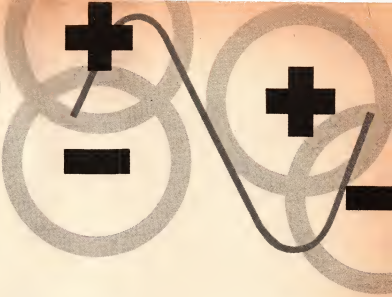
SWITCHING POWER SUPPLIES



IN THE majority of power supplies, the mains transformer and the smoothing and reservoir capacitors account for most of the bulk and weight. This situation, although unavoidable in the past, is unfortunate because the mains transformer, which contributes a major part of the weight, plays no vital part in the functioning of the power supply, its only real purpose being to isolate the mains from the output of the power supply. In practice the main transformer is also used to step down the input voltage to a convenient level, but this could easily be achieved by other means.

The basic concepts behind transformerless, or switching, power supply units have been known for some considerable time. Unfortunately, until two or three years ago, components capable of putting the ideas into practice were not available.

Switching regulators dispense with bulky 50Hz transformers and smoothing components, yet achieve isolation between the mains and power supply output. The reduction in size and weight achieved is in the order of 8 : 1 but as with everything else, one does not get something for nothing. However, in the vast majority of cases, the trade-off is extremely worthwhile. In some cases the performances may not be as high as with linear techniques. This point will be dealt with in more detail later in the article.

OPERATING PRINCIPLES

Transformerless or switching power supplies achieve isolation between mains and output by employing a high-frequency transformer as against the conventional 50Hz transformer and herein lies the secret of the small size of switching power supplies. It is a fundamental fact that the higher the frequency employed the smaller a transformer can become to handle a given amount of power.

The basic principles of switching regulator operation are illustrated in Fig. 1. The mains input is converted to d.c. by a bridge rectifier and smoothing circuit after high frequency filtering. This d.c. is applied to a pair of switching transistors which are driven at tens of kHz by the control circuitry. The square wave output of the switching transistors is applied to a small h.f. transformer, the output of which is rectified and smoothed to provide the output of the power supply. This voltage is compared with a reference voltage and, if a difference exists, an error signal is generated and fed to the control circuitry. The control circuitry adjusts the mark-space ratio of the signal applied to the switching transistors in such a way as to reduce the error signal to zero. Another method relies on a frequency variation. This ensures that the output of the power supply remains constant.

It will be noted that two small high-frequency transformers are employed, one in the main current path and one in the feedback loop, to ensure that the output is isolated from the mains.

The two high-frequency filters stop spurious voltages at the switching frequency and its harmonics from being fed back into the mains wiring and into equipment powered by the power supply.

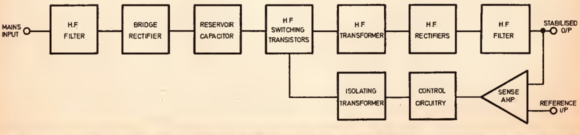


Fig. 1. Block diagram of switching regulator

FIRST SYSTEM

Several circuits have been developed which give a variety of different advantages. The first (see Fig. 2) used a conventional inverter circuit working at 20kHz. This was driven from a multivibrator, the main transistors TR1 and TR2 being alternately on and off.

The output from the transformer is a square wave, which is rectified by fast recovery rectifiers and then smoothed.

The input voltage to the inverter is 150V, thus limiting the peak voltage on the transistors to 300V. To generate this 150V rail, the 240V mains supply is rectified and smoothed to give 340V, which is fed to a switching regulator that reduces the voltage to 150V.

This regulator is a constant frequency circuit with the "on" time of the switching transistor TR3 controlled to keep the rectified output constant via the 150V rail. The two circuits are driven from the same oscillator so that they do not beat together.

Such a unit has four active loss stages and three passive. To remove one of these active loss stages the switching regulator and the inverter must be combined. The normal inverter has alternate stages fully on or fully off, and at all times one stage is on.

The output is set by the turns ratio of the transformers which is fixed, and the input voltage. In the next inverter (Fig. 3) a variable off time is injected between each on period by controlling the ratio of the on and off pulses, thus controlling the output.

The secondary output is a series of pulses of variable mark-space, so that it is now only necessary to filter those pulses to get a mean output, which can then be varied.

CIRCUIT VARIATIONS

Two variations of the circuit are possible depending on the manner in which the mark-space ratio is varied. We can have either a constant on pulse with a variable off time, or a fixed frequency with variable on and off times.

Fixed pulse width gives a system that is free of restraints and is thus more able to overcome sudden overloads interference or mains loss. Since the pulse width determines the ripple voltage for a given choke and output capacitance value, the ripple will remain constant against line and load variations. Also the circuit can give very large swings of output voltage and input voltage without unlocking. The main disadvantages are that since it operates near the audio range it can, under light load conditions, break into the audio range. Furthermore, as the ripple frequency is variable, it is more difficult to filter out.

Transformerless 4½ to 6V, 50A power supply

The other system (constant frequency) offers an almost exact complement to the fixed pulse width. It is completely quiet under normal working conditions, and filters used external to the equipment can be tuned to give maximum attenuation at this frequency.

It cannot be used over such a wide range of input and output variations, however, and is more prone to jump into an uncontrolled frequency mode of operation.

Both systems are currently in use, depending upon the application.

COMPONENT CONSIDERATIONS

In these two circuits, the components under most danger are the inverting transistors. By using the series type of inverter to limit the peak transistor volts, we have both transistors in series across the line. Control circuits must ensure that both transistors are not turned on at the same time, or a short circuit would be placed across the line, thus destroying one or both of the transistors.

Also, the pulse widths supplied to both transistors on alternate cycles must be identical, or the energy drawn from the series capacitors will be unbalanced. If this happens, the centre voltage will move towards the greater pulse width and the transformer will tend towards saturation.

The output voltage of one side will then fall, and if it falls too low it will not bring its rectifier into conduction. Such a condition is much easier to control in the constant pulse width system.

CONTROL

All control in these systems is by non-dissipating elements apart from saturated switches. Thus the highest dissipation is in the high current output rectifiers. Fast recovery rectifiers have been used for some years with proven reliability, but their saturation voltage is of the order 1 to 1·2V at the currents being used.

Schottky diodes offer an answer to the high dissipation problem in that they have a forward voltage drop of only 0·4V at very high currents and thus considerably reduce dissipation. At present, they only offer an increase in efficiency and not a reduction in size of the heat sink required. This is because their maximum junction temperature is 100°C, so they have to be kept extremely cool.

Transformerless supplies, examples of which are shown in the accompanying photographs, offer three major advantages that are very difficult to provide with linear units. They can operate from mains voltages of from 200 to 264V without tap changes; they can maintain their output voltage at full load with a mains interruption of 30ms, and they can be used over a 0V to 6V range at full current with no tap changes.

In fact they run cooler with lower output voltages, and a 250A 2V unit could easily be produced if it were required. They are thus ideal for use as constant-current units or as bench variables.

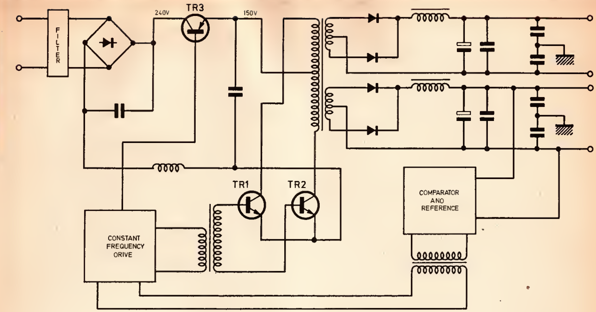


Fig. 2. Conventional inverter circuit diagram

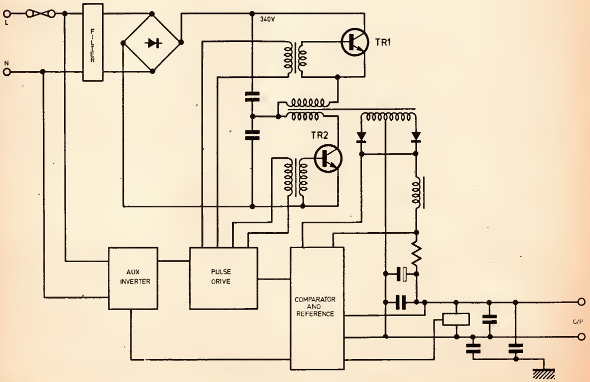


Fig. 3. Variable output inverters

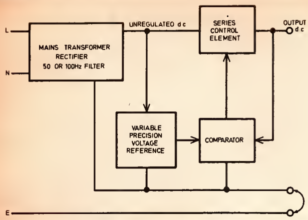


Fig. 4. Linear regulator block diagram

The output specification of these units is satisfactory for TTL circuits, and their use in lightweight desktop equipment is advantageous because of their size and weight.

If any communications equipment is used with these power units, additional screening will probably be required; but even with a large amount of screening their size will prove most attractive.

LIMITATIONS

For highly critical applications, the switching regulator would not normally be used because, inevitably, a small amount of ripple at the switching frequency appears on the output and the transient response is not up to the best that can be achieved by good linear regulators.

However, for many purposes these factors are of no consequence and then the switching regulator really comes into its own. From the equipment manufacturer's point of view, the space and weight savings enable more compact equipment to be produced at a lower cost.

ONE STEP FURTHER

Having looked at the relative advantages and disadvantages of the switching regulator when compared with the linear regulator, it is now necessary to look at one of the disadvantages of the conventional linear regulator. A block diagram of a typical linear regulator appears in Fig. 4.

The output voltage is compared with a precision voltage reference. If the two differ the comparator either increases or decreases the impedance of the series control transistor to correct the output voltage. To allow the series control element to do its job, the unregulated d.c. from the transformer and rectifier assembly must always be of a higher voltage than the output voltage.

If the power supply had an output which could be varied from 0 to 50V at 10A then the unregulated d.c. supply must be around 55V. At 1V, 10A output, 54V would be dropped across the series control element and 540W would be dissipated in it. This problem is usually overcome by having a range switch which varies the output of the unregulated section so as to limit the power dissipation in the series control element to a reasonable value.

However, large efficient heat sinks are needed for the series control transistor which add to the bulk of the power supply. Due care must be taken with cooling air-flow through the power supply, further adding to the size and weight problems.

A new approach has been recently announced which was developed by APT Electronics Ltd. This involves combining switching and linear regulators in an attempt to achieve the best of both worlds.

COMBINED TECHNIQUES

A number of the disadvantages of both switching and linear regulators can be overcome or minimised by a new technique which combines both linear and

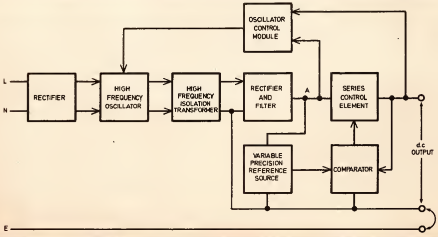


Fig. 5. Power unit incorporating both linear and switching principles

switching regulators in a single unit. A block diagram of a laboratory bench power supply, currently being manufactured by APT, is shown in Fig 5.

Operation of the system is best described by imagining that the unit is switched on and is supplying an output, say 40V, to a load. Point A on the circuit must be at a potential of more than 40V for the series control element to function. For reasons which will become clear later we will state that point A is at 45V.

If the voltage reference source output is deliberately lowered to 30V the comparator will provide an output which will increase the impedance of the series control transistor so as to reduce the output of the power supply to 30V. As this is taking place the voltage drop across the series control element would tend to rise. The oscillator control module senses this increase and lowers the duty cycle of the oscillator so the input voltage to the series element falls. Circuit values are such that the voltage across the series element is maintained at 5V.

With 30V now at the output, therefore, point A will be at 35V. The technique ensures that even for a 0 to 50V 10A power supply, power dissipation in the series control element is limited to 50W even at the normal worst case condition of 1V output at 10A.

The main advantages of the technique are therefore the elimination of the 500W mains transformer and bulky 100Hz smoothing components, and a considerable reduction in internal power dissipation allowing smaller heat sinks to be used.

Such a power supply does not perform as well as a good quality series linear regulator but is much better than a straight switching regulator. For a 50V, 10A power supply the relative advantages of the linear series, switching and combined switching series regulators are summarised in Table 1.

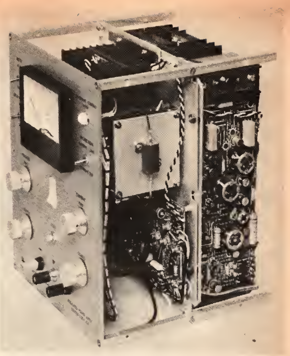
Table 1.

Parameter	Linear	Switching	Linear/ Switching
Regulation	Excellent	Good	Good
Transient response	Excellent	Poor	Fair
Ripple and noise	Excellent	Poor	Good
Ease of output voltage adjustment	Fairly easy	Fairly difficult	Easy
Size	Very large	Very small	Small
Weight	Very heavy (90lb)	Very light (10lb)	Very light (16lb)

A photograph of the combined switching and linear regulator is shown.

THE FUTURE

Power supply performance will continue to improve and will be assisted by monolithic integrated circuit and thick film hybrid microcircuit developments.



The SSU 10-50, 0 to 50V, 500W laboratory power supply from APT Electronics

Thick film microcircuits consists of a substrate (or base material) on which the circuit to be manufactured is printed. Conductors are printed with palladium, or similar ink and resistors will be formed by printing with one of the many inks available for this purpose. The printed substrate is "baked" in a furnace and then active components such as transistors and integrated circuits are added.

Hybrid microcircuits are very reliable, much more reliable than the printed circuit board with separate components, and can be designed to have a uniformity of performance very difficult to achieve by other means.

This last point is very important in power supply manufacture and indeed complete regulator control circuits using monolithic chips and discrete components are manufactured in hybrid microcircuit form at Coutant's Ilfracombe factory.

Any improvement in the monolithic results in an improvement in the hybrid. The two techniques are therefore complementary. ★

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