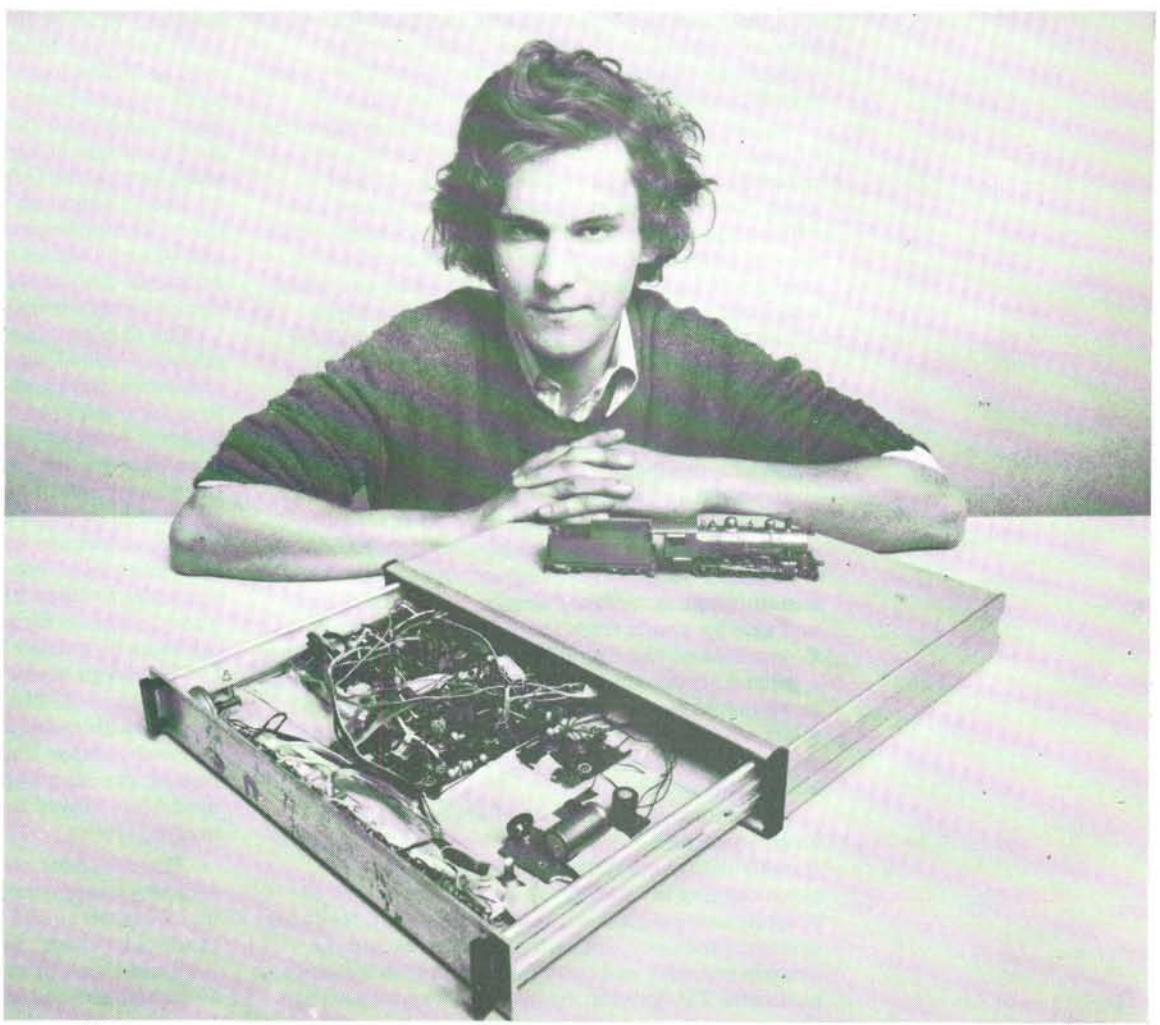
A. Stewart
Ampleforth College

A Project to Design a Steam Train Noise Synthesiser

This note aims to set out the background rather than the technical detail of the project. Jonathan Stewart was first used as a guinea pig by his father who wanted to teach Nuffield circuit boards to 11 year olds, having not taught this age range before. Jonathan was aged 8 and found the subject interesting and easy, and was shortly afterwards given a 'Mykit 50 in 1' electronics kit for Christmas, followed by the 150 in 1 kit the following year, both of which he had worked through within a week or so of receiving them. At 13 he was making practical projects using simple op. amp. I.C's – e.g. a communication system so that we could hear the telephone ring in the garden, and be told who was ringing if someone answered the phone in the house. (It is perhaps relevant to state that I am his father as well as his 'A' level Electronic Systems master).

At about 15 or so, before taking his Physics 'O' levels, he was secretary of the 'Radio Room' (electronics club), and was duplicating notes on transistors and passive components for members of the club, written by himself, having had no formal instruction in electronics at all. He now started an interest in audio electronics by acquiring the mechanics of an old cassette deck and designing and building his own tape recorder. Within a year or so,



Jonathan Stewart, Ampleforth College, York, shown here with the steam train noise simulator he designed for model train enthusiasts.

having had no instruction in passive or active filtering techniques he had designed and made his own 'Dolby-type' hiss filter. Not unnaturally, having no knowledge of the necessary maths, his cut-off frequencies were rather widely out, and although we entered this project for the Schools Design Prize in the under 18 age group for that year, it was not adjudged worthy of a prize.

In July 1977 the A.E.B. 'Electronics System' 'A' level course was approved for general teaching schools by the Schools Council, and Ampleforth was one of the first schools to take it up – in fact we were the first to get our order for the necessary equipment in to the suppliers, Messrs. Feedback Limited, after the course 'went public'. The course is growing exponentially, 28 centres offered it last year, and over 50 will be offering it next year, and the growth would probably be faster but for the present financial climate, but as it is still relatively unknown a few details here may be helpful. The course aims to teach a 'systems' approach via electronics systems, which are relatively cheap and easy to handle and obtain in a school laboratory. The linear electronic systems used are largely based on the 741 op. amp., and the digital systems are all TTL, but because of the systems approach will not have to keep on investing in new equipment as technology changes, except insofar as boys' projects may introduce new techniques, as they often do.

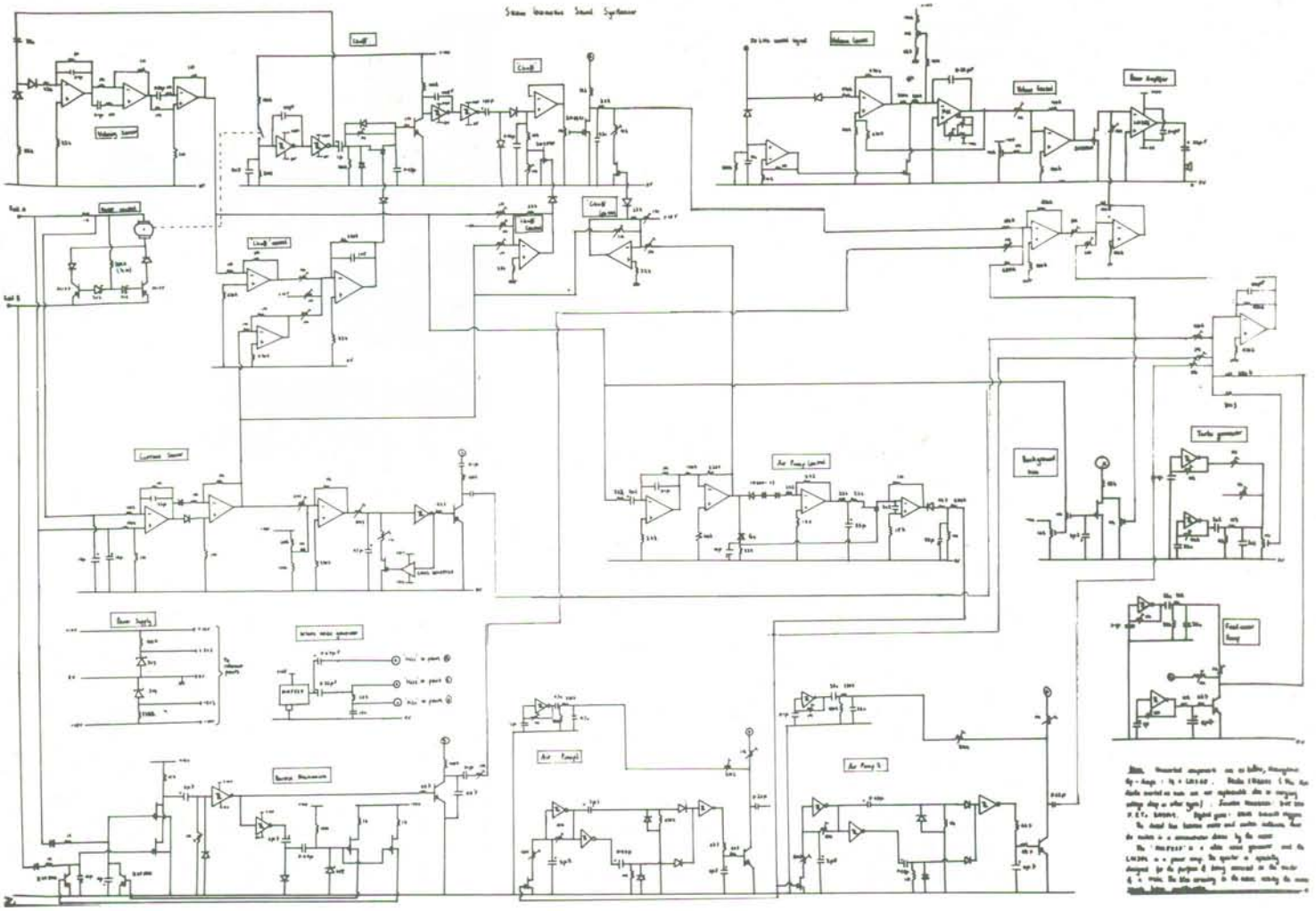
As the systems approach is applicable in all forms of engineering, and in many allied fields such as computer science and systems analysis, as well as many fields of pure science, and as the course also offers an introduction to modern technologies which are not covered in any other 'A' level course, or at least not in such depth, and as it also offers examined practicals and projects within these technologies which encourage design talents within the context of an academic 'A' level course, I thought that it was almost exactly what we were looking for, and persuaded the school authorities to start it. I was helped in this by having acquired a useful range of equipment – analogue computers, both commercial and designed and made at the school, a servo-mechanism and allied test and analysis equipment, a chart recorder and several oscilloscopes – in earlier years by scrounging from several firms and universities, notably Messrs. Ferranti Limited, and also by grants from the Research in Schools Committee of the Royal Society. I had been running a general studies course on analogue computers and servo-mechanisms with this equipment for several years, and this is highly relevant to the 'feedback' section of the new 'A' level course which forms about 30% of the course.

The course itself consists of about 10% basic electronics, and 30% each of processing systems (largely digital computers, including some programming in 'BASIC', and a fruitful source of projects using digital arithmetic and logic), feedback systems (analogue computers and servos and op. amps in general), and communication systems (audio, radio and TV systems, mainly receivers rather than transmitters, and including simple active filters based on the 741 op. amp. and a TTL logic board used to generate patterns on a domestic TV screen). The approach in each of the main topics is to discuss the human systems to which the electronic system is relevant, e.g. the arithmetic and memory functions of the brain, the control of muscles by the nervous system, and the capabilities and limitations of the ear and eye, and then show how the electronic systems can be made to serve, augment or substitute for the human capability. There are a total of 11 major practicals (3 or 4 per major section) plus some basic electronic practicals, and there are two compulsory projects, of which 6 of the major practicals and both projects are internally examined and externally moderated. The projects are supposed to take about 10 hours of construction time in the labs. – design time is extra to this. With board permission major projects may be submitted as a double project, and this was done in Jonathan's case, since his project took about 250 hours of construction time and about 10 hours of design time.

The project was suggested to him by the managing director of Messrs. Micrometalsmiths Limited, Mr. C.W. Shaw, to whom most of the credit for stimulating Jonathan to undertake the work is due. He had lectured to the 6th form on running one's own business, and advised them to start by sweeping factory floors for someone who had done so. I took him at his word and got Jonathan a job at his factory the following holidays. Within 3 weeks he offered Jonathan the job of designing and making the noise synthesiser, at which an I.T.T. engineer had already had an unsuccessful attempt. At first Jonathan did not think that he could do it, but later agreed to take it on.

The firm provided the necessary materials, the school provided the oscilloscope, audio oscillator, and power packs, and the agreed payment by the firm for a working design was £250. The firm's main business is precision castings, notably of micro-wave radar waveguides, but it has recently diversified into the production of high quality model locomotives, retailing in the USA at between £200 and £600 each, and the simulator was to produce all the noises associated with one of these. It is a 3-cylinder steam locomotive which has a turbo-alienator, feedwater pump, and two reciprocating air pumps, running at the same frequency but a-synchronously, used to top up the air brake reservoirs after the brakes have been used. The simulator produces the 'chuff' varying with speed and load, the whine of the turbo-alternator, and also the sound of the various pumps, the air pumps only coming on after the model has slowed down, simulating the use of the brakes.

The simulator also produces a 'clunk' and hiss of escaping steam when reverse gear is engaged, and also produces the sound of the safety valve lifting at random intervals, which increase in frequency as the train slows or stops. In the prototype made by Jonathan the synthesiser is in a box by the side of



Above: Diagram of the steam locomotive sound synthesiser circuit.

the track and sends the sound signals via a 50 kHz carrier wave along the rails to a small loudspeaker in the tender of the engine, the final production version may be reduced to an LSI chip in the tender itself.

The 'chuffing' sound is proportional in frequency to locomotive speed and number of cylinders, and can be varied for other types with different numbers of cylinders; it is synchronised by a make and break contact on one of the driving wheels. The intensity of the sound is made to depend on current drawn by the electric motor which powers the locomotive, and the sound pulses are also 'shaped' by various active and passive filters to stimulate the way in which both intensity an quality of the exhaust sound varies with speed and load of the locomotive.

The heart of the system is a white noise chip, which is modulated at different frequencies for the various pumps, etc. The modulating frequencies are generated in Schmitt trigger oscillators, and the pulses are then shaped in various filters. A differentiating circuit measures the speed of the train and various integrating circuits are also used as timing devices. Switching is largely done by Field Effect Transistors, and most of the circuitry (Schmitt Triggers, etc.) is CMOS because of its greater tolerance to wide variations in power supplies which can be expected with model trains.

Jonathan started this project in April 1978 and finished it in August 1978, spanning the third term of his 1st 'A' level year. He had completed the digital electronic section of the course, and part of the feedback section, but had had no formal instruction on the course on CMOS devices, FET switches, or the use of an op. amp. as a differentiator, nor the use of Schmitt triggers as oscillators. He had had no instruction in the communications section of the course, so his modulation and filtering work was also entirely self-taught. He did get a little private instruction from me in FET switches which I use in one of my home-made analogue computers, in a differentiating circuit, and in fine trimming of integrators, but that was about all the advice he got from me. Of the 15 circuits in the final design he took over one from the I.T.T. engineer who was his predecessor on the project, and also the white noise chip, the remainder of the circuitry was entirely original. (The one taken over was a power pack, later changed).

His original intention was to build a breadboard model and then a second which would be put into a metal case for demonstrations, mainly in the USA. Time overtook his intention, and the breadboard model was sawn up, stuck in a metal case using insulating tape, and flown to America the same day, where it worked perfectly on arrival.

In common with two or three other projects on the same course (of 6 'A' level candidates), Jonathan knew far more about the technicalities of his project than I or anyone else did, and in discussion with other masters teaching the same 'A' level course I find that this is normal – only with the weaker candidates does 'sir' know as much as or more than the examinee. This is a wholly excellent thing for several reasons:– (i) it ensures genuinely original work by the candidate (original to him, that is), (ii) it ensures that his report must be intelligible to someone who knows less about it than he does, and (not least) (iii) it induces a proper degree of humility in schoolmasters who are perhaps a little too often persuaded by their everyday work that they know more than everyone else present in the room.