A Systems Approach to Designing and Making in Electronics

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In the post-Dearing curriculum the place of electronics will be in Design and Technology. The challenge that this poses to students of D&T — and their teachers — is considerable. However, the potential electronics has for extending the range and quality of students' work perhaps makes the challenge one worth rising to — if an approach to the teaching of electronics can be established that brings its use as a 'medium' within the range of all of our students. The aim of this article is to show how the consistent use of a systems approach to the teaching of electronics can make both designing and making in electronics accessible to the majority of secondary students.

Background

A practical systems approach to electronics design had been established by the mid 1980s by a working group of the IEE. This group produced a specification for a set of electronic function, or systems electronics, boards which led to the development of commercial products aimed at the schools market. These included Alpha from Unilab and E&L boards from E&L Instruments.

Further support for a systems approach to teaching electronics in D&T was established when QuickTrack (printed circuit board (PCB) design software for the BBC Master computer) was published by NCET in 1990. This remarkably friendly (for a BBC) software provided support for a systems approach to making that was consistent with design work based on the commercial kits.

The driving force behind both of these developments was a desire to place designing and making in electronics within the grasp of all students (as opposed to the elite who were, perhaps, able to cope with O level or GCSE courses in Electronics and the associated mathematical and scientific understandings that these courses required), and also to mirror more closely the approach to electronics design taken by professional electronics engineers.

In the light of these developments, the fact that electronics has not been widely adopted in D&T departments across the country, nor across the ability range within most departments where support for some electronics remains, is surprising. I believe that two things have conspired to submerge these developments. The most significant of these was the publication of the National Curriculum Orders for Technology, which provided very little support for any departmental investment in electronics and none at all for a systems approach to electronics. That the Science Orders, in both incarnations, had a significant section on electronics, further absolved D&T departments from responsibility in this area. Meanwhile, on a completely different front, rapid (and generally welcome) developments in computer technology left the BBC Master looking both rather outdated and something of a niche computer. School investment in hardware and software tended to go to newer machines for which no equivalent to Quick-Track existed.

The upshot of these developments was to leave the teaching of electronics in the hands of science departments, with the focus much more on details of component function rather than on the use of electronics for a purpose.

New Developments

There are, now, a number of reasons for D&T departments to revive their interest in electronics and in a systems approach:

- The new, post-Dearing, National Curriculum has moved electronics entirely out of science and into D&T
- The focus of D&T project work has moved much more towards the designing and making of complete products that incorporate a range of technologies, of which electronics might be one. This means that students have a limited amount of time to study electronics, even in a 'full' course with electronics at its focus. The amount of detailed electronics that can be learnt is low yet the possible design applications are wide. A systems approach can meet these demands. The proposals for Technology recognise this and support a systems approach to the teaching of electronics.
- PCB design software that can be used to support a systems approach is finally appearing for modern computer platforms.

A Note on Systems vs Components

There has, at times, been a dichotomy drawn between a 'systems' approach and a 'components' approach to the teaching of electronics. A number of publications (the QuickTrack manual, for example, and NEMEC's *Science and Technology with*

Electronics series, Unilab's Alpha Resource) have explored this debate; the main conclusion to be drawn is that the division is an artificial one. Any teaching of electronics will in some parts be system based and in others component based. The balance between the two will depend on the experience and sophistication of the students, a greater emphasis on systems being found in elementary courses with an increasing emphasis on component level design as the students progress and increase in their mathematical ability.

The rest of this article will give a brief overview of some teaching materials and approaches that can support a systems approach to designing and making within electronics. The needs of typical Key Stage 4 students will be kept in view, and much of what is said will be appropriate for students in Key Stage 3.

The process of designing and making electronic circuits is divided into three stages:

- Electronic design for all: systems boards in prototyping electronic solutions
- From prototype to PCB: a systems approach to PCB design
- A successful population strategy: systems in the support of making.

Electronic Design for All — systems boards in prototyping electronic solutions

Both Alpha and E&L boards can be used to prototype electronic circuits rapidly for the purposes of testing and refining design ideas. Though these two products use different approaches in their physical design, they provide broadly equivalent systems functions in most cases. The independent development of the two systems since the original IEE specification means that they do not entirely overlap and there is a greater range of functions available in Alpha.

Both products have associated publications (*The E&L File,* and *Alpha Resource*) that provide teachers and students with practical support. The latter is particularly comprehensive.

Signals

A central idea for students to have, if they are to progress in their understanding of the use of systems boards in electronic design, is that of the *signal.* An electronic circuit receives a signal from the physical world; this requires an input transducer (a sensor) to convert a physical signal into an electronic signal. This electronic signal is processed in some way, and the resulting (different) electronic signal is then usually communicated back to the physical world, this requiring an output transducer (an actuator) to convert it into a physical signal. This idea gives rise to a familiar figure where the arrows show the route of the signal into, through and out of the system (see Figure 1 below).

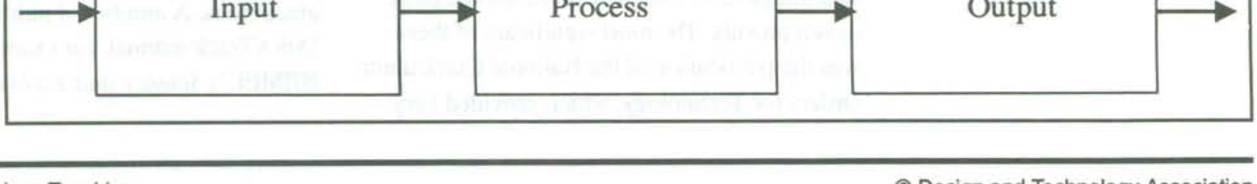
The hardware for both Alpha and E&L emphasises the route of the signal through a circuit and students' attention should be focused on this route. Such a focus on the signal allows the students' design questions to be at a level of function that is appropriate to their ability. Questions such as 'What kinds of physical signal are going into the circuit?' direct attention to the input sub-systems that are needed, and 'What needs to happen to the signal between the input and the output?' looks at the function of the various process sub-systems available.

Practical use of the kits

It needs to be noted that, though Figure 1 seems to suggest that an electronic circuit will have just three sub-systems in it, a practical implementation of any electronic circuit is likely to need five stages where each stage may require one or more sub-systems (see Figure 2).

Power supply boards are useful because, in addition to providing the correct voltage levels, they provide a degree of protection to the rest of the sub-systems at the inevitable moment

Figure 1



Power supply	Input	Process	Driver	Output

Figure 2

when a student connects an inappropriate power source. A driver is usually required to boost the power of the signal from the process stage. In principle a driver should not change the size of the signal at all, it should just ensure that the output device has sufficient power — power that process boards usually cannot provide. However, a confusion in some sub-systems is that the division between 'process' and 'driver' can be blurred; some boards both process (change) the signal and drive (boost the power of) it as well. The distinction between process and driver needs to be made clear to students and the sub-systems that sit across the boundary should be pointed out.

In the initial stages of students' exposure to electronics it is helpful to present systems boards to them grouped in the categories shown in Figure 2, and to limit the number of choices in each category. This keeps to a reasonable level the number of new subsystems whose function students need to be familiar with, and the possible design options are manageable. The information that students then need so that they can engage in electronic design, relates to the effect of the various available sub-systems on the signal, the 'what it does' being of much more significance at this level than 'how it does it'. One level of progression can be the provision of a widening range of available sub-systems; the range of process sub-systems is particularly significant as the function of some sub-systems is much easier to understand than others.

A wide range of different circuits can be made with a quite limited range of subsystems, particularly once the context within which the circuit is embedded is taken into account; a circuit to provide a signal when a particular temperature is reached has myriad applications, although each application effectively leads to a different circuit since not only might the output devices differ but the temperature trigger point will also need to be appropriate to the context.

From Prototype to Printed Circuit Board — a systems approach to PCB design

The use of a systems approach can lead to a high-quality electronic design solution quite rapidly. If this prototype is the end point of students' electronic experience in D&T, as is the case in many schools, the experience is an impoverished one for a number of reasons:

- The need for efficient use of resources means that circuits need to be dismantled at the end of each teaching session and reassembled at the start of the next one; this is de-motivating and time consuming
- The resultant, rather unwieldy, circuit cannot be integrated with the other technologies that are being used in the product; thus the final product will be incomplete in an important way
- Students are deprived of insight into industrial practices relating to electronic circuit production and quality control
- Students do not gain increasing familiarity with the components that electronic circuits are made of in the context of their own designs; such familiarity is the first step in students' progression to understanding about components.

The reason that a 'prototype' made of sub-systems becomes the end point of students' work in electronics is easy to find; it is quite hard to move from this set of sub-systems to a reliable PCB mask because the following, difficult, steps need to be taken:

- Translation from the systems design into a circuit diagram
- Translation from the circuit diagram into a PCB mask
- Drawing out of a high-quality mask.

Each of these steps requires the use of process skills that are beyond the capabilities of a wide range of students. The complete process is rigorous and time consuming even for those experienced in electronic design.

However, the process is also mechanical and thus an ideal candidate for solution through computer power. Thus electronics provides a context where CAD can allow students to achieve that which would be impossible for them without it.

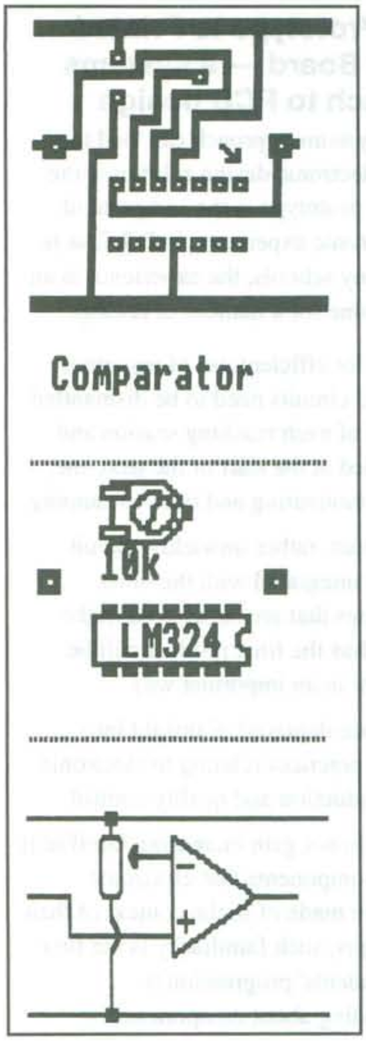


Figure 3

QuickTrack

Although technologically outdated, QuickTrack is sophisticated and well thought through in terms of its educational objectives. Its features are worth detailing in that they provide a standard against which to judge modern PCB design packages:

- It is a general schematic (circuit diagram drawing) and PCB design package, so the needs of the most able student are catered for.
- It incorporates the ability to save files in a library structure. These files can be joined together on screen to produce designs quickly and in a way that is accessible to a wide range of student abilities.
- It comes with an extensive library of files that are electronically isomorphic to the sub-systems of the Alpha and E&L kits. Each of these sub-system files places on the screen a PCB mask for the sub-system, its name, a component layout and the schematic diagram. Figure 3 shows the file for a 'comparator' sub-system.
- Tools are included to manipulate these library blocks — for instance the PCB mask for a light-sensing input sub-system can be inverted around a horizontal axis to choose between light and dark sensitivity.
- All the provided library files have been extensively tested with each other to ensure functional and electronic compatibility; the resulting PCB masks are therefore electronically robust and reliable.
- Each library sub-system is documented for students (in the manual) with information on its function, the components needed, mounting information and procedures for testing and fault finding (see Figure 4).
- The total number of components that a department needs to stock to make any combination of the sub-systems is 50 — an important consideration in the light of the DATA survey on capitation allowances in D&T departments
- There is a link to a spreadsheet to enable students to produce a component shopping list from their PCB design
- The accompanying manual is an excellent, and practical, support tool for classroom work for both students and their teachers.

In my view the software is probably worth buying for the manual alone since its cost is so low. If a D&T department could assemble the BBC Masters, it would also provide a perfectly adequate base for the kind of work described in this article.

Software for modern computer platforms

The reality for most D&T departments is that they need software for the newer computer platforms. However, PCB software with the features offered by QuickTrack has been relatively slow to hit the market. It seems to me that the critical features that such software must provide are:

- use of the machine's WIMP environment. Given the small amount of time time that each student will spend with the software, the time taken to learn to use it must be minimal. This reduction in learning (and remembering) time is the great strength of WIMP environments in educational situations. The development of (reasonably costed) PCB software has been particularly slow in the IBM-compatible Windows environment.
- support for library files that can be merged on the screen. It is this feature that allows the systems approach advocated here to be pursued; much, otherwise very useful, software is not able to do this.

Other features of QuickTrack can be added if these two features are present. In particular, I believe that there are significant advantages to incorporating the library files used in QuickTrack since they are proven and bring with them such features as the limited component set. Agreement between NCET, which has a degree of ownership over the copyright of these files, and software providers needs to be secured to allow this to happen.

It is worrying that there are a number of groups of teachers around the country who, through their commitment to the approach advocated here, are working to create their own sets of masks for each sub-system. Apart from the time and energy that this consumes, the concern is that, without the testing and design time (and cost) that were invested in the QuickTrack masks, the resulting masks may well end up being far less robust. The end result of this could be circuits that do not work reliably, or at all, and thus reduce students' often already

weak confidence in their ability to 'do' electronics.

The software that currently seems to me to be the best for each platform is:

Archimedes: Fast Trax from Techsoft
IBM compatibles: Quickroute 3, from Power Ware or Economatics

(At the time of writing I have not been able to find PCB software for Macintosh computers that meets the second criterion above. I would be very grateful to hear of such software if it exists.)

This is not to say that there is no other software that is equally suitable. These are merely those that I have found that meet the above criteria, are reasonably priced and are, in my clearly subjective view, the easiest for students to use. Of the two, Fast Trax has the friendlier user interface, and can also directly drive a Roland CAMM2 to engrave the PCB mask onto copper-clad board. If a D&T department already has a CAMM2 this is a cleaner and cheaper method of producing PCBs than chemical etching and a good (if non-standard) demonstration of the power of CAD/CAM.

However, most D&T departments won't have the luxury of choosing between platforms.

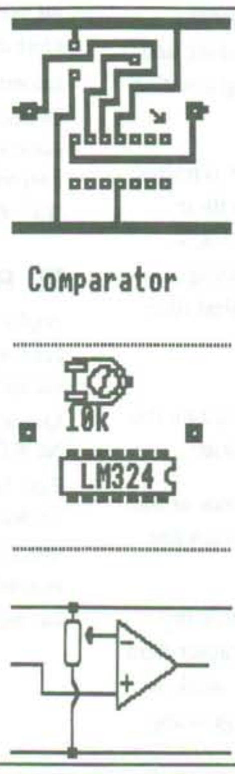
Neither of these at present has full sets of the sub-systems files needed, but discussion is going on with the authors and NCET to have these files incorporated.

■ A Successful Population Strategy — systems in the support of making

An experience familiar to most teachers who have been involved in making in electronics is that of being under siege as pupils approach with PCBs that they have populated with components and which do not 'work'. To students the reasons why their board does not work is usually entirely mysterious, as is the process by which their teacher (sometimes) provides the magical cure. To the teacher the reasons why a board does not work may be equally mysterious, and, even if it is not, the cause will usually require some concentrated detective work. During this time the rest of the class is unattended and queues can build rapidly. All of this is not conducive to good order in a classroom, is de-motivating for the student and only serves to reinforce the student's notion that electronics is 'hard'.

The solution to this problem lies in pushing responsibility for quality control in making back onto the students. A systems approach to the population of a board with components and to the testing of the board as it is being populated, can allow students to take on this responsibility in a way that is matched

Figure 4



Comparator – Process Sub-system

Function This sub-system provides a comparator.

Components One LM324 IC. One 10kΩ potentiometer.

Construction Build and test the sub-system supplying the signal coming into this sub-system first.

Make sure that pin 1 is placed at the top right.

Testing Check that the signal going out is high when the signal coming in is high and that the signal going out is low when the signal coming in is low. Check that the switch-over level can be adjusted with the potentiometer.

Fault Finding If there is a fault check that:

- the voltage on pin 11 is low (0V)
- the voltage on pin 4 is high (the supply voltage)
- the signal on pin 5 is equal to the signal coming in
- the voltage on pin 6 varies when the potentiometer is turned
- the signal on pin 7 is equal to the signal going out

If there is a fault check the relevant track and solder joints.

realistically to their capability and experience of electronics. A suggested procedure is:

- Populate the sub-systems one at a time, starting from the power supply and working from input stage to output. Each sub-system will only have a small handful of components associated with it, so each stage of the making becomes manageable even with relatively complex circuits. Appropriate data sheets can show the components required and their location and orientation on the PCB (see Figure 4).
- After each sub-system is populated it should be tested by checking that the signal emerging from the sub-system is as expected. Data sheets can support this testing and outline the procedures to be followed if a fault is found; those provided with QuickTrack are good examples of what is possible.
- Progress from one sub-system to the next should only occur when the current one is working satisfactorily.

Thus at each stage the checks needed to ensure correct functioning are limited and there are only the newly soldered components to check if a fault is discovered.

Advantages of this process are that, as well as saving the teacher from the cameo described above, the student gains experience of electronic testing and fault-tracing procedures in a systematic environment. This experience builds useful practical skills in students, enhances their electronic understanding and de-mystifies electronics by bringing it within their control.

In trials of this approach it has been reported by teachers that for the first time in their experience they were getting up to 100% success rates in classes who were being introduced to PCB making for the first time.

Summary

The approach outlined has been based on the consistent use of just a few basic ideas:

- The use of electronic sub-systems as the fundamental units in circuit design and making
- Knowledge about a sub-system being limited to its function ('what' rather than 'how') at least in introductory work, a feature of progression being a growing understanding of the function of a range of components
- A focus on the path of a signal through a circuit so that the knowledge required about a sub-system relates to what it does to the signal.

A further benefit of this approach is that it contains a degree of future proofing in the face of the march of technology; the functions that are required of a circuit are likely to remain the same, the way that a function is implemented may well change. Students' primary need at 16+ is to understand the scope of electronics rather than the detail. Perhaps too, a systems approach could free us from the obsession that examination boards have had with such outdated components as the 741 op-amp or the 555 timer.

It is to be hoped that curriculum materials developed to support the new D&T curriculum will support a systems approach to electronics teaching and thus make electronics accessible to all students.

References and further reading

NEMEC, *Science and Technology with Electronics series*: Module 3 — Learning Electronics through Systems and Module 6 — Developing Systems Electronics

NEMEC, *An Introduction to the systems approach using Alpha* (a set of student worksheets with teacher support)

NCET, *Quick Track*, 1990

Unilab, *Alpha Resource*

Economatics, *The E&L File*

Pilliner and Snashall, *Systems Electronics: A course for GCSE and Practical Systems Electronics*, Macmillan

IEE, *Electronics Education* journal

Resources

Alpha systems boards are available from Unilab

E&L systems boards are available from E&L or Economatics

Quick Track for BBC Master is available from NCET

Fast Trax for Archimedes is available from Techsoft

Quickroute for IBM-compatible (with Windows) is available from Power Ware or Economatics.

