NRL Report 6940

# A Simplified DC-to-DC Converter With Constant Average Output Voltage

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## ABSTRACT

A dc-to-dc static converter circuit providing a constant average output voltage over a wide range of input voltages was proposed in NRL Report 6714, "A DC-to-DC Converter with Constant Output Voltage." Since the publication of that report, a much simpler circuit has been devised which operates on the same principles and accomplishes the same results.

The output, a pulsating dc, is basically pulse-width modulated to obtain a constant average voltage. The system consists of an unsymmetrical converter utilizing a square-loop magnetic core with the characteristic such that the secondary voltage is directly proportional to the primary voltage and the time to saturate the core is inversely proportional to the primary voltage. Each cycle is triggered by a unijunction oscillator at a constant frequency.

## PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases continues.

## AUTHORIZATION

NRL Problem E01-06
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# A SIMPLIFIED DC-TO-DC CONVERTER WITH CONSTANT AVERAGE OUTPUT VOLTAGE

## INTRODUCTION

The technique of using a static converter, triggered at a constant frequency, to obtain a pulsating dc output, having a constant average dc output voltage regardless of the input voltage, was explained in a previous report.* This result was derived from the fact that the square-wave output pulses had a magnitude directly proportional to and a duration inversely proportional to the input voltage, while maintaining a constant output frequency. This relationship was obtained by using a square-loop saturable core converter whose characteristics were such that the secondary voltage was directly proportional to the primary voltage and the time for the core to saturate was inversely proportional to the primary voltage. The circuit proposed operated quite satisfactorily over a very wide range of input voltages.

Since that time an even simpler method of obtaining the desired result has been devised and tested. In its simplest form an approximately constant average output voltage can be obtained over any desired range of input voltages. The addition of a simple input voltage regulator to the trigger circuit will provide a very precise and constant average output voltage. The range of operation can be very broad, limited only by the maximum ratings of the transistors employed. The converter also eliminates the usual requirement for an output voltage regulator in the conventional static converter circuit.

## CONVERTER CIRCUIT

The circuit diagram for the proposed dc-to-dc converter in its simplest form is shown in Fig. 1. It consists of an unsymmetrical static converter, each cycle triggered by a simple unijunction oscillator. The circuit is conventional, except that a silicon-controlled rectifier is inserted in one of the base drive circuits to inhibit the free-running feature of the conventional inverter. The output circuit is a half-wave rectifier. The converter is started on each cycle by a pulse from the trigger circuit, runs through one complete cycle, and waits for the next trigger pulse. It is designed so that the duration of one inverter cycle, at the lowest operating input voltage, is less than the time between successive pulses of the trigger circuit. The long-duration half-cycle is used to supply power to the load. The short-duration half-cycle is used only to reset the core, with losses limited to core magtizing and transistor base drive currents.

The triggering circuit consists of a simple unijunction oscillator to generate the short triggering pulses at a relatively constant frequency. The two-stage amplifier increases the power in the triggering pulses and serves to isolate the oscillator from the power converter.

The unijunction oscillator frequency is remarkably stable over a wide variation of input voltages; thus the circuit in Fig. 1 provides a relatively constant average output voltage to the load. However, the oscillator's frequency does vary slightly with its input voltage, and as the constancy of the converter's output depends upon the stability of the

*NRL Report 6714, "A DC-to-DC Converter with Constant Output Voltage," by Joseph M. Marzolf, May 7, 1968.

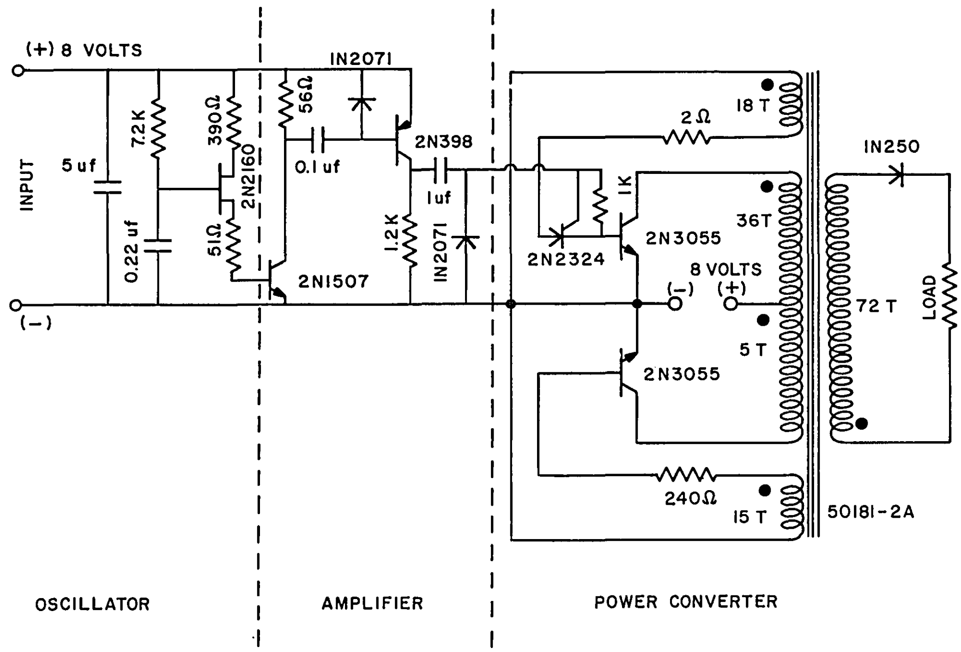


Fig. 1 - Basic circuit

triggering frequency, the converter's operation is improved by regulating the voltage input to the trigger circuit. Note that only the input voltage to the trigger circuit is regulated. The input to the power converter is not altered in any way.

For some applications the circuit in Fig. 1 can be used as shown, but for more precise applications an input circuit from either Fig. 2b or Fig. 2c should be chosen. The circuit in Fig. 2a, a voltage divider, was used with the circuit in Fig. 1, because the oscillator was designed for a lower input voltage than the power source to permit the insertion of a regulator. This represents the unregulated condition, since the oscillator input voltage is directly proportional to the power source voltage. The oscillator could be redesigned to operate directly from the power source and thus eliminate the voltage divider.

Figure 2b shows a zener diode regulator which operates quite satisfactorily over a limited range, and is quite adequate for those applications where the input voltage excursions are limited. For very wide variations in input voltage, the excessive voltage dropped across the limiting resistor represents a large efficiency loss. Thus for practical applications, such a circuit would limit the inherently wide capabilities of the basic converter circuit.

For very wide variations in input voltage the circuit in Fig. 2c is quite satisfactory. It is a relatively simple voltage regulator circuit and allows the basic converter to operate over a very wide range.

## CONVERTER OPERATION

The wave shapes shown in Fig. 3 were all obtained across a 50-ohm resistive load, and the input voltage regulator for the triggering circuit shown in Fig. 2c was used. Note that as the input voltage increases, the pulse amplitude increases, the pulse width decreases, and the frequency remains constant.

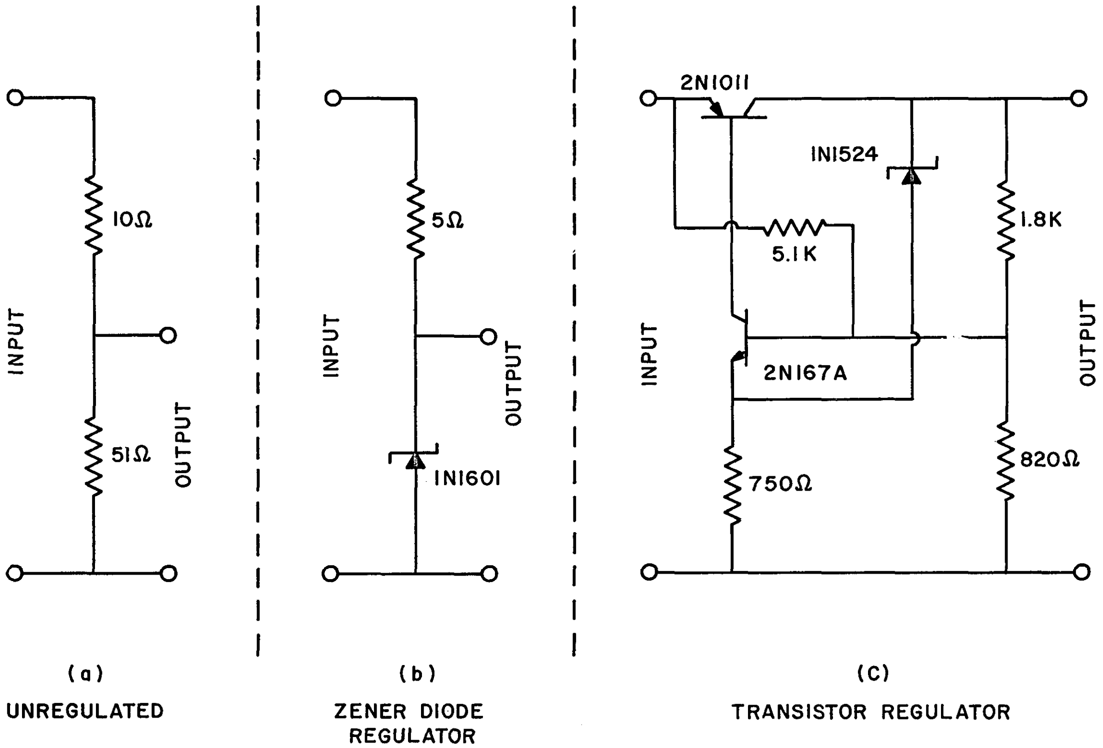


Fig. 2 - Trigger input circuits

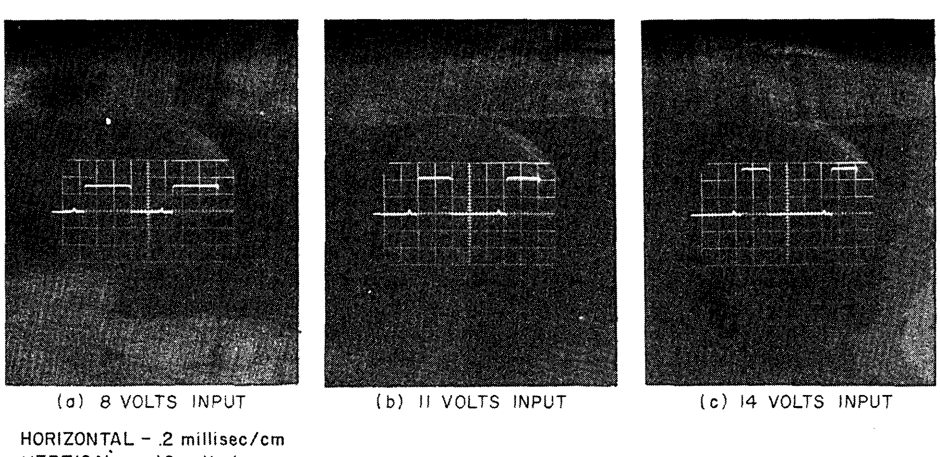


Fig. 3 - Output wave shapes

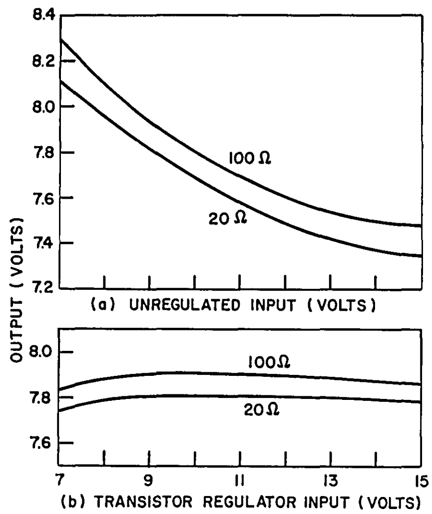


Fig. 4 - Output vs input voltage curves

The curves shown in Fig. 4a and 4b were obtained with loads of 20 and 100 ohms, and with input voltages varying from 7 to 15 volts, a change by a factor of 114%. The basic converter, with no input regulator on the trigger circuit, had a maximum output voltage variation of 9.7% (Fig. 4a). With the regulator circuit shown in Fig. 2c the output voltage had a maximum change of 1% (Fig. 4b). The output voltage is pulsating dc. The data mentioned above were measured using a D'Arsonval type dc meter, whose response was much too low to follow the instantaneous values. The meter readings and data are therefore average values.

## OUTPUT CONSIDERATIONS

The output wave shape produced by this converter is a constant-frequency pulsating dc (square-wave) form. This wave form has certain aspects that may need consideration in a practical application. Although the average value of current and voltage (in a resistive load) is constant throughout the entire operating range, the power transmitted to the load is not constant. This apparent anomaly can easily be demonstrated by simple algebra, as shown in the appendix. The actual power is higher for the smaller on-to-off ratios, where the instantaneous amplitudes are greater.

If the load contains reactive components, such a power source might be completely unacceptable. In effect, this type of output is dc with an excessive ripple content. Therefore, in many practical circuits an output filter of some type would be mandatory. This is not a simple problem. Conventional filter circuits, relying on the temporary storage of energy in large capacitors or inductors, are affected by maximum amplitudes as well as average values. A filter can usually be designed only for a given load and a limited range of input variations. This aspect of the problem requires much more study and is not considered to be within the scope of this report. It is a problem which is common to all pulse-width-modulated regulators, and the filter design will probably depend upon the specific application.

## CONCLUSIONS

The triggered, unsymmetrical, dc-to-dc converter circuit explained above represents a relatively simple method of maintaining a constant average output voltage for extremely wide variations in input voltage. In effect, it incorporates the pulse-width-modulating regulator as an inherent part of the converter, thus eliminating the need for an external regulator as is usually required in a practical circuit employing conventional static converters.

## Appendix

## OUTPUT POWER

Consider the dc square wave voltage pulses of Fig. A1, having a maximum amplitude of E volts, a time for one cycle of t seconds, and an "on" time for $t'$ seconds.

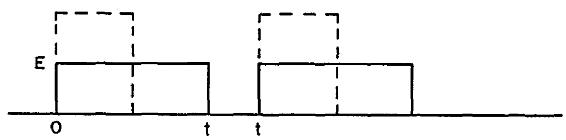


Fig. A1 - Voltage output vs time

The average dc voltage over the entire cycle is $Et'/t$. Similarly in a resistive load, the average dc current over the entire cycle would be $It'/t$, and the product of the average voltage and the average current equals $EI(t'/t)^2$.

The actual power to the load, if $t' = t$ (pulse duration for the entire cycle), would be the product of the voltage and current, or EI. However, since $t' = t$, the power is only "on" for $t'/t$ of the full cycle, thus the actual power to the load would equal $EI(t'/t)$.

It may be seen from the above that the average power to the load, $EI(t'/t)$, is not equal to the product of the average voltage and the average current, $EI(t'/t)^2$, showing that different wave shapes, having equal average voltages and currents, do not transmit equal power to the load. To demonstrate this, consider the different wave shapes of Fig. A1. The dotted version has twice the amplitude but half the pulse duration of the solid version. Their average and actual values of power are shown in Table A1.

Table A1
Comparison of the Two Wave Shapes in Fig. A1

| Wave Shape | Average Voltage ($E_A$) | Average Current ($I_A$) | Average Voltage × Average Current | Actual Power |
|---|---|---|---|---|
| Solid | $Et'/t$ | $It'/t$ | $EI(t'/t)^2$ | $EI(t'/t)$ |
| Dashed | $(2E)(t'/2)/t = Et'/t$ | $(2I)(t'/2)/t = It'/t$ | $EI(t'/t)^2$ | $(2E)(2I)(t'/2)/t =$ $2EIt'/t$ |

Thus, although both wave shapes have identical average voltages and currents the actual power imparted to the load is not the same for both wave shapes. In fact, the dotted shape transmits twice the power to the load that the solid wave shape does.

In pulsating dc circuits, the product of the average voltage and average current cannot be used to calculate the power.

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| Energy conversion | | | | | | |
| Pulse modulation | | | | | | |

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