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AGILENT TECHNOLOGIES (www.agilent.com)

IC industry hits boom

Aging fostered for technology

Green power laser developed for industry

Good prospects for college leavers

Gun diode gets new lease of life

Sat-nav saved

Supercomputer could point the way for Cry

Europe must invest t8e

Big magnet — jewel in the crown

CLASS-A IMAGINEERING: PART V

"High Fidelity" specifications based upon steady sinewave input-output testing procedures with a resistor load have not guaranteed genuinely realistic sounding reproduction. Graham Maynard continues his investigations

SIMULATING POWER MOSFETS

In this new four part series using the Microcap software, Cyril Bateman introduces a hands on approach to Spice circuit simulation and the use of user created power MosFet models, able to accurately mimic actual power MosFet operation.

PIC CRYS TAL TESTER AND FREQUENCY COUNTER

Ever ramped up in the junk box and found unidentified crystals?

Or even wanted to verify the presence of a resistor load?

Running out of time

Partners sought to develop novel embedded systems for use in MICROMOUSE competitions

MORE...

Every few weeks the popular press features a new article relating to potential health dangers of mobile phones or base stations. Large sums of money are being spent on research in laboratories all over the world. In this article Brian Collins reviews the sources of non-ionising radiation to which we are exposed, and our present state of knowledge on their effects.

38 THE CATT ANOMALY

Correspondence on the CATT Anomaly has erupted again recently, and Ian Hickman was prompted to take a closer look. Here are some of his thoughts on the subject, a topic of which he has been vaguely aware for many years.

44 CIRCUIT IDEAS

- Controlling electrical appliances using PC
- Current-mode oscillator
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The new month universes with their pseudo executive CEO — Veet, Clinton/President — all the way down to so-called line managers (formerly HODs), manufacturing university graduates like a well-oiled production line, accountable to their corporations and some of them are getting away with being paid real world executive salaries. How can this be? Is this how we want to shape the money coming from? Many of these institutions are still governed by numerous dead wood overpaid university dons from the 30s era and are now infiltrated mostly by clones of themselves, who have fresh ideas to bring forward to this millennium. None have the honesty to even admit that the whole system is in shambles, let alone stand up against any government using them as a rubbish heap for mostly unemployable and misguided youths. Sadly, these are the real world victims, but not me at all, I have my own troubles, remember my battle is to protect my pension funds, no time to fight the cause of the future generation’s education.

Lesson number 2 - make sure you are financially independent by age 45, you will have to make your million by then, because by the time you retire at 65, your million will have the buying power of less than 10% of its initial value - if you are lucky and a wizard at financial management. If you are not awake to it yet, try reading a book paid for by a politician, but I must warn you, you have to be smarter than even this book’s author R.Kiyosaki. Someone in the world in which we work and ket out looking for shareholders, property, and other investments and not even having to work just doesn’t add up, whether as an engineer, lawyer, carpenters and of course engineers? A high-school diploma is not enough to work for another major multinational. They trained me to top management, in marketing, finance and business administration, all the things I initially lacked. Guess what? I was made redundant during the September 2001 crash, with a reasonable severance payment, but I believe that all these will be added up to that sum. But it is still not enough, and I will explain why.

I started life as an undergraduate in the 1970s and struggled through university at considerable expense. I had good grades (a Bachelor’s degree with honours was worth a lot in those days) and I was immediately offered a job with one of the main British electronic manufacturers whom we shall just call Company X. I stayed for a little over a year and left in spite of the temptation of a higher salary and promotions as I had solved one of their project’s problems which made millions in later years. I returned to university and some feature in my CV, but my employer offered me a scholarship and he insisted that I was PhD material. (It was the first time in my career that the job was really boring to my young mind, I could not have cared less about my salary, all I wanted was to be for magazines like WW now EW and many others, I would have been bored to death from intellectual starvation here you to survive at all). More important to me was that under him it all, I was not convinced by Company X’s promotion in spite of the salary that they generously pumped in millions. Company X went under three years after I left. Lesson no. 1: "Better to be a broken king than an empty head" (Charley Swann). The university system is so inferior! I went on from being a PhD student to being a faculty member of a world-class university of excellence. Then after nearly two decades service in academia, I was threatened with the possibility of having bringing in collaborative research grants worth millions, produced other PhDs, taught myself to death in over-crowded lecture halls, I was dumped at the age of 45 with compensation that I had bought over my 40 year career. This scene is getting worse today. The new mega

**Running out of time!**

**M**any of you must have heard by now that the new CEO of WH Smith seems to think that readers of specialist magazines such as ours are persons non-grata on the basis of their revenue account. Quite wisely he has decided to lock on subscriptions to my favourite magazines a few years ago. I have also just taken on an electronic mail service for my personal use and one other. I have sold two of my favourite electronic magazines (not EW), simply because space is running out on my shelves and in the long run we cannot stop progress. You will gather by now I read profusely and keeping up to date is not an onerous task for me. But it is still not enough, and I will explain why.

My basic theme is simple; we have got to be sophisticated. For publishing, whether anything you do nowadays, is a commercial enterprise of some sort. I can think of many reasons why WH Smith and others are displaying specialist magazines a liability and not an asset, but I don’t have time to go into it here.

Jot and Stone is an undergraduate in the 1970s and struggled through university at considerable expense. I had good grades (a Bachelor’s degree with honours was worth a lot in those days) and I was immediately offered a job with one of the main British electronic manufacturers’ whom we shall just call Company X. I stayed for a little over a year and left in spite of the temptation of a higher salary and promotions as I had solved one of their project’s problems which made millions in later years. I returned to university and some feature in my CV, but my employer offered me a scholarship and he insisted that I was PhD material. (It was the first time in my career that the job was really boring to my young mind, I could not have cared less about my salary, all I wanted was to be for magazines like WW now EW and many others, I would have been bored to death from intellectual starvation here you to survive at all). More important to me was that under him it all, I was not convinced by Company X’s promotion in spite of the salary that they generously pumped in millions. Company X went under three years after I left. Lesson no. 1: "Better to be a broken king than an empty head" (Charley Swann). The university system is so inferior! I went on from being a PhD student to being a faculty member of a world-class university of excellence. Then after nearly two decades service in academia, I was threatened with the possibility of having bringing in collaborative research grants worth millions, produced other PhDs, taught myself to death in overcrowded lecture halls, I was dumped at the age of 45 with compensation that I had bought over my 40 year career. This scene is getting worse today. The new mega
Partners sought to develop novel embedded RAM

IMEC, the Belgian powerhouse for IC research, has begun a project to develop the next generation of memory for production using 45 nanometre process rules. Potential collaborators are invited to participate in an IMEC industrial affiliation program on embedded RAM concepts for second and higher levels of on-chip cache memory”, said IMEC.

The programme will study three concepts: direct tunnelling RAM, ferroelectric and floating body cell devices. “The three concepts will be implemented in silicon by year-end to demonstrate their feasibility,” said IMEC.

Direct-tunnelling RAM uses a very thin (around 1.5nm) oxide flash memory structure in which charge can be stored on either a floating gate or on a charge-trapping layer.

What is the problem with conventional SRAM cache?

IMEC view is: that fast first-level cache memory, which has been and probably will continue to be addressed by static RAMs, are reaching their scaling limits already today due to their drastic increase in relative cell size.

Many high-end microprocessor-based chips will need relatively large amounts of on-chip memory. “Their [the memory] footprint is expected to increase to 80-90 per cent of the chip area in some of these major applications. At the same time, embedded dynamic RAM has never been widely accepted as a mainstream technology option because of limited availability, process complexity and cost issues.”

With so much space eaten by first-level cache, new technology is needed to compress the size of second and higher-level embedded volatile memory.

IBM stores charge on individual atoms

Scientists at IBM’s Zurich Research Lab and Chalmers University of Technology, Gothenburg have manipulated the charge state of individual atoms.

IBM scientists Jascha Repp and Gerhard Meyer placed and removed a single electron on an individual gold (Au) atom by positioning the tip of a low-temperature scanning tunnelling microscope (STM) above the atom and applying a voltage pulse.

Cruical to the charge remaining on the atom is a two atom thick layer of sodium chloride (NaCl) between the gold atoms and the metal substrate.

Charge in the NaCl redistributes as the gold charges, forming a stable local state. In principle, data could be stored long-term on such a structure.

“Both charge states of the atom are stable, that is, an additional electron remains on it until it is removed by a voltage pulse of reversed sign,” said IBM.

Owing to the film’s large ionic polarisation, in the STM image the new charge state of the gold atom appears as a circular trough around the atom.

IC industry hits boom

Worldwide chip sales grew 35 per cent in the first half of 2004, allowing the semiconductor market to reach $102bn.

Figures from market research firm IC Insights show a resurgent chip industry, at least in terms of revenue.

The top ten suppliers of ICs are spreading globally, with the top five being Intel, Samsung, Texas Instruments, Renesas and Infineon.

Four of the top ten firms – Samsung, TSMC, TI and Infineon – grew at a rate above the average for the top ten. With huge growth in flash memory sales, Samsung grew a staggering 80 per cent when compared with the first half of 2003.

Most analyst firms, including IC Insights, Future Horizons and ISET, believe the chip market growth will reach 2.5 per cent of GDP by 2005, when public funding for science will reach £5bn, about 0.4 per cent of GDP.

Alongside extra Government spending comes further investment from private sources. The Wellcome Trust has agreed to commit £1.5bn to UK science in the next five years. The aim is to encourage collaboration between businesses and universities.

"Only by working with our business and research charity partners will we achieve our goal of R&D in the UK reaching 2.5 per cent of GDP," added Brown.

Extra money also goes to science roots in schools.

Higher salaries will be given to ‘advanced skills teachers’ – up to £45,000 in London, teacher training bursaries for science graduates of £7,000, and ‘golden hello’ payments of £5,000.

Funding boost for technology

Science and technology research received a £1bn boost from the Government in its latest spending review.

Chancellor Gordon Brown outlined the Government’s plans to increase UK spending on research and development to 2.5 per cent of GDP in the next ten years.

This funding plan equates to nearly six per cent rise in science spending per year until 2006, when public funding for science will reach £5bn, about 0.4 per cent of GDP.
Green power laser developed for industry

US laser firm Aculight has produced a 60W 532nm, frequency-doubled, large mode area (LMA) fibre laser. "We’ve achieved something very unique with our new fibre laser system," said Roy Mead, Aculight’s vp. "We wanted to produce a high-power green laser for special applications that was either continuous wave (CW) or quasi-CW. It needed to have excellent beam quality, be highly efficient, lightweight, compact and rugged. Our new system provides 60W of green output at a 10kHz pulsed repetition rate - and it can be even faster than that if we want. We have surpassed all of our goals," said Mead. Company engineers initially developed the technology for a military customer. After considering and rejecting modifying a conventional diode-pumped solid-state (DPSS) laser, they chose to develop a fibre system. "There was an opportunity to bring existing technologies to something that had even better performance in all of the characteristics that our customers wanted," said Mead. "It involved working with LMA fibres.

At the heart of the resulting laser is a ytterbium-doped LMA fibre amplifier capable of achieving high average power, while allowing substantial peak power without the onset of non-linear effects - characteristics essential for efficient frequency doubling, said Aculight.

A seed laser source consisting of a 1.8W 532nm fibre oscillator, an amplitude modulator and a preamplifier provides input pulses to the LMA amplifier, which is wound onto a small mandrel to provide good transverse mode purity and polarisation purity. The amplifier is pumped at the output end by free-space coupling optics. Its output is directed into a pair of frequency-doubling LBO crystals. "The result is a quasi-CW output with excellent beam quality and electrical-to-optical efficiency," said Aculight.

"Today’s green laser marketplace is dominated by DPSS and argon-ion lasers that produce less than 20W, or function at moderate repetition rates," said Mead. "Our system surpasses those performance characteristics and will likely extend past the 60W that we’ve achieved so far. And the techniques we’ve used to wavelength convert can apply to a variety of fibre systems, so will also allow us access to a wide range of wavelengths. This LMA fibre system really fits into a different region of the product space."

Good prospects for college leavers

Graduate salaries are increasing, with college leavers entering electronics seeing slightly above average levels of starting pay.

This conclusion comes from a report by the Association of Graduate Recruiters, which also found that the number of vacancies for graduates is increasing in the UK. The average starting salary for graduates is now £21,000, up from £20,300 last year, while in electronics starters can expect to earn £21,100.

The days of escalating starting salaries for graduates appear to be over. Employers are providing graduates with training and development and a remuneration package that is competitive rather than extravagant, covering the cost of living increases," said Cate Ryan, chief executive of theAGR.

"The findings are good news for the graduate recruitment industry and great news for graduates themselves. Vacancy levels have risen and we expect both salaries and vacancies to continue to remain stable in 2005," said Gilleard.

The biggest rise in vacancies, with 52 per cent more jobs available, was in software development.

The AGR surveyed employers across the UK and found that after three years of shrinking job prospects, the job market has started expanding once more. This year there are 15.5 per cent more graduate positions on offer.

"The green laser can be used to image skin and could be a vital tool for GPs and other health professionals to check for cancer. But this technology could also be used in a large range of other commercial sectors which include research through to wireless office communications."

"We hope to develop an inexpensive semi-conductor device which incorporates a Gunn diode capable of emitting Terahertz pulses. Terahertz radiation reacts strongly with human tissue, and can be used to image skin and show up potentially dangerous melanoma. If caught early enough, melanoma could be curable."

"Gunn diodes have knowledge-based products that threatened the future of the semiconductor industry. It could enable the technique. The students "did it forwards conduction curve."

The AGR surveyed employers across the UK and found that after three years of shrinking job prospects, the job market has started expanding once more. This year there are 15.5 per cent more graduate positions on offer.

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Supercomputer could point the way for Cray

Red Storm will be a 4.3Tflop computer when it is finished. Being assembled at Sandia Labs in New Mexico, one quarter of the machines should be ready in running in January next year.

Performance testing will begin in early 2005. By the end of 2005, the machine should be capable of 100Tflops - following an upgrade to an IBM single-processor AMD Opteron chip is replaced with a double processor chip, each running 25 per cent faster than the original.

Developed with supercomputer pioneer Cray, the firm may become the centre of the firm’s future product line. “From Cray’s point of view, the approach we’re pioneering here is so powerful they may want their next supercomputers to follow suit,” said a Sandia spokesman.

The design is scalable from a single cabinet (96 processors) to approximately 300 cabinets (30,000 processors). In addition, the system was designed to monitor and manage itself. One of the project aims is to cut power consumption.

Japan’s Earth Simulator is currently the world’s fastest supercomputer at 3.65Tflop, consumes 88Mw peak, Sandia compared to a projected 2MW for air-cooled Red Storm. Red Storm will also only take up one third the floor space needed by Earth Simulator.

The machine has four processors to a board and 24 boards to a cabinet. Each processor can have up to 512Gbyte of memory.

Four Cray SeaStar networking chips sit on a daughter board over each processor board. The SeaStars talk to each other “like a Rubik cube with lots of squares on each face,” said Sandia. “Cray SeaStars are about a factor of five faster than any current competing processor.”

Processor to processor bandwidth is 4.5Gbyte bidirectionally.

Europe must invest €6bn

Public/private partnerships need to find €6bn per year if Europe is to benefit from research into nano-electronics.

That message came from the European Commission in a report drawn up by CEOs from leading companies and research groups.

“Nanoelectronics is a strategic area for Europe,” said Pistorio, chief executive of STMicroelectronics. “We can’t afford to miss this window of opportunity for our industries and competitiveness in most other industrial sectors,” said Enterprise and Information Society Commissioner Erkki Liikanen.

Along with electronics firms, the EU has established the European Nanotechnology Initiative Advisory Council (ENIAC), chaired by Pasquale Pistolla, chief executive of STMicroelectronics.

It aims to identify a strategic research agenda for nano-electronics in Europe and implement it.

“Europe cannot afford to miss the next generation of electronic applications that will be for our future economy what oil is for today’s economy,” said Research Commissioner Philippe Busquin.

Developing nano-electronics will require better co-operation across disciplines and more co-ordinated research.

“Leading the transition to nano-electronics is a challenge that requires our best researchers to work together and our public and private investors to profit from economies of scale,” said Busquin. www.cordis.lu/nanotechnology

Big magnet – jewel in the crown

Following 13 years of development, the US National High Magnetic Field Laboratory has put the world’s strongest superconducting magnet aimed at nuclear magnetic resonance (NMR) research into service.

The machine is 5m tall, weighs over 3tonnes and holds 40MJ of energy in its field. The maximum field it can reach up to 10Tm in diameter can be contained in its ‘warm’ (non-cryogenic) bore. The cold part of the machine will remain at full field for five years.

“Such a powerful and ultra-wide bore magnet was an extremely challenging system to build, and it represents a significant engineering accomplishment,” said director Greg Boebinger. “It is the crown jewel of the laboratory’s NMR spectroscopy and imaging program.”

The magnet is a concentric assembly of ten coiling sections connected in series and operated at 1.8K. Each coil is wound with a monolithic superconductor, composed of either niobium-tin (Nb-Ti) or niobium-titanium (Nb-Ti) filaments in a copper matrix. To support the magnetic loading, the coils are held with stainless steel over-banding and are vacuum impregnated with cryogenically-tough epoxy. The magnetic field produced is uniform to one part in one billion, claims the lab, in a volume 64 times larger than standard models in a 21.7Tesla research-grade NMR systems. Fine-tuning of field homogeneity is achieved with a set of superconducting shim coils.

Operating frequency is 900MHz and both NMR spectroscopy and magnetic resonance imaging (MRI) are possible. “Science performed on this resource will range from materials research to macro-molecular biological structure determination and non-invasive magnetic resonance imaging of laboratory animals,” said the lab.
'High Fidelity' specifications based upon steady sinewave input-output testing procedures with a resistor load have not guaranteed genuinely realistic sounding reproduction, however the simple procedures outlined below should assist in our quest for being able predict at outset which designs will, or will not, drive loudspeakers more accurately. Graham Maynard continues his investigations.

Douglas Selt, stating that 'back EMFs from reactive loads do not cause detectable intermodulation and even if they did, a higher feedback factor would surely reduce rather than increase the effect'. Through the years Mr. Selt has written so many excellent reference articles, but unfortunately he appeared to not check out my suggestion whilst additionally stating his dislike for my written presentation, which, although being based upon real-world aural observation and intuitive cerebral analysis, was not necessarily wrong just because my brief letter did not offer practical suggestions for any examination methods that could be visualised in a lecture theatre presentation. I was left feeling completely gobsmacked, and I wondered why I had bothered to write at all. There really was no point in me doing so again because my suggestion for testing whether reverse impeding loudspeakers generated back EMFs do actually modulate amplifier output - as I, many stage performers and hi-fi aficionados had long experienced in real life - had just received a somewhat scornful, if eminent, burial. I felt that a possible furtherance of widespread understanding via these shared pages, with their additional potential for follow-up and thus overall improvements in sound reproduction for everyone, had been individually undermined by one of my most influential writers.

Ten years have passed, with many recently published designs and present day discussion comments suggesting that precautions for minimising loudspeaker back EMF generated amplifier distortion products are still not being routinely implemented. Also, circuit simulation software can now be used by budding enthusiasts as a first line of design, with programmers suggesting the use of multi-cycle sinewave testing to calculate THD figures in a manner that masks capabilities for investigating other already experienced sound reproduction problems. Multi-cycle simulation cannot fail to assist in establishing the lowest THD figures because this methodology knowingly uses a steady sinewave to optimise waveform averaging about the zero axis (much as does fundamental testing at the output terminal and this totally ignores all of the dynamically induced level changes that arise due to the start-up of an initially asymmetric sound waveform which has to initially charge and drive all components and devices in a manner that cannot fail to initiate a momentary shift between alternating voltage and current zeros as the circuit singly amplifies sinewave and copes with reactively induced dynamic loudspeaker back EMFs under the controlling influence of propagation delayed (lagging) NFB. If it is possible to hear differences when headphone monitoring amplifier output when switching between resistor and loudspeaker loading, then we need a computer program capable of evaluating loudspeaker induced first cycle changes.

Granted, computers will not burn our fingers and deplete our pocket books if one experimentalist arrives at a construction after another eventually were to end up in the round filing cabinet, and they can save our environment from some of those occasional releases of acrid black smoke which manufacturers like Motorola and Toshiba somehow manage to compress and encapsulate within their devices, but if anyone has yet to choose software, it is better to be aware that some products which rely upon ten or more cycle averaging because they do not fully set up operating conditions before simulating, sometimes cannot be made to complete the Fourier series calculation necessary to produce a distortion figure for any specified single sinewave, and especially for the waveform error percentages in the first cycle of any series, where distortion can be much worse when a virtual crossover inclusive loudspeaker system is the circuit load instead of a passive resistor.

There are many mainstream writers who report upon the behaviour of amplifiers being reverse driven by a separate audio source that mimics loudspeaker back EMFs: see, Rod Elliott's Sound Impairment Monitor at http://sound.westwood.co.uk/sim.htm. Mr. Elliott's work usefully employs potentiometers to calculate THD figures by illustrating the potential for load induced output stage crossover distortion, but at the same time stating he does not immediately mention the amplifier signal path control delay, thus the circuit impedance and first cycle issues I outline here.

Sinewave evaluation. For decades testers have been determined to amplify the 'damaging factor' via examinations that are equivalent to reverse driving the output stage with a steady sinewave via a nominal load resistor and then dividing the alternating voltage of the driving source by that measured at the output terminal. Some amplifiers have their drenching factors specified at different frequencies, though without the reasons for any variation. With frequency and most subsequent significance for higher level plus higher frequency dynamic loudspeaker reproduction being so complexly modified by reverse impinging and high frequency 'reactive loudspeaker back EMF' as the lagging NFB generated output response constantly attempts, but never quite manages, to recover control. Also, computer simulation would allow these observations to be made without any need to 'break' a closed NFB loop, which could otherwise lead to unnecessarily discursive theoretical arguments as to where or how this may or may not be done because of the circuit operation changes that are already so well known to influence findings, and thus provide an opening for objective arguments that could internally whilst leaving in the shade the originally imperfect fundamental circuit action which is what should really be being considered due to the prior subjective observation of degraded reproduction.

I could simulate that 1994 evaluation suggestion on any amplifier circuit and study the outline results without needing expensive test equipment; thus I could make additional precautionary checks upon the performance of my own already constructed designs, prior to submitting them for publication. Figure 11 shows the simulated amplitude and phase plots for swept frequency generator reverse injection of my Part 4 Graph 10, class-A, 25Watt output via a nominal 8Ω load resistor in series with its output terminals.

My non-complementary pure class-A amplifier circuit holds the output terminal potential (that at 0.97dB (-0.1%)) for all audio frequencies, with a slight but inconsequential phase lead of 5 degrees by 10kHz. This leading phase is due to the NFB loop's natural inability to make the amplifier respond as quickly due to internal driver and output stage transistor base related capacitance, which due to the entirely natural bias current limitations and the 22pF high frequency NFB response correction capacitor in parallel with the NFB loop reverse input resistor. This is a good and most satisfying result for such a simple topology; indeed, maybe this fine performance is due entirely to its circuitry being so basic!

During the early days of 'Hi-FI' testing, 1kHz was often a reference frequency for measuring specifications, yet examination here will not necessarily reveal all the problems capable of affecting sound reproduction, especially with lowly biased class-B or B1 type amplifiers. I have no interest in 'going easy' on any amplifier in order to present impressive specification figures, and this is why I am much more concerned about them as an audio signal amplifying circuit behaves at 10kHz. The Figure 11 swept sinewave simulation indicates that its circuitry generates an internal resistance of 300Ω (-64db) in...
of every component, their leads, and fabrication will interpose impedances proverbial 'straight wire with gain'; reverse driving resistor which is thus unavoidably degrade the circuit's equivalent values are effectively in all other interconnects which must investigation only, as is the truly instantaneous dynamic capabilities when the loudspeaker generates back EMFs affect an amplifier's driving capabilities as it attempts to simultaneously forward amplify complex and constantly changing large amplitude music waveforms. Thus I include Figure 13, which simulates the dynamic response of my '25W-8Ω' circuit whilst being reverse driven by a 10kHz sine wave from 50. This dynamic response examination reveals the output terminal error potential development due to unavoidably delayed closed NFB loop control behaviour in the presence of a reverse (loudspeaker generated) impingement of 1V RMS (125mA RMS) 10kHz sine wave via its series 'load' resistance of 8Ω, the latter being used in this investigation to preserve nominal closed loop and amplifier output stage operating conditions. The initial, and near instantaneous leading edge, 'load' driven output terminal potential shift is of low level, smoothly controlled and fully settled within 100ns, prior to it subsequently increasing in amplitude to equal that of the steady sinewave -46dBp response with its 8 degree shift. The rising edge simulation in Figure 13 with slight overshoot on 20ns illustrates how circuit propagation delay within the NFB loop has denigrated the derived capability of the truly instantaneous dynamic control necessary to counter output node error, while the steady sinewave response of Figure 11 merely illustrates the continuously generated damping activity of the amplifier's internal NFB loop reduced output impedance. Here the significant dynamic response figures are 13µV (-80dBp) of initial error at 20ns, which is then followed by the 60µV RMS (4.8dBp) of near phase coherent steady sinewave (Figure 11) error. If both the initial/dynamic and full first order of the amplifier's response are more than 500μV, we will use the amplifier in the circuit.}

Series with 10ΩH (+8 degrees at 10kHz) and 3 Farads (+8 degrees at 4kHz). Note that the 10ΩH and 7ΩH equivalent values are effectively in series with the initial 5Ω NFB loop generated output resistance, and are not separately in series with the reverse driving resistor which is externally connected to the NFB output node/amplifier terminal. When we consider loudspeaker driving capabilities this is getting close to the proverbial 'straight wire with gain'; however, the complex characteristics of every component, their leads, and all other interconnects which must physically be used for any real-world fabrication will interpose impedances that cannot fail to alter node current flows and voltage developments, and driven output terminal error propagation delay within its closed FB loop. Figure 12 shows that the reverse injection characteristics of my Part 4 Figure 20 circuit when its output driving capability is modified by the reactivity of an integral 4mΩ series output capacitor.

Figure 12: The reverse injection characteristics of my Part 4 Figure 20 circuit when its output driving capability is modified by the reactivity of an integral 4mΩ series output capacitor.

Figure 13: The 'GM125-S' class-B amplifier's simulated reverse driven output terminal error at 10kHz due to propagation delay within its closed FB loop.
cycle/steady sinewave responses had been shown within a single timesemne, then there would be difficulty in resolving the high normal speed of initial class-A + amplifier error correction. From a circuit viewpoint there is nothing to worry about here, no matter how much the signal / frequency change might be observable within the back EMF improvement of a dynamically reacing loudspeaker w.r.t. prior NFB loop controlled amplifier drive. The competant analogue simulation of this circuit’s load driven output potential development has been achieved within the same time period a typical digital amplifier takes to switch once between fully ‘on’ and fully ‘off’ conductor states.

At audio frequencies my computer simulated class-A / circuit is behaving less inductively than the integrating loudspeaker ohmiring that would become necessary for real world usage. The illustrated 139,000V potential that develops as the output terminal plus the current shunt internal to the class-A high frequency preamp introduced a first cycle delay such that the sinewave induced error correction process is already generated from t=0. Nor would I be able to predict the level of music, waveform generated by the loudspeaker w.r.t. the amplifier’s source equivalent to the above distributions at 1 kHz and beyond, not necessarily from any ‘amplitude only’ based damping figure (0.00063 1) and the 8 degrees Sine ‘resistance’ notation. By multiplying ratio (0.1 392), all at lOkHz, we get 0.0001 24V or 124mV. The difference between the former simulated load induced leading error and this the due to any software anomaly, but to

**Figure 14:** The reverse testing circuit for a 20th century 25W-8Ω bipolar class-B amplifier with Miller bias and integral series output choke.

**Figure 15:** The covered-band amplitude and phase simulation characteristics of the generic 25W-8Ω class-B amplifier.

**Figure 16:** The simulated class-B amplifier’s output reverse injection error at kHz due to its internal propagation delay and series output choke impedance.
amplifier’s testing ‘load’ having been rendered representatively ‘reactive’, the series output choke can be seen allowing the amplifier’s output terminal waveform potential to become parasitically modulated in a manner that no amount of NFB can control. This is not a type of distortion that could be measured w.r.t. input in a conventional sine wave driven test situation, because the “back EMF” can be repeatedly pulsed on and off, as effectively as it is musically induced dynamic loudspeaker plus crossover delay-storage-energy reactions, then the sudden and independently generated step-like potentials and on-going error would occur long before a sinusoidal distortion measuring test set is capable of stabilising. Also, as these errors recur they would not only ‘characterise’ and smear the sound but shift about average the time and voltage reference points that are essential for any kind of valid steady sine wave distortion measurement to be undertaken and observed in isolation at a Figure 14 like amplifier’s output terminal in the first place!

The sudden 7mV of transient error for a 250mV peak to peak sine wave driven output level of 1kHz sinusoidal back EMF, separately illustrates a route whereby everyday bass-mid loudspeaker driver and crossover back EMFs could, at ordinary audio frequencies and normal listening levels, cause this generic class-B amplifier’s output terminal step like quadrature waveforms to integrate, and thus allow the choke potential to modulate the dynamic waveform of the NFB loop controlled output. With mid-frequency cone flexing and an impedance dip at 3kHz, this highly energetic tweeter driving ‘amplifier’ induction potential could rise to 50Vp-p equivalent to 180mV RMS of back EMF, so what value does a steady sine wave driven figure like 0.1% really have then? When my approximated virtual Ariel loudspeaker is the driven load for testing a Figure 14 circuit the leading error becomes 57mV at 6kHz due to the sudden noise and distortions of the amplifier’s output choke degrading the sine wave reproduction.

Here is an additional explanation for the cleanliness of bass-trip and triamped audio because even with choke coupled amplifiers mid-bass induced potentials cannot drive a tweeter etc., and this is why correctly designed valve amplifiers with high quality output transformers or a Miller C-dom-less and chokeless class-A can be so satisfying and non-fatiguing due to both types; not having a basically high pre NFB output impedance, such that correction need only be adjusted between halves rather than be constantly developed and switched between halves via delayed NFB loop control; having a minimal C-bcMiller capacitance cut of their high frequency open loop bandwidth at times when the NFB loop is unable to function linearly; and, normally deriving their NFB loop control potentials directly from the amplifier’s loadbank connection terminal. Here too though, is further explanation for the clarity of mid-bass crossovered mid-small-driver PA loudspeakers and line sources when being driven by choke coupled solid state class-B amplifiers, for these often have less reactively generated mid-band back EMF with which to induce additional high frequency waveform changes, also their fundamental bass resonance occurs at a relatively low frequency such that there is very little choke voltage generation.

When large and efficient full range or mid-bass drivers plus tweeters are energized by a choke coupled amplifier however, then unavoidable mid band tone resonance and break-up modes, which are already bad enough in their own right, could lead to significant additional back EMF generation, especially during loud stage and studio situations, then the more frequently ongoing and greater these back EMF induced and crossover section ‘tuned’ errors will become, with the likes of voice, high energy pop music and high power sound reproduction reproduction being rendered subliminally distracting. Do note however that reactive induced loudspeaker back EMFs arise at frequencies that are specific to the amplifier- loudspeaker combination itself and thus are different to the waveforms which energised them, the difference arising due to sudden amplifier output changes carrying entirely natural, and asymmetrical wide spectrum amplitude variation, not just a pure single frequency sine wave.

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Another important point is to mention that “bracketed” class-B arises at frequencies that are specific to the amplifier- loudspeaker combination itself and thus are different to the waveforms which energised them, the difference arising due to sudden amplifier output changes carrying entirely natural, and asymmetrical wide spectrum amplitude variation, not just a pure single frequency sine wave.

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electrostatic loudspeakers. Indeed, an old ‘pipe and splice’ Hi-Fi amplifier introducing notable propagation delay and having both series output terminal voltage and inductive output characteristics which will lead to it measuring poorly for an equivocal compromise, because Mr. Hood’s bipolar class-B design cannot generate the series output choke inductance of voltage, leading output waveforms w.r.t. ultra-low impedance NF voltages, and as has been simulated in this article. The series output (or a series output) portion of output terminal voltage that develops w.r.t. the NF loop controlled output node, linearly follows any dynamically generated back EMF waveform from zero without any sudden leading choke-loudspeaker induction potential penalty should be at the loudspeaker, in series with, and be appropriate for employing a loudspeaker voice coil. Once again I question myself about the simulation validity of using a ‘load’ resistor during this reverse injection examination. I conclude that it is acceptable because I am inverting output terminal current flow through the NF loop controlled output node in the same way as will any loudspeaker generated back EMF, where that loudspeaker has a complex impedance or not; a complex impedance that can only further exacerbate any series output terminal voltage and inductive effects occurring due to the composite loudspeaker phase change generated complex having an equal loudspeaker feedback or driver frequency responses. Electrostatic loudspeakers do not store and return energy in the same way, as does a voice-coil energised driver, thus this reverse testing allows for a loudspeaker amplifier that is intended solely for use with series resistor fed simulation via load resistance as originally conducted on my own 25W class-A circuit; the resulting output terminal voltage being shown in Figure 10. After 500ns of Miller connected VAS C.domin indication, the propagation delay of the 10kHz-IV RMS 8Ω load injected sine wave gives rise to a near instantaneous rise of notably triangulated and 90 degree leading 6mVp-p output waveform which might still be designed to be as being minus 54dB, or providing a damping factor of 50.0.

Yet it is somewhat disconcerting too, for it shows that the loudspeaker circuitry itself is not only being like the inductor that theory suggests and naturally does – that is, that the output terminal error potential that increases linearly with frequency, but also that the resulting triangulation shows internal amplifier current errors are being badly enough distorted by output stage drive current reversals to indicate that there should be a VAS C.domin induced slew rate non-linearity modulation, which was not previously observed, even the reverse tested full Figure 14 circuit because its presence was being masked by the voltage load already introduced by the series output choke during the output circuit arrangement could have enough NF to achieve a reasonable contemporary voltage THD distortion figure, yet under 5kHz back EMF testing conducted at 8Ω load. Thus it can be considered that the output THD is of a loudspeaker load induced output error generation has here become exaggerated, even though still not as extreme as it could become with efficiency and≧100% driven loudspeakers when high power audio driven back EMFs initiate or instigate volume change storage effects, and the Miller C.domin connected load current flows then cause additional differential input stage non-linearity where speedy and linear feedback might be able to overcome output stage conduction-crossover distortion errors. See the simulation in Figure 19 illustrating the reverse induction effect on both output signal output 4V RMS (500mA RMS). Levels greater than about 2V RMS of output signal output 4V RMS 1kHz sine wave superimposed directly upon the output node of the differentially sensing input pairing. So, what was that innate transient’s dynamic response be like when it is reverse activated by an externally impinged ‘looking back EMF’? To find out I repeated the 10kHz-IV RMS sine wave loadspeaker-system interaction at their own output terminal errors during a momentary degradation of NFB loop control caused by input or load transients. ‘Miller C.domin’ – contraindicated

Yet again I could imagine some designers thinking that these findings are not relevant because I have taken away the output choke that is an essential part of their circuit functionality, but they would be wrong, for output voltage error at the NFB loop controlled output node and thus overall amplification linearity itself is affected by load induced current flow, and loudspeaker generated back EMF currents pass whether an output choke has been interposed or not. Thus, when a Miller connected VAS C.domin is being used entirely natural dynamic loudspeaker back EMF generation can cause reverse current driven voltage change at the NF loop output node and simultaneously undermine forward signal amplification processes non-linear w.r.t input whether an output choke is used or not (see Part 6), this is additionally illustrated when the conduction crossover induced speaker extend in both time and amplitude beyond the already non linear and triangulated Miller C.domin input waveform illustrated! The Miller C.domin slew rate induced NF problem thus becomes exacerbated at higher audio frequencies and at higher listening levels with increased loudspeaker efficiency, with output device storage effects that require additional control, and with imbalanced output half characteristics that arise due to the shifted angles of dynamically and electrically reactive loudspeakers, especially when simplistically thinking of the reactive current driving close to a bass loudspeaker’s resonant frequency. The dynamically reactive input stage charging of a Miller connected C.domin by a slowly and fixed bias

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input transistor pairing can render a class-B VAS collector slow enough at higher audio frequencies to allow the output devices to become loudspeaker back EMF reverse driven through a portion of their crossover bias potential, before the propagation delayed NFB loop can properly maximize the differentially sensed output voltage error; subsequent error correction then becoming exaggerated by overshoot and eventual resettlement. The lower the bias, the more readily that loudspeaker induced back EMF will overcome the output stage prior to establishment of propagation delayed NFB loop control, and it is this predominantly Miller C-dom induced distortion that we can empirically minimise as we adjust the bias of a class-B output stage whilst listening to its loudspeaker output.

It is the ninety degree leading Miller connected C-dom loading within the differential input pairing that prevents a near instantaneous control of the very high speed and sharply discontinuous ‘reverse commuting’ (conduction crossover) distortion, as is illustrated by the spiking in Figure 19. Leading input transistor current peaks and their associated voltage error developments are anomalies previously reported by John Ellis in my EW March 2003 reference, yet these signal driven conduction crossover anomalies are not in themselves input-output measurable at a resistor monitored output terminal. The current non-linearities independently arising due to imperfect NFB loop corrected output do however lead to a much greater increase in high audio frequency distortion when efficient and loudly driven dynamic loudspeakers generate back EMFs w.r.t. signal amplified output, and this can sometimes sound like crossover distortion or a voice coil scraping a pole face. And yes of course the distortion can be reduced by increasing NFB, but that means more open loop gain - which means a greater potential for instability within the closed loop - which means more...

It is the signal path, local and global NFB components which are additionally connected to or are missing from any semiconductor topology that lead to a reactive load dynamically generating input or output driven waveform distortions. Applying the very best of transistor parameters to a Figure 14 like circuit makes no significant difference to simulated results, and this mirrors my own real life experience of fitting selected good transistors and not improving the sound through conventional dynamic loudspeakers. I’ve also observed newer and better output transistors actually degrading electrostatic loudspeaker reproduction after they had been fitted as replacements to a high fidelity amplifier that had been optimised for use with older devices. Often there is nothing to be gained from ‘upgrading’ an old amplifier by fitting it with the latest transistors, so unless NFB and stabilisation networks are also going to be competently modified, then maybe it is best to do no more than update the R’s and C’s, check joints, connectors, etc.

Due to the inherent stability of a VAS connected Miller C-dom stabilisation circuit both of the Figure 16 and 18 leading error potentials could have been mathematically determined from the Decibel and sine angle ratios read directly from Figures 15 and 17, as indeed could the capacitor induced first cycle potential shift be calculated from Figure 12; however these steady sine wave based calculations would not necessarily cover the dynamically induced onset of internal signal path capacitance degraded linearity distortion (Figure 18 triangulation) or inadequately controlled output stage conduction crossover distortion at higher output levels (Figure 19 spiking), nor any additional spiky sub-microsecond overshoot due to the reverse driven stability margin on designs which might become dynamically compromised by reactive loading.

Reverse injection simulating with more highly biased input and output pairings or with power Mosfets in place of class-B output bipolars will illustrate the potential for linearising and reducing the transmitted chokeless error waveform between conduction crossovers, thereby recovering a plain leading sine wave phase shift without spiking for the first few back EMF volts. There might then however be temptation for a designer to maintain Mosfet amplifier stability by fitting a single but larger value of Miller connected C-dom in order to overcome possible instability in the 1 to 10MHz region, but then additional capacitive charging currents within the differential input stage could increase the closed NFB loop propagation delay when an input stage mirror is used rather than plain resistors, which could further increase the risks for dynamically induced high frequency back EMF leading voltage (twrnter driving) development, without this showing on a forward steady sine wave and resistor measured nulling display or via a THD specification. If a low angle of reverse driven error cannot be assured at 1kHz, then its dynamically observed NFB loop reverse amplitude response should be extremely fast and stable of low level for high audio frequency NFB loop product generation to be rendered inaudible when driving real world loudspeakers.

I conclude these reverse driven amplifier investigations in Part 6, by relating findings to simulated fundamental nulling at the output of an input driven but virtual loudspeaker loaded Figure 14 circuit to illustrate amplifier-loudspeaker distortion.
Simulating power MosFets

In this, the first of a planned four part series, Cyril Bateman introduces a hands on approach to Spice circuit simulation and the use of user created power MosFet models, able to accurately mimic actual power MosFet behaviour — a new era in realistic Spice simulations.

Memorandum ERL-M520 published in May 1975 by the University of California at Berkeley and still available together with the associated software, describes Laurence Nagel’s development of Spice2, a public domain program which commercial developers have enhanced to become the de-facto low frequency circuit simulation software. Spice, short for ‘Simulation Program with Integrated Circuit Emphasis’, describes both its intent as well as its weaknesses. At the time it was developed, most designers involved discrete transistors only, as an explosion in the variety and complexity of IC designs had begun, mostly targeted to lower frequency components including small signal MosFets, no provision at all was made for modern power MosFets or more recent devices. Capacitors, resistors and inductors were included but only as idealised theoretically perfect components, suited for use in Integrated Circuits, but far removed from almost all discrete, real, components. Since Spice itself has undergone various modifications, with newer versions such as the upgrade called 3DF, now included in some of the more recent package simulators, including the now-cost WinSpice. To benefit from these enhancements, these upgraded simulators often require the use of equally enhanced but scarce, component models. For this reason most commercial Spice versions provide backwaards compatibility with Spice2G6 and include a library of suitably compatible models. Spice2G6, considered by many the definitive Spice, was the last update of Spice2 written in Fortran, the Spice3 series being similar to Spice2 but re-written in ‘C’. Other developments, made using ‘subcircuits’ which can be imported instead of using the conventional Spice2 ‘models’, have since been provided for components such as the DMOS power MosFets used as switches, as well as MosFets, IGBTs etc. Some of the most expensive simulators have also been substantially internally upgraded, for example Hspice, a professional version of Spice specialising in the design of complex IC’s, now provides for some fifty different MosFet model categories, but not lateral power MosFets. Less costly Spice versions are usually limited to just levels one, two and three, making the provision of models suited to calculating power MosFet distortion, uniquely difficult, the main topic for this series of articles.

Component model or subcircuit?

One solution lies in creating a subcircuit, which will be indicated in your schematic as an ‘X’, rather than a MosFet model indicated as an ‘M’ in your drawing. While a Level-1 MosFET ‘M’ model can be simply created using the ‘Model’ program supplied with MC6 and similar simulators, the subcircuit model is constrained to use only those parameters provided in Level-1. In contrast, when using this ‘Model’ program but must be ‘hand carved’, a subcircuit has freedom to include almost any valid Spice2 ‘device’, permitting use of e.g. a voltage multiplier or a voltage to current converter. However as detailed in your Spice software manual, while some of these devices cannot be fully used within a schematic, others may have restrictions used in a subcircuit.

The better Spice2 simulators now provide ‘analogue behavioural’ modelling tools which can be used within a subcircuit, but here the global standardisation implied by Spice2G6 does not allow to specify any limitations for some analogue behavioural model elements unfortunately can vary from one brand of simulator to another, so making some models only able to work in their specified simulator. However quite useful subcircuits can be devised without using complex behavioural elements as shown in Figure 1.

Audio power MosFet modelling was discussed some years ago in a two part Ian Hegglun article.1 Now needing to model audio power MosFet distortion for myself, I had optimistically hoped that with this passage of time, Ian’s reported problems would have disappeared. Not so, as searches for lateral power MosFet and Spice using Google quickly reveal. Almost no models can be found and those that do exist are modelled using the Kirchhoff’s network method, a technique for plotting the IV curves of behavioural elements as shown in Figure 1.

Unfortunately few even of the most recent Spice simulators are compatible with this Parker Skellen MosFet model, even worse I was not able to find a single Parker Skellen MosFet model on the internet other than the one included in this AES pre-print. Some new Spice simulators do provide for the EKV MosFet model1, but again I was not able to find a single EKV compatible power MosFet model.

To allow the software to analyse any circuit, it uses methods similar to those previously used for manual solutions using a slide rule or log tables. At the time Spice2 was developed, portable calculators were rarely available, almost all practising engineers as I well recall, still relied on using their ‘guessing stick’. Even as late as 1975, the ‘Nelson Jones circuit designer滑rule’ which I still on occasion use, was considered an essential tool in the library are forced to use only those combinations of these pre-defined characteristics. Any additional characteristics, such as ideally needed modelling power MosFets could be added by modifying the Spice source code, which must then be re-compiled before use. Such enhancements are only practical as part of a major software upgrade and re-issue. The circuit to be simulated must first be described in a netlist, following a few simple rules. Using a Windows schematic entry version of Spice, this is performed transparently assigning circuit nodes to your schematic drawing which is then automatically converted into a netlist for the simulation, see Figure 2.

Figure 2: Schematic text version using FDPWS data.

In 1960 the AES pre-print 4298 written by Scott and Parker2 of the universities of Sydney and Macquarie published a report highlighting this problem together with their modifications of the new Parker Skellen MosFet model which allowed this model to be used also with power MosFets to produce accurate distortion simulations. Unfortunately few even of the most recent Spice simulators are compatible with this Parker Skellen MosFet model, even worse I was not able to find a single Parker Skellen MosFet model on the internet other than the one included in this AES pre-print. Some new Spice simulators do provide for the EKV Mosfet model1, but again I was not able to find a single EKV compatible power Mosfet model.

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using a number, except for ground or
earth which must be numbered as 0, a
reserved number meaning ground
reference, node zero. This zero node
is a mandatory requirement and
must exist in every circuit. All
other circuit nodes must have two or
more connections, also a DC current
path to this ground node, both are
essential requirements of the Spice2
algorithms.

Today the Windows schematic
versions still use a similar netlist, but
it has been made transparent for most
circuit design needs, except when
creating a new device model
subcircuit to add to your library of
components. As has already been
seen, in the absence of a satisfactory
manufacturer's model, we must
create our new subcircuit model
definition ourselves. This new
component must first be
described as a netlist, following
the simple rules needed to allow the
simulator to recognise the new
subcircuit model. When finished, for
use with a schematic circuit, it must
then be associated with a schematic
circuit drawing 'shape' before
inserting into your component
library.

Using a Windows Spice2 simulator, the
simplest way to produce a new
subcircuit model is to draw it initially
as a schematic circuit, complete with
a stimulus, voltage sources and loads,
and simulate, much as it will eventually
be used, when called from within
your schematic. This allows your model
to be quickly tested by running
simulations, adjusting its components
as necessary by amending values in
the 'model' schematic.

When satisfied, simply output and
save to a file as a Spice2 netfile
netlist, as shown in Figure 3, which
can be opened, modified as needed
then saved, using a simple text editor
which does not insert control codes.
For this I prefer to use Windows
Notepad. (Figure 3: Illustrating
how easily Spice2 can be used to
model insertion loss, the reflected
signal indicating return loss as well
as group-delay of the toroidal
inductor. The box shown as
'Reflection Bridge' represents the
classic reflection bridge part of a
network analyzer. As can be seen to
realistically model an inductor at
frequency, it is necessary to include
additional components representing
its losses.

Spice2 - warts and all

Equipped with a suitable Spice2
software package and a complete
model library, are our simulations
accurate, can we rely on the results?
Provided our models are correctly
designed, suited to our task and used
within their frequency limit the
answer has to be a qualified 'yes'.

The only way to determine whether a
Spice2 model is correctly designed,
is to perform a simulation, then
compare its modelled results against
actual measured results, and
alternatively against the datasheet
values. The best simulator used with
an adequate component model, can
never provide accurate answers.

Since Spice can be used for op-
amp models, mostly these are
relatively simple, small, 'black box' models used to
approximate the op-amp behaviour in
many applications. Reading the small
print attached to each model should
indicate whether it is suited to your
needs or whether you should obtain a
more complete model. The most
complete op-amp models use large
numbers of transistors to closely
replicate the full schematic
drawing. While these transistor level
models produce the most accurate
simulations, they are considerably
more complex so run more slowly
than when using a macromodel.

One good thing in Spice2 is that it
takes no account of whether any
component is being overstressed so
dependent on your design, it may
produce seemingly impossible
outputs, if that is what the Spice2
interpretation of the model used and
your design implies. For this reason
the most complete subcircuit models
do include components to restrict
say the output voltage from an op-amp
to realistic levels. A few of the most
recent switching power Mosfet models
are also this complete, so can indicate
when exceeding their breakdown voltages. However as a
bonus, simulation using Spice2 does
not break overstressed devices,
allowing you to interrogate the circuit
to ascertain potential damaging
conditions, without risking expensive
board components, or destroying a
power amplifier.

Two other points should be noted. When performing an AC (frequency
domain) analysis, Spice2 cannot
take account of any voltage level
dependent non-linearities, but may
account for frequency dependent
parameters. Spice2 effectively
performs only a 'small signal' analysis,
ignoring any voltage
dependencies, even though you may
have specified a very large stimulus voltage.

When performing a transient (time
domain) analysis, Spice2 cannot take
account of any frequency dependent
variables. This is particularly
important with capacitors, which can
both frequency and voltage
dependent parameters. If such a
capacitor has for example its ESR
specified to change by frequency
dependence, it's a problem for AC
analysis. When performing a
transient analysis Spice2 defaults in
its frequency parameter (FREQ) to zero
making the capacitor ESR appear as
infinite, not at all a useful value.

The Spice2 simulator calculates all
results using a process called
'solution', typically using the modified
Newton-Raphson method and
trigonometrical integration.

Essentially, pursuing a route which it
then uses to re-calculate the circuit,
noting the amount and direction of any
tweaks, it then refines the guess
algorithm and repeats the process, in
order to converge towards its final
answer. Occasionally this convergence
process goes wrong and instead of
arriving quickly closer to the final
answer, it diverges until stopped by
the inbuilt error limits or exceeds the
floating-point calculation limits.

This process is rather like
skimming pebbles across a pond.
Mostly the pebbles approach the
water surface at a suitable angle,
bouncing across the surface several
times, just like the actions needed for
a circuit to converge. Occasionally
however, a pebble approaches at
the wrong angle to disappear instantly
beneath the surface, like Spice2
failing to converge.

Each Spice2 simulator includes a
table of global parameters, essentially
simulation error tolerances, which
determine when the simulator has
converged sufficiently towards a
solution. The user selects global
parameters were established during
the Spice2 development so suit the
circuit being modelled many years ago.
Modern circuit needs can be more
difficult to simulate so Spice2 fails to
converge, and the calculation exceeds
the permitted floating-point limits,
displaying error messages. Even
worse on occasion the program shuts
down, so it is wise to save the most
recent design, before running a
simulation.
A subcircuit can easily be called from a netlist simply by a simple op-amp within its core software. This schematic shape will initiate the subcircuit call when creating a subcircuit for our power MosFet, then the DC 0 AC 59 SFFM 0 0.59 Watts TR2

DC 0 AC 0.35 SFFM 0 0.35 1000 = 8 Watts

rest of the subcircuit netlist lines indicates a remark statement.

These problems can often be removed by adjusting the global parameter convergence limits, the maximum permitted step for transient simulations or even slight adjustments to the circuits supply or stimulus voltages. A particular limitation when modelling distortion for power MosFets is that Spice2 models every component using a common temperature control, of which is indicated by the note about temperature, which has every output plot. For many components instructing Spice2 to model using a 55°C ambient temperature may well be correct but not for the power stage which may experience junction temperatures way in excess of 100°C. As study of a schematic software with its two manuals total ling 900 pages and "on standard task than usual, or perhaps it's because I'm getting old. I commend this book to any reader especially useful. At the time it was written, it predicted the Windows software so as to assume using netlist automatically. After a few months 2000 pages and 'on screen' help files, I still find the Tansueng helps, by quickly answering many questions. That's not to say that a Spice2 simulator is difficult, because it isn't, but rather than from time to time I find myself not trying to perform a more difficult or non-standard way or performing it, or perhaps because I'm getting old. I commend this book to any reader wanting to start experimenting with Spice2 software since with its useful work can be performed using one of the many no cost, size limited, student Spice2 versions.

The Spice2 Level-1 MosFet model is quite basic so cannot properly model this subthreshold region. As will be seen later, simulations using a Level-1 MosFet model do not model bias currents or harmonic distortion at all accurately. This applies also to some subcircuit models, mostly simple extensions of a Level-1 model using external capacitances, to better model a MOSFet. These simple subcircuit models also do not accurately model the subthreshold region, so produce unacceptable results when modelling an audio amplifier.

Examining a model using a text editor quickly reveals the models status. Using the conventional, mostly Level-1 models supplied with my simulator, I had no choice but to accept a global simulation temperature. In 1999 a paper by W. Henslow and C. Wheatley, referenced in the FDP063 schematic, described how this problem could be overcome to model the power stages at working temperatures, with the remaining components simulating at their ambient realistic temperature. Unfortunately again I was not able to find any audio power MosFet models, which used this feature. When modelling distortion of a conventional power MosFet audio amplifier, the models' behaviour as one device is turning off and the other remaining to conduct, in the MosFet low current subthreshold region, is crucial.

User defined model

I decided I had no choice but try to produce a more acceptable model myself. My copy of MC6 was provided with a model module intended to facilitate creating one's own semiconductor simulation models, something I had not previously needed to use, despite using this simulator for more than four years. Unfortunately while the MC6 simulator supports Levels 1, 2, 3, 4, 5 and 8 MosFet models, in accompanying model creation program only produces MosFet models at Level-1 and cannot be used to make a subcircuit.

My current and inductor model needs however had been quite different, frequently I was forced to hand craft more acceptable models for these, since a capacitor and inductor model development facility is not provided by the MC6 semiconductor modelling aid. Not having access to a curve tracer I tried following the MosFet maker's published data, but with little success. My interests were mostly for drain currents of three amps and smaller, down to just a few milliamperes for the crossover region. The maker's data which effectively concentrated on drain currents from three amps to the sixteen amps maximum of the chosen device, did not help. Unfortunately I had already selected and obtained these particular transistors, mostly because the datasheets illustrated good matching between N and P types, not apparently available with other lesser-rated devices.

After many trials I obtained a pair of "Level-1" MosFet models which appeared to provide a closer fit to the datasheet at low drain currents than did the models supplied with my simulator. So I commenced my experimental simulations as shown in Figure 5. My original task had looked quite simple, I had hoped to produce simulated distortions in line with the practical measured results made on my modified Maplin amplifier. My new Level-1 MosFet models worked in that I could reproduce the input and output waveforms both open loop and closed loop. The high frequency response curves however looked particularly suspect, clear indication of badly modelled MosFet capacitances, when compared with actual measured waveforms of the amplifier. Worse still, using the same output stage bias currents as used for the measured waveforms, simulating distortion, although the distortion simulated using these new models was smaller than when using the models provided with the simulator, all simulated distortions were many times greater than those measured on the actual amplifier, clearly indicating that the model used did not accurately model the subthreshold region, so produce unacceptable results when modelling an audio amplifier.

Figure 6: While these BU2901/906 models produced less distortion than other Level-1 models tried, distortions in this simulation for exceed those measured on the actual amplifier. Second harmonic of -77.1dB and third of -79.15dB are gross errors compared with the -92.1dB and -94.1dB actually measured on my working amplifier.

Figure 7: Self heating models accurately simulate distortion.

reference documents downloaded from internet, I slowly realised much of the information I presently lacked, could become available, enabling me to devise thermal subcircuit models more suited to simulating audio distortion. Eventually after several weeks work, I managed to produce self contained, self heating models for my BU2901/05D lateral power MosFets, overcoming the Spice2 global temperature restrictions, with models which closely replicate the devices subthreshold conduction.

These self heating models can be included with heater with neat models, to continuously monitor the transistor junction temperature, automatically adjusting the MosFet characteristics with each change in junction temperature just like a real transistor, introducing a new era in realistic Spice simulation for the user. Figure 7. Creating a working power MosFet subcircuit thermal model from a datasheet, forms the topic of my next article.

References

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Figure 7: Self heating models accurately simulate distortion.
PIC crystal tester

and frequency counter

Ever rummaged around in the junk box and found unidentified crystals? Or even wanted to verify the frequency when fault finding? Then Hamid Mustafa’s little box is for you.

This crystal tester was designed for testing the quartz crystal elements used in thin film coating machines. In the machine, a thin piece of quartz is used, attached to an oscillator circuit and as the parts get coated, so does the crystal, which lowers its resonant frequency. The frequency change is a measure of coating thickness in microns. This tester can also be used for testing crystals used in colour TVs and video recorders. Colour decoder TV crystals usually resonate at 4.43MHz (3.58MHz for NTSC).

The heart of the tester is a PIC16F83/4 programmed to function as a frequency counter driving a 4 digit LED display, TSM4000, TSM6734 or Farnell 948-536. In this type of display, data is serially written and only two port pins are needed from the PIC. The PIC itself operates with a 4MHz crystal clock as shown in Figure 1. An LED flashes at 5Hz to indicate that the crystal being tested is OK and its frequency is within the range of the tester.

Because the display has 4 digits, the measured frequency range is 1KHz to 9.999MHz. However the 4 digits are intended to show MHz, and 1KHz will be displayed as 0.001. Although this tester was not intended to be a frequency counter, by adding a second four digit display or a 20 digit LCD display and modifying the software, an 8 digit frequency counter can be made with a range of 1 Hz to 50MHz. If used as a frequency counter, remove the 74HC14 from its socket and feed the signal to be measured to pin 10 of the socket.

The hardware

Figure 1 shows the simplicity of the hardware and the wiring. A 74HC14 hex inverter is used to oscillate the crystal being tested. The pulses from the oscillator are fed to the counter input of the PIC through a 4kΩ resistor and are counted. The counter input pin of the PIC (pin 3) is connected to an I/O pin, pin 2 which is configured as an input (high impedance) while counting. When the counting time is up, pin 2 is configured to be an output, and is switched to LOW. This shorts the counter input to ground preventing further pulses from reaching the counter while the PIC program reads the counter and prescaler values to determine the frequency. The 4-digit display is driven from two port pins of the PIC, pins 10 and 11. A PCB was not made to interface to it. Example code in several popular programming languages are provided. Windows CE and Linux drivers are also available on request.

PIC16F83 or 84
74HC14

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For the project due to the small number of components and wiring. It can be built on a small piece of Veroboard 8cm x 4cm. If a more precise reading of the measured frequency is desirable, replace the 33pF capacitor on pin 16 of the PIC with a 15pF capacitor in parallel with a 50pF variable capacitor and adjust while testing a known crystal.

The author built three prototypes using three different 4MHz CPU crystals and compared frequency measurements with an 8-digit frequency counter and found the accuracy more than adequate.

The 4 digit LED display. The TSM 4000 or TSM 6734 has nine pins. Only two pins are connected to the PIC, the others are for brightness, power, enable etc. If a TSM 6734 cannot be obtained, a Farnell 948-536 can be used instead. When a TSM 6734 is used, link pins 5 and 6 of the PIC. For the Farnell display link pins 6 and 7 of the PIC. Also, for the Farnell 948-536 type display, diodes D1 and D2 and the resistor R4 are not needed. For the Farnell display, leave pins 7 and 9 of the display unconnected. The Farnell 948-536 has a link on either side of the 9-pin connector, these must be jumpered.

How the software works
The PIC program was written in C language and includes lots of comments and explanations. It should be a good starting point for anyone wanting to learn to program PICs in C language.

The entry point of the program is the function main( ). The first thing the program does is configure port B pins as output except bit 0, and port A pins as all input. Next, the display is initialized by taking the data pin low and clocking the clock pin 40 times. This blanks the display by ensuring its internal registers are zeroed. Next, the option register is written with 11100011. This configures TMRO as a counter with a prescaler of 256. This means that every time the prescaler reaches a count of 256 it will overflow, reset to 0 and increment TMRO. Note that the prescaler can count at 50MHz.

The software then waits for exactly 1ms and when the 1ms is up, it short the counter pin to ground by making pin 2 an output and making it LOW. The number of pulses received in 1ms are now safely in TMRO and the prescaler cannot.

To get the count in the prescaler, we clock the counter's input pin (pin 3) using pin 2 (remember, pin2 and 3 are linked). The number of pulses needed to overflow the prescaler and increment TMRO gives us the prescaler count. For example, if the prescaler was holding a count of 200, clocking it 56 times would overflow it. Therefore the prescaler count = 256 - 56 = 200. The only thing left to do is to multiply the value in TMRO by 256 and add it to the prescaler's count. We then convert this total count to 4 digits using printf() and display the 4 digits. After displaying the frequency, we delay 0.2 seconds before measuring again. This prevents possible fast flicker of the last digit.

A kit containing a pre-programmed PIC may be available from EW if there is enough demand. The target price will be £20, $20 or €15, which will include postage, a floppy disk with the C program, assembly code, hex code for programming your own, Veroboard and assembly instructions and photos of the author's prototype. For more details and an order form, please contact Caroline Fisher, details on page 3.

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Because we count pulses in 1ms instead of pulses per second, the frequency displayed will be in KHz. With 4 digits, 443318 Hz will be displayed as 4.433. The value of TMRO can be read directly, but the

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It is widely understood that some kinds of radiation are harmful to human health, although we all live in a world full of natural radiation of every frequency – from noise at the low-frequency end of the radio spectrum to hard ultra-violet (UV) radiation. Without it we would not be here.

Fortunately the earth is surrounded by ionized particles that absorb most of the more harmful radiation at frequencies from UV upwards. Almost all the radiation that reaches the ground is non-ionizing radiation: the energy carried is not sufficient to ionise atoms by knocking out charged particles. At UV and visible light frequencies there is still enough energy to break the bonds that hold molecules together. We are all familiar with plastics which discolour from which the food is made.

As the frequency falls further we enter the radio frequency ('radio waves') carry energy which is transferred into any object which absorbs them. We all know that if we irradiate food with a few milliwatts of microwave energy it will get hot and cook. Today's world is full of sources of RF energy with powers from a small fraction of a watt to kilowatts (kW) and more; we need to understand the effects they can have on our bodies. Clearly we must avoid cooking ourselves, but are there other effects we need to guard against?

Proving negatives

It's clear that there are no major short-term risks in normal levels of exposure to RF fields. If there were we would have seen an epidemic of disease or early death among exposed populations or groups of workers. What is less certain is that continuing exposure to fields at lower intensities causes no long-term ill effects.

The methods of science are not well suited to proving that a suggested cause has no long-term effect. There are two reasons for this.

Firstly, we don_t know for certain what effect we are looking for, and secondly we can only assign some degree of probability to our conclusions. The result of thorough and well-conducted investigations costing millions of pounds/euros/dollars can only be expressed in terms that sound to many laymen like prevarication. Any experimental campaign will conclude at best that in the conditions of the experiment (at the frequency, exposure intensity, duration, modulation scheme &c) the effects searched for (mortality, soft tissue cancers of a particular type, nightmares &c) in the population (or animal or cell type) studied are (within a stated confidence limit) less than (a stated incidence). This inevitable state of affairs means that while investigators can use their best imagination and experience, they can never say that something is absolutely 'safe', and those who assert that an effect has been missed (or worse that something is being hidden) can always make any statement relating to safety look insecure by challenging the conditions and subject of the experiments, whether the right effects were looked for, and the sensitivity of the outcome.

Worse, different groups are seen as having different interests in proving that some situation is 'safe', so the credentials of the investigators and the source of their funds is seen to colour the results. A well known technique is that of epidemiology. Take a sample population (say a million mobile phone users) and compare them for the incidence of some possible effect (say increased hair growth with a control population (say a million people without mobile phones). It sounds easy, yet there are many problems. Is phone use the only factor? How do we measure the different between the populations? Obviously not; in particular how do we find that the mean income of the phone-users is lower than that of the non-phone users. Anyhow, what do we mean by a phone user? Is my wife, who only turns her phone on when she needs to make a call a 'phone user'? The confounding factors, working like noise in a communications system, reduce the sensitivity of the experiment and make the results fuzzy and imprecise.

Even the existence of a study often creates concerns in the popular press. The headline will always read 'Scientists seek (or fear) connection between mobile phones and x', and as we have seen, negative results will always look less than categorical. As far as mobile phone usage is concerned, I believe that my probability of death from the effects of RF radiation from my phone are less than the probability that my phone will at some point save my life (and/or someone else's life).

Individual sensitivity

There's a huge difference between individuals' ability to sense exposure to RF fields. Some individuals are reported to be able to detect when a laboratory signal generator is turned on and off at power levels of only a few milliwatts, even when connected only to a coaxial cable with an open connector placed in front of the test subject. I was recently within 10m of an antenna radiating 600kW at about 1MHz and could sense it was on only because my feet became hot where I stood on a ground conductor. It's natural that people with enhanced sensitivity will be more concerned about any effects of RF fields, and their enhanced sensitivity to RF is often paralleled by enhanced sensitivity to other environmental stimuli. (Try Googling for 'Electromagnetic hypersensitivity' if you are interested.)

Specifying and measuring limits of exposure

There are various ways of measuring the level of exposure to RF fields. For waves propagating in free space the field is characterised by the power density (W/m²). Close to an antenna, consideration must be given to separate criteria for the E-field (V/m) and H-field (A/m). If we wish to investigate the absorption of fields into the body we describe the level of absorption in watts per kilogram (W/kg) of body tissue; this quantity is referred to as the specific absorption rate (SAR). We may be interested in whole-body exposure, or more often the power density in each separate 10g or even 1g of tissue. The body responsible for internationally specified limits is ICNIRP (International Committee on Non-Ionising Radiation Protection). National guidelines are laid down in many countries, often by health and safety administrations; these often coincide with ICNIRP, but sometimes differ – often in the direction of being less stringent. The competent authority in the UK is the National Radiological Protection Board (NRPB), while in the US the FCC, OSHA and IEEE are responsible for various aspects of regulation. The ICNIRP limits have been set with a large factor of safety below any known ill effects.

Calibrated hazard meters are now readily available and are routinely worn by riggers and engineering staff required to climb antenna structures. They usually operate over a wide frequency range and have an audible alarm that sounds if the safety limit is exceeded.

Measuring the absorption of energy in human tissue is difficult, especially as high spatial resolution is needed to make sure there are no small hot-spots which might suffer damage. Measurements are usually made by placing a phone close to a bath of liquid electrolyte with similar
radiated power, EIRP, is the input power to the antenna multiplied by the gain of the antenna in the direction we are interested in, relative to an isotropic radiator (or in decibels, eirp (dBW) = Pout (dBW) + G (dBi)). The larger an antenna, measured in wavelengths, the more directional it can be made. The concept of eirp is not valid when the distance from the antenna to the point of interest is small (certainly when it is less than the longest dimension of the antenna). Fields and power flows close to an antenna are best calculated using an electromagnetic simulation program or by measurement with a small probe.

The power density at a distance from an antenna is easily calculated. If an isotropic antenna radiates p watts, then at a distance r the power density is p/(4πr²) w/m², so for an eirp of P watts the power density is P/(4πr²) w/m² and the associated field strength E (V/m) = P/(120πr²) for these simple relationships apply to the far field of the antenna, which starts about 10m away from a typical base station antenna.

The effects of exposure to high fields

These are well documented. At very high levels of continuous exposure the body is heated and death will be caused by heat stroke when the body’s cooling system is no longer able to cope. Pulsed fields can give rise to sensations such as pining in the ears. Some tissues, notably the retina and the testes can be damaged at sub-lethal exposures, resulting in blindness or sterility. Eyes are particularly at risk from radiation in the upper microwave bands where most energy is deposited in surface tissues (such as the cornea) which have relatively low blood flow, and consequently are not efficiently cooled.

Exposure limits are set with the object of limiting the rise in body temperature to a small value within the normal limits of variation during light exercise. To give some sense of scale, the total power radiated by a GSM mobile phone typically has a peak power of around 1 W, transmitting in short bursts for only 0.1% of the time for which the transmitter is active - a mean power less than 1/8 watt. Summer sunshine in the UK has a typical power flux of around 1000W/m², so when sitting on a sunny day we may be irradiated by 500W of electromagnetic energy, much of which is absorbed by surface tissues in the form of heat.

Most standards recognise acceptable occupational exposure limits and lower limits for the general public, a population which may include potentially more vulnerable individuals - for example children, old people with poor health, pregnant women - and whose exposure may be for much longer time periods than those of a typical worker.

RF exposure in the 21st century

Mobile phones

The currently most publicised source of exposure is the mobile phone and its associated base stations. The mobile phone is the first portable transmitter to be carried and used by a huge number of individuals, so it is natural that its safety should be of great concern. Unlike occupational exposure - generally experienced by healthy adults, mobile phones are used by every section of the community including groups who may be more sensitive to low levels of energy absorption, children, pregnant women, old people, and by people with cirrhotic problems, cancer and other pre-existing medical conditions.

The peak SAR associated with a typical mobile phone is often between 50% and 90% of the ICNIRP limit when operating at maximum output power. The actual power radiated by a mobile phone is automatically reduced to the minimum necessary to establish communication; the largest powers are required when the user is close to a limit of coverage of a base station.

Microwave ovens

The leakage of energy from a microwave oven is required to be less than 5W/m² at a distance of 5cm from any surface of the oven (BS 5175:1976) which is a standard that now({3}) a microwave oven escaping may exceed 0.5 watt - say 1000W (lpt) of total RF power generated - representing a significant effectiveness of only -30dB. It is not surprising that there are stories of people putting mobile phones inside a microwave oven and successfully making calls to them! (You should only be able to do this if you live fairly close to a base station - and if you want very, very poor service, the oven is ON) The door seal will wear and become dirty through use, so the internal field strengths may be lower than when the oven is OFF. The door seal may not be able to hold or even rotate below the levels given in the standard when the oven is OFF.

Exposure to high fields

There is a substantial margin below the recommended limits. This is largely due to an optimistic assumption that whenever a mobile phone is used, the associated eirp is 0 dBW. In practice, users are likely to be too far from the base station to be exposed to the full power of the transmitted signal. At typical distance from a base station the eirp is at least 10dB less than at maximum output power. So the eirp values published in tables of the power radiated by mobile phones should not be taken literally.

Radio and TV transmitters

The highest power densities are radiated by the main UK television transmitters. A total eirp of 6MW is radiated by several TV stations in the UK, but the antennas are even more directional than those used for mobile radio, and the structures are typically 300m high, so the beam maximum is directed at the ground more than 8km from the structure (if the structure is on flat ground) and the ground level power density is very small. A classic epidemiological study was conducted a few years ago around the UHF TV station at Sutton Coldfield (UK).

UHF radio transmitters operate at far lower eirps at frequencies around 100MHz. Although the ground level power densities are modest, this frequency band corresponds to a wavelength of 3m, so body resonances may increase the effect of exposure at these frequencies. There is evidence that this possibility is included in the ICNIRP limit which is correspondingly reduced.

The associated power densities are the same. In order to provide the best possible coverage, the base antennas are built as a vertical array of radiating elements. This focuses the radiated energy into a narrow beam directed just below the horizontal - typically the beam is 6° wide and is directed 5° below the horizontal. On a typical low structure (10m high) the beam centre reaches head level 25m from the mast base.

If we do the calculation, we find that the power density in the example will be 0.013W/m², compared with an ICNIRP limit of 10W/m². Even allowing for side lobes, the ratio between these will be over 1000:1. This is a very pessimistic example as we have used the shortest structure combined with a transmit power close to the horizontal.

TETRA

The TETRA (Trunked Radio) system being introduced for use by the police and other public services. The main source of concern relates to the relatively high power in use at the handsets, and the low frequency of the bursts they transmit. A report published in the 1980s suggested that the spreading of sodium from brain cells was accelerated by exposure to RF signals with a pulse frequency of around 16Hz. A large amount of more recent work has failed to confirm this effect and no health-related effects are thus far identified. A standard RF hazard meter identifies radiation at or below the ICNIRP limits. Future developments in which handsets are expected to be used for longer periods may require additional precautions to meet the limit. TETRA base stations transmit a continuous signal and the associated power densities are generally lower than those used for GSM, so there are no special reasons for concern.

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usually fenced to prevent access to hazardous zones. All high power broadcast systems put on to those working within the radio stations. These personnel are well instructed in these matters and will normally carry personal alarms when they need to work near active antennas. At lower frequencies the heating effect of the fields is relatively low, so permitted power densities are higher. Typical effects are that any large conducting object carries induced currents/voltages and contact with a hand can create a painful burn; even when working in areas within safe limits personnel will usually wear insulating gloves while handling wire ropes and steelwork. Relative powers of all the above are illustrated in Figure 2.

The present state of knowledge
The Stuart Report (UK) is one of the most comprehensive and objective reviews of the possible effects of mobile radio systems. Some comprehensive epidemiological studies are beginning to report results and there are many on-going studies that will report over the next few years. Work on non-thermal effects is examining matters like the change in action potential in cells exposed to RF fields, and looking for effects on memory and perception. While various effects are reported it is not clear whether any has negative health significance.

The UK Independent Expert Group on Mobile Phones (IEGMP), chaired by Sir Richard Doll has reported even more recently. If you are seriously interested in the subject it is well worth reading. The research work reported spans investigations into the incidence of cancers (whether induced by RF fields operating alone or in combination with a number of other factors). The overwhelming impression on reading the document is of the wide scope and diligence of the work reported.

Are the published results biased? Some people see much of the available information as being the result of a conspiracy not to tell the truth about the perceived dangers of sources of electromagnetic fields. They see bias in the experts’ dismissal of positive associations as being unproven, of little statistical significance, or the result of badly designed experiments. When the language of the conclusions of an experimental campaign is careful, guarded and precise the sceptic sees this as lacking in confidence and hiding ‘the truth’. There are several reasons why the actual bias in results is likely to be in the conservative direction. Results reporting positive associations between exposure and health effects are newsworthy and bring publicity to the investigators responsible; granting additional funding is a more likely way to back further investigation of positive results rather than negative (“no effect”) results. A newspaper will headline a positive result, but there are no headlines for solid research producing a conclusion of no adverse effects. This view is confirmed if you dip into the research literature; you may well recognise many of the positive findings, while the bulk of the negative reports are unfamiliar.

Reading the reports of many investigations suggests that there has been too little involvement by engineers with detailed knowledge of radio systems. There is little sign that the media are being led by the nose by technical experts from the mobile radio industry. The strong impression is that many experiments would have been better designed – and more reliable results would have been obtained – if more advice had been taken from engineers before the investigations had begun.

The good news is that the more of the published literature you study, the more you realise just how much investigative work has been done and is in progress. While everyone is properly guarded about the possible emergence of long-term effects, the strong consensus is that no effects on health occur within the ICNIRP exposure limits. The 2003 report of the Independent Advisory Group on Non-Ionizing Radiation (Document of NRBP Vol 14 No 2) concludes: ‘The weight of evidence now available does not suggest that there are adverse health effects from exposures to RF fields below guideline levels’ but the published research on RF exposures and health has limitations, and mobile phones have only been in widespread use for a relatively short time. The possibility therefore remains open that there could be health effects from exposure to RF fields below guideline levels; hence continued research is needed.

The perception paradox
The 2002 report on the possible health effects of mobile phone systems to the French Senate comments on the fact that although most public protest relates to the siting of base stations, most people who oppose their construction use mobile phones and allow their children to use mobile phones, failing to admit that if a risk does exist it is in respect of handsets, which create far higher levels of personal exposure. As we have observed, a well-timed media campaign can create a perception of a risk, which is then treated as a lead into further investigation of the issue. The perception paradox is that while the consensus is that there are no adverse effects, the risk is perceived to exist. The author’s website at www.becasociates.co.uk/links.html carries links to all the successful protesters enjoy a much higher level of RF exposure than those who live across the road from a typical base station.

Further information
There is a vast and fast-growing literature on the limits of RF exposure and the study of possible health effects. The author’s website at www.radiotelemetry.co.uk is one of the most comprehensive and objective reviews of the possible effects of mobile radio systems. Some comprehensive epidemiological studies are beginning to report results and there are many on-going studies that will report over the next few years. Work on non-thermal effects is examining matters like the change in action potential in cells exposed to RF fields, and looking for effects on memory and perception. While various effects are reported it is not clear whether any has negative health significance.

The UK Independent Expert Group on Mobile Phones (IEGMP), chaired by Sir Richard Doll has reported even more recently. If you are seriously interested in the subject it is well worth reading. The research work reported spans investigations into the incidence of cancers (whether induced by RF fields operating alone or in combination with a number of other factors). The overwhelming impression on reading the document is of the wide scope and diligence of the work reported.

Are the published results biased? Some people see much of the available information as being the result of a conspiracy not to tell the truth about the perceived dangers of sources of electromagnetic fields. They see bias in the experts’ dismissal of positive associations as being unproven, of little statistical significance, or the result of badly designed experiments. When the language of the conclusions of an experimental campaign is careful, guarded and precise the sceptic sees this as lacking in confidence and hiding ‘the truth’. There are several reasons why the actual bias in results is likely to be in the conservative direction. Results reporting positive associations between exposure and health effects are newsworthy and bring publicity to the investigators responsible; granting additional funding is a more likely way to back further investigation of positive results rather than negative (“no effect”) results. A newspaper will headline a positive result, but there are no headlines for solid research producing a conclusion of no adverse effects. This view is confirmed if you dip into the research literature; you may well recognise many of the positive findings, while the bulk of the negative reports are unfamiliar.

Reading the reports of many investigations suggests that there has been too little involvement by engineers with detailed knowledge of radio systems. There is little sign that the media are being led by the nose by technical experts from the mobile radio industry. The strong impression is that many experiments would have been better designed – and more reliable results would have been obtained – if more advice had been taken from engineers before the investigations had begun.

The good news is that the more of the published literature you study, the more you realise just how much investigative work has been done and is in progress. While everyone is properly guarded about the possible emergence of long-term effects, the strong consensus is that no effects on health occur within the ICNIRP exposure limits. The 2003 report of the Independent Advisory Group on Non-Ionizing Radiation (Document of NRBP Vol 14 No 2) concludes: ‘The weight of evidence now available does not suggest that there are adverse health effects from exposures to RF fields below guideline levels’ but the published research on RF exposures and health has limitations, and mobile phones have only been in widespread use for a relatively short time. The possibility therefore remains open that there could be health effects from exposure to RF fields below guideline levels; hence continued research is needed.

The perception paradox
The 2002 report on the possible health effects of mobile phone systems to the French Senate comments on the fact that although most public protest relates to the siting of base stations, most people who oppose their construction use mobile phones and allow their children to use mobile phones, failing to admit that if a risk does exist it is in respect of handsets, which create far higher levels of personal exposure. As we have observed, a well-timed media campaign can create a perception of a risk, which is then treated as a lead into further investigation of the issue. The perception paradox is that while the consensus is that there are no adverse effects, the risk is perceived to exist. The author’s website at www.radiotelemetry.co.uk is one of the most comprehensive and objective reviews of the possible effects of mobile radio systems. Some comprehensive epidemiological studies are beginning to report results and there are many on-going studies that will report over the next few years. Work on non-thermal effects is examining matters like the change in action potential in cells exposed to RF fields, and looking for effects on memory and perception. While various effects are reported it is not clear whether any has negative health significance.
The Catt Anomaly

Correspondence on the Catt anomaly has erupted again recently, and Ian Hickman was prompted to take a closer look. Here are some of his thoughts on the subject, a topic which he has been vaguely aware for many years.

I seem to remember reading an article by Ivor Catt in these pages, mentioning that sinewave signals travelled along a feed, and encountered a termination at the far end, consisting of a perfect diode. This, of course, is quite a complicated scenario, since waveform distortion will occur, leading to the generation of harmonic frequencies. However, just recently, as a result of the reappearance of Ivor in these pages, I paid another visit to his website. You can find an animation demonstrating the Catt Anomaly (he prefers to call it the Catt Question) or the E.M. Question which is at http://www.electromagnetism.denmon.co.uk/cattans.htm and it is in fact a very much simpler scenario than that mentioned above. It seems to me, and some of these thoughts are set out below. As usual, my approach has been in terms of the fundamental properties of the circuit, rather than a mathematical description of the phenomena. I have always been surprised that so many engineers, including many of my colleagues when I worked in industry, seemed happy to pass the handle on to the textbook maths and arrive at a working solution, without understanding - or even curiosity - as to the details of what was actually going on, and just how the circuit functioned. (Maths does not explain anything, it simply provides you with the tools to calculate the quantitative relationships between the variables. The maths itself is just arranged to make the results, once they have been understood and explained.)

Figure 5: Showing a voltage step function propagating along a two-wire line.

Vector diagrams, Argand diagrams, Nyquist diagrams, Bode plots and the like can provide an insight into the functioning of a circuit, which an equation does not, at least not to the ordinary mortal. An example is the functioning of a second order phase lock loop; the treatment in my Radio Frequency Handbook uses graphical methods to elucidate the workings, arriving at the result without resort to any complicated mathematics. In the same way, the analysis below is based firmly on the physical properties, the relationships between voltage, current, charge, capacitance, inductance, power, energy etc. in the circuit.

The Catt Anomaly

Figure 1 shows a battery connected to a two wire transmission line of finite length, and we may assume, from the position that the TEM waveform has reached, that the battery was connected a (very!) short while previously. On the part of the line which has already been charged by the source, positive charge appears on the top conductor, and negative charge on the bottom conductor. Electric field lines are indicated, originating on the positive charges and terminating on the negative charges. The electric field strength, in volts per metre, will be equal to the potential difference between the upper and lower conductors, divided by the distance between them. At least, this is the case for the field lines shown, in this two dimensional representation. There will also be longer such lines, starting on the upper conductor and terminating on the lower, in the same plane as the lines shown, but bulging out from the paper, and likewise behind. There are even notional lines, of negligible importance, heading off vertically from the top conductor towards infinity, and likewise downwards from the lower, assuming that the two conductors are located somewhere in free space. The electric force results in an electric flux, of strength depending upon the permittivity of the medium in which the line is immersed. This is analogous to the way magnetic field strength H results in a magnetic flux density B, depending upon the permeability of the medium. For simplicity, let's assume the line is in air.

The Catt Anomaly. As I understand it, it lies in the question as to where the charge appears at any point along the line. With reference to this, the lower conductor comes from, bearing in mind that its greatest concentration will be where the lines of electric force landing on it are most concentrated, i.e. directly under the top conductor. Ivor points out that it cannot be delivered by the display of conduction current flowing between the lines, as displacement current is not a flow of real current1. I would add that the latter has asked well known academics where the negative charge on the lower conductor comes from. He divides those who could be induced to give any answer at all, into "Westerners" and "Southerners". The former say that the charge comes from the source at the left-hand end of the line, and the latter, from within the line itself at that point. But, he maintains, it cannot come from the left-hand end as that would suppose that it travels at the speed of light. But the negative charge consists of electrons, each of which has a small but finite mass (9.109 x 10^{-31} kg), and therefore cannot travel at the speed of light.

The Southerners' explanation entails charge moving from the inside of the material of the line, to the surface i.e. at right angles to the direction of propagation, which would also be he also finds problematic. On the face of it, these two positions seem to be irreconcilable, and perhaps for this reason, Ivor assumes they are both wrong. On the contrary, I maintain, they are in fact both right.

From the outset, I was puzzled by Ivor's fixation on the negative charge on the lower conductor. Surely any complete explanation must account equally for the positive charge on the upper conductor. So that became my point of departure.

A different view

Consider the line before the battery is connected. The metal - let's assume it is 100% pure copper - consists of atoms which are in "fixed" positions, the material being a solid. Although fixed, they are in fact each vibrating about some mean position, meaning the temperature is not absolute zero. Nevertheless, for the purpose of this exercise, that is immaterial. They cannot actually wander around, and they will therefore be regarded as stationary. This applies to the protons and neutrons in the nucleus and also to most of the electrons, in each atom.

But there are also "free electrons" forming a sort of "conducting gas" within the conductor. These may be on a somewhat freer rein, but they too, for the purposes of this argument, can be considered as stationary. Thus at every point along the line there are equal numbers of protons and electrons per unit length. This has been plotted in a graph at top of Figure 2, where the x axis is length, the same as the line itself. Before the switch is closed, the equilibrium net positive charge per unit length is indicated by the black line. There is no net charge on any point on either conductor, and the potential difference between them is everywhere zero.

An atom is not propertorial about its free electron: if the latter departs to the left as part of an electric current, the positive charge on the nucleus is happy to let it go. However, that another electron comes along from the right to take its place, which will always be the case in a current circuit. Now consider the case when the switch is closed, Figure 3.

Conventional current flows into the top conductor of the line, but a conventional current flowing to the right actually consists purely of electrons moving to the left (at least, in a metallic conductor, which unlike a semiconductor - has no mobile positive charges or "holes"). Assuming the velocity of the waveform on the line is the same as the speed of light (for an open air line, it won't be that much less), then after half a nanosecond it will have reached the point indicated by the line A A', and after a further half nanosecond it will have reached B B', as indicated in Figure 3. The instant the switch is closed, the leftmost electron in the upper conductor (the "first" electron) will start to move, eventually passing via the switch and into the matched source, the internal resistance and emf of which have been shown separately. The second electron now finds the third electron closer to it than the first. As like charges repel each other, the closer they get, the closer they are together, the second electron experiences a net force pushing it to the left and starts to move leftwards also. Now, the third electron finds the fourth electron closer to it than the second and also starts to move - and so on. The electrons may be moving at a small fraction relative to the speed of light, but the disturbance just described propagates along the line at the speed of light, reaching B B' in just a nanosecond.

To the right of B B' there are still equal numbers of protons and electrons per unit length of line, so there is no net charge and the voltage on the line there is as yet zero. To the left of B B' the line of electrons is moving to the left at a constant speed, the spacing between the moving electrons being everywhere equal, x = y, slightly greater than the right of B B'. Therefore there is everywhere a slight deficit of electrons per unit length of the upper conductor, their number being represented by the green line "e" in Figure 3 (not to scale). The resultant constant net positive charge per unit length is responsible for the constant positive potential on the line, relative to the lower conductor, indicated in Figure 3 by the red line labelled "V". With a line of electrons all moving at the same speed and with a constant spacing between them, the current in the line to the left of B B' is everywhere constant, indicated by the blue line labelled "I" in Figure 3. The ratio of V to I gives the "characteristic impedance" or "surge impedance" of the line, which I will assume to be 300 ohms, a typical value for a two-wire air-line, though it could be anywhere from about a third to five times that value, depending upon the thickness of the conductors, their spacing and the dielectric separating them.

Exactly the same mechanism which has been used to account for the appearance of a positive charge on the upper conductor, accounts equally well for the appearance of a negative charge on the lower conductor, as the phase reversal occurs.

Figure 3. Conventional current flows from the source into the upper conductor, returns from the lower conductor, into the negative pole of the source. This implies that the negative pole forces electrons into the left-hand end of the lower line. What was the first electron there now finds one closer to it on its left than the second electron and one on its right and -I won't bore you with a blow by blow account again, but to the left of B B' the electrons are slightly closer together (x = y) than to the right, all equally spaced and moving at the same speed. They thus constitute a conventional negative current flow to the left, indicated by the blue line below the baseline in the lower graph in Figure 3. This is the basis for the Westemer view advocated by Dr. Neil MacEwan and similar to the

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Carrying the current. In a line cause a current of $I_a$ to flow would so the applied voltage needed to lines would clearly have very same conductor spacing, these two less than that of light. Assuming the second. The speed with which the electrons entering the lower and leaving the upper conductor per second. The current put in, so the rest must be in the magnetic field. Energy stored = $\mathcal{L}I^2/2$. Therefore, $\mathcal{L}=300$ Joules. Therefore, $L=600$ Henries. It may seem strange to talk of the inductance of a 600nm line which is open circuit, but it is quite logical if the circuit is restricted purely to the in-phase. A more complete analysis during the two nanoseconds the wavefront has travelled, will distribute itself over the circumference of that conductor, in proportion to the density of lines of electrical flux terminating at each point around the circumference. MacEwan explains how the charge got there in a mirror image of the distribution of nuclei short of one attendant very small hole. They all require a power supply of between 10 and 12 v DC 15 0mA. For further details see www.diatv.co.uk Better quality C Mount lenses Economy C mount lenses all fixed focus. 1000 of 1 value £5.00 + vat 12 06 surface mount resistors E12 values 10 ohm to 1M ohm 10 0 of 1 value £1.00 +vat.
source, is propagating, has been presented. This explanation has been extended to the case of an open circuit line of finite length. An explanation, in similar terms, of what happens when a TEM wave from a matched ideal current source propagates along an ideal lossless short-circuited line, can also be developed. However, the situation looks, at first sight, a little more complicated, and I am still thinking about it. So, in common with all the best textbooks, I can only say that this question "is an exercise for the reader". The explanation of the appearance of charge on the lower conductor here given, has been presented not, indeed, entirely without mathematics, but with no more than simple arithmetic, and appeal to universally known relationships in the science of electricity.

The discussion above applies in the case of an ideal lossless line, but applies in broad principle to practical lines. However, there are two unwanted characteristics of real lines which have been ignored attenuation and dispersion. These are interesting, important and well worth studying and becoming familiar with. But this book is not the place for now, so I hope to look at these topics later. For the present then, here endeth the first lesson.

Acknowledgment: The author gratefully acknowledges help and discussion and comments on this article from his old colleague and longtime friend, M. H. Gross, C.Eng., M.I.E.E.

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2. Displacement current, and Maxwell's Equations generally, seem to have fallen into disfavour since I was at college: at one time the subject of a whole course, displacement current is proportional to the rate of change of the electric field strength. In the discussion below I use the name "electric current" rather than a capacitor is used to suppress this. In fact, as early as 1905, displacement current was found to be a much larger quantity than the "conventional" current, and this observation was responsible for many of the ideas in the development of the theory of waves. Therefore the potential on the upper conductor of a line, on which a sudden change of current occurs, is propagating, has been described. Hence in the case of the open circuit, when the voltage gradient in the dielectric changes. In the following sections, we shall see that this is a major difficulty, and one reason why the concept of displacement current cannot be consigned to history.

Is there a difference in the zero of the magnetic potential, and a capacitor, or a 300Ω resistor? At twice the voltage, a capacitor stores four times as much energy, and a resistor dissipates energy at four times the rate. In the case of the open circuit, at 2m, the energy stored at 300V is 600J, and at 4m, at twice the voltage, the energy stored only doubles to 1200J. But after 20 m only a very small fraction of the capacitance of the line, the other half of the energy supplied being stored in the inductance. Thus the energy stored in the line's capacitance quadruples when the voltage doubles to 600V. During the nanoseconds, 1200J has been dissipated in the internal resistance of the line, so the total energy supplied is 2400J. At four nanoseconds, the energy stored in the line is 6.642 x 10N 6.667 x 10N = 1200J, exactly the same as is stored in a 300Ω resistor of the same capacitance as the line. The crucial difference is that if the reactive reactance is connected to a 300Ω resistor, it will deliver an initial 2A, decaying exponentially whereas the charged line will deliver a constant 1A for 4ns, decaying abruptly thereafter. This is a delay line rather than a capacitor is used to supply anode power to a magnetron, which is a time delay circuit.

Conclusions
An explanation of the appearance of negative charge on the lower conductor of a line, on which a Transverse Electric Magnetic wavefront from a matched voltage

- **Graphic Source**: An image showing the position of the electron truck after 3ns.
- **Diagram Information**: The diagram illustrates the movement of electrons in a circuit with labels for positive and negative boundaries.
- **Electrical Components**: The text references specific electrical components such as capacitors and resistors with their specifications.
- **Electrical Calculations**: The text includes calculations for electric field strength and energy stored in the line.
- **Circuit Theory**: The explanation delves into circuit theory, discussing the concepts of displacement current and its impact on circuit behavior.

**Figure 4: The position 3ns after switch closure.**
Controlling electrical appliances using PC

Here is a circuit for using the printer port of a PC for control applications using software and some interface hardware. The interface circuit along with the given software can be used with the printer port of any PC for controlling up to eight pieces of equipment. The interface circuit shown in the figure is drawn for only one device, being controlled by D0 bit at pin 2 of the 25-pin parallel port. Identical circuits for the remaining data bits D1 through D7 (available at pins 3 through 9) have to be similarly wired. The use of an optocoupler ensures complete isolation of the PC from the relay driver circuitry.

Lots of ways to control the hardware can be implemented using software. In C/C++ one can use the outputp(portno, value) function where portno is the parallel port address (usually 378 hex for LPT1) and ‘value’ is the data that is to be sent to the port. For a value=0 all the outputs (D0-D7) are off. For value=4 D0 is ON, value=2 D1 is ON, value=4, D2 is ON and son on e.g. If value=29 (decimal)=000111001(binary)> D0, D2,D3, D4 are ON and the rest are OFF.

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Figure 1: Proposed oscillator configuration.

Figure 2: Current-Mode oscillator configuration.

Current-mode oscillator

Sinusoidal Oscillators play a very important role in many areas including instrumentation, measurements, communication, control systems etc. A great deal of research work has been carried out on the OTA – based sinusoidal oscillators and as a result of these efforts a good number of oscillators have been reported. Almost all the oscillators are voltage mode and it seems that very little work has been carried out on current mode oscillators, which enjoy certain advantageous features over their Voltage-Mode counterparts.

Although these oscillators have several salient features yet they face problems like presence of condition of oscillation to be satisfied, constraints to be imposed on the values of transconductances and passive components, besides having cumbersome design procedure. Some of the oscillator circuits apart from employing excessive number of components use floating capacitors, which are not economically fabricated in IC construction. Moreover from the most of the circuits reported earlier, quadrature type oscillators cannot be obtained through use of additional components or inducing change in the circuit topology or nature of components.

This communication is concerned with the introduction of oscillator circuit that is suitable for implementation in IC form. The main feature of proposed oscillator circuit is that it is free from the preset condition of oscillation besides its frequency of oscillation is electronically tunable and its variation linear over a wide range. The use of two OTAs is essentially required to achieve linearity in the frequency of oscillation. The circuit has been made to generate high frequency sinusoids by using single pole model of Operational Amplifier, the use of which has eliminated the requirement of second capacitor that is a minimum to be employed in a second order oscillator circuit. With the introduction of two CFs the current signals are obtainable at high impedance levels and are also out of phase by 90°.

A routine analysis of the proposed circuit of Figure 1, assuming that OA is characterized by its single pole model at higher operating frequency yields the following equation:

$$f_o = \frac{1}{2\pi} \left[ \frac{g_{o_1} r_{o_1}}{g_2} \right]^{1/2} \frac{1}{C}$$  \hspace{1cm} (2)

For $g_1 = g_2 = g_0$ is given by

$$f_o = \frac{g_0}{2\pi} \frac{1}{C}$$  \hspace{1cm} (3)

Since $g_o = IB/2VT$ the frequency of oscillation is given by

$$f_o = \frac{B}{2\pi} \frac{1}{VC}$$  \hspace{1cm} (4)

As is evident from (4) that the frequency of oscillation is linearly tuneable through bias current of OTAs. The quadrature sinusoidal output signals can be obtained through use of two CFs as shown in Fig. 2. We can sense the output R in the resistor $R$, which is in quadrature with the current $I$ through capacitor $C$.

SENSITIVITY: The active and passive sensitivity of this oscillator are,

$$S_{P} = \frac{S_{PO}}{S_{PO}} = -0.5$$

which are very low.

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A simple and low cost 1000V high voltage driver

High voltage drivers play an important role for driving Piezo devices, electro-optic components, PMT and spectrometry, etc. A simple and low cost 1000V high voltage driver is shown below in Figure 1. We adopted off-line current mode control schemes and a flyback switching power supply design. The UC3844 is a major control part and the operating frequency is set at 100kHz. The UC3844 provides frequency modulation to reduce the switching frequency in the light load and no load conditions.

The feedback voltage, which is derived from the output of error amplifier, is taken as the indicator for load conditions. Once, the feedback voltage is lower than the green-mode frequency modulation to reduce the driver is shown below in Figure 1. The UC3844 is a major control part and the operating frequency is set at 100kHz. The UC3844 provides frequency modulation to reduce the switching frequency in the light load and no load conditions.

Both the primary and secondary auxiliary windings are five turns and six turns, respectively. These are also wired in series. The DC output voltage of Figure 1 is fixed at 1000V and the output current is 10mA. The input voltage is 110VAC. The DC output voltage could be set in a 50V range by adjusting VR1. The line regulation is less than 1%. The load regulation is also less than 1%. The power efficiency is better than 80% at full load.

The circuit is a basic 'flyback' power supply with the vane blocking the beam in IC1. Base current is supplied to TR2 by R4. It is well known that both high-speed transistors and high voltage transistors have low gain. TR2 is a close match to the well-known BU208 horizontal deflection transistor and is both high speed and high voltage, and its Hfe is truly high. The magnetic field in T1 begins to reduce, and in doing so produces a voltage of opposite polarity. The secondary voltage keeps rising until it is high enough to arc across the sparking-plug gap. D2,D3 and D4 clamp the primary voltage to 600V, which allows a maximum secondary voltage of 360V.

The capacitor (condenser) normally connected across TR2 is deliberately returned to the unregulated supply. This increases the coil current and the energy stored in the coil. The output voltage will increase again until the arc re-ignites. At low engine speeds the vane moves across the light source quite slowly, and IC5 is a CMOS 555 timer, used in its most simple form as a Schmitt trigger to sharpen up the edge. This is deliberately returned to the unregulated supply. This increases the coil current and the energy stored in the coil. The output voltage will increase again until the arc re-ignites. At low engine speeds the vane moves across the light source quite slowly, and IC5 is a CMOS 555 timer, used in its most simple form as a Schmitt trigger to sharpen up the edge.

There is now no current sensing as the current is limited by the series resistance and it is necessary to add an anti-saturation clamp consisting of D3 and D4 to TR2 to make sure it turns off quickly. Unfortunately, spark energy is now lower with the starter running, as maximum current is supplied by the battery voltage divided by the coil primary resistance.

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Contactless electronic ignition

Not so long ago the pages of electronics magazines were full of automotive circuits, but now there is so much electronics already under the bonnet that there is little left to add.

This circuit would be of interest to anyone interested in older cars fitted with the standard coil and contact breaker ‘Kettering’ ignition circuit. Such cars are often left in the garage for weeks on end and a circuit that makes them easier to start can be well worth having. An advantage of this circuit is that it can be used with both positive and negative earth vehicles without any changes. A little simplicity is required to construct the optical sensor. The Omron part was chosen as it has fixing holes arranged so that the slot is horizontal. A rotating vane is attached to the shaft of the distributor which intercepts the light passing through IC2 (1 cleaved and bought one Nom the Lumintron web site). IC1 is connected to the rest of the circuit using extra-flexible wire - the base plate of most distributors moves with the vacuum advance.

The circuit is a basic ‘flyback’ power supply with the vane blocking the beam in IC1. Base current is supplied to TR2 by R4. It is well known that both high-speed transistors and high voltage transistors have low gain. TR2 is a close match to the well-known BU208 horizontal deflection transistor and is both high speed and high voltage, and its Hfe is truly high. The magnetic field in T1 begins to reduce, and in doing so produces a voltage of opposite polarity. The secondary voltage keeps rising until it is high enough to arc across the sparking-plug gap. D2,D3 and D4 clamp the primary voltage to 600V, which allows a maximum secondary voltage of 360V.

The capacitor (condenser) normally connected across the primary points should not be left connected across TR2. An advantage of inductive energy storage over capacitance is that should the arc extinguish whilst there is still energy stored in the coil, the output voltage will increase again until the arc re-ignites. At low engine speeds the vane moves across the light source quite slowly, and IC5 is a CMOS 555 timer, used in its most simple form as a Schmitt trigger to sharpen up the edge. This is deliberately returned to the unregulated supply. This increases the coil current and the energy stored in the coil. The output voltage will increase again until the arc re-ignites. At low engine speeds the vane moves across the light source quite slowly, and IC5 is a CMOS 555 timer, used in its most simple form as a Schmitt trigger to sharpen up the edge. This is deliberately returned to the unregulated supply. This increases the coil current and the energy stored in the coil. The output voltage will increase again until the arc re-ignites. At low engine speeds the vane moves across the light source quite slowly, and IC5 is a CMOS 555 timer, used in its most simple form as a Schmitt trigger to sharpen up the edge. This is deliberately returned to the unregulated supply. This increases the coil current and the energy stored in the coil. The output voltage will increase again until the arc re-ignites. At low engine speeds the vane moves across the light source quite slowly, and IC5 is a CMOS 555 timer, used in its most simple form as a Schmitt trigger to sharpen up the edge.
Three phase meter

A friend has a lathe with a 3-phase motor and lives in a country area with only a 1-phase supply. Provision of a 3-phase supply was prohibitive. So he bought a device that converts a single-phase mains supply to three phases. However, it needs manual adjustment of the phase angle when under load. So he asked me to design phases. Thus a safe isolation unit is provided by opto-couplers IC1a & IC3a and then applied to the exclusive OR gates IC3a & b via IC2. The output of the exclusive OR gates is a square wave signal whose mark to space ratio is proportional to the phase difference. These signals are applied to the averaging amplifiers IC4a & b. Diodes D1 & D2 prevent a reverse current through the meters if the phase angle is less than 90°. NB: the exclusive OR gates cannot determine the sign of the phase angle, i.e. -120° will result in the same waveform as +120°. Hence IC4a & b are employed to detect the sign. When switch S3 is open, IC4c inverts the IC3a signal so that the D Types are clocked on the negative edge of this signal. Hence if the sign of the phase is correct, O2 will go Low and O3 High thus illuminating the LEDs. See Figure 5.

In order to calibrate the meters, IC2a is configured as a 3 stage Twisted Ring Counter which generates a 3 phase test waveform. Refer to Figure 4. Note that the phase difference between O2, O3 and O4 is 60° but since O2 is inverted by IC3d, the correct phase differences (120°) are obtained. See Figure 5. The power on reset is generated by IC7. This necessary because the counter would oscillate between these states rather than count in the correct sequence. When S3 is set to the Test position, IC4 switches the test waveforms to IC3a, IC & IC4c. The meters are calibrated by adjusting RV2 & RV3 to set the meters to centre scale (0.5mA which represents 120°) and both LEDs should be lit indicating that the sign of the phase is correct. If switch S3 is closed while S2 is in the Test position, IC4c inverts the phase of the clock signal to IC3a & b thus extinguishing the LEDs.

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Figure 1: Digital section

Figure 2: Analogue section

Figure 3: Count sequence

Parts List

Voltage Regulator
Capacitor 250V Mains rated
Capacitor 50 Volt ceramic
Watt, 1%
Watt, 5%
Watt, 5%
1% Watt, 1%
1% Watt, 1%
1% Watt, 1%
All other resistors are ±5 Watt, ±5%
Digitally controllable, truly state variable bi-quad filter

Controlling the frequencies of filters by using potentiometers would seem simple, however, although the output ratio of potentiometers both mechanical and digital are very accurate, the absolute track resistance is usually specified by the manufacturer as having a tolerance of ±20%, which cannot provide for repeatable results.

By dividing the potential across a resistor terminated into a virtual earth point, the conductance can be reduced thereby increasing the effective resistance. This can be used to control RC time constants independent of the end-to-end track resistance of the pot. To further isolate the physical properties of the pot, the output from the wiper is directed to a voltage follower, reducing the wiper impedance to near zero.

In circuit shown, the R's in the Bi-Quad Filter are multiplied by the division ratio of the potentiometers P'. Using the values shown, the full scale frequency is set to 256Hz such that if a 256 tap digital pot is used, each step will change the frequency by 1Hz meaning that the count sent to the pot will be the centre frequency e.g. 200 counts = 200Hz.

In order to achieve the same 'rational' control of the Q, the pot 'Q' is arranged to control the gain of the feedback loop instead of the attenuation. Using the values shown, the full scale Q is set to 2.56 such that each step in a 256 tap digital pot represents a change in Q of 0.01 e.g. 100 counts = a Q of 1.00. Qs of 25 or more can be reliably and accurately achieved by scaling the resistor values.

By arranging the feedback in this fashion there is also an added benefit; At the output of the gain stage, there is available a band pass signal whose level at the centre frequency is always exactly 0dB, independent of the value of Q.

Though the circuit was primarily designed to be digital controlled, mechanical potentiometers are just as effective giving the same linear scale.

A small word of caution: Do not use the pots around 0%, as most filters do not operate correctly at zero Hz or with zero Q! This one is no exception.

John Charlesworth
Womberton
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UK

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DC to 150MHz
Rise time
2.4ns
Input resistance
10MΩ ±1% if oscilloscope i/p is
1MΩ
Input capacitance
12pf if oscilloscope i/p is 20pf
Compensation range
10-60pf
Working voltage
600V DC or pk-pk AC

Switch position 'Ref'
Probe tip grounded via 9MΩ, scope i/p grounded

Electronics World October 2004
Class A Imaginingering

Someone needs to answer Mr. Maynard’s comments on capacitive coupling before some pot goes out to buy 22mF caps! The ‘error’ voltage shown in his simulation simply the inevitable dc shift that starts during the first half cycle of an applied signal. This phenomenon occurs everywhere capacitive coupling is used regardless of the technology used in the electronics, indeed valve cathode decoupling caps are prime offenders in this regard.

In his haste to rubbish capacitive coupling in output stages he has forgotten that the technology used in the electronic systems is high mechanical 2nd order and above filters. The gain of high pass filters to dc is zero, therefore these ‘errors’ cannot produce an audible output! Capacitive output coupling does deliver the goods down the chain, in the low frequency signal component.

What’s not so easy to defend is transformer coupling. The only way to produce a useful voltage that is related to the primary voltage is to feed from a zero impedance source. This is never done although it could be with some output stage redesign. Ironically it is easier to produce good transformer coupling with an amplifier than with valves, when using output transformers.

By email to Electronics World - Highbury Business, Media House, Azaled Drive, Swansley, Kent, BR8 8HU

Graham Maynard replies: Thank Mr. Macaulay for his letter and agree with him that a potential shift develop during the first half cycle of a waveform is a significant factor. However, most valve engineers are aware of the capacitive filtering effects this produces. Mr. Bailey suggests that my errors are ‘poor sods’ whose amplifiers are split in their case, or bulging at the sides. I wonder if any other reader has experienced this sort of problems I have had with alkaline batteries, checking the ‘rarely used or backup battery’ have had with the use of electrolytic capacitors and the like, I would recommend checking the ‘rarely used or backup battery’ equipment soonest! The circuit will now be ready to set for the testing conditions themselves. There is an error in my article about noise and moving-magnet cartridges. The circuit will now be ready to set for the testing conditions themselves.

Erratum

There is an error in my article about noise and moving-magnet cartridges in Electronics World October 2003. In figure 5, the lower half of the double pole switch is drawn in the wrong position.

In the 40Mb, the 2452Q resistor should be connected to the 33µF bipolar electrolytic. The circuit will now be ready to set for the testing conditions themselves. There is an error in my article about noise and moving-magnet cartridges. The circuit will now be ready to set for the testing conditions themselves.

Errata – Hybrid amp

It has been found that the EC02 can be used instead of the EC100D in the circuit so you can use whatever device can be easily obtained for V1. Note however that the ‘82 heater biasing is different, consult a tube manual for details. The 23220Q should be connected to the 22kΩ resistor, instead of the 33µF, and the 33220Q should be connected to the 22kΩ resistor.

Marcel van de Gevel

Alkaline battery failures 2004

I wonder if any other reader has experienced the sort of problems I have had with alkaline batteries in the last few months. It is a common problem that batteries do not last as long as expected due to the inadequate charging of the battery packs. Due to my own experience, I would recommend checking the ‘rarely used or backup battery’ equipment soonest.

In the 33µF mode, the 2452Q resistor should be disconnected from the 33µF, and 22kΩ should be connected to the 22kΩ resistor.

Graham Maynard

Graham Maynard replies: I sincerely thank Mr. Bailey for his letter and this opportunity for me to cover his comments. I really found reading Mr. Bailey’s pages back in the 96/97’s, they were instrumental in framing my Hi-Fi knowledge.

Mr. Bailey raises several points, however he omits the 4µF capacitor and then goes on to approximate my illustrated tweeter crossover section as if no more than two inductors in series as a potential divider. However it is the capacitor that has the greatest series impedance, and this component shown in my Figure 1. This is an inductive potential divider with a ratio of 2000:1. If the series resistor has a capacitor across it, but at 20kHz, the resistance of 4µF is about 0.9µF and the series resistor is small enough to account for the deviation.

What is now termed as ‘sub-bass’ interaction. So all the output inductors do is to give a reduced tweeter sensitivity over an active range of some 0.1 to 8kHz. This is hardly a distortion and being so small it would not be expected to be audible. Heating up the resistor against a source of audio input tapering, but these methods present more problems than the results are worth. The worst case is when a larger volume component is such a simple remedy.

Mr. Bailey refers to ‘poor sods’ whose amplifiers are split in their case, or bulging at the sides. I wonder if any other reader has experienced this sort of problems I have had with alkaline batteries, checking the ‘rarely used or backup battery’ equipment soonest!

So basically series output chokes are trying to prove that a small series inductor in series with the output of an audio amplifier can have serious effects on the output fidelity.

Firstly, referring to the “error” signal, he quotes in Figure 8. Here he is comparing the drive signals to the first node of the tweeter crossover network with and without a 4µF inductor that has a parallel 8R2 resistor. There, sure will be a difference -it would be expected. At frequencies above the crossover frequency then we can largely ignore the 4µF capacitor and we are then left with the circuit shown in my Figure 1. This is an inductive potential divider with a ratio of 2000:1. If the series resistor has a capacitor across it, but at 20kHz, the resistance of 4µF is about 0.9µF and the series resistor is small enough to account for the deviation.

What is now termed as ‘sub-bass’ distortion NFB loop controlled interaction. Graham Maynard replies:

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In the 33µF mode, the 2452Q resistor should be disconnected from the 33µF, and 22kΩ should be connected to the 22kΩ resistor.
CD-R failure

In response to Simon Wright who in EW July 2004 wrote a letter about CD-R failure, I am a short article on the following internet address that may be of interest:

http://www.imagex.de/mark/art/doc/ permanent/CD-RDocument

This is an article on the permanence of CD-R media in English by Jacob Tock. Another short article can be found at:

http://www.medialinenews.com/iss/ 2005/06/02/article14.1.shtml by the same author. The articles conclude with the same finding as that of Simon Wright.

CD-R is a permanent CD-R's permanence under the Royal Danish Academy of Fine Arts, School of Conservation and the Conservation Office. The article contains several photographs demonstrating in his many articles.

In the May Article Iann Hickman says that he was aware of the correctness of the argument pointed out by me in the past, which is well demonstrated in his many articles.

In just ice to Newton

I have just published in the Scientific American, August 2003 pp6-55 Entitled "In the Holographic Universe". The term 'holographic universe' was coined by the Reith Lectures of 2003, although stating that he didn’t want to go that far.

Support for some of these conclusions emerge from the work of EFL, which may also come from the Apollo Project, due to come on stream this year, utilising mirrors left on the moon by the Apollo and Polaris, towns in Italy, mathematical theory? Or maybe it twice the size of those on the facing page. I showed in his article far! and so the fundamental equation look like a five-year-old has drawn (resulting from the integration) gives

\[
F = m(dv/dt) + v(dm/dt).
\]

By email

Mystery of magnetic lines of force

Will James asked for any enlightenment on the question of the existence of magnetic lines (Letters, August 304) which is what Jacob Beckenham did when he wrote about his article in Scientific American, August 2003 pp6-55 Entitled "In the Holographic Universe". Surveying the article, under "Augurs of a Revolution", he states that: "although the holographic way of thinking is not fully understood, it seems to be here to stay. And with it comes a realisation that the fundamental belief, prevalent for 50 years, that field theory is the ultimate language of physics must give way." The fundamental theory, "is a final theory, must be concerned not with fields, not even with space-time, but rather with the way the language of space-time changes among physical processes."

Consciousness and language will be part of final theory and in this respect "a global network of sensors" is being built to police the Nuclear Test Ban Treaty (which will also provide us with useful data about: tectonic, seismic, resonance anam backwards, animals down the spine (or up, Kundalini?!) and haunted houses inter alia - e.g. the communication, the language the article Beckenhein did (ibid, pp57-63) is perhaps a target for what’s to come.

In the article, entitled Questioning the Dolphin Oracle, the authors explain that Apollo’s priestess sat over a mantle, from which ethylene issued, to induce a higher state of consciousness which enhanced her ability to prophesy the future. Her name, Puthia (Pythia in English) is inappropriate for a sweet smelling gas. So is Apollo, it is not derived from 'pollux' (molly), according to Cartwright, who used the technique, empathise mistakes made by early scholars in assigning provenance, including the notion that particular interest in people’s names (vide: ‘Cratylus’) following Socrates, we understand that "true" tales of whose sounds capture the entity’s name are created by ancient ‘legislators’ who had specific insights. The root ‘apo’ means ‘turn around’ or ‘break’ which suggests a special perception, one that I can tell the difference between, but I would suspect that everyone is countable as just one to her? The “natural”, or non-humans were not. In mathematics in human terms, I would state the basic mathematical postulate as: computer. Printers were 9-pin dot- in time trajectory, as we look further up due to it being for a couple of local ‘a global network of mathematicians...

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The Kölnarena, Germany's largest ultra modern, multifunctional events forum has installed a set of the art digital announcement system manufactured by Laauser & Vohl, the designers and manufacturers of digital voice announcements solutions. Specified and installed by Lauzer & Van, the TRONCER system is used as a public address system providing visitors with information and guidance. The TRONCER can be installed in a variety of environments and has been designed to provide high quality audio messages and control visual information displays. Audio is saved as WAV at any available sampling rate including full CD quality. The product's headquarters are in Canada with subsidiary locations in the USA and U.K.

Changes to hazardous waste

A new guide published by Environwe helps management teams to deal with new EU hazardous waste rules which came into force in July 2004. The publication, Hazardous Waste Management - essential information for business (GG469), alerts senior managers to the opportunities and risks posed by the Landfill Directive and the forthcoming implementation of the European Hazardous Waste List. To order a copy visit www.envirowise.gov.uk/hazardwaste

Component Kits

A range of component kits is available from new supplier Fast Components. "Our customers are becoming more difficult to find, and suppliers are imposing 'small order' or high shipping charges," says Fast Components' Managing Director Thomas Arundel. "As former product designers we were frustrated with time and effort it took to build a decent stock of bench-top components. Once we started investigating a supply chain, we realised that we could sell its commonly required components at a third of the price they would cost separately." Fast Components has opened its range with kits containing, 1000 ±1% metal film resistors, spread over 93 values, 240 50V ceramic capacitors spread over 24 values, 90 radial electrolytic capacitors spread over 12 values, and 100 miniature polyester capacitors spread over 9 values. The resistor kit retail at £9.99, and the capacitor kit at £4.99. Customers can order direct from www.fastcomponents.co.uk, where they can pay securely with credit cards, PayPal or Cheque Postal Order. Full Adobe PDF datasheets of all kits are available on the website.

“We’ve started with a useful collection of kits to get hobbyists (especially newcomers) started" says Thomas. "We’re planning to follow up with more passives, surface mount kits, mechanical hardware kits and semiconductors through the autumn." Postage & packaging is at cost with no minimum order charge. Fast Components Ltd www.fastcomponents.co.uk

Gear-tooth sensor

A Hall-effect gear-tooth sensor module ideal for obtaining speed and direction-cycle information in automotive applications such as transmission speed sensing has been introduced by Allegro Microsystems Europe. The new device, AT8643LH, combines a Hall-effect sensor IC and magnet in an optimised configuration to provide a user-friendly solution for true zero-speed digital gear-tooth sensing in two applications. The integrated circuit incorporates a dual Hall-effect sensor and signal-processing circuitry that switches in response to differential magnetic signals created by ferrous toothed gears. The device contains a sophisticated compensating circuit to eliminate magnet and system offset. The regulated current output is configured for two-wire operation, and the unit maintains a precise duty cycle over a wide temperature range. Power consumption is less than 2 ms. The package (8 mm diameter x 5.5 mm long) can be easily assembled and used in conjunction with a variety of gear shapes and sizes, and is immune to the effects of vibration and operating temperature range is -40°C to +150°C, with a supply voltage range from 4 to 30V, and undervoltage lockout. Allegro Microsystems Europe Ltd www.allegromicro.com

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