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ELECTRONICS AND THE UNIVERSITIES*

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INTRODUCTION

There is only one profession older than that of education and it is timeless and unchanging. By contrast educators, particularly in recent decades, have been indulging in a frenzy of self-criticism, discussion and innovation. It must be observed that change does not necessarily bring improvement, as witnessed by the fact that our schools seem to be turning out a larger proportion of illiterate and innumerate young people than ever before. Nevertheless educators cannot be accused of being complacent or indifferent to the needs of the country. This is particularly so at university level and in engineering where the syllabus is a constant topic of conversation. In my own department we rarely seem to teach the same material two years running, such is the rate of progress at the present time. In this respect electronics probably suffers more than any other engineering discipline, and in order to appreciate the magnitude of the problem it is worthwhile mentioning some of the current developments.

ELECTRONICS

Electronics is a relatively young, but a vigorous and demanding subject. Surprisingly, it was being suggested in some quarters a decade ago that, as a topic it had come of age, so that while steady advances might be expected, no further revolutions were likely, and for major changes one should begin to look to the biological sciences. That prediction seems to have been a little premature, for the rate of progress seems to be accelerating rather than the reverse. For example, in the device field in 1965 it was possible to produce a few integrated logic circuits on a comparatively large slice of silicon, say 3 mm × 3 mm. By 1970 this had been improved by an order of magnitude. Today we are in the realm of large-scale integration where several thousand logic circuits (not just circuit elements) are available on a single chip, at a cost not greatly above that of the early primitive chips. This development has already produced the pocket programmable computer, the electronic wristwatch accurate to a few seconds per year, and electronic games for the masses. We are just entering the age of cheap micro processors, the impact of which is only just beginning to be felt.

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Waiting in the wings, as it were, is the next stage of V.L.S.I. (i.e. very-large-scale integration) – a development which is inevitable but which poses many problems including financial and sociological ones. V.L.S.I. is capable of an appreciably greater density of components, perhaps as many as 20,000/mm^2, with an even further cost reduction from the £3 per function of yesterday and the 1p per function of today, to something even lower. The number of functions performed on a single chip doubles each year and accompanying the higher component density will come higher performance, greater circuit complexity and a lower cost per function.

The availability of integrated circuits of a greater degree of sophistication and economy has considerably stimulated and enlarged the whole electronics industry out of all proportion to the value of the product, and affects every aspect of the profession. The financial problems arise from the enormous investment necessary to set up the required manufacturing plant, investment so large that in most cases it can only be undertaken on a national or in our own case, perhaps a European scale. Yet despite the difficult decisions to be taken concerning the various techniques, circuit types, method of financing and organization, the question is basically a straightforward one – should the United Kingdom embark on V.L.S.I. and maintain a viable electronics industry or should it opt out and simply purchase its components from overseas suppliers? The question has only to be posed in this form for the answer to be immediately apparent. Not whether but how?

Another major field we might expect to see suddenly blossom and have a major impact is that of optical electronics. So far, much has been promised but little produced in the way of practical equipments. What has been lacking is a suitable propagating path, the equivalent of a copper wire to an electric current. However, starting from a research idea only twelve years ago we now have light 'conductors', i.e. optical fibres, smaller and more flexible than coaxial cables and more transparent than the earth's atmosphere on an ideal day. Already optical fibre systems are being installed experimentally in telephone and power system networks and an entire community in a new town in Japan is being interconnected experimentally with optical fibres. Thus the bandwidth available, on an interactive basis, to the individual home enables data, facsimile and video communications to be carried out. Here is a pilot project of major significance involving both technological engineering and social engineering.

One could continue in this vein at length and discuss the major impacts which might be made in electronics and on society in the future, for example in pattern recognition, digital techniques, interactive computing, distributed computers, communications, but above all by the enormous increase in information processing power, in progressively smaller size, and at lower cost per function, which will be brought about by V.L.S.I.

Far from electronics being played out as a subject, its impact is only just beginning, and the future holds far more exciting and socially challenging, as well as technologically difficult, developments than any we have seen in the past.

THE UNIVERSITIES

What part do the universities in the U.K. play in the development of electronics and its impact on society? First and foremost, naturally, they play an educational role which is reasonably straightforward and perfectly understandable in the case of non-professional faculties such as the arts, humanities and even science. But the task of the engineering educator, and the same applies in other professional subjects such as law and medicine, is far more complex. This is because we have to introduce an element of professional training, in our case an introduction to electronic technology, and to current practice and design. Even though many of the techniques taught will rapidly become obsolete, this part of undergraduate training is essential in order to emphasize the relevance of academic studies to the industrial world, and to give the student as good an idea as possible of what engineering is really all about.

Of equally vital importance is the need to develop the capacity of the student to learn by his own resources, and above all to be adaptable to new topics and situations. As I have indicated above, electronic techniques are advancing at a rate which is little short of alarming. Our graduates are in a field in which the basic technologies are likely to change several times during their career, and it is essential that the educational base from which they operate should be secure yet flexible. Thus, in addition to education in the general sense of the word, they must acquire a fundamental training which will stand the rigours of time and enable them to face new situations throughout their working lives.

Another difficulty is the need to develop in the student a critical and inventive approach to the solution of engineering problems. This is a crucial factor, because at its highest level engineering is a process of invention and innovation. Basically, pure science is concerned with analysis, the breaking down of the complex processes of nature into their simplest elements, whereas engineering is a synthesis of a wide range of complex factors, some incompletely understood, into a greater structure which, hopefully, is of benefit to mankind.

After I had written this paper I discovered that Saint Thomas Aquinas[1] was of much the same opinion when, in the thirteenth century, he wrote 'practical sciences proceed by building up; theoretical sciences by resolving into components'. I really despair of ever being able to say anything new on education!

Synthesis alone, while essential, is not enough, becoming dry and lifeless unless allied to creativity. We must therefore somehow train our students continually to question existing theories and established precedent, since an inventor has been described as 'a fellow who does not take his education seriously'. For example, if Marconi had not ignored all the advice and theories of the leading experts of his day, he would not have attempted the classic experiment which demonstrated the feasibility of long-distance radio communication. It is interesting, but perhaps not very helpful, to observe that if the Science Research Council had existed at that time, Marconi's application for a research grant would probably have been rejected out of hand.

In summary, then, four of the requirements of an engineering undergraduate course, and there are others which could only be dealt with in a much longer article, are to provide a sound knowledge of the scientific principles underlying a chosen field of technology, to provide some knowledge of current practice, to develop the student's ability to learn by his own resources and to develop a critical but inventive approach to the solution of engineering problems.

The product of the university is required to be a mature young person capable, after training and appropriate experience, of becoming a high-grade professional engineer with all that the latter term implies. Some of the processing we have to apply I have just described. The material on which we have to operate consists, ideally, of bright and enthusiastic young people of good ability in mathematics and physics (many university engineering departments have entrants with high entry qualifications) having a fair understanding of basic physical science but little idea of the relevance of their school studies to the outside world nor even of how, or why, such knowledge is to be applied. The transformation required is thus a very major one, and the time available for the universities to perform their processing function is ridiculously short, namely three years each of thirty working weeks of 4½ days, (or something equivalent to this on a thin sandwich course) making a total of 400 days. Rather a formidable task.

In the circumstances, given the task and the dwindling facilities available, I believe the universities do a remarkably good job with a productivity which is unmatched in almost any other country in terms of the quality of the product and the time available. Judging by a recent report in the *Times* the shadow Minister of Education[2] is of the same view.

There are, of course, many criticisms made of the universities, often by people who have never visited one or who made no great success at their own studies, much of it unfounded and based on ignorance of the functions and performance of engineering departments. It is as fallacious to consider oneself an expert on education just because one went to school, as it is to claim to be a surgeon on the grounds that one's appendix has been removed. If, as in the usual fairy tale, I had three wishes, the first would be that no-one should make public comments on universities without having spent several days, within the preceding five years, at a university, studying the real, rather than the imagined, situation.

Despite the excellent work which, I believe, university engineering departments are doing, there is no room for complacency. Within the time-span of a present-day degree course not all the desirable aspects of the subject can be covered. Furthermore, there is hardly any opportunity of dealing adequately with the broader aspects of professional engineering such as accountancy, industrial organization, social responsibility, and so on. Indeed, the increasingly variable background of our entrants, which will be further accentuated if the new sixth-form, school-leaving examination and syllabus proposals in the U.K. are approved, will cause even greater difficulty in maintaining, let alone improving, the present quality of our graduates. In the very competitive world of today, a much higher degree of professionalism is required, and engineering educators have long been of the opinion that three years are simply no longer adequate if this country is to try to regain something of its former stature among industrial nations.

Fortunately, this view is beginning to gain credence, and the University Grants

Committee has recently set up four-year degree courses, orientated towards manufacturing engineering, at a few universities. This is a start, and one hopes that four-year degree courses will become available for all professional engineers. High-quality engineers are required not only on the factory floor but also in design, sales, development, management and research. There is no point in having excellent production facilities for inferior or poorly-conceived equipment. The provision of better-educated production engineers is therefore unlikely to have more than a marginal effect on the quality of our engineering products, since quality is something which has to be built into a component or system in the early design stage, and cannot be simply tacked on as an afterthought in the production line.

One might go further and say that by giving embryo production engineers a four-year undergraduate training it does not necessarily follow that they will take up a *career* in production engineering. Why is it that the best graduates are not queuing up for jobs in this field already? The answer, I fear, may not be entirely unrelated to working conditions, the intellectual challenge and the rewards provided by industry. For example, recent surveys have shown that the salaries of professional engineers in manufacturing industry in the U.K. are not only low compared with those in nationalized industries, public corporations, local government, the civil service and in other professions, but they are steadily falling further behind. Young people in schools choosing careers, and graduating students, are well aware of the situation, and the best production engineers in the world cannot improve industrial productivity unless they can be attracted into that sphere of activity.

Because engineering innovation, design, development and production are highly interrelated activities, I believe that four-year degree courses should eventually become available for all engineering students. This raises the question of which subjects should be covered in the extra year. Generally speaking, most existing three-year courses probably are successful in providing an adequate basic education in engineering and applied science. However, some of the additional time is needed to provide a firmer basis for these engineering studies because of the diversity of school syllabuses and subjects. In addition, however, the need to strengthen the professional element in degree programmes has long been recognized, and such topics as business studies, accounting (if we are to compete at Board level with accountants on their own terms), industrial organization and law must be included. The new courses should emphasize integrated studies in professional engineering, including both social as well as the technological aspects, preferably through individual and group projects having as much industrial contact as possible. Project work is valuable not only because it excites and motivates the student but also because it offers him the opportunities to develop organizational and communication skills.

While engineering degree courses should be broadened by introducing professional subjects, the technological base itself must be soundly laid and within a particular discipline. It used to be thought that there is a subject called 'engineering' and that it must be taught to all first-year, and sometimes second-year engineers. This form of 'engineering' comprised a range of subjects drawn so widely and diffusely as to provide little real knowledge and no intellectual training. The same dangers lie in any scheme aimed at producing a general engineer. If a university training means anything, it involves training in depth in a particular field so as to produce a sharpening and a stretching of the mind. People educated properly in this way should be able to tackle completely new problems, including a transfer to other disciplines, such as management after proper training, otherwise the universities have failed.

The argument has been put much more eloquently by Lord Ashby in a book[3] which ought to be compulsory reading for all new engineering teachers. He said, paraphrasing slightly, that 'the essence of technological humanism is the habit of apprehending a technology in its completeness and this is what we should expect education in higher technology to achieve. I believe it could be achieved by making specialist studies the *core*, around which are grouped liberal studies.* But they must be relevant; the path to culture (professionalism) should be *through* a man's specialism, not *by-passing* it . . . . . A student who can weave his technology into the fabric of society may be said to have a liberal education; a student who *cannot* weave his technology into the fabric of society cannot claim even to be a good technologist.'

My sincere hope, therefore, is that the new U.G.C. four-year courses will not set out to produce engineering managers having a smattering of technology but good technologists capable of developing into first-rate managers.

COLLABORATION WITH INDUSTRY

The need for university collaboration with industry is strong, but let it not be thought that this collaboration does not already exist. Firstly, a large fraction of engineering staff in universities have industrial experience. To take one example, a recent survey shows that, on average, each member of the engineering staff at Southampton has spent 5 years in industry and 3 years in government establishments. Added to that is the fact that 80% of the staff are engaged from time to time as consultants to outside bodies, and in addition we have 7 industrial units which are self-supporting and have no direct subsidy from the University. They take on work ranging from consulting to prototype equipment production.

Furthermore, the support provided to departments through the University Grants Committee is now barely adequate to ensure a proper level of teaching activity and for the bulk of our research we have to seek funds elsewhere. Last year our Faculty of Engineering attracted as much money from outside sources as the amount it received via the U.G.C.; namely some £1.6M, of which 65% came from industry or industrial-type sources. It is a nonsense to say that universities, or at least their engineering faculties, are ivory towers having no interest or contact with the 'real' world. I would go so far as to suggest that the comments of universities on industry may be more soundly based than those of industry on universities, but having said that, let me stress that the emphasis should be *not* on criticism, other than of the constructive kind, but on co-operation and partnership where,

*Here I would add professional studies.

given the existing constraints on both sides, the situation is reasonably good but needs continual nurturing.

While I am in this somewhat aggressive frame of mind, perhaps I might be allowed one further comment. It is frequently stated in the media, and believed by many politicians, that contacts with industry are stronger in the polytechnics and technological universities than in the 'traditional' engineering schools. I hope the situation I have just described will show that such statements are not necessarily true. Similar remarks are made about sandwich courses, but here again about 40% of the electronic students entering Southampton this year are on thick sandwich schemes, spending twelve months in industry before starting their academic studies, and returning to their firms in the 'vacations'. This does not happen by accident, and requires much negotiation by the teaching staff together with visits to the students during their industrial periods. Seldom are 'traditional' universities given much credit for this kind of initiative. Many of the misconceptions which arise concerning the functions and performance of engineering departments arise because the statistics for engineering are frequently lumped in with those of science to produce a very misleading picture.

The second of my three wishes would be that in any assessment of universities, the performance of engineering should be considered separately from that of science, arts and other faculties.

The number of science students in the country greatly exceeds the number of engineering students, and maybe this situation should be reversed. Industrialists with whom I talked on a recent extended visit to Japan were greatly surprised at the situation in the U.K., since in their country there are twice as many engineering, as science, students. In the latest U.G.C. publication[4] 'Statistics of Education', the proportion of engineering undergraduates in this country is 14% compared with 23% studying science – surely there should be a major redress of these figures? As Sir Ieuan Maddock has pointed out[5], in terms of its population, this country has an outstanding record in the acquisition of Nobel Prizes, but what we really need at present, and have needed for a long time, is a better overall industrial performance. Arguably, more, but without doubt higher calibre, graduate engineers are urgently needed, and who says we cannot afford it? One day's loss of the British Steel Corporation would finance four-year degree programmes for many years to come. Conversely, by reducing the intake to engineering departments by 25%, then four-year courses could be operated with only a small additional cost while the lower-quality tail of weaker students could be removed.

Teaching is the activity which receives most public attention, but it is only a part, albeit an important one, of the function of a university. Even so, undergraduates form only a part of the teaching load, and in addition there are M.Sc. and research students who are in residence for the whole of the year and comprise, in our case at Southampton, about one third of the undergraduate load. Furthermore, while the undergraduates are enjoying their 'vacation' (and what a misnomer *that* word is as far as university staffs in the U.K. are concerned!) when they are, or should be, engaged in private study and undertaking vacation training, the university engineering staff continue to teach students on 12-month M.Sc. and research courses, carry out their own research, organize conferences and run post-experience courses which are increasingly necessary.

Quoting examples from my own University and Department might savour of slightly bad taste and if so I apologize, but the local situation is certainly the one that I know best. Furthermore universities are normally reticent in stating their own cases, so perhaps I should redress the balance somewhat.

CONTRIBUTION TO SOCIETY

Universities also make a valuable contribution to the life of the nation through research, not only in terms of scholarship and the training it provides, but equally importantly in producing a reservoir of skills, as well as producing new processes and results. In recent years considerable changes have taken place. It used to be thought that too much money was being spent on fundamental (in some peoples' minds this means frivolous) investigations, and while this was rarely true of engineering schools it is certainly not the case today. The point has already been made that money from U.G.C. sources is very scarce, and research money has to be attracted from outside bodies so that the pressures to look only at short-term practical problems is intense. The situation is exacerbated by the severe cutting-back of the normal research studentships by the Science Research Council in favour of C.A.S.E. awards (Co-operative Awards in Science and Engineering), which have to be carried out in collaboration with industry, and while this is no bad thing in itself, such schemes can only be based on existing expertise and are unlikely to generate new skills for the future.

Universities should not expend all their research energies on tackling the industrial problems of today but should be, at least partially, engaged in longer-term work, generating the ideas that will be required by industry *tomorrow, and* producing innovation. Long-term research is no longer being done on any scale in industry or government research establishments, and if not encouraged in universities it will not be done at all in this country. For a limited time we can survive on existing knowledge, on our fat as it were, but when that is exhausted the situation will be serious and possibly irremediable. Perhaps too much fundamental research has been supported in the past, although this has been mainly in the 'big' sciences, not engineering, but the pendulum has now swung too far in the reverse direction, and long-term engineering research is in danger, with possibly serious repercussions. It is the classic situation where governments and government agencies have not so much responded *too late* but have responded *too much*. The proverb about not throwing out the baby with the bath water is very pertinent here.

The comment is frequently heard that university research is a narrow specialist activity in which more and more is learned about less and less, so that after three pedantic postgraduate years at university, the Ph.D. graduate is completely useless to industry. For the reasons already given I would again like to take a personal example. My research group is concerned with optical fibre communications. We fabricate optical fibres and therefore need to know a lot about a certain type of glass technology, about materials processing at extremely high purity levels (better than 1 part impurity in 10^8), and about the optical absorptive and dispersive properties of glasses. None of the group has any formal training in any of these aspects but are simply high-quality electronic and electrical power engineers, together with one mechanical engineer and two mathematicians. We need to have a very detailed knowledge of: electromagnetic wave propagation in fibres; sophisticated mathematical techniques; microprocessors for control of fabrication and instrumentation; plastic coating and fibre strength measurements; some knowledge of cabling processes; detailed experience with lasers, light-emitting diodes, detectors, modulation techniques; design of joints, connectors and couplers; optical fibre system design, high-temperature furnace design; some aspects of optical system design. A particular research student needs to be expert in about half of the topics mentioned and be familiar with the others. Not, I would have thought, a narrowing experience, but one likely to produce versatile and adaptable engineers. All our Ph.D. graduates have taken up posts in industry.

Many of the equipments and techniques we have developed have been taken up directly by industry and research organizations all over the world, and the revenue thereby earned has gone to the funding bodies supporting our work. We can therefore even claim to have contributed, in a very modest way, to increasing exports from the U.K.! This example could be matched by other research groups at Southampton and at most other universities, and the only point of my argument is that engineering departments do, through their research and development work, make very direct and practical contributions to industry.

CONCLUSIONS

In this discourse a number of aspects have been stressed. For example, the wide spectrum of electronics, both in its applications and its fundamentals; the speed of advance of electronic technology and its increasing social impact; the need for a sound and flexible intellectual education for our future professional engineers. There is also need for a smooth, non-reflective and well-matched interface between educational establishments and industry, since universities are no more able to produce trained professional engineers than industry is able to give them a sound fundamental academic training.

The range of electronic techniques requires a wide variety of skills from materials science, mathematics and software, to large-system design and installation, and to production. More and more computer-controlled processes are emerging, and the production engineer must work hand-in-hand with the software or systems engineer, and is increasingly dependent on him.

I have illustrated the rapid advances being made in electronics by saying that 11 years ago there was no such subject as optical fibre communications, while today optical fibre cables are being produced, and experimental optical systems are already being installed in telephone networks, electrical power systems, ships and aircraft. There are many other similar examples, so that continuing education is vital if, as engineers, we are to keep abreast of our subject. The universities are already involved, not as heavily as they would be if adequate additional resources were made available, but the post-experience aspect of university work could, and should, be strengthened, as envisaged in the discussion document[6] 'Higher Education in the 1990s'.

Thus, there must be increased interaction and dialogue between establishments of higher education and industry. The professional institutions also have an educational role to play, but there is no space to deal with their contribution here. If this tripartite dialogue produces effective action, then the interface with government is a smooth one. If, as engineers from all sectors, we fail to put our house in order to the satisfaction of the world at large, then we must not be surprised at government intervention; but perhaps this should not surprise us anyway! I have stressed the contribution of the universities, and made the point that their relations with industry are far closer than is generally thought. Polytechnics in the U.K. also have a strong contribution to make, but I have not taken up cudgels on their behalf, partly because I do not feel qualified by experience to do so, and also because I feel they are given adequate and fair coverage by the media. Universities, on the other hand, receive less than justice on many occasions and seem reluctant to state their case forcibly.

Finally, however inspired are the responses to the needs of the nation by universities, polytechnics, and the institutions, the ultimate remedy for improving the status and performance of the electronics profession must lie largely with industry and government. Industry alone has the power to convince young people that it can provide challenging, interesting and financially rewarding occupations. Government has the responsibility for changing social attitudes to industry, and to the concept of professionalism and excellence, and for allowing industry to provide adequate financial incentives.

The third of my three wishes would be for all the various bodies concerned to collaborate successfully so as to produce good professional engineers and thereby a healthy and influential profession, capable of leading this country back to a state of industrial excellence and national prosperity.

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ABSTRACTS–ENGLISH, FRENCH, GERMAN, SPANISH

Electronics and the universities

This is a shortened version of the presidential address given to the Institution of Electronic and Radio Engineers in London in January, 1978.

Électronique et les universités

Cet article est une version abrégée du discours présidentiel prononcé à l'Institution of Electronic and Radio Engineers à Londres en janvier 1978.

Die Elektronik und die Universitäten
Dies ist eine gekürzte Fassung der Ansprache des Präsidenten der 'Institution of Electronic and Radio Engineers' in London, Januar 1978.

La Electrónica y las Universidades
Es una versión resumida del discurso presidencial dirigido al Instituto de Ingenieros Electrónicos y de Radio en Londres en Enero de 1978.

BOOK REVIEW

Semiconductor Circuit Design (for a.f. and d.c. amplification and switching): J. WATSON (Adam Hilger, 1977, 536 pp. + xi, £7.50)

Now entering its 3rd edition, this text-book provides a comprehensive undergraduate course in circuit design. As in earlier editions, the emphasis is mainly on the linear aspects of semiconductor device behaviour, although the design of bipolar switching circuits is also covered. The book has been thoroughly revised, involving the removal of obsolete material and addition of a substantial amount of new material. Considerable reorganisation of the text has also been carried out to improve the continuity of the treatment.

The development of the subject in the early chapters is fairly conventional, proceeding through the characteristics of diodes and bipolar transistors to consider small-signal models and equivalent circuits. Operation of the transistor as an amplifier is followed by the introduction of the feedback concept and an examination of stability criteria. A discussion of d.c. amplification and the design techniques associated with differential amplifiers is included as a forerunner to a later chapter which deals in detail with linear microcircuits and operational amplifiers.

An entire chapter has been devoted to a comprehensive analysis of the subject of noise, with particular reference to bipolar transistor amplifier circuits. Further mention of this subject with specific reference to operational amplifiers and F.E.T.'s is made later, in chapters dealing separately with these devices. A section of the book covering special-purpose amplifiers includes frequency-selective amplifiers (active filters), oscillators and power amplifiers. Circuits utilizing the switching properties of bipolar transistors are dealt with in a chapter that also describes several non-linear integrated devices such as comparators and timer modules. No attempt has been made to cover digital electronics or logic circuitry.

A chapter which examines F.E.T.'s includes a treatment of one of the most recent products of M.O.S. technology, the charge-coupled device (C.C.D.). Subsequent sections of the book cover miscellaneous discrete semiconductor devices such as zener diodes, thyristors and a selection of transducers, and examine some of their applications. Another chapter reviews power supplies, while the book ends with a brief survey of electronic systems.

A useful feature of the book, particularly from the student's point of view, is the provision of fully-worked design examples at numerous points in the text. In most cases these have been up-dated to use modern devices, thus bringing them into line with current design practice. Another example uses the popular 741 to illustrate some of the basic principles of designing with integrated circuit operational amplifiers. A section containing problems at the end of the book, has solutions provided.

The modest price, comprehensive treatment and easily-readable style of presentation combine to make this a book that can be safely recommended for undergraduate electronics courses, both at core and subsidiary level.

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