

Perennial

Our friend the

BATTERY

CHARGING

-by type

-on **USB**

-sealed lead-acid



Winter care

VEHICLE BATTERY JOGGER

hibernation without deterioration

Cyberclocks on USB

programmable
clock generators



Message from Australia

Dear Jan — Congratulations for a well done and well presented restyled Elektor Electronics. I am glad you have done this. It gives our profession and interesting hobby a new life!

At this day and age of ICT (Information and Communication Technology), more and more electronics magazines have dropped out, for example here in Australia we used to have three publications but now we are down to one (Silicon Chip) — when there were Electronics Australia and Electronics International Today).

Similarly in the UK we used to have Radio & Electronics World, Hobby Electronics, Maplin Electronics, Practical Electronics, Everyday Electronics (now known as Everyday Practical Electronics), ETI UK whereas today we are left with Elektor Electronics and Electronics World.

In the USA, we used to have Radio Electronics, Popular Electronics (merged as Poptronics), Electronics Now, Audio Xpress and Nuts & Volts. We are now left with Audio Xpress and Nuts & Volts. Audio Xpress specialises only on audio electronics areas.

There are now more computing magazines than electronics magazines. The fact is, it is easier to learn computing today than yesterday where only professionals could work on them as they were mainly mainframe computers. Today with desktop, laptops, and portable computers and Windows as opposed to MVS life in ICT is easier. On the whole, I hope Elektor will draw young readers in with your restyled look.

Restyled alone is not a winner. Elektor has provided 're-interest' in the field of electronics. Every issue is getting more

exciting. Reading is much more pleasant and topics published are superb! Excellent work from you and your team. For the record I have been subscribing to Elektor since 1974 when you first started. I believe I have every issue of Elektor.

Michael Ong

Like you we do not fail to observe the on-going slimming down of the market for specialist magazines and regret the demise and mergers of so many renowned magazines on electronics. However, we're holding our own and are proud to have been around without failure these past 30 years.

Missed opportunity or future project?

Dear Jan — A while ago I had a go at the USB/RS232 converter item you published (April 2003, Ed.). I gave up at the PCB layout stage, as there were too many via's required under the two small SMT chips — one mounted opposite each other (top and bottom) on PCB. I was going to have another go at the layout, bringing the tracks (and via's) out from under the devices, but have not had the time.

I was interested to see therefore, the approach of Jim Spence in his Swiss Army Knife (September 2004, Ed.), where the interface (USB or RS232) could be changed with a different plug in module. This is an ideal solution to the PC Serial Port Legacy problem. Has Elektor missed an opportunity here? In the original project, the pdf's of the layout were available, but the blank PCB could not be purchased. In this latest project, the USB section is physically part of the entire Swiss Army Knife project.

Why not publish as a project (or just market the pcb's) with the USB interface on it's own? Regarding the PCB, this could be the USB section from the Army Knife project, duplicated 3 or 4 times, to make the pcb production cost worthwhile. I am sure most home engineers would have a need for more than one interface and this pcb would fit the bill, perfectly.

Ian King



An excellent idea which has been copied into our design lab. I'm sure you've noticed that the USB interface for the SAK project does not supply 'real' RS232 levels although that functionality is easily obtained by adding a MAX213 chip.

By the way, regarding the 'original' project (April 2003), any PCB that's not supplied by our Readers Services may be obtained from our business partner 'The PCBShop' (EuroCircuits).



Polyswitch Looking at the components list for the USB UART project (December 2001) I noticed an unfamiliar

description '100 mA polyswitch' to identify R2. I believe a resistance value should be expressed in ohms, and I have no idea what 'polyswitch' means. Can you enlighten me and perhaps tell me where such a device can be bought?

M. van Engelenburg

A polyswitch is a PTC (positive temperature coefficient) resistor. In this case, if the device passes a current exceeding 100 mA it will run hot and as a result increase its resistance abruptly from less than 1 ohm to a value in the kilo-ohms range. In this way the polyswitch acts as a current limiter. Once cooled down, its resistance drops again, allowing the current to rise. If you are unable to obtain a real polyswitch, you may substitute an



ordinary resistor of 1 ohm. Although this will not provide self-restoring protection, it is better than nothing as the resistor will burn out in response to excessive current flow. A 100-mA fuse will also do although it too is a disposable component! Regarding availability, polyswitches are stocked by mail order companies like RS Components and Farnell.

Item Tracer in trouble

When launching my EIT (Elektor Item tracer) software I

was often greeted by 'overflow' errors. After some researching, the problem could be narrowed down to my version of Microsoft Data Access Components (MDAC). Fortunately, Microsoft have a hotfix available, see Q329414 on microsoft.com: support.microsoft.com/default.aspx?scid=kb;en-us;Q329414. The EIT will run fine and no overflow errors pop up if you use MDAC version 2.7.

Reading AT micros

Dear Editor — triggered by your articles I've just started experiments with Atmel microcontrollers. Is it possible to read code from these devices? Programming is no problem for me. I am using the Elektor 89S8252 Flash Micro board. Do I have to use a separate programmer for each controller type?

M. Verwoord

The AT89S8252 can be read out only if the security bits are not programmed. The software we supply is however unable to read the controller contents. To do this, you need a dedicated reader, for example, B. Kainka's 'atmelips.zip', which may be found at <http://b.kainka.bei.t-online.de/basismi.htm> (scroll to bottom of page). Our Multi Programmer on USB (June 2004) handles many different microcontrollers including the 89S8252.

IDE disk on USB

Dear Editor — what do you think of this suggestion: a USB2.0 interface for a portable hard disk! Now that looks like the perfect project for Elektor readers as I'm

sure many will have old IDE hard drives lying around. As I see it, such an interface should not be too hard to design and dedicated chips are probably available.

(a subscriber)

You may have missed that this type of interface is now widely available from computer shops at prices that defeat any attempt at home construction. As to cost, the interface circuit would probably match the value of the old hard disk and conversely it would be just as expensive as a new external USB hard disk. Consequently, such interfaces are typically bought by people regretting to part with dear old hardware.

NiCd batteries — environment vs. quick profits

Dear Editor — today's rechargeable batteries are vastly superior to the old Nickel-Cadmium units of 30-odd years ago. They have several times the charge density, don't suffer the memory problems, and don't contain highly toxic cadmium. Why, then, do so many products still come to market with NiCd cells in them? What possible advantage do they offer to manufacturer or consumer?

Second question: since NiMH cells have the same voltage and at least twice as much current capacity as NiCd, is it safe to replace NiCd cell packs with NiMH units of similar voltage and size? I'd love to extend the life of my cordless screwdriver, phone, shaver, etc.

George Price, Atlanta, Georgia

NiCd batteries still proliferate (also in new consumer electronics) due to commercial forces. You may

have missed that over the past few years the NiCd production process has matured to the extent that impressive capacity (exceeding 2 Ah for AA cells) can be achieved at very low cost. The production of NiCd batteries will be banned soon but considering the vast production capacity (and stocks) of Far Eastern and Chinese battery manufacturers we fear NiCd technology will be around for quite a few years to come. You cannot charge a NiMH cell with a NiCd charger unless it has an adapted end-of-charge detector. See also the article 'ABC of Rechargeable Batteries' in this issue.

Radio articles resource on the web

Good morning Jan, it is many years since we last spoke and I submitted articles to Elektor. I hope that you are well. I have recently set up my own business. One element of this is a website that I have run for a number of years. I have recently given it a major overhaul and I am re-launching it. Its aim is to be a resource of free information, articles and data about radio and electronics.

The URL is www.radio-electronics.com
Ian Poole

Thanks Ian, the word is being passed on.

I-see adapters

Dear Sir — for those of us that are older who enjoy electronics as a hobby and want to use the smaller format of integrated circuit packages.

I am sure that there many of us who would like to obtain adapter PCBs to convert from

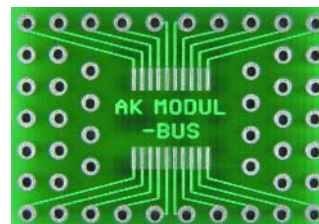
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I have noticed in RadioSpares these cost about £5.00 each.

If you know a source for these useful parts I would appreciate their address.

E. Lea

Thanks for the suggestion which has been copied into our design department. Meanwhile, for ICs in TSSOP or SSOP cases with up to 20 pins have a look at the adapter board sold by AK MODUL BUS, www.ak-modul-bus.de



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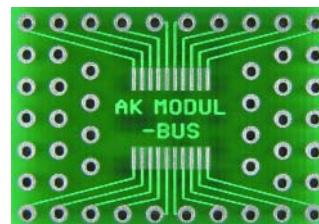
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ABC OF RECHARGEABLE BATTERIES

Basics, pitfalls & recommendations

Gert Helles, Maxim Integrated Products Inc., Hadsten, Denmark

The use of batteries has never been greater. Batteries are becoming smaller and lighter even as they package more and more energy per unit volume. The main driving force for battery development has been the boom in portable equipment such as mobile phones, laptops, camcorders, and MP3 players.

The following brief overview of charging methods and current battery technologies is intended to lend a better understanding of the batteries used in portable devices. It includes discussions of nickel-cadmium (NiCd), nickel-metal-hydride (NiMH) and lithium-ion (Li+) battery chemistries. The article also describes a product for protection of single-cell lithium-ion and lithium-polymer batteries.

Definition of a battery

Calling a battery an energy storage system poses a definition that also includes such things as flywheels and clock springs. In the context of modern technology, however, batteries are usually portable, self-contained chemical systems that produce electrical energy.

Disposable batteries (called non-rechargeable or primary cells) create electricity from a chemical reaction that permanently transforms the cell. Discharging a primary cell leads to a permanent and irreversible change in the cell chemicals. By contrast, rechargeable batteries, also called secondary cells, can be recharged by a charger after having been discharged by the application.

The charge or discharge current is usually expressed (in ampères) as a multiple of the rated capacity (called the C-rate). For example, a C/10 discharge current for a battery rated at one ampère-hour (1 Ah) is $1 \text{ Ah}/10 = 100 \text{ mA}$. The rated capacity of a cell or battery (in Ah or mAh) is the amount of electricity that it can store (produce) when fully charged under specified conditions. Thus, the total energy of a battery is its capacity multiplied by its voltage, resulting in a measurement of watt-hours.

Defining battery performance

The chemistry and the design of a battery cell together limit the current it can source. Barring the practical factors that limit performance, a battery could produce an infinite current, if only briefly. The main impediments to

infinite current are the basic reaction rates of the chemicals, the cell design, and the area over which the reaction takes place. Some cells are inherently able to produce high currents. Shorting a nickel-cadmium cell, for instance, produces currents high enough to melt metals and start fires. Other batteries can produce only weak currents.

The net effect of all chemical and mechanical factors in a battery can be expressed as a single mathematical factor called the equivalent internal resistance. Lowering the internal resistance enables higher currents.

No battery stores energy forever. Unavoidably, the cell chemicals react and slowly degrade, causing degradation in charge stored by the battery. The ratio of battery capacity to weight (or size) is called the battery's storage density. High storage density enables the storage of more energy in a cell of given size or weight.

Table 1 lists nominal voltage and storage density (expressed in watt-hours per kilogram of weight, or Wh/kg) for the major chemistries used in storage batteries for personal computers and cell phones: **Table 2** contains quick comparison data to enable designers to choose the best cell type for a particular application (note that NiCd will be banned soon).

So why not always choose secondary cells, if primary and secondary cells fulfil the same purpose? Secondary cells have drawbacks:

- All practical secondary cells lose their electrical charge relatively quickly, through self discharge.
- Secondary cells must be charged before use.
- Secondary batteries supply less energy at the same volume and weight.

Charging batteries

A new rechargeable battery or battery pack (several batteries in one package) is not guaranteed to be fully

CHARGEABLE BATTERIES

charged; in fact, it is likely to be nearly discharged. The first thing to do, therefore, is to charge the battery/pack in accordance with the manufacturer's chemistry-dependent guidelines.

Every charging operation applies voltage and current in a sequence that depends on the battery chemistry. Thus, a look at battery-cell chemistries reveals different requirements to be met by the charger and the charging algorithm. The terms most commonly found in battery charging are constant current (CC), used for NiCd and NiMH cells, and constant current/constant voltage (CC/CV), applied to lithium-ion and lithium-polymer cells (**Figures 1-6**). **Table 3** summarizes today's most frequently used charging techniques and the associated parameters per cell type. The methods to determine the very important 'end of charge' moment are listed separately in **Table 4**.

Charging nickel-cadmium cells

NiCd cells are charged by applying a constant current in the range 0.05 C to more than 1 C. Some low-cost chargers terminate the charge by means of absolute temperature. Though simple and inexpensive, that method of charge termination is not accurate. A better choice is to terminate charging when the condition of full charge is indicated by a drop in voltage. The $-\Delta V$ phenomenon is most useful for charging NiCd cells at 0.5 C or greater. The $-\Delta V$ end-of-charge detection should be combined with battery-temperature measurement as well, because aging cells and mismatched cells can reduce the voltage delta.

You can achieve a more precise full-charge detection by sensing the rate of temperature increase (dT/dt), and that method of charge detection is kinder to the battery than is a fixed-temperature cut-off. Charge termination based on a combination of $\Delta T/dt$ and $-\Delta V$ cut-off enables a longer life cycle by avoiding overcharge.

Fast charging improves charge efficiency. At 1 C, the efficiency is close to 1.1 (91%), and the charge time for an empty pack will be slightly more than one hour. When applying a 0.1 C charge, the efficiency drops to 1.4 (71%) with a charge time of about 14 hours.

Because the charge acceptance of a NiCd battery is close to 100%, almost all energy is absorbed during the initial 70% of charging, and the battery remains cool. Ultra-fast chargers use this phenomenon to charge a battery to the 70 percent level within minutes, applying currents equal to several times the C-rating without heat build-up. Above 70% the charging continues at a lower rate until the battery is fully charged. Eventually, you top off the battery by applying a trickle charge in the range 0.02 C to 0.1 C.

Charging nickel-metal-hydride cells

Though similar to NiCd chargers, an NiMH charger employs the $\Delta T/dt$ method, which is by far the best

Table 1. Storage density values.

Cell type	Nominal voltage	Storage density (typ.)
Lead Acid	2.1 volts	30 Wh/kg
Nickel Cadmium	1.2 volts	40 to 60 Wh/kg
Nickel Metal Hydride	1.2 volts	60 to 80 Wh/kg
Circular Lithium Ion	3.6 volts	90 to 100 Wh/kg
Prismatic Lithium Ion	3.6 volts	100 to 110 Wh/kg
Polymer Lithium Ion	3.6 volts	130 to 150 Wh/kg

Table 2. Quick comparison chart.

Attribute	Nickel Cadmium	Nickel Metal Hydride	Lithium-Ion
Energy Density	Low	Medium	High
Energy Storage	Low	Medium	Medium
Cycle Life	High	High	High
Cost	Low	Medium	High
Safety	High	High	Medium
Environment	Low	Medium	Medium

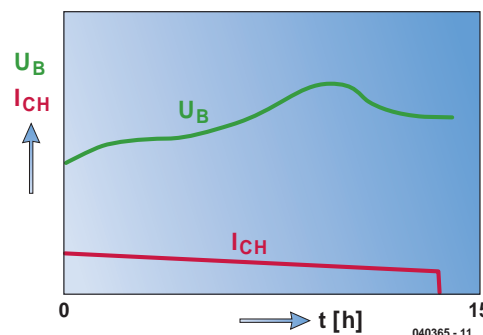


Figure 1. Semi-constant current charging — chiefly used in applications like shavers, cordless phones and toys.

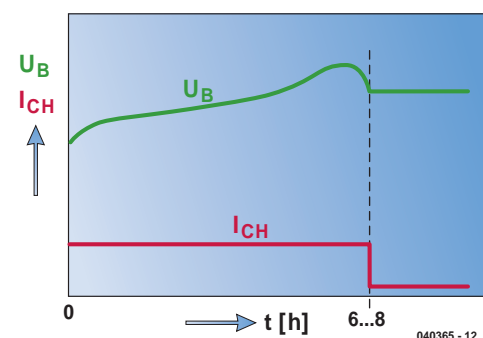


Figure 2. Timer-controlled charging is used mainly in applications like notebooks, data terminals, wireless equipment and cellular phones.

Table 3. Battery charging methods.

Chemistry	Charging Method	Feature	# of terminals	Charge time	Charge Current	Trickle Current	Charge level at End of charge	Figure
Nickel based (NiCd & NiMH)	Semi-constant current charging.	Most typical system Simple and low cost.	2	15 Hours	0.1 C mA	—	—	1
	Timer Controlled charging	More reliable than semi-constant current system. Relatively simple and low-cost	2	6-8 hours	0.2 C mA	1/20-1/30 C mA	Approx. 120%	2
	-ΔV cut-off charging	Most popular More complex	2	1-2 hours	0.5-1 C mA	1/20-1/30 C mA	Approx. 110-120%	3
	DT/dt cut-off charging	More costly but over-charging can be avoided enabling longer life cycle than the others	3 or 4	1-2 hours	> 1 C mA	1/20-1/30 C mA	Approx. 100-110%	4
	Trickle charging	Simple and low cost Applicable for continuous charging	2	15 hours	0.1 C mA	—	—	5
Lithium based	Constant Current – Constant Voltage (CCCV)	Not recommended for the main charge control system for NiCd /NiMH batteries. Prevailing charge method for Li-ion and Li Polymer Relatively complex charger design	2	1-3 Hours	1C mA	—	Approx. 100%	6

method for charging NiMH cells. The end-of-charge voltage decrease for NiMH batteries is smaller, and for small charge rates (below 0.5 C, depending on temperature) there may be no voltage decrease at all.

New NiMH batteries can show false peaks early in the charge cycle, causing the charger to terminate prematurely. Moreover, an end-of-charge termination by -ΔV

detection alone almost certainly ensures an overcharge, which in turn limits the number of charge/discharge cycles possible before the battery fails.

It seems there is no available -dV/dt algorithm that works well for charging NiMH batteries under all conditions: new or old, hot or cold, and fully or partly discharged. For that reason, don't charge a NiMH battery with a NiCad charger unless it utilizes the dT/dt method for end-of-charge termination. And because NiMH cells do not absorb overcharge well, the trickle charge must be lower (about 0.05 C) than that recommended for NiCd cells.

Table 4. End-of-charge detection.

Chemistry	NiCd	NiMH	Li+
Charging	Constant current	Constant current	Constant current / constant Voltage
Full charge detect	-ΔV/dt and/or ΔT/dt	ΔV/dt = 0 and/or ΔT/dt	I _{charge} = eg 0.03C and/or time

Slow-charging a NiMH battery is difficult if not impossible, because the voltage and temperature profiles associated with a C-rate of 0.1 C to 0.3 C do not provide a sufficiently accurate and unambiguous indication of the full-charge state. The slow charger must therefore rely on a timer to indicate when the charge cycle should be terminated. Thus, to fully charge a NiMH battery you should apply a rapid charge of approximately 1 C (or a rate specified by the battery manufacturer), while monitoring both voltage (ΔV=0)

and temperature (dT/dt) to determine when the charge should be terminated.

Charging lithium-ion and lithium-polymer cells

Whereas chargers for nickel-based batteries are current-limiting devices, chargers for lithium-ion batteries limit both voltage and current. The first lithium-ion cells called for a charge-voltage limit of 4.10 V/cell. Higher voltage means greater capacity, and cell voltages as high as 4.2 V have been achieved by adding chemical additives. Modern Li-ion cells are typically charged to 4.20 V with a tolerance of ± 0.05 V/cell.

Full charge is achieved after the terminal voltage has reached the voltage threshold and the charging current has dropped below 0.03 C, which is approximately 3% of I_{charge} (Figure 6). The time for most chargers to achieve a full charge is about three hours, though some linear chargers claim to charge a Li+ battery in about one hour. Such chargers usually terminate the charge when the battery's terminal voltage reaches 4.2 V. That kind of charge determination, however, charges the battery only to 70% of its capacity.

A higher charging current does not shorten the charge time by much. Higher current lets you reach the voltage peak earlier, but then the topping charge takes longer. As a rule of thumb, the topping charge will take twice as long as the initial charge.

Protection modes

Overvoltage: If the cell voltage sensed at V_{DD} exceeds the overvoltage threshold V_{OV} for a period longer than the overvoltage delay t_{OVD} , the DS2720 shuts off the external charge FET and sets the OV flag in the protection register. The discharge path remains open during overvoltage. The charge FET is re-enabled (unless blocked by another protection condition) when the cell voltage falls below the charge-enable threshold V_{CE} , or discharging causes $V_{\text{DD}} - V_{\text{PLS}} > V_{\text{OC}}$.

Undervoltage. If the cell voltage sensed at V_{DD} drops below the undervoltage threshold V_{UV} for a period longer than the undervoltage delay t_{UVD} , the DS2720 (see inset) shuts off the charge and discharge FETs, sets the UV flag in the protection register, and enters sleep mode. After the cell voltage rises above V_{UV} and a charger is present, the IC turns on the charge and discharge FETs.

Short Circuit. If the cell voltage sensed at V_{DD} drops below the depletion threshold V_{SC} for a period of t_{SCD} , the DS2720 shuts off the charge and discharge FETs and sets the DOC flag in the protection register. The current path through the charge and discharge FETs is not re-established until the voltage on PLS rises above $V_{\text{DD}} - V_{\text{OC}}$. The DS2720 provides a test current through internal resistor R_{TST} (from V_{DD} to PLS) to pull up PLS when V_{DD} rises above V_{SC} . This test current allows the DS2720 to detect removal of the offending low-impedance load. In addition, it enables a recovery charge path

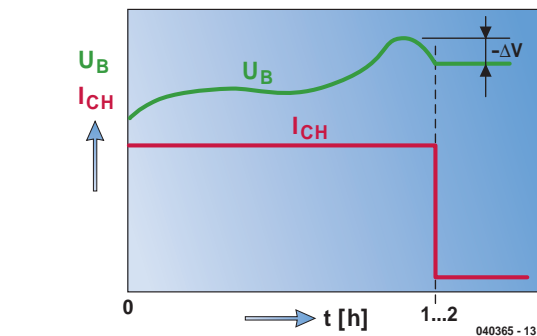


Figure 3. Charging is terminated via $-\Delta V$ cut-off in applications like notebooks, data terminals, cam-corders, wireless equipment, and cellular phones.

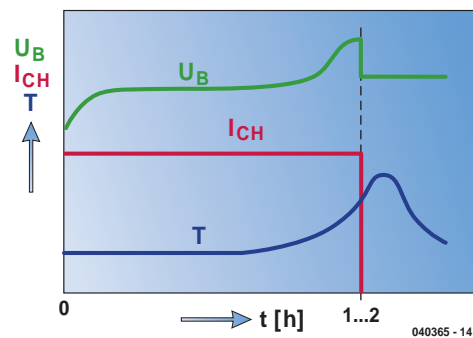


Figure 4. Charging is terminated via $-dT/dt$ cut-off in applications like power tools and electric tools.

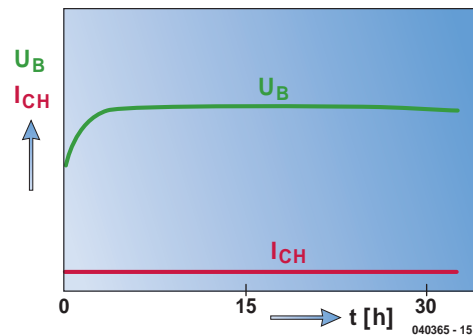


Figure 5. Trickle charging is mainly used in applications like emergency lights, guide lights, and memory backup.

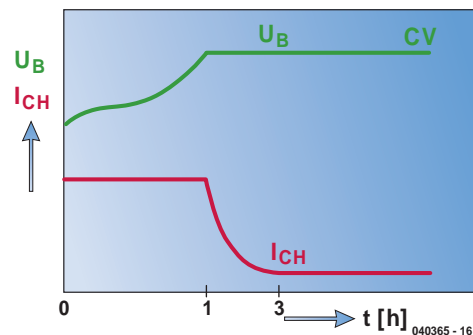


Figure 6. Constant-current, constant-voltage charging is used in applications like cellular phones, wireless equipment and Notebook PCs.

through R_{TST} from PLS to V_{DD} .

Overcurrent: If voltage across the protection FETs ($V_{\text{DD}} - V_{\text{PLS}}$) is greater than V_{OC} for a period longer than t_{OCD} , the DS2720 shuts off the external charge and discharge FETs and sets the DOC flag in the protection register. The current path is not re-established until

the voltage on PLS rises above $V_{DD}-V_{OC}$. The DS2720 provides a test current through internal resistor R_{TST} (from V_{DD} to PLS) to detect removal of the offending low-impedance load.

Overtemperature. If the DS2720 temperature exceeds T_{MAX} , the device immediately shuts off the external charge and discharge FETs. The FETs are not turned back on until two conditions are met: cell temperature drops below T_{MAX} , and the host resets the OT bit.

Charging at high and low temperatures. Efforts should be made to charge at room temperature. Nickel-based batteries should only be fast-charged between 10°C to 30°C (50°F to 86°F). Below 5°C (41°F) and above 45°C (113°F), the charge acceptance of nickel-based batteries is drastically reduced. Li-ion batteries offer reasonably good charge performance through-

out the temperature range, but below 5°C (41°F) the charge rate should be less than 1 C.

Conclusion

NiMH chargers can accommodate NiCd batteries, but not the other way around. Chargers dedicated to NiCd batteries will overcharge a NiMH battery. The cycle life and performance of nickel-based batteries are enhanced by fast charging because it reduces the memory effect due to formation of internal crystals. Nickel- and lithium-based batteries call for different charge algorithms. Li+ batteries need protection circuitry to monitor and protect against overcurrent, short circuits, over- and under-voltage, and excessive temperature. Remember to remove a battery from its charger when the battery is not used regularly, and apply a topping-charge before use.

(040365-1)

Lithium-ion safety — meet the DS2720

Because overcharging (or overdischarging) a Li-ion cell can cause it to explode and injure people, safety is a major concern in handling this type of storage cell. As a result, commercial Li-ion battery packs contain a protection circuit such as the DS2720

(Figure A), which provides all electronic safety functions required for applications involving rechargeable Li+ batteries: protecting the battery during charge, protecting the circuit against excess current flow, and maximizing battery life by limiting the level of cell depletion.

DS2720 ICs control the conduction paths for charge and discharge currents with external switching devices such as low-cost n-channel power MOSFETs. The IC's internal 9-V charge pump provides high-side drive to the external n-channel MOSFETs, yielding lower on-resistances than do the same FETs operating in a more common low-side protection circuit. FET on-resistance actually decreases as the battery discharges (Figure B).

The DS2720 lets you control the external FETs from the data interface or from a dedicated input, thereby eliminating the redundant power-switch controls otherwise required in a rechargeable Li+ battery system. Through its 1-wire interface, a DS2720 provides the host system with read/write access to the status and control registers, instrumentation registers, and general-purpose data storage. A factory-programmed 64-bit net address allows each device to be individually addressed by the host system.

The DS2720 provides two types of user memory for battery-information storage, EEPROM and lockable EEPROM. EEPROM is a true non-volatile (NV) memory whose contents (important battery data) remain unaffected by severe battery depletion, accidental shorts, or ESD events. When locked, a lockable EEPROM becomes a read-only memory (ROM) that provides additional security for unchanging battery data.

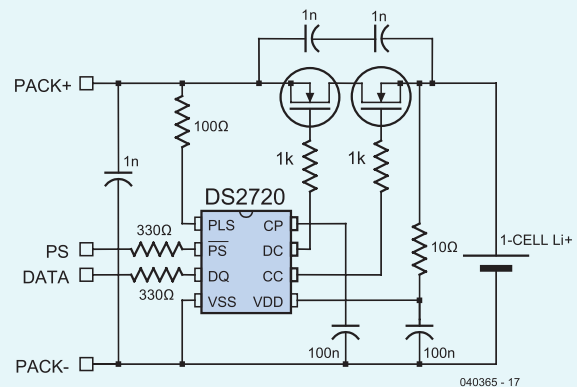


Figure A. Typical application diagram for the DS2720 lithium-cell protection IC.

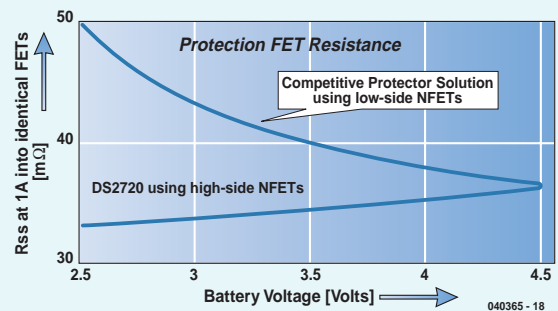


Figure B. The resistance of protection FETs controlled by the DS2720 ('high-side mode') is lower than FETs operating in the traditional low-side mode. FET resistance-controlled by the DS2720 actually drops with battery voltage.

VEHICLE BATTERY



Karel Walraven

This design is a follow-up to the triumphant 'Battery Revitaliser' project published in the September 2001 issue of *Elector Electronics*. From numerous reader responses, it appears that defective batteries are a common problem. Since prevention is naturally better than cure, here we present a circuit that can keep your battery in shape in a simple but effective manner.

JOGGER

keep your battery fresh and young

The quality of lead-acid storage batteries has always been an awkward subject. Motorcyclists among our readers will be the first to agree with this. The most common example is a motorcycle that's put in storage for the winter and proves to have battery problems when spring comes. This involves more than just the fact that the battery has become partially discharged, since in many cases the battery has also noticeably deteriorated. That can be seen from the fact that even immediately after being charged, it performs poorly and quickly loses its charge.

This is also true for all situations in which lead-acid batteries are not used for an extended length of time. You might immediately think of cars 'put away' for the winter, but this problem also occurs in other situations, such as batteries in backup power supplies (UPSs) that are not used for a while, batteries used with voltage inverters (in caravans), and batteries in pleasure boats that simply sit around doing nothing for most of the year after the boating season is over. It's thus easy to think of situations in which lead-acid batteries age prematurely due to lack of use. The inset provides additional information about the background of the process responsible for all of this, which is called 'sulphation'.

Idleness is deadly

For the purpose of this article, it's actually not necessary to know exactly why unused batteries deteriorate. It's sufficient to note that a bit of exercise at the right time can help keep them in shape. And that's what the circuit described here provides.

Unlike the 'Battery Revitaliser' described in the September 2001 issue of *Elektor Electronics*, this design is not intended to resuscitate apparently defective batteries, but instead to prevent premature aging due to lack of use. To avoid possible misunderstandings, it should be noted that this circuit cannot counteract normal aging or other conditions that can lead to defects.

As the whole idea is to keep the bat-

tery a little bit active, the circuit does not require a separate power supply. The necessary energy is simply taken directly from the battery itself. In the process, sulphation is prevented by loading the battery with a hefty current (40 A) for a short interval (50 μ s) approximately every two minutes. Of course, this will ultimately cause the battery to discharge more quickly, but a fully charged car or motorcycle battery will easily make it through the winter. After all, the current consumption at 12 V is only around 2 mA.

Operation

The first 555 timer (IC1 in **Figure 1**) operates as an astable multivibrator and generates a continuous stream of pulses. The second 555 is a monostable multivibrator that is triggered on each negative edge of the pulses coming from its companion. As a result, it generates short pulses that drive power FET T1 fully on. The FET connects the battery directly to a power resistor, causing a heavy current to flow. The size of this current is primarily determined by the value of resistor R8.

The FET is intentionally driven here via a gate stopper resistor with a relatively high value. This causes it to switch on and off somewhat more slowly, which reduces the amount of interference generated. In this case, 'slow' means a few microseconds; a FET that's driven hard switches within a few nanoseconds. Here it isn't necessary to switch quickly, and there's no need to be concerned about a bit of extra power dissipation. Despite the relatively slow switching, rather large voltage spikes can occur when the FET switches off. It is thus essential to connect a **fast** Zener diode (D5) across the FET for protection.

Construction

It's important to ensure that the ICs and IC sockets are fitted with the correct orientation. The sockets usually have a notched or bevelled corner, and the ICs have a dimple in the package. As seen

from above, the topmost pin to the left of this marking is pin 1. It's best to use CMOS versions of the ICs, since this will keep the standby current consumption as low as possible. Several different manufacturers make the CMOS version of the 555, so type numbers such as TLC555, ICM7555 and LMC555 (as well as many others) all refer to the same kind of IC. However, the NE555, SE555 and LM555 are not CMOS types. They can also be used, but the current consumption will then be quite a bit higher (more than 10 mA).

Most of the current is actually used by the LED, so you should use a low-current type here (also referred to as a '2-mA LED'). When fitting it to the circuit board, make sure the long lead goes next to the triangle marking.

The capacitors in the circuit (except for the electrolytic capacitors) are ceramic types. That's because component value tolerance is not terribly important in this case, and a bit of temperature dependence also doesn't particularly matter.

New electrolytic capacitors also have one lead that's longer than the other one. That's usually the positive lead. On the circuit board, it must be placed next to the open rectangle. There's usually also a white stripe with minus (-) signs printed on the case of the capacitor. This marks the negative lead, which is indicated on the circuit board by a solid rectangle (the open rectangle is the + terminal).

Safety

Most people don't realise that despite the modest voltage, working with vehicle batteries can be quite hazardous. This is because such batteries can deliver especially high currents. That means you have to be especially careful with metal objects in the vicinity of a charged battery. A dangerous short circuit can be caused not only by a simple screwdriver or wrench, but also by dangling jewellery and wrist-watches, both of which are notorious causes of avoidable suffering.

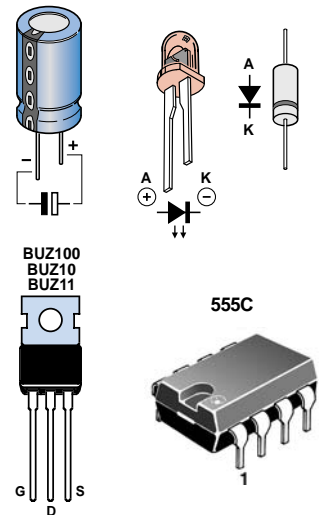
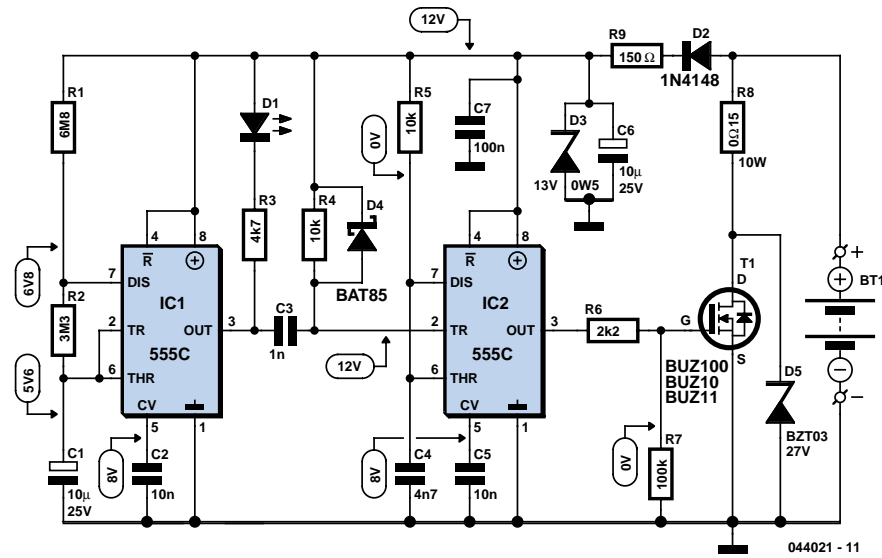
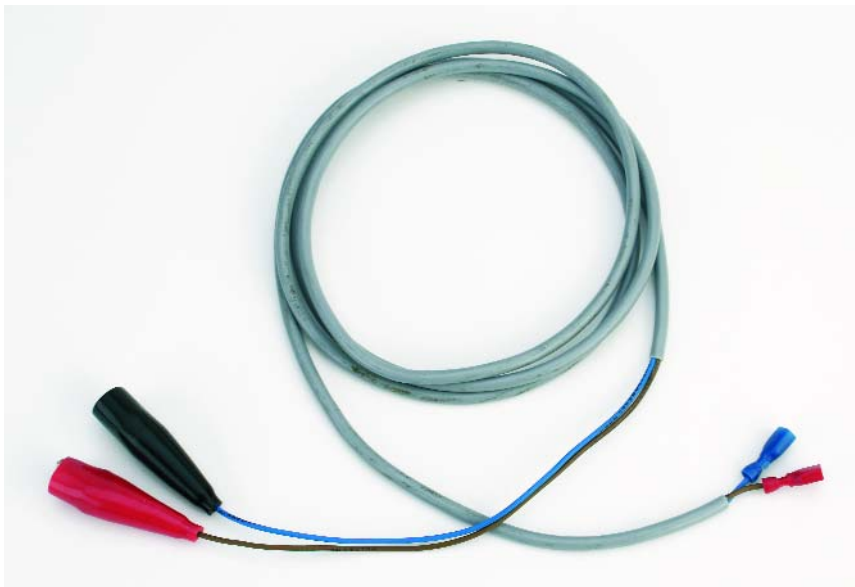


Figure 1. The general-purpose 555 once again proves its merits.



Prevent short circuits; make sure you use a properly insulated cord!

If something goes wrong with the circuit, there's thus an especially good chance that something will be destroyed. Normally, the victim will be the power resistor, the FET (see the inset) or a track on the circuit board. It's certainly possible for this to be accompanied by the release of heat, or even a bang and a bit of smoke. Consequently, you should always fit the circuit in an enclosure and ensure that no flammable materials are in the vicinity. Disconnect the circuit before charging the battery in the usual manner. Use flexible mains cable with a reasonably large cross-section ($2 \times 0.75 \text{ mm}^2$, for example) for the connections to the battery.

Everything OK?

For initial testing, we recommend leaving C1 off the circuit board and tem-

Figure 2. The circuit can be safely built using this printed circuit board design. Copper track layout available from our website.

COMPONENTS LIST

Resistors:

- R1 = $6\text{M}\Omega$
- R2 = $3\text{M}\Omega$
- R3 = $4\text{k}\Omega$
- R4, R5 = $10\text{k}\Omega$
- R6 = $2\text{k}\Omega$
- R7 = $100\text{k}\Omega$
- R8 = 0Ω 1.5, 5W or 10W
- R9 = 150Ω

Capacitors:

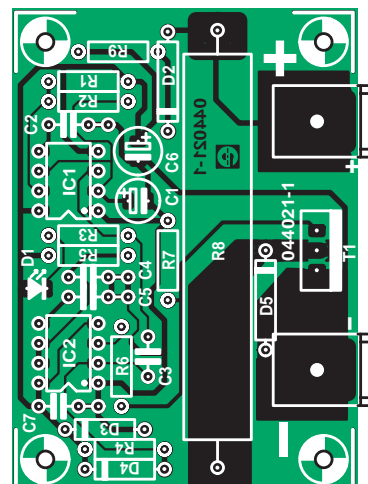
- C1, C6 = $10\mu\text{F}$ 25V, radial
- C2, C5 = 10nF

- C3 = 1nF
- C4 = 4nF
- C7 = 100nF

Semiconductors:

- D1 = LED, low current
- D2 = 1N4148
- D3 = zener diode, 13V 0.5W
- D4 = Schottky diode, e.g., BAT43, BAT85
- D5 = fast zener diode, e.g., BZT03 24V, 27V or 33V
- T1 = BUZ10, BUZ11, BUZ100 or IRF540

IC1, IC2 = 7555 (CMOS)
 PCB, ready-made, order code **044021-1** (see Readers Services page). PCB layout available from Free Downloads section on www.elektor-electronics.co.uk



FETs

We have listed several options for FET T1, but the choice here is not critical. It's also unnecessary to make any changes to the circuit if you use it at 6 V. Still, in this case the preferred type for T1 is the IRF540. That's because this type of FET works with a lower gate voltage than the FETs in the BUZ family. For the same reason, FETs designated as 'logic-level FETs' are more suitable if you want to use the circuit at 6V, but they aren't essential. In principle, you can thus use any desired type of n-channel power FET that can handle at least 20 A at 50 V.

You're probably wondering how a FET rated at 20 A can handle a current of 40 A or more. To understand why this is possible, have a look at the 'Safe Operating Area' chart for the BUZ10 (**Figure 3**). It shows how much current can flow continuously (20 A), and how much current can flow for a short time. As the FET only conducts for a few tens of microseconds each time, the maximum allowable current during this short interval is just under 100 A. This information can also be obtained from the 'Absolute Maximum Ratings' in the date sheet, which specify 23 A and 92 A respectively.

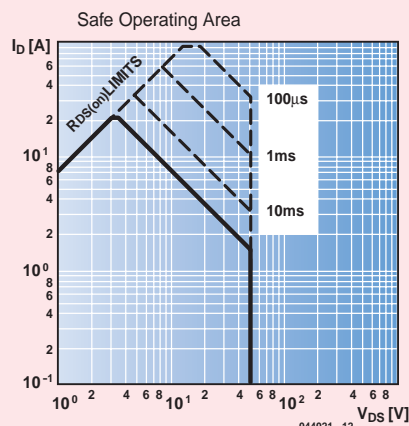


Figure 3. Safe Operating Area: maximum currents and voltages for the BUZ10.

porarily soldering a 100-nF capacitor to the board in its place. The LED should then flash approximately once a second. With a 10- μ F capacitor fitted in this position, the period is a lot longer (2 to 3 minutes), and that's not so nice for testing. If the lamp blinks, you can confidently solder the 10- μ F capacitor in place on the circuit board.

Voltages are marked at various places on the schematic diagram. If the circuit does not immediately work the way it should, you can compare your circuit with our tried & tested prototype by measuring these voltages. Here we should note that if you make measurements on pin 2, 6 or 7 of IC1, proper operation of IC1 will temporarily be disturbed, and you may have to wait a little while for the reading to stabilise. The stated values were measured using an electronic multimeter (10 M Ω impedance).

Six volts too

Many old-timers (vintage cars and motorcycles) use 6-volt batteries. Strictly speaking, this voltage is usually a bit on the low side for switching a

CAR AND DEEP CYCLE BATTERY FAQ

Car and Deep Cycle battery answers to Frequently Asked Questions (FAQs), tips, information, references and hyperlinks are contained on this free consumer oriented Web site about car, motorcycle, power sports, truck, boat, marine, RV (recreational vehicle), and other starting and deep cycle applications.

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You can learn a lot more about lead-acid batteries and the dreaded sulphation process (among other things) at www.uuhome.de/william.darden/.

FET fully on. As a result, in practice the current through T1 will be a bit smaller, but it will still be sufficient to ensure obtaining the proper effect (keeping the battery fresh). It's thus

not necessary to reduce the value of R8, since the circuit is designed to be used with 6-volt and 12-volt batteries without any modifications.

Sulphation

The capacity of a lead-acid battery gradually decreases during its service life due to normal wear and tear, for a variety of reasons. However, the aging process is considerably accelerated if an uncharged battery is stored for longer than a week at a temperature below 10 °C or remains unused (while charged) for an extended length of time. That's because in such situations, a layer of non-conductive lead sulphate (PbSO₄) forms on and around the electrodes. This reduces the effective surface area of the electrodes, thus decreasing the capacity of the battery. This process is difficult or impossible to reverse by normal charging and discharging.

However, it is possible to break down sulphate crystals into lead and sulphuric acid by using high (or very high) charging currents. This method can be used to restore at least part of the lost capacity (see 'Lead-acid battery revitaliser' in the September 2001 issue). Still, it's better to prevent the formation of sulphate. One way to do this is to periodically apply a load to the idle battery. The circuit described in this article is especially suitable for this purpose.

SEALED LEAD-A

SLAs still going strong



Lead-acid batteries still form an essential part of the on-board power systems in cars, motorcycles, boats and caravans. In its new form, featuring a fixed electrolyte and a sealed enclosure, this veteran battery technology (invented in 1850!) is now more versatile than ever.

Sealed batteries with a fixed electrolyte have been in production for more than forty years. The electrolyte (dilute sulphuric acid) is fixed either using silica gel (lead-gel, or 'dryfit' battery) or using a glass fibre mat (AGM or 'absorbed glass mat' technology). This allows the oxygen produced at the positive electrode when the battery is overcharged to diffuse to the negative plate where it can recombine into water. This cycle of recombination makes the battery emit practically nothing in the way of gases, and so it can be built into a sealed enclosure. To prevent rupture in the event of the pressure getting too high, the cells (as in almost every sealed battery) are equipped with self-closing safety valves. The combination of fixed electrolyte and a sealed enclosure allows operation in any orientation (although AGM batteries must not be charged upside-down). The most important advantages

of sealed lead-acid batteries, besides their low price, are their low self discharge, simple charging method, and long life, especially when continuously charged.

Although the basic principles of operation of the sealed lead-acid battery have not changed, steady development over the years has led to significantly better battery characteristics:

- Improved behaviour when overcharged
- Relatively low sensitivity to deep discharge
- Improved life
- Higher specific capacity
- Improved cycle life
- Quicker charging
- Improved current output

CID BATTERIES

Manufacturers such as Yuasa, Panasonic and Sonnenschein/Exide offer various ranges of batteries optimised for one (or more) different applications. So, for example, there are batteries available optimised for long life designed to last for 20 years and 1500 cycles. The most important application areas today are emergency power supplies of various types (for example for alarm systems, IT equipment, lighting, and medical devices), electric vehicles (such as golf buggies and wheelchairs), electric starter motors, on-board power supplies in boats, caravans and gliders, and, last but not least, solar power systems that are independent of the mains.

Voltage, current and capacity

The state of charge of a lead-acid battery can be determined by measuring its no-load voltage. **Figure 1** shows typical values for sealed 6 V and 12 V batteries. The figure also indicates the accuracy that can be expected using this measurement: the voltage varies from around 2.2 V for a fully-charged cell to 1.9 V for a discharged cell. These values are valid at room temperature (20 °C). If the battery has recently been charged or discharged, the values are respectively higher and lower. The usable capacity C of a sealed lead-acid battery, measured in amp-hours (Ah), depends to a great extent on the discharge current. The lower the discharge current, the lower the losses during discharge, and so the higher the usable capacity. For this reason, the discharge current is generally quoted in CA, giving the current as a fraction of the nominal capacity C . For example, a capacity C specified at $C/10$ (or 0.1 CA) for a 1 Ah battery means that the capacity given is valid for a discharge current of 0.1 A (100 mA). In this case the capacity may also be written as C_{10} (capacity for 10-hour discharge). Nominal capacities of lead-acid batteries quoted according to the German DIN standard are given for a 20-hour discharge (i.e., at 0.05 CA) and with a final discharge voltage of 1.75 V per cell.

Charging

In principle sealed lead-acid batteries can be charged at a constant voltage. The maximum charge voltage that can be used depends on the temperature, and it is important that this voltage is not exceeded during charging. **Figure 2** shows the relationship between temperature and voltage for two different charging regimes. The higher value is used for normal (cyclical) operation, while the lower value is for when the battery is trickle-charged to maintain its condition over a long period. In standby operation a voltage that is even only slightly too high will have a negative impact on the life of the battery, and so if the operating temperature will not be constant a temperature-compensated charging circuit is essential. What can happen if the charge voltage is not adjusted to suit the temperature is clearly shown in **Figure 3**.

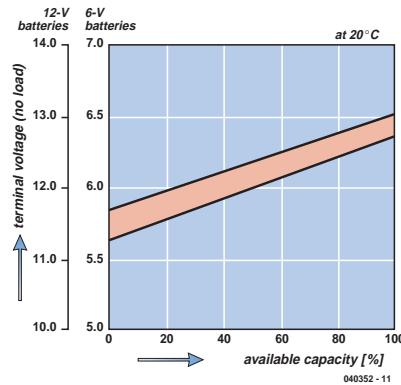


Figure 1. Relationship between measured open-circuit voltage and remaining capacity.

Charging at constant voltage is very simple. Any regulated power supply can be used as long as its output voltage can be set to the correct value. At room temperature (20 °C) a value of 2.45 V (say between 2.4 V and 2.5 V) per cell is suitable for normal cyclical charging; for trickle charging a suitable value is 2.275 V (say between 2.25 V and 2.3 V) per cell. Cells should not be charged for too long at higher voltages. One criterion that can be used to determine when to stop charging is to test when the charge current, which falls continuously during the first few hours of charging, reaches 0.07 CA (or less) and remains unchanged for three further hours. If this test is not used, then time-controlled charging should be limited to a maximum of 16 to 20 hours. The initial charge current is determined by the internal resistance (or, if available, current limiting) of the power supply. Raising the maximum initial current does not reduce the charge time as much as might be expected.

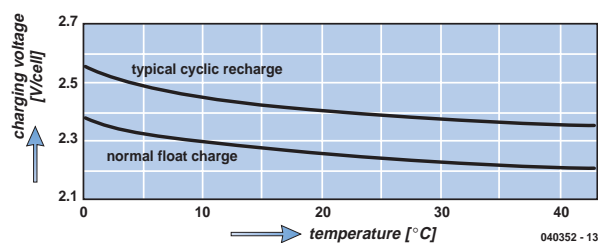


Figure 2. Charge voltage (per cell) in relation to temperature for cyclic charging (above) and trickle charging (below).

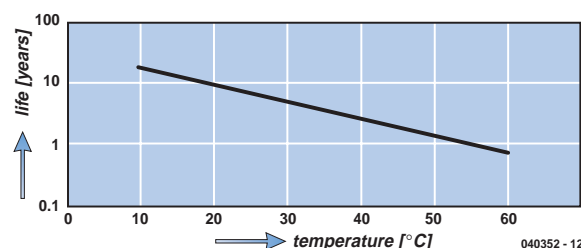


Figure 3. Effect of temperature on battery life with continuous charging at a constant 2.275 V per cell.

Figure 4. Charging behaviour at constant 2.275 V per cell at four different current limit settings.

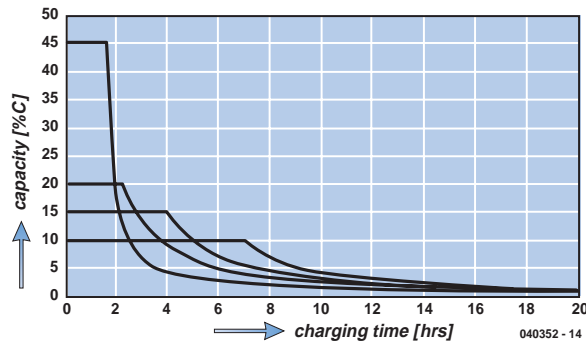


Figure 5. Effect of depth of discharge on life in cyclic operation.

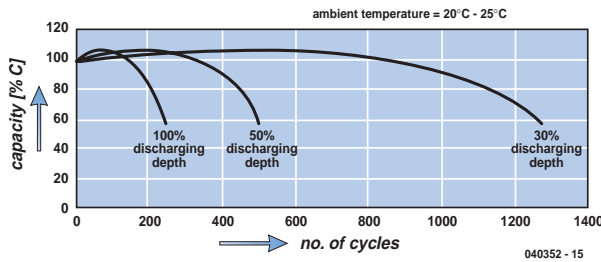


Figure 6. Typical fall-off in capacity in trickle-charged operation.

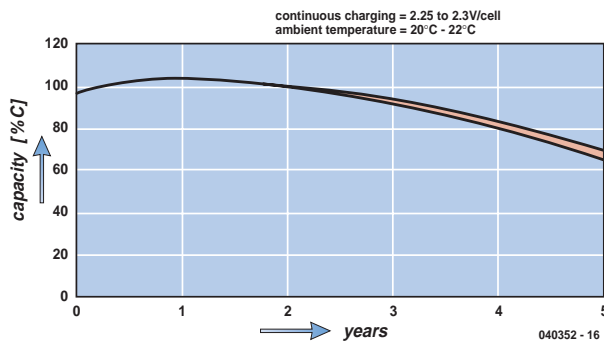
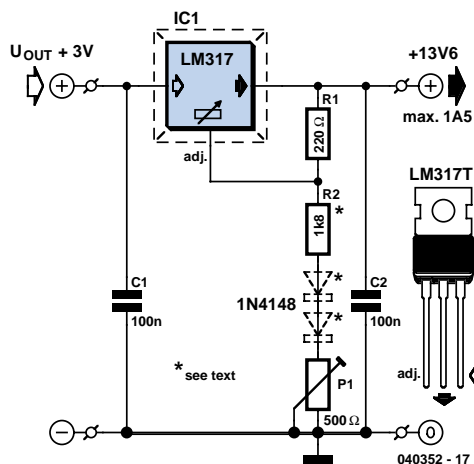


Figure 4 shows how the charge current changes when the charge voltage is set to 2.275 V using four different current limit settings. The charge current (in amps) is shown on the vertical axis as a percentage of the battery capacity C_{10} . If the C_{10} capacity is, for example, 1 Ah, then we are considering initial currents from 450 mA (or 45 % of C_{10}) down to 100 mA (10% of C_{10}). The figure shows that the initial limit current only flows at the begin-

Figure 7. This simple circuit meets all the manufacturers' main recommendations for charging sealed lead-acid batteries.



Typical values

(all voltage data are per cell and at 20 °C)

Recommended charging voltage:

2.45 V (2.4 V to 2.5 V) for normal charging
2.275 V (2.25 V to 2.3 V) for trickle charging

Recommended current limit:

0.25 CA to 0.4 CA

Maximum charge time (normal charging):

16 h to 20 h

Final discharge voltage:

1.75 V

Open circuit voltage:

2.2 V (charged)
2.1 V (half-discharged)
1.9 V (discharged)

ning of the charge cycle. The current proceeds to fall off exponentially, almost to zero at the end of the charging procedure. Manufacturers recommend initial current limit values in the range from 0.25 CA to 0.4 CA; values above 0.5 CA are best avoided in the interests of preserving the life of the battery.

Battery life

The life of the battery depends to a great extent on the depth of discharge, expressed as a percentage of the nominal capacity. Figure 5 gives an idea of the effect of cyclic operation on battery life. To maximise the number of useful cycles it is best to choose a battery with a larger capacity so that the depth of discharge is reduced. Although discharge depth is the main factor, temperature also has an effect on life. Temperatures above 50 °C should be avoided, and below -15 °C there is a significant drop in capacity. Charging at too high a voltage, or for too long, will damage the battery. Temperature and charging voltage are the main factors affecting life in continuously-charged operation.

Figure 6 illustrates typical performance in this case, where 60 % of the battery's capacity still remains available after 5 years' use. The 60 % level is considered to mark the end of the useful life of the battery in industrial applications.

In addition to the factors mentioned above, the construction of the battery also affects its life. For example, in standby operation the small charge current that continuously flows results in the plates gradually becoming thinner and thinner. Batteries with sturdier plates last considerably longer in such use. There are also batteries available that are optimised for cycle life. Exact specifications for the various ranges can be found on the manufacturers' websites (see list).

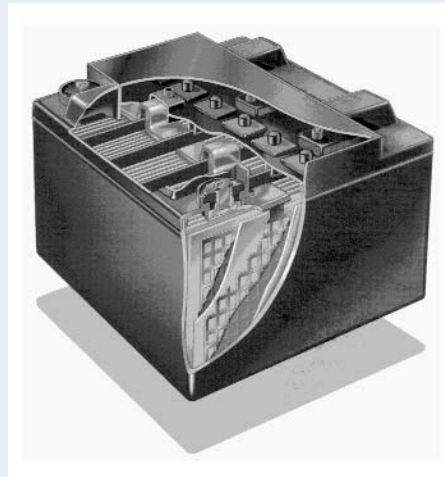
Not recharging the battery after a deep discharge also has a negative effect. Sealed lead-acid batteries should

Gel and AGM-lead batteries

Conventional lead-acid batteries have a few decisive disadvantages: they are filled with highly acid and therefore hazardous liquids which may spill into the environment not just when the battery case is cracked but also when far from positioned upright. Also, these batteries are marked by a high degree of self-discharging and a limited number of charging cycles. This may be tolerable for a vehicle starter battery, but if the battery is to power a vehicle supply system (and be subject to complete charging cycles including deep discharging) then it will protest by developing amounts of sulphate.

With the above in mind, it is not surprising to see lead-acid batteries with fixed electrolytes used in such applications as back-up PSUs and solar systems. These variants are sealed, maintenance-free and will not easily spill their contents. Sulphation can hardly occur because the free sulphuric acids are 'captured' by the internal gel mass. Self-discharging is noticeably smaller, although charging instructions must be observed closely. Unfortunately sealed lead-acid (SLA) batteries exhibit considerably lower energy densities than their liquid acid counterparts, which makes them generally unsuitable for use as vehicle starter batteries.

Apart from the well-known lead-gel technology there is another method to fix electrolyte in a lead-acid battery: AGM. AGM stands for 'absorbent glass mat'; a separating layer pressed between the electrodes. The construction of an AGM battery is shown diagrammatically in the illustration (source: Hawker). The capillary action of the mat causes the electrolyte to be fully absorbed, preventing it from moving around freely. AGM batteries typically supply higher currents than gel types and are also cheaper. On the down side, they are marked by some excess electrolyte as well as worse heat dissipation — at high temperatures, AGM batteries are susceptible to drying out.



not be left in a deeply-discharged state for more than a few days, and should be recharged as soon as possible. The deep discharge capability of a battery indicates whether (and how quickly) it will accept charge again after being left discharged for a long period. Modern AGM-type batteries accept charging relatively quickly after a month in a deeply-discharged state and subsequently return to their normal charging characteristics. To avoid the possibility of leaving the batteries discharged for a long time, they should be stored in the charged state. Recharging is recommended when the open-circuit voltage reaches 2.1 V per cell, which corresponds to a self-discharge to about 50 % of the nominal capacity. A healthy battery at room temperature will discharge so slowly that this value will only be reached after about 18 months. At 30 °C it will take around 9 months to reach half capacity, and at 40 °C, around 4.5 months. At lower temperatures (down to -15 °C) charge is lost even more slowly than at room temperature. The low self-discharge and associated long storage life, along with long life in standby operation, are the most important advantages of sealed lead-acid batteries over other battery technologies.

In practice

Most battery manufacturers recommend charging using a constant voltage and current limiting, with temperature compensation. A simple charging circuit that satisfies these recommendations is shown in **Figure 7**. An LM317 is used as the voltage regulator with a current limit of 1.5 A. To ensure that the charge voltage is maintained at the level set by P1, the voltage at the input to the LM317 must be kept at least 3 V higher than that at the output. The input voltage can be provided from a (plug-in) mains adaptor (unregulated is fine) or from a 14 V boat power supply. The latter option is only suitable if the battery to be charged contains no more than four

cells.

The charge voltage is set using P1 to the optimal value for the number of cells, battery type (see manufacturer's data) and type of charging (normal or trickle). The voltage at the output of the charger should be checked using a digital multimeter with the battery not connected. The range of voltages offered by P1 can be altered if necessary by changing R2 to suit the number of cells in the battery.

If charging is always to be carried out at room temperature, the temperature compensation diodes between R2 and P1 (shown dotted) can be dispensed with. Otherwise it is necessary to find out what temperature coefficient (TC) the manufacturer recommends for compensation. A TC value in the range from -2 to -5 mV/°C can be realised using our circuit as follows.

Inserting as many 1N4148 diodes in series between R2 and P1 as there are cells in the battery will give a TC of -2 mV/°C: for a 12 V battery, that means six diodes. If the number of diodes is doubled to 12, the TC value will be -4 mV/°C; with nine diodes, the value will be -3 mV/°C. As you can see, the TC can easily be adjusted by varying the number of diodes. In order to correct for the voltage drop across the diodes, the resistance of R2 must be decreased by about 120 Ω for each diode added.

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Web pointers:

<http://www.yuasabatteries.com>

<http://www.networkpower.exide.com/>

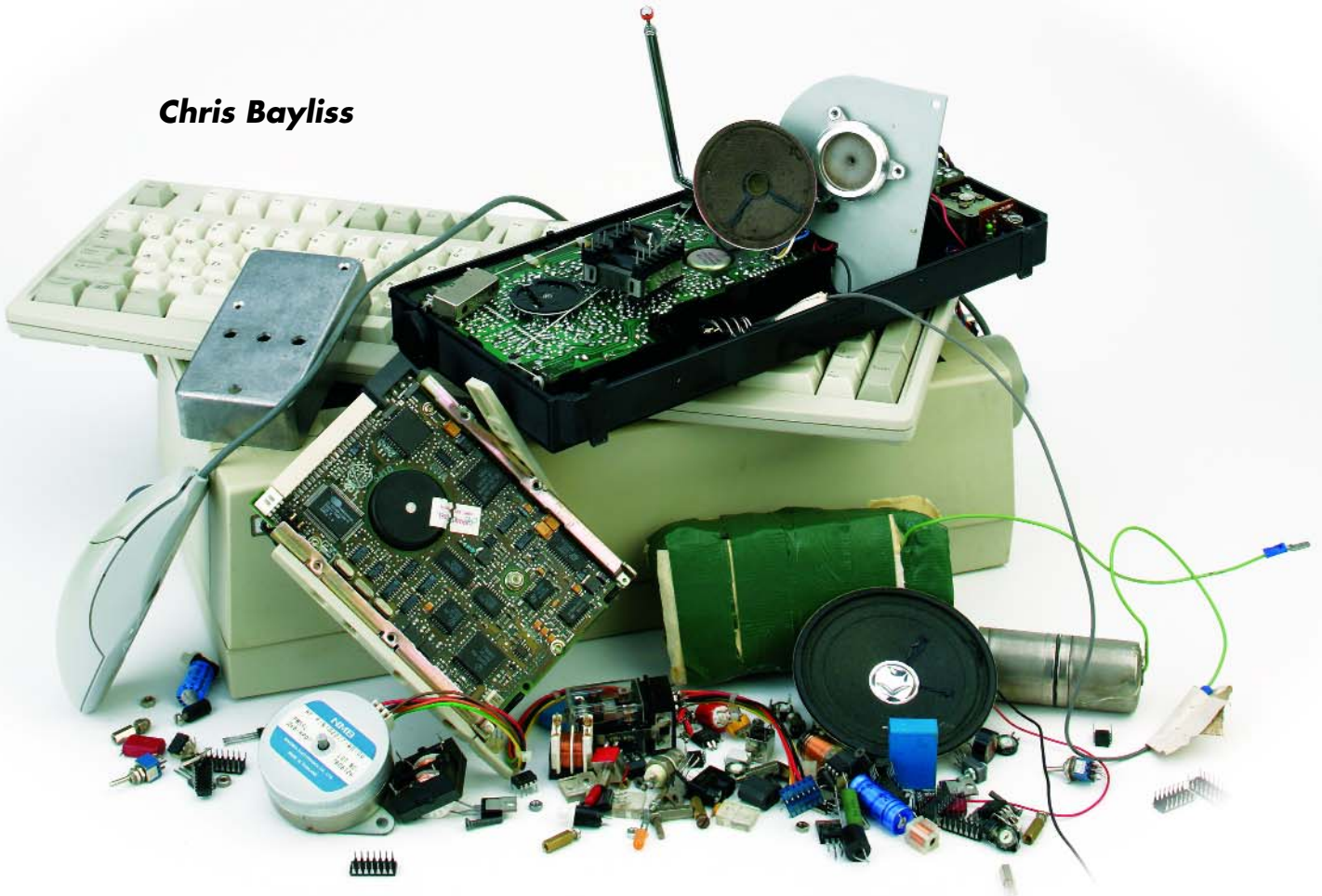
<http://www.batterypoweronline.com/>

<http://www.panasonic.com/industrial/battery/>

<http://www.panasonic.com/industrial/battery/oem/chem/seal/index.html>

BRING OUT YOU

Chris Bayliss



In 2006 European legislation on electrical and electronic waste comes into full force. Across North America, states are passing laws to deal with electronics waste. These measures reflect a hidden but growing problem.

As any electronics enthusiast who has recently tried to repair a consumer product will know, it is more likely to be cheaper to dispose of and replace an item than to repair it. Worse still, many items on the market are likely to be in good working order at the end of their life. The keen electronics consumer faces a dilemma; a desire to own the latest technology leaves perfectly good products obsolete. At the root of this problem manufacturers are beginning to supersede their own technologies and products at an unsustainable rate. The EU estimates that 4% of household waste consists of electrical and electronics products and this figure is increasing at a worrying rate

of 16-28% every five years.

A glance at the statistics and listening to green organizations would suggest a depressing future. There exists however, a movement to exploit the electronics waste problem where a positive attitude and creativity results in novel solutions.

It's all around us

A potential mountain of electronic waste surrounds us all in our homes and offices. The gap between recognizing the electronics waste problem and acting upon it has left

R DEAD

Solutions to electronic waste

us with products not designed to be repaired, or disposed of efficiently or safely.

Substances & methods

Common substances found in electrical and electronic waste include cadmium, PCB's, mercury, lead and bromine. The sheer volume and toxicity of these materials means landfill is no longer an option. After taking away the small percentage of goods sold on as 'second hand' a large quantity of obsolete and unwanted goods remain. If these are to avoid the landfill then a method of recycling is required.

Recycling an electronics product involves reducing it to component parts and converting these back into usable parts or raw materials. This can be performed by one of two methods, manual disassembly or destructive disassembly. Put simply, destructive disassembly involves the product passing through an industrial grinder. The granules produced are smelted and the raw materials separated for re-use. Considering the toxicity of some of the materials involved destructive disassembly is a rather crude method. A large quantity of destructive disassembly is performed in the Far East where labour costs are low and environmental laws relaxed. Ironically, many of these countries sell the salvaged raw materials back to the countries that exported them. A greener and more economically viable solution may be provided by manual disassembly.

If it ain't broke...

Electronics from waste products has undergone a 'burn in' period and as such, could be considered to be of a proven quality and equal to or more reliable than components fresh off the production line. The lifespan of many components now realistically exceeds that of the parent product. In theory 'harvested' components can be re-used in new products. Research has suggested that whilst theoretically possible, a psychological barrier exists at the manufacturer and consumer level at the thought of utilizing harvested components in new products.

Electronic Data Logging (EDL)

Researchers at the power tool manufacturer Bosch have made a suggestion that may help to overcome the above (quite natural) fear, the Electronic Data Logging (EDL) device.

EDL records general information ranging from life hours of the product to more specific component operating history. In theory, this information could be retrieved by the recycling agency via a 'green port' on the device with re-usable parts identified, harvested and incorporated directly into new products. Successful implementation of



Figure 1. Student at CIDA University of Johannesburg. PCs donated by Computer Aid International.

EDL in the future may promote more recycling of parts. If harvesting offers an opportunity for a greener electronics future then how would this be performed?

Current harvesting operations are either performed manually or using robotics. Manual disassembly involves the application of heat to remove components from boards and is a labour-intensive operation. It has enabled charities and other non-profit organizations to recycle old electronics for good causes. Computer Aid for example refurbishes PCs from corporate donors and distributes them to worthy causes in the developing world (Figure 1).

Many charities have also been successful in raising funds from the sale of re-conditioned or recycled mobile phones to Eastern Europe. Manual harvesting has one major drawback. The cost of skilled labour required to perform the task has proven a barrier to widespread commercial parts harvesting. This makes robotic harvesting a more attractive option. Whilst efficient for large batches of the same product, robots have to be programmed to disassemble each new product they encounter. This can make the disassembly of small batches or single electronics products impractical. The search for a commercially viable method of disassembling batches of small and



Figure 2. IZM/EE Toolbox promotional image. (Fraunhofer Institute)



Figure 3. Blu-Ray player; 25-GB cartridge; front and rear view of disc. (Sony)

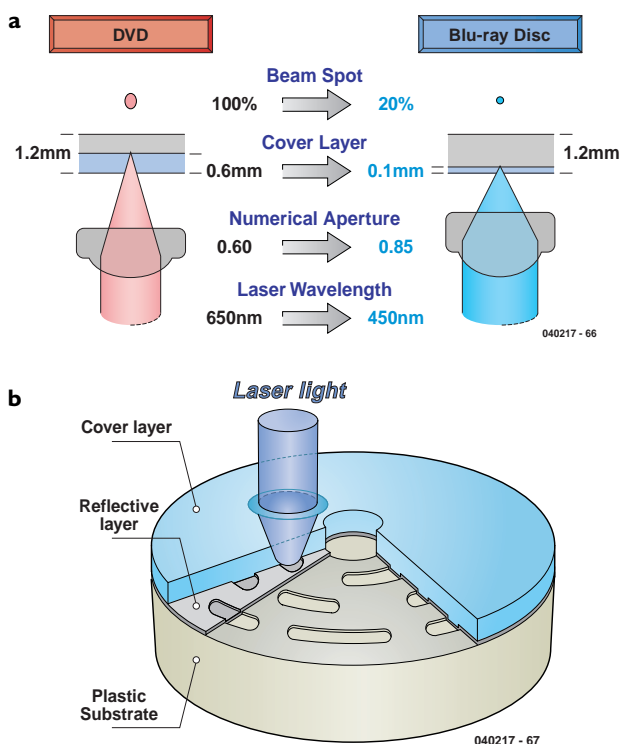


Figure 4. (a) DVD vs Blu-Ray comparison chart; (b) structure of Blu-Ray disc.

mixed electronics waste could be considered the holy grail of the emerging electronics waste industry.

An alternative: ADSM

Like all good problems a surprisingly simple solution emerged, a team from Brunel University in the UK developed the self-disassembling product. The method known as 'Active Disassembly Using Smart Materials' (ADSM) involves the incorporation of actuators and components made from smart metals and plastics. At a pre-defined value above the ambient and operating temperature, these materials change shape. Now imagine these smart materials integrated into an electronics product. Disassembly of the product is achieved by the application of heat, no costly labour or robotics requiring programming. Smart material screws shrink and simply fall out of the product, a carefully placed smart material actuator such as a spring expands splitting open the housing. Internal components break loose from the main assembly ready for easy removal. The self-disassembling product offers an exciting future for recycling. Assuming the majority of manufacturers chose to use smart materials, recycling of mixed batches of electronics waste becomes possible. Self-disassembly offers a cheap solution, neatly sidestepping costly robotics and harmful destructive disassembly.

Designing for minimum waste

The Fraunhofer Institute has developed a software product to assist the electronics designer. The software-based IZM/EE Toolbox (Figure 2) enables the electronics designer to investigate a range of areas from toxicity and recyclability of a design to more abstract areas such as the energy required to produce the raw materials required, even the energy consumed by the product. In the future the electronics designer may integrate complex green issues at the design stage with the push of a button. Creative thinking at the design stage has the potential to both clean up the product life cycle and provide the consumer with desirable new technologies. Sony recently demonstrated this with their Blu-ray disc.

(Figure 3). Consisting of 51% paper, the new disc provides greater data storage than existing DVD technology (Figure 4) and offers greener mass production opportunities. At the end of its working life the product can simply be shredded and recycled, offering both a green end of life solution and enhanced data security.

Dealing with electronics waste effectively either at the design or end of life stage could be considered an insurance policy for the electronics industry. The European Union already predicts that 10,500 new jobs could be created by electronics waste recycling. For the electronics consumer and enthusiast the future not only looks greener but we could be seeing some innovative new technologies emerge. Today's green electronics pioneers will lead the market tomorrow.

Looking East

ADSM and EDL offer pioneering solutions using available technology. All this technology still requires one essential

ingredient, imagination. If we want to see electronics waste management in action then look no further than the heartland of electronics, Japan.

In 2001 Japan implemented its Electrical Home Appliances recycling law. The recycling law covers only four types of appliances; air conditioning units, televisions, fridges and washing machines. These were found to constitute a significant proportion of Japanese consumer waste.

Consumers in Japan can now return their old appliance to the vendor of their new purchase irrespective of the brand. The vendor passes the used appliance over to a recycling company. Each returned product is tagged and its recycling history recorded and stored for three years. This gives companies a unique perspective on the life cycle of their product and provides an overall picture on recycling. From the consumer end the returned product can be tracked via websites. Information regarding where the product was recycled is available. If this sounds too good to be true then you would be right. The Japanese consumer covers the cost of transporting and recycling the waste.

And West again..

Absorbing the cost of recycling the product may not prove to be a popular option with the European consumer. Avoiding added cost means returning to the drawing board and thinking about the design process. All electronics products begin their life as a design. An integral part of this is the product life cycle. Traditionally the life cycle of an electronics product ended at the consumer. Legislation and corporate social responsibility now means manufacturers look at the impact of their product from the manufacturing process through to product disposal. To make electronics recycling work, all parts of the industry need to be involved. Realistically, not all companies have the funds or the resources available to spend time looking at issues such as recyclability and toxicity of their products. However, over recent years computer software has been developed to address this issue. Examples include two more utilities from Fraunhofer's IZM/EE Toolbox: the Toxic Potentials Indicator (TPI) (Figures 5, 6, 7) and the Recycling Potential Indicator (RPI) (Figure 8). Just before printing this article, Fraunhofer Institute kindly advised that an updated and extended version of the IZM/EE Toolbox documentation is due for release by the end of this year.

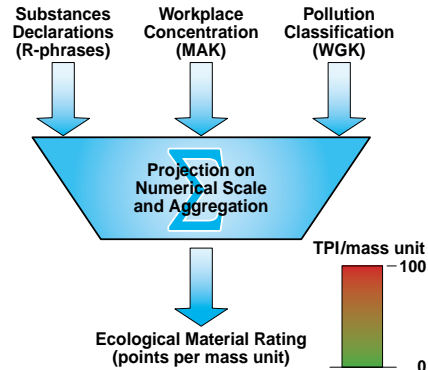


Figure 5. Toxic Potential Indicator (TPI) software enables calculation of product toxicity during product design stage. (Fraunhofer Institute)

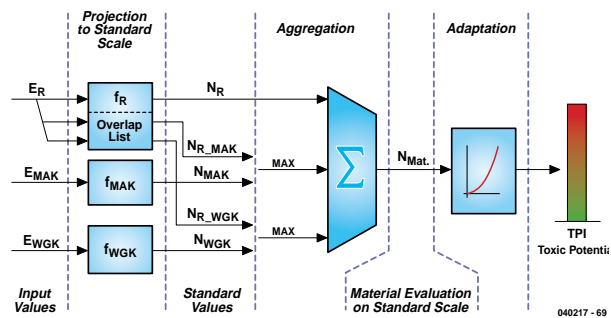


Figure 6. A more in-depth description of the TPI calculation process. (Fraunhofer Institute)

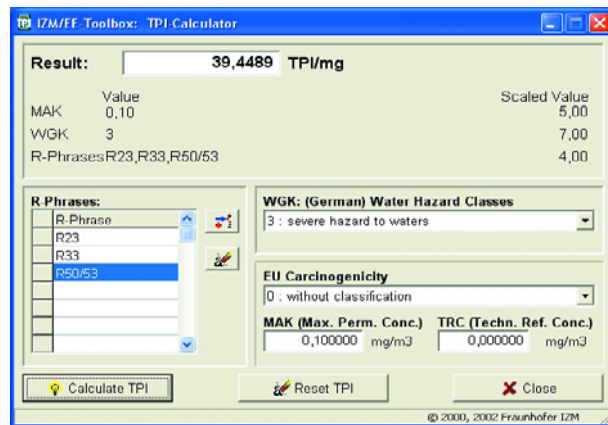


Figure 7. Example of TPI in action. (Fraunhofer Institute)

Web Pointers

- [1] <http://europa.eu.int/scadplus/leg/en/lvb/l21210.htm>
- [2] www.ban.org
- [3] www.computer-aid.org
- [4] www.brunel.ac.uk/research/adsm/home.html
- [5] www.matsushita.co.jp/environment/en/metec/index.html
- [6] www.pb.izm.fhg.de/ee/O70_services/75_toolbox/O10_Einleitung.html
- [7] www.blu-raydisc-official.org/
- [8] www.electronicrecycling.org <http://www.icer.org.uk/>

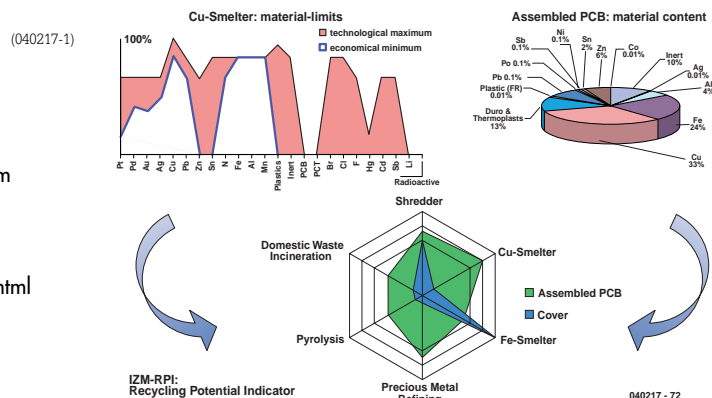


Figure 8. The Recycling Potential Indicator (RPI) utility from the IZM/EE Toolbox allows calculation of proportion of recyclable material in product at an early stage. (Fraunhofer Institute)

PICXEX18 AND PIC

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This article describes the development of a multi-tasking operating system for the PIC18xxx micro controller from Microchip. The code and RAM memory requirements are minimal and the basic idea straightforward, but it can simplify the implementation of an application on this micro controller considerably.

Applications are easier to specify, design, code and debug if you start off by separating it into functional elements, or call it tasks. A software structure to handle the tasks could then look like **Figure 1**.

Here our 'operating system' is nothing more than a couple of CALL instructions with a GOTO MAIN instruction at the end. The CALL instruction activates the task, and the task must cooperate by executing a RETURN instruction to pass control back to the operating system. The above could do for some small applications, but usually the functions/tasks making up our application require some form of control over their own execution and that of other tasks. For example a key-scanner task could continuously monitor a few push buttons. When one is operated the task associated with that button needs to be activated by the key-scanner task. Or a sequence (task) could be executing one of its (many)

steps and then proceed to the next step (code section) once a particular condition is met. It is clear that we will require more than RETURN instructions for the scanner and sequence tasks above to cooperate in a system. The key-scanner task needs to activate one of a few dormant (switched OFF) tasks, while the sequence task must have the ability to modify its own entry point so that only a particular section of its code (i.e. the active step and its criteria) is executed at a time. A task's entry point is the memory location at which the task's code will start executing when the operating system passes control to that task.

PICXEX18 functionality

In PICXEX18 the following functions are provided in the form of macros that the programmer uses in his task code.

XexTaskON TaskNr

With this macro the user can activate any task in the application. It can also be used in code outside a task, for instance an interrupt service routine can start a task.

XexTaskOFF TaskNr

With this macro the user can deactivate any task in the application. It can also be used in any code.

XexTaskExit

A macro used in a task to pass control back to the operating system.

XexSetEPoint TaskNr, EPoint

Modify a task's entry point. It can also be used in any code.

XexEPNext TaskNr

Set a task's entry point to the next instruction. Only to be

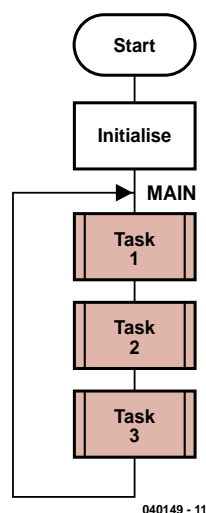


Figure 1. A basic software structure for implementing an application that is divided into 3 functional elements, or tasks.

used in the code of the task of which the entry point is to be modified.

In Figure 1 the operating system's 'task activation code' is a single CALL TASK_X instruction. This will have to be extended. Firstly we need to add a test to prevent a task from being activated if it is switched OFF. Secondly we must be able to change a task's entry point during run-time, in which case a CALL instruction cannot be used as the destination address of this instruction is fixed at assembly time.

The ON/OFF test for a task is implemented by assigning a bit variable to each CYCLE TASK, which if set, will indicate that the task is in the active state. The facility to modify a task's entry point is implemented by using the PIC18's ability to push an address on its return stack. So the CYCLE TASK activation code needs to first test the task's ON/OFF flag, if it is set then get the task's current entry point value, push it on the Return Stack, and execute a RETURN instruction.

For each CYCLE TASK 3 RAM bytes are reserved. The first byte holds the ON/OFF flag in its Bit<7>, and the next two bytes the task's current Entry Point value.

Application design can be further simplified by adding to our operating system the ability to execute tasks at selectable time rates. This allows the programmer to concentrate on the task code itself without having to be concerned about how to code timing or counting mechanisms to regulate execution of that code.

PICEX18 allows for 8 TIME TASKS with the execution rate of each task being set at assembly time in the file xextask1.def. As their execution depends on time these tasks cannot be switched ON or OFF by the user, and their entry points cannot be modified. PICEX18 uses a CALL instruction to activate a TIME TASK. This allows for a simple activation mechanism — if the task's ON/OFF flag is set then CALL the task's code. To pass control back to the operating system the programmer uses the Xex-TaskExit macro inside the task code. If you look at the actual code for this macro you will see that a RETURN instruction will do the same job. Using the macro is just a better way of indicating in your code where the task's exit point is.

The basics of the PICEX18 multitasker can now be described by referring to **Figure 2**. Before a CYCLE TASK is activated a test is made to determine if there are any TIME TASKS waiting to be executed. If there is, then control is passed (with a CALL MAIN01 instruction) to the code in **Figure 3**.

Here those TIME TASKS, of which the Task Request Bits are set, will be executed. At the end of the TIME TASK list is a RETURN instruction, which will take us back into the CYCLE TASK loop of Figure 2, so execution of CYCLE TASKS carry on from where it left off.

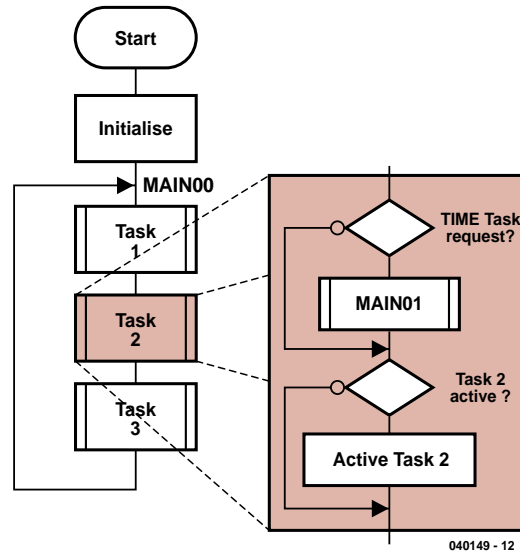


Figure 2. Main Cycle Task loop of PICEX18 showing how the test for TIME TASK request is done before a CYCLE TASK is activated.

As shown in Figure 2 we test for requests to execute TIME TASKS between the executions of CYCLE TASKS. It is therefore important for CYCLE TASKS not to retain control of the CPU for longer than about 5 ms. A PIC running at a modest 8 MHz can get through a lot of code in 5 ms! A scheduler subroutine in PICEX18 controls the activation of TIME TASKS by setting the Task Request Bits at the required times.

For the scheduler to function your code must provide for a timer routine to CALL the scheduler subroutine every 10 ms.

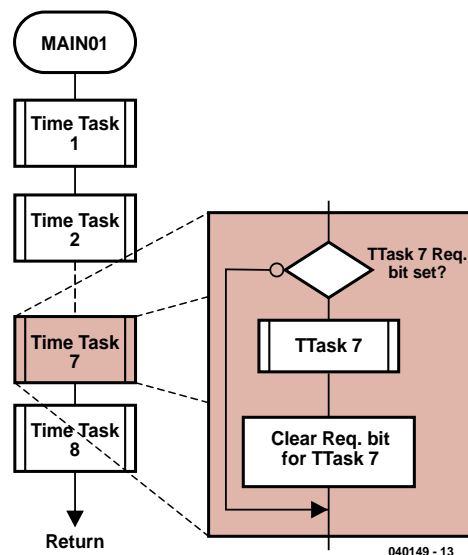


Figure 3. The operating system will execute a CALL MAIN01 instruction if any TIME TASK Request Bit is set. MAIN01 will activate all TIME TASKS of which the Request Bit is set.

Figure 4. For the TIME TASK scheduler of PICXEX18 to function the user must arrange for a timer routine to execute a CALL SCHED00 instruction every 10 ms.

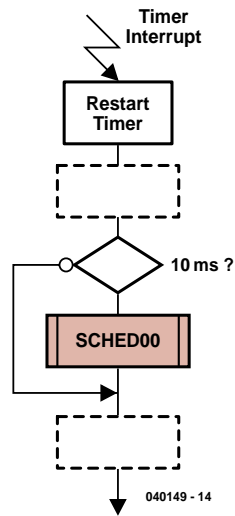


Figure 4 gives the basics of a timer interrupt service routine (which is your code) containing a call to the subroutine SCHED00. The following execution rates (in ms) are available for Time Tasks:

10, 20, 40, 50, 100, 200

The time task scheduler uses a 20-entry look-up table to save the task timing information. Every 10 ms the scheduler routine fetches the next entry in this table and OR it to the RAM location holding the 8 TIME TASK request bits. The entries in the look up table are generated at assembly time using information from the file xextask1.def. The source code for PICXEX18 is contained in the following three files:

Xextask1.def
Xex18tsk.mac
Xex18mak.asm

Xextask1.def

This is the only file that requires modification. The file is used to define the following:
Number of CYCLE TASKS.
Label at the start of each TIME TASK.
Execution rate for each TIME TASK.
Bias time for each TIME TASK.

Xex18tsk.mac

Source code for task control macros.

Xex18mak.asm

This file contains the code for PICXEX18. When this file is assembled it will generate the CYCLE and TIME TASK loops and the scheduler table.

Using PICXEX18

The archive file **040149-11.zip** you can download for free from our website contains all the source code required for the following example application to demonstrate the use of PICXEX18. To generate the .HEX file simply assemble the file ELEKTOR.ASM using the MPASM assembler (free from Microchip). The latter file contains

Figure 5. Functional diagram of the example application, a combined Pulse/Ramp Generator.

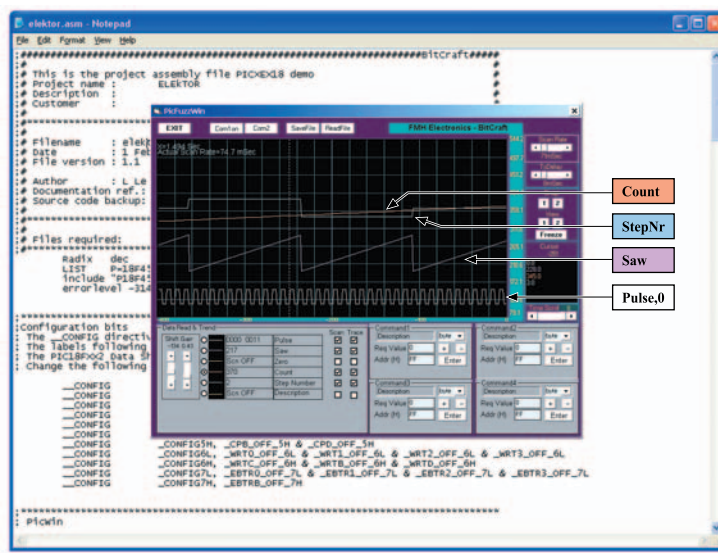
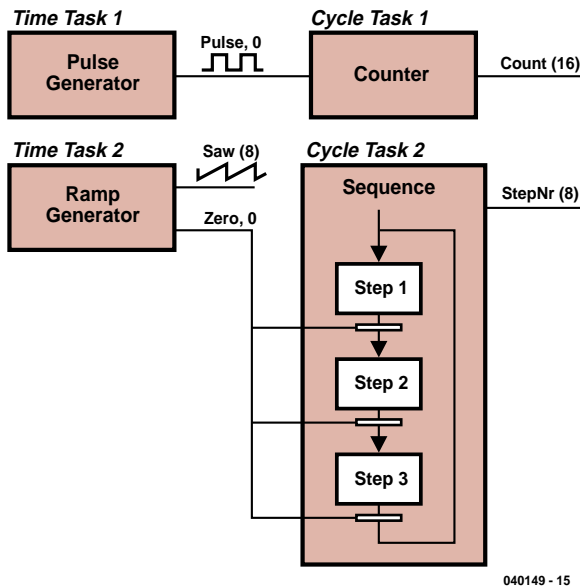


Figure 6. PicWin8 monitor in action. Here, the 'Fuzzy' version is shown (still under development).

Free Downloads

All assembler files for PICXEX18 and the Pulse/Ramp demo program. PICWin8 executable and user guide.

File number: 040149-11.zip

www.elektor-electronics.co.uk/dl/dl.htm,

select month of publication.

the directives to include the other files required. The application contains two Cycle Tasks and two Time Tasks.

Time Task 1 is a pulse generator. It will pulse the bit 'Pulse,0' at a rate of one pulse every 400 ms.

Time Task 2 is a sawtooth generator. It will cause the byte 'Saw' to ramp up in 2550 ms to a value of 255 and then reset to 0. On every reset the bit 'Zero,0' is set (it will be reset by the active step of the sequence).

Cycle Task 1 is a pulse counter. Every rising edge on the bit 'Pulse,0' will increment the 16-bit value 'Count'.

Cycle Task 2 is a sequence with three steps. The sequence will remain in a step until the bit 'Zero,0' is set. This bit will be cleared and the sequence advance to the next step. When in the third step and bit 'Zero,0' is set, then the sequence will revert back to step number 1. The byte 'StepNr' indicates the number of the current step. Once you have assembled this application, it can be tested by running it using the MPLAB simulator. To verify that the two time tasks are in fact being executed at the required rates of 200 and 40 ms, use a breakpoint at the tasks's starting point (PULSE_GEN and RAMP_GEN) and MPLAB's Stopwatch function to see how long it takes between executions. The application was programmed into a PIC18F452 clocked at 8 MHz.

PICWin8

When testing an application where a few things are happening at the same time it is very helpful to be able to

see how the different signals are behaving. In the ELEKTOR.ASM file, right after the setting of the configuration bits, you'll find a statement to set the assembler variable 'PicWin'. This is used to include the assembly code for an interrupt service routine for the UART to handle the data exchange with a PC utility to monitor and modify variables in the PIC. The screenshot of the PicWin monitor in action, **Figure 6**, shows trend traces of the four variables of our application, which, as you can see, is functioning as required.

The 'PicWin' monitor has the following features:

- VB6 application
- Baud rate 9600 (fixed)
- Can display & trend up to 6 values simultaneously
- 4 fields supplied for commands (modify PIC RAM locations).
- Each trend buffer = 800 samples. Display = 400 samples with scroll
- Data types: bit, byte, word, Fpoint
- Adjustable scan rate
- Performance: the screenshot shows four traces scanned at 87 ms. Each trace was shifted to get a better view of what's happening.

A user guide and setup instructions for the PicWin monitor may be found in a text file included in the zip archive for this project. Happy Pic'king!

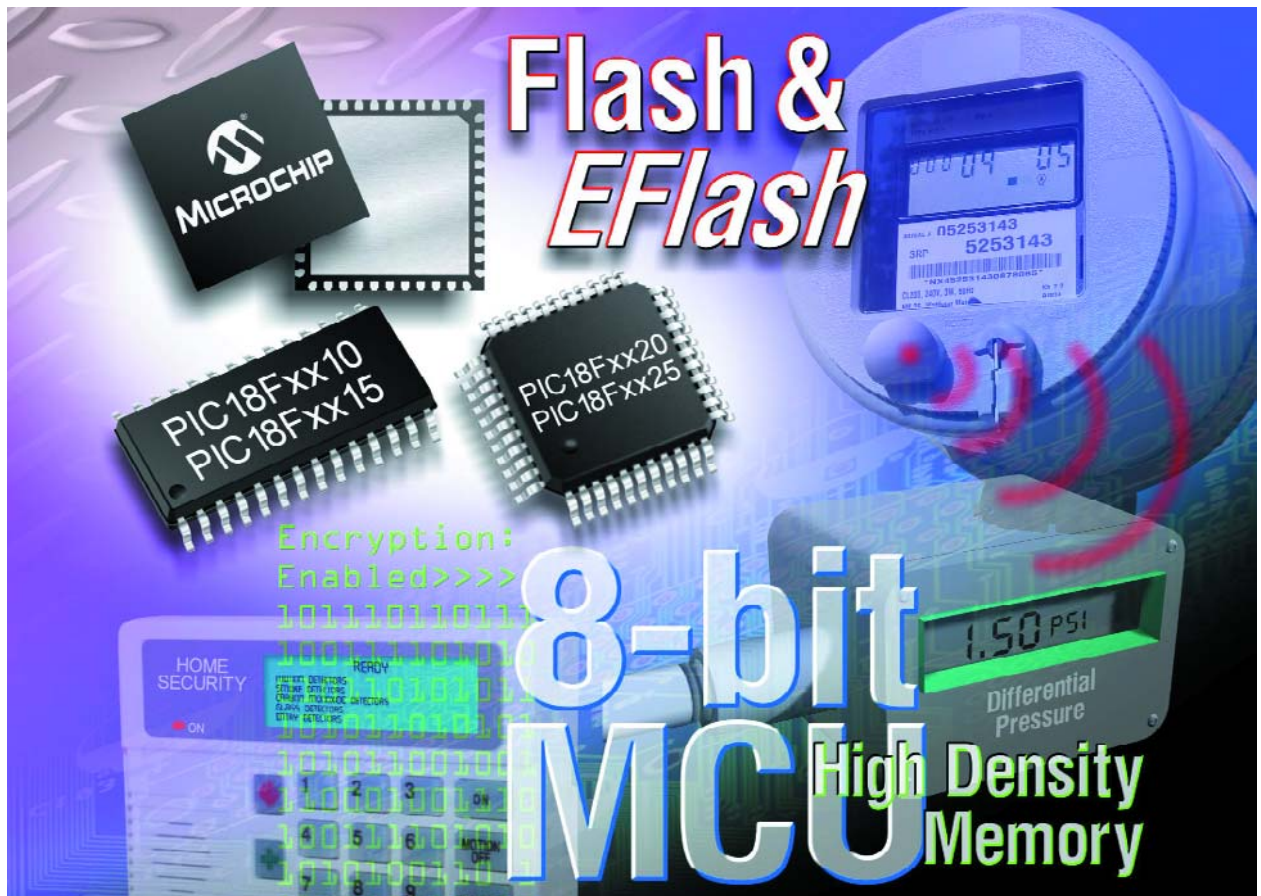
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Advertisement

GOODBYE '16, WELCOME '16

Part 2: ROM (program memory) and long lookup tables

Ron Coates



The 18Fxx2 series of processors have either 16 k or 32 k of Flash ROM. However, each program instruction takes at least one word (i.e., two bytes) so in terms of the number of lines of program code you could write, you are looking at a maximum of 8 k or 16 k. Consequently, in terms of programming, you can only ever address even numbered ROM locations.

COME PIC18F

If you look at the program memory window for a 16F series program, the program address increments by one for each line, i.e., 0000, 0001, 0002 etc. The same code in an 18F would produce a program where each line incremented by two; 0000, 0002, 0004 etc. This doesn't matter in the normal course of events, but when we come to lookup tables, it does. The whole of the ROM memory is completely linear and there are no problems with CALL or GOTO instructions, no matter what the length of the program.

Look up tables

One of the features of PIC processors which has come in for some criticism in the past has been that lookup tables of any reasonable length were difficult to implement. One of the most useful features of the '18 series is that you can write lookup tables of virtually any length that will fit in the amount of Flash ROM available. It might be useful at this point to look in detail at the only way you could implement a look up table in the '16 series.

This was called a 'computed goto' by Microchip and required the programmer to prepare the lookup table as a subroutine starting with the command to add the value in the W register to the program counter. This was followed by a list of the values that were to be returned. To use the table you had to ensure that the value in W was the required table position before you called the subroutine. After the subroutine, the main program would have the looked up value in W.

The following example would return the maximum speed a driver should do in any intermediate gear. We will call the subroutine SPEED.

SPEED	ADDWF	PCL
	RETLW	0xFF
	RETLW	0x0A
	RETLW	0x20
	RETLW	0x3C
	RETLW	0x50

If the main program had the value of the gear (1, 2, 3 or 4) in W, then calling this subroutine would cause the program to jump to the line corresponding to the gear and return the maximum speed as a hex number. Note that the first line of the table corresponds to a value in W of zero. Since in this instance we would never have a value of zero, a dummy value (FF) is inserted.

The limitation of the above is that the value in W can only vary between 00 and FF (or 0 to 255 in decimal). And so you can only have 256 lines in the table. If you need a longer table than this, you have to split your table into 256 line chunks and use additional calculations to make sure you look up the right chunk. Clearly for values of several thousand, this is not practical.

The above method can still be used on the '18 series and is still useful for short tables. However the situation is even worse now, as the program counter only recognises even numbers. This means that whether W contains 0 or 1 makes no difference and the program will jump to the first line of the table (0xFF in the above example). For the program above to work properly with an 18F, you would need values of 2, 4, 6 and 8 in W. This also means that the maximum length of your table is now only 128.

If you need longer look up tables, you need to use an alternative method. This is described in detail in section 5 of the Data Sheet but these are general principles only. Any amount of the available Flash ROM can be used by the programmer as a lookup table (or series of lookup tables). So if we were using a chip with 32 k of ROM and we only needed 4 k for the program itself (remember this would be the equivalent of about two thousand lines of code), then 28 k would be available as look up table space. This is a very significant step forward and may well mean that applications which previously used an external EPROM to store data can now become true 'single-chip' applications with considerable savings in complexity, PCB size and, of course, cost.

There are also larger 18F chips available with up to 128 k of ROM. Consult the Microchip website for the latest information on these.

The ability to address this amount of space hinges on table pointers. There are three of these, TBLPTRU (Table Pointer Upper) only 5 bits of which are available, TBLPTRH (Table Pointer High) and TBLPTRL (Table Pointer Low). Together these are used to form a 21-bit long address which can access up to two megabytes. In practice, with the processors that we are talking about, TBLPTRU can be left at zero since the sixteen bits of the other pointers is more than sufficient to address the amount of ROM available.

These tables can be read and written to during program operation so you need to be careful with the setting of the pointers as it is perfectly possible to overwrite your program code.

So how do we get the data into these tables? This is a point where the data sheet is strangely silent. What you can't do is write it in with the program, in the way that you do with the computed go to. You can go to the Program Memory window in MPLAB and directly amend the values, and indeed this is useful for debugging purposes. However there is no way of saving these amendments and as soon as you exit the editor, the information is lost. In any case if you have got an eight kilobyte look up table you hardly want to input all the values by hand! We can think of two ways of doing it, and perhaps readers could suggest others. As an example let's take the values of a sound sampled musical instrument, for example, a piano. It would be normal to use a PC to manipulate and store data of this type, so we will assume that the table you want to get into the PIC is presently residing as a file in your PC.

If you can write a suitable program for the PC, then either the parallel or serial port could be used to download the file. The PICs we are discussing all incorporate a hardware USART (Universal Synchronous/Asynchronous Receiver Transmitter) which can easily be set up to communicate with the RS232 serial port of a PC.

If your skills do not extend to programming PCs, then an alternative method is to use an EPROM programmer to transfer the information to an EPROM, and then write a program in the PIC to transfer the information from the EPROM to the PIC's memory. This is rather long winded as it means you have to program in the code (using a PICSTART programmer or equivalent), then transfer the PIC to a board which has been made up just to transfer data from EPROM to PIC, before finally using the PIC in the target application.

Transferring an existing 16F application

Page one of the 18FXX2 data sheet has the rather optimistic statement that the 18F is 'source code compatible with 16C ...instruction sets'. This might make you think that all you have to do with an existing application is amend the references to the model number of the PIC and all will be well. In fact you will probably get a long list of error messages but it is not difficult to sort this out. First of all, the status register bits RPO and RP1 which were used for bank switching in the 16F, no longer exist. You will certainly have references to these as you could not otherwise have set up the I/O ports with the TRIS reg-

isters. All references to these must therefore be deleted. Another problem will exist only if your original program used indexed addressing. If it did, you will certainly have made references to the FSR registers. We now have three FSR registers labelled FSR0, FSR1 and FSR2 and each of these has a low and high byte. So all references to FSR will have to be changed to FSR0L. A similar problem will occur with references to the INDF register. These can be quickly sorted out by using the search and replace facility in the editor.

Finally, if you embed your CONFIG statements in the source code, these will also show up as an error. The CONFIG statements for the 18F series are completely different in format to the 16F and the best way is to delete the 16F statements and start again using the 18F INCLUDE file as a guide.

Syntax errors like these can be quickly sorted out. It is just as important that you review the program structure to make sure you are taking advantage of all the goodies these new chips provide.

Further outlook: DSP

Up until the beginning of this year, the 18F series were the most powerful processors that Microchip produced. That all changed a few months ago with the introduction of the dsPIC series. These are full 16 bit processors which also incorporate features usually found only on Digital Signal Processors (DSPs). As always *Elektor Electronics* will be the first to bring you details of these. Watch this space...

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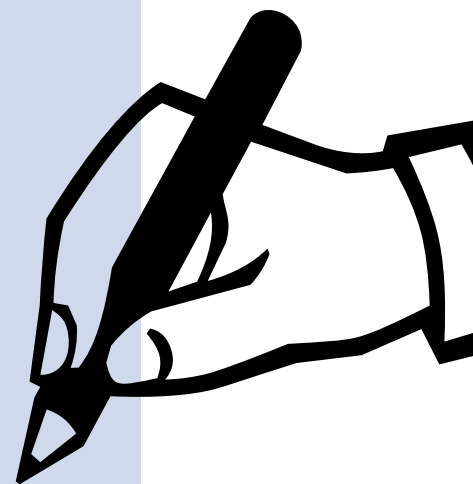
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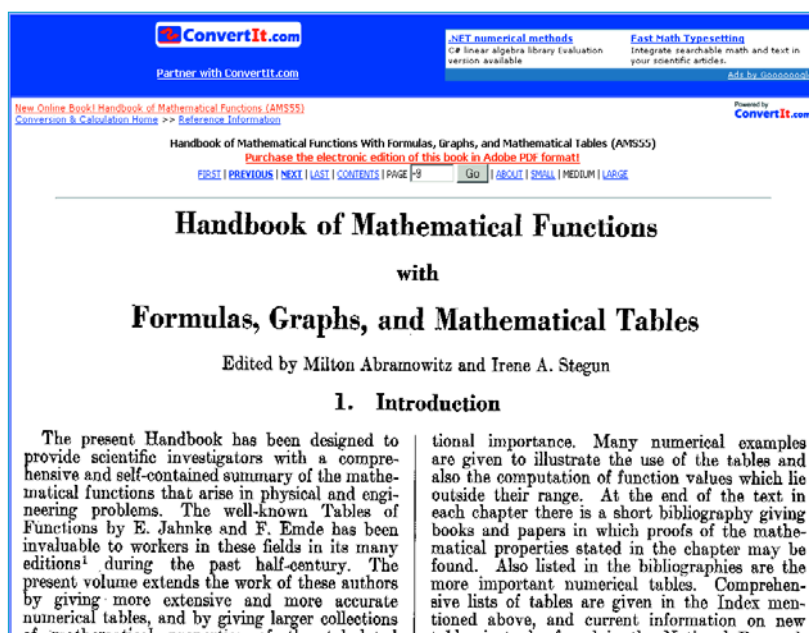


EQUATIONS, EQUATIONS

Calculate and convert

Harry Baggen

Electronics is not always plain sailing. Although a small circuit can be built quickly without jotting down complex formulas, a deeper or more theoretical approach soon calls for equations and basic maths. There is no need however to know everything from the top of your head as the Internet is available to assist.



Electronics can be downright easy... but also horrendously difficult. Once you've mastered a few basic 'laws' and have an idea of the operation of a number of passive and active parts, you'll get remarkably far in designing a circuit. However, far more learning is in order for a theoretical approach or more accurate calculations on electronic circuits. Soon, you may feel drowned in formulae and equations and the fun wears off quickly. Those of you who have completed a formal education in electronics probably don't have to be told how complex a circuit design can turn out to be.

In addition to a solid base in electronics and mathematics there are many bits of knowledge you do not need every day — just think of the horrors of a Laplace transformation or a

Fourier series. In those cases it is useful to have an overview handy of where to find such subjects. Sure, they are covered in electronics textbooks, but where exactly?

The Internet contains nice compilations of calculations for a multitude of electronics subjects. Even if you do not have your maths ready just there and then, it is good to know you can almost instantly refresh your memory. A good base for such a 'calculus collection' is found at the **RF Cafe** [1]. Right at the top of the homepage you'll find a table that begins with *Equations & References*. Below it you can click on two links, *Electrical* and *General*. Both supply an alphabetical list of technical subjects, where the first is of course the most interesting to us. Although the RF Cafe is mostly dedicated to high frequency (radio) design, this overview does not fail to cover a much wider range: from the size of miniature bulbs right up to the design of PCB microstrips. Even browsing around in this overview will soon enable you to pick out some really useful bits like the elementary calculations for various passive components and all filter transfer functions. Not forgetting, of course, copper wire gauge comparison tables and resistor series. The more RF inclined among you will certainly appreciate the VSWR calculations and the Smith chart.

Nearly all subjects have their own page in the RF Cafe website. Some links head off to other websites, unfortunately including some dead ones. However, the amount of ready to use information crammed into the website is such that these errors can be excused. On the *General* page you'll find general-purpose information like bolt & nut sizes, the Greek alphabet, global timezones, sound properties in different materials, thermocouples and heatsink calculations just to mention a few. Although the *Calculator* section contains several links to commercial software packages, it does include lots of nifty calculation programs for direct use.

The RF Cafe has lots more to offer, particularly of course on RF design. We'll hold the subject over to another instalment of electronics online; else we should have called this instalment 'RF Cafe' straight way! There's one link however we simply must tell you about: on the *Electrical Conversions, Formulas & References* page is a reference to the entire (scanned) *Handbook of Mathematical Functions*, a more than 1,000 pages thick standard textbook containing just about any formula, graph and table we could think of. The entire book (originally published in 1964) is available free of charge from **ConvertIt** [2].

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<p>Series Capacitors</p> $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}$	<p>Parallel Capacitors</p> $C_p = C_1 + C_2 + \dots + C_n$																																																																																																																																																												
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Internet addresses

- [1] RF Cafe:
<http://www.rfcafe.com/references/electrical.htm>
- [2] Handbook of Mathematical Functions:
<http://www.convertit.com/Go/ConvertIt/Reference/AMS55.ASP>

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- Microstrip Equations -

You can work these formulas manually, or download this great free calculator (TX Line) from AMR.

Effective Width and Height

$$W_{eff} = w + \frac{1}{\pi} \left(\ln \left(\frac{2h}{t} \right) + 1 \right)$$

$$H = h \cdot 2t$$

$$\lambda = \frac{c}{f \sqrt{\epsilon_{eff}}}$$

wavelength

$$\theta = \frac{2\pi}{\lambda}$$

phase

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12 \left(\frac{H}{W} \right)}}$$

$$Z = \frac{120 \pi}{\sqrt{\epsilon_{eff}} \left[\frac{W}{H} + 1.393 + \frac{2}{3} \ln \left(\frac{W}{H} + 1.444 \right) \right]}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12 \left(\frac{H}{W} \right)}}$$

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[\frac{1}{\sqrt{1 + 12 \left(\frac{H}{W} \right)}} + 0.4 \left(1 - \frac{W}{H} \right)^2 \right]$$

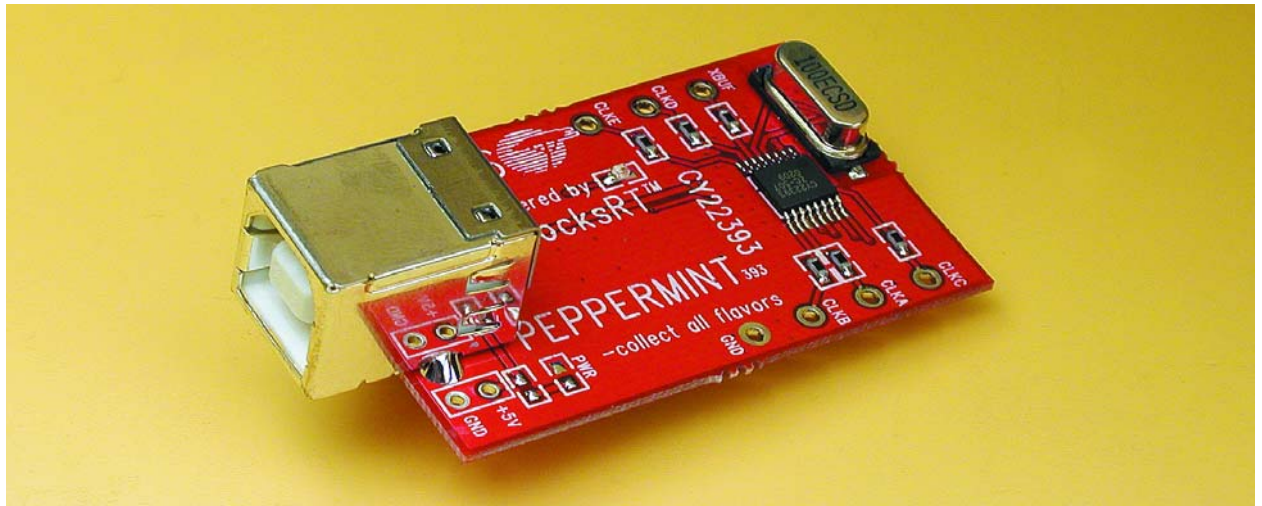
$$Z = \frac{60}{\sqrt{\epsilon_{eff}}} \ln \left(8 \frac{H}{W} + 0.25 \frac{W}{H} \right)$$

$\frac{W}{H} > 1$

$\frac{W}{H} < 1$

USB - CYBERCL

Burkhard Kainka



Quartz oscillators are the way to go when you need a precise, stable frequency source but what do you do when an application calls for a non-standard frequency? Custom-made crystals are an expensive option but now Cypress has come up with a cheaper alternative...

The buzzword is CyberClock and describes a relatively new technology in the field of clock generators for use in complex systems like PC motherboards. If you take a look at an old motherboard it is easy to spot the crystal generators dotted around the board providing all the different clock sources. More modern systems are increasingly employing just a single clock generator and deriving all the other signals from this one source.

PLL Technology

The clock generator chips contain a Phase Locked Loop (PLL) with the fastest versions having an output frequency range from 100 MHz to 400 MHz. The PLL layout is shown in **Figure 1**. It differs from a standard PLL by having programmable dividers at the input and output and in the feedback path. The input clock F_{REF} (typically a crystal) is connected to a programmable divider Q . This clock signal is now compared in the Phase Detector (PD) with the output frequency from the Voltage Controlled Oscillator (VCO) divided by P and fed to the Charge Pump (CP). The CP output is a function of the phase difference and controls the VCO. The VCO output is passed through the output divider N to produce F_{OUT} . Altogether

there are three dividers (Q , P and N) all of which can be independently programmed.

We shall take a closer look at two of the Cypress clock chips. Firstly the CY22393 ('Three-PLL Serial Programmable, Flash Programmable Clock Generator') has six configurable outputs (**Figure 2**). The device can be flash-programmed (non volatile) from a special external programmer. The programming algorithm is not in the public domain presumably for licence protection and to guard against over-clocking or similar abuse. While the oscillator is running it is possible for the contents of internal registers can be overwritten via the I²C-Bus but this storage is volatile and they will be lost on power down.

The CY27EE16 ('One-PLL In-System Programmable Clock Generator with Individual 16K EEPROM') is particularly interesting for low volume production applications or circuit development. The internal EEPROM does not need a special programmer; it can be programmed via the built-in I²C bus interface. Register contents can also be overwritten 'on the fly' as above. A default configuration can be programmed into the chip and this will be loaded each time at power up. This facility brings the concept of an individually programmable oscillator one step closer. The internal structure of the chip (**Figure 3**) shows the

CLOCKS For low-noise VCOs & PLLs

possibilities for clock generation using just one PLL. The output dividers can be internally connected to either the VCO output or directly from the reference clock. One frequency can be freely chosen while the other outputs must be derived from the VCO or reference frequency. Both ICs allow direct connection of a crystal in the range between 8 MHz and 30 MHz. The output frequency is selectable up to 200 MHz.

A range of evaluation boards from Cypress featuring USB connectivity supports the family of clock generator chips. These boards are known as 'Candy Boards' (presumably because they are simple to use). The 'Peppermint board' has the CY22393 fitted while the 'Blueberry board' contains the CY27EE16. Each of these evaluation boards is a versatile stand-alone universal frequency generator and can be used in many applications. CyberClocks (Figure 4) is a free program that greatly simplifies the process of directly programming and controlling the Candy Boards.

Cypress also produces free downloadable software supporting the entire range of clock generators. From the CyberClock start menu select the sub-family then the chip part number. The CY22393 can be found under CyberClocksRT while the CY27EE16 is under ISR.

The program displays a window for the selected chip with the programming options. The desired output frequency and the input clock frequency can be entered along with the pin-out configuration and the software will calculate the division factors Q , P and N and also all the necessary internal register values. The settings can be saved in a JEDEC format file that is compatible with most hardware programmers. The starter boards also feature a USB interface.

The Peppermint Board

The demo board type CY30701 (Peppermint Board) is fitted with the CY22393 and contains an on-board 10 MHz crystal together with a USB interface. The CyberClocks program can be used to configure the chip once the desired output frequencies are entered.

The example in Figure 5 shows the generation of three different frequencies in the range between 6.55 MHz and 122 MHz. A buffered output clock from the quartz oscillator is also used as an output. With the software in Advanced Mode it is possible to see all the configuration settings. Details of each of the PLL and divider settings as well as all the internal links are shown. Another program feature that proved useful during system development is the Bit-Viewer, this displays the contents of all the internal registers.

When the Peppermint board is first connected to the PC it should be automatically detected and the appropriate Human Interface Device (HID) driver will be loaded by Windows. An on-board status LED will blink to indicate successful USB communication.

The board takes its power directly from the +5 V USB and has an on-board 3.3 V voltage regulator. Pro-

grammed settings will be retained on the board as long as it is powered up. Once power is disconnected the settings will revert to their default example values.

The Blueberry Board

For use in the lab the Blueberry Board (CY30703) with the CY27EE16 is particularly interesting. The double 'E' in the part number gives away the fact that the chip contains an EEPROM. This has space to store 2 kbits for reg-

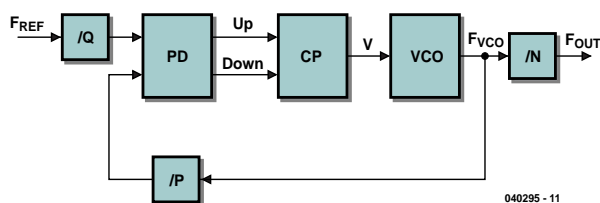


Figure 1. The PLL principle with feedback divider.

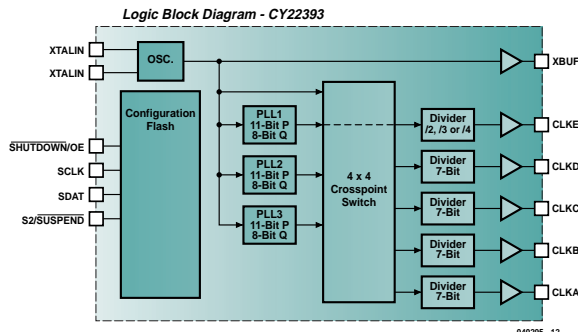


Figure 2. The CY22393 block diagram.

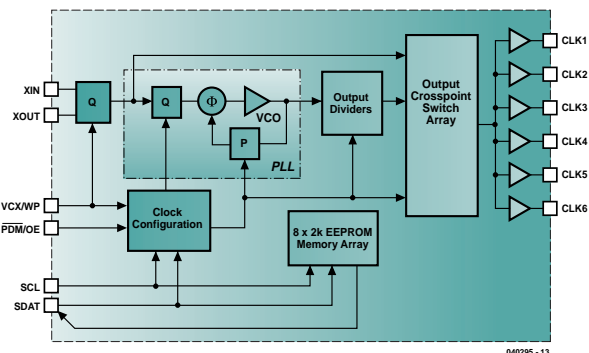


Figure 3. The CY27EE16 PLL and divider.

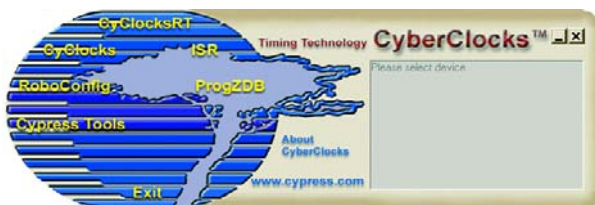


Figure 4. The CyberClocks programming tool.

ister contents and a further 16 kbits for general program use. No special hardware is necessary to program the device. The clock configuration parameters can be stored either in RAM or EEPROM. Storing to RAM allows the clock to be configured 'on the fly'. After a power down/up cycle the clock will be reconfigured to the

parameters stored in EEPROM.

This chip has only one internal PLL but with careful programming of the dividers many different clock frequencies can be generated. To increase flexibility the output dividers can be switched to either the PLL output or to the oscillator frequency and an output crosspoint switch matrix routes the clocks to the user defined output pins.

RF applications

These signal generators are essentially intended as clock sources for microprocessor systems and their peripherals but we are all in favour of a bit of experimentation so why shouldn't we try it out for RF applications? The main concern is whether the generator can meet the more stringent requirements of an RF environment. In particular the increased level of phase noise in a PLL system compared to a Direct Digital Synthesiser (DDS) could impact on a receiver's performance. The acid test would be to use it in place of the synthesised signal at the first injection oscillator input to the digital (DRM) receiver published in March 2004 of *Elektor Electronics*. For example, to receive DRM transmissions from the German station RTL (broadcasting on 6095 kHz) we require a first oscillator of 6550 kHz (with an IF of 455 kHz, $6095 + 455 = 6550$ kHz). After substituting the PLL clock for the DDS clock the resulting performance was surprising good: The DRM signal was completely clean and indistinguishable from the quality achieved with the DDS clock source. Based on this result there seems to be no good reason why the programmable oscillator should not be considered for use in critical RF applications also.

Anyone who has worked with PLLs will be aware of the usual problems: A VCO is controlled by the output signal from a phase comparator and a loop filter, this configuration gives rise to relatively high levels of phase noise and the effects of loop resonance. In critical RF applications LC oscillators with high Q characteristics are used to reduce these tendencies but never the less PLL based receivers usually tend to have higher levels of phase noise than for example, DDS controlled receivers. The performance achieved here is therefore remarkably good.

The *VCO Calculator* in *CyberClocks* details how 6.550 MHz is derived from the 10 MHz clock. The Q divider is set to 4, giving a fairly high comparison frequency of 2.5 MHz. The PLL (the P divider) multiplies the frequency by a factor of 131 to produce 327.5 MHz. The VCO output is divided by 50 in the output dividers to give an output of: $10 \text{ MHz} / 4 \cdot 131 / 50 = 6.550 \text{ MHz}$.

The secret of the high quality signal lies in the fact that the VCO and comparison frequency are relatively high and the VCO phase noise on the output signal is effectively divided down by the output divider chain (N). By comparison a conventional PLL system with a channel spacing of 10 kHz would typically use a comparison frequency of 10 kHz with the output frequency sourced directly from the VCO output, this set-up makes it far more difficult to produce a clean signal.

The Blueberry board can generate signals higher than those produced by the DDS of the *Elektor Electronics* DRM receiver so it is now possible to explore the short wave region around 26 MHz. The receiver design uses a wideband first mixer stage connected directly to the aerial so it is also possible to push the oscillator frequency up a bit more and receive signals in the VHF band. It is perfectly possible to cover transmissions in the aircraft and 2 m amateur radio band; all we need now are some DRM stations up there to listen to.

Figure 5. Frequency selection on the peppermint board.

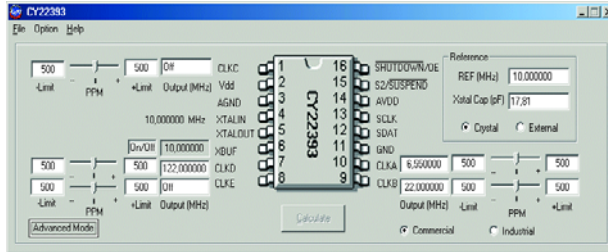


Figure 6. USB data transfer.

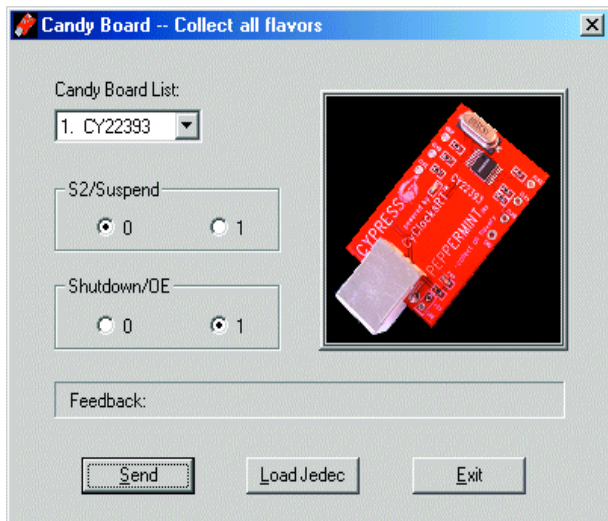


Figure 7. Programming the settings into EEPROM.

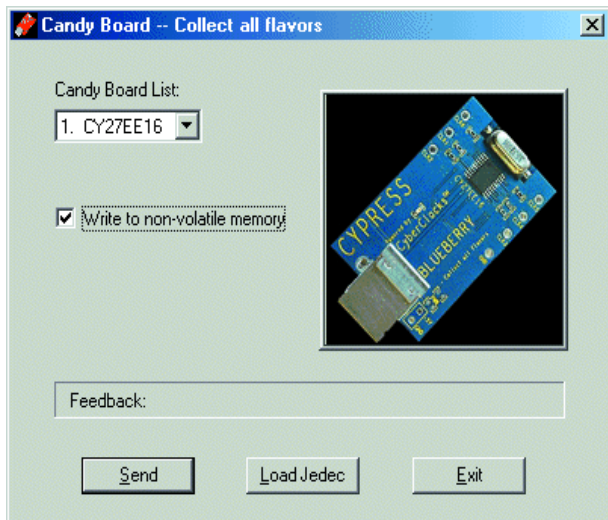
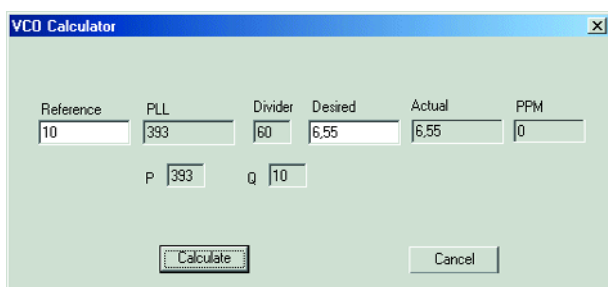


Figure 8. Factors P, Q and N in the VCO calculator.

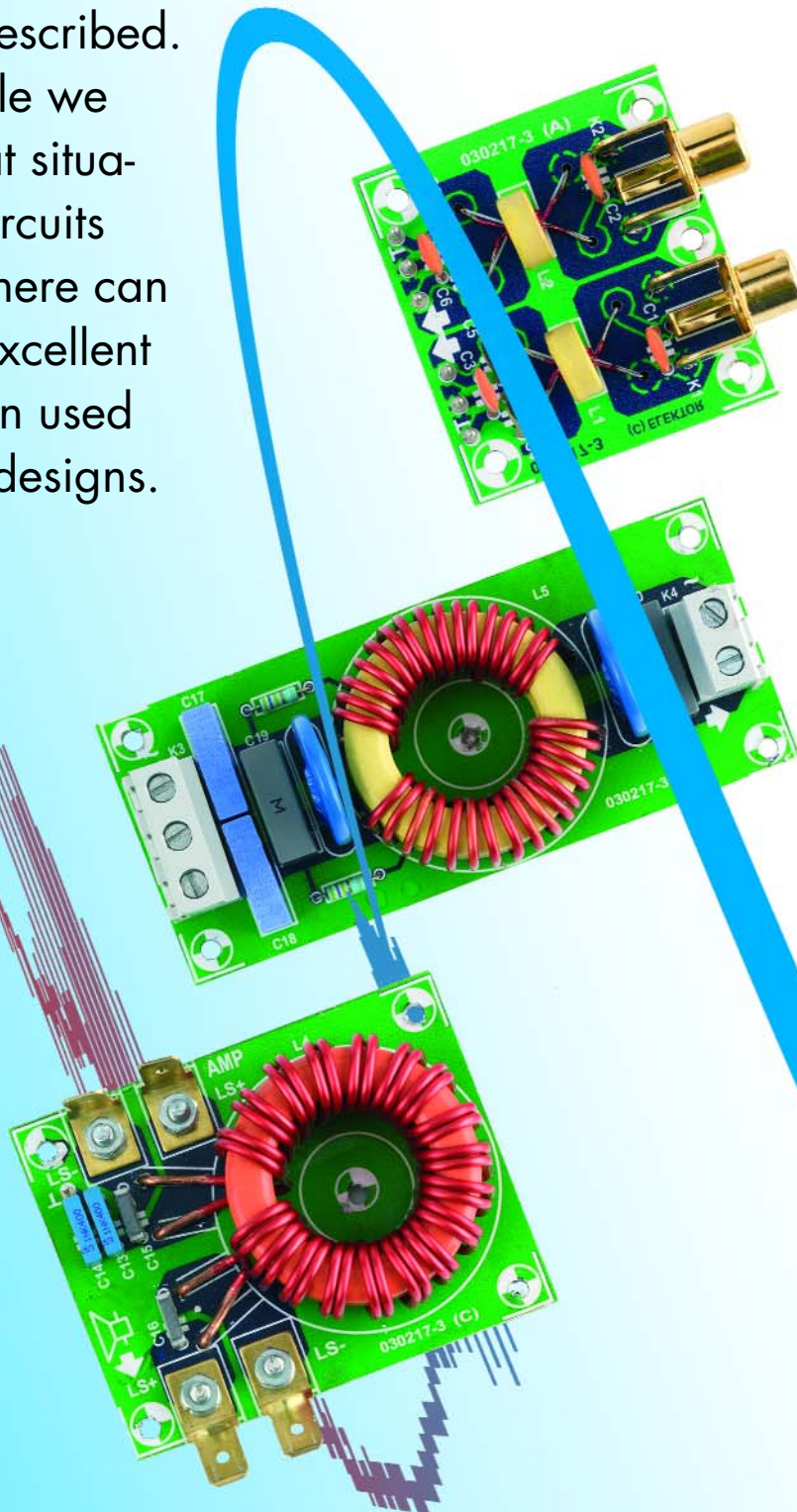


NOISE SUPPRESSION

Ton Giesberts

In the three-part article for the ClariTy 2 x 300-W final amplifier, the various input and output filters were not described.

In this article we remedy that situation. The circuits described here can also give excellent results when used with other designs.



FILTERS

For ClariTy and other final amps

Extremely high currents at relatively high frequencies are present in amplifiers such as our ClariTy design (*Elektor Electronics* June, September, October 2004). In such situations it is recommended to take measures to suppress interference signals (electromagnetic interference, or EMI for short). This can be done by using additional filters for all connections to the outside world. For an amplifier, three different types of filters are necessary. They are respectively used for the loudspeaker connections, the signal inputs and the 230-V mains connection.

For the inputs and the loudspeaker connections, it is common practice to filter only the interference currents shared by the two conductors (signal and ground), which is called 'common-mode suppression'. This causes the least possible effect on the audio spectrum. At the inputs to the $2 \times 300\text{-W}$ amplifier, for example, it is clear that only common-mode interference can be present. This is because an analogue gain stage is present at the input of the TA3030 amplifier IC, and there is also no question of interference arising directly from the signal source.

Another factor is that here the loudspeaker outputs drive loads having very low impedance, which means large currents can occur. However, the filters already present on the circuit board of the ClariTy amplifier suppress only the PWM signal. Such a signal is actually a purely differential-mode interference signal.

In the case of this amplifier, common-mode interference primarily arises from the amplifier as a whole. This interference can thus be found on all of its connections. That means that separate filters for suppressing common-mode interference must also be used for the loudspeakers in order to reduce EMI. As a PWM amplifier also loads its power source with a 'nasty' signal, it's a good idea to use a combination of common-mode and differential-mode suppression for the mains filter. This

can be implemented relatively easily by winding the filter coil in a special manner.

Toroidal cores are used for all of the filters described here. This minimises inductive coupling to the surroundings. Another advantage of using toroidal cores is that they make it possible to wind inductors that only generate an inductance for common-mode signals. By now it should thus be clear that inductors for mains filters generally have to be wound differently than inductors for loudspeaker filters.

Input filter

Let's start at the beginning: the input. In practice, it's clear from measurements made using an Audio Precision analyser that a sturdy input filter can provide significant benefits. Without such a filter, the measurements made on the ClariTy amplifier were unstable and in fact unusable.

The input filter (**Figure 1**) thus provides common-mode isolation between the signal source and the amplifier. In addition, capacitors for differential-mode suppression are included as a precaution. We prefer not to use ceramic capacitors in the signal path for audio applications, but in this case they are present in parallel with the output of the preamplifier for audio signals. If the preamplifier has low output impedance, the effect on the sound quality will be negligible. The two channels are kept fully apart on the circuit board, so the entire signal path between the preamplifier and the final amplifier remains separate for the two channels. The two grounds must be connected together at a single point at the analogue power supply neutral potential. In the case of our amplifier, this point is thus on the amplifier board. The filter also prevents ground loops from arising.

The inductor uses a very small toroidal core with dimensions of 10×4 mm. It has two windings, each just a bit more

than a single turn. In practice, this proves to be more than adequate (for our application). Two short (but sufficiently long) lengths of 0.5-mm diameter enamelled copper wire (ECW) are passed through the centre of the small toroidal core and wound together around the core (bifilar) in a single loop. The other ends thus emerge on the opposite side of the core. This yields a self-inductance of twice $14 \mu\text{H}$ and a leakage inductance of less than 100 nH . The leakage inductance is the virtual inductor that contributes to the differential-mode effect of the filter. Incidentally, it's difficult to measure the leakage inductance.

From the value of $14 \mu\text{H}$, it's apparent that each winding behaves as though it had nearly two turns. This can be seen from the fact that according to the data sheet, the value of the A_L factor for this toroidal core is 3470 nH . You can calculate this for yourself using the formula $L = N^2 \times A_L$ (where N is the number of turns).

Just as for the filters described later on, a printed circuit board has been designed for this filter. The inductor should be fitted vertically on the circuit board, and its leads must be pulled tight and soldered to the circuit board under tension. This avoids the need for any additional fastening. The component overlay (**Figure 2**) and photo (**Figure 1**) clearly show what is intended. Cinch sockets can also be fitted to the circuit board. The board should be fixed firmly in place using the five mounting holes.

The connections marked with the 'output' arrows and ground symbols must be connected to the amplifier inputs using good-quality screened audio cable. The pin between these connections must be connected to the enclosure via the shortest possible path. This can be done by fitting an M3 washer with soldering lugs to one of the fastening screws.

In the dimensioning of the capacitors, the primary consideration was the

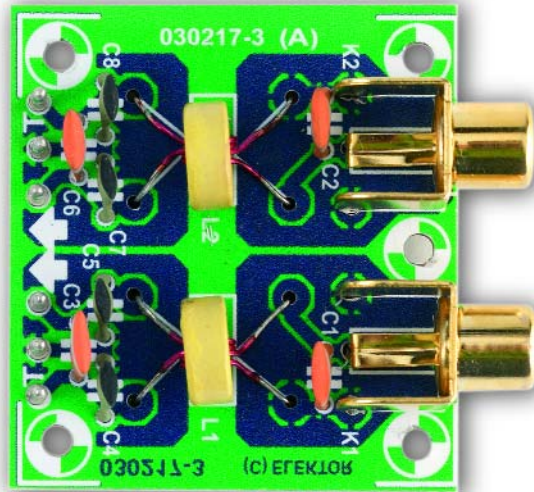
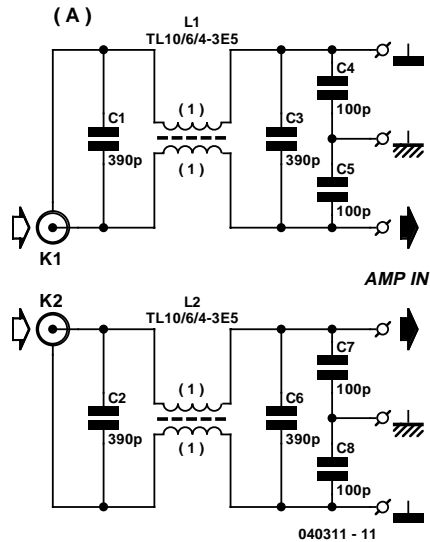


Figure 1. The input filter suppresses both common-mode and differential-mode signals. Pay particular attention to how the inductors must be wound and placed. Copper track layouts from our website.

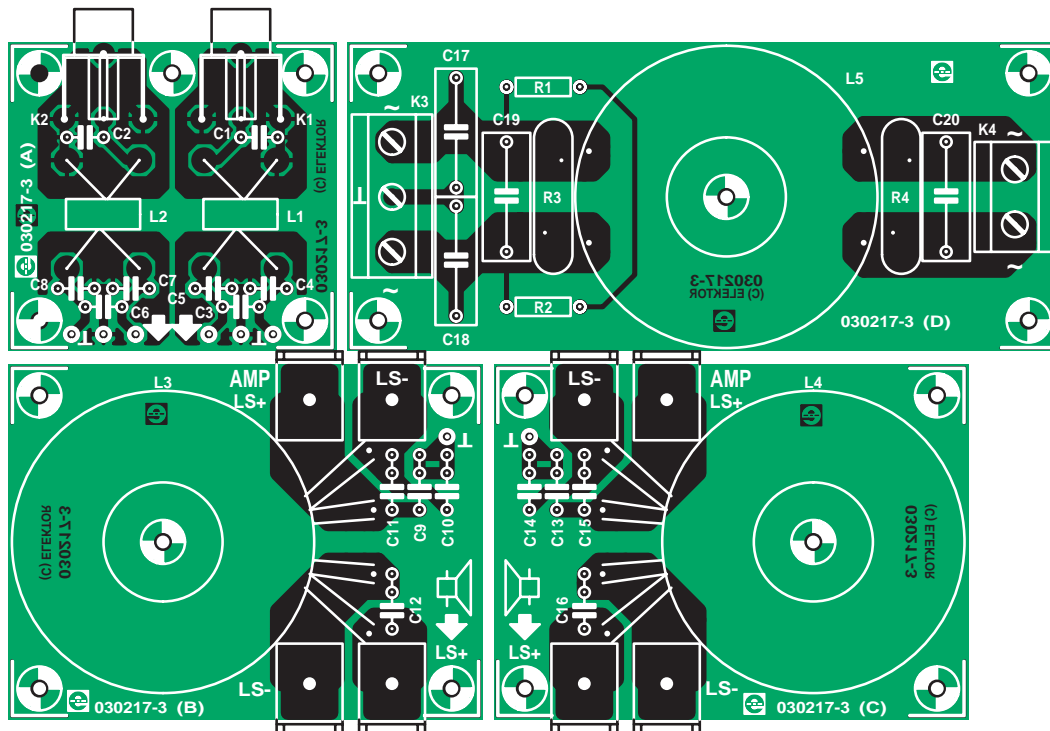


Figure 2. A single printed circuit board has been designed for all of the filters. The portions for the loudspeaker filters are laid out as mirror images of each other.

Components list

Resistors:

R1, R2 = 470k Ω
 R3, R4 = Varistor 275V (Epcos SIOV-S20K275, Farnell # 580-284)

Capacitors:

C1, C2, C3, C6 = 390pF
 C4, C5, C7, C8 = 100pF
 C9, C10, C13, C14 = 1nF 400V, lead pitch 5mm or 7.5 mm

C11, C12, C15, C16 = 10nF 400V, lead pitch 5mm or 7.5 mm
 C17, C18 = 10nF 275 V_{AC}, Class X2, lead pitch 15mm
 C19, C20 = 100nF 275 V_{AC}, Class X2, lead pitch 15mm

Inductors:

L1, L2 = 2 x 1 turn (bifilar) 0.5mm dia. (SWG26) enamelled copper wire on Ferroxcube core TL10/6/4-3E5 (Farnell # 305-6960)
 L3, L4 = 2 x 18 turns (bifilar) 1.5mm dia. (SWG16) enamelled copper wire on Ferroxcube core TX36/23/15-3E25 (Farnell # 305-7021)

L5 = 2 x 16 turns 1.5mm dia. (SWG16) enamelled copper wire on core TN36/23/15-3E5 (Farnell # 305-7010)

Miscellaneous:

K1, K2 = PCB mount cinch socket (T-709G from Monacor/Monarch)
 K3 = 3-way PCB terminal block, lead pitch 7.5mm
 K4 = 2-way PCB terminal block, lead pitch 7.5mm
 8 x spade terminal (fast-on), PCB mount, 3mm screw mounting
 PCB, order code **030217-1** (see Readers Services)

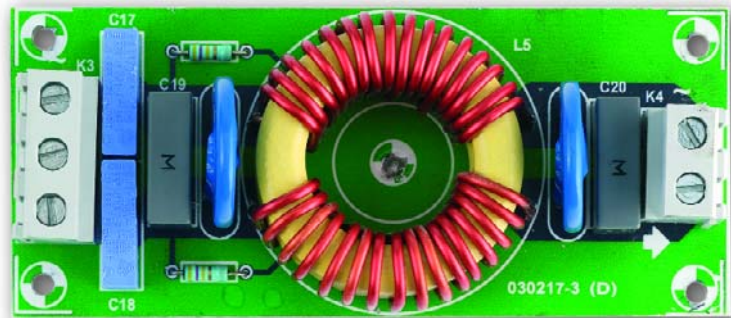
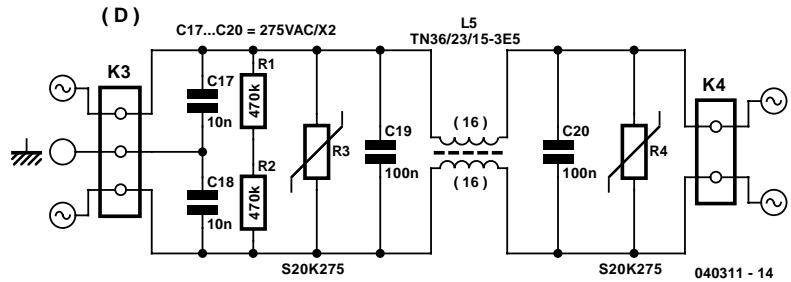


Figure 3. The mains filter is a quite conventional design, and like the input filter it suppresses both common-mode and differential-mode signals. For safety, the two inductor windings must be separated as far as possible.

capacitive load on the preamplifier. With this filter, it is only 880 pF (C1 + C3 + C5).

Mains filter

The mains inlet naturally amounts to a second input. Here we chose a conventional design (Figure 3). We used the largest possible core here (in terms of availability), which results in a large load capacity as well as high inductance. For mains filters, the inductance normally decreases as the load impedance increases (for the same dimensions). By using a large core (36 mm outside diameter) with 1.5-mm diameter wire wound in only a singly layer (which increases the maximum permissible current), we obtained a filter that can easily handle loads as high as 1000 VA.

The inductor has two identical windings, which are well coupled but separate. The separation is important due to the mains voltage connected between the two windings. For superior coupling, we selected 3E5 core material. It has very high permeability; the A_L factor for this core is no less than 11,400 nH.

The two windings are wound tightly on the core. This takes a certain amount of strength, since they are wound using 1.5-mm copper wire and a gap of at least 3 mm must remain between the opposing windings (for Class 1 insulation). If you can't manage this, just reduce each winding by one turn. Note that the two windings

must be as nearly possible identical. This prevents premature saturation of the core.

With 16 turns per winding, you will have two windings with a self-inductance of somewhat more than 3 mH $\pm 30\%$ (which is also the self-inductance of the inductor for common-mode signals) and a leakage inductance of around 15 μ H.

The filter also contains two robust varistors that provide additional protection against sporadic mains disturbances (transients), although they don't protect against common-mode transients.

R1 and R2 ensure that the capacitors are quickly discharged if no mains voltage is present (and after it's disconnected). This prevents dangerous voltages from remaining present on the mains connector. For safety, use plastic stand-off bushes for mounting the circuit board in order to maintain adequate clearance between the circuit board tracks and protruding connections on the copper side and the metal parts of the enclosure. For a Class-1 device, a separation of 3 mm is in principle sufficient, but 6 mm is recommended.

As the inductor is attached to the circuit board quite securely by its four leads, additional mechanical fastening is not required. For anyone who nevertheless considers mechanical fastening necessary, a hole is provided in the circuit board in the middle of the inductor. Be sure to use only plastic parts for any such fastening, in order to avoid affecting the inductance of the coils. The layout of the printed circuit

board is shown in Figure 3.

Capacitors C19 and C20 form part of the differential-mode suppression network, but given the low impedance of the power supply and mains network, they have less effect than C17 and C18, which provide common-mode suppression. These two capacitors are configured in parallel for common-mode signals, so they constitute a 20-nF capacitor that forms an LC filter in combination with the self-inductance of L5.

The impedance of the amplifier for common-mode signals primarily depends on the parasitic capacitance between the primary and secondary windings of the supply transformer (as well as the impedance of the wiring inside the enclosure), and it is reasonably high. This means that the self-inductance of the inductor is primarily responsible for filtering common-mode signals.

The values of C17 and C18 cannot easily be increased, since they also generate leakage currents to ground when the filter is connected to the mains voltage (via one of the two capacitors, depending on which one is connected to the live mains lead).

The ground rail of the filter is connected to the enclosure together with the ground connection of the mains inlet connector.

Speaker filter

In contrast to the mains filter, the inductors for the loudspeaker filters (Figure 4) are wound bifilar (see Figure 5). Consequently you have to wind

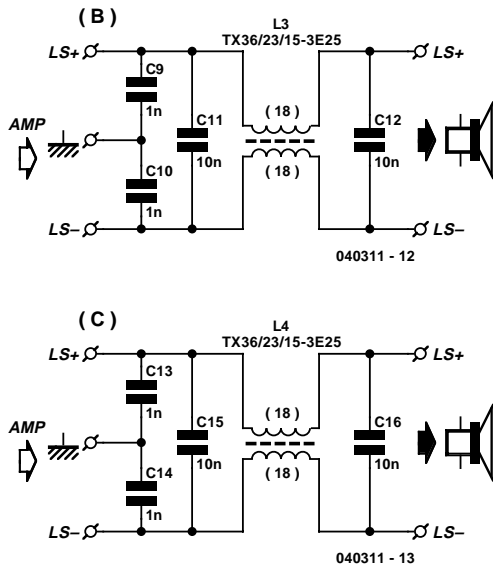


Figure 4. The output filter for the loudspeaker signals is specifically intended to provide common-mode suppression.

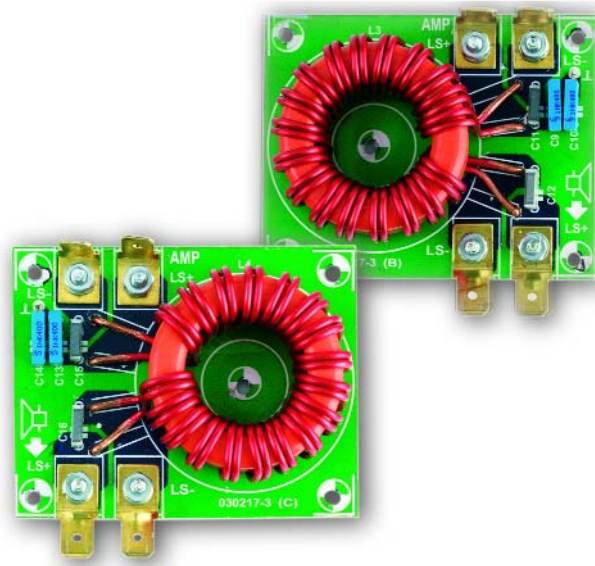


Figure 5. The inductors are wound bifilar.

two lengths of 1.5-mm copper wire on the core at the same time, which takes even more strength.

Bifilar winding ensures excellent coupling between the two windings and causes the leakage inductance to be very small. You have to bear in mind that peak currents of around 20 A can flow through the wires of the inductor. If the windings are not identical, the inductor will saturate and the filter will be ineffective.

Naturally, using these filters slightly increases the output impedance of the amplifier. Flat tab connectors are used for the connections, due to the potentially high currents. This also makes it possible to connect leads directly to the circuit board using M3 solder lugs (spade terminals). This helps avoid a certain amount of contact resistance. Another possibility is to solder the leads directly to the copper side.

Here we selected 3E25 core material. It has somewhat lower permeability than 3E5 material, but it can be used over a wider frequency range and is less prone to saturation (although that isn't so important if the inductor is wound properly). The selected core has the same dimensions as the one used in the mains filter.

As no special insulation between the two windings is necessary here (although the copper wires must naturally have a heavy enamel coating), it's easily possible to add two more turns. The two 18-turn windings of 1.5-mm enamelled copper wire yield an inductor with a self-inductance of approxi-

mately $2 \times 2.4 \text{ mH} \pm 25\%$ and a leakage inductance of only $2 \mu\text{H}$.

Be sure to leave the windings long enough to allow them to be properly fitted to the circuit board. This will require a bit of 'cut and try'. The inductor is held reasonably firmly on the board by its four leads, but we recommend using a small sheet of plastic and plastic screw to secure it to the circuit board. These filters should be placed as close as possible to the amplifier outputs.

Next a few remarks about the capacitors. C1, C12, C15 and C16 are actually intended to filter out RF interference (in differential mode); they do not have any effect on common-mode signals. However, they are connected in parallel with the output of the amplifier, so they have intentionally been kept rather small in order to keep their effect as small as possible. They increase the filter capacitance by just less than 10%.

There are also capacitors in the filter that do provide common-mode suppression: C9, C10, C13 and C14. They are effectively in series for differential-mode signals, so they can practically be ignored for such signals. For common-mode signals, by contrast, they are effectively in parallel and provide a capacitance of 2 nF. The junction of C9/C10 and C13/C14 must be connected to the enclosure.

If you use our printed circuit board design, be sure to pay attention to the polarisation of the filters for two-chan-

nel applications, since they are opposite to each other. For stereo use, swapping the phases of the outputs wouldn't be obvious, but if the amplifier is used in bridge mode, it is essential ensure that the phasing is correct. For this reason, the circuit boards for the two channels are designed as mirror images of each other, so equivalent connections are close together and on the same side of the board.

Speaker cables

Finally, we mustn't forget the cabling. Generally speaking, cables make excellent aeri- als, with a common-mode impedance of approximately 150 Ω . Particularly with the pulse-width modulated signals coming from our amplifier, the cables can be blamed for a significant portion of the interference radiated to the surroundings.

The simplest way to counter this is to keep the distance between the amplifier and the loudspeakers as short as possible. Another possibility is to slide a pair of substantial ferrite cores over the cables (at the amplifier end), which can increase the common-mode impedance by a factor of as much as several hundred. Another option is to run the loudspeaker cables inside metal screens connected to the amplifier enclosure.

Ferrite cores of various sizes can also be fitted to the other cables (mains cable and input signal cables).

(040311-1)

THERMOELEMENT

Easy processing with the MAX6675

Design engineers like to use thermoelements when it comes to probing around in really wide temperature ranges. Modern integrated circuits are available that act as sensor interfaces to a microcontroller.

The operation of thermoelements is based on the Seebeck effect: a temperature difference across a wire causes movement of free electrons. The amount of charge displacement is dependent on the electrical properties of the wire.

As illustrated in **Figure 1**, thermal energy is applied to electrons normally moving inside a crystal grid structure. The applied energy causes the electrons to move faster and eventually diffuse from the hot to the cold end. There they slow down again, releasing their energy. As electrons concentrate at the cold end, a negative electrode is formed relative to the hot end. At the same time an elec-

trical field is established maintaining a dynamic balance between the electrons.

If the voltage between the hot and the cold end is to be measured, one thing you have to do is connect the hot end to an electrical conductor that's also exposed to the temperature changes. If this second conductor has the same electrical properties as the first one, then no voltage can be measured between the charge density points. However if two different conductors are used, a voltage exists between the two 'cold' ends that's dependent on the temperature difference and the electrical properties of both conductors.

In the test arrangement shown in **Figure 2**, no absolute thermovoltage can be measured, only differential levels. In order to establish the temperature at the measurement point, the temperature at the connection terminal has to be known as well as constant. Datasheet values like 'thermovoltage at 200 °C' always relate to a comparison to the thermovoltage at 0 °C.

If the end of the thermoelement is at an unknown temperature (and far removed from the measurement electronics) it has to be extended right into the area of known temperature (comparison point), using a special compensating conductor. A problem arises with the measurement of thermovoltage using an instrument whose connection terminals are made of a different material. These create two additional thermoelements, which may be compensated, though, either by keeping the comparison point at a known temperature, or perform an appropriate correction at the instrument terminals.

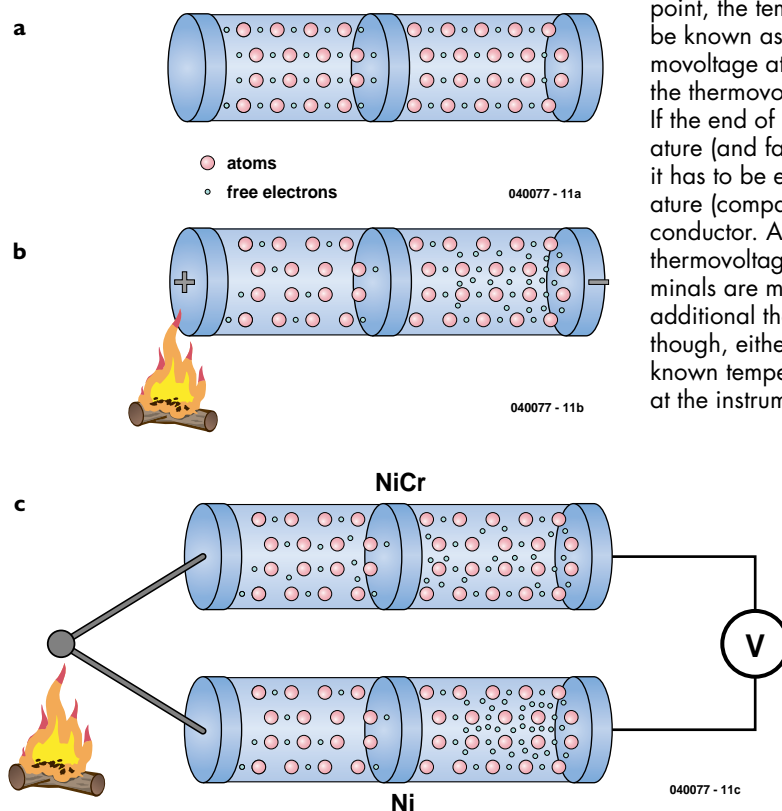


Figure 1. In a conductor, valence electrons are equally distributed (a), but diffuse to the cold side when the conductor is heated on one side (b). If two conductors of different material are connected at the hot sides, the free electrons cause a voltage difference by concentrating at the cold side.

ENTS

Thermoelements

The voltage caused by the thermoelectric effect is very small at just a few millivolts per Kelvin, depending on the metal or alloy combination. As a result, thermoelements are not used for measurements in the range $-30\text{ }^{\circ}\text{C}$ to $+50\text{ }^{\circ}\text{C}$ because the temperature difference with the reference is simply too small to ensure a reliable signal. Consequently thermoelements are typically used for measurements up to $1000\text{ }^{\circ}\text{C}$.

From the multitude of metal and alloy combinations, a few have been selected and their voltage series laid down in DIN standard EN 60584 (types L and U are obsolete and now replaced by J and T). The element types differ in respect of maximum temperature and their characteristics as shown in **Figure 3**. The maximum temperature is the highest value at which the tolerance is maintained. Under 'defined up to' you find the highest temperature at which the thermovoltage complies with the standard. With the thermocouples listed, the first material is always the positive terminal.

As you can see from the response curves, the voltage supplied by thermoelements is not a perfectly linear function of applied temperature. If you want really accurate readings, then a linearisation circuit is required specifically designed for each type of element. **Figure 4** shows that for a K element the maximum deviation from the linear function is no more than 0.5 K at $750\text{ }^{\circ}\text{C}$. If you can live with such a small error in a relatively narrow measurement range, then a complex linearisation circuit is not in order.

Processing the values

In a previous publication from our archive, 'Fast, Precise Thermometer' (*Elektronik* January 1992), we already proposed a thermoelement application. In that circuit, the comparison point compensation was handled by discrete components. Today, the semiconductor industry supplies complete, dedicated converters in a chip. An example is the MAX6675, a 12-bit A/D converter with SPI interface (and complementary control) and a noise-suppressing, buffered differential measurement amplifier in front of it (not shown). The internal diagram (**Figure 4**) also reveals a compensation diode that captures the temperature at the comparison point and so provides the necessary correction of the measured value. The MAX6675 is ready for measurement point temperatures from $0\text{ }^{\circ}\text{C}$ to $1023.75\text{ }^{\circ}\text{C}$ and is capable of compensating comparison point temperatures of -20 to $+85\text{ }^{\circ}\text{C}$. This results in an impressive resolution of $0.25\text{ }^{\circ}\text{C}$. By comparison, another IC from the series, the MAX7774 with 10-bit resolution achieves a resolution of $1\text{ }^{\circ}\text{C}$.

SPI

The 'cleaned' measurement value is finally digitized by the A/D converter, serialized, and may be requested by a microcontroller (read-only). The extremely simple SPI proto-

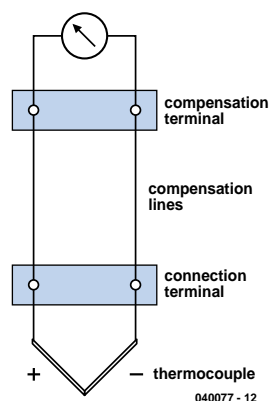


Figure 2. Structure of a thermoelement with a hot measurement junction and a cold comparison junction. A compensation wire allows the comparison point to be remote from the connection point.

col supplies a 16-bit word in response to a clock signal. Not much needs to be said about the timing, as lots of literature on the protocol is available from Internet. **Figure 5** shows the structure of the 16-bit word. A sequence of zeroes at positions 3 (LSB) through 14 (MSB) means a temperature of $0\text{ }^{\circ}\text{C}$, while twelve ones indicate $1023.75\text{ }^{\circ}\text{C}$ which is just another rather uncomfortable level.

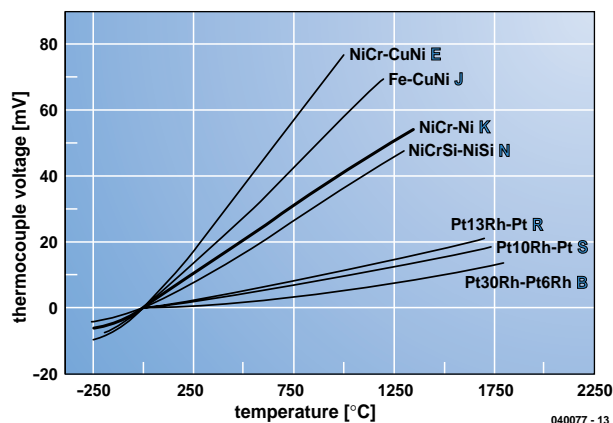


Figure 3. Thermovoltages from a number of standardised metal and alloy combinations.

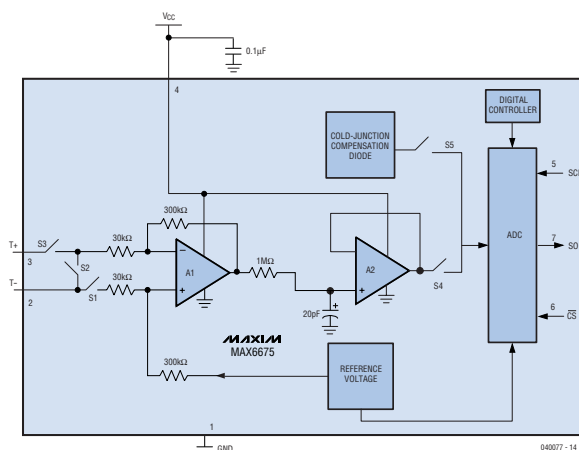


Figure 4. Internal diagram of the MAX6675.

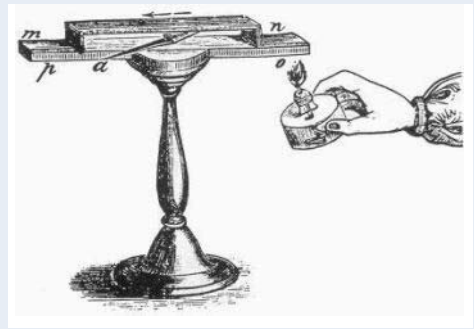
Thomas Johann Seebeck



Thomas Johann Seebeck was born on April 9, 1770, in Reval, now Tallinn, the capital of Estonia, into a wealthy merchant family. His father being of German origin, medical science studies at the Universities of Berlin and Göttingen were more or less imposed on young Thomas Johann. In 1802 he graduated as a medical doctor and although he did set up practice in Göttingen, Seebeck decided to change to physics research, hence he is known from his experiments in physics rather than his achievements as a general practitioner.

Mostly self-educated and a 'freeman student' he went to Jena, Bayreuth and Nürnberg where he deepened his knowledge of physics. He met Johann Wolfgang von Goethe and joined him in his work on the (anti-Newtonian) theory of colour and coloured light.

Seebeck investigated the heating effect of different colours in the solar light spectrum. In 1808, he was the first to produce potassium-amalgam and in 1810 he noticed the colour susceptibility of moist silver oxide (a precursor to colour photography). In the same year, Seebeck observed the magnetic properties of nickel and cobalt. A few years later, in 1818, he discovered the optical activity (rotation of the polarized area) of sugar solutions. He then returned to the University of Berlin where he researched electrical magnetization of iron and steel. In 1821



Seebeck discovered the thermoelectric effect and two years later proposed a thermoelectric voltage series as well as published the fruits of his research in 'Magnetic Polarization of Metals and Ores by Temperature Difference. Proceedings of the Prussian Academy of Sciences'. Seebeck continued to work at the Berlin Academy for 13 years. He died in Berlin on 10 December 1831.

Element	Max. temperature	Defined up to	Positive terminal
J: Fe-CuNi	750 °C	1,200 °C	black
T: Cu-CuNi	350 °C	400 °C	brown
K: NiCr-Ni	1,200 °C	1,370 °C	green
E: NiCr-CuNi	900 °C	1,000 °C	violet
N: NiCrSi-NiSi	1,200 °C	1,300 °C	lilac
S: Pt10Rh-Pt	1,600 °C	1,540 °C	orange
R: Pt13Rh-Pt	1,600 °C	1,760 °C	orange
B: Pt30Rh-Pt6Rh	1,700 °C	1,820 °C	-

Bit 2 has a special function. It is normally low, but will carry a High when the thermocouple input is open, for example, as the result of a cable malfunction. This will only work, however, when the T- input is grounded (as close as possible to the GND connection).

Practical use

A number of requirements should be fulfilled in order to achieve maximum accuracy.

- Self-heating of the MAX6675 should be avoided. Provide for sufficient ventilation and large ground planes.
- The thicker the wire used for the thermoelement and the compensation line, the smaller the risk of measured values being corrupted by the wire resistance(s).
- If you cannot avoid the use of a thin thermoelement, you still need to employ a thick compensation wire.
- Mechanical stress on the cable and the element is to be avoided.

- Twisted-pair cable should be used with long thermoelement connections.
- Sudden temperature changes are to be avoided.
- Users should always observe the maximum temperature specified for the thermoelement, as well as the much lower value for the compensation line.
- The mechanical loading of the element is to be matched to the application.
- Despite the use of a low-noise measurement amplifier inside the MAX6675, the thermoelement, all wires and connections should be kept far removed from of electrical noise sources.

(040077-1)

For further reading

MAX6675 datasheet
<http://pdfserv.maxim-ic.com/en/ds/MAX6675.pdf>

[http://en.wikipedia.org/wiki/T. J. Seebeck](http://en.wikipedia.org/wiki/T._J._Seebeck)

Figure 5. Structure of the 16-bit word supplied by the MAX6675.

BIT	DUMMY SIGN BIT	12-BIT TEMPERATURE READING											THERMOCOUPLE INPUT	DEVICE ID	STATE	
		14	13	12	11	10	9	8	7	6	5	4				3
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	0	MSB											LSB		0	Three-state

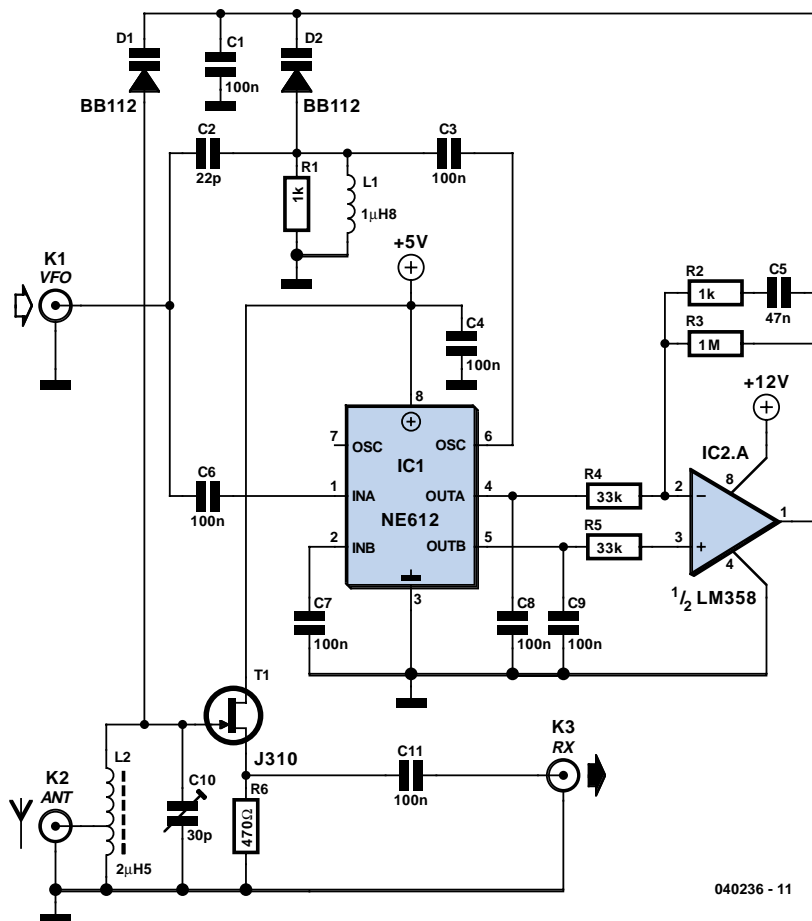
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AUTOMATIC PRESEL

for our DRM receiver

Burkhard Kainka

A PC-controlled receiver is very convenient, especially for DRM, since it makes it easy to locate your favourite stations. However, this advantage is lost if you have a manual preselector and must tune the antenna by hand: an automatic preselector is what you need!



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With a PLL-controlled receiver things are very simple. The PLL tuning voltage can be used simultaneously to control the first RF stage. Instead of one varicap diode two are used. If DDS tuning is used, then although we have better phase purity, which is a decisive advantage in DRM applications, there is no tuning voltage available for the

first stage. What is needed is a circuit to generate a suitable tuning voltage automatically.

Tracking Filter

The circuit can be seen as a kind of passive PLL. Rather than a tracking oscillator, here we have a tracking res-

onant circuit. The resonant frequency of the circuit is made to track the frequency of the controlling signal.

At the heart of the tracking circuit is an NE612 mixer (IC1) which is used here as a phase detector. The NE612 was used in a similar way by Gert Baars in 'Alignment-free FM Detector'

LECTOR

in the July/August 2001 issue of *Elektronik*.

The controlling input signal can, for example, be taken directly from the VFO pin on the TUF-1 ring mixer in the DRM receiver. This goes directly to the mixer input (pin 1) of the NE612 as well as to the oscillator input (pin 6) via a resonant circuit tuned by a varicap diode (L1 and D2). A DC difference signal is available at the output of the mixer which carries information as to the phase lag between the direct signal and that coupled through the resonant circuit. At resonance the phase difference and hence the differential voltage is zero.

The control loop amplifier constructed around IC2.A controls the resonant frequency in such a way that it tracks the VFO frequency. The output voltage thus automatically follows this frequency as well. The final result is that we have at the output of the operational amplifier a tuning voltage that varies from about 1 V at 5.7 MHz to 7 V at 16 MHz. These values are obtained with a BB112 tuning diode for D2 and a fixed 1.8 μ H inductor for L1. The resonant circuit needs to be fairly heavily damped by a 1 k Ω resistor (R1) to prevent the control loop oscillating.

The second varicap diode (D1) receives the same control voltage and thus automatically tunes the first stage resonant circuit formed by L2 and C10. As in any superheterodyne receiver it is not easy to achieve optimal tracking between oscillator and input circuit. The received frequency always lies 455 kHz below the oscillator frequency. L2 in the input circuit is a tunable coil and can be adjusted for maximum sensitivity at the lower end of the tuning range. A similar adjustment for the upper end of the range can be made using trimmer capacitor C10. This

should then also give good tracking over the middle part of the range. Our prototype worked without problems from 5 MHz up to 16 MHz.

The first amplifier stage itself is a JFET source-follower built around T1. A BF245 may be used instead of the J310. The resonant circuit is only lightly damped. The voltage gain is determined by the transformer ratio between the antenna input and the resonant circuit. In our prototype we used 15 turns of 0.3 mm enamelled copper wire on a ferrite coil former with a diameter of 5 mm. The antenna tap was on the third turn.

The BB112 has a capacitance of about 500 pF with a tuning voltage of 1 V. Higher values can be achieved by reducing the voltage further, down to nearly 0 V. The disadvantage of doing this is that the Q factor falls rapidly. In practice tuning works without problems in the 75 m band, and so the DRM station at 3995 kHz can be received. In this case the tuning voltage is only around 0.1 V.

Hints and tips

Varicap diodes for AM frequencies are not easy to get hold of. The BB112 can be obtained from Geist Electronic in Germany and from the online shop of the German magazine *Funkamateure*. Equally suitable are the dual tuning diode type BB313 and the similar KV1270NT from Toko. Most of the AM varicap diodes that are still available appear to come from surplus stock. However, they must still be being made somewhere (presumably in China) as otherwise we would have no PLL-based medium wave, shortwave or long wave receivers! There are probably considerably more broken radios thrown away every year than there is

demand for varicap diodes for home-built receivers: a few minutes with a soldering iron can prove very worthwhile: see, for example, www.bkainka.de/bastel99.htm (in German). Finally, a brief note on using the automatically-tuned preamplifier. In most cases DRM will work perfectly well without preselection. In just a few cases is the SNR significantly improved by preselection. The device is of course particularly useful when there is interference at the image frequency.

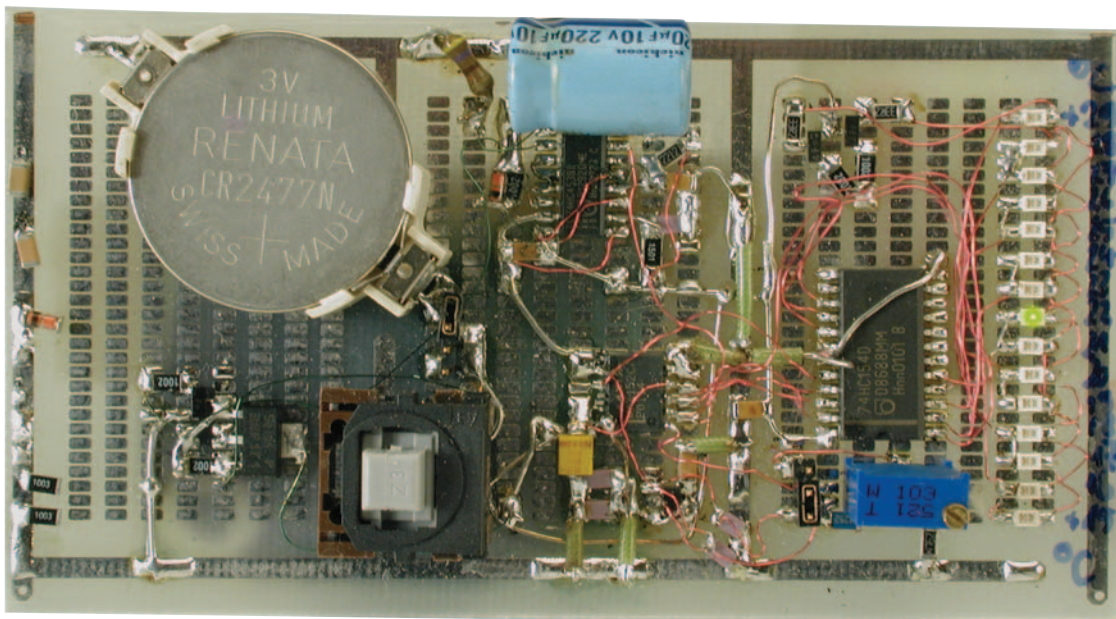
However, in AM mode there is a significant improvement. Every dB of image frequency attenuation can reduce interference by 1 dB. For example, the Austrian ORF transmissions on 6155 kHz (Ö1) often suffer interference from strong SSB transmitters in the 40 m band. The automatic preselector completely solves this problem. The effect is even more marked when trying to pick out very weak amateur transmissions from among the broadcast programmes: in this case a tuned preamplifier is essential.

With a little extra effort a second preselection stage can be added for even greater image rejection. Either a two-stage tuneable bandpass filter can be used or a further tuning circuit can be added after the preamplifier, that is, between C11 and the output connector.

(040236-1)

ROOM THERMOMETER

Gregor Kleine



Just add an A/D converter and a few discrete LEDs to this temperature sensor chip and you get a simple thermometer. This application builds an accurate and stable thermometer displaying room temperature with a resolution of 1 °C.

The MAX6610 from MAXIM is a relative newcomer to the field of temperature sensing IC's. The chip has a built-in voltage reference and an analogue output scaled to simplify integration with an 8 or 10-bit A/D converter (see textbox). A simple room thermometer does not usually require such precision and we run a risk of being accused of using a sledgehammer to crack a nut but the chip is quite versatile and this

application provides a useful introduction to some of the features of the device. For more information on this device see the inset.

The complete room thermometer block diagram is shown in **Figure 1**. The MAX6610 precision temperature sensor outputs an analogue signal that's linearly proportional to temperature. The signal is converted into a digital value by the 8-bit MAX152 analogue to

digital (A/D) converter. Only five bits of the output byte are used by the decoder to light a single LED to indicate room temperature. Finally two monostables (monoflops) are used to generate all the timing signals necessary to control events in the circuit. The first produces the conversion signal to the A-D converter while the second controls a MOSFET in the power supply line to maintain power to the

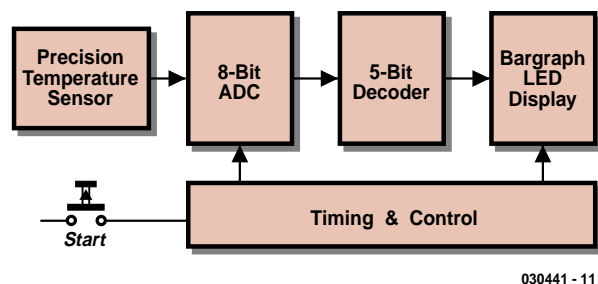


Figure 1. The room thermometer block diagram.

circuit during the measurement process. After an adjustable period it switches the thermometer off. It is only necessary to press S1 briefly to activate the circuit and the temperature will be displayed for a few seconds.

On closer inspection

Figure 2 shows the complete circuit diagram of the room thermometer. IC1 contains the temperature sensing element and can be used in the temperature range from $-40\text{ }^{\circ}\text{C}$ to $+125\text{ }^{\circ}\text{C}$. The sensor contains an on-board reference so that it does not require any calibration and is designed to interface with an analogue to digital (A-D) converter. It outputs a reference voltage of 2.560 V from pin 5. Pin 4 is the analogue TEMP output; the voltage level at this pin is proportional to temperature. If an 8-bit A-D converter is used to produce a digital value each single bit change corresponds to exactly $1\text{ }^{\circ}\text{C}$ temperature change. With a V_{REF} of 2.560 V and an 8-bit A-D converter each bit change of the output is equal to an input change of 10 mV . IC1 produces an output signal with a characteristic of 10 mV/K with a DC offset of 0.750 V . The voltage V_{TEMP} is given by:

$$V_{\text{TEMP}} = 750\text{ mV} + T \times 10\text{ mV}$$

(with T in $^{\circ}\text{C}$)

Table 1 shows the output from an A-D converter represented as decimal (dec) hexadecimal (hex) and binary (bin) values.

The sensor will be used at room temperatures so it is not necessary to display the complete temperature range. Table 1 shows that we only need to look at the least significant five bits at

the output of the ADC if the displayed temperature range is limited from $+5\text{ }^{\circ}\text{C}$ (0101 0000) to $+36\text{ }^{\circ}\text{C}$ (0111 1111). The codes between these temperatures are not repeated. Table 2 lists the digital output values for temperatures within this range.

Each degree is represented by a single LED so a total of 32 LEDs are required if a temperature range of 32 degrees is to be displayed. A 4 to 16 way decoder is used to decode bits D1 to D4 from the output of IC2. The least significant bit, D0, is used to switch either transistor T3 or T4, these drive two columns of eight LEDs. T4 is

conducting when D0 output is low while T3 conducts when D0 is high. This arrangement effectively produces a 5 to 32-way decoder function. Only one of the green LEDs will be lit at any one time so current limiting on each column can be performed by a single resistor (R6 and R7).

Although the decoding is available to display a temperature range of $32\text{ }^{\circ}\text{C}$ this can be reduced by simply omitting any LEDs that are not required. The circuit diagram shows just 15 LEDs fitted to display a range from $+15\text{ }^{\circ}\text{C}$ to $+29\text{ }^{\circ}\text{C}$. Any other range can be chosen providing it falls within $+5\text{ }^{\circ}\text{C}$ to $36\text{ }^{\circ}\text{C}$.

Table 1. Correlation between temperature, sensor output voltage and digitised measurement value.

Temperature	V_{TEMP}	ADC _{dez}	ADC _{hex}	ADC _{bin}
$-40\text{ }^{\circ}\text{C}$	0.350 V	35	23	0010 0011
$-20\text{ }^{\circ}\text{C}$	0.550 V	55	37	0011 0111
$-10\text{ }^{\circ}\text{C}$	0.650 V	65	41	0100 0001
$-5\text{ }^{\circ}\text{C}$	0.700 V	70	46	0100 0110
$0\text{ }^{\circ}\text{C}$	0.750 V	75	4B	0100 1011
$+5\text{ }^{\circ}\text{C}$	0.800 V	80	50	0101 0000
$+10\text{ }^{\circ}\text{C}$	0.850 V	85	55	0101 0101
$+15\text{ }^{\circ}\text{C}$	0.900 V	90	5A	0101 1010
$+20\text{ }^{\circ}\text{C}$	0.950 V	95	5F	0101 1111
$+25\text{ }^{\circ}\text{C}$	1.000 V	100	64	0110 0100
$+30\text{ }^{\circ}\text{C}$	1.050 V	105	69	0110 1001
$+35\text{ }^{\circ}\text{C}$	1.100 V	110	6E	0110 1110
$+40\text{ }^{\circ}\text{C}$	1.150 V	115	73	0111 0011
$+50\text{ }^{\circ}\text{C}$	1.250 V	125	7D	0111 1101
$+80\text{ }^{\circ}\text{C}$	1.550 V	155	9B	1001 1011
$+100\text{ }^{\circ}\text{C}$	1.750 V	175	AF	1010 1111
$+125\text{ }^{\circ}\text{C}$	2.000 V	200	C8	1100 1000

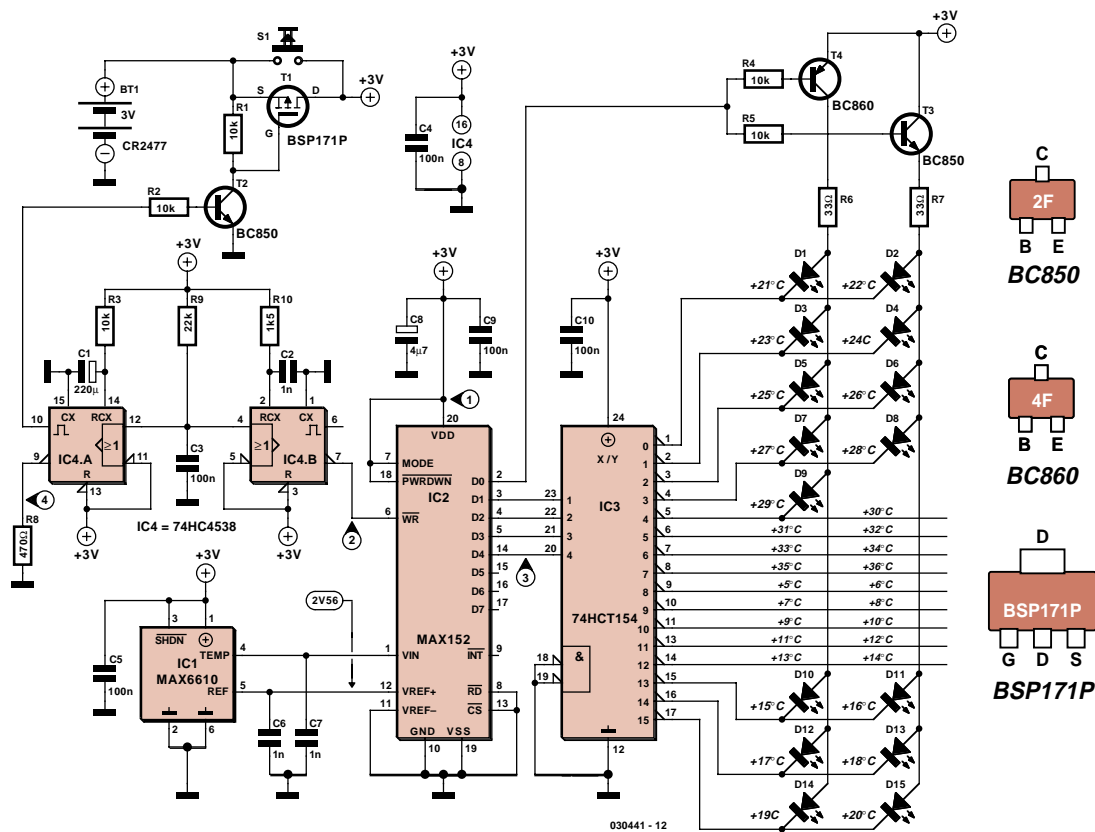


Figure 2. The circuit diagram showing test points and voltage levels.

Table 2. Digitised temperature values within measurement range.

Temperature	V _{TEMP}	ADC _{bin}	T3 / T4	IC3
+5 °C	0.800 V	0101 0000	T4	Q8
+6 °C	0.810 V	0101 0001	T3	Q8
+7 °C	0.820 V	0101 0010	T4	Q9
+8 °C	0.830 V	0101 0011	T3	Q9
...
+17 °C	0.920 V	0101 1100	T4	Q14
+18 °C	0.930 V	0101 1101	T3	Q14
+19 °C	0.940 V	0101 1110	T4	Q15
+20 °C	0.950 V	0101 1111	T3	Q15
+21 °C	0.960 V	0110 0000	T4	Q0
+22 °C	0.970 V	0110 0001	T3	Q0
+23 °C	0.980 V	0110 0010	T4	Q1
+24 °C	0.990 V	0110 0011	T3	Q1
+25 °C	1.000 V	0110 0100	T4	Q2
+26 °C	1.010 V	0110 0101	T3	Q2
....
+31 °C	1.060 V	0110 1010	T4	Q5
+32 °C	1.070 V	0110 1011	T3	Q5
+33 °C	1.080 V	0110 1100	T4	Q6
+34 °C	1.090 V	0110 1101	T3	Q6
+35 °C	1.100 V	0110 1110	T4	Q7
+36 °C	1.110 V	0110 1111	T3	Q7

Temperature sampling

The MAX152 (IC2) 8-bit A-D converter operating from a +3 V supply is used to digitise the analogue output voltage from IC1. A logic low on the read input (\overline{RD} , pin 8) and the chip select input (\overline{CS} , pin 13) configures IC2 to stand-alone mode so that a pulse at the \overline{WR} (pin 6) input will cause the converter to sample the analogue input voltage and output its digital value. The digital data is valid approximately 2 μ s after the rising edge of the \overline{WR} pulse. **Figure 3** shows the timing diagrams corresponding to the numbered test points on the circuit.

Pressing S1 switches power to the circuit and starts the temperature measuring process. The monoflop IC4.B supplies the \overline{WR} pulse to the A/D converter but the start of this pulse is delayed ($T1 \approx 500 \mu$ s) by C3 and R9 to allow the temperature sensor (IC1) to stabilise before its output is sampled. The \overline{WR} pulse width ($T2 \approx 1 \mu$ s) is governed by R10 and C2. The conversion time (T3) of IC2 is approximately 2 μ s so the output signals to the decoder (IC3) and transistors T3/T4 will be stable after a total time of $T1+T2+T3$

Author profile

Gregor Kleine (41) has been a development engineer with a well-known Munich-based test equipment manufacturer for the past 10 years. He is currently designing signal generator equipment for the RF spectrum up to 6 GHz used mainly for digital TV testing. He graduated from Aachen Technical University in 1989. He has contributed many articles both analogue and digital for *Elektor Electronics* in the past 20 years and has also penned many informative articles on communication technology including Digital TV, ADSL, UMTS and Bluetooth.



(503 μ s). This time period is so short that any LED that may incorrectly light during this period should go unnoticed. The trigger for monoflop IC4.A is also produced by the C3/R9 network during power-up and generates a 3-second pulse (pin 10) to switch transistor T2 and MOSFET T1. The MOSFET is connected in parallel to S1 so the pushbutton can be released and monoflop IC4.A ensures that the circuit will stay powered for about 3 seconds.

Resistor R8 discharges the supply at the end of the timing period to ensure that the supply voltage falls to zero relatively quickly when the circuit switches off (Figure 3). At the end of the 3-second measurement period the inverting output of IC4.A (pin 9) will go high and residual charge in the supply is discharged through R8. This ensures that the circuit will be ready to take

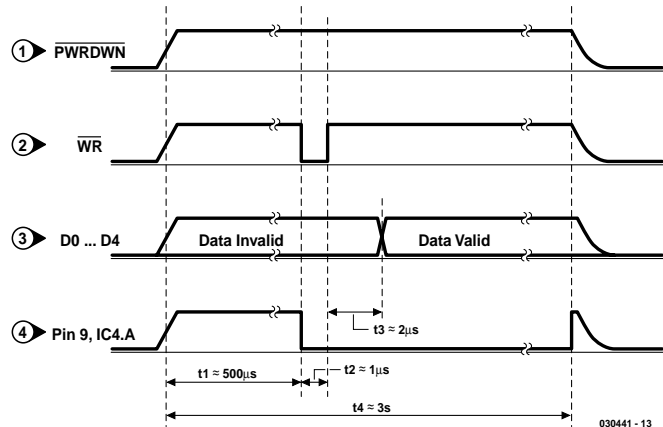


Figure 3. Timing waveforms at the circuit test points.

another temperature reading again relatively quickly after each measurement cycle is completed. (030441-1)

A precision temperature sensor

The MAX6610/MAX6611 is a temperature sensor with a built-in voltage reference. The digital output is conveniently scaled so that when it is connected to an 8-bit A/D converter the LSB of the output is equivalent to 1 °C change of temperature. With a 10-bit A/D the output LSB is equal to a temperature change of 0.25 °C. The reference output features a proprietary temperature-coefficient, curvature-correction circuit and laser-trimmed thin film resistors that result in a maximum temperature coefficient of 50 ppm/°C and an initial accuracy of ± 0.5 %. During normal operation the maximum current consumption is 250 μ A, this is reduced to 1 μ A in shutdown mode. The supply voltage range is 4.5 V to 5.5 V for the MAX6611 and 3.0 V to 5.5 V for the MAX6610.

The MAX6610/MAX6611 reference output voltage can be used by an external A/D converter. It can supply a maximum of 1 mA with a maximum loading capacitance of 1 μ F. The reference voltage has been chosen so that if an 8-bit A-D converter is used each step value of the digital output represents a 10-mV change of the analogue input voltage. A 10-bit A-D converter will offer greater resolution with each step in output representing 2.5 mV change of the analogue input.

The analogue temperature output voltage is a linear function of the chips die temperature:

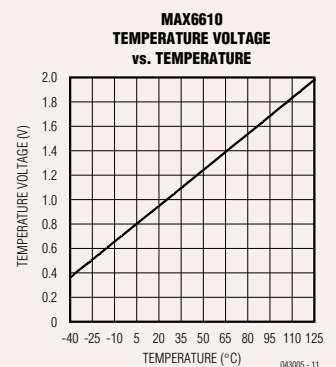
$$V_{TEMP} = 1.2 \text{ V} + (T^{\circ}\text{C} \times 16 \text{ mV}/^{\circ}\text{C}) \text{ [MAX6611]}$$

$$V_{TEMP} = 0.75 \text{ V} + (T^{\circ}\text{C} \times 10 \text{ mV}/^{\circ}\text{C}) \text{ [MAX6610]}$$

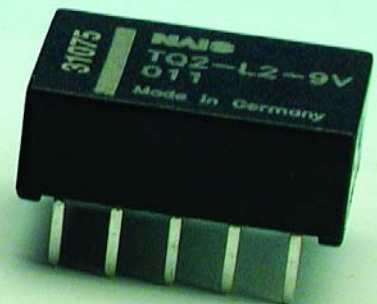
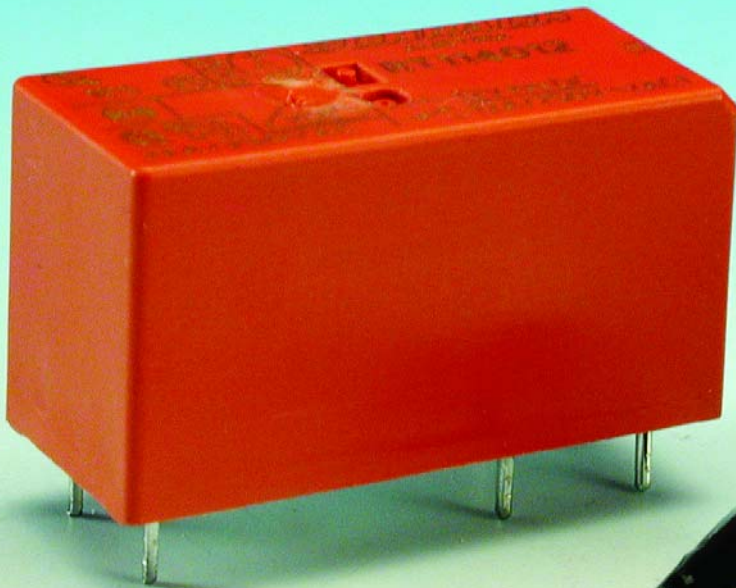
The slope of the output voltage is equal to $V_{REF}/256$ per °C (16 mV/°C for the MAX6611 and 10 mV/°C for the MAX6610). The MAX6610/MAX6611 have an active low shutdown input (SHDN). In this mode the reference voltage is pulled to ground via a 150 k Ω resistor and the TEMP output is switched into a high impedance state. Current consumption in this mode is less than 1 μ A. SHDN should be connected to V_{CC} if this feature is not needed.

If the MAX6610/MAX6611 is used to measure the temperature of an active component for example, the chip must be mounted in close proximity to or on that component. There is a good thermal path between the sensing element in the chip and its external pins, this ensures that the device will accurately measure the temperature of the PCB on which it is mounted.

The MAX6610/MAX6611 is a low-power device and the self-heating effect produced by its own power dissipation is negligibly small.



BISTABLE RELAY



By **B. Chiron**

Although bistable relays boast significant advantages, their use appears limited to niche applications, probably because their practical use requires just a tad more attention to design details than classic relays. Those days may be over soon with the introduction of a special driver IC from Quasinil (what's in a name?).

It appears that most manufacturers of bistable relays have now succeeded in simplifying their products to the extent that a demagnetising circuit is no longer required, and a single switching signal does the job. In some cases it is possible to realise a driver circuit based on just a few discrete components. In this article we show the intricacies of bistable relay control, analyse a few simple circuits, mention the pros and cons and, finally, introduce the dedicated drivers type DRT5 and DRL5.

Pros and cons of bistable relays

Advantages

The main advantage of a bistable relay is evident from its name: as soon as the relay has switched, it remains in

that position without consuming energy. This unique characteristic has quite a few consequences: no current consumption means less heat production, hence smaller heatsinks while the (rechargeable) battery sees its load current much reduced. In some cases, the use of a bistable relay allows a circuit to be simplified.

Disadvantages

– In general, the drive circuit is a little more complex than with a classic relay. Depending on the type of bistable relay, we need to either reverse the current flow or drive just one of the two coils. If we are looking at demagnetisation circuits, then it is also necessary to limit the current in compliance with the manufacturer's specifications.

DRIVER

- To be able to benefit from the bistable character of the relay the driver needs to have a timing element in the form of an RC network or an IC with a few passive components around it.
- If we're after energy reduction only, then the bistable character can work against us. To enable the relay to toggle when the supply voltage drops, a small amount of energy needs to be stored for use by the relay circuit watching the supply level.

Classes of bistable relay

Bistable relay with two coils

This is the most commonly found type. Each coil is responsible for a certain state of the relay. Some manufacturers indicate that series connection of the two coils allows the relay to be controlled as if it had just one coil.

Bistable relay with one coil

Less frequently seen, but very interesting if you are after significant energy reductions in your circuit. The entire coil is used to energize the contacts, as opposed to just half the coil length in the case of a 2-coil relay. With relays requiring a demagnetisation circuit, the demagnetisation has to be effected by means of a special resistor. In general, reversing the current in a coil is a bit more difficult. Further on in this article, a special circuit is shown for that purpose.

What to take into account

- To begin with, there's the minimum drive signal length, which should not be confused with the relay's energising time. We're looking at the time needed to make the relay change over to its new position and remain in that state. If this time is specified in the datasheets, it is usually called 'min. signal width' or 'pulse length'. Lacking this information we may use the 'set time' and 'reset time' specifications and add a safety margin.
- Minimum switching voltage: 'must operate voltage', thus is the lowest voltage at which the relay is guaranteed to toggle. It is essential to check whether the drive voltage reaches this level during the minimum pulse duration.
- Maximum switching voltage: just as with a classic relay, this voltage may not be exceeded.
- With regard to isolation and contact ratings, the same applies as with traditional relays. If a relay is used as an isolator for the sake of electrical safety in a circuit, then a lower coil resistance results in better isolation properties.
- Distance to other relays: some manufacturers specify a smallest distance to other relays in order to minimise mutual disturbances.
- Maximum energising time: some relays do not withstand continuous driving, having been optimised for the duration of the switching pulse only. With this type of

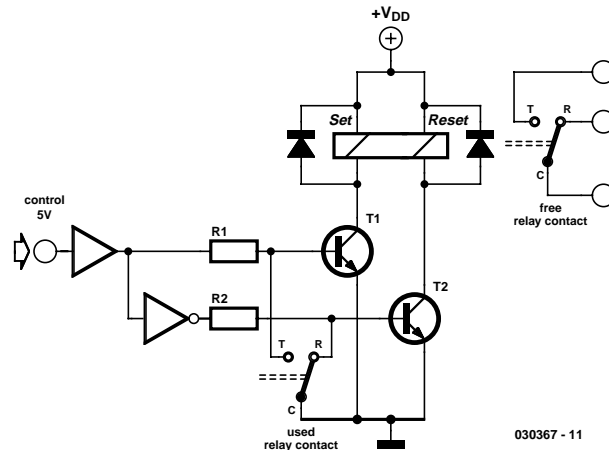


Figure 1. Relay control based on a classic contact-hold configuration.

relay, pay special attention to an accurately defined switching pulse.

Some really thrifty control circuits

Relay drive with hold by way of switching contacts (Figure 1)

Principle

When a logic High level is applied, T1 will conduct and current will flow through coil 'SET'. As soon as the relay pulls in, T1 blocks, cutting the relay coil current. When the control signal goes logic Low, the same happens with T2 and the 'RESET' coil.

Advantages

- Excellent for equipment that needs to be turned on, even in the case of a malfunction or a slowly rising supply voltage.
- Suitable for a 5-V supply.
- No capacitor required.

Disadvantages

- One relay contact is sacrificed for the control method.
- Isolation sets higher demands to board layout.
- Depending on the relay type used, the relay switching time may be shorter than the prescribed minimum switching time, hence a risk of intermittent switching is created.
- The position of the contacts when powering off depends on the decay time of the supply voltage.

Adaptations

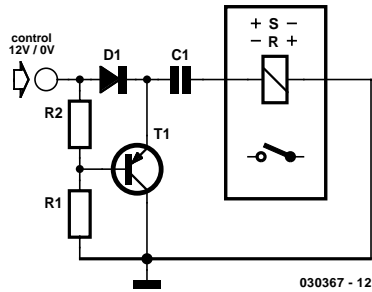
- Add energy buffer for switch-off phase.
- Add bridge rectifier for single-coil variant.
- Delay switching contacts to increase switching time.

Relay drive with a series capacitor (Figure 2)

Principle

At an input voltage of 12 V, C1 is charged, causing a brief current through the coil so the relay toggles. Next, the current remains limited to level determined by R1. If the input voltage drops abruptly to 0 V, the capacitor dis-

Figure 2. Relay drive using a capacitor.



charges via the relay coil with a reversed current, causing the relay to change to the reset state.

Advantage

- Simple structure for applications with clearly defined switching voltages.

Disadvantages

- Short pulses at the input may charge or discharge C1 without the relay switching (for example, while the supply is switched on or off).
- Functions badly at switching voltages of just 5 V.

Adaptations

- Schmitt trigger to be added when faced with slowly rising or dropping supply voltages.
- Modification possible for 2-coil relays.
- Possibility to add an energy-wise control input.

The DRT5 driver

The Quasinel company offers a series of driver ICs specifically designed for driving bistable relays. The ICs are best described with the aid of a few examples. In the first of these, the basic operation is explained, while the second allows us to benefit from one of the most interesting and worthwhile characteristics: low-energy drive. A third example, finally, shows an example illustrating guaranteed switching levels.

Switching by logic level (Figure 3)

With $V_{CC} = 5\text{ V}$ and $C_{de} = 5\text{ V}$ the driver switches the relay to the ON position (10 ms pulse). When C_{de} returns to 0 V, the OFF state is switched on (20 ms pulse). Take into account that the driver will attempt to switch the relay to the OFF state when V_{CC} drops below about 3.7 V. The success of this operation is wholly dependent on V_{CC} .

Advantages

- Uncluttered, only one part needed.
- Suitable for 5-V powering.
- No capacitor required

Disadvantages

- Slightly lags the control signal (approx. 20 ms).
- V_{CC} not allowed to exceed 5.5 V.
- If V_{CC} drops too quickly, the relay may not make it to the OFF state.

Adaptations

- Also works with 2-coil relays.
- For a simple method of supply voltage detection it is sufficient to connect C_{ap} and C_{de} (although in that case the supply voltage has to drop very slowly).

Dusk/dawn switch (Figure 4)

Principle

Direct current furnished by solar cells charges capacitor C_{ext} . When the voltage across C_{ext} exceeds about 4.4 V, the relay will switch to ON. When the light intensity

Figure 3. Switching with the aid of a logic signal and a DRT5.

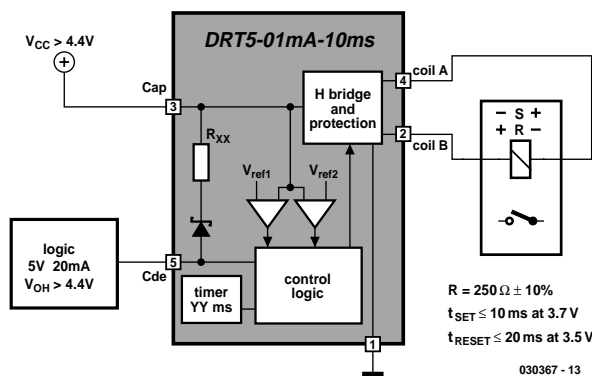
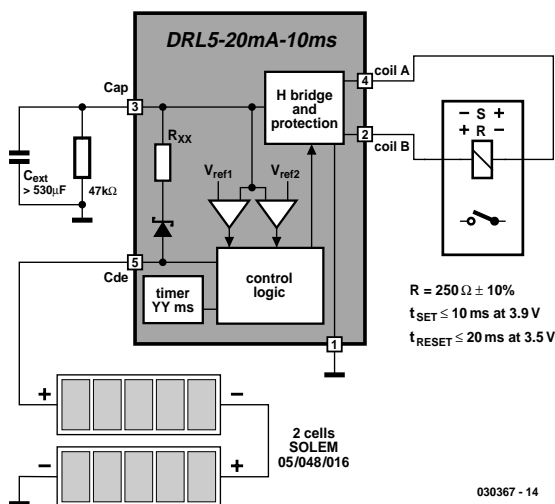


Figure 4. A simple dusk/dawn switch.



drops, the voltage across C_{ap} drops also. At a level of 3.7 V, the relay switches to OFF again.

Advantage

- No battery required.

Disadvantages

- Relatively long charge and discharge times (approx. 1 minute assuming two solar cells exposed to daylight).
- Large hysteresis: much more light is required to switch the relay to ON than to OFF

Adaptations

- For poor light conditions, use solar cells that supply a higher voltage. Protect the circuit with a low-drop voltage regulator (LP2950CZ-5).
- Although the configuration may also be used with a 2-coil relay, this option is less appealing because the capacitor becomes larger and with it the charge time.
- This type of circuit (typ. current consumption 20 mA) represents a cheap alternative to an optocoupler input. Depending on the source and the length of the cable it may be necessary to protect the driver's C_{de} input.
- Employ a power relay if larger currents are to be switched.

Controlling the mains supply in an USB device (Figure 5)

When the PC is switched on, capacitor C_{ext} is charged via a current limiting resistor. Once the capacitor voltage has risen to 4.4 V, the relay follows the state of the USB microcontroller, switching to ON. When the PC is switched off, the relay returns to its initial state. In this way, the supply in a peripheral device is switched synchronously with the PC.

Advantage

- OFF state guaranteed when PC is switched off.

Disadvantages

- Slightly lags the control signal (approx. 20 ms).
- Supply voltage not to exceed 5.5 V.
- Driver is relatively expensive.

Adaptations

- The relay in the example is a power relay, hence the value of the capacitor. Depending on the power to be switched and the desired degree of isolation, a small relay may be chosen. A single-coil relay allows a smaller capacitor to be used.
- If the peripheral is to receive its supply voltage together with the PC, the microcontroller is not required. Simply connect the 5 V of the USB connector to C_{de} and fit a 100-k Ω resistor between C_{de} and ground.

Choice between DRT5 and DRL5

In the three above examples we discussed a few aspects of these new driver ICs. The choice of the type of driver is closely related to the application and the relay to be

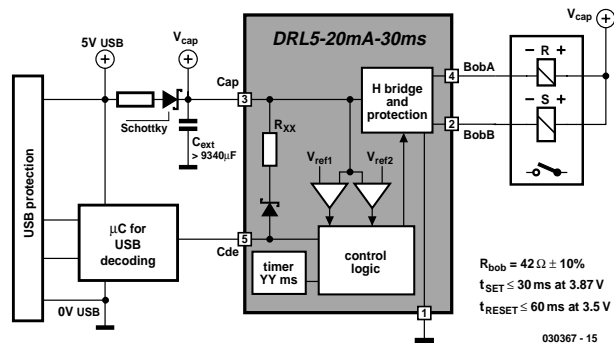


Figure 5. Switching a SB internal supply on and off.

controlled. Below is a short discussion of the parameters for these drivers and some advice to choose the right type.

DRT or DRL: The DRL5 driver is suitable for use in equipment with a supply or control voltage greater than 4.75 V. By contrast, the DRT5 may be used at a lower supply level starting at 4.4 V. This difference in supply voltage is also relevant to applications using an external capacitor.

Maximum current of the control input: This parameter is especially important if the driver is used without a power supply. In that case, capacitor C_{ext} needs to be charged from, say, a logic gate. Depending on the allowed or desired control current we choose the version with current limiting at 1 mA, 10 mA, 20 mA or 50 mA.

Control pulse length: This time has to exceed the 'minimum switching time' required by the relay. Possible times are 5, 10, 20, 30 or 50 ms. The OFF switching pulse is twice as long, which allows the value of the external capacitor to be optimised if necessary.

Really useful!

Compared with existing solutions, the DRT5/DRL5 drivers enable relays to be controlled with very low currents indeed, take the switching characteristics of the relay fully into account and guarantee the state of the relay when the equipment is switched off. Unfortunately the down side of the new drivers is their relatively high cost. Of course, we hope that the price will drop with volume production. In any case, these new devices offer the electronics designer extra options in circuits where energy consumption is a prime consideration, such as all newly designed equipment powered by batteries or solar cells.

More information on these components may be obtained from Quasinil's Internet site at <http://www.quasinil.com> and in particular this address http://20gp.ovh.net/~quasinil/drivers_eng.htm

(030367-1)

kitchen table

EAR BOGGLE

Experience
an auditory illusion



Rev. Thomas Scarborough

This month we invite all fans of the 'kitchen table' series to build a classic auditory illusion that has had psychologists and neuroscientists puzzled for decades. Although we're presenting a mini project built from a handful of cheap parts, it will not fail to produce stunning effects and results.

This article is of the 'zero-hardware / huge background' variety and as such fits perfectly in our 'kitchen table' series of mini projects aimed not only at developing electronics skills but also at triggering experimentation. This month, a dead simple two-tone two-phase oscillator produces a mind-boggling effect (quite literally) — guaranteed to cause a good deal of wonder &

excitement in the physics and electronics classroom.

In a nutshell

A two-tone 'siren' or octave switcher plays into stereo headphones. To best create the illusion you or your guinea pig(s) are about to experience, the two tones are separated by one octave (a

factor of two in frequency) and alternate at about 4 Hz (250 ms). The siren is played out of phase into each headphone.

According to biology textbooks, each ear would hear a two-tone siren. However what you will actually perceive is best described as a two-tone ping-pong effect which seems to jump from ear to ear. So what has our mind done

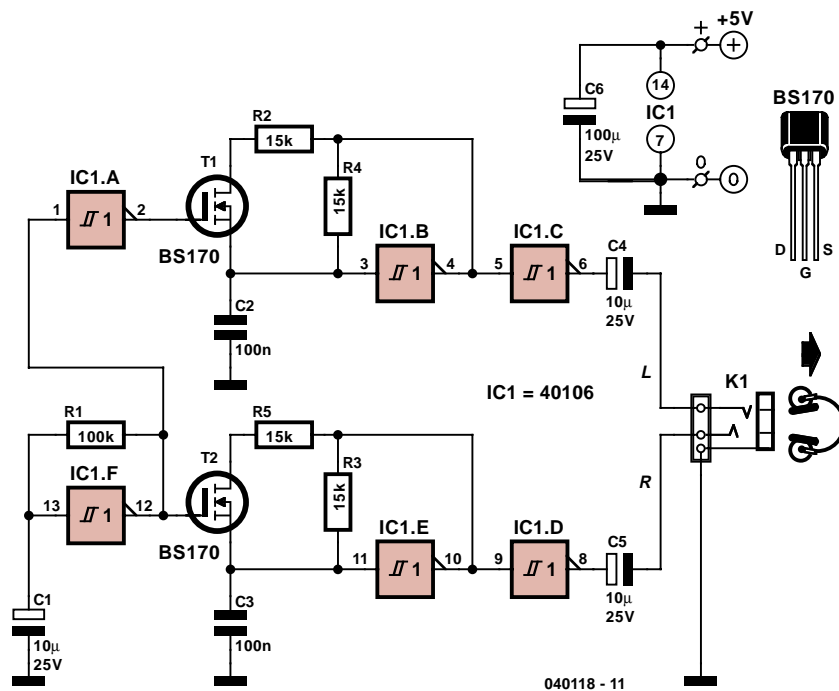


Figure 1. Just another synchronised dual-tone oscillator, sure, but wait until you've actually listened to the output on headphones.

The circuit

Figure 1 shows a circuit diagram that's low in confusion and rich in simplicity. Two oscillators, IC1.B and IC1.E are buffered by IC1.C and IC1.D respectively to play into stereo headphones. The frequency of the oscillators is being modified by switching R2 and R5 in or out of parallel with R4 and R3, by means of T1 and T2. These two FETs are in turn being switched on alternatively ('out of phase') by means of slow square wave oscillator IC1.F and inverter IC1.A. Since the oscillation frequency of IC1.B (IC1.E) doubles as R2 (R5) is shunted into circuit by T1 (T2), a regular jump of one octave is achieved.

Although almost any power MOSFET should be suitable for T1 and T2, we've opted for a small-signal FET type BS170 which also achieves clean switching and a sufficiently low 'on' resistance in the drain-source junction. In this circuit, you should aim at using frequency determining components, i.e., R2, R4, C2, R5, R3 and C3, to make sure the tones played into each channel match each other — the better the match, the better the illusory effect.

The circuit is powered from a stable 5-VDC source like a lab supply or an

with the missing tones? Are they being suppressed or what? To add to the confusion, just reverse headphones and — depending on the person's

handedness — the tones are likely to jump back to where they were before. However, let's not get carried away and first look at the electronics.

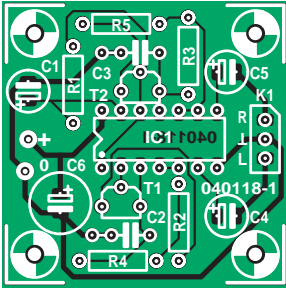
Dichotic Effect, Octave Illusion and Handedness

Are you still there? The illusion comprises an octave interval played high-low in one ear, and low-high in the other ear. It is important to listen with headphones so that the signal to each ear is well separated. Where do you hear the high pitch? Right-handers typically hear the high pitch in the right ear and the low pitch in the left ear. For left-handers the results are mixed. For some, the illusion does not work well. Now reverse the headphones. Where do you hear the high pitch now? Most people hear it in the same ear as before. So, how did the high pitch switch channels? Well, it did not — this is the illusion. High-low is played to each in opposite order, however, one ear hears high tone – silence – high tone – silence and the other: silence – low tone – silence – low tone

The psychoacoustic details of the illusion are still not fully understood, but Diana Deutsch was inquisitive enough to discover the effect as early as in 1974. Deutsch reported on her research at the Spring 1974 Meeting of the Acoustical Society and in *Nature*, 1974, 251, 307-309. Further investigations into the basics of the octave illusion appeared in the *Journal of Experimental Psychology* and the *Journal of the Acoustical Society of America (JASA)*.

It seems the illusion is correlated with what is known as brain lateralization and that certain functions are localized to one hemisphere or the other. It has also been discovered, first by Paul Broca (a French neurosurgeon) in the 1800's that right-handed people have language functions in the left brain hemisphere and spatial functions in the right hemisphere. Whereas left-handed people can have the same lateralization as right-handers or sometimes the opposite! More recent research using PET scans indicates that brain lateralization is not so simple and that the brain is a highly interconnected network with many regions active or 'firing' when complex tasks are performed. Hopefully that excludes reading this article!

[source: IllusionForum]



COMPONENTS LIST

Resistors:

R1 = 100k Ω
R2-R5 = 15k Ω

Capacitors:

C1, C4, C5 = 10 μ F 25V, radial

C2, C3 = 100nF
C6 = 100 μ F 25V radial

Semiconductors:

T1, T2 = BS170
IC1 = 40106

Miscellaneous:

PCB no. 040118-1, available from The PCBShop (EuroCircuits)

Figure 2. Component mounting plan of the small PCB designed for the project. The copper track layout may be found on our website (Free Downloads).

existing supply using a 7805 regulator IC. Current consumption will be no more than a few milliamps.

Construction

The circuit may be built on Veroboard or, for a touch of sophistication, on the printed circuit board shown in **Figure 2**. The copper track layout of the board may be found on our website, look for file no. **040118-1** in the Free Downloads section, under month of

publication. Ready-made boards may be ordered from The PCBShop (EuroCircuits).

Building up the board should not pose insurmountable problems as long as you stick closely to the parts list and the component overlay. Polarized components like the four electrolytics, the two FETs and the 40106 IC must, of course, be fitted the right way around, not forgetting the 5-volt power supply wires!

Warning. This circuit is not approved for medical use or research. When using headphones, every precaution should be taken to prevent ear damage by excessive sound levels. The experiments described in this article should not be carried out on persons suffering from seizures or epilepsy.

(040118-1)

Further reading

Musical Illusions and Paradoxes, Diana Deutsch (1995).

Postings on www.auditory.org

Advertisement

David Daamen

READY, STEADY, FATTY

Body Fat Monitor Scales

Sensible people look after their health: no smoking, moderate drinking, regular exercise and a healthy diet. And of course you want to keep an eye on your condition, for example with scales that also show your body fat percentage. Perhaps you already have one of these at home, but how do they work?

It wasn't that long ago when the body weight was the most important quantity when we looked to see if we were overweight. These days your body fat percentage is considered to give a better indication of your overall health. It tells you something about the chances of developing certain illnesses when you are too fat, such as heart and circulatory diseases, certain types of cancer and type-2 diabetes. Too little fat can also give rise to problems, especially in women. It can affect the menstruation and there is a greater chance of

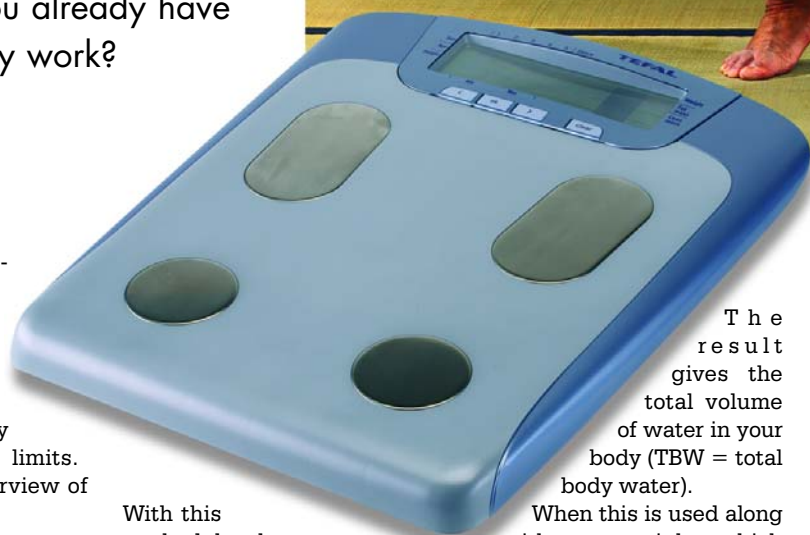
developing osteoporosis (calcium deficiency in bones).

It is generally accepted that it is sensible to keep your percentage body fat within certain limits.

Table 1 gives an overview of the ideal values.

Determining the body fat percentage

Good electronic scales use the so-called bioelectrical impedance analysis (BIA) to calculate your body fat percentage.



The result gives the total volume of water in your body (TBW = total body water).

With this method the electrical impedance Z of the body is measured. This is put into a formula along with the length of the 'conductor', l , (in this case your body) and the resistivity of body tissue ρ :

$$TBW = \rho \times l / Z$$

When this is used along with your weight, which was measured at the same time, a good estimate can be made of your body fat percentage.

This method is widely used in the medical world and normally uses electrodes on leads,

How to obtain the best results

You should first go to a specialist for an accurate body fat measurement. This result can then be used to estimate how accurate your body fat monitor scales are. There is little point in comparing your score with that of others. You should only use the body fat monitor to observe any changes. The following guidelines will help keep any possible measurement errors as small (and constant) as possible:

- Take the measurement at a fixed time of the day.
- Take the measurement at the same ambient temperature, as the temperature of the skin affects its conductivity.

- Make sure that your feet are clean and dry. For the best result you should use alcohol.
- One hour before every measurement you should drink an identical amount of water.
- Don't take a measurement directly after exercise. The perspiration causes a loss of body fluids, which affects the measurement.

	18-30 years	31-40 years	> 40 years
Men	15 %	17,5 %	20 to 25 %
Women	25 %	27,5 %	30 to 35 %

Table 1. Ideal body fat percentage for different age groups and gender.

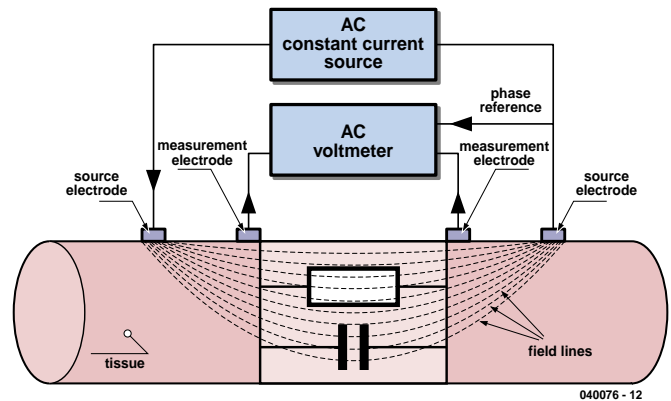


Figure 1. The impedance is measured using a constant current AC source and four electrodes.

which are connected to the wrist and ankle, causing the alternating measurement current to flow through the whole body. On body fat monitor scales for use in the home we have to make do with fixed electrodes, which are underneath the feet.

Operation

BIA is based on the difference in conductivity between fatty and lean tissue in the body. A constant alternating current is fed through the body via two electrodes, with one placed underneath each foot. Typical values are about 800 μA and 50 kHz. The resulting voltage is measured using two different electrodes, also placed underneath the feet (Figure 1). This then allows us to calculate the impedance of the body.

The impedance of lean tissue, which contains the most intracellular fluids and electrolytes, is lower than that of fatty tissue. The measured impedance therefore gives an indication of the total volume of water in the body. An estimate of the

total quantity of lean tissue can now be made with the help of several standardised formulae. The amount of fatty tissue is then calculated by subtracting the weight of lean tissue from the total body weight.

Better accuracy

A more accurate result can be achieved when you take into account that tissue consists of a combination of resistive and capacitive conductors (Figure 2). The fluids inside the body provide the resistive part of the impedance, whereas cell membranes have a capacitive effect. Fat cells don't have cell membranes, so they don't contribute to the capacitive part of the impedance.

When a wide-band signal is used to measure the impedance over a larger frequency spectrum, a better distinction can be made between the contribution of extracellular fluid (low frequencies) and the impedance of all fluids (higher frequencies). This method is often called 'multi-frequency BIA'. The Tefal

scales that we looked at in the lab also operates according to this principle.

Dependability

Although the BIA method is based on known physical phenomena, a few question marks remain about its dependability. For example, it assumes that the body can be represented by a uniform cylinder filled with tissues. You don't have to be an expert to see that this is not the case.

In general we can assume that a simple setup (with electrodes only connected to the

feet), which is used in uncontrolled conditions (as far as temperature, hydration and orientation of the body are concerned), is unsuitable for taking absolute measurements.

Scales with a (multi-frequency) BIA can be used to keep track of changes in the body fat percentage over the long term. More so when several ground rules are followed when taking the measurements (see inset).

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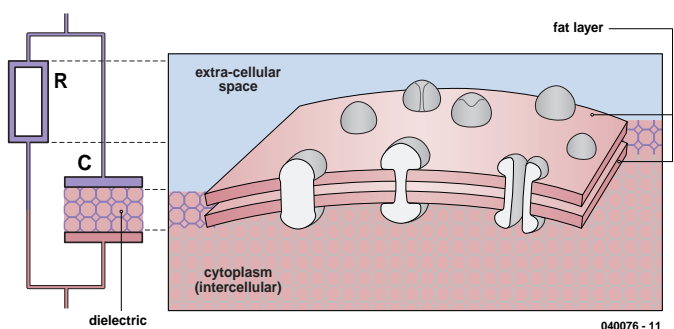


Figure 2. Body tissue can be represented by an RC equivalent.

Battery Charging on USB

Harry Baggen

Besides being handy for connecting and disconnecting equipment while the computer is running, USB includes a built-in supply line that can provide a certain amount of power to connected devices. That can be handy for quickly charging a battery when you can't find a real charger.

Nowadays every computer has several USB ports, which have taken over the task formerly handled by the RS232 bus. USB cables have different connectors at each end to prevent incorrect connections. **Figure 1** shows types of device receptacles, which are used in peripheral equipment.

A USB connection has only four lines, consisting of a data line in each direction, a ground line, and a supply line. The supply line can be used to power peripheral devices. The host device (a PC or notebook computer) can source a maximum of 500 mA from each USB port. In USB terms, this is called five unit loads. A hub with its own power supply can provide the same amount, but a bus-powered hub can provide only one unit load per port. However, the host will only provide a current of 500 mA after communication with the connected USB device. Immediately after a connection to a USB device has been established, the device cannot draw more than 100 mA from the bus. The host does not decide whether to allow the device to draw a maximum current of 500 mA until the identification phase ('enumer-

ation') has been completed. Simple devices actually do not need this enumeration, as long as they ensure that they don't draw more than 100 mA from the bus. This can be exploited to simply tap off a bit of current from a USB port without causing the computer any problems. Some examples are mini-lamps and small fans with USB cables, which are currently sold for use with notebook computers. They 'misuse' the USB port in exactly this manner. This 100 mA can also be used to charge a couple of batteries when you don't have a real charger to hand. That's very easy to do, as can be seen from **Figure 2**. A diode and a resistor are sufficient for charging two AA (penlight) or AAA cells connected in series, either NiCd or NiMH. It takes a while, since you're limited to a current of 100 mA, but in an emergency it's a perfectly good solution.

The component values for the circuit assume that the supply voltage on the USB line has a nominal value of 5 V and a minimum value of 4.5 V. The diode is for protection, to prevent damage to the USB port if the batteries are connected backwards.

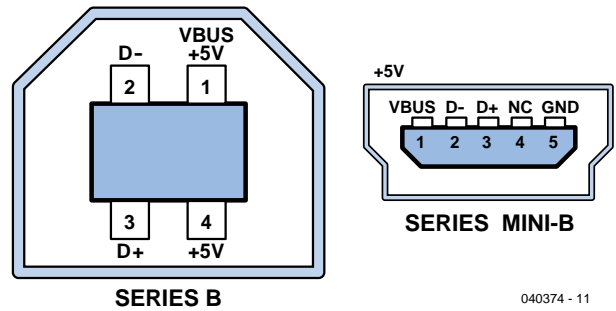


Figure 1. Two commonly used types of connectors for USB ports on peripheral devices.

Resistor R1 is dimensioned for a current of approximately 90 mA through the two NiCd or NiMH cells. They can handle this for days on end without becoming overcharged, but it also means that they can't be fully charged in just a few hours. But once again, this is intended as a makeshift solution.

Professional products

Various semiconductor manufacturers have now developed special products for charging batteries using a USB port. Some of them are intended to be used for charging lithium-ion batteries, but that's not particularly interesting for DIY circuits, due to the difficulty of obtaining that type of battery.

Maxim has developed an idea for powering a circuit from a single NiMH cell that can be recharged from the USB port.

Figure 3 shows such a design using two Maxim ICs. The MAX1692 (U1) is a DC/DC step-down converter with current limiting. It charges the NiMH penlight cell (B1) from the USB supply line at a current of 300 to 400 mA. Although the converter is not actually a true current source, it is

good enough (even with a shorted cell) to effectively charge the battery. The advantage of using a DC/DC converter is that the current drawn from the USB port is only 150 mA when the NiMH cell is being charged at current of 400 mA. This leaves 350 mA for directly powering the connected device, in addition to the charging current. The second IC, U2, is a DC/DC boost converter (MAX1722) that transforms the voltage from the single rechargeable battery back to 3.3 V. When the battery is being charged, this converter is disabled and the output voltage is 4.7 V (derived from the USB voltage via diode D1). The drawback of the charging circuit in **Figure 3** is the absence of overcharge protection; the user must manually disconnect the circuit from the USB port when the battery is fully charged.

Protection

The USB specifications do not make any clearly defined statements regarding protection of USB ports. Some PC manufacturers provide reliable electronic current limiting for each port, while others only provide simple fuses on the circuit board. It is thus pos-

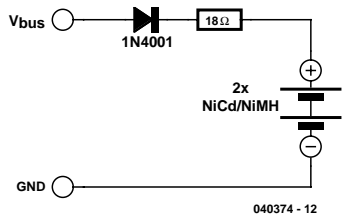


Figure 2. Two NiCd or NiMH batteries connected in series can easily be charged using a diode and a resistor.

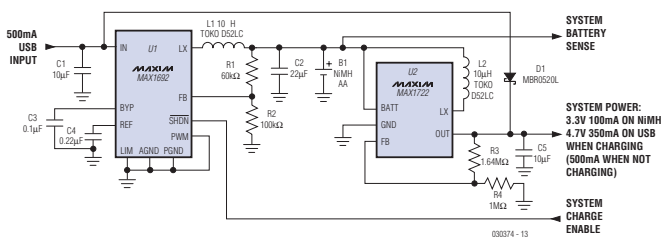
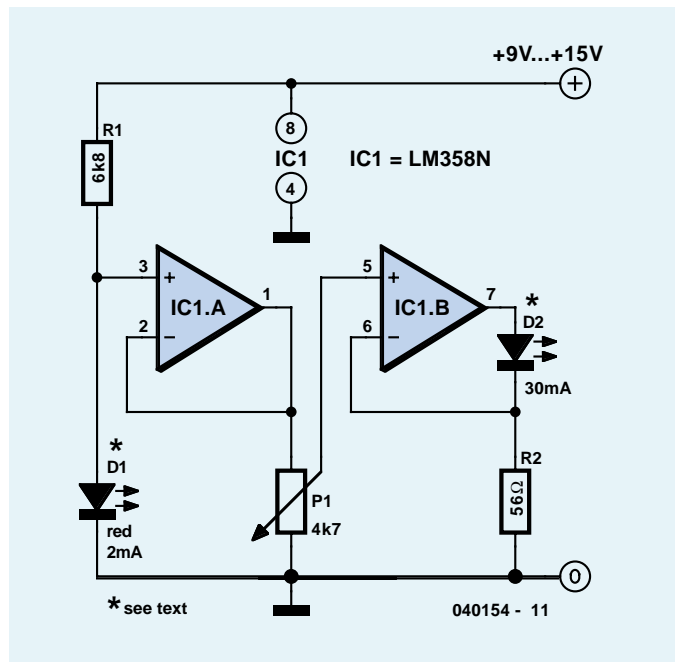


Figure 3. This Maxim design uses two DC/DC converters to charge a NiMH cell and power the connected circuit with a supply voltage of at least 3.3 V.



sible to 'blow up' a USB port if you try to draw too much current from it. National Semiconductor has developed a special IC that protects host ports against excessive output currents. The block diagram of this IC (LM3525) is shown in **Figure 4**. As soon as the output voltage drops more than 100 mV below the input supply voltage, the output current is limited to 1 A by the built-in power FET. Even with simple charging circuits such as the one shown in Figure 1, it's a good

idea to include an LM3525 between the USB connector and the charging circuit, in order to prevent damage to the PC or notebook computer.

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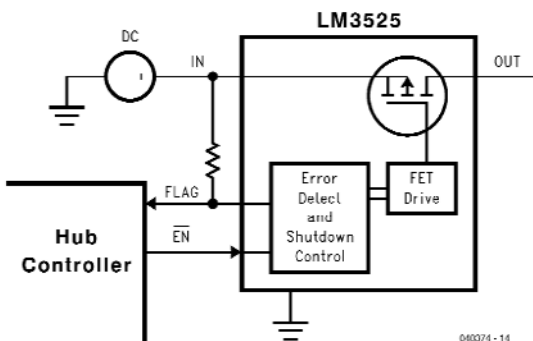


Figure 4. The National Semiconductor LM3525 provides a simple solution for protecting USB host ports against overloads.

30-mA LED Dimmer

Eberhard Haug

If you've ever tried dimming a LED with a simple potentiometer, you know that the approach does not work very well. Just as with ordinary diodes, the voltage-current characteristic of LEDs is far from linear. The result — depending on the potentiometer setting the LED brightness will hardly change most of the time as the pot is turned and a sudden variation at the end.

The best method to tackle this problem is to power the LED from a current source with zero to 100% adjustment range. The circuit shown here is an example. A low-current LED (D1) is used to generate a reference voltage that's first buffered by one half of an LM358. The actual current source that powers the LED(s) is built around the second opamp in the chip. The potentiometer allows the output current to be adjusted, with R2 acting as a current sense, the resistor dropping the same voltage as the one obtained from the pot. Using Ohm's law we find

that the maximum current through R2 amounts to about 29 mA ($I_{LED} = 1.6 \text{ V} / 56 \Omega$).

If necessary, the current may be adapted to suit other LED types, for example, 20 mA is obtained with $R2 = 82 \Omega$ and 10 mA at $R2 = 150 \Omega$.

It is also possible to connect several LEDs in series. The total voltage available for the LEDs is determined by the voltage drop across series resistor and the opamp, and, of course, the supply voltage. In this way, the highest number of LEDs may be found from $U_{LED, total} = U_{batt} - 5.1 \text{ V}$. In principle, it is possible to increase the supply voltage to 30 V in order to connect even more LEDs in series. This does, however, call for the value of series resistor R1 to be increased to prevent overloading the low-current LED used in the voltage reference.

If you intend to experiment with larger numbers of LEDs (say, in arrays) then the maximum loading of the opamps becomes an issue. The DIP version of the LM358 may dissipate up to 830 mW. The power, P, is calculated from $P = U_{batt} - 1.6 - U_{LED, total} \times I_{LED, max}$

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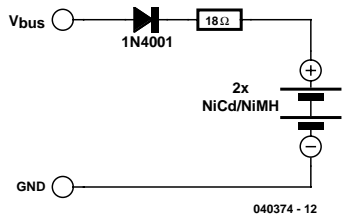


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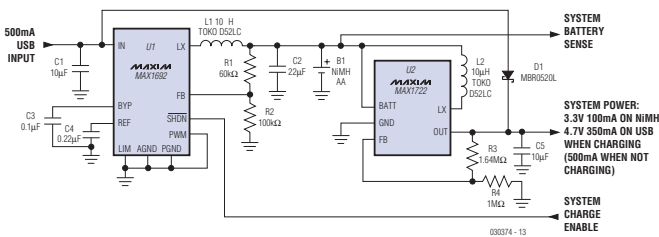


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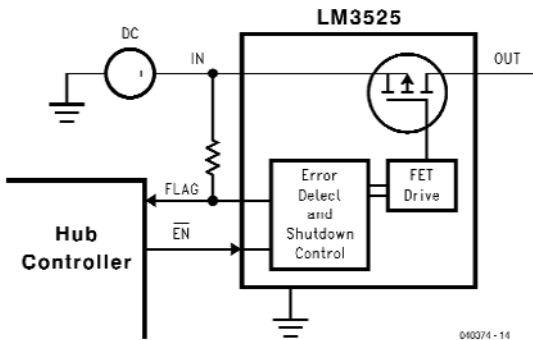
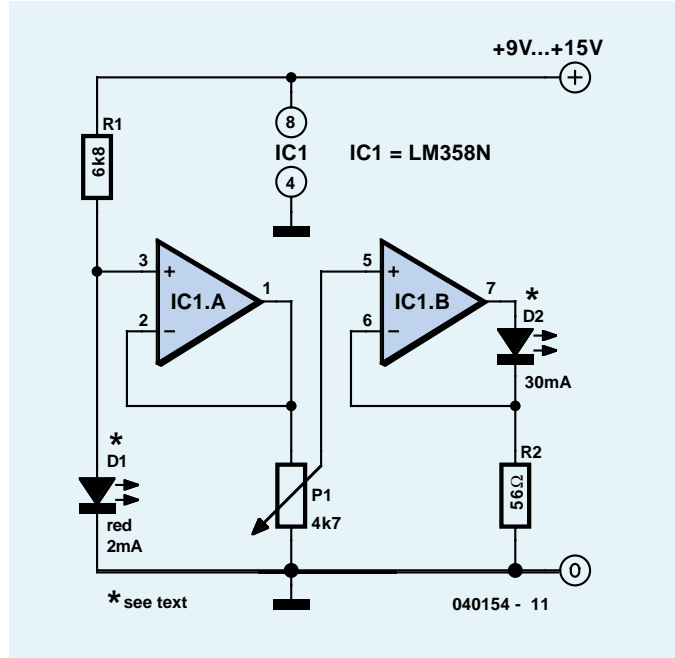


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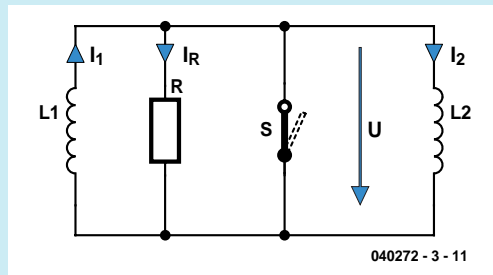
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QUIZZ'AWAY

As of the September 2004 issue Quizz'away is a regular feature in Elektor Electronics. The problems to solve are supplied by Professor Martin Ohsmann of Aachen Technical University.

Assuming ideal components are being used and $L_1 = L_2 = 2 \text{ mH}$, inductor L_1 initially ($t < 0$) passes a current $I_1(0) = 1 \text{ A}$ while for L_2 $I_2(0) = 0$. At instant $t = 0$ switch S is opened.

How much energy W_R is converted into heat by resistor R if you wait infinitely long?



Hint 1:

$$W_R = \frac{1}{2} L_1 \cdot I_1^2(0) = 1 \text{ mWs}$$

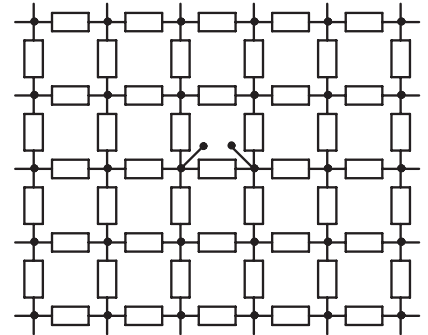
the likely solution for ideal, lossless inductors is not correct in this case.

Hint 2:

Make use of 'dual notions' like
 voltage \Leftrightarrow current
 capacitor \Leftrightarrow inductor
 resistance \Leftrightarrow conductivity
 charge retention \Leftrightarrow ?
 electrical energy \Leftrightarrow magnetic energy
 series network \Leftrightarrow parallel network
 switch open \Leftrightarrow switch closed
 perfect conductivity \Leftrightarrow perfect isolation

Solution to the September 2004 problem

(p. 80, resistance measured in an infinite array)



Inject a current of 1 mA into one test node; call it node A. By **symmetry** the current will divide equally among the 4 resistors terminating at node A; i.e. 0.25 mA per resistor. Extract a current of 1 mA (the return current) from the test node adjacent to node A; call it node B. Again by symmetry, the current converges in equal values from each of the 4 resistors terminating at node B, i.e., 0.25 mA per resistor.

Using **superposition** and observing the current directions, the injected and extracted currents flowing in the resistor linking nodes A & B are **algebraically summed**, adding up to 0.5 mA through R_{AB} .

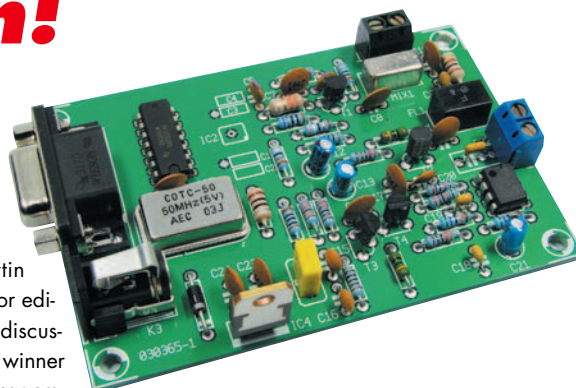
A resistance of $1 \text{ k}\Omega \times 0.5 \text{ mA}$ gives $V_{AB} = 0.5 \text{ V}$. For an injected/extracted current of 1 mA, $R_{AB} = 500 \text{ mV}/1 \text{ mA} = 500 \Omega$.



Quizz'away and win!

Send in the best answer to this month's Quizz'away question and win this

DRM Receiver Board worth £85 (www.ak-modul-bus.de).



All answers are processed by Martin Ohsmann in co-operation with Elektor editorial staff. Results are not open to discussion or correspondence and a lucky winner is drawn in case of several correct answers.

Quizz'away conditions

Please send your answer to this month's Quizz'away problem by email, fax or letter to:

Quizz'away, Elektor Electronics, PO Box 190, Tunbridge Wells TN5 7WY, England.

Fax (+44) (0)1580 200616.

Email editor@elektor-electronics.co.uk, subject: 'quizzaway 11-04'.

The closing date is 22 November 2004

(solution published in January 2005 issue). The outcome of the quiz is final. The quiz is not open to employees of Segment b.v., its business partners and/or associated publishing houses.