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A 12 Volt to 12 Volt Converter

The title of this article appears at first sight to be the introduction to an April Fool's joke but upon reflection, one of the following problems may have been experienced with your communication equipment.

– You are planning an extended mains-independent use of the field-day rig and you are looking for an optimum source of primary power. You have come to the conclusion, that the use of primary elements is much more advantageous than accumulators, an alkaline-magnesium mono-cell has a capacity of about 10 ampère-hours (a.h.), a nickel-cadmium (nicad), of the same physical size, only about 4 a.h. But that is'nt the whole story. When a dry battery is being discharged to complete exhaustion, the terminal voltage sinks gradually to about half its initial value. The re-chargeable battery, on the other hand, has a negligible voltage decline until at the limits of discharge, the voltage fails catastrophically. Will your battery transceiver work with only 6 V?. To take more battery cells is also no solution as the equipment runs the risk of over-voltage. What is required then, is a low-loss converter that, when fed with an input voltage of 10 to 20 volt, will deliver a stable voltage of 12 volt. If the transceiver has digital circuits on board then it would be convenient to have a 5 V regulated voltage available, as the normal supply method of dropping it via a series-pass transistor is not too economical on batteries.

– Say a computer is taken along on a field-day to be used as a log book. In order that the entire memory content is not lost in the event of a power-set failure (...who's forgotten to fill up the petrol tank again?), the computer is connected to the automobile battery. The required 5 volts is no problem and the quiescent battery voltage of 12 V can supply both the disc-drives and the screen monitor. But what happens when the motor is started to charge the batteries and the supply voltage to the computer equipment rises to some 14 to 15 volt complete with voltage surges?

In both instances, the solution is the employment of a converter which will work with an input voltage of between 10 and 20 volt and deliver an output at a constant 12 volt. The desirable characteristics of such a converter could be summarized as follows:

* **output voltage 1: 12 to 14 V adjustable, at 3 to 5 Amps.**
* **output voltage 2: 5 V at 2 A**
* **input: protected from both low and high voltages**
* **output: short-circuit proof**

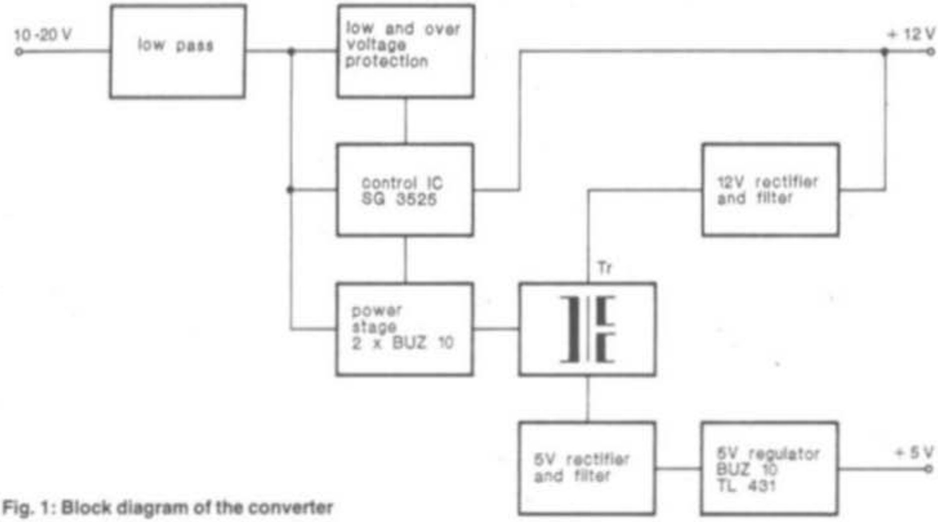


Fig. 1: Block diagram of the converter

1. THE CIRCUIT CONCEPTS

From the target data, outlined above, it may be deduced that the converter must deliver a power of 60 W. This corresponds to a primary supply current of a 6 A at the minimum input voltage of 10 V. From the literature, and e.g. (1), there are three basic circuits to choose from: the forward converter, the single-choke converter and the full-wave forward converter. The half and full bridges, used in 220 V switching power supplies, are unsuitable for low-voltage supplies as the switching current must pass through two series power semi-conductors and the potential difference lost across them is proportionately more at 10 V than at 220 V.

If the converter had been designed around a forward converter, then relatively high currents would have to be switched (this particularly applies to the blocking converter) as power is only delivered during up to 50 % of a period.

For this reason, the full-wave converter has to be the chosen concept. Since normal integrated control circuits have two differential outputs anyway, the external requirements are limited to another power transistor. The use of power MOSFET's, e.g. BUZ 10, with the control chip SG 3525 renders the use of intermediate power driver stages unnecessary.

One disadvantage of the push-pull converter should not, however, go unmentioned. It possesses a relatively poor "cross-coupling". When there are several secondary windings, a load variation on one of them is transmitted to other windings in a relatively strong manner. A blocking converter is much easier to control in this respect.

Using the Siemens application note (2), the mutually-coupled storage chokes of the secondary rectifier can be improved in order to combat this effect. In spite of this, it was necessary to include a series-pass linear regulator in the 5 V output line to prevent interaction between the two outputs – this was also necessary in (3). A MOSFET was used for the series-pass element, this reducing the PD loss to 0.2 V which represents a minimal power loss. The block diagram of the converter is shown in **fig. 1**.

2. THE CONVERTER CIRCUIT DETAILS

The detailed circuit diagram of the converter is shown in **fig. 2**:

The power stage of the converter consists of the transducer Tr and the two MOSFETs BUZ 10. The input voltage is taken via a current measuring circuit and a low-pass filter to the centre-tap of the transducer primary winding. The low-pass filter comprises a ring-cored choke of 220 μH and a 470 μF electrolytic and is included to prevent the contamination of the input supply line with switching frequency impulses and also to inhibit the introduction of pulsating DC when the battery is being charged by the car motor charging system.

The entire control circuitry is encapsulated in the SG 3525 integrated circuit with the exception of the oscillator frequency-determining components which are external, and connected via pins 5, 6 and 7. The oscillator is pulse-width modulated and controls the switching MOSFETs via an internal driver and pins 11 and 14. The 12 V output voltage is monitored at pin 1 after being suitably attenuated by a preset potentiometer P1 and two auxiliary resistors. Frequency compensation for this is provided by an RC circuit to pin 9. At pin 16, a 5 V reference voltage is available. The slow-start input is applied to pin 8 together with a low-voltage detector which blocks the pulse-width modulator when the input supply voltage falls below 8 V. The supply voltage to the SG 3525 is taken via an LED (which also serves as an "on" indicator) having a PD across it of

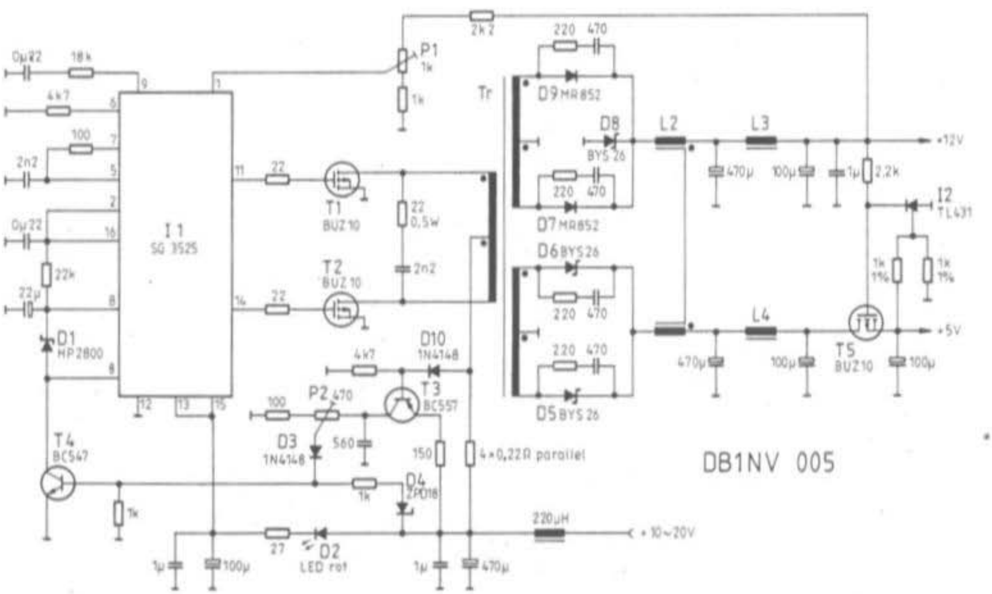


Fig. 2: Converter circuit schematic

2 V. The "low-voltage" threshold is thereby fixed at a 10 volt supply battery potential.

If pin 8 is earthed via the switching transistor T4, the output from the control chip is suppressed. This facility is utilised by the current limiter and over-voltage protection circuits. A current mirror T3 monitors the transducer primary current. If the voltage, as pre-set by P2, is exceeded, T4 is switched and the control chip is effectively switched off. If the supply battery voltage rises above 19 volt, T4 is likewise switched, this time via the 18 V zenner diode and, again, shutting down the converter.

The power transducer Tr has two inter-leaved secondary windings which each supply two full-wave rectifiers. Whilst the 5 V rectifier is equipped with a Schottky diode BYS 26, ordinary fast-switching diodes MR 852 are used in the 12 volt section owing to the high-voltage breakdown (70 V) requirements in this circuit. If high-voltage Schottky-diodes, such as the BYS 26-90, could be employed, an increase in efficiency would result.

Both rectifiers work into a two-stage filter circuit with choke input – both chokes being wound on a common CC 36 core with air-gap (A^L = 250). This mutual coupling of magnetic fields in the storage chokes improves the cross regulation considerably.

The second part of the filter chain comprises a rod-cored choke and a further electrolytic, by means of which, the switching frequency ripple is reduced to the order of a few millivolts. The residual value of the ripple is determined by the so-called ESR (equivalent series resistance) which is the HF internal resistance of the capacitor. This, of course, is dependent upon its quality!

The sample voltage is taken from the 12 volt output. The 5 V output consists of a simple series-regulator MOSFET (T5) and ancillary component I 2 – a variable zenner diode (TL 431). Even with full-lead output, this circuit functions with a minimum of voltage drop across the series MOSFET (about 0.2 V). A three-terminal rectifier would, on the other hand, exhibit a series PD of some 2 to 3 V at the same load current. An additional advantage of this circuit is, that a short-circuit across the 12 V output also results in the 5 V line being shut-down.

3. CONSTRUCTION

In order to facilitate the construction of this project, a printed crcuit board DB 1 NV 005 was developed. The dimensions are 155 x 70 mm and is also plated on the component side. The layout plan is shown in **fig. 3**.

The construction is best commenced with the fabrication of the wound components. The simplest are the two rod-cored chokes for the output circuit. Two rod-cores, type Valvo 4322 020 36810, are wound with 15 turns of 1 mm lacquered copper wire. One of the ends is threaded through the core so that the choke can be mounted upright on the PCB.

The storage choke L2 is wound on an air-gapped core CC 36 (A_L = 250) with two windings of 18 and 35 turns of HF Litz 60 x 0.1 mm. The beginnings and ends are marked so that the ends of the 35 turn winding can be identified and used for the 12 volt output circuit – the 18 winding choke is used in the 5 V portion of the circuit. Note the end polarities when fitting to the board!

The power transducer Tr comprises an ETD 34 core kit without an air-gap. In order to achieve a good winding symmetry, the two halves of the windings are bifilar wound and all the connections, including the centre-taps, are connected in series according to polarity. All windings are carried out with HF Litz wire 60 x 0.1 mm. The primary has 2 x 9 turns, the 12 V side has 2 x 15 turns and the 5 V side 2 x 8 turns. The ends of the HF Litz wire should be carefully stripped of insulation and wired, according to the component plan, to the solder pins on the body of the coil former.

Afterwards, all the components, with the exception of the converter transistors T1 and T2, can be mounted and soldered to the board. It should not be forgotten that power MOSFETs are sensitive to static charges and should be carefully handled in the appropriate manner.

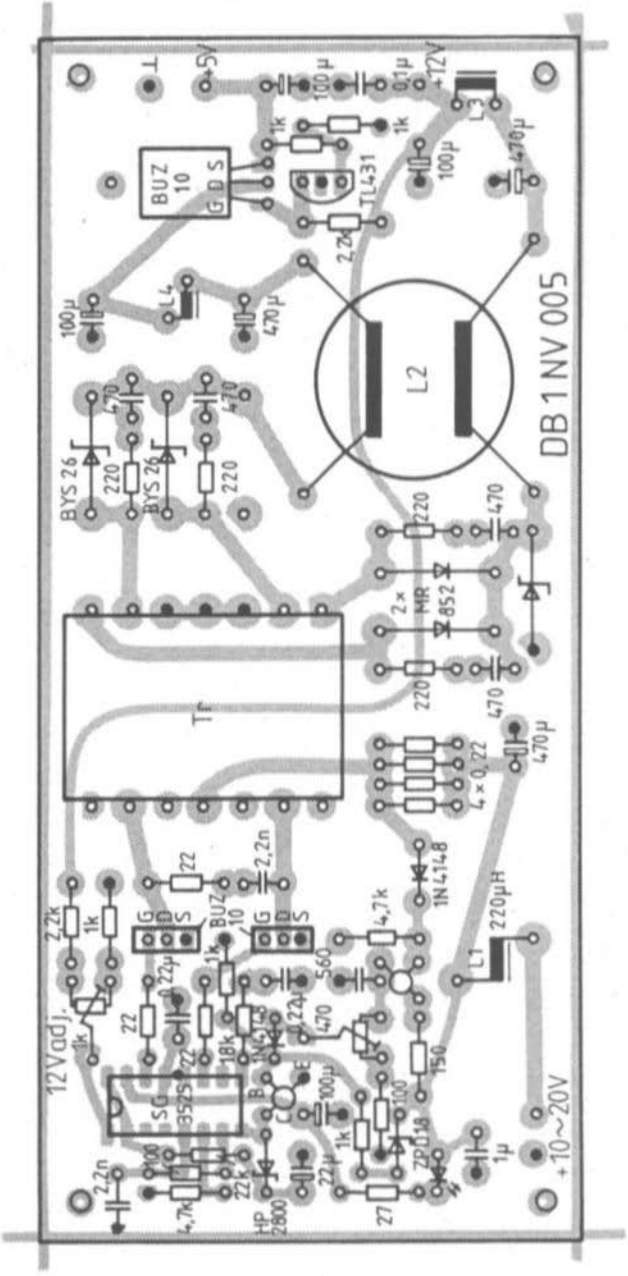


Fig. 3: Converter board component layout plan

3.1. Components

Semi-conductors:

I1:	SG 3525; Silicon General, Motorola, Texas Instruments
I2:	TL 431; Texas Instruments, Motorola
T1, T2, T5:	BUZ 10, BUZ 71; Siemens, Valvo
T3:	BC 557
T4:	BC 547
D1:	HP 2800, 1 N 6263; Hewlett-Packard
D2:	LED red
D3:	1 N 4148, BAW 76
D4:	ZPD 18
D5, D6, D8:	BYS 26 (Schottky diode 3 A/45 V); Siemens
D7, D9:	MR 851, MR 852 (fast diode 3 A/100 V); Motorola

Resistors:
Carbon or metal film RM 10
Preset pot'meter horizontal RM 5/10

Capacitors:
Ceramic and foil types RM 5
Electrolytics: Upright versions

Wound components:
Tnsfr.: Core kit ETD 34 without air-gap, primary 2 x 9 turns, secondary 2 x 8 turns (5 V winding) and 2 x 15 turns (12 V winding), HF Litz 60 x 0.1 mm (see text)

Storage choke: CC 36 Core with air-gap, $A^L = 250$, winding 1 with 35 turns, winding 2 with 18 turns, HF Litz 60 x 0.1 mm, polarity of windings important!

Input choke L1: Ring-core-suppression choke for Triac circuitry, 220 μH/6 A.

Suppression choke L3, L4: 15 turns on Valvo rod core 4322 020 36810 lacquered 1 mm copper wire.

Miscellaneous:
1 heat sink 40 x 40 x 40 x 1.5 mm (angled) aluminium strip for T1 and T2
1 U-formed heat sink 25 x 25 x 18 mm for T5
Insulation washer and mounting material for T1, T2 and T5
Solder pins
1 Brass or plastic screw M 4 x 40 with nut and washer to secure L2.

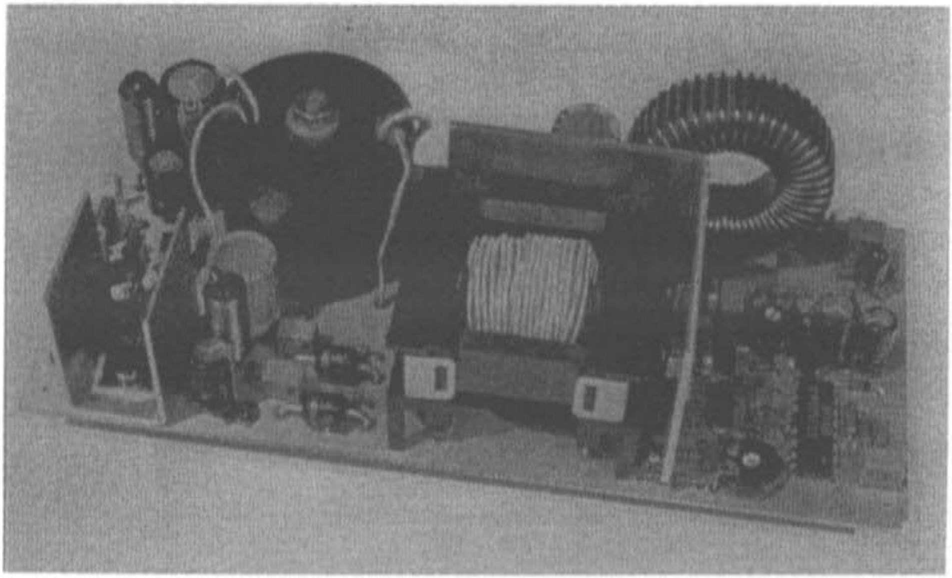
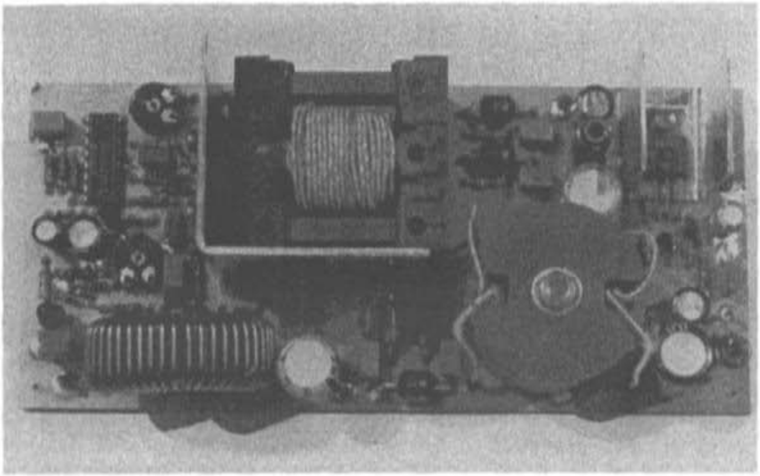


Fig. 4: The completed converter



4. COMMISSIONING

The two preset potentiometers P1 and P2 are first of all turned to their mid-range position and the input connected to a laboratory power supply. At a supply input of 12 V, the input current from the test supply should be about 20 mA.

An oscilloscope is then connected to the MOS-FET gate circuit and an approximately 60 kHz pulse train should be observed with a very nearly 50 % duty cycle and 10 V amplitude. Check that these pulses disappear when the input voltage is lower than about 10 V and also when it is higher than 19 V, thereby checking the over/under-voltage protection circuits.

The transistors T1 and T2 are now soldered into the board and the input voltage set to 12 V. A quiescent current of 30 to 50 mA should result. Adjust P1 for an output voltage of exactly 12 V.

The 5 V portion does'nt need any adjustment, normally, owing to the tight component tolerances of I2 but, if necessary, one of the two 1 kΩ 1 % resistors could be changed. A departure from nominal of more than 0.2 V would indicate a defective component or a circuit fault.

Now, the output can be connected to a load resistance and the regulation checked with both varying load and input voltage. This check must be carried out with a load current of at least 0.2 A at the 12 V output in order that the 5 V output can be loaded fully. The maximum load can be checked and the current-limit threshold set with P2.

The prototype converter is shown in the photographs of **fig. 4**.

5. REFERENCES

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