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From the creators of Quickroute, Electronic Design Studio (EDS) is an entirely new program designed to integrate your projects, and through OLE2, EDS integrates applications.

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The versatile software has a user-defined toolbar with which over 50 instrument settings can be saved on disk. This enables the creation of a library of measured signals. Text balloons can be added to a signal, for special comments. The color print outs can be supplied with three common text lines (e.g. company info) on three lines with measurement specific information.

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 80 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.

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Measured signals and instrument settings can be saved on disk. This enables the creation of a library of measured signals. Text balloons can be added to a signal, for special comments. The color print outs can be supplied with three common text lines (e.g. company info) on three lines with measurement specific information.

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.

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A murmur of breaking glass?

Back in July 1998, with Windows 98 about to be launched, Electronics World carried an editorial about the Microsoft operating system monopoly. With Windows 2000 almost here, it is an appropriate time to review the situation.

The 1998 editorial was concerned with the abuses that often follow in monopolistic situations. As the subsequent lawsuits pages in Electronics World loudly pointed out, the bias was clearly against Windows, yes indeed, for what reasonable person could support a greedy giant selling faulted software at such vast profit?

However, not even I imagined the extent of the bullying that Judge T. P. Jackson revealed. Moreover, the bullying has not stopped, despite the court ruling. Microsoft is now selling systems engineers that they will lose their Microsoft certification unless they take, and pass, an exam for Windows 2000.

It seems that Microsoft is determined to stuff Windows 2000 down the throats of NT4 and 98 users whether they like it or not. Naturally, this is being done on the receiving end of this monstrous threat are unhappy, but then they are only small fry and unlikely to have sufficient muscle to resist Microsoft. Looking back a few years, it is astonishing how we all hurried to the store, money in hand and only too eager to hand the stuff over, to acquire such a poorly-designed, over-priced and unstable operating system.

With the benefit of hindsight, the stimulants was not that Windows was good - but that the alternatives were so bad. Everyone was too pleased to get something marginally better. This situation caused the start of the rise. True, the enforced popularity of Windows, fuelled by hypot not from Microsoft but by some sectors of the PC press, led to a standardisation of a sort with Windows as the common operating system. But even today this 'standardisation' is fragmented between NT, 98 and 95. Some are even sticking to 16-bit Windows 3.1 or 3.11, no doubt hoping for something better than 95, 98 or 2000 to appear.

However, judging from the number of published complaints, standardisation on a system with flaws is worse than no standardisation. There have been improvements to the various Windows versions, but not the clear-cut, mis-marked, mis-labeled, user friendly product that were expected - particularly with regard to stability. Bill Gates’ very own public blue-screen experience showed everyone that operating system instability remains an issue.

I believe that users were hoping that 95 would be more stable, and they hoped the same for 98. But it has been pointed out that Windows is, like a house built on sand, still reliant on DOS despite all the camouflage.

Houses built on shaky foundations can be propped up by a process called under-pinning. This is a laborious and not very satisfactory practice, but it does stop the house falling down - and it is cheaper than rebuilding. Is there any analogue here with Windows?

Thank heavens then for the menace of Linux. It is now supported by an impressive number of big names, many of who have signed up in the last few months. Its success seems assured. The contrast to Microsoft’s product could not be starker. Linux source code is free to anyone who wants to use it, or Windows.

Linux has an established reputation for built-in stability. It has done so to the extent that it is currently being handed abroad by the Europeans. If you can to crash Windows once a month, then you can expect to crash Linux in a year; if you crash Windows once a year, you will not crash until once every 12 years...

Despite Linux having such widespread support and a reputation for stability, the field of electronics engineering is not well served. I know of no program for circuit simulation, pcb design or autotechnology written for Linux.

Surely there is an opportunity? The first CAD company in this field with a Linux program is bound to attract the interest of every designer disillusioned with Windows - and this will definitely place the operating system ahead of the competition. Simon Wright

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New Digital Models

There are so many we have not enough room here to list them. Please see our web site at www.looking.co.uk/spice for a full list.

The UK's government has snubbed its country's engineers by rejecting a cross-party call to appoint a special engineering adviser in the Cabinet Office, according to an engineering association.

Lichfield Tory Michael Fabricant, who staged a special half-hour debate on the subject at Westminster recently, said it was wrong that issues to do with engineering are merely part of the brief of Chief Scientific Adviser Sir Robert May.

"The government's continued refusal to accept that engineering is wealth creating, and different from science, helps to perpetuate the myth that engineers are of a lower status," said Fabricant. "That is a dangerous and ignorant over-simplification of reality."

Fabricant's concerns over the implications for the status of engineers were backed by fellow Chartered Engineer and Labour MP Claire Curtis-Thompson.

"The government's persistence in not employing an engineering adviser to the Cabinet sends an unfortunate message to the two million or so engineers in the UK, which is that their status and their contribution to the quality of our lives are not acknowledged or understood at the highest level of government," said Curtis-Thompson.

Fabricant said he had no criticism of Sir Robert, who despite having training in chemical engineering was essentially a natural scientist, but added: "Engineering forms part of his brief because the government sees engineering as no more than a branch of science, a sub-set on a Venn diagram."

And he continued: "Every measure, engineers enjoy — if that is the word — a lower status in the UK than in France, Germany, the USA or Japan."

Trade and Industry Minister Patricia Hewitt rejected the plea, saying: "We are very happy with our Chief Scientific Adviser. My understanding is that, contrary to what has been said, most other countries have a Chief Scientific Adviser who embraces engineering. Hewitt insisted the government had "a deep understanding and appreciation of the extraordinary contribution that engineers make to the quality of our lives and the strength of our economy."
Suggestions that GPRS mobile phones with data speeds of 100kbit/s will be available in the middle of this year have been branded as "wildly optimistic" by mobile operator Orange.

In its report 'The Future of Mobile Data Technologies' the company said there has been much conflicting and frequently misleading information about the availability and potential of next generation technologies.

Orange believes deployment of GPRS could be available within two years but "extremely unlikely" as terminals will not be available until 2001. It says the data rates offered will initially be 14.4kbit/s rising to 57.6kbits/s by the end of 2001. 'Orange is not advising HSCSD technology as a soon-to-be-available alternative rather than waiting possibly two years, said the report.

Revel company Vodafone believes GPRS will be available in 2000 and intends to start trials in the first quarter. It sees the technology being introduced here as a matter of being a "few years behind the year.

But a spokeswoman said: "We believe in GPRS as a technology that will become widely available in 2001." Orange's report also shows EDGE, the last evolution before 3G mobiles, will happen in 2002 at the earliest.

School design & technology opt out attacked

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Tory ghost haunts UK’s chip capability

Restrictions imposed by the last Tory government could jeopardise the country’s capability in high-end chip design by barring UK participation in European R&D programmes, writes David Manser.

Next generation European microelectronics R&D will focus on system-on-chip technology, said Dr Jurgen Koenker, chairman of MEDEA, the pan-European chip R&D organisation, in Paris late last year. However, UK participation in European programmes is restricted to companies with under 250 employees and to universities with small company links. This debar both UK universities and small companies because university R&D tends to get funded by larger companies, while small companies have found it too expensive and time-consuming to get into European programmes.

“We had a meeting with the DTI but they do not expect any change in the rules,” said MEDEA’s director, Gerard Mahtors. At the Department of Trade and Industry, Dr Tim Scragg, said: “We’re taking a strong interest. I believe we need to have the whole infrastructure across the supply side to the design side. The roles on participation are always being reviewed.”

“There is a danger that the UK microelectronics design community could lose their edge if they are excluded from the systems knowledge gained from collaborative R&D,” warned industry analyst, Malcolm Penn.

According to Ian Barnett, chairman of PEM, which represents companies supplying the chip industry, many small UK firms which qualify under DTI rules are excluded from participating because they do not have the time or resources to apply for European projects. “Exclusion means our members only get European-generated IP when it is generally available – not when the participants get it. In areas of design, knowledge is power and months really count,” said Barnett.

NTL and Alcatel trial 6Mbit/s ADSL phone links in UK

Telecoms operator NTL has teamed up with Alcatel for a trial of broadband ADSL technology applications for businesses in Surrey.

The trial, one of two or three in the UK, involves a small number of customers in Woking and Guildford and is more about configuration of the network rather than the ADSL (asymmetric digital subscriber line) technology itself, NTL already agrees does works. The intention is to roll it out towards the end of this year.

Part of the trial will involve direct access for being worked via a cable modem to their ADSL-linked company networks. It is believed to be the first time a cable modem to ADSL modem link has been optimised in the UK.

“We’re sitting for seamless integration across a number of transmission technologies,” said Stephen Rowles, NTL’s group MD of business solutions.

“The company sees a role for copper cable-based ADSL technology even in its largely optical fibre network. “There is a place for ADSL among our fibre,” said Rowles, “and as the local loop gets unbundled we are well placed to roll it out.”

The trials will demonstrate applications at speeds up to 6Mbit/s. Pricing of the service has not yet been determined but NTL is “watching others very keenly.”

In a separate move Internet service provider Cerbernet is inviting up to 50 companies to take part in the second phase of BT’s ADSL broadband communications trial.

A full commercial service, using BT’s ADSL network technology, will be available in March 2000. The first phase of the trial began in early 1999.

“Cerbernet has worked with BT in the development and trials of ADSL technology since day one, and the business applications of ADSL than any other UK service provider,” said technical director of Cerbernet, Justin Keeney.

BT is upgrading 400 local exchanges with ADSL technology, which supports up to 6Mbit/s downstream existing telephone lines to the user.

Retina chip implant may let Stevie see for the first time

Soul star Stevie Wonder, who went blind shortly after birth, apparently wants to undergo an experimental medical procedure to regain limited vision through the use of a chip implanted on his retina.

Wonder lost his sight as a prematurely-born infant after being given too much oxygen while in an incubator.

The procedure, which involves placing a chip on the retina and stimulating cells within the eye, and the visual centre of the brain, would in theory allow the patient to regain sight for up to 30 minutes at a time, according to published reports.

Such a device would have to run on very low power levels so as to not injure the eye by generating heat, says Gerald Chader, the chief scientific officer of the Foundation Fighting Blindness. He described the area where the chip is implanted as having the consistency of wet tissue paper. Such a chip would not confer full sight on its wearer, but instead allow them to see varying shades of light and shapes Chader said.

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Spray without sputter

Ever tried spray painting? If you have, you will appreciate the benefits of an electronic system that can hear when your spray gun's about to clog. Such technology is not yet within the reach of domestic users, but as Roy Rubenstein explains, the prize-winning technique that can hear clogged jets does work. And it could well have implications in other areas.

If you want to summarise the essence of DSP, it's about transforming signals or extracting information from them. The nature of the information being looked for can be extraordinarily subtle.

Take a car production line - and in particular the spray guns used to paint them. At present there is no way to give the user feedback regarding the state of the spray gun. Instead preventative cleaning is required if problems such as the gun clogging are to be avoided. Inevitably though, taking time to clean the gun affects productivity.

Joerg Kuechen of German firm Gavitec has looked at using the wavelet transform to monitor the spray process. Wavelet theory offers an alternative approach to the traditional fast Fourier transform (FFT) when analysing signals. In particular it is suited to tackling short duration signals, an area where the FFT falls short.

Kuechen has investigated applying the wavelet transform to the audio signal given off by the gun, to quickly detect any abnormalities. For example, air in the lacquer can cause 'spitting', resulting in 'bulbs' being deposited on the car's surface.

His entry was the competition winner of Hunt Engineering's innovation competition. The Somerset-based DSP systems specialist has used the competition to gain application ideas for its products.

To monitor the spray gun, a small microphone is placed near the nozzle and its output signal is sampled at 44.1kHz to a 16-bit resolution. Kuechen's design uses two Texas Instruments TMS320C6201 very-long-instruction-word DSPs to process the audio signal.

The first DSP performs the wavelet transform, and passes the results to a second device for analysis. Up to 24 nozzles can be monitored using the two DSPs.

When the gun begins to clog, or the viscosity of the paint changes, the pressure and the air mixture can be changed to ensure the quality of the spraying. Productivity also improves by reducing the downtime needed for the gun's cleaning.

Hunt Engineering has supplied Kuechen with an eight channel a-to-d card and two C6201 DSPs. He has six months to implement the process control system.

According to Kuechen, the technique can be applied to a variety of industrial processes. One application already being considered is the control of a laser welding process. Here impurities in the material being welded, the focus of the laser and other difficulties can require that the laser power be adjusted. These difficulties can be tackled by applying the same technique to the sound of the welding process.

See www.hunteng.co.uk for more...
Digital signal processing (DSP) on the other hand does have real benefit does a microprocessor powered toaster bring? Traditionally analogue systems, the digital revolution has not passed hearing instruments by, and DSP is allowing manufacturers to use a whole new range of algorithms.

"Since the first hearing instruments appeared on the market the complexity has grown by about 100 times," says Gys Leenen, head of DSP and IC development at the newly merged Beltone/Philips Hearing Technologies. "The most complex devices on the market have more than one million transistors."

Companies shifting to the brave new digital world include the recently merged Beltone and Philips, GNRSound, Phonak and Siemens Hearing Instruments. DSPs are also coming from Mitel Semiconductor, Menlovia, Infineon Technologies and Texas Instruments.

"We are in one of the few fields where chip area is a concern," Leenen at Philips points out. Just to make a chip and package designed to fit snugly in the ear canal is a major task. To then make it last a whole week before changing the battery is another incredibly difficult challenge.

Most companies use a two or three chip configuration. Philips has a complex ASIC for all signal processing and data conversion, while the second chip is an EEPROM. Philips' ASIC holds everything except the non-volatile memory, including a 24-bit converter, DSP, microcontroller and their associated RAM and ROM, oscillators and a special class D output stage.

"Then we have quite extensive power supply circuitry," says Leenen. The DSP is designed specifically for the hearing algorithms required. "We use very long instruction words (VLIW) to do up to 10 things in parallel in the ear canal," says Leenen. "We want to do things in parallel to keep the clock speed low."

Therefore voltage can be reduced and hence power reduced. "The highest clock frequency we have is 10MHz, but we still have hundreds of Mips," Berg points out.

Like Philips, Phonak insists that a custom DSP is needed in such a power sensitive application. "Voltage and hence clock frequency must be kept low, which means using a parallel processor. A general-purpose DSP would have an order of magnitude greater power consumption," Berg claims. "They would have to drain 10mA."

Phonak uses several further techniques to reduce power. "We try to optimise the system for minimum memory access," Berg says. The DSP uses gated clocks and the multiple execution units. "The very long instruction words to the DSP can be up to 650 bits long. The DSP and pulse width modulation controller for speakers are fabricated in a 0.25µm digital chip, while three a-to-d converters, FSK remote control receiver and power management are made in a 0.35µm mixed signal process. Along with a 64K EEPROM, the chips are stacked together in a single package.

"At 1V it is used to be exotic — but not any more," says Berg.

In order to reduce problems as much as possible, Phonak always tries to use well understood semiconductor processes. "We have a 0.35µm mixed signal and a 0.25µm digital process and the technology is absolutely superb," Berg says. "Using unknown, exotic technology is not on the cards: "You're bound to run into trouble."" Texas Instruments (TI) has a roadmap for its C5000 family of DSPs that leads to 0.5V devices next year. These, the firm says will be targeted at, among other things, hearing instruments.

"We see the hearing aid market as very demanding in terms of power," says Gwiatrz Toquet, TI's manager for its C5000 cores. "Next year we will be able to provide 30Mips at 0.9V. However, the use of Mips as a metric can be misleading, as these types of processor often have special instructions replacing several simple instructions."

"The C5000 has some very specific instructions such as FIR that can reduce the number of instructions and therefore the power consumption versus general purpose DSPs," Toquet points out.

The evolution of hearing instruments from analogue systems through hardwired digital to the latest programmable DSP powered models has brought software to the party. There is an increasing importance placed upon software, Toquet says. Hearing instruments are being designed that allow a choice of algorithm, depending on the environment and these can be tailored to an individual's hearing loss.

Toquet says that although its lowest power C5000 devices will not be ready until next year, designers are using existing chips to test out algorithms and system designs.

**LISTEN with DSP**

Swiss precision... Phonak's behind-the-ear hearing aids use its VLIW, parallel processing DSP architecture. The device manages around 130Mips at just 10MHz clock frequency. By the way, they're not normally transparent.

**Infineon's Carmel DSP and hearing applications**

Infineon Technologies' Carmel DSP is also being used for use in hearing applications. Like the Philips and Phonak devices, it uses a VLIW approach with multiple execution units. Carmel can perform up to 15 basic operations in parallel.

At normal voltages of 2.5V, power consumption is claimed to be 180mW at 120MHz. Dropping the supply to 1V (reduces power by 80 per cent) and dropping the clock down to a few megahertz would bring Carmel into the realm of the hearing aid DSP.
It may surprise you that the largest independent research centre in Europe is in Belgium, and that last year it made 46 patent applications and was granted 14 patents. Richard Ball looks at IMEC.

Tucked away in a small corner of Belgium is Europe's largest independent microelectronics research centre. From the small university town of Leuven, IMEC has produced some of the most important semiconductor process technologies of the nineties. From humble beginnings in 1984, IMEC currently has a budget of $78m and employs over 850 people. The centre's research programmes are typically about five years ahead of commercial industrial needs. As such it works with almost every field of semiconductor technology from lithography and dielectrics to ferroelectric materials and high-level design tools.

Last year, the centre published 183 papers, delivered 372 conference papers, made 45 patent applications and was granted 14 patents – not bad for a collaboration of relatively small Belgian universities.

"Today it's the largest independent research centre in Europe," says Gilbert Declerck, president of IMEC. "We are working on the design of integrated information and communication systems, semiconductor process technology, silicon technology and device integration, material components, packaging and training.

This year's contract research is worth $45m. While just under a third comes from Flemish industry, the biggest source – over 40 per cent – comes from industrial partners, split 50/50 between US and European firms.

With EU funded research dropping away, much more work is being done with semiconductor firms from the US and Europe. In order to cope with the complexity we are working with all the major industrial companies," says Ludo Deferm, IMEC's v-p of business development.

No single company could hope to develop all the critical technology themselves. Cooperation is the key, and for big companies such as AMD, Intel and Motorola to do so means IMEC is both trusted to be independent and up to the task.

At the highest level of IC development, IMEC is working on design methods, including a C++ development environment. VHDL is not good enough anymore, says Deferm, therefore IMEC is using C++ for an object oriented approach.

IMEC's programme is called OCAPI, which is testing at various companies.

In process technology, IMEC's major research area, it is figuring out how to continue scaling down the size of CMOS devices.

"We need higher frequency operation, so we need to scale down the CMOS process as fast as possible," points out Deferm. "The 193nm programme has been successfully started and is running at high speed."

193nm lithography is needed for 0.13, 0.10 and 0.07µm transistors. "But this programme is not ready and will not be for two years, therefore it is behind what the industry needs," Deferm says.

IMEC and its partners are working on third generation lithography techniques such as optical proximity correction and phase shift masks in order to do so.

"Another programme which has just started, and is another bottleneck, is high-k gate dielectric materials," says Deferm. "Materials with high-k, a high dielectric constant, are needed in order to get a thinner gate insulating material without electrons tunnelling through.

"There are materials developed for DRAM, but these are not suitable," says Deferm. "Materials such as tantalam pentoxide and strontium titanium oxide don't interface directly to silicon, and can't be used in a standard high-temperature CMOS process.

IMEC recently agreed to work together with ASM International to use atomic layer CVD (chemical vapour deposition). This can put down layers of molecules at a time, producing well ordered structures with relatively few defects. IMEC hopes this will help fix the gate oxide problem at the 100nm level.

At the back end of the chip process is the metallisation. IMEC is researching the use of low-k dielectric material and copper for metal.

Low-k means a value of less than 2.0 – half that of the silicon dioxide being used today. Reducing the capacitance of the material surrounding metal lines reduces crosstalk and improves propagation delay through long lines.

While researching these new materials will cause some headaches for semiconductor companies, the problems are not insurmountable, believes Deferm: "I don't see any limitation for CMOS in the next ten years."

Memory is also important, but IMEC's size limits its research capability, so it has focussed on non-volatile RAM, specifically ferroelectric RAM and magnetic RAM.

"We focused on non-volatile memory technology. We have a patent on embedded flash technology which we are transferring to AMI in the US," Deferm says. "Also we started about five or six years ago a ferroelectric memory technology."

This is now being transferred to STMicroelectronics.

Memory

New materials research has led to a possible magnetic RAM technology, quite different to Motorola's attempts to develop MRAM.

"We worked with tunnelling cells to see if we could use this as a memory," says Deferm. Like FRAM, but unlike other forms of non-volatile memory, MRAM can use a low voltage. "The problem with MRAM is power. To make a magnetic field you need a large amount of power," Deferm points out. The requirement is to develop materials that change resistance with a very small magnetic field, which would thereby reduce current and power. Magnetic materials also bring other problems, including a processing temperature limit of around 400°C. Therefore oxide layers need to be sputtered and not deposited in the normal way.
Adaptable active speaker system

Unhappy with existing loudspeaker configurations, Christof Heinzerling set to work designing a three-way active system. It involves a squarewave-in, squarewave-out crossover network, electronic bass roll-off compensation and spherical enclosures for minimal diffraction.

I have enjoyed numerous live concerts, but I have yet to hear a sound system that could faithfully reproduce live sound in my living room. So I decided to build the ultimate loudspeaker system. I investigated many technical papers before embarking on the design. There seems to be a lot of detail on bass reproduction, but there is little information on closed-box all-round concepts of the type that could suit my needs. But, after a lot of searching, trial and error, I believe I have found the solution.

Design goals
My wife appreciates good sound quality, but prefers it to come from an enclosure that is ideally invisible. Despite the enclosure size restriction, I decided that the bass should extend...

Fig. 1. If the bass unit's response is to be lowered from 40Hz to 20Hz, a sound-pressure increase of nearly 20dB is necessary to achieve the same perceived level, as these loudness contours show.

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February 2000 ELECTRONICS WORLD
**Table 1. Specifications of the TDA 1514A 50W high-performance audio amplifier.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>min</th>
<th>typ</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply voltage range</td>
<td>±10V</td>
<td>±5V</td>
<td>±30V</td>
</tr>
<tr>
<td>Peak output current</td>
<td>6A</td>
<td>3A</td>
<td>10A</td>
</tr>
<tr>
<td>Total quiescent current</td>
<td>±12mA</td>
<td>±1mA</td>
<td>±10mA</td>
</tr>
<tr>
<td>Power out at ±25V, THD-60dB, Rl=4Ω</td>
<td>28W</td>
<td>26W</td>
<td>30W</td>
</tr>
<tr>
<td>Power out at ±25V, THD-60dB, RL=8Ω</td>
<td>48W</td>
<td>45W</td>
<td>50W</td>
</tr>
<tr>
<td>Total harmonic distortion at 32W</td>
<td>-90dB</td>
<td>-95dB</td>
<td>-96dB</td>
</tr>
<tr>
<td>Slew rate</td>
<td>14V/µs</td>
<td>12V/µs</td>
<td>16V/µs</td>
</tr>
<tr>
<td>Signal-to-noise ratio at 50mW</td>
<td>-30dB</td>
<td>-32dB</td>
<td>-33dB</td>
</tr>
<tr>
<td>Output offset voltage</td>
<td>7mV</td>
<td>5mV</td>
<td>10mV</td>
</tr>
<tr>
<td>Input bias current</td>
<td>0.1µA</td>
<td>0.05µA</td>
<td>0.3µA</td>
</tr>
<tr>
<td>Supply voltage ripple rejection</td>
<td>56dB</td>
<td>50dB</td>
<td>64dB</td>
</tr>
</tbody>
</table>

---

The concept

In Fig. 5, taken from reference 2, you can see that at 20Hz, around 80dB is necessary to produce the same sound pressure in contrast to 10dB at 1kHz. Similarly, 100dB at 20Hz is necessary to produce the same pressure as 60dB at 1kHz. A large bass membrane area is indicated by these figures. To keep the enclosure small, it is possible to apply a woofer in the side of the cabinet, but this degrades the stereo image, so multiple smaller speakers are a good compromise.

In spite of the very low 20Hz requirement, I chose closed box, as suggested once in Speakers’ Corner5. As the sound pressure rolls off at exactly 12dB/ octave it is possible to compensate for the roll-off with well known filter circuits. A blameless physical -- and also mathematical solution.

---

**Fig. 2a.** This is the circuit of one complete power amplifier. The metal area on the back side of the chip connects the negative supply voltage -UBB. The reservoir capacitors are soldered directly to plus 4.7µF. Corner frequencies are 3.2kHz and >1MHz.

**Fig. 2b.** The strip-line board measures 5cm by 5cm. Each is mounted on a 2mm-thick aluminium angle bracket measuring 20mm by 30mm and 50mm long. This bracket is large enough to allow testing. In use, the main heatsink is needed to remove additional heat caused by continuous operation. The metal connects the negative supply voltage -UBB.

**Fig. 3.** Principle crossover-filter in its simplest form. It shows that an input square-wave is exactly reproduced as an output square-wave. Input steps will not be distorted, resulting in a 'correct-step difference filter'.

**Fig. 4a.** Simple high-pass filter is replaced by a second-order Butterworth high-pass filter (Rl / R2 = √2/R1) with a corner-frequency of around 1kHz.

**Fig. 4b.** Amplitude and phase response of the high-pass section are standard. The response of the low-pass channel is for illustration purposes only. Response roll-off is poor, at only half of the corner-frequency of the used filter.

**Fig. 4c.** The step response of the high-pass filter shows overshoot but the phase shift is not visible. That means that the overshoot of a Butterworth filter adds no distortion in the time domain.
Fig. 5. This is the whole control circuit. Op-amp $U_{2}$ supplies the high passes of the three frequency bands. The upper frequency band is then subtracted from the next lower band in a difference amplifier. In this way, the corner-frequencies are reproduced exactly. The allowable load is $50\Omega$ so linear potentiometers can be connected without buffering. These feed the inputs of the power-amplifiers as, in the case of the woofer, the bass filter. The bass filter provides box equalization and bass-lift to compensate for attenuation in the sub-bass area. The frequency values represent $6000\,\text{Hz}$.

$\text{Fig. 6a). Equalization. The natural box response is characterized by } L_C=25\,\text{Hz} \text{ and } C_{\text{ref}}=0.06. \text{ As an equalled response of } y_{\text{in}}=25\,\text{Hz} \text{ and } C_{\text{ref}}=0.06 \text{ is required it is necessary to implement the circuit in } 6b) \text{ to generate the equalization response. This simple method is possible because the slope of the closed box is indeed exactly } +12\,\text{dB/octave.}$

Fig. 6b). Well known bass-equalization around $U_{2}$. Calculating the properties of box A gives the values shown in the circuit. The bass-boost around $U_{2}$ is a simple Bassandall circuit. When throwing a party you can save your woofer by reducing the driving voltage with the bass-boost potentiometer.

Is loudness control necessary?

Take a look at the phon values of the loudness contours at 1kHz and 20kHz in Fig. 8. You will notice a difference of 60phon if you look at the 1kHz-60phon contour. At the 1kHz-20phon contour you will see a difference of 60phon.

That means that if the sound image at normal sound pressure is balanced, there must be a considerable deficit if the sound pressure is reduced to a low level. And this deficit gets worse as the frequency gets lower. The same effect arises at the high-frequency end, worsening with the age of the listener.

Because of these effects, correction at both ends of the frequency spectrum is needed to ensure that all parts of the spectrum are properly represented as the volume control is raised and lowered.
Filter details

Figure 4a shows a second-order Butterworth filter in the high-pass section. It has a corner frequency of 1kHz. The value shown results in an amplitude of -3dB, a phase of +90° and an ascending slope of 12dB/oct to the HP output. All this is well known. If you subtract this HP signal from the input signal you get the frequency responses in Fig. 4b).

The high-pass section is conventional. The low-pass section is only for illustration purposes. From it, you can ascertain that there is a slope of only -6dB/ octave -34° at the corner frequency of 1kHz. -6dB/oct. This slope is independent of the bass reproduction. In addition the electronic filters, mechanical constructions and the damping associated with vented enclosures were relatively complicated. As there is bass lift, Fig. 6a), about +1.9dB and it has a phase angle of about -90° at the speaker frequency range. But if you look at the double corner frequency of 2kHz you will see that the high-pass stage has reached its final amplitude and a phase of +43° is measured. The difference cut-off is now unnecessary. Then see to be no need for an extended frequency behaviour of the bass unit above double the corner frequency.

In the time domain, the properties of the filter are excellent. A Butterworth filter shows overshoot, which results in undesirable distortions in transient musical events. But if you look at the step response of filter Fig. 4c) you will see that this overshoot is compensated in the difference output, making it insignificant. In other words, transient events will be exactly reproduced. Depending on the applied filter characteristic, resulting in clear sound.

Control circuitry

Now I’ll explain the control circuit, Fig. 5. In reference 2, Ben Dennis tested the distortion behaviour of audio op-amps and of those tested, the NE5532 came out best. But as this amplifier is compensated to provide stability at unity gain, its slew rate is only 96V/µs. If you replace this amplifier with an OP-275, the slew rate rises to 221V/µs and a cleaner sound results. The voltage noise density is slightly higher, but this is of little consequence. Its price though is double that of the NE5532, at about £1.

Distortion is well below 0.001% if the maximum signal amplitude stays below 3V. In the interests of low noise and minimal errors, 10kΩ resistors were used throughout.

Figure 4b) shows the high-pass filter in a three-pole low-pass filter, the treble, the middle-range and bass. The treble filter has a low corner frequency of 4kHz. Its output, at op-amp U9, feeds the treble potentiometer whose inner resistance doesn’t exceed 600Ω. This treble signal also connects to the inverting branch of the upper difference amplifier U8, to limit the high-frequency domain in 4kHz.

With a corner frequency of 400Hz, the mid-range filter works in the same way. This frequency is relatively high. It allows the use of small mid-range speakers with low membrane mass, while the woofer only has to work up to 1kHz.

The second-order high-pass in the bass branch, comprising R5R6C10, works together with the high-pass of the input circuit C9, R1. This yields a third-order Bessel high-pass filter with 20Hz, a lower corner frequency at the output of op-amp U7. As the output of op-amp U5 is the bass channel, which drives the internal bass potentiometer. As mentioned above, the closed-loop equalisation is easy to realise. In Fig. 4b) the line shows the natural response of the built-in speakers with f, and 1kHz. Correction values f, and f, are chosen to produce the bold line, in the equalised response. Equalisation is provided by the well-known network shown in Fig. 6b).

Calculations for determining the resonance and correction values are presented in a separate panel. The values here are for the small box ‘A’.

Finally, there follows the deep-bass booster. It is an ordinary Basswood bass control with a range of ±12dB and an upper corner frequency of 94Hz.

Setting up

A quick check of the signal voltages within Fig. 5 can be made to ensure proper working. Assuming an output power of about 40W at the bass speaker with a 4Ω load, an effective output voltage of 12.7V is needed, which requires 1.27V at the input of the power amplifier.

As there is bass lift, Fig. 6a), about 0.2V needs to be delivered to the internal bass potentiometer and also to the input. This is because the filter circuit here has a voltage gain of unity, which represents a good compromise between distortion and noise.

The control potentiometers are linear. As the power amplifiers have a capacitive input, no precautions are needed to suppress offset voltages at the output of the control circuit. As a result, the circuit is simple and is safe.

Conventionally, the power supply is built with a toroidal transformer of 2x18V/120W and (6x220µF/55V) for box ‘A’. A voltage of the control circuit is derived from the supply of the power amplifiers and stabilised by 7815 and 7915 regulators. Every op-amp’s pin 4 and 8 are direct connected to each via an 100µF capacitor.

All the circuits are impedance so there should be little hum and noise. With an input resistance of 60kΩ there was -81dBV noise and hum at the woofer and -90dBV at the treble connections measured in JAS.

Designing the enclosures

There are three cases to design for the different speakers. Firstly the bass speakers.

My experiments with vented enclosures did not lead to a satisfying bass reproduction. In addition the electronic filters, mechanical constructions and the damping associated with vented enclosures were relatively complicated. So I chose the infinite baffle solution, which is very easy to damp effectively with sheep’s wool. This agrees with reference 3, as above earlier.

In Fig. 7, front board D is 19mm beech plywood. Building the side and rear boards A, B and C of 16mm chipboard with beech limitation veneer is a cheap solution. The front and rear panel involve the baffle cuts.

To avoid precise wood working, the front panel protrudes on all sides around 1cm. The woofers drive in opposite directions, so there is no need for heavy wood construction. Dimensions for diverse layouts are shown in Table 2.

For the mid and high-range speakers, I used wool-filled styrpore speakers with diameters of 7.5 and 10cm for the small 4cm tweeters. As the mid-range speakers need a small volume of air, hollow spheres of 15, 20 and 25cm diameter can be used depending on the enclosure configuration you choose.

In Fig. 8 you can see the spheres with some speakers at the right side and other materials I used. At 2cm, the thickness of the styropore wall provides
very good damping so no sound from the rear of the speaker radiates into the environment. The sphere surface cause no diffractions, and this justifies a precise stereo image, the instruments are fixed in the room and the stereo area is enlarged.

The closed boxes are damped with sheep's wool. The speakers in the mid-range section exhibit Qec values of about 6.0-7.0, which I can live with. I built the speaker parts in very soft, they have to be stabilised. Here begins the artistic phase of the design, because I recommended coating the surfaces with paper mache. The stability increases enormously, but each sphere requires about an hour of art work.

With the speaker mounted, the sphere will roll due to its weight so a counterbalance is needed. A paper mache surface doesn't look very nice. I applied a second coat of a cement-based material, which resulted in a very high quality surface. This coating increased the weight too, giving me a perfect enclosure for a total of about 63 kg.

The tweeter spheres are set up that their voice coils are vertically in line with those of the mid-range drivers, whose voice coils are in turn lined up with those of the bass units. In this way, all the speakers radiate from the same plane, resulting in phase-linear radiation. Figure 9 shows the results of my efforts.

Mounting details
Mounting the speakers into the styropor is a little difficult. A 2cm deep hole whose diameter suits the mounting requirements of the chosen speaker needs to be sawn. Next, stabilise the speaker surface with PVA glue. Smaller speakers can now be fixed with silicone adhesive. With larger mid-range units, I advise using an adhesive to glue a wooden ring on to the face of the sphere and screw the speaker to the ring, ensuring perfect coupling to the bass units. In this way, the spheres act as a sphere an d screw the speaker to the rear of the speaker radiates into the room and the stereo area is enlarged.

In summary
Listening to music from these boxes comes close to my dream. They sound good, but they also look good - so good that in fact my wife finds them acceptable!

Speaker sources
Seas and Monitor loudspeakers are available from Wilmslow Audio, tel. 01465 286603, www.wilmslow-audio.co.uk. Gradient products can be found at www.speakerland.com.

Continued on page 164...

References
INSTRUMENTATION

Power factor and how to measure it

Michael Slifkin and Yosef Chernobrodov explain the importance of power factor and present a means of measuring it.

Power factor is one of those parameters that engineers learn about at the beginning of their careers but often have only a sketchy idea of what it means. Yet, an understanding of power factor and what it implies is important to anyone working with electrical and electronic equipment.

Four parameters describe the quality of the mains supply and are important in their own way. These are the frequency, the voltage, the harmonic content, and the power factor. At one time, it was not uncommon for the clocks maintained that the mains were not driven from the mains. Except during times of high loading and voltage shedding, the mains frequency was used to drive clocks and synchronous motors. There was hardly a lounge or parlor in the land that did not have an electric clock on the mantel driven from the mains.

One time, it was not uncommon to run droppers from synchronous motors driven from the mains via a gearbox to give a range of accurate rotational frequencies. In the UK, a voltage drop is very rare but in less developed countries it is not uncommon to have nominal voltage fall to as low as 180V from 230V during peak usage. An instrument not seen in the UK, but common in such countries is a small plug-in voltmeter fitting in a domestic socket to monitor the mains voltage.

Harmonic content

Harmonic content is a big problem in all situations where there are appliances that use a lot of electricity, such as inductive motors. These can create havoc with electronic instruments. Large spikes caused by switching heavy loads in the near vicinity can cause severe overloading and the destruction of ICs on a large scale.

The power factor is a less obvious phenomenon, but not one that should be ignored. There seems to be a lot of misunderstanding about the power factor. During the course of preparing this article we surfed the Web to see what others had written and found at least two Web sites which stated that the power factor could take values from zero to infinity. One of the Web sites actually belongs to a firm manufacturing power factor correction equipment! These have since been corrected.

So what is power factor?

In an AC circuit, power is expended when current flows through a resistive element such as an electric fire. The

Specifications of the power factor meter

- Input voltage: 60 to 240V rms
- Current input: 500mA to 17.5A
- Frequency range: 40 to 70Hz
- Power factor: 1 to d or 90 degrees, depending on the phase angle. The power factor may be corrected to any degree in the second quadrant.
Circuit diagram of the power-factor meter comprises the external load for inputting the mains voltage and current, the frequency and phase detector section and the microcontroller together with its associated EPROM.

power used is recorded on the power meter supplied by the electricity company. For peak current I and peak voltage V, the power is simply VxI. If there are reactive elements in use such as capacitance or inductance often associated with fluorescent lights and electric motors, then although current flows through these, there is no consumption of energy even though extra current is being drawn from the electricity supply. This is because the current is exactly 90° out of phase with the voltage. Unfortunately for the electricity companies, this extra current is not recorded on the power meter.
In capacitance, the current leads the voltage whereas in inductance, the voltage leads the current. In most situations, the power factor is likely to be influenced by inductance. This situation is termed ‘lagging power factor’ as the voltage lags behind the current. Hence, most power correction systems normally consist of banks of capacitors, which are switched automatically to adjust the power factor upwards.

Continued on page 147...
Holes and poles - active filters come in all shapes and sizes, but one important class is the notch filter, and its inverse, the 'notch pass', or narrow band selective filter. The notch knocks a narrow 'hole' in the frequency response of signal path, while its inverse, the narrow band-pass produces a frequency response like a tent-pole sticking up from zero response. Here, Ian Hickman looks at various implementations of these useful circuits, some familiar and some less so - a feast of useful circuits.

Regardless of the frequency band in which they are to be used, filters all fall into one or other of a limited number of categories. The main categories are low-pass, high-pass, band-pass, band-stop and all-pass. I have produced a CAD program to assist in the design of yet another category - the all-stop filter. I hope to see it published in the April issue. This article is concerned with one class of active filters, the notch, and its cousin the notch-pass. I lump these together as one class, as their realisation is closely connected, both types could have a positive feedback, the provided that the value of $R_3$ is less than $2\pi R_2$, the positive feedback will be less than the negative, and the circuit will be stable. If $R_3$ is greater than $2\pi R_2$, the positive feedback outweighs the negative, and the circuit will oscillate. The more nearly $R_3$ approaches $2\pi$ from below, the greater the gain at $f_c$. At dc, the gain is zero, due to the series $C_4$ and also at infinity, due to the shunt $C$.

Figure 4 shows the response for the case where $R_1$ equals $20k$ and $R_2$ equals $10k\Omega$. The peak gain is $+37.5\text{dB}$, and is $0\text{dB}$ at $3.2$ times higher or lower than $f_c$. In Fig. 7. A $1\%$ increase in $R_3$, or a $1\%$ decrease in $R_2$, results in a $3.5\text{dB}$ decrease in gain. This makes close-tolerance high-stability resistors a must.

As always, when obtaining a high-Q response from a basically low-$Q$ circuit by means of positive feedback, the result is very sensitive to component tolerances and stability.

...and an oscillator. If the series and shunt CR arms in Fig. 3 are interchanged, and the input short-circuited, you have the basic conventional Wien bridge oscillator. But the Fig. 3 arrangement would also make a usable sine-wave oscillator, provided $R_2$ includes a resistor with a negative temperature coefficient, such as a thermistor. Alternatively, $R_3$ could have a positive temperature coefficient component, provided for example by a very low-wattage filament lamp.

The Wien network has also been used in an ingenious tone control circuit-

Twin-tee based circuits

The twin tee is not the most convenient of circuits to work with, on account of using three resistors and three capacitors to achieve its null. However, both its input and output ports are balanced.

The Wien bridge on the other hand has an unbalanced input, but needs a differential input amplifier at its output. This makes the twin tee handy in fixed-frequency applications. But the notched out to be even 'lazier' than that of the Wien bridge, being $3\text{dB}$ down on the zero and infinite frequency response at $1.22$ times higher and lower than $f_c$, rather than $3.2$ times.

Figure 5 shows the basic twin-tee circuit, and Fig. 6 its circle diagram. A circle diagram shows the response at various points in a circuit, as the frequency varies from zero to infinity. Figure 6 shows the locus of the tips of the vectors representing the voltages at $X$ and $Y$.

Superimposed on the circle diagram is the voltage vector diagram for the particular frequency $f_c$ at which the notch occurs. The vectors showing the voltages across $C_3$ and $R_3$ at $f_c$ have been offset a tad for clarity, as they

وعلى غيرها من الطلبات الأخرى.

As you can see, the response at $B$ passes through zero (ground) at $f_c$.

The basic twin-tee circuit uses the component values shown, where again, $f_c = \frac{1}{2\pi R_3 C_3}$

As with the Wien bridge, the circuit can be analysed mentally. Imagine that unity gain buffer amplifiers...
In the basic twin tee C1 = C2 = C3 = C, R1 = R2 = R, R3 = 2RC (X and Y: see text)...

Voltage at point X will be 3dB down, but lagging by 45°, and voltage at point Y will also be 3dB down, but lagging by 45°. The voltage between X and Y is applied by the buffers to the series C and R, and forms the base of another (zero) circle diagram. Thus at Y, the output voltage is zero.

Voltage at point A will be 3dB down, and in phase with it. Likewise, the voltage at point B will fall from Y, zero, 90° lagging. At X, the voltage at point X will be 3dB down on the input, leading by 45°, and in the case where unity feedback is applied, the output is also effectively zero.

Without the buffers, assuming that the input is driven by a zero impedance source effectively ground, the impedance seen looking back from point Y at Y is not B but R2. This is because at the notch frequency, the output is also effectively ground.

So C3 must be 2xRC to give the required 45° phase at Y. Likewise looking in at point X, there are two capacitors of value C in parallel, so the resistor from there to ground must be R2. The voltage vector diagram of Fig. 6 is then as shown for the case of equals C and Rs with buffers; only the current vector diagram, which is not shown, differs.

A sharper notch... Loading of the output CR on the load and input sections is responsible for the lazy shape of the notch. With the equal component values plus buffers case mentioned above, the 3dB point is only 2.4 times shown and below the notch frequency, as against 3.2 times for the twin-tee circuit.

However, the basic twin-tee circuit less buffers can be sharpened up even more, by the judicious application of positive feedback, as in Fig. 7. To see how this works, consider the input frequency rising from 0Hz, up towards the notch frequency. If the R2 and 2C were grounded, the response would fail as with the circuit of Fig. 6. But in fact, it is bootstrapped very neatly up to the same voltage as that at B in Fig. 5. Consequently, the attenuation due to the twin-tee network is greatly reduced at frequencies approaching f0.

But at exactly f0, this argument must break down, so a zero response will still in fact be observed. With the values shown, the notch is sharpened up considerably, Fig. 8. A less extreme notch results from tapping the feedback point further down the op-amp's output. In this case the feedback voltage may need buffering, to keep its impedance low.

The extra selectivity is bought by the positive feedback, and at a price. As always with positive feedback, distortion, noise and variation of gain with component tolerances and ageing, are all increased.

Chebyshev response The twin-tee circuit is capable of some other useful tricks. For example, if capacitor C1 is connected not to the input, but tapped down a potentiometer chain at a fraction f, a notch is still observed, but while the output is still equal to the input at f=0Hz, it is only 40dB in infinite frequency. Thus the circuit provides a second-order Chebyshev (or Tchebyshev) response. As f approaches zero, the notch moves out to infinite frequency, leaving a low-pass response.

Further, let the fraction of the output fed back to the shunt R2, 2C arm, as in Fig. 7, be m. Then with the 22k resistor changed to 3kΩ (m=0.37), and k=0.5, the response becomes as in Fig. 9 — a second-order elliptic response. Such sections can be used to build up an elliptic filter of any desired order.

A search through my files failed to unearth a copy of reference 3, but I unearth a copy of reference 4, if the modification to the R and C values in the twin tee.

Chebyshev response

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Fig. 11. Bridged tee circuits may have either a C or R shunt leg. a) capacitive shunt leg. b) resistive shunt leg.

Fig. 12. Response of the bridged tee circuit with resistive shunt leg (Fig. 11b).

Fig. 13. A bridged tee circuit with feedback to sharpen the notch.

Fig. 14. Circuit of Fig. 13 gives a 20dB notch at 50Hz, but is flat within 3dB from 60Hz up.

Fig. 15. This notch-pass selective amplifier is tuned by \( R_p \).

Fig. 16. A canonical notch circuit. Notch frequency \( f_0 = 1/(2\pi C R) \).

Fig. 17. Notch circuit using a simulated inductor, which resonates with \( C_2 \).

References
4. 'Oscillator uses passive voltage gain network,' Wireless World Vol. 81 No. 1472, April 1975, p. 175.

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**February 2000 ELECTRONICS WORLD**
Get the most from your scope

In this set of articles, Les Green explains what types of oscilloscope are available, and looks at how to apply them for best results. His first article covers oscilloscope basics, benefits and limitations.

It is not possible to see electricity so we have to rely on instrumentation. This makes it necessary to know about the limitations and accuracy of every piece of test gear we use, in order to get answers that can be believed.

This article will help you pick the right type of oscilloscope for your application, and to get the best measurements possible using a few tricks of the trade.

What’s in an alias?

Technically, an alias occurs in a sampling system when there is a significant amount of signal at a frequency of more than twice the sampling rate. Viewing a sine wave with a totally inadequate sampling rate can create a signal that looks quite normal, except that it appears to be at a rate that is not very useful. However, if you want to look at signals well above 1GHz or rise-times less than 300ps you do not have much choice.

Storage scopes come in two basic types, tube-storage, i.e. analogue, and digital storage. A tube-storage scope uses a special type of display tube that stores the trace on its inner surface structure. They are difficult to use and will not store a trace for a long time. This technology is long dead but I have no doubt that some such scopes are still in use because they are not actually broken.

Size matters

You can write this in bold letters, “Equipment that is difficult to use, or too heavy to move about, will not be used as much as it should be”. It is often the case that engineers are pushed for time; tests that are difficult to do, on equipment that is switched to use, will tend to get neglected to a minimum or skipped entirely.

Such test equipment is a liability, not an asset, and would be better off in the bin. If you love your old tube-storage scope I apologise unreservedly.

In addition to the basic types mentioned, there are at least two other hybrid types available. Sampling scopes are now available in a digital storage format. They are easier to use than the older type but should not be confused with digital storage oscilloscopes, or DSOs. You have to read the fine print to see that they are not useful as a general purpose DSO replacement.

The other hybrid type is the combination real-time and digital storage scope. These tend to be neither good real-time scopes nor good DSOs but they do have a place in general purpose applications. So we now have sampling scopes for use above 1GHz, with digital versions being necessary for repetition rates below about 10kHz. This is the last time that I will be mentioning them. For the rest of the measurements I will only compare real-time scopes and DSOs.

Types of measurement

You must use the right piece of equipment to measure your circuit’s performance. An AVO 8 is a perfectly good piece of equipment. For any alien life forms reading this, an AVO is an old moving coil multimeter characterised by being in a solid, heavy, black case that can not be pulled off the work bench by 15A test leads and having a working life at least equal to that of the average engineer.

But if you try to measure a 100MHz voltage with an AVO, you will not get a sensible answer. If you then blame the meter for giving you the wrong answer, you are only demonstrating your complete and utter ignorance of the subject. Just because you have a scope probe in your hand, do not mean that you should measure everything with it. Scopes are good at looking at changing voltages; if you use one to measure steady direct voltages, then the answers you get will not necessarily be very accurate.

Scope accuracies are generally around the 1% to 5% range. If you then use it to measure a signal with a noise of 1% then you have a 5% uncertainty. If that is all the accuracy you need then there is no problem. However, even the most modest of bench DMMs will give you a far more accurate answer.

Probe adjustment

While we are on the subject of 101 probe accuracy there is another point that is sometimes overlooked – probe adjustment. For rectangular waveforms above 1kHz, the pulse response is totally dependent on the adjustment of the probe. The “probe calibrator” output on the front of an oscilloscope facilitates this. Each probe has to be set up for each oscilloscope and for each channel. There is no guarantee that the inputs of any particular scope are matched to any degree at all. If you swap a probe from one channel to another it is vital that you re-tweak the probe to get the correct pulse response.

Calibration is generally done at 1kHz. Beware of probe calibrators that change frequency within the timebase. Although they have a definite advantage for experienced users in that the VHF performance of the probe can be optimised (there are often hidden trimming points within 101 probes) they are a definite liability for the general user.

The problem is that if the timebase is set too high the probe will give a squarer edge response regardless of the trimmer position. Thus the unwary user can think that the probe is trimmed correctly when it is not. It is common practice to probe a circuit with an oscilloscope, checking for oscillations and noise, before going on to get an accurate reading on a DMM. Note that a DMM set to read DC volts will measure a 5V DC level with 1V of 1MHz sinusoidal oscillation on it and tell you the answer is 5V, maybe.
INSTRUMENTATION

It is also possible for a DMM to give an incorrect reading due to internal asymmetrical slew-rate limiting. The point is that the result is no longer defined and it's not the DMM's fault, but yours! I should also mention that putting a DMM on some circuits causes them to oscillate. Some DMMs have large input capacitances - say 100pF - which can cause problems.

Test leads can also capacitively couple to/from sensitive nodes causing oscillation. To fix this, all you have to do is to put a capacitor in series with one or both test leads; 100Ω to 1kΩ is usually enough, but it needs to be as close to the probe tip, or as close to it as possible, for maximum effect. Alternatively, keep your scope connected to the circuit when you probe with your DMM; this at least warns you of any circuit malfunction that may occur. Without wishing to stray from scopes too far, I must point out that it is not just DMMs that cause oscillations. Even a 10:1 scope probe with 100Ω input resistance and 1.5pF input capacitance can cause or stop an oscillation. Unfortunately these oscillations can be well out of hand for the equipment being used. Low-level gigahertz-rate oscillations just will not show up on an oscilloscope.

A faulty DC-300MHz preamplifier board caused the oscillation shown in Fig. 1. When connected to a 400MHz Tektronix 2465B real-time scope - arguably the best real-time scope in the world - this oscillation was not visible. In fact gigahertz oscillations often cause mysterious DC offsets that just don't make any sense and which change as you probe around the circuit.

When a spectrum analyser is best
For anyone working with transistors having a f0 of 2GHz or more, a final check on a piece of equipment would have to include a quick scan with a spectrum analyser. Even the fastest scopes will not detect the peaking of a noise band that is indicative of a circuit being on the edge of stability. One could easily make a case for insisting that spectrum analyser test equipment is used on prototypes, as it does not cost much to hire a simple spectrum analyser for a few days.

It is easy to use a spectrum analyser for such a task. All that is needed is a conventional 10:1 probe and probably a BNC to type-N adapter. The spectrum analyser will almost certainly have a 50Ω type-N input but this does not matter; its signals will easily pass through the probe and register on the spectrum analyser. The presence of an oscillation, or latent oscillation, is more important than its actual amplitude.

In his next article, Les looks at the problems involved in making specific types of measurement with an oscilloscope.
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Involved with boats or battery charging?

Alternator controllers supplied with the alternator are inefficient at charging discharged batteries deeply because, since battery voltage is measured at the alternator, the measurement does not take account of wiring or blocking-diode voltage drops.

Further, the regulator normally starts to trickle charge too soon, at about 13.5V or 14V instead of the correct 16V (the voltage across a fully charged lead-acid battery). Add-on controllers to avoid these problems are expensive and often charge at too high a current.

To cater for the undercharging, the scheme shown in Fig. 1 is effective, in that the regulator is "tricked" into detecting a battery voltage 2V lower than it is by the use of an LM317T regulator, set up so that the output is always lower than the input. The LM317T is switched by a relay to prevent overcharging, the potentiometer being set to make the relay RL operate at 16V, switching out the LM317T with one contact and latching RL on. At switch off, the relays drop out and are ready for normal operation at the next switch-on.

Figures 2 and 4 illustrate the method of use, Fig. 2 showing charging with a built-in regulator and Fig. 4 indicating the use of a separate one. Figure 3 shows the connections. On the alternator, remove the wire connected to terminal F and connect the green wire from the controller, connecting blue from the controller to the wire just removed. (A separate regulator has red and black.)

Connect green from the controller to alternator positive, removing the original wire and connecting blue to it instead.

To alternator field

Andrew Bird
Burnswod

Two identical crystals – what’s the difference?

This produces a rectangular wave output at the difference frequency of two crystal oscillators, needing no counter/dividers and using only two integrated circuits. The nand gate, IC1, forms both crystal oscillators and a mixer, the output of the mixer being at the frequency f1-f2: the difference between the two oscillators. After buffering, this signal goes to the envelope detector, which suppresses all but components to give the output pulse at the difference frequency.

With components shown, the detector bandwidth is up to 10kHz with a crystal frequency of 3MHz.

Pekka Vihakangas
Lekila
Finland

Self-powered amplifier/squarer

Some inputs to this circuit are amplified and squared without the use of an additional power source. Inputs in the range 20Hz–20kHz drive a voltage doubler rectifier to supply the power and the first stage of the 4069 hex inverter functions as a linear amplifier, succeeding gates taking care of the squaring. Output with an input of 1–2.5Vrms produces a 50:50 m:s ratio.

Minimum input voltage for reliable working is 750mV, although using germanium diodes lowers the minimum.

Flavio Dellepiane
Cerconv
Italy

£50 winner

This amplifier and squarer needs no external power rail, taking its power from the input signal.

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Micro 540µm grabber test clips for the Pionix IC packages are available from Winkick Test Supplies. Made by Pionix, they are for prototype design and debugging. These grabber clips are available - short and long tips for 0.6 to 0.9mm test photos and one for 0.10mm down to 0.3mm. They can be used with QFP, PQFP, S08P, TSOPI and TSSOP packages.

P-channel MOSFET

Fairchild now produces a 30V p-channel MOSFET -- the FDS6675 -- using the firm's Powerrench process. On-state resistance is 0.014Ω at a VGS of 10V. It is for use as a power-management tool switching loads such as HDD, backlighting or docking power switches. It can also be used as a battery switch to control the charging current. Safe charge is 20mA at 5V typical.

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Digital pots

Xicor now makes two quad 64-bit digital potentiometers. The X3001 and X3040 operate from one power supply and are for use in digital communications subsystems, cellular communications and data link transceivers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. The X3001 only includes 8-bit digital potentiometers, the X3040 includes 16-bit digital potentiometers. 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PC audio accelerator
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Philips Semiconductors
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LSI Logic has announced the new LT1461 2.5V, 33°C, low dropout reference reference with an initial accuracy of ±40µV per cent at 1MHz. It draws 1mA maximum supply current. Operating temperature can be 0 to +70°C. ±40 to +80°C or 0 to +125°C. Input voltage range is 2.8 to 5.5V. Applications include battery powered equipment, industrial controls and temperature measurement equipment. Dropout voltage is 300mV at an output current of ±1mA. Linear Technology
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Enquiry No 516

DC/DC converters
The SM packaging of the new LT895 3.3V to 10V non-isolated DC-DC converters is compatible with pick-and-place and solder reflow processes. The converters measure 16 x 16 x 7.5mm and can be installed using vacuum-pickup, automatic pick and place equipment. Linear Technology
Tel: 01256 688444
Enquiry No 516

DC/DC in SM
The SM packaging of DAPO's L1295 300mA to 6A DC-DC converters is compatible with pick-and-place and solder reflow processes. The converters measure 16 x 16 x 7mm and can be installed using vacuum-pickup, automatic pick and place equipment. DAPO
Tel: 01256 680444
Enquiry No 515

Cable to PCB connector
The NiDC from Robinson Nugent is a NiCu cable to board connector using a contact design developed for laptop, mobile and handheld devices. It has a three-letter button option for either side of the connector - pop up, fold away or lidged. They are for use with types I, II or III cards and have eight gold-plated contacts. Options include standard or reverse PCB orientation. Robinson Nugent
Tel: 01732 798972
Enquiry No 511

Mini-edge card connectors
Sammtec's MEC1 mini-edge card connectors have a double row of beryllium copper contacts on 1mm pitch for reprod card interfaces. These sockets are available in seven sizes from five to 68 contacts per row for a total of 336 I/Os in as little as shrink of PCB area. The sockets are normally polarised to avoid pin free mating, however, smaller sizes with up to 30 contacts per side may be specified without polarisation to increase I/O density. The firm also has MBI micro bay interfaces for mating with 0.8 and 1.6mm mini-card sockets with 26, 30, 40 or 50 contacts on 1mm pitch with 2.5mm long card guides to align-through holes to the contacts. Sammtec
Tel: 01254 412121
Enquiry No 517

PC card bus connectors
Hewlett has introduced a single-ended PC card bus connector, the 1C15. These card bus connectors option with a balist height less than 15mm., an one-touch locking and ejection system, and self alignment when mating. Contact counts are 40, 50, 68, 80 and 100 positions. The 100 position model is a multi-link system. Current rating is ±500mA per contact and the inductor material is US 4W-0 select. Robinson Nugent
Tel: 01227 794498
Enquiry No 518

Embedded PCI
Quicksense has announced three embedded standard product (ISP) Quick/PCI devices - the QL5023, QL5130 and QL5232 - bringing the family up to five devices. These combine embedded PCI controllers with programmable logic. PCI has performance up to 600Mbyte/s with zero wait states and independent back and clock speeds up to 100MHz. Reference development kit is available with boards, devices and software drives are available. They are for 32 and 64-bit PCI buses at speeds of 33, 66 and 133MHz.
QuickSense
Tel: 020 7428 8004
Enquiry No 519

Resettable fuse
Raychem has launched the low-profile TYPF117 resettable fuse for battery protection. Hold current is 2A allowing inrush current and overtemperature protection for...
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PCB calculation software

The CITS 25 field-solving controlled impedance calculator from Polaris has been upgraded to include impedance calculation equations for coiled, embedded, offset and other complex structures. Windo-based, it can be used on IBM or with CAD tools, and can calculate design and yield for manufacturers involved in manufacturing printed circuit boards.

Polaris Instruments
Tel: 01477 239881
Enquiry No 524

PC audio accelerator

Aluminium electrolytic capacitors with a 150°C temperature rating for automotive, aerospace and industrial applications have been released by Vishay. The axial-style devices are for smoothing, filtering, coupling and circuits. When the terminals of a pack are shorted, causing an overcurrent, a coefficient fuse that functions as a battery protection.

Vishay
Tel: 00 49 07661 37 253
Tel: 00 32 70 233 041

Cylindrical inductors

Inductance values are from 1 to 22,000 µH with tolerances of ±1 to ±20 percent. Voltage rating is 10, 16, 25 or 60 V with maximum current ratings up to 3.9 A.

Volex Interotechnology
Tel: 00 49 07611 37 263
Enquiry No 525

Magnetic sensor comes with reverse battery protection

For position sensing in pneumatic cylinders, the ADM207-07 magnetic sensor from Rayport is based on giant magneto-resistive (GMR) technology. It has a digital output with nonvolatile ‘on/off’ and release points. Features include reverse battery protection; it can also detect short and directed currents. The GMR effect changes the electrical resistance when stacked layers of ferromagnetic and non-magnetic materials are exposed to a magnetic field.

Rayport Components
Tel: 01602 773903
Enquiry No 521

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Powerfactor

Continued from page 118

The combination of resistive power and reactive power gives rise to total power as shown in the phasor diagram, Fig. 1. It is assumed that the voltage is horizontal so that the phasor diagram shows the direction of the current. Only the resistive power is available to the consumer. Is the phasor diagram resistive, i.e. usable, power is denoted as kilowatts, or kW. The total power is normally denoted as kVA. The reactive power is denoted as kVAR.

Phase angles

The angle between the total power and the resistive power is usually represented by the Greek letter psi, ψ. The ratio of resistive to total power is called the power factor and can take any value from zero representing very bad, to one representing very good. For those who still remember their school trigonometry, this ratio is also the cosine of ψ, usually written cos ψ. Although we have drawn the diagram with current leading, we could equally have drawn it with the current lagging. This makes no difference to the definition of power factor that can clearly not exceed 1.

There are disadvantages in having too low a power factor. Considerably more current has to be supplied than is actually used. Thus, much more demands are made on the supply equipment and on the wiring of the consumer. Too low a power factor with inadequately rated wiring can give rise to overheating and even fires. There can be a voltage drop at the consumer's outlet due to excessive current in the supply. The electricity supply companies do not like this as they too have to use much higher rating wiring than they would need and are supplying electric current that they do not get paid for. Supply companies lay down minimum power factors for their customers and usually extract hefty payments from those not conforming.

So how do I measure it?

The measurement of power factor is important not only for the supplier, but also for the consumer. We have designed and built a cpu controlled digital meter to measure both power factor, voltage and frequency of the supply.

What the meter does not measure is harmonic content. We should emphasise that the measurement of the power factor is complicated where there is considerable harmonic content. This device simply measures the difference in phase between the current and the voltage.

The instrument works by measuring the interval between where the current crosses zero and where the voltage crosses zero, by counting pulses of known frequency 32 KHz between

The local pub that would enable one to reduce one's electricity bill.

However, as you can see from the phasor diagram, one can certainly take more electricity from the supply, but there is no way one can reduce the bill using the same apparatus. On the contrary. Any added capacitance or inductance will have some resistance associated with it. While of no use to the consumer, it will in fact increase his or her electricity bill, and the chance of overloading the wiring.

Fig. 1. A combination of resistive and reactive power gives rise to total power.

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Fig. 1. A combination of resistive and reactive power gives rise to total power.
the two states. Knowing the frequency of the pulses and the frequency of the supply, which is also measured, this interval is converted into a phase angle or power factor.

As the main interest in this device would presumably be in countries with rather erratic supply, we have also included a rechargeable battery. It is possible that at the extremes of low voltage and erratic frequency, the device would not work well without it.

The circuit diagram consists of several sub-modules. These are the external load for inputting the mains voltage and current, the frequency and phase detector section, the microcontroller together with its associated control lines, in which reside the program to operate the instrument.

Auxiliary circuits

The crystal oscillator gives the pulses used to measure the frequency and phase differences. Other auxiliary circuits are the overload detector, the power supply and the battery charger, which can of course be omitted.

The alphanumeric LCD display made by Citizen is a sub-unit consisting of the display itself together with two onboard driver chips, HD44780AM and HD44780BH. This unit now appears to be obsolete but similar units are available from Seiko and Sony, with the same device number and programming. A wide range of characters is available on the display, which has a 16x2 matrix. You will need to get the data sheet to learn what codes give what alphanumeric characters.

The digital and analogue sections have their own separate earths. The instrument is shown in schematic form in Fig. 3. The marked PPI are programmable peripheral interfaces.

Figure 5 shows in schematic form how the frequency is measured while Fig. 4 illustrates the measurement of phase. Fig. 5 shows how the voltage is measured and Fig. 6 is a drawing of the front panel and the LCD.

It is not possible to use a number of resistors in parallel because the currents add rather than sum in voltage. We have provided three ranges:

- 0.5 to 7.5 A, 0.14Ω
- 7.5 to 12.5 A, 0.27Ω
- 12.5 to 17.5 A, 0.7Ω

We have included a control circuit so that if the current is too much for the lower range resistor then the others remain switched in using the Reed relays or switched out to the lower ranges if required. It is not possible to find a sufficiently low resistor, i.e. there is overload, then the overload indicator light comes on and more importantly the loudspeaker emits a very loud tone.

Although we have included this section in our instrument box, this is rather problematic, so due to the high currents and voltage there is a possibility of fire. It would almost certainly be safer to put these resistors and control in a separate grounded metal box.

Software

While the hardware of this project might seem rather complex, this is nothing in comparison to the programming. There are several hundred lines of code. It is not possible to an
INSTRUMENTATION

article like this to give the source code. However the object code is shown. The source code given with annotations is available from Electronics World.

To give some idea of the complexity of the program we present a flow chart of the program in Fig. 7. Subroutine SHIT checks whether the internal resistors are of the right values and if not changes them. Resetting and initialisation of the LCD is carried out by LCD-INT and COD writes the alphanumeric messages to the screen.

Code headed TED-HAZ sends the frequency to the LCD display while PHA-HAZ, sends the phase to the LCD display. The voltage waveform is created by the program COST, which then sends it to the LCD display. Finally, VOLTI calculates the voltage and sends it to the LCD display.

There is a reset switch when one is ready to take new measurements. In view of the frequencies involved the layout is not important but it is a considerable amount of components to be included, it will need to be built on stacked circuit boards. There should be adequate spacing between them for proper evaporation of air and good heat shielding needs to be used for transistors and similar components carrying heavy current. Finally one should make sure that the cable used to sample the mains current is of adequate thickness. It was difficult to test the instrument because of the high quality of our electricity supply. We artificially altered the power factor by using large values of inductance and capacitance. However these were done only briefly in order not to annoy the electricity company.

This instrument should be useful in any situation where voltage, frequency and power factor needs to be monitored. It could also be adapted to control power factor by switching in capacitors to move the power factor closer to 1.

Software availability

If you purchase this device in electronic form, email or fax your request to the address below, and it will be forwarded to you in a text embedded in an e-mail. It will not be passed on unless we are informed by you to avoid distributing viruses. If you receive the text in an e-mail, and again free of charge, send us a disk with all your text that you wish. If you receive the text in a text file, and again free of charge, send us a disk with all your text that you wish.

The file contains the complete source code of the instrument and is available for free to anyone who wishes to use it.

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Now to PICs or just wanting to learn new tricks?

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Joe Carr presents six tips to help you get more out of your RF signal generator.

Signal generators come in a number of different flavours, capabilities and quality levels. Some are used for troubleshooting equipment and circuits, whereas others are used for making more precise measurements. Whatever they all have in common is that they produce some sort of controlled output signal.

Unfortunately, the output signal is not always clean. Although the purity of the output signal is one of the things that differentiates lower quality and higher quality generators, they all produce signals other than the one desired.

Figure 1 shows a typical spectrum output. This display is what might be seen on a spectrum analyser. The main signal is a continuous sine wave, so ideally you would expect only one single spike, with a height proportional to the output level. But there’s a lot of other signals in there.

First, note that the main signal is spread out by phase noise. This noise is random variation around the main frequency. When integrated over a specified bandwidth, e.g., 300 to 3000Hz, the phase noise is called residual FM.

Second, there are harmonics present. If the main signal has a frequency of F, the harmonics have frequencies of nF, where n is an integer. For example, the second harmonic is 2F, and the third harmonic is 3F. In many cases, the third harmonic is stronger than the second, but generally the higher harmonics are weaker than lower harmonics.

There are also sometimes sub-harmonics. These are integer quotients of the main signal: if the main signal frequency is F, then nF/2 represents the sub-harmonics. Typically, unless something is interfering with the output signal, sub-harmonics are not as prominent. One thing that does make sub-harmonics prominent, however, is the use of frequency multiplier or divider stages—which is the case in many modern generators.

Finally, there are miscellaneous spurious signals, or
'spurs', found on some generators. These might be due to power supply ripple modulating the output signal, parasitic oscillations, digital noise from counter or phase-locked-loop circuits, and other sources.

**Method 1: Improving spectral purity**

Certain high quality measurements are very sensitive to extraneous signals coming out of a signal generator. Many signal generators put out harmonics that are ~30dB down from the main signal, i.e. the carrier, while other signals may be either higher or lower than this level. The way to get rid of these extraneous signals is to place a frequency-selective filter between the output of the signal generator and the device under test.

**Figure 2** shows the use of a low-pass filter to eliminate the harmonics and any spurs that are above the main signal. Select a filter with a -3dB point somewhere between the main signal and the first extra signal, and an attenuation slope enough to reduce the 'bad' signals as much as possible.

If there are any sub-harmonics — or spurs lower than the main signal — then either use a band-pass filter or add a high-pass filter with a ~3dB cut-off between the main signal and the sub-harmonic.

There is a cautionary note, however. Real filters do not have the nice flat response seen in some textbooks. They will have pass-band ripple, and some odd responses out of band. Also, LC filters are not always impedance matched. In any electronic circuit, the maximum power transfer occurs when the impedances are matched. There may be an inherent mismatch problem in either the signal generator or the load, and almost certainly in the cables or other devices connected in line with the signal generator.

For example, assume a signal generator with a VSWR of 1.9:1, and a device under test with a VSWR of 1.6:1 connected in the normal way, Fig. 3a. The mismatch loss can be found once we know the reflection coefficients: source, $ho_s = \text{SWR} - 1 = 1.9 - 1 = 0.9 \approx 0.31$ and load, $ho_l = \text{SWR} + 1 = 1.9 + 1 = 2.9$. The mismatch loss becomes $\text{Loss}_{\text{mismatch}} = 20 \log \{1 + \rho_s \rho_l \} = 20 \log \{1 + 0.31 \times 0.31 \} = 20 \log \{1 + 0.0969 \} = 20 \times 0.03 = 0.60$ dB.

**Method 2: Improving mismatch loss**

Mismatch error occurs because the load and the signal generator are not impedance matched. In any electronic circuit, the maximum power transfer occurs when the impedances are matched. There may be an inherent mismatch problem in either the signal generator or the load, and almost certainly in the cables or other devices connected in line with the signal generator.

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**Method 3: Improving third-order intercept performance**

One of the most important specifications for an amplifier or receiver is the third-order intercept point, also referred to as TOIP or IP3. This specification tells you something about the device's dynamic performance — especially in the presence of multiple input signals.

If you listen to any shortwave receiver, AM or FM BCB receiver, or any scanner receiver you will realise that most
Signal generator

Fig. 7. Adding an amplifier and filter boosts output level.

Amplifier
Filter
Device under test

Adjustable step attenuator
Device under test

Low-cost signal generator

Adjustable step attenuator
Frequency counter
Device under test

Fig. 9. Adding an attenuator, RF voltmeter and a shielded cage solves a lot of problems with cheapie generators.

Low-cost signal generator

RF voltmeter

Method 5: Reducing the output level

There are times when you might want to reduce the signal generator output level. One reason for doing this is that you need a very small signal at the device under test, but need a higher signal to act as a reference or be fed to a frequency counter.

I sometimes do this when using one of my elderly analogue signal generators. It has an inaccurate analogue frequency dial, but the output attenuator is well calibrated. To get a higher level for the counter, while providing a low level signal to the amplifier or receiver being tested, I use a set-up like Fig. 8. In other cases, you will simply need a lower signal level than the generator can provide. Figure 8 works for that purpose as well.

The attenuator should be calibrated type. You can obtain continuously variable calibrated attenuator. These are costly, but some tend to come on to the surplus market. A lower cost alternative is to use a precision step attenuator. These devices have switch selectable attenuation levels in various steps. The total attenuation is the sum of all the individual attenuations. You can build step attenuators. But the work you are well advised to buy one. The resistors for precision attenuation levels are really odd values, although they can be approximated.

Method 6: Using a cheapie signal generator

Many of the tests and measurements done with signal generators can only be done with rather expensive instruments. Unfortunately, a large number of people are forced to use low-cost "service shop" grade signal generators. And these can be a problem.

Of course, if you are lucky enough to find surplus "lab-grade" or military signal generators, you are way ahead of the game. Good quality signal generators are easily found on the surplus market. I've seen high quality units go for nothing. I bought a 10 MHz unit, even though the asking price was quite reasonable. Indeed, a friend of mine made quite a living buying hamfest specials, reconditioning them, and re-selling them.

But what do you do if the only signal generator you can use is a service grade instrument? Indeed, what's wrong with service grade instruments?

In summary

I hope that the methods discussed in this article will make quite a lot more use of the signal generator, but that is not the case. Even if your signal generator is a low-cost service grade type, these methods will help.

February 2000 ELECTRONICS WORLD
Bench testing for EMC

Ian Darney attempts to bring EMC down to Earth using a simple model structure that is easy to verify on the bench.

Confusion and frustration are the normal by-products of any attempt to glean a simple set of circuit guidelines from the literature on electromagnetic compatibility. On the practical side, a plethora of design tips and strategies can be found, many of which conflict with other design considerations.

Delving into the subject of electromagnetic theory reveals a morass of ever more complex mathematics. A simple method of applying the design process to interference problems is nowhere to be found.

The purpose of this article is to introduce such a method. The approach is based on the idea of creating an accurate circuit model of the signal coupling between cable and structure, or between conductors routed over the structure. The model can then be used to analyse the interference signals, whatever form they take.

Conclusions of such an analysis can only be assessed in the light of practical results, and bench testing is the simplest way of obtaining such data. So, the design and use of such equipment are described too.

Confidence in the validity of the approach is established by building a test rig, measuring the coupling characteristics between a twin conductor and structure, and comparing analytical results with test data.

The key features of my approach are the utilisation of general-purpose software to analyse the results, and the simplicity and ease of use of the test equipment. This reduces EMC from a black art to a design problem.

Background

One of the basic assumptions of circuit theory is that the voltage across any two-terminal device is a function only of the current in that device. This is in direct contradiction to the concepts of electromagnetic theory, which lead to the conclusion that the voltage of any conductor is a function of the current to all conductors.

In fact, this simplifying assumption is one of the reasons why circuit theory is the more useful. By avoiding consequential detail, it allows the bigger picture to become visible. Circuit diagrams enable us to visualise what is happening to the various signals in a system.

Since circuit components and electromagnetic parameters are entirely different entities, any combination can result in confusion. Maintaining strict separation can be achieved by defining components of circuit models as being of type 'circuit', just as some numbers can be defined as being of type 'integer'.

Equations can be derived to relate the electromagnetic field round a set of conductors to the currents and voltages in those conductors. Since these are the simplest relationships possible, the parameters can be described as 'primitives', a term borrowed from the ideas of operational systems. Primitive equations describe the behaviour of the assembly as an antenna.

In electronic systems, signals are routed from one element of the system to another on interconnecting cables that act as multi-conductor transmission lines. The most convenient way of analysing the coupling between such signals is to define a set of loops, each loop linking a pair of conductors. Parameters involved here can be described as 'loop' impedances.

To distinguish between 'primitive', 'loop', and 'circuit', parameters, an extra letter is added to the appropriate symbol, e.g. $Z_g$, $Z_l$, and $Z_c$.

Circuit diagrams enable us to visualise what is happening to the various signals in a system.

Confidence in the validity of the approach is assessed in the light of practical results, and bench testing is the simplest way of obtaining such data. The model is improved by converting each branch to a T-network.

Creating a circuit model

By using such identifiers in a systematic way, formulae can be derived for the inductors, capacitors, and resistors associated with these conductors. The primitive equations are set out in the panel entitled 'Formulation' and summarised in Figs 1 to 4. Note that the process does not involve anything more difficult than addition, subtraction, and substitution.

However, the response of the circuit of Fig. 4 deviates from the actual response as the frequency approaches resonance. A much better simulation can be achieved by representing each impedance as a T network, as shown in Fig. 5.

This model is perfectly adequate for analysing the performance of the assembly. However, it is more conventional to visualise capacitance as a component that couples two conductors. A star-to-delta transformation as shown on Fig. 6 takes care of this. For delta components, the component symbol is followed by the letter 'd', and the identification numbers refer to nodes.

This leads to the circuit model of Fig. 7. If the physical dimensions of the line are known, equations (8), (10), and (11) can be used to determine component values.

Circuit analysis software

Even this model is crude in terms of transmission-line theory. It presents a daunting challenge to anyone attempting to analyse its response armed with only a hand calculator. Fortunately, there is no need to attempt such an exercise. Circuit analysis software is readily available, and the processing power of desktop computers is more than adequate to the task.

With such a facility, all that is necessary is to draw the circuit on the screen and define component values. A selection is made of whether frequency analysis or transient analysis is desired, the test limits are defined, and the signals to be examined are then selected. At the touch of a key, the results are computed and presented on the screen as a smooth curve.

Test gear

At this point, all the analytical tools have been introduced. The second half of the exercise is to design and build some test gear to allow interference coupling parameters to be measured. Such an exercise is described below.

The first step was to build a unit rig. This consisted of a length of copper pipe to simulate a structure, and a wire pair to represent the cable under test. A strip of wood laid along the pipe was used to achieve a fixed separation between the cable and the structure.

The test equipment was about as simple as it could be: an oscilloscope, a signal generator, and a few locally purchased components.

Injection transformer

A small injection transformer was constructed, using ten turns of enamelled copper wire on a toroidal core as the primary winding. The winding was connected to the output of the signal generator via a coaxial cable. Fig. 8. A 50Ω resistor was connected in parallel with the primary winding to minimise reflections at the transformer end of the cable.

To monitor the injected voltage, a tightly wound single turn of wire was added round the core, and the loop closed by 510Ω in series with 56Ω. A coaxial cable connected the test fixture across the 56Ω to one input of the oscilloscope. The resistors act as a potential divider, and as characteristic impedance to terminate the cable. Figure 8 also defines the relationship between transformer output voltage and the oscilloscope input.

Unlike the transformers used in EMC test facilities, this transformer lacks the ability to clamp off the cable under test. From the point of view of bench testing, this is no real disadvantage. The cable can be threaded through the transformer core during assembly, and removed afterwards; a few minutes work.

Being small, the transformer is a low power device. Operating at high power levels when investigating interference is an insurmountable activity, so low power levels are desirable.

Fig. 6. Star-to-delta transformation helps visualise how a capacitor couples two conductors.

Fig. 7. General circuit model of three conductor lines.

Fig. 8. Injection transformer circuitry – part of the kit needed to evaluate the model.
It is also a low-cost assembly, easy to modify to suit the application.

**Current transformer**

To monitor current in the cables, an identical toroid was used to construct a current transformer. This time the primary was the intended loop-under-test and the secondary was ten turns of enamelled copper wire. A 36Ω resistor was connected across the secondary, allowing any voltage across the resistor to be monitored by the oscilloscope.

The 22Ω resistor was used to match the transformer termination to the coaxial line. Figure 9 illustrates the set up, and defines the relationship between current in the cable and voltage at the oscilloscope.

**Loop admittance test**

The test equipment was connected to the test rig, as shown on Fig. 10. One conductor of the wire pair was connected to structure at both ends to form a loop, and simulate a "return" conductor with both ends grounded.

The "signal" conductor was terminated at one end in a short circuit to structure, and at the other end by a load consisting of 51Ω and 56Ω resistors in series. This load’s purpose was to allow a subsequent test to measure the common mode rejection of the set up.

The injection transformer was used to inject a sinusoidal voltage of about one volt peak to peak into the cable/structure loop, to simulate signal induced by an external source. Such an external source could be electromagnetic radiation causing spurious currents in the structure, or an adjacent cable carrying other signals in the system.

The current transformer was used to monitor the resultant current. Measurements were carried out at a number of spot frequencies, and a record kept of frequency, input voltage, and output current. When resonance was detected, several measurements were taken at and around the peak of the graph in the response.

**Analysing the results**

Physical data, as recorded in Fig. 10, was used to calculate component values for the circuit model of the set-up, using equations (8), (10) and (11). Then the general circuit model of Fig. 7 was converted to the specific circuit model of Fig. 11.

The model was completed by shorting the terminations at the right hand side, adding the monitor resistors to the left-hand side, including a 1V source to represent the output of the transformer, and adding a 0.2Ω resistor to simulate the load presented by the current transformer.

Using Geca and Spieca, as mentioned earlier under "Circuit analysis software", I calculated the frequency response of the new model. In this case, the output selected was the current in the 0.2Ω resistor. This resulted in the solid curve of Fig. 12.

Test data was then processed to give admittance values, and the results added to the curve as a set of test points.

**Working out**

Assume that the three isolated conductors of Fig. 1 represent a section of a wiring assembly, or an adjacent pair of conductors. If there is current in the conductors, then there is also an electromagnetic field, and vice versa. The absolute potential of each conductor is related to the current in all three conductors by the primitive equations:

\[
V_p(1) = Z_{p11}(1)I_1 + Z_{p12}(1)I_2 + Z_{p13}(1)I_3
\]

Here, the parenthesis numbers in the subscripts define the conductors. One feature of primitive impedances is that they are symmetrical, if and are used to identify conducting currents, then:

\[
Z_{p11} = Z_{p22} = Z_{p33} = -Z_{p21} = -Z_{p32} = -Z_{p13}
\]

If the current is generated by a voltage source between the ends of the conductors and 2, with a short between conductors 3, as in Fig. 2, then the loop currents of Fig. 2 can be related to the primitive currents of Fig. 1.

\[
L_p = Z_{p11} = Z_{p22} = Z_{p33} = -Z_{p21} = -Z_{p32} = -Z_{p13}
\]

Relationships between current and voltage of equation 1 remain unchanged, so the primitive currents can be replaced by the loop currents. Loop voltages are the difference in potential between pairs of conductors, so a set of loop equations can be derived.

\[
V_p = V_{p1} = V_{p2} = V_{p3} = Z_{p11}I_1 + Z_{p22}I_2 + Z_{p33}I_3
\]

\[
0 = V_{p2} - V_{p1} = Z_{p12}I_1 + Z_{p22}I_2 + Z_{p32}I_3
\]

\[
0 = V_{p3} - V_{p2} = Z_{p13}I_1 + Z_{p23}I_2 + Z_{p33}I_3
\]

\[
0 = V_{p1} - V_{p3} = Z_{p11}I_1 + Z_{p21}I_2 + Z_{p31}I_3
\]

\[
0 = V_{p2} - V_{p3} = Z_{p21}I_1 + Z_{p22}I_2 + Z_{p23}I_3
\]

\[
0 = V_{p3} - V_{p1} = Z_{p31}I_1 + Z_{p32}I_2 + Z_{p33}I_3
\]

Because primitive impedances are symmetrical, so are loop impedances. For loop parameters, the numbers in the subscripts refer to loops. The next action is to create a circuit diagram that contains two loops, with one impedance common to both loops. Fig. 3. This is an exercise in lateral thinking, and is the most important step in the whole procedure.

Circuit 1

The model used for the set-up is a twin loop assembly with mesh currents and voltages of equation set 5. The model is identical to Fig. 3, except now the conductors have been replaced by inductors, and the conductors have been replaced by resistors. Resistor values can be obtained by inspecting equation set 6 and then calculating end-to-end resistance.


**Reference**


February 2000 ELECTRONICS WORLD
This book is the definitive study of the life and works of one of Britain's most important inventors who, due to a cruel set of circumstances, has all but been overlooked by history.

Alan Dowler Blumlein led an extraordinary life in which his inventive output rate easily surpassed that of Edison, but whose early death during the darkest days of World War Two led to a shroud of secrecy which has covered his life and achievements ever since.

His 1931 Patent for a Binaural Recording System was so revolutionary that most of his contemporaries regarded it as more than 20 years ahead of its time. Even years after his death, the full magnitude of its detail had not been fully utilized. Among his 128 patents are the principal electronic circuits critical to the development of the world's first electronic television system. During his short working life, Blumlein produced patent after patent breaking entirely new ground in electronic and audio engineering.

During the Second World War, Alan Blumlein was deeply engaged in the very secret work of radar development and contributed enormously to the system eventually to become 'H2S' - blind-bombing radar. Tragically, during an experimental H2S flight in June 1942, the Halifax bomber in which Blumlein and several colleagues were flying, crashed and all aboard were killed. He was just days short of his thirty-ninth birthday.

For many years there have been rumours about a biography of Alan Blumlein, yet none has been forthcoming. This is the world's first study of a man whose achievements should rank among those of the greatest Britain has produced. This book provides detailed knowledge of every one of his patents and the process behind them, while giving an in-depth study of the life and times of this quite extraordinary man.

Contents

Earliest days

telegraphy and telephony

The audio patents

Television

EMI and the Television Commission

The high-definition television period

From television to radar

The story of radar development

H2S - The coming of centimetric radar

The loss of Halifax V9977

Legacy

To Goodrich Castle and beyond
Adaptable active speaker system

Design details

Calculating equalisation network, box 'A'
The following equations are from reference 7.
First choose \( R_s \) or the desired input-impedance:

\[
R_s = \frac{23}{R_a}
\]

\[
R_c = \left( \frac{\omega_s}{\omega_a} \right) R_s
\]

\[
C_c = \frac{1}{2} \ln(1 + k)
\]

\[
C_e = \frac{1}{2} \ln(1 + k)
\]

\[
\alpha_s = \frac{\omega_s}{\omega_a}
\]

\[
\alpha_c = \frac{\omega_c}{\omega_a}
\]

Calculated values

\[
\omega_c = \frac{R_c C_c}{2R_s + R_c}
\]

\[
\omega_e = \frac{R_e C_e}{2R_s + R_e}
\]

Calculated values

<table>
<thead>
<tr>
<th>Measured values</th>
<th>Actual values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \omega_c = 63.1,\text{Hz} )</td>
<td>( \omega_c = 63.1,\text{Hz} )</td>
</tr>
<tr>
<td>( \omega_c = 42,\text{Hz} )</td>
<td>( \omega_c = 42,\text{Hz} )</td>
</tr>
<tr>
<td>( \alpha_s = 258,\Omega )</td>
<td>( \alpha_s = 258,\Omega )</td>
</tr>
<tr>
<td>( \alpha_c = 258,\Omega )</td>
<td>( \alpha_c = 258,\Omega )</td>
</tr>
</tbody>
</table>

I believe these deviations to be acceptable. You will find these values at the righthand side of Fig. 5. You should now be able to design the box with a pocket-calculator.

Data for mid-range box 'A'
The internal volume of the 15 cm diameter mid-range sphere is,

\[
V_r = \frac{4}{3} \pi r^3 = 4.189\,\text{litre}
\]

\[
R = \frac{1}{2}(15\text{cm} - 2\times2\text{cm}) = 5.5\,\text{cm}
\]

\[
V_o = 0.7\,\text{litre}
\]

From Table 4, you can find that \( L = 93\,\text{Hz} \), \( Q_p = 0.33 \) and \( V_o = 0.7\,\text{litre} \). And using the \( L \) equation given earlier, you get:

\[
f_c = \frac{93\,\text{Hz} \times 9.71}{V_o} = 93\,\text{Hz} \times 9.71 = 179\,\text{Hz}
\]

and

\[
Q_c = \frac{93\,\text{Hz} \times 9.71}{V_o} = 93\,\text{Hz} \times 9.71 = 179\,\text{Hz}
\]

The butterworth high-pass filter

Select the corner frequency \( f_c \) and the value of \( C \) for \( f_c = 400\,\text{Hz} \).

\[
C_f = C = \frac{1}{2\pi f_c / V_o}
\]

The necessary equalised values are:

\[
\omega_c = 93\,\text{Hz}
\]

\[
\omega_e = 0.33\,\text{Hz}
\]

\[
\alpha_s = 258\,\Omega
\]

\[
\alpha_c = 258\,\Omega
\]

Calculated values

\[
k = 1.291
\]

\[
R_a = 10\,\Omega
\]

\[
R_e = 238\,\Omega
\]

\[
R_c = 238\,\Omega
\]

\[
C_c = 0.563\,\text{F}
\]

\[
C_e = 0.563\,\text{F}
\]

\[
C_s = 0.563\,\text{F}
\]

\[
C_a = 120\,\text{F}
\]

To find box volume expands by about 20%. As the volume of the speaker's components amount to about 0.23\,\text{g}, the full value of 21.5 \,\text{litre} is maintained. To find total \( Q \) for the two bass speakers,\(^{13}\)

\[
f_c = \frac{2V_c}{V_o}
\]

\[
= 40\,\text{Hz} \times \frac{2 \times 167}{\sqrt{21.57}} = 1.291
\]

\[
= 40\,\text{Hz} \times \frac{1.577}{63.73}
\]

\[
= 0.42 \times \frac{1.577}{63.73} = 0.0662
\]

If you treasure your vinyl collection, this book is for you. Featuring articles from the pages of the US magazine Audio Amateur and other sources, it contains absolutely everything the serious LP music collector needs to get the most out of both vintage records and the highest quality new pressings.

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Digital TV - a botched start to the Millennium?

While digital TV offers many advantages over analogue TV in terms of picture and sound quality and programme choice, I do not consider that enough has been done to integrate the three modes of reception - namely conventional terrestrial, cable and satellite - in one receiver. Nor has enough been done to ensure digital TV's economic servicing by the trade. I ask myself how much confidence has been given to the implications of the fact that digital TV receivers will break down, and will have to be serviced?

By the time analogue TV is discontinued there may be as many as 40 million digital TV sets in the UK. This represents a huge volume of production, with high potential for economies of scale if all receivers were made identical in the reception and signal processing areas. In those areas, individual manufacturers can do little to affect the outcome in terms of picture quality and appeal anyhow.

I am sure that the savings here would more than pay for the inclusion of facilities for reception of all three modes, and a diagnostic tool allowing easy servicing via a PC.

There would be no need for set-top boxes, and manufacturers would be free to design their power supply, tube circuitry, controls, speakers and cabinets to give their sets consumer appeal. There could be firms similar to M-C unlikely to repair the modules quickly and cheaply, so that those in the trade who cannot cope with SIM components or digital fault diagnosis could still get their customers' sets minded economically. A new module might even be affordable.

Digital satellite TV is chaotic, with many different encrypting systems from rival broadcasters. Most have Common Interface (CI), but products adhering to this standard are expensive - at about £40 each.

BSkyB has given the public a set-top box that makes it difficult to access programmes from alternative sources, and that looks clunky. Satellite viewers will need a further set-top box, and using output switching - neither of which is handy or cheap. If someone ever cracks the VideoCode code used by BSkyB, users will be left with a lot of expensive junk, and providers will have to give the public a whole new set of free set-top boxes. It would serve them right.

Robert E Littlewood

Gainsborough Lincolnshire

RMS power indeed

I enjoyed the two articles by Joe Carr on the measurement of RF power (Nov/Dec '99) - a topic not well understood in general. Joe displayed some considerable understanding of the topic, and yet I would venture to say he has not appreciated his own message in the term "RMS power".

RMS power is itself a valid mathematical expression, but not used in practice. RMS power is the square root of the average of the squares of a number of readings of power. It is not the same as the product of RMS voltage and RMS current, since the product of two RMS values is not commutatively RMS (cos "phi").

The reading of power that is useful, since it indicates the...
Wien and Christmas
I was interested in Ian Hickman's article about Wien bridge oscilloscopes in the January issue. But for my needs, the H25 thermometer mentioned won rather extravagant.

Waiting a simple Wien oscillator as a little tone source, I found that a cheap alternative is a 12-Volt Christmas tree lamp. Since it has a positive temperature coefficient rather than the negative one of the H25, it has to be placed in the ground leg of the feedback network, and a fixed resistor of around 1200 ohms is needed in the upper leg. I have made two of these oscillators and they have been very satisfactory for their purpose. Woolworths is useful source of space lamps. The circuit below shows the simple holiday-powered tone source with its attenuator.

Michael Tung
Twickenham Middlesex

Phase-linear misconception
I think Mr de Boute's letter in the November issue misinterpreted my aim in designing the phase-linear crossover on page 779 of the September issue. The rate of attenuation of the high-pass response was not of prime concern as the design was primarily intended for an electronic high-frequency unit with a wide frequency response.

The aim was to produce a crossover with the lowest possible distortion. I would gladly trade off a 'mellow' response for phase linearity, flat time delay, good damping and impulse response (virtually no ringing, undershoot, overshoot) fast rise and settling times.

I built the design mentioned in National Semiconductor's Audio Design handbook in 1981, pp132-134.

We hope to present a full article on the history, development and application of the perfect transistor - the current-conveyor - in the next issue.

Ed.
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