When the student runs the program the number of shots per unit time $S\%$, is selected by the machine and is used to calculate a theoretical half life in the following way.

Initially there are $6300$ parent atoms present. The chance of a particular atom surviving one shot is $6299/6300$. This probability remains the same for each subsequent shot, so that over $n$ shots the probability of survival becomes

$$\left(\frac{6299}{6300}\right)^n$$

Over a time interval of one half life $T$, the probability of survival is 0.5 and the total number of shots in that time would be

$$n = S\% \times T$$

hence

$$\left(\frac{6299}{6300}\right)^{(S\% \times T)} = 0.5$$

so that

$$T = \frac{\log(2)}{\log\left(\frac{6300}{6299}\right) \times S\%}$$

The program samples over twenty time intervals and between each sample stops until prompted. The figure shows a typical screen display during the decay process. Parent atoms are coloured yellow and the daughter atoms blue on the colour display. The results are then presented in a table which provides data for a graph of the number remaining ($N$) against time. An estimate of the half life can be made from this curve. An activity–time graph can also be plotted, and this will show considerable scatter since the rate of decay becomes small over twenty time intervals. (A similar effect is seen in experimental data from thoron decay using one of the standard A-level methods.) Finally the exponential character of the process can be shown if the graph is linearized by plotting $\ln(N)$ against $t$.

The program provides a safe and simple way of simulating a random decay with a sufficient number of 'atoms' to make the statistical trends significant. It gives a visual and aural illustration of the real process and helps students relate the important concept of exponential decay to a physical situation.

Power conditioning for computers

Marie Parker-Jenkins and William Parker-Jenkins, University of Nottingham

Many teachers and instructors responsible for computer studies in schools and colleges today, are frequently preoccupied with obtaining the most suitable microprocessor-storage device and display combination in sufficient numbers for their student needs. Once the decision to purchase a particular model or standardize on a certain manufacturer's product has been made, the problem of selecting adequate power conditioning for the system is usually ignored or, at best, left to an unqualified third party. Reliable, clean power is a fundamental necessity for implementing a successful computing course, if time is not to be wasted through program malfunction, data loss and peripheral damage. A knowledge of the equipment available to remedy problem power, together with its capabilities and limitations will enable key personnel to identify and help specify the corrective devices necessary to keep sensitive hardware functioning properly. In addition, the article contains suggestions for a powerline conditioner which electronic hobbyists in school may wish to construct as an alternative to purchasing a commercial unit.

WHAT CONSTITUTES ACCEPTABLE POWER?

Four factors affect the quality of the power entering a computer installation; frequency and voltage stability; supply reliability and purity of the power waveform. In the United Kingdom, the frequency is generally stable at 50 Hz and by statute is allowed to vary only by 1 per cent or $\pm 0.5$ Hz, except under emergency conditions. Most computer equipment
can tolerate momentary variations within these limits without malfunction. Voltage levels are again governed by law and vary by ±6 per cent of the consumer's terminal voltage. However, over and undervoltage conditions do occur with surprising regularity and can precipitate hardware damage. Table 1 summarizes these allowable variations for 240 V residential/small institutional services and 415 V, 3-phase industrial/large institutional accounts. These two voltage levels are standard across the country and help Electricity Boards and manufacturers co-ordinate efficient service and equipment design.

Table 1

<table>
<thead>
<tr>
<th>Consumer's terminal voltage</th>
<th>Lower limit</th>
<th>Upper limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>240 V, 1 phase</td>
<td>226 V</td>
<td>254 V</td>
</tr>
<tr>
<td>415 V, 3 phase</td>
<td>390 V</td>
<td>440 V</td>
</tr>
</tbody>
</table>

The small computer user may well find that the cost of replacing the local Electricity Board’s supply in times of failure is prohibitive, since back-up equipment must be sized, purchased and regularly maintained. Supply reliability in the United Kingdom is, except in times of crisis, very high and only larger computer installations such as universities and polytechnics should consider some form of uninterruptible power system (UPS).

Waveform purity is, at present, an indefinite area without regulatory standards, but it is probable that guidelines will be introduced within the next decade. Basically, the waveform ultimately entering the computer load should be perfectly sinusoidal, but in practice this ideal criterion is impossible to attain because electrical noise and spikes generated by loads connected to the same distribution network distort the supply.

THE PROBLEMS

Powerline disturbances can be classified in five general categories which are outlined below—all of which can adversely affect computer installations.

1. **Short-term undervoltages** (sags) or **overvoltages** (surges) are created when large loads are applied to and removed from the utility line. The sudden demand for power literally drags the system voltage down for all of the consumers connected at that time, and when switched off, the excess, unrequired power momentarily allows the voltage level to rise. If large pumps, motors or banks of lighting fixtures are switched on inside the building where the computer is installed, or in neighbouring premises, the sag or surge can last from one-half to several seconds.

2. **Voltage interruptions** (blackouts or flickers) occur due to lightning, accidents or unavoidable breakdown in utility power. They can last from seconds to several hours. Flickers tend to be momentary outages caused by network switching or fault clearing equipment.
3. *High frequency transient voltages* (spikes) are commonly caused by electrical and electronic devices being switched on and off the supply system. The spike appears at the leading and trailing edges of the power pulse and may last from a few microseconds to milliseconds while reaching 10 to 100 times the line voltage.

4. *Frequency variations* cause problems particularly in synchronous computer peripheral equipment, such as tape or disk drives. It can be periodic in nature due to large...
Industrial loads coming on-line, but it is an uncommon occurrence in the United Kingdom because of the interconnected grid supply system which can tolerate large instantaneous heavy power demand.

5. Line noise causes program execution errors, false jumps or garbled data. Any electrical or electronic device operating from a powerline or atmospheric disturbance can feed noise back into the network. Without adequate suppression, a computer is vulnerable to control, memory and circuit damage.

The majority of computer users in institutional (and domestic) environments typically experience three particular powerline problems: electrical noise; transients (spikes) and momentary blackouts.

Two types of noise predominate: radio frequency interference (RFI) and electromagnetic interference (EMI), both of which enter a computer via its power supply. RFI is caused by radio frequency emitters such as: broadcasting agencies (TV and radio transmitters, taxis, emergency services etc.); discharge lighting (fluorescent, sodium and mercury); vehicle electronic ignition and large inductive electrical machines. EMI is created when a changing magnetic field impinges an electrical power conductor thereby imposing a disturbance on the mains waveform. Lightning striking overhead supply lines, arc welders (found in school craft workshops), electronic typewriters and any solenoid-operated equipment (including vending machines) can be sources of EMI.

Transients are very short-term high-voltage perturbations imposed on the mains waveform and are frequently caused by: utility load and power factor correction switching operations; lightning and inductive loads such as motors at start-up. If for example a 15 A armature current is interrupted in an air conditioner motor of inductance 0.5 henrys in 2 milliseconds, then a back emf spike of \( c = L\frac{di}{dt} = 3750 \text{ V} \) is impressed on the 240 V mains. Clearly, higher values of current and inductance associated with faster switching times can produce even greater deleterious effects on micropower computer circuitry.

Long-term power interruption is an infrequent occurrence in this country, but when it is experienced by computer users, program and volatile memory (RAM) contents are irretrievably lost. Most computer equipment will however, withstand numerous daily flickers without crashing, but inevitably some power breaks will generate unexplained errors or data loss and necessitate time-consuming reprogramming.

THE SOLUTIONS

Few of the remedial devices on the market today, short of a comprehensive automatic UPS facility, can eliminate all powerline disturbances due to the varying nature of the problems. This section outlines the type of regulatory systems available to computer users, by which incoming mains power can be 'cleaned up' or replaced in times of failure.

Many companies specialize in supplying power conditioning equipment to commercial and institutional establishments. Potential customers should endeavour to inspect prospective vendor's earlier installations, contact any references proferred and most
importantly, obtain alternative quotations. Often suppliers will at zero or nominal cost, monitor a suspect power supply for a set period (usually a week) in order to determine the type and frequency of any incoming disturbances. From the result, recommendations can be made regarding the amount and type of correction equipment required for an application. It should be stressed that some of the simpler powerline disturbances can be effectively removed from the mains by straightforward techniques detailed in a later section.

1. **Surge protectors** (main-suppressors) resemble ceramic disc capacitors in appearance, and are connected across the input live and neutral lines. Two types of devices, which operate on different principles, are commonly available at around 70p each from electronic component stockists: metal oxide varistors (MOV's) and zener-type silicon diodes. Surge protectors have little effect on a clean supply waveform, but if a spike occurs, which exceeds the peak level of the mains input \( (240 \times \sqrt{2} = 339 \text{ V}) \), the device impedance quickly falls and the pulse energy is safely dissipated before it can enter the power supply and cause damage. MOV's are usually preferred to their zener counterparts, even though they turn-on five times slower, at 25 nanoseconds, because they can handle significantly higher pulse energies.

2. **Line voltage regulators** are designed to maintain a constant terminal voltage at the computer load. If the mains voltage is consistently high or low, a variable-ratio transformer with switchable, or continuously variable taps can be installed—this would be particularly useful in rural schools which may be at the end of a distribution line. A line regulator will not raise or lower a voltage by a large increment as in a conventional transformer, but adjust it continuously over a small range. Typically, they have response times of 100 milliseconds and in addition to smoothing out disturbances, they can also compensate for short-term undervoltage conditions.

3. **Noise isolation transformers** provide noise immunity to computers by having specially constructed primary and secondary windings with a very low mutual capacitance. Thus high frequency noise is prevented from being transferred from the mains to the supply input. These devices do not offer protection against high voltage spikes, sags or flickers. Neither do they provide voltage regulation or power ride-through. Some manufacturers combine a low power noise isolation device with a mains suppressor to form a 'noise filter', since noise and transients often coexist on the waveform. These 'plug-in' protective units are becoming increasingly popular with small computer users and are being sold by High Street retailers and discount appliance centres.

4. **Motor generators** (MG sets) consist of an a.c. motor coupled to an a.c. generator and uses the principle of mechanical inertia to ride through power interruptions for periods from 300 milliseconds to one minute. This also effectively prevents transients and noise from causing disruption by having the supply isolated from the computer input. Further, short-term brownouts—lowering of supply voltage under excess demand conditions can be tolerated.

5. **Line conditioners** are the electronic counterparts of MG sets and are usually not as expensive. They comprise a noise isolation transformer, surge suppressor and a voltage regulator. Line conditioners therefore offer an excellent protection facility for computer installations and only fall short in times of direct lightning strikes or power failure. It should be noted, however, that some manufacturers are marketing line conditioning equipment with a small internal power source which can support a computer load for a short period in times of mains failure, thus the distinguishing characteristics between UPS and modern line conditioners are beginning to overlap. The benefit of a small secondary power source is that if a power break occurs, the current program and data can be conveniently downloaded to a storage medium, and retrieved when the mains is re-established.

6. **Uninterruptible power supplies** or no-break systems are used primarily to back-up utility power during blackouts or permanently reduced voltage conditions. They represent a total solution to powerline problems and their costs reflect this level of sophistication. Two basic types of UPS are available: static, which features rechargeable batteries as a power source; and rotary, which incorporates a standby (diesel) generator. Only larger institutions requiring a permanent mains supply should consider a UPS installation since the costs must take account of installation, maintenance and fuel.
Figure 1 illustrates the basic configuration of a static UPS system, the key components being: an a.c. to d.c. rectifier/battery charger; storage batteries (usually lead-calcium); d.c. to a.c. inverter and an automatic transfer switch which connects and removes mains power when required. Static UPS systems can economically provide up to 30 minutes of support, beyond which a rotary UPS/standby generator becomes viable.

![Figure 1. Static UPS block diagram](image)

Protective equipment should be located as close to the computer load as is physically possible in order to minimize noise pick-up. If power contamination problems exist after remedial action has been taken, then more radical (and expensive) measures worthy of investigation include:

1. Balancing the computer load on a 3-phase supply.
2. Improving the computer grounding by installing a separate network from the building earth.
3. Installing a dual power feeder for consistent supply.
4. Reducing the length of unshielded power and transmission cables.

Static electricity which, although not categorized as a powerline disturbance, can disrupt computer operation. If the outside temperature and humidity are low, then students can build up 20 000 to 30 000 V just by walking across a computer room carpet. Shock absorber mats and rugs can reduce or eliminate equipment malfunction, discomfort and downtime—they also reduce dust problems.

### Guide to Power Supply Problems

<table>
<thead>
<tr>
<th>Power problem</th>
<th>Voltage spikes/ surges</th>
<th>Transients</th>
<th>Line noise</th>
<th>Brownouts (undervoltage)</th>
<th>Short duration Blackouts (&lt;8 ms) (flickers)</th>
<th>Long duration Blackouts (&gt;8 ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection</td>
<td>Surge protector Yes within limits</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Voltage regulator Yes</td>
<td>Yes</td>
<td>No protection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Noise isolation transformer Yes</td>
<td>Yes</td>
<td>No protection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Motor generator set Yes</td>
<td>Yes</td>
<td>No protection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Line conditioner Yes</td>
<td>Yes</td>
<td>No protection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>UPS system Yes</td>
<td>Yes</td>
<td>No protection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 2. Relative power line protection
The cost of powerline protection varies proportionally with the size of the computer load, the amount of protection provided and the degree of sophistication required by the user. Table 3 indicates typical equipment costs only—installation costs are not included. When selecting power conditioning equipment, users should opt for the amount of protection which matches their dependence upon the continuation of their system operation. Obviously this will differ for a school which might possess an eclectic group of micro's sprinkled around the premises than for a computer science building in a polytechnic or a university.

Table 3. Powerline protection equipment costs

<table>
<thead>
<tr>
<th>Surge protector</th>
<th>Voltage regulator</th>
<th>Noise isolation transformer</th>
<th>MG set</th>
<th>Line conditioner</th>
<th>Static UPS</th>
<th>Rotary UPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment size</td>
<td>Typical costs</td>
<td>Maintenance costs/year</td>
<td>Operating efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 VA–60 kVA</td>
<td>£15–£500</td>
<td>None</td>
<td>90%</td>
<td>60–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>30 VA–1 MVA</td>
<td>£200–£50 k</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>250 VA–100 kVA</td>
<td>£200–£20 k</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>2 kVA–750 kVA</td>
<td>£200–£3000</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>500 VA–100 kVA</td>
<td>£200–£20 k</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>500 VA–100 kVA</td>
<td>£200–£3000</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>100 kVA–500 kVA</td>
<td>£500–£100 k</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>100 kVA–1 MVA</td>
<td>£500–£100 k</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>1 MVA</td>
<td>£7000 and up</td>
<td>None</td>
<td>90%</td>
<td>80–90%</td>
<td>85%</td>
<td></td>
</tr>
</tbody>
</table>

PROJECT SUGGESTIONS

The majority of commercial poweline conditioning equipment contains at the very minimum, a transient suppressor and a filter which smooth out spikes and noise respectively. In combination, these two devices will effectively remove the bulk of supply problems experienced by school computer users and, as an alternative to purchasing more expensive, ready-made units, electronic hobbyists can easily install these components themselves.

![Figure 2. MOV fitted to 13 A plug](image)

Individual mains suppressors (preferably MOVs) should be fitted across the 240 V live (brown wire) and neutral (blue wire) pins of every 13 A plug used to power a computer or peripheral. With a little patience and dexterity, the MOV should fit inside the standard plug as shown in Figure 2. This single MOV will protect equipment against differential-mode transients but not common-mode spikes, which requires two additional suppressors connected between the live, neutral and earth conductors as indicated in Figure 3. It is unlikely that a 13 A plug could accommodate three MOVs, but they could be fitted inside a 'power-bloc' or 'multi-plug' socket outlet which is used to distribute power to several loads as illustrated in Figure 4.

![Figure 3. MOV connection](image)
Mains borne radio frequency noise can be intercepted before it enters a computer's power supply and disrupts or damages the internal circuitry, by installing a filter in the input. Commercial noise filters are based on combinations of 'π' and 'T' networks of inductors and capacitors which attenuate the unwanted RFI and EMI signals, while allowing through unheeded the 50 Hz power waveform. Figure 5 represents a noise filter which can be built in to a 'multi-plug' distribution socket together with the transient suppressors detailed above. The components are readily obtainable from electronics suppliers such as Maplin and Radio Spares.
Computer users interested in installing some degree of powerline protection should, before contemplating project construction, compare the costs of components and time with the price of an 'off-the-shelf' unit, since they often prove more economical. An alternative method of housing the suppressors and noise filter is to incorporate them into a dedicated power board as shown in Figure 6. A set of single or twin-gang portable protected boards can be made up for all of the computer equipment used around the school premises.

**Harmonics in a square wave**

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The superposition of waves of frequencies $f$, $3f$, $5f$, etc. with suitable amplitudes and phases produces a square wave, as illustrated in standard textbooks on sound. The statement may be inverted in the form: a square wave contains the fundamental frequency plus all the odd harmonics. In what sense is a harmonic 'present' in such a wave? One very practical answer is: if the wave impinges on oscillators of natural frequencies $3f$, $5f$, etc, then such oscillators will be set in vibration.

Given a signal generator with a square wave power output, and a standard vibrator unit, this is very easy to demonstrate. The vibrator is placed on thick padding on the bench, to minimize the sound-board effect (see figure). A polypropylene measuring cylinder, held in the hand, is then rested gently on top of the vibrator. When a square wave signal is fed in, the vibration of the base of the cylinder is transferred to the air column, and if the fundamental frequency of the column is matched it resonates loudly. By pouring water into the cylinder, thus changing the length of the column, matching frequencies can therefore be identified.

Suitable values are: 250 cm$^3$ cylinder, length about 0.25 m. This has a fundamental wavelength of 1 m, frequency therefore about 340 Hz. Using 400 Hz, resonances are heard, as water is poured in, at 400 Hz, 1200 Hz, 2000 Hz, etc. Once these have been heard, the experiment can be repeated using about 120 Hz. This time more resonances can be attained, at frequencies 360 Hz, 600 Hz, 840 Hz, etc.