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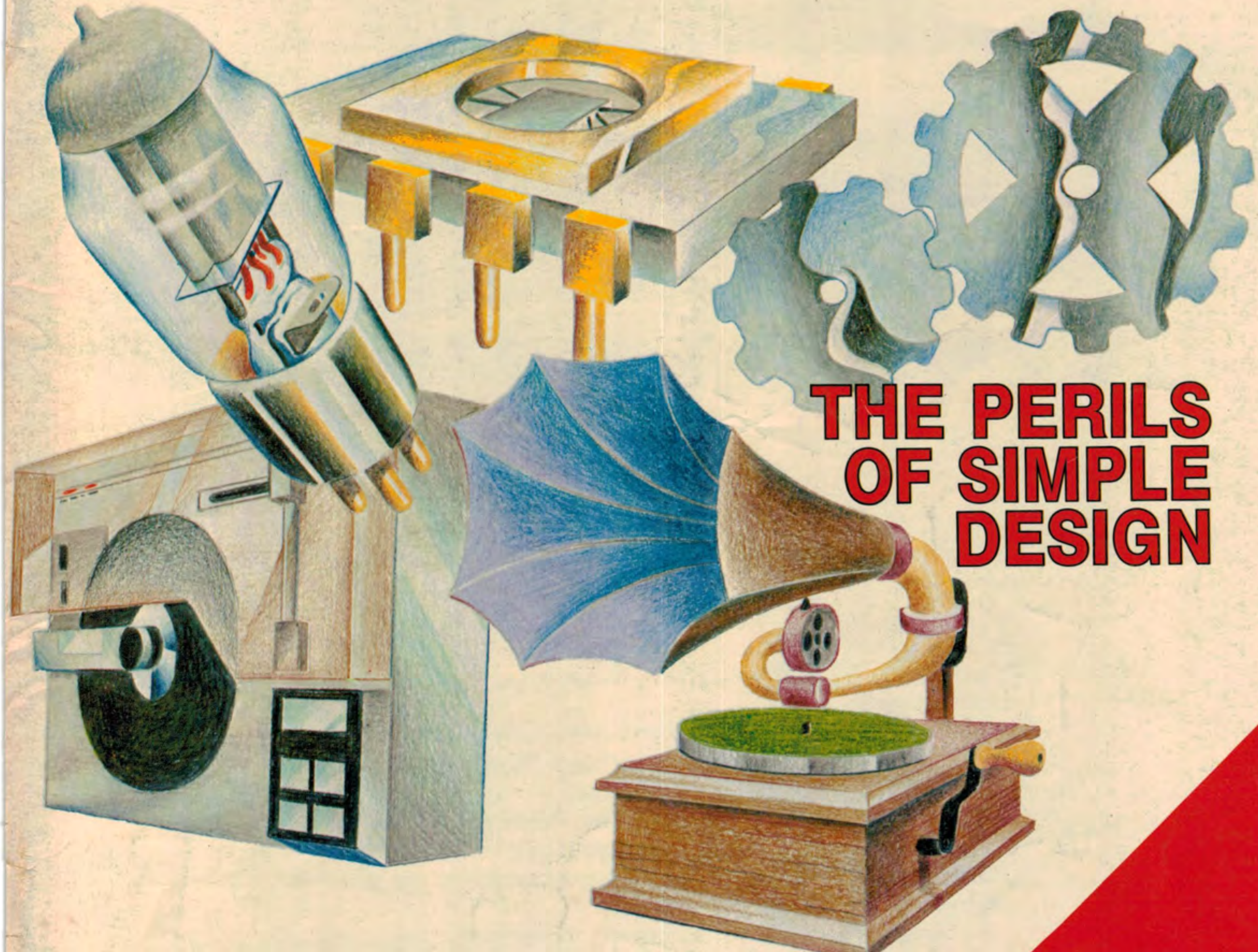

THE PERILS OF SIMPLE DESIGN

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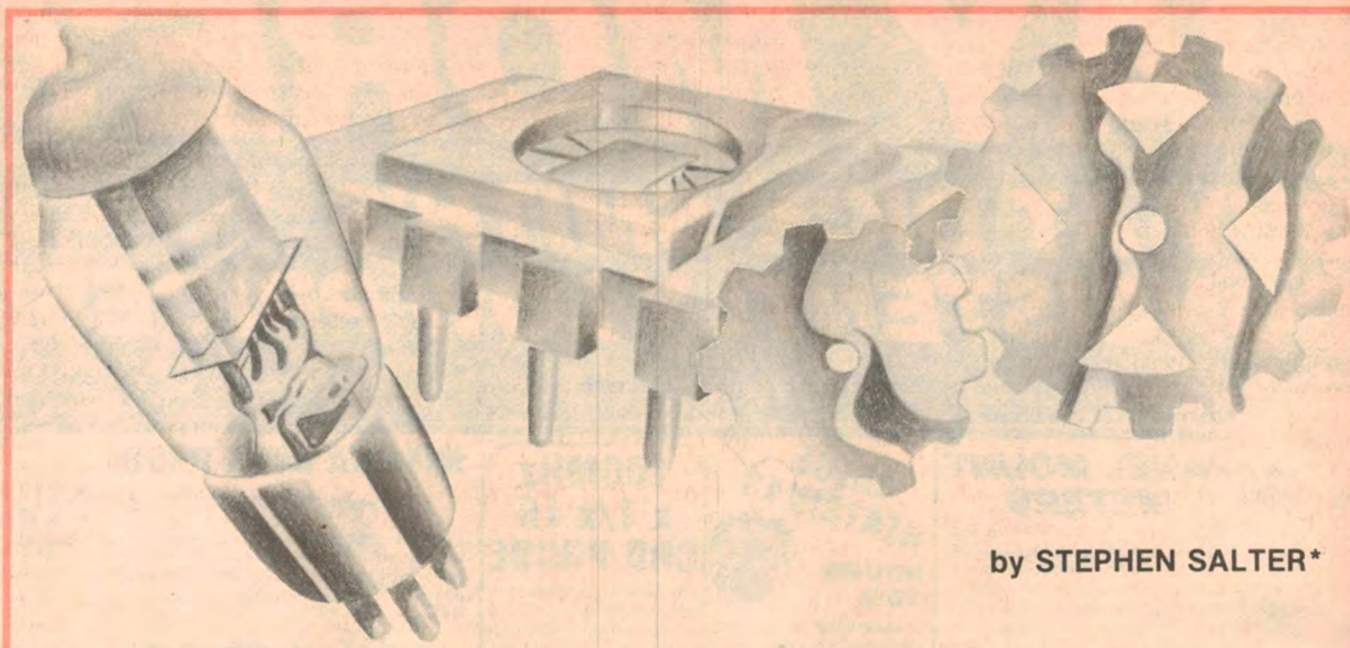

by STEPHEN SALTER*

The perils of simple design

Simplicity has gained a false supremacy. Complicated devices work better, are easier to use, and are more reliable!

IF ALL ENGINEERS and scientists in a country accepted some monstrous fallacy – such as that force equalled mass times velocity – we would expect that the projects selected for research and the designs selected for production would suffer as a result. Engineering equipment would perform indifferently and the country would lose out to nations with a better grasp of such an important piece of physics.

I believe that many people, in all countries, suffer from a disadvantage of similar magnitude. If we ask a random selection of engineers, technical administrators or politicians whether they prefer a simple engineering design to a complicated one the answer is almost invariably on the side of simplicity. Most textbooks on design (except the remarkable series by Gordon Glegg, when a lecturer in engineering at the University of Cambridge) emphasise its importance. The BBC program *Tomorrow's World* uses it for everything. Inventors proudly claim simplicity for their new inventions. Selection committees base their decisions heavily on it. I want to convince this large majority that it is wrong.

Most people accept that engineering gets along much better when we agree on systems of units to measure quantities and develop the instruments to give numerical answers about their values. We can measure the tensile strength of a material or the value of a voltage and then calculate whether a part can sustain a load or pass a current. Unfortunately there are no units for measuring simplicity. We cannot scan a probe over engineering drawings or clip leads into a circuit test-point. We have instead to rely on subjective psychological judgements made by "experts". I ask the reader to imagine that we are trying to make a "simplicity meter" by collecting groups of subjects, posing them carefully chosen questions and then analysing the replies. I suggest that we confine our attention to measurements of the simplicity of the engineering solutions to problems rather than the simplicity of the problems themselves.

The first observation is that the meter gives different answers according to the background and training of the subjects. Civil engineers pale at computer circuit diagrams while electronics people shudder at the problems of building a bridge in the middle of winter.

Secondly, the simplicity meter gives different readings at different periods of history. A striking example of this came from a letter to the Institution of Electrical Engineers' journal *Electronics and Power* in May 1981. The author of this letter thought it *axiomatic* that any engineer prefer simple solutions to complex ones. He cited the bicycle as an instance of a simple solution. (Axioms are powerful things. They mean that you have shut your mind to all other possibilities.)

Let me make it clear that I am not attacking bicycles. Bicycles are superbly efficient and successful machines. Most people would agree that they are indeed simpler than cars and aeroplanes. But

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bicycle technology is mature. Bicycles evolved during the last half of the 19th century to reach their present state of development by about 1905. To be successful, they needed the invention, development and production of ball bearings, sprockets, roller chains, the free-wheel and gear-changing mechanisms. The pneumatic tyre required advances in the processing of rubber. Lightweight frames needed thin-walled drawn steel tubing. (The most expensive bicycles today use tubing with carefully graded wall thickness to give extra strength near the ends.)

If you think that bicycles are simple, try building one with the tools and materials in a blacksmith's forge. These would be an accurate example of the resources available to the bicycle pioneers. The plain fact is that bicycles were *complicated* solutions to the problem of providing cheap personal transport to people who would otherwise have walked or ridden horses. They would have appeared totally unbelievable and impossibily complicated to the leading engineers of the preceding age.

Our meter readings of simplicity are also distorted with respect to the two sides of the front panel of a machine. For example, the first screw-cutting lathes came with a set of change wheels. The turner had to calculate the ratios needed for the pitch of his thread, select wheels with the suitable number of teeth and mount them on the machine. This arrangement lasted about a hundred years. A modern lathe has a group of levers or dials which select a wide range of gear ratios from a complicated enclosed box. The older system was undoubtedly simpler from the point of view of the lathe factory. But the modern arrangement is simpler from the point of view of the lathe operator, who makes quicker changes with fewer mistakes. Gears are cleaner, better lubricated and safer.

“A truly simple car would have a single cylinder engine with straight-through clutchless transmission.”

The lathes in my workshop even have a clever gadget which prevents me engaging the lead screw nut except at the right moment and then disengages it for me when the exact length of thread has been cut. The modern lathe-person enjoys simplicity of operation thanks to a complicated mechanism with lots of moving parts hidden from sight. Simplicity on one side of the controls means complexity on the other.

This pattern is universal. We may believe that electronic circuit design has been simplified by the availability of cheap reliable microcircuits. A television manufacturer mounted a recent advertising campaign around this very point. But we must look at the whole scene. Inside the factory that makes the microcircuits that go into the "simplified" television set are extremely complicated machines with superb optical and mechanical accuracy. Materials are purified to an astonishing degree and extraordinary levels of cleanliness are necessary. The substitution of electronic parts for mechanical ones invariably requires large increases in *overall* complexity. This is done because it leads to cheapness, reliability and improved specifications. The overwhelming trend of modern technology is to simplify final use by increasing complexity everywhere else.

It begins to look as if our simplicity meter has some unfortunate characteristics. It gives different readings to different users. The readings change with time. They are even different when measurements are made in different stages of a chain of production and use. But perhaps with further design effort we can produce correcting networks and carefully controlled methods of statistical analysis which may produce a more satisfactory instrument. I ask you to imagine that we have done this and that now our selection committee can place a range of designs in rank order of simplicity. Let us see whether this rank order is a good pointer to ultimate performance. The advocates of simplicity will win their case if the majority of examples fulfil their predictions.

They will not do well if they choose, for instance, the development of firearms. We moved decisively away from muzzle-loading smooth-bore matchlocks to rifled barrels with automatic breech-loading. We are now adding telescopic sights and image intensifiers. At every stage firearms have pushed design and machine-tool technology to their limits as extra and more accurate moving parts are added.

What about photography? The first cameras were wooden boxes with elementary lenses. Exposures were made by removing the lens cap. Modern single-lens reflex cameras have over one hundred accurate moving parts. They have multi-element lenses with low *f*-numbers that are computer-designed to approach the diffraction limit of resolution. Molecular layer coatings provide superb light transmission. Many lenses have zooming and close focusing. Shutter speeds are controlled by measurements of light from the film during the actual exposure, and they span five orders of magnitude. Signals can be sent to terminate electronic flashes. Motorised wind-on and even automatic focusing are possible. What is even more extraordinary is that despite superior performance and inflation the cost of cameras has steadily fallen.

In music, the valveless bugle produces the trumpet, the harp becomes the piano. In telecommunications, the STD exchange replaces operators, and satellites replace undersea cables. Epoxy resins replace animal- and starch-based glues. Shakeproof washers are added to stop nuts coming loose. Heat treatment increases the hardness and strength of metals. Plywood gives better overall strength than natural wood. In navigation, we have moved from cross-staff and compass through sextant and chronometer to Decca, Loran, inertial platforms and Doppler radars. In arithmetic we move from Napier's bones and books of tables to the slide-rule and then to electronic calculators, in optics from the magnifying glass to the compound microscope and from the telescope to prismatic binoculars. In cars, crash gears give way to synchromesh and then to automatic transmission. Beam axles give way to independent suspension. Front wheel drive is superseding rear wheel drive. Fuel injection will replace the carburettor and electronic ignition the contact breaker. Overhead camshafts have beaten side-valves. Hydraulic servo-assisted brakes have swept away rod-actuated ones and we can expect anti-

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locking devices to become widespread.

Despite such examples, a leading car manufacturer announced a recent model with the headline: "Simple is efficient". The advertisements went on to contradict the statement by listing all the attractive, new and complicated design features. A truly simple car would have a single cylinder engine with straight-through clutchless transmission, no differential or suspension, and nothing in the way of heaters, windscreen wipers or lights.

For a long time I have been provoking colleagues and acquaintances by asking them to produce examples of the success of simplicity in any field or human endeavour. Only three have emerged. I now extend the challenge to readers. There are only two rules. First, you must consider the whole sequence of events from the designer's drawing board through all the factories which produce component parts. Secondly, you must compare each design with those competing with it, those it supersedes and the later design which will supersede it.

Can it be that "simplicity", this complicated word, is changing its meaning? The Bible gives us a splendid view of English in the 17th century. In every single occurrence of the word *simplicity* the meaning is negative. It is taken to be the antonym of wisdom and subtlety — not at all what engineers should aim for (see *Proverbs* ch 1 v 4 and 22). We can trace later usages of the word in the *Oxford English Dictionary,* and again more than half the examples are pejorative.

Can we learn anything from current spoken language? I have for some time noted the use of the word in technical discussion. Readers may learn much from repeating this exercise. Five examples stand out.

My first (best given in a bored casual drawl) goes something like this: "Extending the fifth order hyperbolic convolution polynomial transforms to non-integral numbers of dimensions is basically quite simple." The speaker covers eight blackboards faster than his audience can blink. The translation is plain: "If I find this stuff simple while you don't I must be a very clever fellow, far above you lot and therefore long overdue for promotion".

A second usage arises when someone has been striving to understand what may be quite a complicated idea. If, after a struggle, insight suddenly arrives and if the idea is elegant, subtle or fresh, he may smile warmly, drive his fist into the palm of his hand, slap a thigh, and say "Of course. I see. How beautiful. It's so *simple*". He feels satisfaction at understanding the new concept and he needs to demonstrate his mastery to others. It would be embarrassing to ask why it has taken humanity so long to come up with the idea. I learned a better expression for this meaning from students at the Massachusetts Institute of Technology. It was "real neat". No verbal confusions over there.

A third case is frequent in technical advertising. The product being sold uses a higher level of technology than the customer has been used to. The advertiser needs to reassure him that the new device will not reveal his inferiority. "X x x pressure transducers are simple and reliable" is immediately contradicted in the next breath: "They use third generation silicon technology for the diaphragm element." I am all in favour of third-generation silicon but to call it simple is a lie. The advertiser is trying to conceal the bloody struggles of two generations.

When used of their work by inventors, *simple* means "Supporting this project won't cost you millions in R&D". This use shows that they are ignorant of the daunting tasks ahead and the ghastly concealed problems waiting to pounce. The thought is "If we call it simple often enough the gods will make it so". But they don't.

> **"The thought is: if we call it simple often enough the gods will make it so. But they don't."**

My final example of the technical use of the word comes in a last-ditch defence of an obsolete and inferior design challenged by a superior one: "These aluminium pressure die-castings look flashy enough and of course they are a bit lighter. But our old cast iron sand mouldings are much simpler. Do we really need the lighter design? The new plant is very expensive." Appeals to simplicity are being used to delay investment and hold back improvements in design. One can hear the dying echoes of the last words of the British motorcycle industry.

What can have led to this deplorable state of affairs in which a word can threaten our entire commercial future? Is it that there are sound principles which may be mistaken for simplicity? It is certainly good to use design features which save material or machining operations. It is certainly right to avoid tortuous drive routes, unnecessary parts, conflicting constraints and stress concentrations. We should be in favour of elegance, style, clever economies and downright cunning. It is wise to use mechanisms with modes of behaviour which are within your methods of mathematical analysis and materials with chemical interactions which you understand. But all such considerations can be examined with sharp quantitative arguments. We can weigh the metal, count the components, time the machining operations and calculate the stress distributions. We can select the best designs and further improve them by using precise numbers rather than nebulous value judgements or simplicity levels which serve only to stifle creative thought.

It is my belief that simplicity has won its false supremacy because of the restrictions in time and money that are so often placed on engineers by politicians. The ground work is cheaper and quicker for simple projects than for complicated ones. Nothing is more certain to cause failure than the lack of proper research development and testing. If time and money are fixed too low the simpler designs have an unfair advantage. The most complicated of them that can just be properly researched within the constraints will win. We can all think of cases where an ambitious project is given too little time or money, and fails through a trivial cause. The failure is wrongly attributed to its complexity. Simplicity gains an undeserved victory. But time and money can be restricted only locally. If an idea is good there will be another place and another time when engineers who are properly supported will make the idea succeed.

It is tempting to hope that correct understanding of these issues could lead to a renaissance in British engineering. Bright-eyed youngsters would flock to the profession. A wind of change would rid us of simpletons. Our shipyards would have to work double time to supply the vessels which, laden to the gunwhales, would carry advanced technology exports to the despairing Japanese. Our goods would once again be renowned for their design, reliability and longevity.