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An electronic universe

Designing for EMC

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Quality second-user test & measurement equipment

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Marcow 2955A £1250
Marcow 2955A £1250
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Rohde & Schwarz CMT 55 (2GHz) £7995
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Schlumberger Stablock 400 £1300
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- OPTOCOUPLER, order small pack, 5 or 10. Order Ref: 309.
- POT POTentiometer, order large size with DP switch, good for all use. Order Ref: 1184.
- COMPONENT MOUNTING PANEL, heavy gauge, has 0.6mm thick copper binding. Order Ref: 793C.
- SMALL REED RELAY, 12vdc, Measures 50 x 25 mm, fitted, heavy thread, fully encapsulated. Order Ref: 1022.
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**Editorial**

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**Changing times**

Welcome to the August issue of Electronic World and let me introduce myself as your new editor. My name is Phil Reed and I'll tell you a bit about myself later on in this letter. But firstly, I'd like to thank Martin Eccles for many years of superb editorial support of this respected journal and I can only hope that I come up to the high standards he has already set.

So, who on earth is Phil Reed? Well, I am an engineer by trade, having worked in the broadcast industry for the last 32 years. Whilst I have rarely had to pay the mortgage by designing electronics— I do understand most of what goes on in these pages—and have certainly had to fix some of the circuitry designed by some EW readers! It was only a couple of weeks ago that my soldering prowess was earning me a crust (a burnt thumb). My career has taken me all around the corners of the broadcast world from acquisition to post production and even touching upon delivery technologies, shorting out of control, working on a spreadsheet was never new to scrapping for a living, either.

I have written regular columns in the broadcast trade press and my journalism career has been on the new horizon since I was editing the legendary 'International Broadcast Engineer' magazine. But I have decided that I needed to get back to my roots and have done some proper engineering. In my spare time I'm engineering for a London based post production company, and I'm looking forward to doing some complex tasks, and doing some looking and watching some of the technical problems with a popular reality TV series, based in Elstree film studios. I used to be an avid reader of EW's predecessor, Wireless World, for many years and it has been an eye-opener to me to see how the design industry has moved on in the intervening 20 years or so! I am quite thrilled to be involved in this side of the business and look forward to being able to serve the readership with some ideas of my own. As with all things technical, the industry is changing rapidly— only a few years ago the things that you can do with a PC would have seemed impossible. The same thing goes for DSP chips whose power to do ridiculously clever things in a cheap mass produced package is legendary and I hope to reflect some of these profound changes in these pages in the future.

As you can imagine, there are lots of boxes of article and circuit ideas that I've inherited—and it's going to take some while to go through them all, so if you were expecting a reply about any submissions you've made—it might be a good idea to send me an email to remind me. But do keep the circuit ideas and article submissions rolling in.

I will start the process of making some subtle changes to EW, nothing major you understand, just some small adjustments now and then feedback from you, which came from our 2002 reader survey. It appears that most of you (70%) are electronics professionals, 31% of you spend over £200 on components each month and 71% of you have a PC with internet access. So, armed with all this info, I’ll be tweaking the communal to suit. Say enough to say, that any comments are always welcome (even negative ones) and the best ones will be published. Editorial comments should be sent to me directly at p.reed@highburybiz.com.
Half a million on broadband

Over half a million broadband connections have been set up in the UK, claims telecoms watchdog OfTEL. "With over 200,000 broadband connections a week, the current level of growth makes the equivalent demand for mobile phones and dial-up Internet when they were first introduced," said David Edmonds, OfTEL's director general of telecoms. The figures include all four main access technologies, cable modems, DSL, technology, broadband fixed wireless and broadband satellite services.

The lure of broadband access will continue, Edmonds said. "Over 10 million homes use the traditional dial-up Internet access, including four million with unretired packages.

"I am confident that more Internet users will take up high speed broadband as the range of services increases and prices fall."

Douglas Alexander, the Government's e-commerce minister, said: "The milestone of half a million connections represents a 54 per cent increase since the beginning of 2002. Of course there is more to do, but the work of building Broadband Britain is under way."

Carbon in missing link

The continued research into carbon nanotubes continues with IBM of the US and Infiniton Technologies of Germany pushing the integration of nanotubes with silicon. IBM has taken a major step towards transistors and ICs made from carbon nanotubes by proving that devices can outperform silicon transistors. Researchers at the firm created prototype nanotube transistors with twice the transconductance of the best prototype silicon devices, IBM said.

"Proving that carbon nanotube transistors can outperform silicon transistors opens the door for more research related to the commercial viability of nanotubes," said Dr Phd Rosendal, manager of nanotube research at IBM Research.

Avouris' team used single walled nanotubes (SWNTs) in a conventional Mosfet-like structure, with the nanotube forming the channel between the source and drain. However, the gate dielectric was thicker than a Mosfet, at 10 to 15nm, even at gate voltages of 1V. Transconductance of 2300uA/mV is more than double that of a 15nm length Mosfet with a 14nm gate oxide.

IBM was also able to make both p- and n-type nanotube Mosfet. Meanwhile Infiniton has managed the controlled placement of nanotubes on standard 150mm silicon wafers. The firm sees nanotubes replacing both the Pd and the interconnect in integrated circuits. Nanotubes allow current densities up to

The first US airborne laser missile defence aircraft, a modified Boeing 747-400 freighter, is being prepared for flight testing later this summer. Flight testing will be followed by a trip to Edwards Air Force Base in California where the laser and optics will be fitted.

A flash gun with more than 100mW/cm2 of light power is enough to ignite SWNTs, which reach temperatures of at least 1,500°C, said the team. The light leads to a photoacoustic effect caused by the expansion and contraction of trapped gases. The high thermal conductivity of nanotubes helps propagate heat through a bundle.
Green power gets go-ahead

The Department of Trade and Industry has rubber stamped plans for the country’s largest wind farm at Cefn Croes, near Aberystwyth. With 39 turbines, the £23m project will be one of the largest of its type in Europe, said the Renewable Development Company, which is backing the project.

The scheme is part of the Government’s plan to supply ten per cent of the UK’s energy needs through renewable sources by 2010.

Zetex moves to p-channel

Analogic chip specialist Zetex has developed a p-channel Mosfield using its trench semiconductor process.

Zetex licensed techniques from an unnamed company that allow the Fets to be made without any critical alignment steps.

"P-channel Mosfets are tricky to make," said company product development manager Peter Blair.

Swapping materials in a existing n-channel design is not the answer, "there are additional challenges", he said.

The photo shows the device mid-process, with two and a bit recessed polysilicon gates in trenches. Oxide will back-fill the trenches to make a

p-lower surface for metallisation after sources are implanted in the mesa sides.

The oxide layer on the mesa tops is sacrificial and will be removed before metal deposition.

The first devices made using the p-channel Fets will be 40V, 70mΩ SOT223 for digital audio.

Dual bit memory is very flash

A new flash memory cell that stores two bits per cell without using multi-level techniques has been announced.

AMD calls the technology MirrorBit and partner Fujitsu calls it MirrorFlash.

There are two main differences between MirrorBit and normal flash: the transistor is symmetrical in MirrorBit and the floating gate in which data is stored is insulating silicon nitride, not the usual conductive polysilicon.

The new floating gate is the critical element as, being insulating, is can store regions of different charge.

In a normal floating gate injected electrons swim about as they wish. In an insulating gate electrons "are injected into traps in the nitride," said Joe Raushmayer, v-p of engineering at AMD.

Trapping allows electrons that make up one bit of data to be stored at one end of the gate while the second bit resides at the other end. Being symmetrical, the underlying transistor allows both ends of the floating gate to be treated equally.

Reading and writing the bits involves manipulating the two transistor electrodes appropriately.

Government pushes RF tags

Major UK firms have signed up to a Home Office initiative to add radio frequency identification (RFID) tags to consumer goods.

Woolworths, Dell, EM1 and Asda are part of the scheme, which aims to stamp out the trade in stolen and counterfeit goods. Items tagged will include CDs, laptop PC's and clothing.

Goods will be fitted with a unique tag that stores information such as their origin, current location and final retail destination. "As criminals are using increasingly sophisticated methods so we must harness the latest technology available to us if we are to catch them," said Crime Reduction Minister John Denham.

The Government is putting £50m into its Chipping of Goods initiative. It has already tested the system on mobile phones, watches, alcohol and boats.
Sensor is all hot air

US firm Memsic has developed a two-axis accelerometer that uses a bubble of hot gas as the proof mass. The Massachusetts-based firm is selling its hot gas accelerometers in 5x5x2mm surface mount packages. Using a bubble of gas brings two immediate benefits - high shock resistance and low noise.

"There are no moving parts except air. It will survive 50,000g," claimed Mike Higgins, marketing and sales manager at Memsic, where g is acceleration due to gravity (9.8 ms^-2), not grams.

This seems like overkill for any imaginable application, but Higgins sees it as a safety margin above normal production processes. "Snapping a circuit board out can produce 3,000g," he said.

Noise is particularly low, and was recently halved by changing the working gas. "We can resolve very small g-forces: better than 1mg," said Higgins. Over frequency he claims 0.2mg\(\sqrt{Hz}\) on some variants. Accuracy in the devices, which range from 1 to 10g full-scale with options to 100g, is 0.2 per cent typical, 0.4 per cent max. Due to the tiny amount of air involved, response time is small, 40ms and 120ms worst case claims Higgins. So what are the disadvantages of thermal accelerometers?

"Dependence on temperature. The sensitivity changes and this has to be compensated externally," said Higgins. Although he points out that the compensation curve does not vary between devices as it derives from the gas law.

A datasheet and application note including compensation circuits is available from the company website. Power consumption small - 3.6mA at 3V - can be cut by pulsing, but may be too delicate to use in some battery powered applications. As noise is so low, well under 1\(\sqrt{Hz}\) if it can be measured, the accelerometers could be used to control circuits in portable devices where tilting the device moves the sensor or view. Car alarms, rollover detectors and navigation are all being considered as well. www.memsic.com

How it works

In principle, the hot air accelerometer is simple. Hot air is less dense than cold air. If they co-exist in a sealed environment and the environment is accelerated the hot air gets displaced in the direction of acceleration.

A similar effect can be seen if a toy helium balloon is let loose in a car. Accelerate the car and the balloon moves towards the windscreen. Brake and it moves towards the boot. Memsic devises work in two-dimensions. The gas is held in a domed void with a flat silicon bottom within the chip packaging. In the centre of the silicon is a heater. This maintains the hot air "bubble" as Memsic's Higgins describes it. "Silicon" thermopile "sensor under the bubble detect the way it moves," he said.

The chip, which includes conditioning circuitry and is made by TSMC, is standard CMOS except that the heater trench is added post-foundry by Memsic in its own Chinese plant.

Jelly foils fingerprint checks

A Japanese mathematician has broken the security on 11 fingerprint sensors by copying fingerprint patterns using cheap kitchen ingredients such as gelatine.

Tsutomu Matsumoto, from the graduate school of environment and information sciences at Yokohama National University, can fool fingerprint detectors 80 per cent of the time with his jelly-mould fingers.

His technique is to take an impression of a finger in a plastic mould, easily available in hobby shops, and then pour in liquid gelatine, which sets to form the fake finger. From start to finish the whole process takes less than one hour.

Fingerprint sensors can usually detect when a silicone prosthetic is used, but Matsumoto's use of gelatine deceives the technology. He can also fool sensors that claim to detect only "live" fingers, by moistening the gelatine before pressing onto the sensor.

In a presentation to the International Telecommunications Union's workshop on security, Matsumoto said: "The experimental study on the dummy fingers will have considerable impact on security assessment of fingerprint systems."

More significantly, Matsumoto is able to copy prints made on surfaces such as glass. The process involves fixing and enhancing the print with cyano-acrylate (super-glue) forms and photographing it, exactly as forensic scientists would do. The image is then enhanced in a software package such as Photoshop and then copied onto a blank copper PCB. The print is then etched and pressed into a mould ready for the gelatine.

Whether copying fingers direct, or reproducing them from prints on glass, Matsumoto was able to break 11 commercially available sensing systems. These included optical and capacitive systems.

In his conclusions, Matsumoto pointed out that manufacturers and users of biometric systems should carefully check their security against artificial clones.

Scots go for power dressing

Practical power generating fabrics are possible, is the conclusion of a research project at Heriot-Watt University in Edinburgh, although the team has not actually made any yet.

"We can see several ways to put silicon photo-voltaics directly onto fabrics without a glass substrate," said Professor John Wilson of the university.

What the team has done is to make photo-sensitive cloth and prove that photo-coated cloth can be stable, flexible and reasonably durable.

Polymer and similar organic photo-sensor developers may in future be ideal for photo-cloth, but were rejected from the project as they are too immature. Instead thin-film silicon was chosen and has been coated onto both woven and non-woven (felt-like) materials.

To make a cloth photo-sensor, silicon layers and electrodes are plasma-coated onto the fabric over a sealing layer.

The result is a cell which follows the contours of the fabric strands and is flexible. "The cell is unlikely to be the problem," said Wilson. "Reliable connections between cells are more difficult."

Photo-clothing is far into the future. Wilson sees photo-voltaic lorry tarps and smudge as initial applications. "A roll-up canvas photo cell would be much easier to transport over rough roads than a glass one. Finding a large-scale roll-to-roll plasma coating processes should not be a problem for production, as these are currently under development for a number of markets and, said Wilson, some carpets are currently being coated using a related high-tech process. Heriot-Watt is seeking partners and funding for the next project phase.
New life for old filaments

Good old tungsten-filament bulbs, currently left behind in the efficiency stakes, could catch up through a development at Sandia National Laboratories in New Mexico.

The lab has combined a traditional filament with a recently invented structure called a photonic crystal lattice. These lattices consist of loosely spaced regular two-dimensional arrays of rods or bulbs. By tuning the spacing, object size and lattice type, the optical properties of the resulting structure can be varied. Lenses, prisms and filters can in principle be made.

The problem with conventional filaments is that most energy is emitted at infra-red wavelengths, so most energy fed into a light bulb is wasted as heat. Sandia researchers reasoned that a photonic filament designed to block the passage of infra-red radiation might somehow emit more light than heat, and experiments suggest this is the case.

"This would raise the efficiency of an incandescent electric bulb from five per cent to greater than 60 per cent," said Sandia.

Hard drive hits 300Gbit/in [super2]

Fujitsu is claiming to be able to achieve a record hard disc drive density of 300Gbit/in² after developing a new read head and a new magnetic material.

"The new technologies are expected to lead to the commercial introduction within two to four years of 2.5 inch hard disc drives with capacities up to six times the recording density available today," said the company.

Current-perpendicular-to-plane mode is used in the new giant magnetoresistive (GMR) heads. These are credited with three times the playback output levels of existing hard drive heads which operate in current-in-plane mode as are considered to have a limit of approximately 1/3Gbit/in² said Fujitsu.

Fujitsu engineers have developed a synthetic ferromagnetic media that can handle one million flux changes per inch to surface its proposed discs. Within five years, Fujitsu claims it is likely to be making 360Gb hard drives.

Enhanced "PICAL" ISP PIC Programmer

Kit will program virtually ALL 8 to 40 pin serial and parallel programmed PIC microcontrollers, connects to PIC parallel port. Supplied with fully functional pre-registered PICAL DCS and WINDOWS AVR Software packages, all components and high quality DSPB board. Also programs certain ATMEG, AVR, SCENIX DX and EEPROM 24C devices. New devices can be added to the software as they are released. Blank chip auto detect feature for super-fast bulk programming. Hardware now supports ISP programming, 16 40 pin ZIF socket is included to program 0.3 devices (Order Code AZIF04 $15.00).

Order Ref: Developmental Code, Description, Price:

AZ24114 Enhanced ISP PIC Programmer $74.45
AZ24114CSF Enhanced ISP PIC Programmer (Kit of parts) $88.50

ATMEL 89xxx Programmer

Powerful programmer for ATMEL 8051 microcontrollers. Fully AT and lock bits are programmable. Connects to PC parallel port. Can be used with ANY computer and operating system. A great range of specialized programs are available.

Programs 89C1051, 89C2051, 89C4051, 89C51, 89C651, 89C52, 89LV52, 89S52, 89LV52, 89S552, 89S552, 89S8252, 89S8553 & 89S8553 devices. NO device limitation - uses any terminal emulator program (built into Windows).

Order Ref: Developmental Code, Description, Price:

AT54107 Assembled Board $58.45
AT54108 Assembled Board (with PIC) $66.50

ATmol 89C051 and AVR programmers also available.

PC Data Acquisition & Control Unit

Use a PC parallel port as a real time data interface. Unit can be connected to a mixture of analogue and digital inputs from pressure, temperature, movement, sound, light intensity, weight sensors, etc. (not supplied) to sensing switch and relay inputs. It can then process the input data and use the information to control up to 11 physical devices such as motors, servos, other relays, servo motors & two-stopper motors.

FEATURES:

16 Digital Outputs: Open collector, 500mA, 33V max
16 Digital Inputs: 20V max, Protection 1K in series, 0V to 1V on board
11 Analogue Inputs: 0-5V, 10 bits (1mV/step)
11 Analogue Outputs: 0-5V, 0-10V, 0-20mA, 40mA (Max/Supply)

All components provided including a plastic case (140mm x 110mm x 25mm) with three punched and silk screened front panels to give a professional and attractive finish (see photos) with a panel potentiometer and rear panels supplied. Software utilities & programming examples supplied.

Order Ref: Developmental Code, Description, Price:

AT53947 PC Data Acquisition & Control Unit $214.55
AT53993 Assembled Board $214.55

ABC Mini "Hotchip" Board

Currently learning about microcontrollers? Need to do something more than flash a LED or sound buzzer? The ABC Mini 'Hotchip' Board is based on ATMEL's AVR 8051 RISC technology and will interest both the beginner and expert alike. Beginners will find that they can assemble and test a simple program using the BASIC programming language within an hour or two of connecting it up. Experts will like the power and flexibility of the ATMel microcontroller, as well as the case with which the little Hot chip board can be "designed-in" to a project. The ABC Mini Board 'Starters Pack' includes just about everything you'll need to get up and experimenting right away. On the hardware side, there's a pre-assembled microcontroller board built with both parallel and serial cables for connection to your PC. Windows software included on CD-ROM features an Assembler, BASIC compiler and in-system programming. The pre-assembled boards only are also available separately.

Order Ref: Developmental Code, Description, Price:

ABC-MINIABC Mini "Hotchip" Starter Pack $69.95
ABC-MINT89LV52, 89LV55, 89S825, AVR89S8252, 89S8553, 89S8553 Device Programmer $89.05

Serial Port Isolated I/O Controller

Kit provides eight relay outputs capable of switching 5 amps max and four optically isolated inputs. Can be used in a variety of control and sensing applications including load switching, external switch input sensing, contact closure and external voltage sensing. Programmed via a computer serial port, it is compatible with ANY computer & operating system. After programming, PC can be disconnected. Serial cable can be up to 25m long, allowing remote control. User can easily write batch file programs to control the kit using simple text commands. NO special software required - uses any terminal emulator program (built into Windows). Screw terminal block connections. All components provided including a plastic case with pre-punched and silk screened front panels to give a professional and attractive finish (see photo).

Order Ref: Developmental Code, Description, Price:

AT73120 Serial Port Isolated I/O Controller $169.95
AT73120ASsembled Board $169.95

Credit Card Sales: 01279 467199

See web site for full details and demos

Advanced 32-bit Schematic Capture and Simulation Visual Design Studio

This is a Windows based Circuit Design and Electronic Control System. It contains the following features:

1. Capture 2D and 3D Schematic design, display, printer and simulation.
2. C# source code development, simulation, debugging and breakpoints.
6. IrDA, UART, USB, SPI, Serial, Parallel, DIP, JTAG, ISP.
7. 8051, 8086, 8085, ARM, Freescale, PIC16/18, PIC24, dsPIC30, dsPIC33, ATTiny.
8. Interactive, interactive and animation friendly.
9. Simulation and animation of digital, analogue, picture, sound, animation files, etc.
10. Import and Export of schematic, libraries and projects.

Full details of these items and over 200 other projects can be found at www.QuasarElectronics.com
Calibrating LF antennae using DCF39

There's no need to spend money on expensive instrumentation for calibrating your LF antennas, as Paolo Antoniazzi and Marco Arcco show. It's easy to calibrate LF loops aerials using the high power DCF39 signals at 138.83kHz.

Our first attempt at making an LF loop antenna was disastrous. After months of study, measurements and discussion though, we are now true supporters of the loop antenna for receiving LF signals.

A simple loop with 38 turns at about 80cm diameter is a good compromise for a vertical rod and a 2m diameter loop will result in a superb antenna - the equivalent of 20 to 50m height at 136kHz.

An important question is how to make reliable measurements of the performance of loop antennas and other similar configurations. Here we propose a solution to the problem using the high-powered DCF39 station in Germany in conjunction with a small and simple reference loop.

Bear in mind that a loop antenna that performs wonderfully when receiving signals will not necessarily achieve the wonderful performance when transmitting.

Loop antennas for 136kHz

A loop antenna comprises a large coil wound on a suitable isolated support with an appropriate base. The main advantages of the loop used as an LF receiving antenna are:

- directivity and narrow beam if tuned
- less sensitivity to local electric noises
- smaller dimensions relative to an equivalent vertical rod
- easy to build.

The antenna works by taking energy from the incoming wave, due to the phase differences between the voltages induced in the two vertical opposite sides. When the plane of the loop is perpendicular to the direction of the propagation wave, no voltage results at the aerial terminals. In contrast, when the loop antenna's plane is parallel to the incoming wave, the voltage across the antenna reaches the maximum value.

The directivity of a loop is about 90° in the front and at the back (~3dB perpendicular to the antenna plane) This is certainly an advantage in comparison to a vertical rod because it prevents unwanted signals coming from different paths, Fig.1.

The following relation describes the voltage across a loop receiving aerial submitted to an electric field:

\[ V = \frac{2\pi h \alpha}{\lambda} r \frac{E \lambda^2 \cos \theta}{\sqrt{2}} \]

where:

- \( V \) = voltage at the ends of the loop (mV)
- \( E \) = electric field (mV/m)
- \( h \) = number of turns of the loop
- \( \alpha \) = average turn area (m²)
- \( \lambda \) = wavelength (m)
- \( \theta \) = angle between loop plane and the arriving wave: if the angle is 0°, \( \cos \theta = 1 \) and this term disappears
- \( a \) = antenna equivalent height (m)

This equation is applicable to any loop shape provided that the antenna's dimensions are small compared with the wavelength, i.e. less than approximately 0.1λ. In the low-frequency range, it is very easy to satisfy this requirement.

You can tune the loop by placing a variable capacitor across the antenna terminals. This causes a larger voltage to appear at the balanced preamplifier inputs because of the Q of the parallel-resonant circuit.

We prefer to achieve the insensitiveness to local electric noises, generally man made, by fully balancing the whole antenna circuit: the loop, the capacitance (a fixed capacitor plus varicap diodes for the fine tuning) and the preamplifier.

To match the high impedance of the resonant circuit with the LF receiver’s low impedances, we use an instrumentation amplifier comprising three op-amps. It provides high input impedance, high gain and bandwidth and a relatively low output impedance.

Considering the electrical characteristics of our 38-turn loop, in which \( L = 1.7mH \) and \( Q = 210 \) (Table 1), the parallel resistance of the resonating circuit, \( R_p \), is 2mΩ. At 136kHz this is 0.08Ω. Being in parallel with the 2mΩ input resistance of the operational amplifier, this resistance becomes 2.6Ω.

Such a low resistance deteriorates the merit factor of the antenna circuit from 210 to 182. In other words, the load constituted by the input of the operational amplifier produces an insertion loss of 1.25dB.

This loss figure indicated that it was not possible to increase the loop antenna’s equivalent height as much as we would have liked. Equivalent height is limited by the impedance that can be connected at the input of the operational amplifier. Increasing this impedance also increases noise.

At this point, it is useful to consider the equation for calculating the thermal noise at the preamplifier input:

\[ n_s = \sqrt{4k\ln(8)R} \]

considering a bandwidth of 20Hz and a room ambient temperature of 25°C. Here:

- \( n_s \) = noise voltage (V)
- \( K \) = Boltzmann’s constant, which is 1.374×10⁻²³J/K
- \( T \) = absolute temperature in kelvin
- \( R \) = resistance across which thermal agitation is produced (Ω)
- \( B \) = bandwidth (Hz)

Table 1. Tuned loops comparison at 136kHz.

<table>
<thead>
<tr>
<th>Loop</th>
<th>Turns (N)</th>
<th>Dia (m)</th>
<th>A (m²)</th>
<th>Total Wire Length (m)</th>
<th>N x A</th>
<th>Q (unloaded)</th>
<th>Induct. (μH)</th>
<th>Tuning Cap. (pF)</th>
<th>Equiv. height (m)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop 18MD08</td>
<td>18</td>
<td>0.31</td>
<td>0.0754</td>
<td>17.5</td>
<td>1.36</td>
<td>200</td>
<td>148</td>
<td>8200</td>
<td>0.774</td>
<td>Plastic covered 1.8 mm diameter wires MoPent support</td>
</tr>
<tr>
<td>Loop 38MD47</td>
<td>18</td>
<td>0.40</td>
<td>0.0754</td>
<td>23.5</td>
<td>1.36</td>
<td>200</td>
<td>148</td>
<td>7300</td>
<td>0.774</td>
<td>Plastic covered 1.8 mm diameter wires Wood support</td>
</tr>
<tr>
<td>G3LNP (**)</td>
<td>54</td>
<td>0.90</td>
<td>0.640</td>
<td>153</td>
<td>34.6</td>
<td>70</td>
<td>4320</td>
<td>318</td>
<td>6.90</td>
<td>Lizt Wires Wood support</td>
</tr>
<tr>
<td>Loop 18BM2 (**)</td>
<td>54</td>
<td>1.60</td>
<td>2.00</td>
<td>91</td>
<td>36</td>
<td>200</td>
<td>1032</td>
<td>1327</td>
<td>20.5</td>
<td>Plastic covered 1.8 mm diameter wires Wood support</td>
</tr>
<tr>
<td>Loop 24AM (**)</td>
<td>44</td>
<td>2.26</td>
<td>4.00</td>
<td>171</td>
<td>98</td>
<td>200</td>
<td>2631</td>
<td>520</td>
<td>54.7</td>
<td>Plastic covered 1.8 mm diameter wires Wood support</td>
</tr>
</tbody>
</table>

(*) Tony Preedy, G3LNP (Ref. 16)  
(**) Calculated only
Another limit on how much antenna equivalent height can be obtained is the stray capacitance of the loop. To try to define a limit for the antenna equivalent height, we measured the stray capacitance of our 38-turn loop, Fig. 2. It turned out to be 70 pF. This seems to be a good trade-off between the physical dimensions and the electrical performance. The disadvantage relative to an optimized antenna is only 10xV more thermal noise and about 1dB lower gain.

Key parameter for loop antennas

The product NV^2, where N is the number of turns and V the area of the loop, is the key parameter for loop antennas. However, two antennas with the same NV^2 product may be very different in terms of inductance.

Comparing a loop 'A', which has 54 turns and 0.64 area, against a loop 'B' with 18 turns and 2 area, you can see that there's a 4-to-1 inductance ratio. Higher loop inductance means higher parallel input resistance — and hence amplifier noise.

Component choice

To underline the electrical performances of the operational amplifier to be used, the input noise of the circuit, see Fig. 3, is 0.4 pAV/Hz. This equates to 0.48μV considering an input resistance of 265kΩ and a receiver bandwidth of 20kHz using high quality OP37. The figure increases if TL081 op-amps are used in the first stage.

Gain of the input stage is set at 20dB and gain of the output stage is 6 to 12dB according to your design needs.

You can use a 100Ω direct output or coaxial cable matching with a 300/75Ω output transformer. Full power bandwidth for a 20V pk-pk output is 250kHz.

As you can see from Table 1, our 38-turn loop has an equivalent height of 8.17m — even though its diameter is only 0.77m.

Magnetic-cored loop

Loop antennas can be made using a magnetic core, for instance ferrite, instead of air.

If an air-cored loop is placed in a field, it cuts the lines of the flux without disturbing them. On the other hand, when a ferrite aerial is placed in the field, the nearby field lines are redirected into the loop. This is because the reluctance of the ferrite material is less than that of the air. The reluctance is inversely proportional to the relative permeability of the core (μr).

In this case the equation of the equivalent height becomes:

$$ h_e = \frac{2\pi\mu_0 A N}{J} $$

Using this kind of antenna, it is not possible to reach the equivalent height of a loop-wound on wood and air. For this reason, the best use for ferrite aerials is in compact portable instrumentation.

Applying this criterion, we used the ferrite antenna to perform magnetic field measurement from five metres to five kilometres away from the transmitting antenna.

Magnetic or electric field

The field's nearness to the transmitting antenna, whether it is a vertical rod or loop type, can be calculated using the following equations. They assume that the wave path is parallel to the Earth's surface:

$$ E = \frac{300JU}{d^2} $$

Where:

- $E$ = near electric field (V/m)
- $h_e$ = antenna equivalent height (m)
- $\lambda$ = wavelength (m)

Fig. 4. Measured Values of the Near Field and Far Field (both magnetic and electric fields).

Fig. 5. Principle Circuit of the Reference Loop and Dipole Antennas.

Fig. 6. Ferrite Aerial and Amplified Short Dipole tuned at 138.6kHz and used in the Tests.
Fig. 7. Wave Impedance in the LF Near Field and Far Field.

Fig. 8. Ground and skywave propagation at 136kHz.

<table>
<thead>
<tr>
<th>Distance (Km)</th>
<th>100</th>
<th>200</th>
<th>300</th>
<th>500</th>
<th>700</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwave Good Ground</td>
<td>38.5</td>
<td>30.4</td>
<td>25.9</td>
<td>17.9</td>
<td>12.5</td>
<td>9.8</td>
</tr>
<tr>
<td>Groundwave Poor Ground</td>
<td>54.7</td>
<td>17.4</td>
<td>8.9</td>
<td>4.6</td>
<td>-20.4</td>
<td>-31.5</td>
</tr>
<tr>
<td>Skywave Night</td>
<td>2.6</td>
<td>-10</td>
<td>2.1</td>
<td>5.4</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Skywave Day (*)</td>
<td>-25.1</td>
<td>-14.7</td>
<td>-8.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) Low solar angle (winter or late afternoon)

Table 2. Calculated Field Strength vs. Distance in dBd/V/m, for radiated power 10^1 W.

In the far field condition, the electric field is given by the following equation:

$$E = \frac{20}{\lambda} \sqrt{\frac{P}{\mu_0}}$$

And consequently the magnetic field becomes:

$$H = \frac{2}{\pi} \frac{E}{c}$$

At a distance greater than far field condition (d=351m) the slope of both the magnetic and electric fields versus the distance becomes flat, either doubling or, if you prefer, doubling each decade.

This kind of trend is valid until 300-500km, for the frequency of 136kHz, even if the field is influenced by the imperfect ground conductivity (emu) that worsens the slope as reported in the Fig. 8 where

$$c=10^{7} \text{m/s}$$

and

$$d=10^{3} \text{m}$$

Until now the ground wave has been described. It concerns the electromagnetic fields travelling along the earth surface induced and being induced by the current flowing on and slightly below the earth surface. Sometimes these fields are defined as Surface Waves.

At distances greater than 300-500km the Ground Wave drops down faster and becomes significant compared to the wave reflected by the ionosphere.

The model performs some assumptions to simplify the geometric computation of the Sky Wave:

- the ionosphere is a zero thickness layer having a height of 100km daily and 90km nightly
- the Sky Wave path is a straight line
- the Earth is considered a perfect sphere
- the coefficients (ionospheric reflection and focusing factors, RXTN antenna ground pattern factors) have been introduced in order to make practical measurements with the theory
- the ground conductivity is 4x10^{-3} S/m and the ground relat-}

ative dielectric constant e=15.

The results of these calculations are reported in the right side of Fig. 8 where three cases are represented: the night (the best case independently of season), the day during the winter and the day during the summer (the worst case). For an other important source of information see references 9,10 and 11.

Table 2. is simplified extraction from this very important study.

The contacts (QSO) at distances greater than 1500-2000km can be performed only if a good antenna-ground system is available (the legal power cannot be over the 1W epr) thanks to the Sky Wave.

**DCF39:** An high power radio source

To calibrate LF antennas we need a stable and powerful radio source and the DCF39 station (Obersee, JOS2-180kHz) in Magdeburg (Germany) is the perfect solution emitting a stable and strong signal (Table 3) that can be heard through Europe. The Mark frequency of 138.83kHz can be said also very nicely as a frequency alignment source. The ASCII modulation (200 baud FSK 340kHz shift) switches over the Space frequency every 10 seconds or so. The station is managed by Europische Funk-Rundstehende GmbH (EPR), the transmitter power is 50W and the vertical monopole antenna is 324mm high (see photo in Fig. 9). The emitted

**Table 4. Loop antenna calculation and measured output voltages using DCF39 signal at 750kHz.**

<table>
<thead>
<tr>
<th>Measure</th>
<th>DCF39 Field</th>
<th>Reference Loop (*)</th>
<th>Ferrite Aerial Length-600m</th>
<th>Tuned 125-139kHz Super Loop (*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain (dB)</td>
<td>50</td>
<td>45</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>Output (V)</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>25</td>
</tr>
</tbody>
</table>

(*) Output voltage measured with RL=100ohm and BRV=20Hz.
Fig. 11. The Loop 18, an 18 turn, 21 cm diameter reference loop.

Table. The antennas:

<table>
<thead>
<tr>
<th>Ferrite Rods</th>
<th># of Turns</th>
<th>Length (mm)</th>
<th>Equiv. Diameter (mm)</th>
<th>L/D</th>
<th>Area (mm²)</th>
<th>η0 (dB)</th>
<th>h0 (m)</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>1</td>
<td>200</td>
<td>10</td>
<td>78.5</td>
<td>118</td>
<td>9267</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Two in series</td>
<td>2</td>
<td>400</td>
<td>10</td>
<td>87.5</td>
<td>210</td>
<td>16493</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three in series</td>
<td>3</td>
<td>600</td>
<td>10</td>
<td>60</td>
<td>78.5</td>
<td>260</td>
<td>20420</td>
<td></td>
</tr>
<tr>
<td>Two series and two in parallel</td>
<td>4</td>
<td>400</td>
<td>14</td>
<td>29</td>
<td>154</td>
<td>166</td>
<td>25554</td>
<td>0.89</td>
</tr>
<tr>
<td>Three series and two parallel</td>
<td>6</td>
<td>600</td>
<td>14</td>
<td>43</td>
<td>154</td>
<td>220</td>
<td>33866</td>
<td>1.16</td>
</tr>
<tr>
<td>Three series and three parallel</td>
<td>9</td>
<td>600</td>
<td>17</td>
<td>35</td>
<td>227</td>
<td>185</td>
<td>41991</td>
<td>1.20</td>
</tr>
<tr>
<td>Three series and four parallel</td>
<td>12</td>
<td>600</td>
<td>20</td>
<td>30</td>
<td>314</td>
<td>170</td>
<td>53407</td>
<td>1.82</td>
</tr>
</tbody>
</table>


Table. Multi rod ferrite aerials: Calculations and Measurements.

For the maximum accuracy of the tests it is very important to avoid resonating frequencies and parasitic capacitances. In our 18 turn coil we have: L = 155µH (XL = 1325@ 136kHz) and an antiresonating frequency of 1.2MHz. With a 100kHz input of the impedance test we can measure exactly the open circuit voltage generated by the reference loop and with a 600µH input we have a lead error of only about 1dB.

One secret: all the tests with the DCF39 (at 750kHz from the transmitter) are made using high sensitivity receivers with very narrow bandwidth (example: BW=20kHz).

Starting from the calibrated Reference Antenna we have measured three other interesting aerials: an unwound 38 turn 77cm diameter loop, the same with a tuned and loaded by the parasitic input impedance (Q = 182) and a very portable Ferrite antenna.

These and other results are shown in Table 4. For people interested in the realisation phase of loop antennas the articles in references 16, 17 and 18 are advisable. For the Ferrite Aerials the calculated values for a number of ferrite rods are shown in Table 5. Such antennas mainly utilize the magnetic field component of the signal to be received, and the direction dependent character of the antenna corresponds to that of a short dipole, which is an "m" with a flat maximum and a sharp null. 100 turns of this wire (many thin wires) may be wound on a single rod (basic permeability ≈ 500), or to increase the output, the core may be two or more rods taped together. The ferrite performance is obtained with groups of rods glued end to end contained in a U-shaped electrostatic shield. As shown in the table, the maximum suggested number of ferrite rods is about six. The calculated improvement with nine or 12 rods is not impressive. The equivalent height (η0) of our realization (three rods in series ≈ 2 rods in parallel = six) is about 1 metre (calculated 1.16m). This is a good solution for portable use as secondary reference antennas. For more info on the ferrite aerials see also references 19 and 20.

Conclusions

The Loop Aerials are extremely interesting for receiving in the 136kHz band because of their specific characteristics: high gain, high selectivity, directivity and low interference noise. The possible limits for an optimized big loop at 136kHz (L ≈ 200, BW = 600kHz) are about: area (A) ≈ 10m², N = 30 turns, h0 ≈ 50m. This antenna has a good rejection to the local electric noise and an equivalent height not obtained with any "practical" vertical Marconi antennas.

The more important parameters of a few loop aerials have been tested and the theoretical equivalent heights (η0) calculated using the DCF19 comparison method. Our record in the experimental tested antennas was η0=30m. Other experiments and statistics are necessary to have a more complete knowledge of Signal to Noise optimization of loops.

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Further Reading

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CCIR/ITU, Electromagnetic Characteristics of the Surface of the Earth, REC 527-3, 1992

(*) Reference Data for Engineers is now published by Newnes
During the first half of the last century, interference problems began to manifest themselves in valve equipment. One attempt to solve this problem was to wire all the components to a single point on the chassis. The 'star point ground' was conceived.

The desired effect was noise reduction. The opposite effect was achieved, in fact interference problems were created and these problems persisted for the lifetime of the equipment. In spite of this the idea gained widespread acceptance and some influential engineers still recommend it. As a guideline for circuit designers wishing to achieve Electromagnetic Compatibility (EMC) for their designs, it has been used in the past.

The fact that it retains wide acceptance identifies an even more deep-seated problem; too great a reliance is being placed on guidelines, tips, tricks and the pronouncements of EMC gurus. This is a bit of wishy washy. Guidelines based on technology progress, tips and tricks that work beautifully in one application are disastrous in others and gurus distance themselves from the project before problems appear. This note identifies the fallacy in the star point ground concept and points to a systematic approach to those aspects of design that achieve EMC of the product.

The star ground concept

Star grounding is a method of wiring circuits that minimises the resistive coupling between two separate circuits. Fig. 1, illustrates the idea. The boxes A, B, C, and D can be thought of as printed circuit boards containing interface circuits.

The wiring is organised to carry signal 1 from A to B, and signal 2 from C to D. Return conductors are all routed via the star point, S. Since there is no resistive coupling common to both circuits, there can be no resistive coupling between them. The reasoning is that, if there is no common coupling, there can be no interference.

The fallacy

The fallacy in this reasoning is that it limits its consideration to resistive coupling. Magnetic and electric fields are ignored. If inductive coupling is considered, the picture changes completely. In Fig. 1, the current I1 flows in a loop enclosing a wide area. A great deal of magnetic flux threads through this area. Inevitably, a significant proportion of this flux also threads through the second loop. Transformer action ensures that a relatively high voltage is developed in series with the second loop. This appears as an interference source; an unwelcome addition to the desired signal.

Where there are magnetic fields, you will find electric fields. These manifest themselves as capacitance coupling between the conductors and add their own contribution to the interference. Signal 2 will interfere with signal 1 in exactly the same way. Star point grounding creates a system in which every signal interferes noticeably with every other. If the system interferes with itself, of what use is it when subjected to an environment where the external field is greater than that of the signals being processed?

Alternative approach

If star point grounding is to be abandoned, what should replace it? Perhaps the best approach is to start with an overview of the system and then to implement the lessons learnt from theory. The initial objective can be formulated to transmit one signal from A to B and another from C to D, with minimal interference between the two signals. It is assumed that there are a number of other circuits in the overall system and that cable conductors will be used to carry the signals.

Transmission line concept

Some fundamental concepts of electromagnetic theory and circuit theory are combined in the picture of the transmission line shown in Fig. 3. Current in the upper conductor is induced by the current in the lower conductor, flowing in the opposite direction. Illustrated are the electric and magnetic field vectors, E and H, at the mid-point between the conductors. There is a flow of electromagnetic power from left to right, identified by the 'P' vector. Some simple points can be made, namely, the currents in the supply and return conductors are equal and opposite at every cross section of the transmission line and the vector sum of the currents at any section of the line is zero. The action of the electromagnetic field tends to provide this equalisation. Don't fight it. Use it.

The most efficient way to transmit electric power between two points is to use a transmission line. Minimal power is transmitted to the environment and minimal power is received from the environment. A logical decision is to use transmission line to carry the signals defined in the block diagram. Although the vector sum of the currents is zero in Fig. 3, the power vector clearly indicates which way the signal is going. This allows a very useful correlation to be made between the transmission line and the block diagram.

Wiring Diagram

If the block diagram is modified to include the conductors of the transmission line, the natural result is a wiring diagram and the components of Fig. 4. begin to emerge. In any practical system, there are a fair number of other conductors. These include the supply conductors necessary to distribute power to the various printed circuit boards. Signals on the individual boards are processed with respect to a common conductor, usually designated as the 'ground'. There is also some form of shielding; provided in part by the equipment enclosure. The inclusion of the conductor marked 'structure' in the diagram allows the existence of the grounding and shielding conductors to be recognised. In the illustration of Fig. 4., the return conductors are all grounded to focal points on the structure.

Culprit Circuit

Any interference must have a source, a coupling mechanism, and a receptor. The term 'culprit' can be used to identify a network generating unwanted emissions, while a network which could be susceptible to interference is a potential 'victim'.

In the case under consideration, both culprit and victim are part of the same system, and the coupling mechanism is associated with current in the structure. If the culprit is assumed to be the wiring associated with signal 1, then it is logical to focus first on this segment of the system. A circuit model can be created of the culprit, by treating it as a three conductor transmission line. Fig. 5. is a simplified model, where each conductor is represented by an inductor. Each inductor also possesses the properties of resistance and capacitance, but there is no need to show these in an initial illustration. It is always possible to assign a value to each inductor. Any basic textbook that introduces three-phase power lines will provide equations relating physical dimensions to inductance values. If necessary, tests can be made on a representative assembly to measure the values. From a system point of view, the spurious output of the culprit is transient current in the structure, I3.

Common-mode rejection

There are two loops involved; the differential loop carrying signal current, and the common-mode loop carrying a portion of the signal current via the structure. A wire pair is usually constructed with identical conductors and these are held as close together as in physically possible. The separation between supply and return conductors is usually greater than that between cable and structure. This means that inductors L1 and L2 of Fig. 5. are equal, and have no obvious control. Conversely L3 has a relatively high value.

If the signal source is located on printed circuit board A, and the supply current II flows in L1, then the return current will be shared between L2 and L3. Since L2 is less than L3, a greater proportion of the return current will flow in L2. This means that L3 is less than L2. The ratio between L2 and L3 is even greater. This is a useful amount of common-mode rejection, due to magnetic effects.

Coupling Mechanism

Common-mode current flowing in the structure will generate a voltage across L3, and the amplitude of this voltage can be calculated. Interference created by signal 1 Fig. 7. Block diagram of system under review.

Fig. 3. Transmission line relationship.

Fig. 4. Wiring diagram of system under review.

Fig. 5. Circuit model of culprit section of system.
will manifest itself as a voltage along the structure - 'Vthreat'. Invoking the Norton-Thomas relationship of Fig. 6, allows the action of the culprit loop to be represented as a voltage source, Vthreat, in series with the structure. From the point of view of the victim, interference can be defined as the voltage across the loop formed by structure and cable.

Victim Circuit

This interference source can then be included in the circuit model for the second signal, as shown on Fig. 7. In this model, common-mode current flows in the cable/structure loop and creates a voltage across L. Since L and L act as an inductive potentiometer, the voltage induced in the differential loop will be significantly less than Vthreat. Again, there is a useful amount of common-mode rejection, also due to magnetic effects.

Ground loops

One feature of this approach is that it has introduced two extra loops into the configuration - the common-mode loops of the culprit and victim circuits. It has been shown that the action of the magnetic field in these loops reduces the level of coupling between culprit and victim. Another name can be given to these loops - 'ground loops'. In fact, the terms 'ground loop' and 'common-mode loop' are synonymous.

This means that the landed ground loop, which many individuals believe should be avoided if at all possible, actually helps to improve EMC.

Improving performance

Currents in the ground loop is the prime cause of interference. To improve performance, the objective should be to reduce the amplitude of this current. Increasing the impedance of the loop can do this. The most obvious way to increase loop impedance is to open-circuit it. This leads to the familiar concept of the floating termination. From an examination of Figure 7 it could be assumed that a floating termination would reduce common-mode current to zero, and solve the problem. Alas, it is not to be.

Up till now, attention has been focussed on magnetic effects. The action of the electric field has been ignored. There have been no capacitors in the circuit models. If the victim circuit of Figure 7 is modified to show the existence of these capacitors, to 'float' the receiver interface, and so replace the load Z with an optocoupler, then the picture becomes as shown in Fig. 8.

The capacitors now provide a path for common-mode current. At low frequencies, this current has negligible amplitude, and common-mode rejection can be as high as 60 dB. However, as the frequency of Vthreat increases, common-mode current increases. The common-mode rejection is a function of frequency, and reduces at 20 dB per decade. The combined existence of capacitance and inductance means that, inevitably, there is resonance. At the resonant frequency, the differential voltage can be 10 dB higher than Vthreat. Of even more concern is the fact that the common-mode voltage at the optocoupler (between 'return 2' and structure) can be more than 40 dB higher than Vthreat. This raises more problems.

Implications

These problems can be solved. However and there is no need to describe the solutions here. The point that can now be made is that circuit modelling will provide a clear picture of the coupling mechanisms. When the problem is clearly defined, a solution can always be found.

As well as providing a clear picture, circuit modelling allows actual numbers to be assigned to component values, and for the frequency response of the system to be analysed. Circuit analysis software makes the calculations a simple task.

Simple bench test 2 can be devised to measure the response during prototyping. The circuit can be modified and the analysis repeated, until the system is shown to meet its EMC requirements. The finished product can be submitted for formal EMC Tests with a high degree of confidence.

Conclusion

There are many guidelines, tips, and fixes to be found in the literature on EMC, and there is much advice provided by experts on the subject. Some of it is of dubious value. Using circuit models of the system under analysis, it is possible to identify the hidden assumptions, the limitations, and the errors in any particular recommendation. Circuit modelling allows the electromagnetic coupling mechanisms to be understood and analysed. The systematic use of circuit models will enable any system to be designed to meet its EMC requirements.

References


RF input power, a PA with a nominal output power of 29dBm will be well suited. On the market there are not many low cost PAs which are able to deliver such high output power at 2.4GHz. For instance, Infineon has a Silicon PA family starting from a 22dBm Bluetooth PA up to the largest 29dBm device. All devices are balanced PAs with push-pull input and output stage. The balanced input eases the connection to the often also balanced transceiver output. To save board space and external components many system functions are included in these PA devices, such as power ramping and antenna switch drivers. A nice feature is the power select function. With two digital pins you can select four different output power levels, e.g. according the distance between handset and base stations. For the balanced output we need a balun (balanced-to-unbalanced) to convert

Although radio and amateur radio are a bit old-fashioned, today a lot of engineers have to deal with RF, e.g. on topics like cordless telephones, mobile phones or wireless LAN.

Key Factors in RF Power Amplifier Design

For some main-stream systems like GSM or AMPS, RF power amplifier modules are available from manufacturers like Hitachi, Fujitsu, Alps, etc. That eases the application, because they normally have 50% RF ICs. But such modules are quite expensive. So many companies even a discrete solution might be competitive. In these cases - or for module or chip design - a much more detailed know-how is needed.

On a system level, such things like RF TX power at the antenna, power-time template and spectrum limitations have to be specified. So the way to design a RF PA is starting with a level diagram. From this you get the output power of the PA. After designing the final output stage with its matching network, you get input power needed to drive the last stage. This can be used to meet the PA's efficiency requirements. So the problem is to design a matching network for an ESM 2400MHz power amplifier (free band for industrial/scientific-medicine applications). In the USA, up to 1W (corresponding to 50dBm) antenna power is allowed for this frequency band. In reality some loss occurs in the TX low-pass or band-pass filter and the antenna switch, so the PA is allowed to deliver approx. 31dBm. Because you need some safety margin for component tolerances, temperature drift, changes of supply voltage and
RF Design

Fig. 3. Calculating $R_{\text{imp}}$ via ANPASS

Fig. 4. PA output modelling in CSIMTH and the L-type pre-matching network to 35Ω. Note: The end capacitor has a series inductance of 0.5-9.44Ω as a typical 0603 SMD component.

Fig. 5. LC balun design using ANPASS.

Fig. 6. Measurement results for the 296dm 3Ω PA

Fig. 7. The 2.4GHz PA board with the Infineon 2.4GHz-PA in VQFN20 package

Fig. 8. CSIMTH results of a 1.9 GHz 3-step matching network optimised for wide bandwidth. The MAG (upper curve) shows that the element losses increases at higher frequencies, so it's not easy to get a true flat response.

The push-pull signal to the normally used single-ended signal (e.g. for filters, PIN diode switches and antennas). The output power depends not only on the PA device but also on supply voltage $V_{CC}$ (due to $P_{\text{out}} = (V_{cc} - V_{TH})^2 / 2R_p$) and best efficiency PAE can be expected if the PA is deep in the compression (in this case approx. 46%). This operation is allowed for systems, such as DECT (digital enhanced cordless telephone), HomeRF or Bluetooth (both new standards for general-purpose RF interfaces, LAN, etc.), because they use modulation schemes (in these cases frequency shift keying) with constant RF envelope. For non-constant envelope modulation schemes like QPSK or QPSK (e.g. IEEE802.11b or UMTS), you have to look at the peak power, not the average power. This is needed in these cases because a PA in compression would create too much adjacent channel leakage power. The Infineon device is fabricated in a 4V-2.5GHz silicon process, so for 296dm the recommended supply voltage is 3.1V. Direct operation at 2V, 3.3V or 5V with NIC4NMF cells is possible, because the supply voltage range starts at 1.8V. With this information we can calculate the optimum load impedance $Z_{\text{LO}}$. A nice program to do this is the AdLab tool ANPASS [1]. It uses the formula $R_{\text{imp}} = \frac{3V_{CC}^2}{8V_{TH}^2}$, which is quite accurate for class-A operation (hints available on bubble help). There are some problems: Firstly we can only guess the saturation voltage, which should be close to approx. 0.2V, because it's a low-voltage bipolar design. Secondly we operate in deep compression, so the class-A approximation is not valid. For instance for class-E [2] the voltage swing is not $2\left(V_{CC} - V_{TH}\right)$ but approx. $3.3\left(V_{CC} - V_{TH}\right)$. For the class-A approximation $V_{TH} = 0.6\text{V}$, ANPASS delivers $R_{\text{imp}} = 1.9\Omega$ for a single-ended PA and 19.0Ω for the balanced topology. This shows a clear advantage of the push-pull output, its impedance is already closer to 50Ω.

The result is a real value for the impedance (19.0Ω, to 9.4Ω for each side) which is not truly realistic with real world transistors and finite package inducances. So ANPASS delivers the correct value for an idealised PA. For compressed class-B operation a higher value of $R_{\text{imp}}$ is a big hit for better efficiency (say 11Ω), for class-E operation ANPASS delivers 5.6Ω for single-ended configuration. Using another AdLab tool called CSIMTH we can start with the correct value as the generator impedance and we can add the transistor output capacitance (approx. 3pf with some series resistance representing losses in the silicon substrate) and the bond-wire inductance (approx. 0.4-0.5nH and a small package capacitance) by hand.

Note that CSIMTH is able to use real elements with all their major parasitics like series resistors or inductances, also a frequency sweep with graphical output for gain, MAG, return loss, etc. is available. What we need now is a match from the transistor output to the balun. Because we need a DC-feed, a L-type low-pass structure (high-impedance transmission line acting as a series L followed by a short C) is the easiest solution. In other situations a high-pass is a better choice, e.g. in the interstage match where a DC-break is needed or some compensation of the drop of the transistor gain at higher frequencies is needed.

A balun generally transforms a differential signal to a single-ended one (which is normally 50Ω) and vice versa. A standard LC balun can be designed using ANPASS. One open question is the intermediate balun input impedance. It's a good idea to take an intermediate impedance value (say 50Ω), so that the match is distributed over the first prematching network and the balun. This often gives the largest bandwidth and low tolerances. Other types of baluns are well-known (e.g. with transformers or LC-transmission lines), but the LC all-pass is preferred here because it is very compact. Note, one balun capacitor could be merged with the shunt-C of the prematch.

The resulting circuit is very close to what we have achieved in the lab. Of course in reality some tweaking is always needed in 2GHz circuits due to component parasitics and modelling inaccuracies. Also the impedances at the harmonic frequencies are not important due to large signal operation. This behaviour is known as harmonic matching, but it is not easy to get an advantage from this behaviour at a GHz power amplifier.

For higher output power levels the impedances become very low (e.g. typically 2Ω or GΩ levels) and a single-step matching network would result in a small bandwidth, but more important in tolerance problems. In these cases you need a multi-step match. In principle such a matching network can be designed in the same manner using the Smith chart, although it is not easy to optimise both losses and bandwidth. The main problem is that in the Smith chart you normally calculate at one frequency, so you don't often get the bandwidth advantage of multi-section circuit structures like Chebyshev filters. In CSIMTH you can do such a design, because Monte-Carlo analysis, frequency sweeps and also optimisation (in conjunction with the general-purpose simulator APLAC [3]) are available.

Currently, we are only looking very roughly at the transistor. In fact, so far we only look at its saturation voltage, its current and voltage capabilities and its output capacitance. Of course other
parameters such as feedback capacitance, transition frequency $f_{T}$, maximum frequency of oscillation $f_{MAX}$, maximum available gain $MAG$, stability factor $k$, current gain $B_e$, etc. are important — but not so much for the output match. Often a carefully chosen compromise is needed. For instance transistors with high $f_T$ and $f_{MAX}$, like the new Silicon-Germanium technology have a high power gain $G$, which is advantageous for high PAC and getting a low number of RF stages. But these transistors tend to have lower breakdown voltages and might be less stable. As a rule of thumb: the supply voltage should not exceed the transition voltage $V_{T}$, although breakdown behaviour also depends on the impedance at the transistor base (V$_{CE}$) at the operating frequency ($f_0$), so the MAG is a good indicator of the possible $V_{CE}$ for the device is not stable you need damping elements (e.g. series resistor at the base) or feedback (series or shunt feedback).

Not only the transistor is important but also all layout parasitics, like emitter-ground inductance, parasitics of SMD components and also on-chip parasitics (3). Many chip designers think only the parasitic capacitances and series resistances are critical for their layout, but this is completely wrong for low-impedance RF circuits, such as PAs. Even small metal traces within the interstage match are critical. A typical 300μm metal trace will have an inductance of approx. 0.3μH and a series resistance of 0.5Ω. Note that at 2.4GHz the inductance corresponds to 1.6mH, so the reactive parts might influence the match and the frequency response seriously. Most important is the ground inductance of the emitters (or sources for field-effect transistors) and in a case of (2GHz & P=2W) only chip vias (available in many GaAs or LDNOS technologies) or a balanced concept will help. For a GSM PA the AC peak-to-peak current is in the range of 4A, so even 100μH will cause a ripple of 2.2V, at 900MHz. This is a non-negligible part of the supply voltage and will reduce power gain dramatically and influences also PAC and stability. On the other hand some emitter inductance can help if the input impedances become to low (e.g. <1Ω), which cause matching problems. The bipolar transistor input impedance is approx. $V_{CE}$/$I_{E}$ (it with $Z_{I}$ = $\sqrt{R_{E}R_{I}+R_{i}L_{I}^2}$ and $V_{III}I_{II}$ (AdLab tool SPARAM showing MAG derived from S-parameter data from CSIM [5] )

### Table 1: Summary of key factors in modelling for RF power amplifiers.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Influence</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transistor models</td>
<td>May have a large influence, especially on interstage matching</td>
<td>Gummel Poon may be sufficient for Si, but not in all cases. High current/low voltage region is critical, also quasiresonant and breakdown.</td>
</tr>
<tr>
<td>Capacitance to substrate</td>
<td>Often a low influence (not for transistor or MOS-C capacitances)</td>
<td>This is different to low power/high impedance designs.</td>
</tr>
<tr>
<td>Series resistors</td>
<td>Medium inductance. Look also at the on-chip MOS capacitances</td>
<td>Reduces gain.</td>
</tr>
<tr>
<td>Series inductances</td>
<td>Large inductance. Not only feedback in BIT emitter stages</td>
<td>Changes frequency response.</td>
</tr>
<tr>
<td>On-chip coils</td>
<td>Medium inductance. A peak Q of 5:10 is realistic for Si technologies. Include the lines to the coil.</td>
<td>Modelling is not too difficult, but Q is limited for high Q technologies.</td>
</tr>
<tr>
<td>Package model</td>
<td>Strong influence due to series inductances</td>
<td>Not easy to model.</td>
</tr>
<tr>
<td>Substrate model</td>
<td>Medium inductance on bias and RF performance</td>
<td>Difficult in model, important for mixed mode designs.</td>
</tr>
<tr>
<td>PCB and external components</td>
<td>Large inductance</td>
<td>Grounding and crosstalk are difficult to model.</td>
</tr>
<tr>
<td>Bypassing and biasing</td>
<td>Large inductance on stability and linearity</td>
<td>Don't optimise only at the operation frequency.</td>
</tr>
</tbody>
</table>

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**References**


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**Fig. 9. Effect of parasitic inductance on a 2.2μF SMD capacitor (LCCTL from ELESTA Professional [2]). At 2.4 GHz the component acts as a 2.9μF cap, because we operate not too far from the self-resonant frequency.**

**Fig. 10. MAG for a typical 2W 1.8GHz Si bipolar power transistor with (lower curve) and without 100pF emitter inductance (AdLab tool SPARAM showing MAG derived from S-parameter data from CSIM)**

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Super Regen

I have been following the recent articles on super-regeneration by Eddie Bassam with interest and his suggestion for an electronic tape measure using a Doppler module may well be a perfectly practical proposition. Indeed, under Recent Inventions, the November 1947 Wireless World described something very similar.

A super-regenerative circuit is used both as a transmitter and receiver for short-range radar, the quenched frequency being manually adjusted until it coincides with the time interval between an output and the incoming echo from a distant target, coincident occurrence being when the normal ‘hiss’ ceases in the valve circuit. A patent application, No. 538192, was filed by A.C. Corsier Ltd and P.R.W. Stafford on December 30th, 1942 but there are no information regarding actual performance.

Browsing through Wireless World, I have found a further article, namely ‘Super-Regenerative mixing’ is the topic of recent develeopments by ‘Cathode Ray’ in the June 1946 edition that examines principles in some depth. Certainly, the field of super-regenerative would seem to offer much scope for experimentation and applications are by no means confined to antiquity as some modern car alarm remotes utilise super-regenerative receivers.

J. Bolam
West Sussex U.K.

Star grounding

I cannot agree with Ian Darney’s ‘The star point concept is a thoroughly bad idea, and is based on a needless concern’ (Letters, April 2002). Indeed, having worked in a Department of Arco and Space (Dept of Plasma Physics, Uni of Sydney) for a couple of decades I can report that not eliminating earth loops and other multiple earth paths (i.e. not adopting a star or tree like topology for earth) will most certainly result in some intractable interference problems in many circumstances.

Therein is part of the issue. Not everyone is wrangling small signals is such a hostile environment, but the intelligent approach to interference problems requires that one assesses the nature and cause of the interference and deal with it appropriately. Generally speaking a branched/tree topology will result in far fewer interference problems that one with multiple electrically parallel earth paths.

Judging by Ian’s description of the problems with valve radio I suspect that the problem was not caused by the star topology but primarily by other, bad wiring practices.

The electrical topology of the star and the routing of sensitive wiring (away from hostile parts of the circuit) must take precedence over the physical shape of the star. My feeling is that the position of the star point could have been better chosen, although this can only be confirmed by proper measurement and experiments.

The physical layout of the wiring is important. The area enclosed by a wire signal and earth wires should be as small as possible, otherwise the wires will act like an loop antenna and pick up all sorts of junk. They are prone to radiate as well, and in the RF bands the extra inductance will ruin your matching. For this reason some situations mandate the signal and earth wires (or power and return, for that matter) be twisted together as much as possible, or screened cable be used. This may even apply for some IEC feeds, if the load current is pulsed for example. DC wiring can also act as a receiving antenna that funnels interference into shielded parts of a system.

Ian’s description of a ‘set up where there are several items of equipment’ is altogether too sketchy to draw any but the vaguest conclusions. The nature of the set up, how the equipment is wired internally and interconnected, the range of frequencies, voltages, and currents concerned, all impact on whether there is likely to be a problem with interference. Consider the following example of conducted interference in a real, well-shielded set up.

In the Tokamak Lab in Plasma Physics there was a screened room (approximately 3 metres square) to shield the data taking and control equipment from the tokamak, which included several big sources of interference (like the main field current of about 20kA fed from a 2.5km cable and three 20kW RF sources). On a particular occasion a student was trying to view a signal of about 50V by 50uA on a CRT (Europe), which was triggered by a 50V (3m) trigger pulse. The signal and the trigger pulse were routed diagonally across the screened box from the bulkhead where they entered the room, earth connected, to the CRT (in the opposite corner) through terminated RG8 coax ases.

The signal showed a spurious pedestal and sawtooth waveform, the same, break loop and 20us duration, caused by some of the earth current of the trigger pulse running through the electronic earth shield.

Fixing an isolating pulse transformer at the CRT’s trigger input cured the problem. We had electrically gone to a loop topology for the electronics to a branched (star, tree) topology. Far from causing any intractable problems it cured one.

Generally it was found that equipment used in the screened room had to have its earth through the power disconnected to kill earth loops, although that some unpleasant effects on people who touched a chassis that was otherwise earthed while it was plugged in. There have been numerous other instances such as a rapped PC, a magnetron that apparently consumed more power than it fed, all caused by earth loops. I recall my days as an appliance repairman that there were frequently problems with mains hum in kitchen circuits. Using a small mains earths were connected creating loops with the rest of the stereo system. Earth loops pose serious threats to signal integrity and even to equipment sometimes.

While Ian is not incorrect in his description of skin effect and its role in inferences about wireless applications because the skin depth is appreciably greater than the diameter of most shielded cables over the audio band. This means that the interference punches right through the shield, through the inner signal conductor, and out the other side. The reason shielding still works in these circumstances is that the interfering signal induces (virtually) identical currents and voltages in both the earth and signal conductors, and these currents and voltages cancel. Both the interference and signal currents will be distributed across the entire cross sectional area of the relevant conductor. Skin depth does not define a sharp cut-off anyway, it is an arbitrarily chosen depth at which the current density has dropped a particular fraction of that near the surface, it is the surface area of the current will flow through all areas of the conductor. Superconductors are another story.

Ian may care to ponder the nature and purpose of the lump in the signal cable near the PC monitor on these days. It is a ferrite sleeve acting as a turn count compensation circuit intended to suppress the effects of earth loops at high frequencies. I expect the lump to be the principal contributor to the interference rather than protect the monitor from interference. Whatever, the purpose is to break high frequency earth loops because they are a major cause of interference.

Even in shielded systems earth loops can cause problems, partly because no shield is 100% effective at all frequencies, and the necessity to provide access for assembly and repair, and holes for sensors and feed-throughs, means that most shields have breaks in them.

It should be remembered that much power transformers provide very little isolation at high frequencies due to their high interfering capacitance. Most mains filters and switched mode supplies include a common mode choke. It is possible a high frequency earth loop will be created through interwinding and other parasitic capacitances even when no hard earth connection exists, and the purpose of the common mode choke is to provide at least some impedance. Such chokes have little or no effect on differential mode interference (i.e. between Active and Neutral).

500MHz sampling front end

You have probably received a fair number of comments from other readers concerning Mr. Hackman’s interesting and informative article in the June issue. Nevertheless, I thought I would like to put in my two cents worth on the conservations of my own.

With regard to producing a Shorter Gate 1 sampling pulses, I suspect that the avalanche pulse generator employed has reached the limit of its capability in this direction. Some improvement might be indeed be achieved by using a shorter delay line, L1, and a transistor having a higher transition frequency than the BFR91. Unfortunately, this would inevitably be at the expense of pulse amplitude since most commonly available low cost transistors with higher transition frequencies also tend to have lower avalanche voltages. Therefore, it might be worth considering an alternative method of generating shorter sampling pulses.

The method I have in mind is a variation on the theme of the classic step recovery diode (SRD) impulse generator. However, instead of employing an SRD - which is an unusual device that readers are unlikely to find in the majority of mainstream electronic component distributors’ catalogues - try using an inexpensive UV sensitive PIN switching diode. With suitable biasing some short lifetime epilaxial PIN diodes exhibit behaviour very like that of SRD’s. For example, Agilent Technologies’ HSEP-3200 PIN diode or similar would probably make a suitable candidate for this experiment.

In principle it should be possible to generate sampling pulses, having sufficient bandwidth up to around 300MHz or less using this method.

Douglas R Taylor
By email
Ozoniser

In hot and damp climates, fungus and mould can develop in all places but mainly in books. Ozone (O₃) is a powerful oxidizer that kills microorganisms and had smells in the air.

The quartz bulb inside any mercury vapour lamp emits strong ultra-violet light which energy is enough for the reaction 3O₂→2O₃. This circuit is a driver and timer for a 220V AC 125W mercury lamp powered by a 120VAC mains source. The ballast in series with the lamp operates as a current source so the output is not reduced appreciably when operating at 120V AC but a voltage doubler is needed to start the plasma inside the bulb.

Pressing S1 starts the lamp and powers the timer that sends pulses generated by Q2 to trigger Q1 continuously. After the time selected by P1, IC1 output goes high and Q3 shuts down the pulses, cutting the power.

I use this ioniser when leaving for work to avoid any exposure of UV rays, harmful to eyes and skin, and ozone that burns the lungs.

The outside glass bulb must be broken to expose the quartz bulb and trigger connection inside (a wire with a 33kΩ resistor, R2). I installed the bulb inside a piece of plastic tube with tinfoil glued in the inner wall and put a fan in the bottom to disperse the ozone in the room like a fountain. Be sure to open the windows when you came home again.

Tiaraju Vasconcellos Wagner
Brazil

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Operation of valve portable radios from the mains

There have been many circuits published for the operation of "picnic case portables" from either battery inverters or from mains power supplies. Most of these suffer from either safety problems of mains operated, or interference problems if of the battery driven inverter type.

This circuit overcomes these problems and is intended to operate any battery set from a mains supply in safety and without interference. The heart of the circuit is a mains transformer from a video recorder. These transformers are double insulated as most recorders are not connected to mains earth and have several secondary windings ranging from about 4 to 40 volts.

The voltages of the various windings should be measured and one giving about 4 to 6 volts selected for the valve heaters. The higher voltage windings should be series connected to make up about 1/3rd the required HT voltage. This is then voltage doubled and smoothed for the HT supply. The HT current being low (10-15mA) means that this rectifier convection will give nearly 2.8 times the secondary RMS voltage. This voltage is not critical as in practice it varied widely as the HT battery discharged. Sample capacitive smoothing is all that is required. Voltages up to 150v can be obtained in this manner. The smoothing resistor R2 can also be adjusted for voltage setting.

The LT circuit requires much more care, in terms of voltage control and hum level; an LM337 adjustable regulator is used. This device will only operate down to 1.3 volts, so a diode is connected in series with the output so it operates at 2.1 volts out, 1.4 volts at the filaments. For older sets with 2-volt filaments the diode is omitted. The reverse diode across the regulator is to discharge the output capacitor at switch off. A string of four 1N4002 diodes can be fitted across the output to act as a crowbar in the event of the regulator going short. The unit should have the filament voltage pot set using a dummy load. With good valves this should be 1.3 to 1.35 volts for long life, with older valves that have possibly been overvoltage is permissible to increase the voltage to 1.45V to achieve acceptable performance. R4 can be adjusted to give the required setting range on the pot R1.

For very old battery receivers that require a grid bias supply one of the spare windings is shown utilised for this purpose. The resistor chain R6,7,8 is adjusted for the required output voltage settings.

Ed Dimming
Newcastle

The HS801: the first 100 Mega samples per second measuring instrument that consists of a MOST (Multimeter, Oscilloscope, Spectrum Analyzer and Transient recorder) and an AWG (Arbitrary Waveform Generator). This new MOST portable and compact measuring instrument can solve almost every measurement problem. With the integrated AWG you can generate every signal you want.

- The versatile software has a user-defined toolbar with which over 50 instrument settings quick and easy can be accessed. An intelligent auto setup allows the inexperienced user to perform measurements immediately. Through the use of a setting file, the user has the possibility to save an instrument setup and recall it at a later moment. The setup time of the instrument is hereby reduced to a minimum.

- When a quick indication of the input signal is required, a simple click on the auto setup button will immediately give a good overview of the signal. The auto setup function ensures a proper setup of the time base, the trigger levels and the input sensitivities.

- The sophisticated cursor readouts have 21 possible read outs. Besides the usual read outs, like voltage and time, also quantities like rise time and frequency are displayed.

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- The HS801 has an 8 bit resolution and a maximum sampling speed of 100 MHz. The input range is 0.1 volt full scale to 50 volt full scale. The record length is 32K/64K samples. The AWG has a 10 bit resolution and a sample speed of 25 MHz. The HS801 is connected to the parallel printer port of a computer.

- The minimum system requirement is a PC with a 486 processor and 8 Mbyte RAM available. The software runs in Windows 3.1x / 95 / 98 or Windows NT / 2000 / XP and DOS 3.3 or higher.

- TIE Pie engineering (UK), 28 Stephenson Road, Industrial Estate, St. Ives, Cambridgeshire, PE17 3WJ, UK Tel: 01480-460026, Fax: 01480-460340

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- Web: http://www.tiepie.nl
5W Inverter

This inverter has been designed with readily available components. The transformer is a standard 10VA mains transformer with two 6V windings connected as shown in the schematic. Its purpose is to provide a suitable voltage for all those mains battery chargers that surround us: mobile phones, electric razors, generic battery chargers and even for a 5W electronic neon lamp. Frequency of operation is between 70 and 1900Hz depending on the load. The frequency is not quite the mains frequency but is good enough to supply the intended loads. A small neon light at the output gives an indication of the presence of a dangerous voltage. The circuit will withstand temporary shorts and battery reversals. Some switching chargers require an initial peak current that might look like a short to the inverter. In this case it is necessary to disconnect and reconnect the load until it works. A fuse rated at 2.5A is a useful addition. Reverse one of the windings if the circuit does not oscillate.

D. Di Mario
Milan

Standalone button latch

The conventional way of entering commands from a keyboard employs a scanning encoder. Occasionally when a simple latching circuit is required, independent of complex processors. For two buttons, a pair of cross-coupled NAND gates offers a straightforward solution, but when selection is to be made from any one of say eight buttons, clearly a more versatile method is called for. It is possible to employ a counter, whose clock is stopped when the desired number is reached, but this turns out to be rather messy as it requires a gate for each button. A better method is to use the 74LS138, which is a hexadecimal keyboard encoder with built-in latches, as well as debouncing. To achieve the desired aim of eight illuminated buttons in one row, some rearrangement is necessary and a 3-to-8-line decoder such as the 74LS138 needs to be added, as illustrated in Fig. 2. The encoder scans the eight momentary push-button switches 50 to 57, using an internal clock of about 68Hz set by CT, though an external clock of up to 1kHz can be applied to pin 5 instead. The debounce time is some 22ms, determined by the value of C2 = 2pF shown. The decoder reads one and only one of its eight outputs Yo to Y7 into the low state, and the sinking current is sufficient to illuminate the respective LED. Push-buttons with built-in LEDs are very effective here, and only one current-limiting resistor (R1) is required. Another point to note is that the binary output ABC from the hex-encoder is also available for commands, depending on whether the circuit to be driven wants 8-line or 3-line inputs. In the latter format this circuit has been made up as a sub-board that conveniently mounts behind front panels, with a five-wire ribbon cable (6V, 5V, 5V, 5V, 5V) to the main PCB. The 8-line (Y0 to Y7) version needs a total of ten wires; as it turns out, the same PCB layout can be used, with either a 5-way or a 10-way connector being fitted during the assembly process.

C. J. D. Calle
Cambridge
Timer for battery chargers

Many devices with NiCd or other types of rechargeable cell specify a time for charging. This is usually several hours and it is very easy to put a battery on charge and then forget about it.

This circuit was developed at the request of my son who was given a rechargeable summer at Christmas that required a charge of 8 hours.

On operating the ‘On/Start’ switch the output is live for a preset period of from 2 to 12 hours, after which it is off. Timing is reset by switching ‘On/Start’ off and then on.

The delay is provided by the ICM7242 Timer/Counter chip, which is connected as a monostable and triggered by switch-on. The Timer drives a TLP3063 optical isolator tric with zero crossing turn-on. A PNP transistor, BC232L, buffers the output of the timer as its maximum sink current is 5mA and the optical isolator needs about 5mA. The optical isolator, in turn, controls the gate of a TIC 226M triac. The maximum current for the TLP3063 is 100mA and this current is possibly sufficient for battery chargers up to about 20 watts, but having a larger triac makes the unit more versatile. For example it could be used to switch a light off in the house when unattended. A jumper allows timing and switching functions to be tested over a short interval (20 secs to 2 mins). By simply changing the value of the 470µF capacitor the delay range may be altered.

The low-voltage components were mounted on one PCB and the two triacs are on another, with only the lead drive connecting the two. The output connector is a panel mounting 13A socket (RS part number 847-415), with the ‘running’ neon indicating when that socket is live. The unit is housed in a 150x90x55mm box.

The timer chip, optical isolator and triac are available from RS (parts number 264-793, 261-0211 and 649-403) and their Application Notes may be downloaded from the RS site. Other components came from Maplin.

Tony Meacock
Norwich

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3.3V options supporting speeds up to 200MHz and the 2.5V options supporting speeds up to 166MHz. The bank-switchable devices are organised into 64 banks with a random memory array, surrounded by multiplexing circuitry to allow each bank to be accessed by either port. The devices are capable of supporting frequencies up to 200MHz on buses of various widths, frequencies and voltage levels. The dual ports feature separate, independent clocks on each port to support communication between buses running at different frequencies, even with the two ports set at different voltage levels.

Tel: 01372 266121 www.idt.com

Watch out for miniature crystal
Fox Electronics is offering a miniature watch crystal that measures 7.0 x 1.5mm with a profile of 1.4mm for real time clock (RTC) applications. With a frequency of 32.768kHz, the new FXN327 is optimised for a 12.5pF load capacitance. Frequency tolerance is ±±0.01% at 25°C and frequency stability is ±±0.03% at 50°C over ±±40°C to ±±55°C. Turnover temperature range is ±±20 to ±±30°C operating temperature is ±±40°C and ±±55°C.

P47 Power backplane
Schroff has expanded its range of power backplanes with P47 connections for Compact PCI systems. The backplane supports the connection of up to four power supply units in parallel, with separable fault signals (FALP) (Fail) and DEQA (derating of outputs). This allows for a higher-level monitoring unit to carry out logical operations on the signals before they are forwarded to the CPU. This can be used for studying the monitoring of redundant power supplies in high availability systems at prototype stage. The System Management Bus as specified in PICMG 2.09 is integrated on the board, so with the

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storable geographical address of each slot, information on the status of each power supply in the system can be monitored at a higher level. Schroff
Tel: 01442 240474 www.schroff.co.uk

The RTXS-S family is hardwired logic, which the firm says eliminates the need for software-based triple module redundancy (TMR) and maximises the total number of logic gates available to the designer. The RTXS-S devices offer total ionising dose performance in excess of 100Krad; inherent single-event latchup immunity greater than 3636GeV/cm² single-ended upset performance, and hit-swap capabilities for enhanced soft-spawning capabilities. The family ranges in density from 302,000 to 72,000 typical gates (16,000 to 32,000 ASIC gates). Actel
Tel: 01276 803399 www.actel.com

ATS-3/STM-1 transceiver with 311MHz clock
TEC Semiconductor is offering a SONET/SDH line interface which operates at 155.52Mbps (STS-3 or STM-1) rates and provides a synchronized clock for backplane operating at 311MHz speeds. The 78PF224 interfaces to a 75Ω coaxial cable using CMOS coding and provides all necessary transmit and receive circuitry to interface to a digital framer.

TEC Semiconductor
Tel: 020 8443 7061 www.tidskemiconductor.com

WCDMA test for adjacent channel leakage
Robbe & Schwarz is offering firmware for its EM2010HD signal generator and FSU spectrum analyser to support ACLR (adjacent channel leakage ratio) measurements of WCDMA signals. According to the supplier, with power amplifiers, adjacent channel leakage must be low, especially on the downlink. For a single-carrier WCDMA signal, the signal generator features ACLR of ≥7dB in the adjacent channel and +8dB in the alternate channel. Compared to previously available performance, that

means 7dB more dynamic range and besides SCPA’s (single-carrier power amplifiers), producers of basestations are making increasing use of MCPA’s (multicarrier power amplifiers) for up to four channels.
Robbe & Schwarz
Tel: 01222 810888 www.rsk.de/chrome-schwarz.com

Instrumentation amp on a 2.7V supply
Linear Technology has introduced the LTC2053, a zero-drift instrumentation amplifier that features rail-to-rail input and output, works on a single 3V supply and is available in the tiny MSOP-8 package. It has a

maximum of 10uV offset voltage, a 50uV/°C offset drift and a high common mode rejection ratio of 116dB, which is gain independent. According to the supplier, this level of DC accuracy exceeds the precision specifications of instrumentation amps that until now have been only available in the bigger DIP and SO packages and require close supply decoupling.
Linear Technology
Tel: 01767 677676 www.linear.com

Dual cathode varistor of 15pF capacitance
For applications needing close-tuner diode matching, Zetex has introduced dual cathode varistor varactors. Two devices, the

DDV2830 LT and DDV2831 LT offer high tolerance CV characteristics, low leakage and an accordingly low phase noise performance. Nominal capacitances for the 8318 and 8328 are respectively just 15pF and 22pF for a reverse bias voltage of 2V and a frequency of 1MHz. Reverse voltage leakage current is typically as low as 0.2nA. A maximum footprint of 2.2mm x 2.2mm is required by the component’s 5072 Outline. Typically required for the 2MDC dual varistors include voltage controlled oscillators and tuned phase lock loop circuits. Zetex
Tel: 0161 622 4444 www.zetex.com

Fans look cool on the web
Fan specialist Papst has added product specifying tools to its web site. Working alongside the existing pressure and

airflow unit converter tools, the Airflow and Pressure Drop Calculators are designed to help engineers specify the company’s fans. The objective of this tool is to obtain an initial estimate of what airflow a fan needs to produce, and to deduce what back pressure the fan must overcome to deliver the required flow rate, the user then enters details of the relevant aperture size. By clicking on ‘calculate’ the result is displayed as a value in m³ and is the total available open area for air to travel through
Papst
Tel: 01264 339389 www.papst.com
NEWPRODUCTS

Please quote Electronics World when seeking further information.

Power resistors in a chip
Welwyn Components is finding applications for its range of standard and custom surface mount resistors in the design of DC-DC converters, where the drive efficiency is placing heavy demands on the specifications of components such as chip resistors. The thick film PWC series (Pulse Withstanding Chip), is available in four standard sizes; from 0805 to 2512, it offers a resistance range from 1Ω to 10MΩ, tolerance to ±0.5 per cent and typical TCR of 100ppm/°C. Its special design permits an enhanced power rating (1.5 W at 70°C for 2512) and higher Limiting Element Voltage (500 for 2512). The PCI series of precision chip resistors offers any resistance value within a specified range of 1Ω to 15MΩ, at a tolerance of ±0.1% and TCR of ±50ppm/°C. Welwyn Components Tel: 01449 580858 www.welwyn.co.uk

Dual-port comms RAM is 9Mbit
Cypress Semiconductor is offering a 9Mbit dual-port RAM. The CY7C133V provides 9Mbit of synchronous, pipelined dual-ported memory capable of buffering large packets of data between two independent clock domains. Configured as a 256k x 36-bit wide device, it provides up to 9 Mbit/s of bandwidth and allows for interface to wide buses. Unlike alternative bank-switchable devices this is a true dual-port, providing simultaneous read and write access to any cell in its memory array from either of its two ports. In addition, the two ports may operate at independent clock speeds, allowing complete decoupling of the devices being interfaced. The devices are available in a 172-pin BGA package at up to 133MHz. Cypress Semiconductor Tel: 01707 378799 www.cypress.com

Testing ADSL loop in the field
The LX100 from Yokogawa Martron is a portable test tool for the field troubleshooting of ADSL services over copper cable. The unit displays test data required for effective troubleshooting, including attenuation, noise, TDR measurements, burst noise waveform and complete impedance. Applications include verifying the signal/noise margin necessary for ADSL services, determining the locations of loading coils and bridge taps, estimating the source of crosstalk noise and burst noise, and impedance measurement. It can measure noise down to low levels (±140dBm/Hz), and will carry out measurements on attenuation levels of up to 90dB. There is an autotest mode and the instrument is fitted with a PC compatible PCMCIA memory card slot. Yokogawa Martron Tel: 01494 459200 www.martron.co.uk

Frequency translator has low jitter
Vextas has introduced a low jitter frequency translator designed for clock smoothing applications. The FX-700 is a crystal-based frequency translator that provides output frequency ranges from 1kHz to 77.76MHz with a supply voltage that can be either 3.3V or 5V. The device is hermetically sealed in a 16 pin ceramic SMD package, measuring 5 x 7.5 x 2 mm. Possible applications include SONET/SDH/ATM, WDM, digital cross connect, GSM and CDMA base stations. Vextas Tel: 02830 76205 www.vextas.com

Controller for Pentium 4
Semtech has announced the SC1747 dual-phase power supply controller to supply both V(core) and VID voltages for the mobile Intel Pentium 4 processor. It delivers the 0.600V to 1.750V core voltage up to 40A, and the 1.2V, 200mA VID power. The core voltage is set by a 5-bit DAC accurate to ±0.5 per cent. The dynamic current-sharing feature automatically balances the current in each phase, eliminating hot spots caused by mismatched trace impedances and component tolerances variations, said the firm. A linear regulator controller delivers the 1.2V, 20mA power. Semtech Tel: 020399 79900 www.semtech.com

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NEWPRODUCTS

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drives, while devices are also available in the newer US16 and US20 package styles, which are claimed to have footprints up to 3X6 smaller than equivalent TVSOP and TSSOP packages. The family offers standard logic functions, such as basic gates, bus buffers, bus transceivers, latches and flip-flops. Over-voltage-tolerant inputs and outputs allow the parts to switch as an interface between different supply voltages in the same system, says the supplier. In addition, each device incorporates a power-down-protected I/O structure that means signals can be applied to any I/O pin during both normal operation and power-down modes. Toshiba, along with Fairchild Semiconductor and ON Semiconductor, is a member of the Logic Alliance.

Tel. 01276 644370
www.toshiba-europe.com

Secure controller has USB interface

Atmel is targeting the AVR-based secure flash microcontroller which has a USB full-speed interface. The AT90SC6464C-USB is built around the firm’s AVR 8-bit RISC processor, with 64kbytes of on-chip flash memory and 64kbytes of EEPROM. The USB VI1 full-speed interface (12Mbit/s) gives it a direct high-speed connection to PC, or Internet appliance using e-Token or smartcard supplied, says the company. Examples include electronic signature, user authentication, transfers of large amounts of secure data, high-security financial transactions and access keys for secure software.

Atmel
www.atmel.com

F-class power MosFets for fast switching

IXYS has announced the availability of two power MosFets designed for very fast switching applications. The DXPF 12N5OF is rated at 12A (DC) and 5kV and its R(DS)oc is less than 0.4. The specifications of the higher voltage rated JXFD 6N100F are 1000V, 6A(DC) and 1.9Ω R(DS)oc. Both chip types are available for prototyping in either the TO-247 through-hole package or surface mountable TO-268 packages.

IXYS
Tel. 01444 242482 www.ixys.com.co.uk

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August 2002 ELECTRONICS WORLD
An Electronic Universe

I nability to explain fundamental concepts to a wide audience leads to a severe problem in communication: to be regarded as a 'technician' who hides ignorance behind jargon. The ability to design circuits, but inability to explain everything, causes a frustrating lack of self-confidence for engineers in the boardroom. Jargon without clear explanation leads to shunning by a society which doesn't appreciate more description of crucially important phenomena, e.g., 'capacitance' and 'inductance', and who want proper underlying explanations. So electronics, as jargon-dominated trivia, is being left out of newspapers and TV, despite the increasingly important reliance of society and science upon electronics.

History

A century ago, 'electronics' was the name of the latest and most prestigious science. But the researchers ended up in chaos, with Ampère's original theory of 'current' finally culminating in the calculated typical 1 mm² flow of drifting 'electrons', versus Heaviside's 300,000 km/s transverse electromagnetic (TEM) energy wave (+ those exact speed, like the local speed of light in a medium, is determined solely by the dielectric insulating material, such as air or plastic, between the conductors, not by the nature of the conductors themselves). This particle-versus-wave problem was not a new problem; it had its roots originally in 1668 when Christian Huygens proposed that light is waves, in direct opposition to Isaac Newton's particle theory. Eventually, in 1927, Niels Bohr invented a 'correspondence principle' to suppress critics by accepting 'particle-wave duality', permitting whichever calculation was appropriate for the problem in hand. Consequently, explanations became submerged by semi-empirical equations, while experimental electronic applications flourished. It is obvious that even if the entire mass of the cable was electrons, they would carry negligible kinetic energy travelling at 1 mm/s (since the kinetic energy equation is $E = mv^2$). Hence, a 1 mm² electron current cannot be the predominant mechanism of energy transfer. Ivo Carr (b. 1935) started developing TEM wave-based explanations with David Walton and Malcolm Davidson in May 1978, and published them between 1978-88 as Wireless World articles, which unfortunately were produced in an abysmal manner (absurdly rejecting electric current and displacement current out of hand using Ohm's law, without including a proper replacement theory or using the new facts which they established to produce an understanding of the unanswered problems in science).

Community of electric current in a circuit: a Science Fiction Story

Once upon a time, everyone grasped the basic law of electric currents that currently flow only in complete circuits. It was a simple theory, which was consistent with the known facts.

Sadly, it was a misleading and false theory, because the electric current cannot know if there is a break in the wire at one point until it arrives there, travelling at the speed of light for the dielectric.

Whenever any cable is connected to a power source, the power source will deliver power to the cable, because it has no way of telling whether there is an open circuit or a load at the other end. Only when the electric energy arrives at a break, is the circuit proven open. In the intervening period, electric energy flows at 300,000 km/s if there is no break. So electric current will flow in an open circuit.

It is important to stop at this stage, and carefully examine what happens in the cable that has been carrying electric energy towards the unconnected (open circuit) wire ends of the cable. First, the cable itself acquires an electric charge, the voltage between the capacitor plates connected to a power source. Due to the electric charge, an electric field occurs between the wires of the cable. Second, when the electric energy arrives at the break in the circuit, it has no place to go except to bounce back, which it does, always at the speed of light.

When we close the switch and energy goes off into the open-ended cable at the speed of light for the dielectric between the wires, nos knowing that an open circuit exists at the end of the cable:

1. Ohm's Law is violated because, in its equation $V = IR$, $R$ is the circuit resistance, which is infinitely if there is an open circuit.

2. Kirchhoff's First Law is violated since the law says electric current requires a complete circuit.

Both these problems arise because these old laws assume instantaneous action at a distance, i.e., that the electricity knows whether or not it faces an open circuit before it even sets off at the speed of light when the switch is closed! Ivo Carr's research in computer circuits disproved such nonsense.

Oliver Heaviside around 1875 corrected Ohm's Law by adding to resistance the term $Z$, which is the impedance of the dielectric used in the cable. If there is nothing between the wires in the cable, $Z$ is the impedance of the fabric of free space (vacuum), 377 ohms.

The corrected version of Ohm's law reads: $V = IR + Z$.

If there is no resistance, Ohm's law becomes $V = IZ$.

Hence, any 377 volt source will initially send in a 1 amp electromagnetic pulse (EMP or transverse electromagnetic wave, TEM wave, depending on preference) travelling at 300,000 km/s (300,000 vacuums), into a pair of wires it is connected to, regardless of whether there is a load or an open-circuit at the other end.

A consideration of what happens when the 1 amp of energy reaches the open circuit and reflects back, is the basis for the ingenious calculation (below) by Carr, Davidson, and Walton. This proves that "a capacitor is a transmission line", i.e., that electric current as presently taught in electronics, is an old deception which needs replacement by the new theory presented below.

In Oct-Dec 1978 issue of Wireless World, p.51, Ivo Carr, Malcolm Davidson and Dr. David S. Walton produced the most original and brilliant theoretical calculation in electronics since Maxwell's day: they calculated the real mechanism of charging of a pair of wires (open ended power transmission line) through a resistive $300,000$ km energy being delivered to it, with the energy bouncing back and forth as it charged up, giving a mathematical formula for exactly the same as that empirically found for a charging capacitor. We hereby set out clearly their basic mathematical proof of "a capacitor is a transmission line" and that 'static' electricity is indeed in constant $c$ speed motion:

1. Because the pair of open ended wires being charged up through resistor $R$ are in open circuit, their impedance is that of free space, $Z = 377$.

2. When the switch is closed sending energy at potential $V$ volts through the missing into the wires, the voltage of the energy in the wires is $VZR/(Z+2)$, which will move at the speed of light for the dielectric (air, vacuum, plastic, or whatever) between the wires.

3. When the energy arrives at the open or loose ends of the wires, it will bounce back at the same speed, colliding with more incoming energy which is continually arriving at potential $VZR/(Z+2)$. This adds to the incoming energy potential (since electric fields are scalar, direction does not matter in volume contributions). This gives the pair of wires $VZ(R+2)/2$ volts.

4. If the length of the wires is $x$, and the speed of light $c$, then the number of 2-way passes of the light speed energy in the wires in time $t$ will be simply: $n = x/(ct)$.

5. Each additional reflection at each end of the wires, continues to increase the voltage potential from the existing potential, although due to the difference between $R$ and $Z$, the increase will be by decreasing amounts, since the differential increase on the $n$ number 2-way pass will be: $Vn(R+2)/2(n+1)$.

6. Summing (with a geometric series) all the contributions from $n$ reflective passes of the energy up and down the wire while energy is being put in continuously with potential $VZR/(Z+2)$, gives a total voltage in the wires of $V(1-R+2)/(Z+2)$.

7. In the simple case, $R$ is much larger than $Z$, so $R >> Z$.

8. Since $R >> Z$, it follows that as $n$ becomes very large (as it will do very, very quickly, since the speed of the energy is nearly $300,000,000$ km/s), the voltage formula reduces to simply: $V[1-e^{-2(R+2)/Z}]$.

9. Since we have shown (in step 4 above) $n = x/(ct)$, the voltage at time $t$ in $V[1-e^{-2(R+2)/Z}]$.

10. The term in the exponent above, $czt$ is $3/e$, where $c$ is the speed of light, $z$ is the distance of the pair of wires, so we arrive at the standard result for a charging capacitor: $V[1-e^{-2(R+2)/Z}]$.

Hence Carr, Davidson and Walton discovered the correct mechanism of electricity, proving both 'static' and current are continuous $300,000,000$ km electromagnetic energy flows and showing that the traditional exponential charging formula for a capacitor is just an approximation to the numerous small steps of bouncing $300,000,000$ km TEM wave energy which actually occur in the real physical process.

All "Static" Charge is Oscillating $300,000,000$ Standing Waves of Electromagnetic Energy

1. "Energy can only enter a capacitor at the speed of light."

2. "Once inside, there is no mechanism for the energy current to slow down below the speed of light."

3. "The steady electromagnetically charged capacitor is indistinguishable from the reciprocating, dynamic model."

4. "The dynamic model is necessary to explain the new wave features to be explained, the charging of a capacitor and serves all the purposes previously served by the steady, static model."

(Carr, Electromagnetonium 1, Westfield Press, St. Albans, 1994, p 5).

In addition to this proof that the capacitor is a transmission line, the same thing was done for the inductor, treating it as square-shape for simplicity of calculation, with a lot of mathematical formulas exactly the same as that empirically found for a charging capacitor. We hereby set out clearly...
The Nature of the Electron as Derived from Catt's Results

The above experimental proof, conducted by Ivor Catt, who worked out the theory of mutual induction (cross-talk) in computer circuits, led to the realization that the speed of light, and the energy levels of the electron, are not constant. The proof was first published in Catt and Gibson in Proc. IEEE, vol. 73 (1985), p. 762.

Ivor Catt also did the analysis for a simple oscillator circuit. The magnetic field surrounding a current- and inductor. Traditionally, the circuit is analyzed by equating the potential (voltage) across the capacitor with that across the inductor: (1 - i)x = DC and inductance L = LI. This means that the frequency of oscillation is

\[ \frac{1}{2\pi\sqrt{LC}} \]

where L is the self-inductance and C is the capacitance.

The problem with this traditional analysis is that, as Catt states, it "assumes that when current is switched into the inductor, it appears instantaneously at all points in the circuit of the voltage, the simple, lumped line L implies this. Similarly, it is assumed that the magnetic field density at all points in the capacitor is the same... Work on high-speed logic systems led to a reappraisal of this analysis".

Ivor Catt's reanalysis of the oscillator circuit on the basis of real current flow, showed that the traditional sine wave solution is only an approximation to the reality, which is a large series of small steps due to speed or energy responses in the circuit, and not simply an open-circuit transmission line, while the inductor behaves as a short-circuited transmission line. Catt showed that the speed of very small is the important factor, which is greater than the values of the capacitor or inductor, the smaller is each bouncing pulse of current between the capacitor and inductor, so more time elapses while the capacitor charges and discharges, thereby reducing the 'resonance frequency' of the circuit. Catt published his mathematical proof in Proc. IEEE, vol. 71 (1983), p. 772.

Experimental Proof from the Discharge of a Charged Cable into an Oscilloscope: The idea of a cable being charged up to a steady 10 Volts via a 1 MΩ resistor, then suddenly discharged into a long piece of coax. A 50 V pulse 2 milliseconds into this circuit should show the speed of light for the dielectric. The voltage was half of what one would expect. It appeared that after the switch was closed, some energy must have started off to the left, away from the now closed switch, bounced off the open circuit, and then returned all the way back to the switch and beyond. This paradox is understandable if one postulates that a steady charged capacitor is not steady at all, it contains energy and is accelerating as it travels to the right at the speed of light, and the other half travelling to the left as the speed of light. This only makes sense when the switches are closed, the rightwards travelling energy will exist first, immediately followed by the leftwards-travelling energy and finally the energy out of the open circuit. Any apparently steady field is a combination of two energy currents travelling in opposite directions at the same speed of light.

(1) Catt, Electromagnetics I, Westinghouse Press, St. Alburn, 1994, pp.13-14, condensed here.)
**Keyboard input for PIC projects**

For many PIC microcontroller based projects one of the design problems that needs to be resolved is how to input commands or set up information to a PIC program.

The PIC keyboard software was written for the 16F877 microcontroller but should work with most PIC microcontrollers, however only the 16F87x and 16C74 family has the built in serial port used for testing.

**AT keyboard**

All current PCs are supplied with an AT style keyboard that has a PS/2 type connector. The keyboard was designed by IBM to be software configurable so that there is no need to manufacture different keyboards for different countries. Only the keys top need changing between countries not the keyboard circuit. The software flexibility allows keys to be added. For example, recent addition of the Euro currency key 00, and some keyboards now include dedicated internet browser keys.

**Keyboard internals**

Internally these low cost AT keyboards consist of the keys sitting on a moulded clear rubber mat, this mat is placed on top of two plastic sheets with conductive circuit tracks printed on them. This conductive pattern is a 22 by 6 matrix where pressing down a key will make the connection between the two layers at a unique intersection. The direct keyboard controller continually scans this matrix and determines which key position has been pressed and sends this data to the PC.

The keyboard controller board is a small single-sided printed circuit board consisting of a surface mount controller (hidden under black protective coating), a few discrete components, 18 wire links and the three keyboard LED's. Figure 2 shows the keyboard viewed from underneath, for clarity the two conductive sheets have been removed but they connect to the edge connector at the top of the printed circuit board.

**Power supply**

The keyboard will work off a 5-volt supply, so the same supply can power both the PIC circuit and keyboard. However the electrical characteristics sticker on the base of my ‘Ever Green Touch’ keyboard (manufactured in China) states that it requires 5V ± 170mA. It is hard to imagine that a single customised controller chip requires all this power so I measured the current and found that it was only 80mA, and with all three LEDs on the keyboard consumed a total of 20mA. This is many times what the PIC microcontroller consumes, but if you are considering a battery powered application, then the current the keyboard requires will need to be taken into account.

**Keyboard controller**

The original keyboard had a single chip microprocessor, but now a customised controller chip is used. This keyboard controller chip takes care of all the keyboard matrix scanning, key de-bouncing and communications with the computer, and has an internal buffer if the keystroke data cannot be sent immediately. The PC motherboard decodes the received data via the PS/2 port using interrupt IRQ.

The one thing that these keyboards do not generate is ASCII values. With a typical AT keyboard having more than 101 keys, a single byte could not store codes for all the individual keys, plus these keys along with shift, control, or alt, etc. Also for some functions there is no ASCII equivalent, for example 'page up', 'page down', 'insert', 'home', etc.

When the keyboard controller finds that a key is being pressed or released it will send this keystroke information, known as scan codes, to the PIC microcontroller. There are two different types of scan codes: make codes and break codes.

**Make code**

A make code is sent whenever a key is pressed or held down. Each key, including 'shift', 'control' and 'alt', sends a specific code when pressed. Cursor control keys, 'delete', 'page up', 'page down', 'ins', 'home' and 'end', send extended make codes. The make code is preceded by '0xh' to indicate an extended code. The only exception is the 'pause' key that starts with a unique 'Elh' byte.

**Break code**

A break code is sent when a key is released. The break code is made code preceded by '0xh' byte. For extended keys the break code has an '0xh' preceding the '0xh' and make code value. The only exception is the 'pause' key in as it does not have a break code and does not auto-repeat when held down.

**Key code**

Every key is assigned its own unique code so that the host computer processing the information from the keyboard can determine exactly what happened to which key simply by looking at the scan codes received. There is no direct relationship between the scan code generated by a particular key and the character printed on the key top. The set of make and break codes for each key comprises a scan code set. There are three standard scan code sets: 1-based, 2-based and 3-based within the keyboard controller. Scan code set 1 is retained for compatibility for older IBM XT computers. Scan set 3 is very similar to the set 2 but the extended codes are different. Scan code set 2 is the default for all AT keyboards and all scan codes discussed here are from this set.

**Scan code**

If, for example, you press 'shift' and 'A' then both keys will generate their own scan codes, the 'A' scan code value is not changed if a shift or control key is also pressed. Pressing the letter 'A' generates '0Ch' make code and when released the break code is '0xh', '1Ch'. Pressing 'shift' and 'A' keys will generate the following scan codes:

- The make code for the 'shift' key is sent '0Fh', '12h'.
- The make code for the 'A' key is sent '0Ch', '1Ch'.
- The break code for the 'A' key is sent '0Fh', '14h'.
- The break code for the 'shift' key is sent '0Eh', '12h'.

If the right shift was pressed then the make code is '59h' and break code is '0Fh', '59h' (echo).

By analysing these scan codes the PC software can determine which key was pressed. By looking at the shift keystroke the software can distinguish between upper and lower case.

**Keyboard commands**

The main purpose of the keyboard is to accept typed data and send this information to the host computer, however there are several commands that can be sent to the keyboard controller. Figure 3 shows some of the more common keyboard commands. There are other commands that can be used to change make or break codes for individual keys, but the commands given here are the most useful. The possible keyboard response to these keyboard commands is given in Figure 4.

**Keyboard self test**

When the keyboard is first powered up it runs a self-diagnostic test, this test primarily looks for keys that are ‘stuck’ down. All the LEDs on the keyboard will also briefly switch on and off as part of this self test. When the keyboard is plugged into a PC you may be forgiven for thinking that this was part of the PC start up sequence as it happens around the same time as the PC is powering up and

---

**Fig. 1. Keyboard to PIC block diagram**

**Fig. 2. Picture of keyboard viewed from underneath showing pcb and clear rubber mat.**

---

**Fig. 3. Summary of commands that can be sent to keyboard controller.**

**Fig. 4. Possible keyboard controller response codes.**

**Fig. 5. 74H command keyboard LED data byte.**
When the new scan code is received the keyboard will again reply with 'FA'h. To find out which scan code is currently being used by the keyboard send '00'h instead of a new scan code set number. The keyboard will then respond with scan code number '01'h, '92'h (default) or '10'h. All the scan codes presented here are those actually generated by the keyboard. When the keyboard is plugged into the PC the BIOS may translate some of these scan codes for compatibility reasons. Consequently a PC program may report slightly different scan codes for some keys.

'F3' device identity command
The keyboard will respond to this command with 'FA'h (acknowledge) followed by the keyboard device type numbers 'AB'h, '83'h. When the keyboard is plugged into a PC the computer needs to know what type of device is connected to which PS/2 port. Other PS/2 devices can also be connected, such as a PS/2 mouse, which will respond with ID number '00'h, '00'h.

'FF'h keyboard test command
If the keyboard is wired to the same 5 volt supply as the PIC, then it is possible that the stiff test result will appear with the PIC microcontroller has initialised, particularly if the PIC power up timer is enabled. If the keyboard is already powered then sending command byte 'FF'hui the keyboard to reset and run the test. This command is acknowledged by the keyboard ('FA'h) before the stiff test is executed. Alternatively use the 'F2'h command to get the keyboard device id number.

Typematic
When you press and hold down a key on the keyboard that key becomes typematic. This means the keyboard will keep sending that key's make code until the key is released. The typematic delay is a short delay between the sending of the first and second make scan code. Typematic rate is how many characters per second will appear after this initial delay. The typematic delay can range from 0.25 second to 1 second and the typematic rate can range from 60 characters per second to 30 characters per second.

'F3' set keyboard repeat rate
These typematic values can be changed using the 'F3' command (set auto repeat rate), send 'F3'h and the keyboard will respond with 'FA'h byte, then the keyboard waits for the data byte that specifies the auto-repeat rate and type.

The exception of the "pause" key, all keys will auto repeat. The default delay is 500ms.

Receiving data from keyboard
The keyboard will transmit data to the PIC microcontroller as soon as a key is pressed if both the clock and data lines are high, as this indicates idle status. If the clock line is held low by the PIC microcontroller then the keyboard cannot send the keyboard controller will buffer the keystroke data.

Variable RXbits keeps track of which bit is being received, as RXbits is incremented on each interrupt. Variable RXbits stores the highest bit of the data received from the keyboard. This is achieved by setting the carry flag according to the logic status of the data at port RB1, then using the rotate right PIC instruction to shift the carry bit.
into the keywork variable. If RXbits = 10 this indicates the PIC is processing the parity bit, however this bit is ignored by the PIC program. On receiving RXbits = 11 (loop bit) the Conv flag is set indicating the end of data. Setting this flag causes the routine PromKey to be called from the main program loop. PromKey routine clears the Conv (convert) flag and sends the received keyboard data (contained in variable char) to the Proflkes (print hex) routine in the keypad asm code.

This Proflkes routine converts the binary data into the ASCII suitable for display. Adding 48 to a binary decimal number converts that number to the ASCII text equivalent, if the number is greater than 9 then adding 55 will convert the hexadecimal number into an ASCII character. The Proflkes routine then calls the SendPC routine. This routine waits for the TXOFF flag to be set, this indicates that the serial communications TXREG (transmitter register) is empty. TXREG register is loaded with the char data and this data is automatically transmitted via the serial port to the PC. These routines are not required in keypad asm code.

Sending data to the keyboard
When the PIC microcontroller needs to send data to the keyboard, the kernel ToKey is called. ToKey sets the clock

Fig. 11. Summary of main program loop for keybd.asm.

Fig. 12. Summary of interrupt routine.

PC lOck

Fig. 14. Windows PC screen showing various command options and response received from the keyboard.

line low for 60 milliseconds using timer 0. Bringing the clock line low prevents the keyboard from transmitting data. While the data line in held low the clock line is set to input and the keyboard will start generating a clock signal. To make a port pin an output a '0' is sent to the TRISE (data direction register), a '1' sets relevant port pin to an input. Data to be transmitted is output on the clock interrupt and read by the keyboard on the rising clock edge.

PIC software
Sending the scan codes to the PC is a useful demonstration (and functional test) of the keyboard to PIC connection. It allows specific keyboard scan codes to be verified but it is of very limited application.

The main function of this software is to use the keyboard as an input device to a PIC microcontroller. Rather than send the scan code to the PC, the scan values are stored and checked for various scan codes and appropriate data values modified within the PIC application program.

Assembler listing keybd.asm shows a simple method of reading the keyboard scan codes and if specific keys are pressed, then the keyboard LEDs are turned on or off. The program looks for the letter 'A' (scan code '1C'), when this is pressed all the LEDs are switched on. When the letter 'B' is pressed (scan code '32') all the LEDs are switched off. All other key presses are ignored. These keyboard keys and which LEDs are activated can be changed, or values changed when specific keys are pressed.

Testing the interface
When the PIC is programmed with the keybd.asm code any

Fig. 15. Keyboard alpha numeric scan codes.

Fig. 16. Keyboard scan codes.

key make break

A 1'Ch 10% '1C'
B 32h 70% '32h'
C 21h 73% '21h'
D 23h 70% '23h'
E 24h 70% '24h'
F 28h 70% '28h'
G 24h 70% '24h'
H 23h 70% '23h'
J 38h 70% '38h'
K 22h 70% '22h'
L 48h 70% '48h'
M 3A 70% '3Ah'
N 3Bh 70% '3Bh'
O 44h 70% '44h'
P 2Ah 10% '2Ah'
Q 15h 70% '15h'
R 20h 70% '20h'
S 1Bh 70% '1Bh'
T 2C'h 70% '2Ch'
U 3Ch 70% '3Ch'
V 22h 70% '22h'
W 10h 70% '10h'
X 22h 70% '22h'
Y 35h 70% '35h'
Z 16h 70% '16h'
1 16h 70% '16h'
2 16h 70% '16h'
3 16h 70% '16h'
4 25h 70% '25h'
5 23h 70% '23h'
6 36h 70% '36h'
7 30h 70% '30h'
8 30h 70% '30h'
9 46h 70% '46h'
0 45h 70% '45h'

key make break

A 76h 70% '76h'
B 48h 70% '48h'
C 55h 70% '55h'
D 56h 70% '56h'
E 54h 70% '54h'
F 58h 70% '58h'
G 4Ch 70% '4Ch'
H 52h 70% '52h'
I 3Dh 70% '3Dh'
J 35h 70% '35h'
K 54h 70% '54h'
L 49h 70% '49h'
M 44h 70% '44h'
N 5Ah 70% '5Ah'
O 58h 70% '58h'
P 12h 70% '12h'
Q 14h 70% '14h'
R 11h 70% '11h'
s 29h 70% '29h'
t 11h 70% '11h'
u 72h 70% '72h'
w 12h 70% '12h'
x 72h 70% '72h'
y 35h 70% '35h'
z 16h 70% '16h'
1 16h 70% '16h'
2 16h 70% '16h'
3 16h 70% '16h'
4 76h 70% '76h'
5 70h 70% '70h'
6 70h 70% '70h'
7 70h 70% '70h'
8 70h 70% '70h'
9 70h 70% '70h'
0 70h 70% '70h'
The "AA"h is the result of the keyboard self test, "FA"h is the command acknowledgment for the device identity request. The keyboard responds with device type 'AB' and '83'. The two 'FA'h bytes are acknowledgment of the scan code query command and keyboard processor responds with scan set 2. The final byte, "FA"h is the LED command acknowledge. The program will also show any make or break codes if any keys are pressed on the keyboard.

This Windows program (two versions are available, one for Windows 95/98 and the other for Windows XP) and the two PIC assembler source programs (keyboard.asm and keyboard.s) will be available from EWH - just email: lowe@cumulusmedia.co.uk stating which one you'd like.

Construction
The PIC circuit can be built using strip-board, the 20MHz crystal can be connected to 5V for correct operation. The two inventors and series current limiting resistor are for the optional PIC serial communications. They are not necessary for the keyboard connection. The PIC expects to interface to a serial line driver which to operate would invert the data, as a serial driver is not used then the data has to be inverted. Care is needed when wiring the PS/2 socket - particularly for the power connection. Remember to observe the keyboard self test when the keyboard is installed in the socket. All the LEDs should briefly flash if the wiring is incorrect. If not then disconnect the power supply and check the wiring.

Acknowledgements
My thanks to Andrew Thomas for help with the PIC programming. PIC is a registered trademark of Microchip Technology Incorporated, USA. Windows is a registered trademark of Microsoft Corporation.

Assembler Listings

```asm
ORG 4 ; interrupt
; keybd.asm
; PIC AT-keyboard reader
; written by Roger Thomas
; MASH 23 January 2002

__config H'0922'

TMRO EQU H'01'; timer0
STATUS EQU H'03'; register
C EQU H'00'; carry flag
Z EQU H'02'; zero flag
RPO EQU H'05'; page bit
PORTB EQU H'06'; port B
RBI EQU H'01'; keydata
INTCON EQU H'08'; register
IKQ_RBO EQU H'03';

; TOFIN H'01'
; timerno
IKQ_EFHO H'07'; irq
OPT_REG EQU H'01';

; register

RXBITS EQU H'07'; port B
PERI EQU H'0C'; peripheral
RCPF EQU H'05'; serial clock
RSTA EQU H'18'; serial com
TXSTA EQU H'18'; serial clock
RXSTA EQU H'18'; serial clock
SRB2 EQU H'19'; serial co
TXB EQU H'29'; irq handler
RXQ EQU H'2A'; irq handler
RXQ_EFHO H'2B'; irq handler
RXQ_EFHO H'2C'; irq handler

; output
CHAR EQU H'2D';

TXBYTES EQU H'29';

; keydata
KEYDATA EQU H'30';

; calculate

CPC KEYW EQU H'31';

; call

GOTO EQU H'32';

; transmit
PARITY EQU H'33';

; keyboard

; BIFS

; CONV

; ORG 0

; goto MAIN
```

```asm
; keyboard
make and break scan codes will be sent as ASCII characters to the PIC serial port. This requires the 74LS14 and two resistors to be fitted. A suitable three-wire serial cable to connect the PIC to the PC's serial port will need to be made.

The Windows HIghware HyperTerminal (supplied with Windows) program can be used to view these keyboard generated scan codes as they are transmitted by the PIC as ASCII text. The program properties should be set up as follows - direct to comm, speed at 57600 baud, 8 bits, no parity, no flow control and one stop bit.

Figure 13 is a HyperTerminal screen showing the test self passed byte followed by the scan codes for letters A (make code = '1C'h, break code = '70'h), B (make code = '32'h, break code = 'FO'h, '32'h), C (make code = '21'h, break code = '90'h, '1F'h).

Followed by the extended scan codes generated when pressing the insert key (make code = '6B'h, '70'h, break code = '90'h, '90'h, '90'h) and eight byte extended code when the pause key was pressed (make code = 'E1'h, '14'h, '77'h, 'E1'h, 'FO'h, '14'h, '90'h, '70'h, no break code).

Figure 14 shows an interactive Windows program displaying the keyboard response to various commands sent to the keyboard from the PIC via the serial communications port. The four buttons (reset, keyboard id, echo, and scan code) when pressed will send that particular command to the keyboard and the keyboard's responses can be seen.

The three LEDs can be switched on or off and when the button marked "LED" is pressed this command is sent to the keyboard and the appropriate LEDs should be lit on the keyboard.

```

Assembler listings

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; keybd.asm
; PIC AT-keyboard reader
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; TOFIN H'01'
; timerno
IKQ_EFHO H'07'; irq
OPT_REG EQU H'01';

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RXSTA EQU H'18'; serial clock
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RXQ_EFHO H'2B'; irq handler
RXQ_EFHO H'2C'; irq handler

; output
CHAR EQU H'2D';

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KEYDATA EQU H'30';

; calculate

CPC KEYW EQU H'31';

; call

GOTO EQU H'32';

; transmit
PARITY EQU H'33';

; keyboard

; BIFS

; CONV

; ORG 0

; goto MAIN
```
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