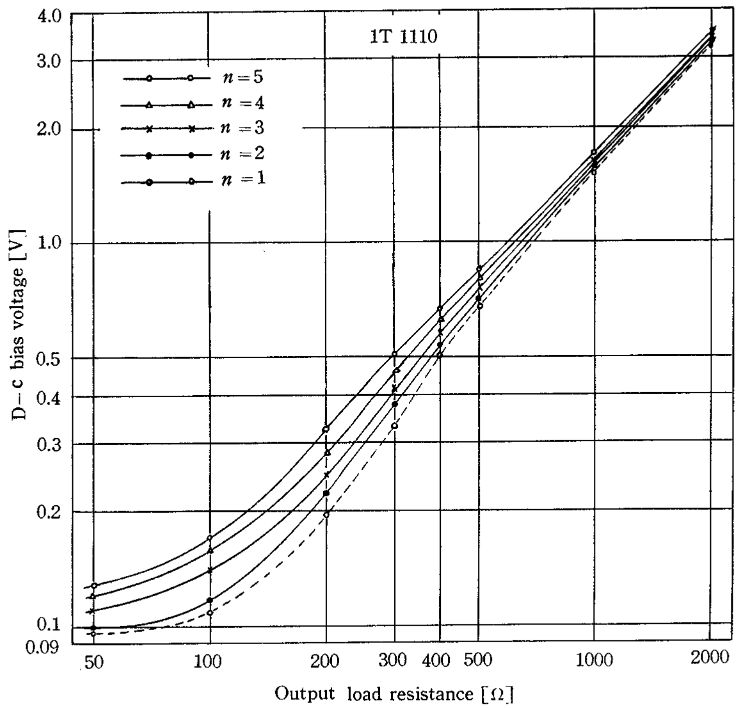
3. Experimental results and their considerations

3.1. Relation between the d-c bias voltage and the output load resistance.

The d-c bias voltage stated here is E_b in Fig. 3. It is clear that if the number of tunnel diode is increased and the value of the output load resistance is made larger, the value of E_b must also be risen. The measured results of the relation between the d-c bias voltage and the output load resistance by tunnel diodes 1T1101 and 1T1110 are as shown in Fig. 5. An internal resistance of power source, used in this case, was 20.4 Ω.

3.2. Linearity of input-output characteristics.

As described above, the larger the value of an output load resistance is made, the better the linearity of input-output characteristics will be. The observed results by making use of 6 pieces of tunnel diode 1T1101 are as shown in Photo. 1. These results are much the same to the experimental results carried out by A. A. Clark and W. H. Ko[1]. From Photo. 1, it is understood that the larger an output load resistance is made, the larger the output voltage must be.



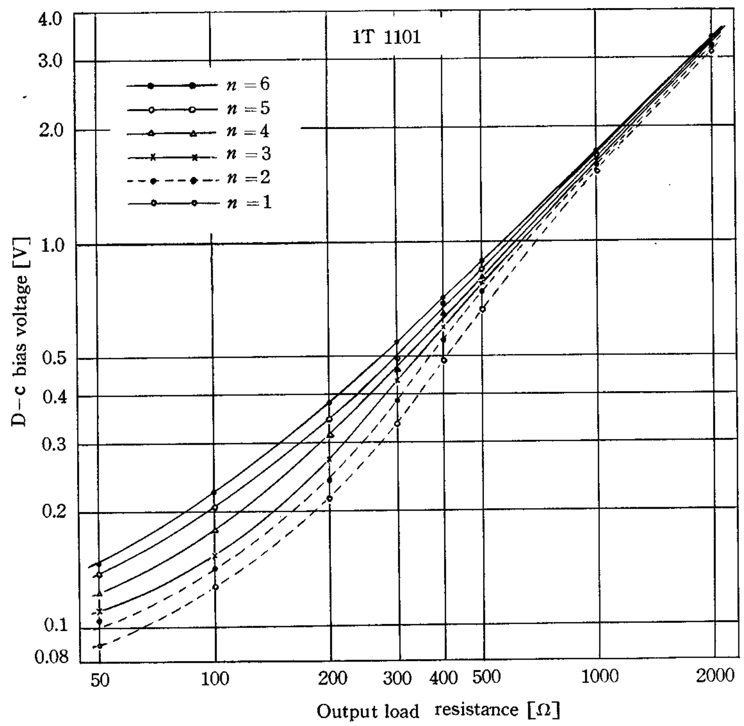


Fig. 5. Relations between d-c bias voltage and output load resistance for a parameter n.

When the value of R_s+R_L is large, points B and Q in Fig. 1 are in positions of large value of currents. Therefore, a mean equivalent resistance between points Q and S is less than that between points B and P. Consequently, the more the number of the tunnel diode which assumes the condition between points Q and S increases, the smaller will be the total equivalent resistance of tunnel diodes. However, the amount of this decrease is small compared with the value of R_s+R_L before the switching. Consequently, because

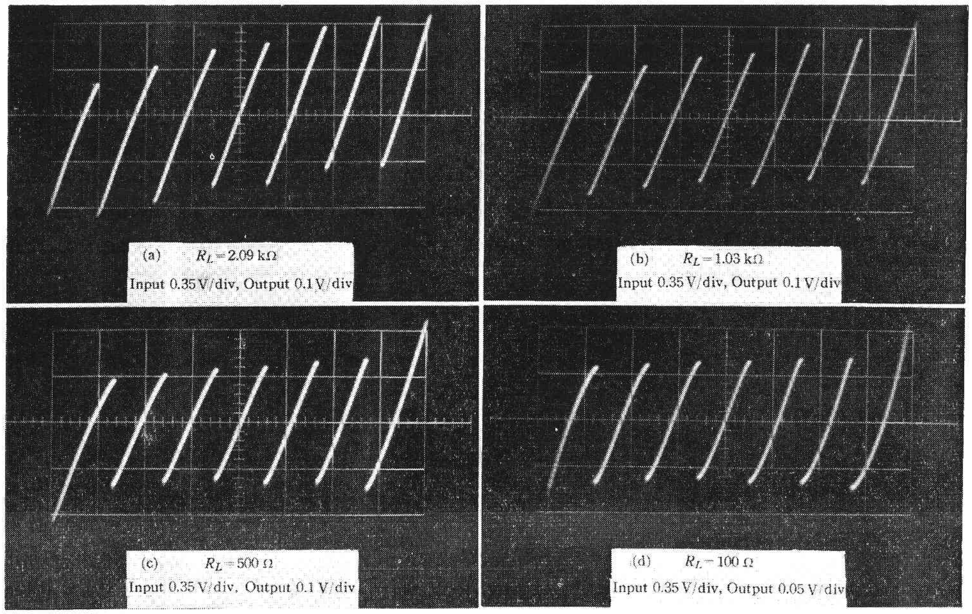


Photo. 1. Output waveforms of pulse compressor using 6 pieces of tunnel diode 1T 1101.

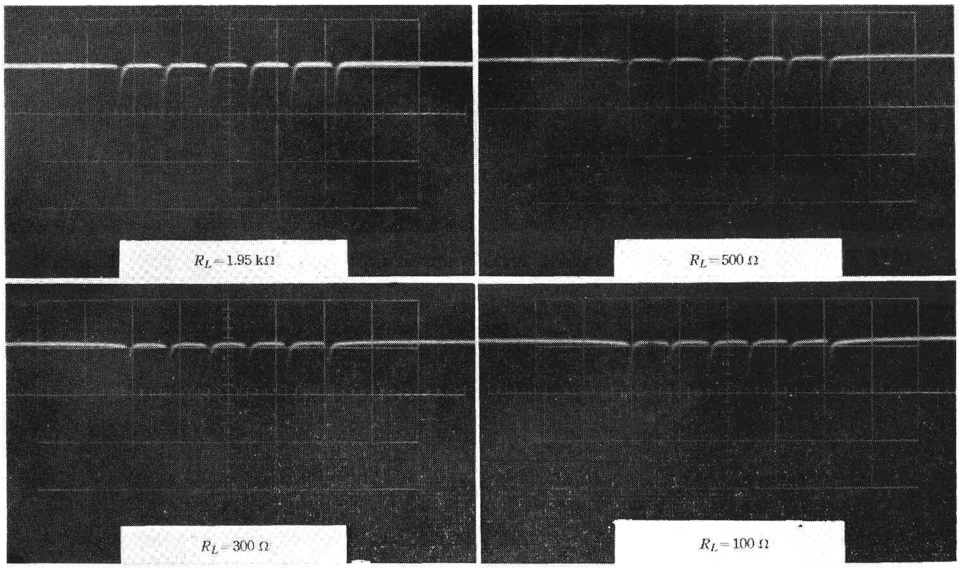
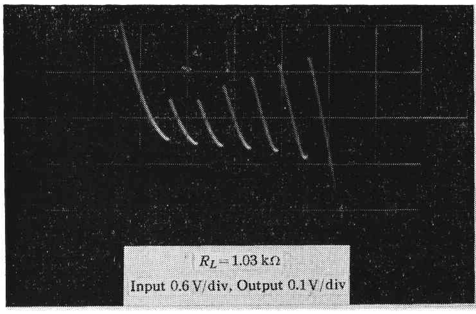


Photo. 2. Differentiated output waveforms of pulse compressor using 6 pieces of tunnel diode 1T 1101.

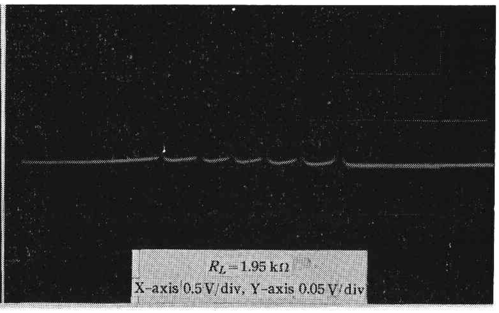
the slope of a load resistance line does almost no change, the value of an output voltage immediately after the finish of the switching increases little by little as can be seen in (a) and (b) of Photo. 1.

In order to observe the linearity of output waveforms of Photo. 1, these outputs were differentiated by a differentiating circuit. These results are as shown in Photo. 2. In Photo. 2, generation of negative pulses is due to the switching action of tunnel diodes, connected in series. If the parts, exclusive of the negative pulses, are on a straight line, the linearity of input-output characteristics of this compressor is very good. It will be understood that if the output load resistance is made larger, the more the differentiated waveform tends to approach such a state.

An output waveform and its differentiated waveform at an input voltage which decreases linearly with time are as shown in Photo. 3. It is understood that the switching



(a) Output waveform.



(b) Differentiated waveform.

Photo. 3. Output waveform and its differentiated waveform at the input voltage which linearly decreases with time.

action in this case is quite different from those observed at the input voltage which increases linearly with time. Now, it is assumed that all of the tunnel diodes have finished the switching action by the voltage which linearly increases with time. Under this condition, the switching action by the voltage which linearly decreases with time is able to illustrate by Fig. 6. First, a tunnel diode which has the largest current in the valley point does the switching and removes with very high speed to another safety point. M. Thus, an across voltage of this tunnel diode rapidly decreases and the current of the circuit rapidly increases. When the input voltage continuously decreases from this condition, the switching action goes on in turns from tunnel diode which has a higher valley current to that of lower one, and finally, all of the tunnel diodes finish the switching action. In this case, because the linearity of the positive resistance part in the neighborhood of the point D is not very good, the more the number of tunnel diode which finished the switching action increases, the more the influence of this part decreases. Therefore, the linearity of input-output characteristics gradually improves according to progressing of the switching action. In case of large output load resistance, a load resistance line has a loose slope and points M and N are in position of low currents. Therefore, a mean equivalent resistance between points L and M is less than that between points D and N, and the difference between these two values is comparatively large. Consequently, the more the number of tunnel diode which assumes the condition between points L and M increases, the smaller the value of

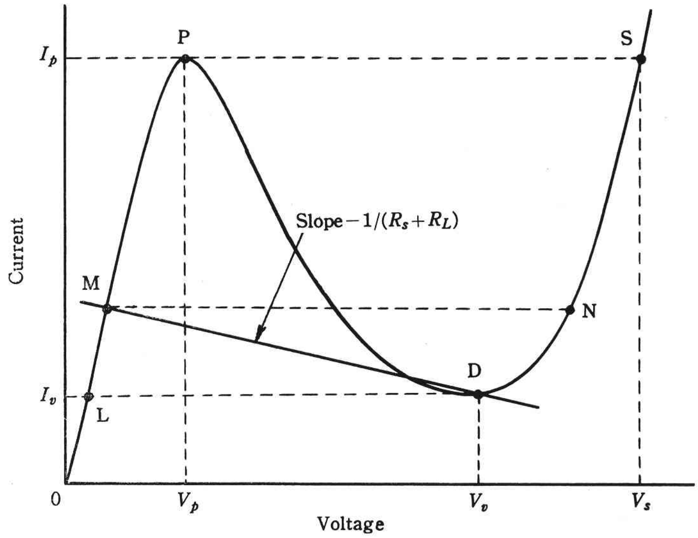


Fig. 6. Voltage-current characteristic of tunnel diode and a load resistance line.

R_s+R_L becomes, and point M removes upward little by little along the characteristic curve of tunnel diode. From this fact, the output voltage immediately after the finish of the switching action tends to increase.

The observed results of output waveforms by applying a sine wave of small amplitude superimposed on the voltage which linearly increases with time are as shown in Photo. 4. In this case, a frequency of sine wave was 335 kc/sec and 6 pieces of tunnel diode 1T1101

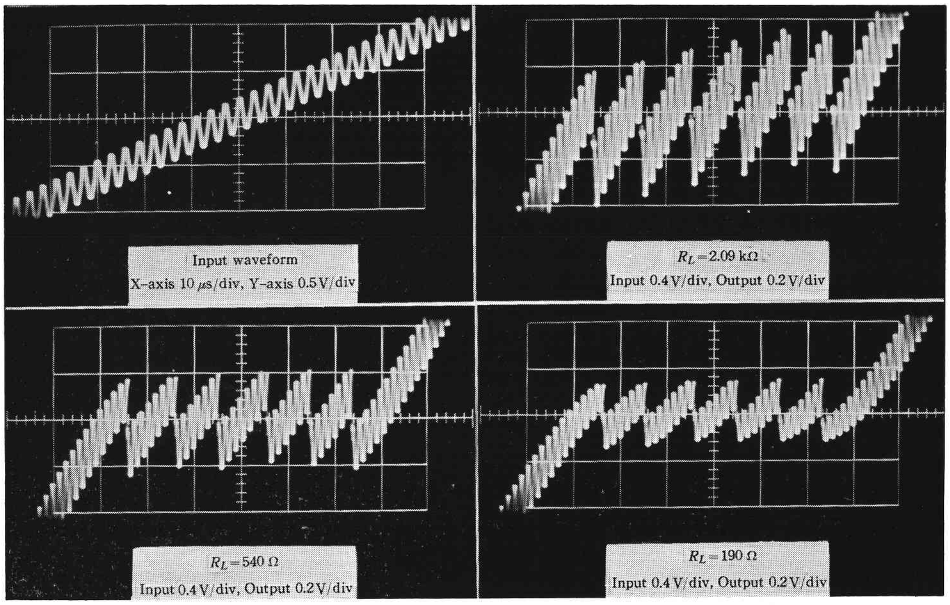


Photo. 4. Output waveforms observed by applying a sine wave of small amplitude superimposed on the voltage which linearly increases with time.

was used. From Photo. 4, it is clearly understood that the smaller an output load resistance is made, the more the linearity of input-output characteristics is deteriorated.

Photo. 5 shows the same results as that shown in Photo. 4 in case of making use of 7 pieces of tunnel diode 1T1103 and 5 pieces of tunenl diode 1T1104.

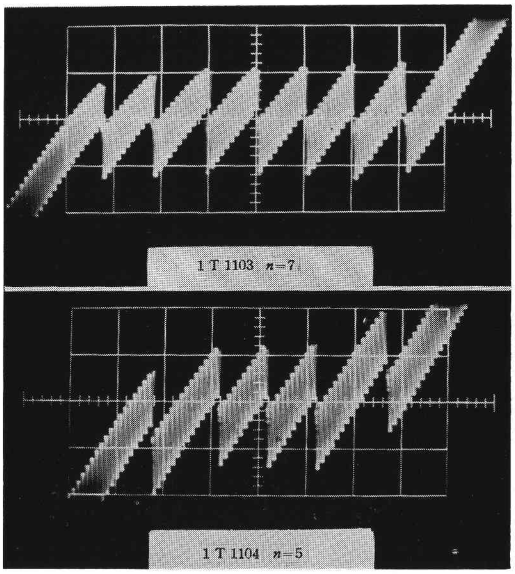


Photo. 5. Output waveforms at the same input voltage as shown in Photo. 4.
(R=1.11 kΩ, Input 0.4 V/div, Output 0.2 V/div)

3.3. Comparisons of the switching voltages at the inputs which linearly increase and decrease with time.

In this experiment, a triangular wave of 1 kc was used as the input voltage and therefore, after the finish of the switching action by the rising part of the input ovltage which linearly increases with time, the second switching action takes place by the falling part of the input voltage which linearly decreases with time. These observed results at various output load resistances are shown in Photo. 6. These results show that the difference

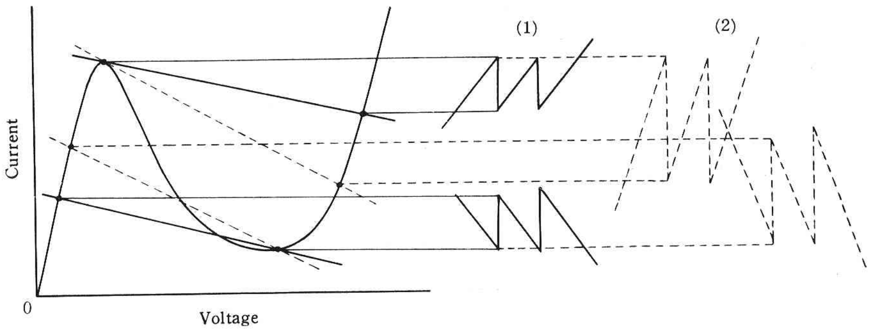


Fig. 7. Switching action by the input triangular wave voltage.

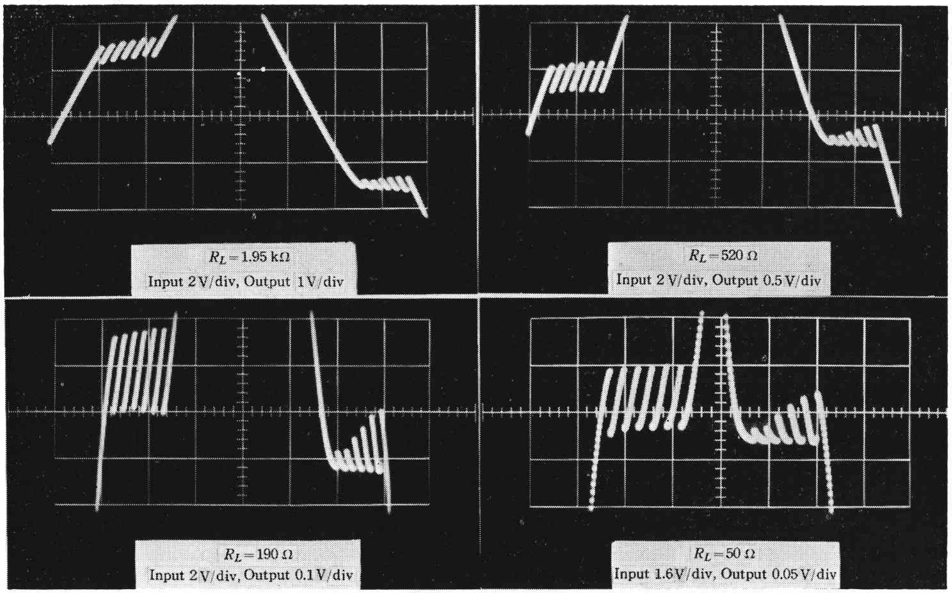


Photo. 6. Output waveforms observed by applying a triangular wave as the input voltage.

between the voltages at the switching time by the inputs of linear increase and those produced by linear decrease is augmented following the increase of an output load resistance. This fact is able to understand by Fig. 7. The curves (1) and (2), are shown in Fig. 7, express the variations of the output currents for large and small values of R_s+R_L respectively.

In practice, the variation of the output voltage is given by the product of a variation of current and the output load resistance. Consequently, from Fig. 7, it is understood that the larger an output load resistance is made, the more the difference between the voltages at the switching time by the input voltages of linear increase and those by the input of the linear decrease is augmented.

3.4. Influence of increasing the amplitude of sine wave signal superimposed on the voltage which linearly increases with time.

It is clear that an amplitude of sine wave signal, superimposed on the voltage which linearly increases with time, is allowed to take large value in case of large output load resistance. In other words, it is necessary to make the output load resistance large, when an amplitude of sine wave signal superimposed on the input pulse is large.

In this experiment, a sine wave of frequency 500 kc was superimposed on the voltage which linearly increases with time. When the amplitude of this sine wave increased, the output waveforms of pulse compressor are disturbed. These results observed are as shown in Photo. 7.

Further, Photo. 8 shows the same results which were made by extending the time axis of the disturbed part in Photo. 7. From Photo. 8, it is able to see roughly the behaviour of going and returning between two safety points on the characteristic curve of tunnel diode.

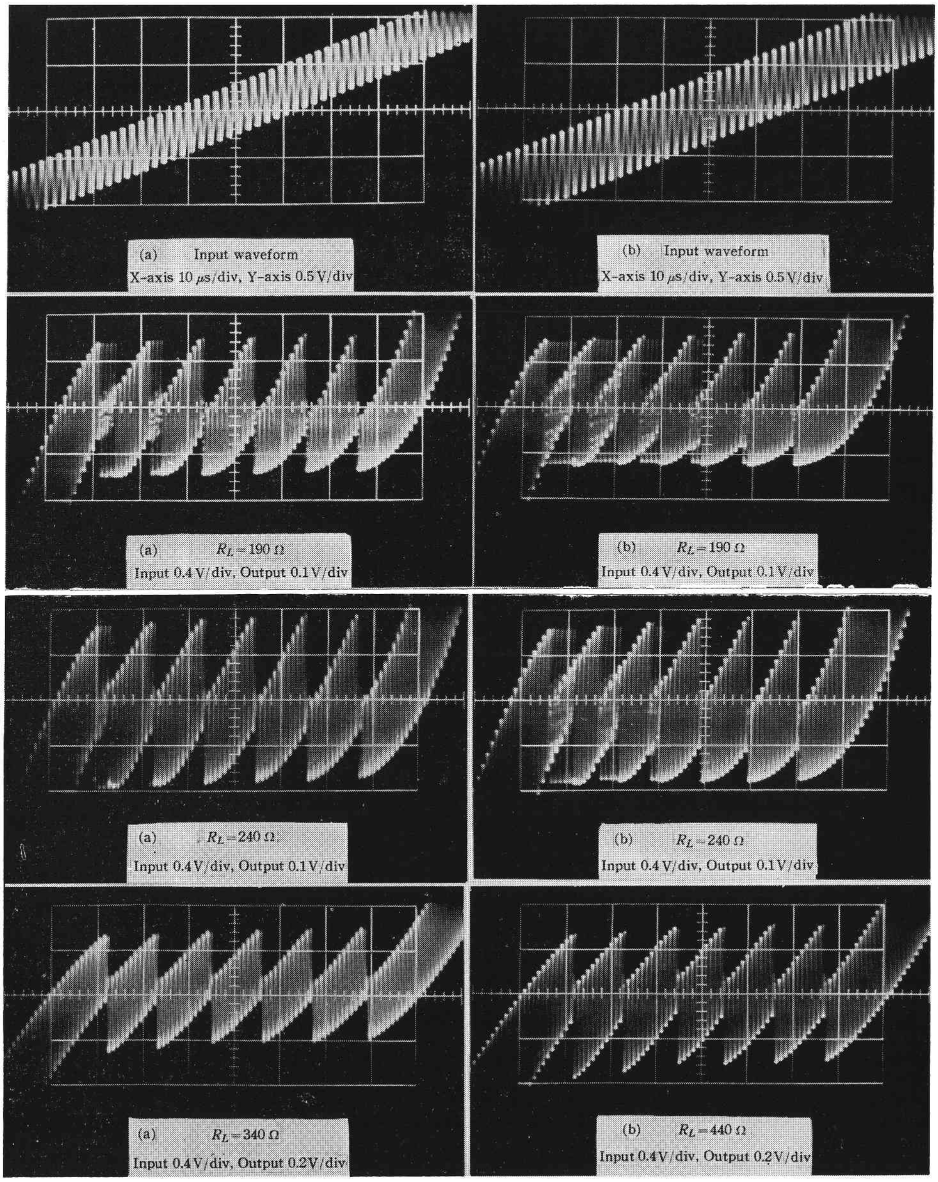


Photo. 7. Disturbanc: of output waveforms resulting f om increase of the amplitude of input sine wave superimposed on the voltage which linearly increases with time.

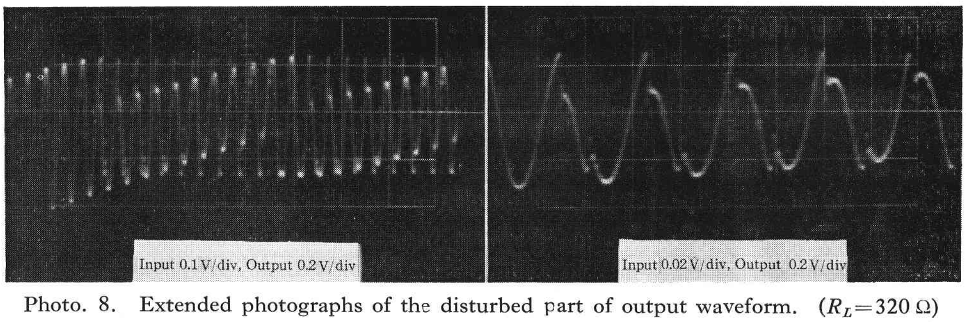


Photo. 8. Extended photographs of the disturbed part of output waveform. (R_L=320 Ω)

3.5. Influence of increasing the slope of input voltage which linearly increases with time.

An influence of the equivalent inductance and capacitance of tunnel diode becomes conspicious by increasing the slope of input voltage. Especially, immediately after the finish of the switching action, it appears as a transient vibration. A rough behaviour of this influence is able to see in Photo. 8.

Photo. 9 shows the observed results of output waveforms by increasing the slope

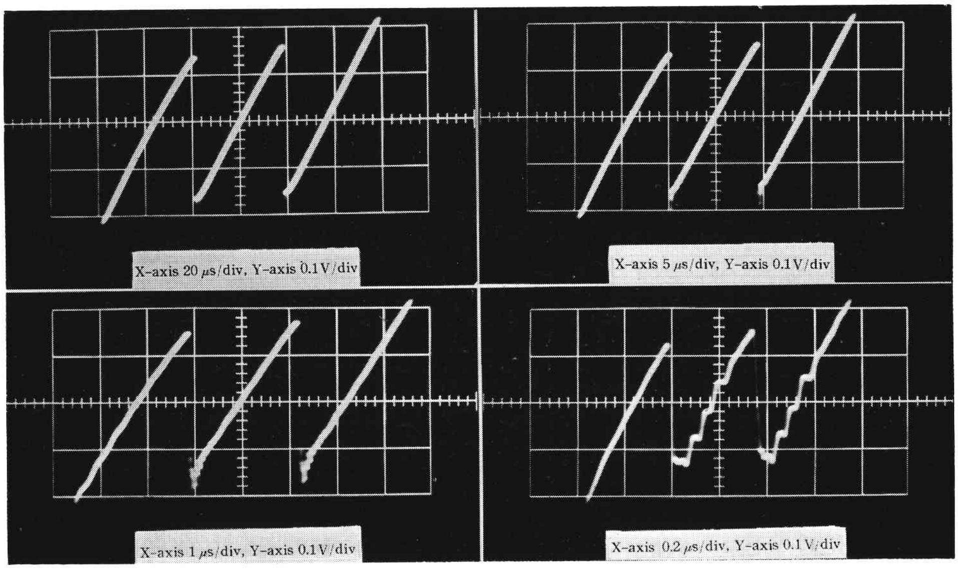


Photo. 9. Disturbance of output waveforms resulting from increase of the slope of input voltage which linearly increases with time.
(R_L=1.05 kΩ, n=2)

of input voltage. From Photo. 9, it is able to understand the behaviour of a transient vibration that takes place immediately after the finish of the switching action. When a small amplitude signal, superimposed on the pulse, is just at the switching time of tunnel diode, this signal is easy to receive such an influence. Consequently, if the variation of amplitude is very rapid and the input signal is in the condition as to produce such a transient vibration, it is necessary to pay close attention to the construction of compressor circuit.

Now, the authors will make some discussions from the fundamental data shown above. Through all experiments carried out by the authors, a part of a triangular wave was used as the voltage which linearly increases with time. Consequently, because a triangular wave has many frequency components, it seems that various experimental results, described in this paper, are able to apply to case of making use of the pulse as the input voltage. The problem of this equipment is in case of making use of the pulses which have only positive amplitude. In this case, the switching action of tunnel diodes by such the pulses goes to only one direction. Therefore, in a practical case where it is drived by such the pulses, it is necessary to insert the reset pulses in suitable position so as to let the system return to the beginning point of operation. There are the various methods for such a system and they are able to put in to practice without much hard. Second, there is a question of transient vibration, it is necessary to decrease the inductive and capacitive components of circuit elements and to pay the attention to the method of supporting tunnel diodes. In the present experiments, each tunnel diode was supported by inserting in two metal pieces which was setted to face each other. However, such a supporting method is decidedly short of satisfactory. As a method, for instance, it is able to plan to reconstruct the present tunnel diode which has two terminals into a cubic type, bearable to the pressure of some amount, and connect the necessary pieces by pushing of springs.

4. Conclusions

From the results of measurement and observation given in this paper, the following principal matters will be stated as conclusions.

(1) The larger an output load resistance is made, the larger the output voltage becomes and the linearity of input-output characteristics is more improved.

(2) When a signal amplitude, superimposed on the pulse, is large, the smaller the disturbance of the output waveforms will be, when the output load resistance made larger.

(3) The linearity of input-output characteristics of this pulse compressor is most wrong immediately before the beginning of the first switching action of tunnel diodes. Consequently, when this lack of linearity is a question, it is desirable to make the value of the d-c bias voltage large so as to put the part of inferior linearity out of action.

(4) It is desirable that the voltage-current characteristic of each tunnel diode is uniform as much as possible and the variations of equivalent resistance immediately before the beginning as well as after the finish of the switching action are small.

(5) The signal at the switching time of tunnel diodes is easy to receive the influence of a transient vibration. Therefore, a working limit of this pulse compressor must be determined by an output response to the signal at the switching time.

References

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2) T.Kasai: Lecture 1131 in Annual Joint Meeting of Four Institutes related with Electrical Engineers of Japan, (April 1961).