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NEW CAPABILITIES

The Super Audio CD provides a number of new capabilities compared with a standard CD.

- It uses a hybrid technique in which two independent data layers are sandwiched. This approach results in a CD that is fully compatible with existing, standard CD players. This is important to the retail trade and consumers alike, since it avoids the necessity of doubling up on CDs containing the same recording.
- One layer is processed in Super Bit Mapping Direct, a technology that results in a DSD (direct stream digital) encoded audio signal being reproduced with better quality even on a standard CD player. This is because the 16-bit resolution of the PCM (pulse-code modulation) signal is used optimally. Without the technique, the value of the last bit is not reliable.
- The additional data on the second layer are processed in DSD, an encoding technique in which a digital audio signal is sampled at a rate of 2.8224 MHz and then processed as a 1-bit digital signal. Conventional CDs use a 16-bit PCM code.
- The digital code on the second layer is compressed in Direct Stream Transfer, a Philips lossless coding method. This applies to normal stereo playback, 6-channel playback, text and graphics. In practice a compression ratio of about 50 per cent is obtained.
- Digital watermark. The illegal copying of CDs is made much more difficult with the aid of visible and invisible markings.

DIRECT STREAM DIGITAL TECHNOLOGY

Since the introduction of the CD, the rate at which signals can be sampled has increased appreciably and the resolution has been refined. Yet, the quality of the reproduced sound has hardly improved. This is because the basic concept of the standard CD cannot be changed. One of the serious limitations is formed by the filters used. These filters are required to pass signals up to 20 kHz (which 98% of people cannot hear) and suppress all signals above 22.05 kHz. A number of methods have been devised to accomplish this, such as oversampling. The effect of these is minimal.

In most PCM recording systems, the analogue data are oversampled x64 with a sigma-delta converter. This means that the system operates with a sampling rate of 2.8224 MHz, which results in a 1-bit digital signal that is converted into a PCM code.

In Direct Stream Digital (DSD) technology, the 1-bit signal is used directly, that is, not converted into PCM code. Since the sigma-delta converter has a relatively high noise floor, a fifth order filter is used to eliminate most of the noise.

Whereas modern tape recording machines used in broadcasting have a bandwidth of 50 kHz at a tape speed of 30 in/sec, DSD technology provides a frequency response from d.c. to over 100 kHz, plus a dynamic range greater than 120 dB across the audio band. Moreover, independent critics and record producers rate DSD sound as ‘relaxed, musical, detailed and transparent, with a far greater sense of space around each instrument and voice’.

Figure 1. The Super Audio CD is similar in concept to the standard CD, but has an additional high-density layer. The two layers are read from the same side. The CD laser reads the Standard Reflective Layer through the Semi-Transmissive Layer.
Both DSD 2-channel stereo and DSD 6-channel sound depend on the lossless coding method Direct Stream Transfer. Such reduction technologies are also used in computers, for instance, the ZIP protocol. They compress (reduce) the original data stream without the loss of a single bit. The algorithm used for the Super Audio CD gives a reduction of about 50 per cent. Other bit rate reduction technologies which ignore redundant data, such as MPEG-2 or Dolby Digital (AC-3) provide a much higher degree of compression. The price paid for this is that decompression provides a signal that looks like the original, but is slightly different.

SUPER BIT MAPPING
Since the Super Audio CD is mastered in DSD technology, the CD layer, compatible with the CD ‘Red Book’ standard, is transferred from DSD in a so-called Super Bit Mapping (SBM) direct down-conversion. This means that the 1-bit wide, \( \times 64 \) oversampled DSD datastream is converted to 16-bit and the usual sampling rate. It is, of course, important that as little information gets lost in this as possible. Sony has developed special SBM processors that enable 20–24-bit accuracy to be obtained with 16-bit signals.

THE NEXT GENERATION
The next generation of CD players, the Super Audio CD players, are fitted with 650 nm lasers to which the high-density layer is reflective. The user of such a new player will have access to 2-channel stereo sound of the highest quality, a 6-channel version of the same sound plus additional text (disc name, artist name, track name, lyrics and liner notes) and graphics.

The available bandwidth for both music versions is 0–100 kHz (compared with 20 Hz to 20 kHz in a standard CD player) with a dynamic range of 120 dB over the audio range (currently 94 dB maximum).

PROTECTION AGAINST PIRATES
It is of the greatest importance to producers and consumers alike that the illegal copying of CDs is stopped. Although the Copy Management System (CSM) restricts the amateur criminal, it does not stop ‘professional’ felons from producing vast numbers of illegal copies.

More stringent protection measures are incorporated in the Super Audio CD. First, with the aid of Digital Watermark, the disc is given a water mark in the form of a pattern of pits on the signal side with Pit Signal Processing (PSP). The pattern is highly recognizable by the user, but can only be produced by the manufacturer of the disc using complex technologies. Needless to say, the pattern cannot be removed, even by the original producer.

Also, there are less easily seen markings, such as barcodes and invisible, irremovable data on the CD.

All these precautions do not make it impossible for criminals to copy the CD, but they should at least make it possible for us, the consumer, to ensure that we are not defrauded by these felons by checking that the CDs we buy carry these markings.

Figure 2. Construction of the Super Audio CD. Note that the laser looks upward from below the disc. A standard CD player’s laser does not ‘see’ the high-density layer.

Figure 3. In standard CD (PCM) processing, filters are required for recording and playback. In super audio CD (DSD) processing, the input filters are not needed and the original 1-bit data are used.
Since the 1960s, light-emitting diodes (LEDs) have come into use for many applications. Many people may not know that these diodes, used in low-cost laser-pens and laser pointers, were developed for CD players. Today, lasers are used in architecture, in automobile engineering to measure all sorts of part, and in high-precision spirit levels, to name but a few. Lasers are also used in crime fighting, for instance, in high-precision speed traps to catch the unwary, speeding motorist. These are but a few examples of the many applications of lasers. This article describes how a simple laser diode can be used to build an inexpensive burglar deterrent/alarm.
SAFETY FIRST!
Any laser, even the smallest, forms a danger for the human eye. In laser technology there is one rule that must be obeyed at all times: Never, ever look into a laser beam or even into its reflection! In this context, it should be borne in mind that even a 1 mW laser is about 1000 times as bright as summer sunlight. Before you start any work on a laser project, take off any rings, watches, bracelets and other shiny personal ornaments that may reflect the laser beam. Also, make sure at all times that there is nobody else in the path of the beam. Children are particularly curious and will want to find out what happens in the beam.

INTRODUCTION
Lasers generate a light beam that, owing to its coherent character, can be used to span large distances. Most lasers available in the retail market are semiconductor types. One version that recently has been in the news (owing to its nefarious use by some unthinking youths) is the laser pointer. This is a small semiconductor laser mounted in a slender, light and easy-to-hold case intended for presentation purposes. The law in most countries limits its output to 1 mW.

Since the light beam emitted by a laser can span relatively large distances, a laser can be used to set up a simple but effective burglar alarm. For instance, a laser and a few mirrors placed in appropriate positions can form an invisible barrier around a building or a valuable object.

A drawback of a laser diode is that it generates a constant beam of light. For the present purpose, it would be much better if the light were modulated so that the intensity of the light beam can be adjusted. Fortunately, this can be done by placing a potentiometer or external laser unit which may use a discrete laser diode or a laser pointer. The brightness of the general-purpose AM receiver demodulated signal may be varied with which modulated laser beam may be varied with a potentiometer or external device. The law in most countries limits its output to 1 mW.

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Classification of laser pointers
Laser pointers, laser pens, and laser diodes available in the retail market are classified in three categories according to NEN (Euro) Norm 60825-1 (available from the British Standards Institute or your particular country's Standards Authority). In the United Kingdom, it may be inspected at many Public Libraries. There is a fourth category, but this deals with lasers for professional applications (which are subject to a licence) only.

Category III
This pertains to lasers with output powers up to 5 mW, which are not safe to use without adequate provisions. At small distances, exposure of eyes for less than a quarter of a second (the eye reflex is longer) leads to irremediable damage to the eye. Its sale to unlicensed private citizens is prohibited.

Category II
Applicable to lasers with output powers <1 mW. In spite of their low power, such lasers cannot be used in gadgets such as keyrings. At distances of ≤1 m (3 ft), exposure of 0.25 s can lead to serious damage to the eyes.

Category I
This category applies to laser diodes with an output power <0.5 mW, which are reasonably safe in use. They can be used in gadgets such as keyrings. Even so, great care is needed when using these lasers.
THE LASER: DESCRIPTION

The circuit of the laser is shown in Figure 1. Diode D₂, in anti-parallel with the laser diode, provides a simple but effective protection against connecting the supply lines with wrong polarity. Should this occur for a brief moment, no harm is done. If, however, the wrong polarity is retained, tantalum capacitor C₃ will explode, but the laser diode will not be damaged.

Depending on the type of laser diode or laser pointer, the value of series resistor R₁ must be adapted, although for most diodes a value of 9-11Ω is fine.

The circuit is built on a small piece of stripboard. If you have the skills and patience, you may well decide to etch a small printed-circuit board to which the components may be soldered at both sides. Note that the rating of zener diode D₂ is 5V, 500 mW.

The module can then be taken into use. Using a regulated power supply of 3.5-6V (at which power losses are smallest) and linking the modulation input to the +ve supply line, the diode should emit light.

Proper modulating voltage may be applied to the modulator input. Thanks to the direct coupling, the potentiometer at the input provides the means for accurate power control. The modulation stage handles sinusoidal signals up to 2MHz before the depth of modulation begins to diminish. It is noteworthy that a depth of modulation of 100% is achieved at frequencies of up to 2MHz, which is not bad for a simple circuit.

RECEIVER

The circuit in Figure 2 shows an amplitude-modulation (AM) receiver that uses a photo-transistor, T₁, as detector. It is followed by an amplifier, IC₁, which is very stable and immune to interference. The sensitivity of the receiver proper is set with multiturn preset R₁.

Note that resistors R₂ and R₃ should be metal film, 1% types. The rating of R₃ is 0.5 W.

A second amplifier, IC₂, drives a small loudspeaker, LS₁. The volume is controlled with R₆. The loudspeaker may, of course, be replaced by a small relay to operate another kind of alarm, perhaps at some distance from the installation.

The overall receiver is decoupled by a number of capacitors. Note that C₁ should be a ceramic type.

The detector may be any type of infra-red photo transistor or diode available. Suitable transistors are, for instance, BPW40 or, better, LPT85A; diodes: SFH205 or BF834.

The receiver is powered by a symmetric supply, which may be provided by two 9V batteries.

The receiver may be housed in a small plastic case. It is not really necessary to design a printed-circuit board for it: it is easily built on a piece of stripboard. Clearly, the construction should be carried out with care and neat soldering to prevent spurious oscillations occurring that may spoil or distort the measurements and would give rise to false alarms.

The phototransistor should be mounted in a small tube of appropriate inner diameter. This prevents not only interference by ambient light and other sources of light, but also gives the detector some directivity. Mind the polarity of the transistor when soldering it into place: the detector will still work with incorrect polarity, but its sensitivity is then much reduced.

Test

Set sensitivity control R₁ to the centre of its travel, volume control R₄ to minimum and connect the receiver to the two batteries or other ±9V power supply as the case may be. When the volume control is turned gently, a dull hum should become audible: this is the 50 Hz hum emitted by the mains supply via the room lights. When the lights are not on, this hum will not be heard, so do turn them on for this test. If you still do not hear anything, there is a fault somewhere. Check all connections, junctions, components, and so on. If all these are all right, the receiver must work satisfactorily.

ALTERNATIVE

It is not always necessary, or convenient, to use a modulated light beam. Often, a simple light-operated switch such as shown in Figure 3 may be used.

When light falls on to photo transistor T₃, transistors T₂ and T₃ come on, whereupon the relay is energized. If therefore the relay contact opens, either the laser beam is interrupted or the power supply has failed. Two good reasons to take action!

Note that R₁ is a multiturn type and resistors R₂ and R₃ are metal film, 1% types. The relay is a small-signal type, 12 V, ±50 mA.

The detector may be any type of infra-red photo transistor or diode available. Suitable transistors are, for instance, BPW40 or, better, LPT85A; diodes: SFH205 or BF834.

References:


The Laser Guidebook by Jeff Hecht, ISBN 0 07 0277370; McGraw-Hill, 1992

Note that, if you as a private person use a laser in your own home or garage (as long as unauthorized people have no access) you may do with what you wish, as long as it does not harm life or property of third parties (including burglars!).

Insurance

If you are an employer, you have, of course, the necessary insurance(s) to cover your liabilities. Beware, however, because most policies explicitly exclude any damage, direct or indirect, caused by laser beams. You must, therefore, make absolutely certain that a relevant clause regarding liability for such damage is included. Many people are not aware of the exclusion.
The combination of a wire loop with the size of an A4 sheet, coupled to a carefully matched and easily tuned amplifier offers high-quality MW/LW/SW radio reception in your living room. The excellent performance of the two ‘all-portable’ directional active antennas described in this article makes them direct rivals of many extensive outdoor antennas. Meet the Omega-2 and Omega-3!

The active antenna designs discussed in this article are the result of many years of comparative signal level monitoring using various long-wave, medium-wave and short-wave antennas for indoor and outdoor use. The antennas available for this research work were a 5-m high vertical ground plane, a magnetic loop with a diameter of 1.2 m, an active ‘rod’ antenna [1] and various small magnetic antennas including round and square loops, and ferrite rods coupled to suitably dimensioned amplifiers.

General antenna theory tells us that long wires and rod antennas are only sensitive to the electric component of the received signal. When used indoors, they lose 70-90% of the received voltage as compared with a mounting position on the roof. By contrast, small loop-antennas exhibit a totally different behaviour, mainly because they are sensitive to the magnetic component of the RF signal produced by the transmitter. As long as the thickness of the ‘wall’ or other obstacle to be traversed is much smaller than the wavelength, a magnetic field is hardly reduced in strength. Consequently, the level differences between magnetic antennas mounted indoors and outdoors were found to range from negligible to 50% at the highest...
on one occasion.

There are still other marked differences between antennas responding to the 'electric' field, and their counterparts designed to convert the magnetic component into an electric voltage. Whereas the currently popular active electric antenna (say, the combination of the small telescopic rod with a matching amplifier) typically exhibits wideband behaviour, magnetic antennas generate competitive voltage levels only in resonance, that is, when accurately tuned to the desired receive frequency. Wideband systems unfortunately suffer from susceptibility to intermodulation in the vicinity of strong transmitters, a problem that calls for rather special remedy [2].

Another advantage of magnetic active antennas is that they supply an RF signal with an unusually low background noise level.

**W-2 Antenna for LW/MW/SW**
The first antenna discussed here provides seamless coverage of the LW/MW/SW frequency range from 150 kHz to 30 MHz. It is powered by either the receiver or its own power supply, via the RF output cable and a simple RF/DC splitter. Current consumption will be of the order of 20 mA at a supply voltage of 9 V or 12 V. The amplifier accepts a number of inductive loops and coils, including experimental ones, which are simply ‘plugged in’.

**The Electronics**
Although the two-stage amplifier shown in Figure 1 is based on the design presented in [1], a short discussion on its operation.

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**Figure 1.** Circuit diagram of the Omega-2 active magnetic antenna for LW/MW/SW reception from 150 kHz to 30 MHz in four ranges. Note that the amplifier is only suitable for the indicated loop antenna. The heavy lines in the diagram indicate connections made in solid wire to preserve the Q factor of the antenna.

**Figure 2.** Construction details of the transformers and the LW/MW rod antenna used in the Omega-2.
Enamelled copper wire, but a Teflon-antenna is not wound using ordinary ferrite rods. That is why the MW/LW ferrite antenna is not tuned across a frequency range with its operating resistance of 75 $\Omega$ exists in parallel with the base and emitter of the next transistor rather than with respect to ground. The BFR193 is an SMA bipolar RF transistor whose frequency response is 'linearised' by means of strong feedback ($R_2 \gg r_P$). In contrast with the FET, it is easily dimensioned to supply the necessary (but still quite low) voltage gain. Remember that the main purpose of the amplifier is to provide the best possible impedance match to the loop antenna, while ensuring that severe intermodulation owing to nearby multi-kilowatt transmitters (utility or broadcast) does not occur easily. High gains are not generally required or indeed desirable ahead of any SW receiver input.

Depending on the frequency range selected using rotary switch SIA-S1B (0.15-0.7 MHz, 0.5-1.7 MHz, 1.7-8.2 MHz or 7-30 MHz), different magnetic antennas are connected to the amplifier input. In the highest range, only the 1-turn loop is connected, while in the lowest range, the amplifier receives the voltage produced by two series-connected coils on a ferrite rod. A 700-pF (350+350) variable capacitor, C1-C2, enables the antenna circuit to be tuned across a frequency range with a high/low ratio of about 4.8. For the lower SW bands, a loop with 4 turns appears to be the best choice. The solution adopted here is, however, more elegant, using a transformer (L1-L2) with a step-up ratio of 1:4.5. Interestingly, the combination of a 1-turn loop and the transformer yields roughly the same quality factor (Q) and output signal level as the classic 4-turn loop. In practice, the use of a single 1-turn loop for two SW ranges is simply convenient!

For medium-wave (MW) and long-wave (LW) reception, the traditional ferrite rod still offers good performance. Using a rod with a diameter of 10 mm and a length of 200 mm, made from 4B1 material ($\mu_r = 250$, Philips Components) an effective permeability, $\mu_{eff}$ of about 115 is obtained, which is equal to an air-cored inductor having an unprocessed size 71x115mm. Using a rod with a diameter of 250 mm, Philips Components) an effective permeability, $\mu_{eff}$ of about 115 is obtained, which is equal to an air-cored inductor having an unprocessed size 71x115mm. Using a rod with a diameter of 250 mm, Philips Components) an effective permeability, $\mu_{eff}$ of about 115 is obtained, which is equal to an air-cored inductor having an unprocessed size 71x115mm.
coated alternative called Tefzel.

The amplifier’s output signal appears across L6 at an impedance of about 50 Ω. As you can see, it is coupled out inductively, the amplifier’s supply voltage being applied to the primary of the 1:1 output transformer (L5-L6). This is coupled to the amplifier using an arbitrary length of 50-Ω coax cable and a BNC or similar plug.

The value of R6 depends on the supply voltage used: use 220 Ω for 7.5–9 V, or 330 Ω if your supply (or receiver) delivers 10–15 V.

Coil winding, soldering & mechanical work

The construction of the Ω-2 active antenna involves a fair bit of drilling, filing, cutting and winding of inductors. We’ll start with the latter.

Three transformers, L1-L2, L3-L4 and L5-L6, are wound using two-hole (‘binocular’) ferrite cores as illustrated in Figures 2a and 2b. L3-L4 and L5-L6 are wound using bifilar wire which is easily made by twisting together two lengths of wire until a pitch of 3 to 5 turns per cm is obtained. After winding, the wire ends have to be identified with the aid of a multimeter. Winding data and materials used are stated in the Components List.

The coils on the ferrite rod (L7-L8) are wound in ‘compartments’ of formers normally used for pot cores (Figure 2c). L7 has four compartments with 25 turns each of 0.3 mm dia. (30AWG) Teflon-coated copper wire. The smaller coil, L8, has a total of 36 turns of ordinary 0.6-mm copper lacquer wire divided equally over two compartments. Note that two compartments remain empty.

Having made these inductors you are ready to tackle the circuit board. The copper track layouts and component mounting plan of the double-sided PCB are given in Figure 3. This PCB is available ready-made from the Publishers. The amplifier proper is largely built from SMA (surface mount assembly) parts. To facilitate soldering by hand, the relevant copper spots are purposely made a little larger than usual for SMA components. To keep its cost within reason, the PCB is not through-plated, and a total of seven component wires, plus the wire ends of L3-L4, have to be soldered at both sides of the board.

Using aluminium sheet with a thickness of 1.5 mm, a chassis is cut, drilled and bent as illustrated in Figure 4. Six holes with a diameter of 2.5 mm allow one of two types of ‘Hopt’ variable (tuning) capacitor to be firmly secured. Similar tuning capacitors from other manufacturers may require different mountings. One of the Hopt types the author picked up at a rally has only two AM sections; the other, two AM sections and two FM sections. Both are equally suitable. The AM sections are connected in parallel to produce a maximum tuning capacitance of about 700 pF, to be connected between ground and the PCB terminal marked ‘CVAR’. A large knob makes for precise tuning, hence two 0.5 mm thick washers are used to make sure the centre of the tuning capacitor spindle is exactly half-way the height of the enclosure. The drilling details for the plastic case itself are shown in Figure 5. Seven holes have to be drilled, including one to pass the output coax cable. One additional, larger, hole may be required for a pivot assembly, a turntable or ball-bearing that enables the antenna to be rotated.

The internal construction of the Omega-2 amplifier is further illustrated in Figure 6. The two wander sockets are cut to a total length of 14 mm. The
spindle length of the band selection switch is reduced by 13 mm. The insulated wander socket (to the right in the picture) is fitted with a solder tag for wiring to the PCB. In the suggested construction, there is no room for the M10 nut that comes with the rotary switch. Consequently, the locking ring is either omitted or secured in position '4' using two-component glue. The four 2-compartment formers (for pot cores) are first glued together, and then to the PCB. Two compartments remain empty. Later, the ferrite rod is passed through the formers and the holes in the case panels and the PCB, before it is secured with a nylon cable strap.

The loop antennas
The shortwave antenna for the Omega-2 is made by bending 4-mm dia. brass or copper tubing, or massive copper, using a bottle or similar round object as a 77-mm dia. bending aid. Before you start bending the tube, mark the locations of the corners at ±90 and ±300 mm. The final size of the antenna should be 201x261 mm measured from the tube centres, although a few millimetres tolerance is perfectly acceptable. The tube ends are cut off until they are 82 mm apart. Using an electric cooking plate or similar heating...
device the antenna and the wander plugs are preheated and then soldered.

An alternative to the ferrite rod is the ‘classic’ MW loop antenna consisting of 17 turns of 0.6-mm dia. enameled copper wire wound on a wooden frame of dimensions 22x22x4 cm which is either home-made or obtained from a handicraft shop. The turns should be spaced by about 2 mm, and are best held in position by grooves cut in the four corners of the frame. This antenna will typically produce a signal level which is four times higher than that of the ferrite rod. Like the 1-turn loop for the two SW ranges, the MW window is plugged into the Omega-2 amplifier box by means of two banana plugs. To use this excellent antenna, select the 7-30 MHz range. The finished MW loop is pictured in the introductory photograph, together with the Omega-2 amplifier. Its frequency coverage is 0.51-1.9 MHz.

**W-3 Antenna for SW ONLY**

Abroad, in a hotel with awful interference levels caused by airco systems and TV sets, or in a modern office, where computer noise thwarts any attempt at serious shortwave reception, you may expect little from your pocket-size shortwave receiver with its telescopic antenna, or even a wire antenna with a length of 5 m.

If your receiver has a socket for an external active antenna, you should not fail to experiment with very simple magnetic antennas based on FETs. As already mentioned, voltage gain is not required because the small receiver will be designed to handle small signals.

**Figure 7** shows the circuit diagram of the Omega-3 active antenna. As you can see, it is simpler than the Omega-2, mainly because the LW and MW bands are not covered. For holiday use, however, the Omega-3 is the perfect choice!

Offering a transconductance of about 0.4 mS the BF245 FET supplies a gain of about 0.8 times at a load impedance of 200 Ω presented by the Sony ICF-SW100 receiver. The internal FET amplifier has a fairly high and frequency-dependent input impedance to match the built-in telescopic antenna. When an external active antenna is connected, its mono jack plug connects the 220-Ω resistor to ground, causing a nearly constant load of 200-220 Ω to be presented to the active antenna output, while reducing the influence of the telescopic antenna. High-pass and VHF trap filters (block F) leave a usable bandwidth of 1.6 to 30 MHz. The CCITT weighted sensitivity of the author’s ICF-SW100 is around 0.25 µV at the input jack, for (S+N)/N = 10 dB at 80% amplitude modulation.

Compared with the receiver’s telescopic antenna, the Omega-3 guarantees a noticeable volume increase, not even mentioning much reduced background interference levels.

The few parts that make up the Omega-3 are connected ‘in the air’. As shown in **Figure 8**, the antenna is plugged in at the sides of the case.

**References:**


More interesting articles on antenna design which appeared in Elektor Electronics:

- The QTC Loop Antenna, June 1991.
- An experimental all-waveband ferrite rod antenna, May 1990.
- The miser’s T/R Loop Antenna, November 1990.


- Mark-Two 80/40 QTC Loop Antenna, July/August 1992.
- Wideband active telescopic antenna, July/August 1992.

- External ferrite aerial units for SW/MW/SW radios, May 1993.
- Small loop antennas for MW AM BCB, LF and VLF reception, June and July/August 1994.
- Ultima Loopstick VLF Antenna, July/August 1998.

**Figure 8.** Omega-3 shortwave active magnetic antenna: easily stowed away in your holiday luggage, excellent SW reception guaranteed!
how does a digital loudspeaker system work?

Digital loudspeaker system
Type DS4 from Visaton

The design of a digital loudspeaker system presents grave difficulties owing to the requirements for low quantization, low spurious noises and good directivity.

The key to a good design lies in the digital signal processor, DSP. The electro-acoustic conversion remains traditional, of course, but a DSP unit is added to the digital audio chain in which a digital-to-analogue converter (DAC) precedes the normal amplifier and loudspeaker.

Over the past few years, digital signal processing has become more and more important. Compute-intensive filter operations are gradually being replaced by powerful digital signal processors—DSPs. Computing speeds have increased so much that it is now possible with a digital protocol to design crossover networks for active loudspeaker systems which can undertake the error correction for the entire signal chain. Such a network or, rather, controller, is at the heart of the active, digital, four-way loudspeaker system Type DS4 from Visaton (Figure 1).

The controller is a combination of a digital preamplifier, digital crossover filter, digital error correction network for the entire chain, and digital protection network. The electronic and acoustic
Window functions

The frequency characteristic of a digital filter is a periodic function related to the sampling period, $T$, which can be expanded as a Fourier series. The coefficients of this series represents the impulse response of the filter. When, in a practical case, this infinite series has to be truncated to $n$ terms, the sharp cut-off leads to overshoots and oscillations in the characteristic. This is known as the Gibbs phenomenon and the effect can be minimized by multiplying the impulse response by a weighting factor described as a window function $w(n)$. This function can easily be incorporated in the design of an FIR. Some of the common window functions have the mathematical form listed below.

- **Rectangular**
  
  \[ w(n) = 1 \quad 0 \leq n \leq (N-1) \]

- **Triangular**
  
  \[ w(n) = 2n/(N-1) \quad 0 \leq n \leq (N-1)/2 \]

- **Bartlett**
  
  \[ w(n) = 2-|2n/(N-1)| \quad 0 \leq n \leq (N-1)/2 \]

- **Hanning**
  
  \[ w(n) = 0.5 - 0.5\cos[(2\pi n)/(N-1)] \quad 0 \leq n \leq (N-1) \]

- **Hamming**
  
  \[ w(n) = 0.54 - 0.46\cos[(2\pi n)/(N-1)] \quad 0 \leq n \leq (N-1) \]

The converted signals at the analogue input can be passed to the digital output with a word length of 24 bits. This function (digital insert) is needed for calibration purposes.

FILTERING

The signals in the two stereo channels are processed discretely by two Motorola DSPs: a Type 56009 and a Type 56007. To obtain a bounded computer power and results in a (relatively) long signal delay. To prevent overshoot of the leading and trailing edges caused by truncating the number of filter terms (only a filter of infinite length is error-free), special window functions (see box) are built into the filter function.

To make the best possible use of the
The system is equalized by evaluating one output value in the sus band, so it is possible to compute 8000 input values for one output value in the SUB band, so that correction of the transfer function is expanded into a filter function. However, as already mentioned, in practice there is always a delay which depends on the quality of equalization.

Of course, high-quality equalization over the frequency range makes sense only if efficient loudspeakers are used. If this were not so, the error correction would need too much amplifying power which the loudspeaker would not be able to handle or the resulting sound pressure delivered by it would be too small.

So as to limit the number of errors resulting from rounding-off (unavoidable with the large number of computing operations), processing is carried out with long internal words. The word length between the functions shown in Figure 1 is 48 bits, but that used internally by the processor is even greater. At the next processing step, the resulting, complex-inverted transfer function is expanded into a filter function (for instance, band-pass — see Figure 3c). This process enables phase-locked filters with a skirt steepness of up to 300 dB per octave to be designed.

The bandpass response (see Figure 3a) meets the demands of the filters needed for equalization, although each band has its own result. The digital output of these filters describes the signal needed to drive the relevant loudspeaker.

**More Facilities**

Digital signal processing offers more possibilities than described so far. For instance, from the specification of the relevant components, such as the amplifier or loudspeaker, it is possible to find statements in the digital data stream pertinent to the real load. This is, however, only so if none but linear errors occur in the loudspeaker, amplifier and other components in the system. These may be recognized by the fact that the percentage error remains the same when the signal level is varied. Linear errors are ascertained and corrected during calibration.

Errors caused, for instance, by partial oscillations or too small a maximum linear deflection of the loudspeaker cone are non-linear errors. When the signal level is raised, the percentage of these errors increases. Such errors cannot be corrected by the digital controller. It is, of course, possible to keep them to an absolute minimum by the use of high-quality components. If this is the case, as for instance in the DS4, no active control is used (or needed) in the bass band. Such control would result in system feedback, causing an unbounded impulse response, which is, of course, incompatible with the basic design of an error-free loudspeaker system with finite (bounded) impulse response.

**Limiting Values**

Provided that the components following the digital controller operate linearly, it is possible to correct all linear errors in the digital data stream. The limiting values of the individual components that program the controller permit an early warning when operation of the system goes outside the linear range, for instance, when one of the components is overloaded. The limiter functions in the program then come into operation.

Limiter functions provide protection for the various components by interrupting the data stream when limiting values are reached. This is not done by a power-off, but by a specific limitation of the output signal of the digital controller. Owing to this limitation, signal components that lie above the limiting values will be distorted but will not cause any damage. If the distortion factor is accepted at peak levels, a loudspeaker reproducing music at mid-frequencies can be operated at higher volume levels. To ensure distortion-free reproduction, the limiter function represents the upper thresh-
The digital controller of the DS4 system provides three different limiter functions:

- a peak limiter that reacts to peak impulses;
- a thermal limiter, which reacts to thermal loads on the loudspeaker via temperature sensors on the magnet and voice coil;
- an overshoot limiter, which enables better utilization of the power supply of the output amplifier since the short-term pulse power output is normally higher than the continuous power output.

**BACK TO ANALOGUE**

The final step in the controller process is the reconversion of the digital signal into an analogue one. In this, the word length is reduced to 24 bits, while the SUB/BASS band is computed by real 24-bit x 4 oversampling, and the MID/HIGH band by real 24-bit x 8 oversampling. Oversampling should be seen as an interpolation at equal increases of the sampling rate. This results in a large number of intermediate values which enable much higher quality digital-to-analogue conversion.

The digital data stream is also output in 48-bit words and applied to the dither† and noise shaper. In the dither, a digital noise signal is superimposed on the data stream, so that the rectangular shape of the signal that ensues when low level signals are sampled is resolved.

The noise shaper following the dither stage is a high-pass section that acts only on the superimposed noise signal and shifts the noise floor to an irrelevant high frequency range. At the same time, the 48-bit signal is converted into 20-bit words needed for the digital-to-analogue conversion. This conversion is performed in each band by a 20-bit DAC from Burr-Brown.

The resulting analogue signal is applied to the single output amplifier via balanced XLR links. These links are highly immune to noise. An amplifier, whose output is linked directly to the appropriate driver in the loudspeaker, is needed for each band.

**LOUDSPEAKER CONSTRUCTION**

The radiation pattern of a loudspeaker affects the energy mix in the listening room. This means that loudspeakers with different radiation patterns, even when they have the same transfer function at 0°, produce differently coloured sound in a room. The shape of the DS4 enclosure (Figure 5) produces sound focusing that is proportional to the frequency. This is considered the most favourable method by the AES (Audio Engineering Society).

The signal chain is corrected over the entire audio range as regards frequency response, phase response (constant group transit time), and decay time with the aid of a digital controller. With skirt steepnesses up to 300 dB per octave, crossover ranges are virtually non-existent, so that the acoustic drawbacks of traditional multi-way loudspeakers are eliminated.
The DS4 system was tested in an anechoic room, during which the controller ‘gets acquainted’ with all errors, which are later corrected in real time. The controller is delivered with two correction variants and can be fully adapted to the listening room by a sound engineer.

Each loudspeaker in the DS4 system requires four amplifiers, for instance, two stereo output units Type NAD218. The output in the SUB band is 400 watts into 4 Ω, and that in the other three bands, 250 W into 8 Ω.

Figures 6–9 show some acoustically measured characteristics that represent the results of the digitally corrected signal chain in the DS4.

**Figure 6.** The amplitude vs frequency response, measured along the axis of the tweeter (typical listening position) at a distance of 3 metres from the unit, shows that the –3 dB range extends from 30 Hz to 22 kHz. The residual ripple is within ±0.5 dB.

**Figure 7.** The impulse response curve, measured with an impulse width of 50 µs, is almost ideal, which points to an error-free frequency and phase response. Note the previously mentioned relatively large group delay of 110 ms, which, fortunately, in stereophonic music reproduction cannot be discerned.

**Figure 8.** The correction in the transient response of the equalized DS4 system compared with that of an analogue system when a toneburst of 500 Hz is applied is clearly recognizable.

**Figure 9.** A loudspeaker can acoustically reproduce a square-wave signal only if the phase response and amplitude response are corrected simultaneously. The ideal way of doing so is by means of an FIR filter.

[980032]

* The name ‘impulse’ is used since the samples, that is, instantaneous values of the varying analogue signal, are regarded as impulses.

† Dither is low-level noise added to the signal input to randomize encoding errors at the level of the LSB. Dither effectively eliminates quantizing errors and acts to extend a system’s dynamic range to well below its normal floor.

After this article had been prepared, it was learnt that the world’s first digital loudspeaker has been developed by Cambridge-based research group 1...Limited. This consists of a flat panel matrix of small piezoelectric transducers, each of which is driven directly by digital signals. More details of the design will be published in a forthcoming issue of Elektor Electronics.

[Editor]
Intelligent IC Tester
March 1998, 980029

Pin 39 of the processor (IC3) is connected to pin 1 of the firmware GAL (IC5). Due to specific signal load conditions, this connection may cause problems with certain GAL brands.

The remedy is simple: instead of pin 39, use pin 40 of the processor as the oscillator output. The two PCB drawings show how the modification is made. Using a sharp hobby knife, a track is cut. Next, the new connection is made using a short length of thin, insulated wire.

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Various electronics mail order outlets are currently advertising simple and relatively cheap wireless control system for use in and around the house. Although these systems are type-approved, that is no warrant whatsoever for sufficient range and reliability. The 433/418 MHz wireless control system discussed in this article does not aim to compete with these low-cost systems. Instead, it offers high-quality technology for a large number of applications, with special emphasis on reliability, security and connectivity.

**Main Specifications**

- High-quality licence-exempt transmitter and receiver modules
- Transmitter power 1 mW or 10 mW.
- 8 universal control outputs with protection diodes.
- 6 different receiver modes.
- Up to 256 transmitter idents.
- High transmission security
- Multiple transmitters with one receiver
- Low current consumption

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1. Readers should note that wireless signalling using short-range devices (SRDs) and certain allocated frequencies in the 70-cm band is subject to country-specific regulations. In the UK, Regulation no. MPT1340 applies, the full text of which is available from the DTI. MPT1340 specifies that the band section identified as '433 MHz' is for vehicle keys only. All other telecommand, telemetry and alarm systems should use a band section around 418 MHz.

This article is based on SRDs which are type-approved in Germany. Where '433 MHz' is mentioned in relation to remote control, UK readers should read '418 MHz' (also for type numbers). When constructing the project described here, all readers should make sure the equipment complies with the SRD regulations that apply in their country.
Building your own transmitter for these frequencies is only possible (1) if you are a licensed radio amateur, and (2) you comply with radio amateur regulations specified for the 70-cm band (430-440 MHz). The alternative is to use a type-approved, licence-exempt SRD module as supplied by a number of manufacturers, including Radio Tech and Germany-based Heiland Electronics. The article ‘418/433 MHz short-range communication’ in Elektor Electronics May 1998 contains much useful information on 70-cm SRDs. These type-approved modules not only ensure that no undue interference is caused to other services sharing the 70-cm band, but also contribute considerably to the repeatability and reliability of a project for home construction.

**Transmitter**

The circuit diagram of the handheld transmitter (Figure 1) remains quite simple thanks to the use of a ready-made module. The module type HE433-1/T (or optionally the HE433-10T) is a frequency-modulated transmitter operating on 433.92 MHz. An SAW (surface-acoustic wave) resonator is used to stabilize the transmitter frequency. Modulation with a 5-V digital signal causes a frequency deviation of ±20 kHz. The highest data rate is limited to 10 kbit/s to prevent an excessive output bandwidth.

The ‘standard’ module type HE433-1/T used here has an internal antenna in the form of a copper track on the PCB. Transmitter output power is rated at 1 mW. The alternative type HE433-10/T supplies 10 mW and has a quarter-wave (17 cm) wire antenna. The design technology of this module was discussed in some detail in the above-mentioned article.

The modulation input of the RF module is connected to the output of the digital receiver/transmitter chip type HE8 (IC2), which supplies the data to be transmitted. This chip is a custom-designed microcontroller that can be used as an encoder as well as a decoder for serial data transmission systems. At a clock rate of 8 MHz, produced by a quartz crystal, the HE8 supplies a data rate of 9600 bit/s. The eight address inputs, ADDR0-ADDR7 (pin 20-27) allow up to 256 addresses to be set on the transmitter has to be set. Here, the address selection is realized by means of DIP switches or jumpers. Each of these pulls an input to ground. Normally, a single jumper is sufficient to select one of eight addresses. As a matter of course, the address set on the transmitter has to match that on the receiver. Push-button S11 (shift) is provided to enable you to switch from one receiver to another in a simple way. Because the push-button replaces the jumper in position S1-1, the latter may, of course, not be installed.

Like the address bits, the data inputs DAT0-DAT7 (pins 12-19) are switched to ground to apply a databit.

While transmitting, the control input SE/QT (pin 9) allows one of two modes to be selected. When this input is tied to ground, the appearance of at least one databit at the input port (DA0-DA17) triggers a transmission. Any transmission consists of at least five times the full data protocol packet, even when the databit is applied briefly. In all other cases, the transmission simply lasts as long as data are available.

In addition to this ‘multiple send’ feature, the security of the radio link is further guaranteed by parity checking and checksum appending.

The other transmission mode is selected when the SE/QT input is not at ground potential when the HE8 is switched on. In that case, databits applied to the input port are not copied and transmitted before the control input is pulled to ground. A five-fold transmission also takes place when a short ‘low’ pulse is applied. Else, the transmission simply takes as long as pin 9 is held ‘low’.

The first mode is suitable for information ‘bursts’ as typically transmitted by hand-held transmitters (vehicle keys). By contrast, the second mode allows databytes to be sent, as for instance, in a system for wireless transmission of measurement data. For our hand-held transmitter, both modes are employed, as will be seen further on.

The DS/DE output (pin 8) remains logic high as long as data is being transmitted, and so allows a functional check on the IC to be implemented. The circuit of the transmitter is designed such that the supply voltage is only applied when the ‘transmit’ button is pressed. This results in very short ‘on’ periods, so that the overall current consumption is modest in spite of the relatively high current demand while transmitting. When the 10-mW transmitter is used, the current consumption is 50 mA. The 1-mW module...
is not much more economical at about 30 mA. LED D1 provides a useful ‘transmitter on’ indication because it lights whenever a button is pressed. The positive battery terminal has a fixed connection to the input of the 5-volt regulator. The negative terminal, however, is taken to the transmitter. New, however, is the decoder IC as the transmitter. It is capable of demodulating AM as well as FM signals. To select FM demodulation, the FM/AM-IN input (pin 3) of the module is tied to the FM output (pin 4). This is also the case in the circuit diagram of the receiver shown in Figure 2. In case AM demodulation is required, the AM output (pin 2) is simply connected to pin 3. In FM mode, the AM output acts as a signal strength meter output supplying a direct voltage between 0 and 0.75 V which is logarithmically proportional to the RF input level.

FM-OUT and AM-OUT are analogue demodulator outputs. The FM output is internally connected to a comparator stage that converts received pulses into a TTL-compatible output signal available at the data output (DIG-OUT, pin 8). The comparator reference voltage is also available at the REF output (pin 2). It has a level of 2.4 V ±100 mV, and can be loaded with up to 1 mA.

In the circuit diagram of the receiver, the digital output, DIG-OUT, is directly connected to the TX/RX input of the decoder (IC1), which receives the data signal.

The configuration of the HE8 with its external quartz oscillator and DIP switch array is the same as in the transmitter. New, however, is the decoder

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**Figure 2. The receiver employs the same data encoder/decoder IC as the transmitter. The behaviour of the eight outputs is determined by six different modes selected by DIP switches in array S1.**
mode selection by means of an ana-
logue voltage at pin 6 (FUNC). This
voltage is set up by a voltage divider
whose configuration is determined by
the switches in array S1. An overview
of the individual modes that may be
selected using the DIP switches may be
found in the text inset. DIP switch S4 is
only effective if mode 3 has been
selected with S1-3. Mode 3 allows the
behaviour (bistable or monostable) of
the individual control outputs to be
controlled. If, for example, contact S4-
1 is closed (ON), then control output 1
is in bistable mode, while all others are
in monostable mode (i.e., only logic as
long as the push-button on the trans-
mitter is held depressed).

LED D1 acts as a simple reception
indicator. It flashes whenever a signal
is received from a transmitter set to the
same address as the receiver.

Changes made in the setting of the
DIP switches are only effective after
push-button S2 is pressed.

The eight switching channels of the
receiver have relatively powerful out-
puts thanks to the use of an output
buffer type ULN2803 (IC2). The
ULN2803 is an inverting buffer/driver
with open-collector outputs capable of
driving relays or d.c. motors directly
because the internal output transistors
are protected by inte-
grated surge suppres-
sion diodes, and they
are capable of switching
voltages up to 50 V to
ground, at currents of up to 0.5 A per
driver. The total driver output current
supplied at one time may not exceed
1 A, however, so that a maximum load
of 100 mA per output would appear to
be a safe choice. The connection Um
(max. voltage) is then connected to the
positive supply rail (max. 50 V) used by
the load (which is switched to ground).

When 5-V relays are used, they are
connected to the 5-V line, together
with the Um terminal.

If you do not want to the relays to
load the voltage regulator, IC3, then
the relay coils may be operated from
an unregulated voltage which will be
between 10 and 12 V.

CONSTRUCTION AND
TEST
If the ready-made PCB is used, it has to
be cut in two to separate the transmitter
(Figure 3) and receiver sections (Fig-
ure 4). The compact size and high track
density of these boards require care
and precision when you fit and solder
the components. In particular, be sure
to fit all wire links and observe the
polarity of the diodes and (mostly ver-
tically mounted) electrolytic capacitors.

Very important: the transmitter only
works properly when the push-but-
tons stated in the parts
list are used, and they
are fitted the right way
around! This is because

the PCB design is based on the fact that
these keys have two pins that are
always interconnected. If you want to
use different push-buttons, you have
to make sure the relevant connections

Figure 3. Copper track
layout and component
mounting plan of the
transmitter section of
the PCB.
Case: Heddic type HE222 (Heiland PCB, order code 980063-2, see S3, S4 = 8-way DIP switch S2 = push-button, 1 make contact S1 = 6-way DIP switch X1 = 8MHz quartz crystal M1 = HE433-2/R (Heiland Electronics)

Miscellaneous: IC3 = 7805 IC2 = ULN2803 IC1 = HE8 (Heiland Electronics) D3 = LED, red, high efficiency D2 = 1N4001 D1 = LED, green, high efficiency

Semiconductors: C6 = 10uF 10V radial C4 = 100uF 25V radial C5, C7, C8 = 100nF ceramic C3 = 100nF MKT C1, C2 = 22pF ceramic

Capacitors: R13 = 8 x 270k (SIL) R11, R14 = 1k (SIL) R8, R9, R10, R12 = 47k (SIL) R6 = 2k (SIL) R5 = 4k (SIL) R4 = 8k (SIL) R3, R7 = 12k (SIL) R2 = 22k (SIL) R1 = 39k (SIL)

Resistors: Receiver

COMPONENTS LIST

are made using insulated wires. The indicated push-buttons consist of a square cap and the switch base (with connecting pins) which is marked by one bevelled corner. Because of lack of space, it was not possible to indicate this corner on the component overlay. To make sure the switch is fitted the right way around on the PCB, it has to be positioned such that the bevelled corner points to the long edge of the board (no matter which one), so, either in the direction of D26/D13 or D6/D19. Probably the simplest way of getting it all right is to decide on one particular mounting position and then make sure all push-buttons are mounted the same way around.

The diodes are soldered directly at the solder (copper) side of the PCB. The PCB will only fit in the case if the diodes are mounted flat against the PCB surface.

The connecting pads for the RF modules are designed to accept either one of the two alternative types stated in the parts list. Notes on the use of SRD modules from other

Figure 4. Receiver section of the PCB.

Figure 5. Ready populated transmitter board.

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manufacturers may be found further on in this article under the heading *Alternative SRD modules*.

On the receiver board, resistors R1-R5 are fitted vertically. Their top terminals are ‘commoned’ and taken to R1 (see circuit diagram and photograph of the prototype board).

The large holes allow the boards to be secured in a suitable case. This is not necessary if the case stated in the parts list is used, and the relevant PCB pieces can be cut off.

Both the 10-mW transmitter and the receiver have a wire antenna made from flexible ‘litz’ (multi-strand) wire. Provided it is kept as short as possible, this wire may also be used to connect to the base of a telescopic antenna. The reason for keeping this connection as short as possible is that the length of the wire goes into the electrical length of the antenna, which has to be 17 cm.

To be able to use the transmitter you only need a 9-V battery. For the receiver, any common-or-garden mains adaptor will do if it supplies an unregulated direct voltage between 9 and 12 V. Current consumption of the receiver proper is modest at about 25 mA when the control outputs are not loaded. Of this current, only 8 mA goes on account of the HE433-2/R module.

For a quick first test, the control outputs are best connected to an array of LEDs. Each LED is then connected to the +5 V rail by way of a 330-Ω resistor. Do not forget to connect Um (at pin 10 of IC2) to +5 V as well!

As soon as one of the keys on the transmitter is pressed (that’s any one except S11), LED D1 should light to indicate that IC2 is transmitting pulses. If it does not, first check the supply voltage. If the correct level of 5 V is measured at C2, IC2 (pin 1) and the RF module (pin 3), then the whole board should be given a thorough inspection — you may have missed something! If the 5 V is missing, the fault may be in the battery circuit, the voltage regulator, or the 5-V rail is short-circuited to ground somewhere.

On the receiver, D3 should light immediately after the supply voltage is applied. Use a multimeter to check that the supply voltage is actually 5 V.

Before checking the system functions by using the transmitter and the receiver in a ‘real’ wireless link, DIP switch S1-6 in array S1 has to be closed (ON) — all other DIP switches remain OFF (monostable output mode). It is best to switch all contacts of S4 to OFF. At this point, it is important for S3 to be set to the same address (switch configuration) as the transmitter board. Next, you press the ‘clear/rest’ key, S2, to enable IC1 to copy the address set on the switch array.

Try a couple of the channel control switches (S3-S10) on the transmitter. If the system works, not only D1 on the transmitter lights up, but also D1 on the receiver (reception indicator, flashing), and, of course, the LED connected to the relevant control output. If, for example, S3 is pressed (channel 8), then the LED at control output 8 (pin 11 of IC2) has to light. Remember, with the receiver data outputs set to monostable mode, the LED will only light as long as the transmitter is keyed.

If the above checks are successful, the other modes may be tested one by one.

In case the receiver does not respond at all to the transmitter signal, you should be able to identify the cause as either the RF link or the function of one of the boards.

The problem is easily solved by connecting D0 on the receiver board to IC2 pin 7 (TX/RX) on the transmitter board, not forgetting the ground wire, of course. This creates a wire link between the transmitter and the receiver. If the above tests are then successful, the problem can be isolated down to one of the RF modules.

Finally, an important note on safety. In case the receiver is used to control mains-operated loads, you should observe the electrical safety precautions which are regularly printed in this magazine, particularly in respect of insulation and minimum insulation distances for any connection at mains potential. Another important point to observe is the contact rating of the relays used, both in respect of the permissible contact current and contact voltage.

**Range**

The range of the wireless control system depends not only on the RF power supplied by the transmitter module, but also on the surroundings and interference levels within the range of the receiver. The frequency used here, 433.92 MHz, is by no means exclusive, in fact it has the same status as any other channel in the licence-exempt section of the 70-cm band: users must accept mutual interference. In many European countries where only the 433-MHz section is allocated for licence-exempt SRDs, the band is quite crowded in urban areas, so that interference from other users can not be excluded. Fortunately, the typical SRD vehicle key is marked by short transmission bursts, increasing the chance of finding a free ‘slot’ to reach the receiver. In the UK, there is a clear and fortunate distinction between the 418 MHz and 433 MHz bands as far as their usage is concerned, vehicle keys being allowed to work on 433 MHz only.

Without the deteriorating effects of interfering signals, the range of a system like the one described here will typically depend on the path loss which exists between the transmitter and the receiver. Inside buildings, this path loss will be much higher than for a (quasi) line-of-sight link in open terrain. Under these (optimum) circumstances, ranges of 1 to 3 km may be expected (the latter only when the 10-mW transmitter is used). In built-up areas, this is reduced to a couple of hundred metres, while inside concrete buildings it may not even be possible to reach the next floor. When mounting the receiver, make sure the antenna is as far removed as possible from steel cabinets, steel beams or other support structures and similar RF obstacles. In certain situations, it may be useful to measure the strength of the received signal using a meter connected to the AM output (pin 2) of the receiver. This can be relied on to supply a fairly accurate (though relative) field strength indication, allowing the best possible location for the receiver to be found. During the measurement, you have to key the transmitter, of course.
MULTIPLE TRANSMITTERS

‘Multi-transmitter’ operation as indicated under the available modes will require some clarification. First, however, we should note that even without this special mode it is also possible to use more than one transmitter for one receiver, the single condition being that the address set on each transmitter matches that of the receiver. In this way, several transmitters may be used in different locations in and around your home, and one will always be at hand.

A special feature of the ‘multiple transmitter’ mode (mode 2) is that the receiver will only process the last four address bits. Consequently, only the DIP switches on lines ADDR4 through ADDR7 of the HE8 chips on the receiver and the transmitter have to be set to give an identical address. The other four bits are then not relevant, although they may be used to convey identification data from each individual transmitter to the receiver. These lower four bits, ADDR0 through ADDR3, are copied to the pins with the same names on the receiver chip, allowing each individual transmitter to be identified when the multi-transmitter mode is being used. The first four bits then represent the ‘transmitter ID’ and the last four bits, the ‘message’.

MULTIPLE RECEIVERS

Push-button S11 on the transmitter enables ready switching between two addresses and, consequently, between two receivers. If the full address range is exploited, a single transmitter is capable of selectively addressing up to 256 different receivers. If the receivers are in one and the same location, they can even share one 433-MHz receiver module. On the board you will see a connection D0 that allows a data signal from a single receiver module to be fed to several receiver boards. Similar ‘distribution’ points are available for the 5-V supply and the reset key. If you use this option, then push-button S2, as well as components D2, C4, C5 and IC3 have to be fitted on one receiver board only. The relays are then powered separately to prevent overloading of the on-board voltage regulator.

ALTERNATIVE RF MODULES

The printed circuit boards are specifically designed to accept the RF modules from Heiland Electronics. However, that should not be taken to mean that only these modules can be used. In principle, the system should function with any pair of SRD modules that guarantees secure data transmission. Even AM modules may be employed, although these will provide shorter ranges and inferior signal quality as compared with SRD modules designed for FM.

In case you already have SRD modules, these may be used provided they comply with the following points:
- 5 V supply voltage (or modify to 5 V);
- Transmitter input accepts 5 V (TTL level) swing;
- Receiver output supplies 5-V (TTL level) swing
- Module can be connected properly by wires to PCB.

For the circuits of the transmitter and the receiver it is, in principle, immaterial how the data signal travels from TX/RX pin of the encoder chip to that of the decoder chip, provided it arrives in good shape, that is, with ‘clean’ 5-V pulses. So, it is even possible to use the receiver and transmitter boards without recourse to any kind of RF modules whatsoever. An infrared link, fibre-optics and even the simplest connection by way of two wires, are just a few alternatives.

Source:
The basic application circuits and technical data for the 433-MHz modules were obtained from product datasheets supplied by Heiland Electronic, D-48351 Everswinkel, Germany. Tel. (+49) 2582-7550, fax (+49) 2582-7987.

Receiver Modes

DIP switch S1 allows the user to select one of six different modes for the receiver. To select a particular mode, close only the indicated switch, and leave all others ‘open’. Changes in the configuration are not effective until the circuit is reset.

Mode 1: Overwrite (S1-1)
Any selected channel remains active until the ‘clear’ button is pressed on the transmitter, or the reset button on the receiver.

Mode 2: Multi-transmitter (S1-2)
In this mode the address is only 4 bits wide, using S3-4 through S3-8. In this mode, outputs may also be programmed as in Mode 3.

Mode 3: Programmable (S1-3)
The DIP switches in array S4 enable each individual output to be programmed as bistable (as in Mode 5) or monostable (as in Mode 6). A closed switch selects bistable operation of the relevant output.

Mode 4: Latching (S1-4)
Actuated outputs remain on until the reset key on the receiver is pressed.

Mode 5: Bistable (S1-5)
When the transmitter is keyed, the relevant channel is switched on. The next key action de-actuates the relevant channel.

Mode 6: Monostable (S1-6)
Selected channel output only remains active as long as the transmitter key is held depressed.
multiple test card

for microcontrollers

It is often necessary for an electrical quantity to be measured and displayed, so that a certain action can be instigated if and when it has reached a limiting value. Today, this is readily accomplished with the aid of a processor and a good quality analogue-to-digital converter (ADC). This article describes the design of such a setup, complete with power supply and a number of input and output facilities.

Features

- 12-bit converter operating at up 70,000 samples/sec
- general-purpose preamplifier
- on-board power supply
- printed-circuit board allows experimental layouts
- CPU options: Matchbox for simple programming
  AT89S8252 for fast programming via a PC and adaptor
  87C51 for economy
- may be used as general-purpose card for an 8051 controller
- Interfaces: 12-bit analogue input
  RS232
  LCD (parallel or I2C)
  two relays
  ports for I/O
  SPI with AT89S8252 CPU
  I2C with Matchbox CPU

Design by M. Ohsmann
The test card consists of a 12-bit analogue-to-digital converter (ADC) that can operate at up to 70,000 samples/sec, a preamplifier that enables the ADC to work with a number of inputs, and a controller that drives the ADC and processes the quantized samples.

The controller may, for instance, be a Matchbox single-board computer (SBC), programmed in BASIC, which also provides a liquid crystal display (LCD) and an I²C bus.

Another possibility is the use of an AT9888252, which can be programmed ready by a PC via a suitable adaptor. This controller is specially intended for real-time applications that use the maximum processor power.

A similarly programmed Type 87C51 controller may also be used. The data may then be applied to the PC via an RS232 interface, or displayed on the LCD, or used to drive computer ports or relays.

Several interesting applications are possible as shown in the features list. The controller ports must, of course, not be used for other than light loads. If, for instance, it is desired to drive a relay, a buffer stage or stages such as those at ports P3.7 (RD) and P3.6 (WR) should be used.

The printed-circuit board for the test card (Figure 8) contains a number of terminal strips to which a sprinkling of small extensions may be connected.

ANALOGUE SECTION
The analogue section of the circuit in Figure 1 consists of a two-stage preamplifier that enables various inputs to be linked to analogue-to-digital converter IC9. Although this part of the circuit looks rather complex, bear in mind that not all components are used for all possible applications. The relevant components (marked with an * in Figure 1) are not soldered on to the PCB, but are inserted into two 16-way direct-in-line (DIL) sockets. This makes their omission or exchange for various applications straightforward. The arrangement makes it possible for the relevant components for a certain application to be soldered on to a suitable plug which can then be inserted into the DIL socket as a small unit.

Operational amplifier IC3 is config-
ures as an inverter, whose basic circuit is shown in Figure 2. This basic circuit enables the requisite values of certain components to be calculated.

Reverting to Figure 1, if needed for an application, C1 may be added to form a low-pass filter at the input. The amplification of IC3 is set with P4, while its off-set compensation is set with P1. Depending on the type of op amp used, the wiper of P1 may be linked to the positive or the negative supply line.

The output of IC3 is applied to a second op amp, IC4, via R5 or R6. This makes it possible for IC4 to be used as an inverting or a non-inverting amplifier. The exact reference from the ADC can be added as an offset, whose level is set with P2, to the positive-input signal via R19 or to the negative-input signal via R20.

The amplification of IC4 is determined either by R21 in conjunction with R18 or by R7. The output of this op amp is applied to analogue-to-digital converter (ADC) IC9 via R15 and R14.

AMPLIFIER OPTIONS
To clarify some of the many possibilities available, here are some examples.

Input 0–1 V
If the input voltage is 0–1 V, the signal must be amplified by 4.096 to enable the ADC to quantize it over the range 0–4.096 V. It is, of course, preferable for the ADC to be driven over the full range. In this application, the circuit of which is shown in Figure 3, the input impedance should be high, if at all possible. In Figure 2, \( R_A = 30.096 \text{ k}\Omega \), \( R_B = 10 \text{ k}\Omega \), \( R_C = 0 \), \( U_A = 0 \), \( U_B = U_m \), where \( U_m \) is the measured voltage.

The Matchbox program for voltage adaptation is shown in Figure 4.

```
: XMESS1.MBL
RESOURCE 8051-IRAM 10H BYTES @ 070H
RESOURCE IIC-EEPROM 0200H BYTES @ 05000H : ST24C04

INTEGER K, ADvalue

START:
P1.0 := 1 ; CS inactive
P1.1 := 0 ; set clock line LOW
P1.0 := 0 ; CS active
P1.1 := 1 ; clock high
ADvalue := 0 ; get AD result there
K := 11 ; MAX 187 is ready here
WHILE K > 0 DO
    P1.1 := 0 ; clock goes low
    ADvalue := (ADvalue SHL 1) + P1.2
    P1.1 := 1 ; clock high again
    K := K -1
    P1.1 := 0 ; shift in the bit
    P1.1 := 1 ; do 12 bits
WHEND
FORMAT(RS232 D DP=3 DPSHOW=3 l N LENGTH=6 ) ; RS232 decimal output
PRINT( SCALE(ADvalue,1000,4096)," Volt "0D"0A") ; display AD*1000/4096
GOTO START ; restart again

END
```
Reverting to Figure 1, the exact amplification is set with \( P_4 \) and the offset compensation with \( P_2 \). In this example, Type LF356 op amps are used, which means that the compensation voltage is derived from the positive supply line via \( R_{17} \) and \( P_1 \).

The Matchbox must, of course, be programmed as appropriate to display the input signal level. This is accomplished by driving the ADC, whereupon the result of the conversion is weighted (with the correction of the amplification factor) and read in 12-bit form. The complete program is shown in Figure 4.

**Input 0–100 V**

If the input voltage is in the range 0–100 V, the input terminal may be preceded by a 100:1 potential divider. Its tolerance can be nullified with \( P_4 \). Then, the signal must be amplified \( \times 4.096 \). In view of the noise and offset voltages, this is not a good solution. A better alternative is shown in Figure 5. Here, the potential divider formed by \( R_5 \) and \( R_8 \) provides a signal at the non-inverting input of IC3 of 3.754 V (which is close to the wanted level of 4.096 V) when the input is 100 V. The correct amplification is obtained by giving suitable values to \( R_1 \) and \( R_2 \), and setting \( P_4 \) as appropriate.

**Current –1 A to +1 A**

Currents between –1 A and +1 A are measured with the circuit configured as in Figure 6. Since this current range is symmetrical around 0 A, the input to the ADC when the current is zero must be 4.096/2 = 2.048 V. This is accomplished by using IC3 as a current-to-voltage converter and \( R_8 \) as the current sensor.

When the current is +1 A, the voltage drop across \( R_8 \) is 0.1 V. This level must be amplified by 20.48 to obtain the correct input level to the ADC. The values of the various components, assuming that \( R_1 \) is 2.2 k\( \Omega \), are determined from

\[
1 + \frac{R_2 + P_4}{R_3} = 20.48
\]

\[
\therefore \frac{R_2 + P_4}{R_3} = 19.48 R_1 = 42.656 \text{k}\Omega.
\]

These values ensure that the output voltage of the op amp has a range of –2.048 V to +2.048 V.

Operational amplifier IC4 is arranged as an inverting amplifier whose output voltage is

\[
U_{\text{out}} = U_{\text{in}} + \frac{U_{\text{ref}}}{2}.
\]

This is accomplished by giving the components in Figure 2 these values: \( R_8 = R_{10} = 10 \text{k}\Omega \); \( R_3 = 30.95 \text{k}\Omega \) and \( U_{\text{in}} = U_{\text{ref}} = 4.096 \text{V} \).

The offset voltage is needed to shift...
the output of IC4 into the positive range, which is imperative for correct operation of the ADC.

When the output data of the ADC are being evaluated, the offset and inversion must be taken into account by IC2 so that the relevant line in the program is changed to

\[
\text{PRINT( SCALE(2048-ADvalue,1000,2048),' Amp "0D"0A'); display AD*1000/4096}
\]

The displayed value of \((2048-AD)\) \times 1000\%/2048 accords exactly with the current in amperes. The factor 1000 is corrected by the decimal point.

When a rectifier or true-rms converter is connected at the input, alternating voltages may also be measured. Other test adapters, such as a negative-temperature-coefficient (NTC) or positive-temperature-coefficient (PTC) resistors, or magnetic-field...
sensors, may also be used. The controller does not only compute the test results, but also carries out any requisite linearization.

CPU OPTIONS

The digital section of the circuit in Figure 4 is a straightforward design. The central processing unit (CPU) is linked to the outside world via an RS232 interface. Circuit IC2 converts the single 5 V supply into ±12 to ±15 V as required in RS232 communications.

The ports of the CPU are used for the various inputs and outputs. Depending on the CPU used, a variety of facilities are possible.

There is also an I2C EEPROM available, not only for compatibility with the Matchbox, but also for use with a number of other applications, for instance, the storing of measurement data.

Matchbox

The printed-circuit board is designed to cater for a number of different CPUs. The best of these for less experienced readers is the Matchbox. This controller enables an application to be programmed in BASIC, whereupon all the input and output facilities as well as the various interfaces are operated via the controller.

AT89S8252

If use of the full speed of an 8051 controller is desired, that is, by programming in the assembler, the AT89S8252 is recommended. The program generated in the PC is then stored in an internal EEPROM via a simple interface. A special programming unit is not needed.

87C51

Neither the AT89S8252 nor the Matchbox is cheap. If there is no objection to the use of a number of test cards with fixed programs, the well-known 87C51, AT89C51 or AT89C52 may be used. These are the most economical controllers available, but they need a special programming unit, which is probably available to many readers.

FINALLY ...

The test card permits the parallel connection of a liquid-crystal display (LCD) to port P2 (4-bit mode). If, however, the Matchbox is used, its excellent LCD output capabilities should not be ignored, but made full use of via the I2C bus—see Figure 7.

The power supply of the test card provides a regulated +5 V line for the digital section and a regulated ±8 V line for the analogue section of the circuit. The regulator for the +5 V line, IC9, is connected to a fairly high input voltage and dissipates about 2 W when the relays are energized. It must, therefore, be fitted on a suitable heat sink.

The relatively high supply voltage for the analogue section obviates the need for rail-to-rail op amps in the IC3 and IC4 positions to drive the converter over its full range. If, apart from the two op amps, no other loads are connected to the ±8 V line, regulators IC7 and IC8 do not need heat sinks.

There is not much that need to be said about the construction and use of the test card other than has already been mentioned. One important point is that all ICs should be seated in an appropriate socket.

Before the card is taken into use, the supply lines should be checked carefully before the ICs are inserted into their sockets.

Applications:

- multimeter with serial output
- heating controller
- serial test network
- data processor monitor
- processing controller
- linearized thermometer
- a.c. measurement with dB display
- data logger

Parts list

| Resistors: |
| R1–R8, R16–R21 = see text |
| R9 = 47 kΩ |
| R10 = 1 kΩ |
| R11–R13, R23 = 3.3 kΩ |
| R14, R15 = 100 Ω |
| P1 = see text |
| P2–P4 = preset, 10 kΩ |

| Capacitors: |
| C1, C2 = 22 µF |
| C3–C6, C8, C13 = 10 µF, 16 V, radial |
| C7, C12, C18–C23 = 0.1 µF |
| C9 = not used |
| C10 = 2200 µF, 25 V, radial |
| C11 = 1 µF, 16 V, radial |
| C14, C15, C17 = 10 µF, 25 V, radial |
| C16 = 220 µF, 25 V, radial |

| Semiconductors: |
| B3 = rectifier bridge B80C1500 |
| D1–D4 = 1N4148 |
| T1, T2 = BC560 |

| Integrated circuits: |
| IC1 = 87C51PLC44 |
| IC2 = MAX232 |
| IC3, IC4 = TL071 |
| IC5 = PCF8582 or ST24C02 |
| IC6 = 7805 |
| IC7 = 7808 |
| IC8 = 7908 |
| IC9 = MAX187 |

| Miscellaneous: |
| X1 = crystal 11.0592 MHz |
| PC1–PC5 = PCB pin |
| P1 = 2.54 mm pin strip and pin jumper |
| Re1, Re2 = 6 V relay with 2 change-over contacts for board mounting |
| Tr1 = mains transformer with 2 × 9 V secondary, 4.5 VA |
| K1, K4 = 8-way terminal strip |
| K2 = 14-way terminal strip |
| K3, K6–K9 = 3-way terminal strip |
| K5 = 6-way terminal strip |
| K10 = 2-way mains terminal board (insulated) |

[980074]
This article describes an isolating transformer that is, in fact, composed of two standard transformers. Like a much more expensive commercial unit, it isolates any equipment on test or being repaired from the mains supply. During the design, it proved convenient to add a signal tracer, a regulated 9 V power supply and a continuity tester.

It should be noted, however, that a Class 2 (double-insulated) isolating transformer to BS3535 has no earth connection on the secondary side. In the event of a circuit supplied from such a transformer developing a live fault to an exposed conductive part, there would be no path for a shock current to flow. An inadvertent connection to earth, or interconnection with other circuits, would render the protection useless. [IEE Wiring Regulations]
SAFETY
It cannot be stressed too much that in the construction, testing, repair and maintenance of electronic equipment operated from the mains power supply the greatest care must be taken. It is easy to become nonchalant in our home workshop, but remember that every year hundreds of people die — most at home — owing to electric shock. In fact, in a public place, such as a school or college, or a home workshop open to outsiders, there is a statutory duty on ensuring safety from electric shock. In the United Kingdom, the Health and Safety Executive produces guidance notes for such public places.

One common and advisable means of ensuring safety when work is carried out on a mains-operated equipment is the use of an isolating transformer to BS3535. Such a device ensures that (a) the equipment on test is electrically isolated from the mains supply, and (b) the current through the equipment on test is limited by the transformer rating (and relevant fuse). Mind any inadvertent earth connection, however, as pointed out in the note in the introduction to this article.

COMPOSITE TRANSFORMER
An isolating transformer is fairly expensive, which is probably the reason that it is not found in most small workshops (but how much is your life worth to you?). A less expensive one may be made from two identical mains transformers as shown in the wiring diagram in Figure 1.

The 2 × 15 V secondary windings of each of the two transformers are connected in series and then interconnected as shown. So, looked at from the mains entry, transformer T2 converts the 240 V mains voltage to 30 V, after which T1 converts the 30 V back to 240 V.

The L(ive) mains line is connected to the relevant input terminal of T2 via fuse F1 and on/off switch S1. [Two comments here: (1) it is advisable to use a double-pole switch and, in line with common practice, also switch the N(central) mains line, and (2) although the letter L is used for the live mains line, the letter P for phase is commonly used in many publications. The letter L is preferred here since it coincides with the designation of the live mains line in most domestic installations and appliances. Editor].

TRACER & TESTER
Since the composite transformer makes a low voltage available, the designer felt that some additional components, which cost relatively little, would make the circuit even more useful in the small or home workshop. The additions are a signal tracer for high-frequency (100 kHz – 10 MHz) and low-frequency (50 Hz – 20 kHz) signals with variable sensitivity, a simple continuity tester, and a regulated 9 V power supply.

The signal tracer is very handy, in...
Parts list

Resistors:
- R1, R7 = 10 kΩ
- R2, R3 = 100 kΩ
- R4 = 1.5 MΩ
- R6 = 1 kΩ
- R8 = 470 Ω
- R9 = 8.2 Ω
- R10, R11 = 2.2 kΩ
- P1 = 220 kΩ, linear

Capacitors:
- C1, C2 = 150 pF, ceramic
- C3 = 0.0047 µF, metallized polyester
- C4, C9 = 10 µF, 16 V, radial
- C5 = 100 pF, ceramic
- C6 = 470 µF, 16 V, radial
- C7 = 2200 µF, 25 V, radial
- C8, C10 = 0.1 µF, ceramic

Semiconductors:
- D1, D2 = 1N4148
- D3, D8 = LED, low current
- D4–D7 = 1N4002
- T1 = BC547B
- T2 = BC557B

Integrated circuits:
- IC1 = TLC272CP
- IC2 = 7809

Miscellaneous:
- F1 = fuse holder and fuse, 1 A, slow
- LS1 = miniature loudspeaker, 8 Ω, 500 mW
- Tr1, Tr2 = 180 VA mains transformer with 2 x 15 V secondary
- S1 = mains on/off switch, double pole preferred, see text
- K1 = heat sink for IC2, 5 K W⁻¹
- 8 off banana socket
- 1 off mains entry
- 1 off mains output socket (panel mounting)

conjunction with a suitable signal source, to test signal paths. It may seem odd, but it appears that many small or home workshops have a function generator available, but not a signal tracer.

The continuity tester (test LED) is a bit of a gismo, while the 9 V power supply is intended primarily to power the signal tracer circuitry, but may be used for experimental purposes.

CIRCUIT DESCRIPTION
The circuit diagram of the composite isolating transformer is shown in Figure 2.

The input for the 9 V regulated power supply is taken from the 15 V secondary of Tr1. This voltage is rectified by bridge D4–D7, smoothed by capacitor C7, and stabilized by regula-
tor IC2 at 9 V. If IC2 is mounted on a suitable heat sink, it can handle currents up to 1 A. Since the signal tracer draws a current of only 50 mA, there is ample reserve for experimental purposes.

The continuity tester circuit consists merely of light-emitting diode D3, protection diode D2, and bias resistor R10. The positive and negative input of the circuit may be used as low-voltage tester. When the positive terminal is linked to the positive terminal of the 9 V power supply, the circuit may be used as continuity tester.

The signal tracer section is basically a small, sensitive amplifier, consisting of two op amps and two transistors, which makes the detected test tones audible via a small loudspeaker. There are separate inputs for low-frequency (LF) and high-frequency (HF) signals. Signals applied to the LF input are fed via low-pass filter R1-R2-R3-C2 to the non-inverting input of op amp IC1a. The filter has a cut-off frequency of 20 kHz.

Signals applied to the HF input are fed to the non-inverting input of op amp IC1a via AM detector R1C1-D1 and filter R2-C2.

The d.c. operating point of IC1a is arranged by R4 and R5 to ensure maximum drive to the op amp. Any residual direct voltage is blocked by capacitor C3.

Since the feedback is variable, the amplification of IC1a can be varied continuously between unity and x 221. To avoid overdriving the stage, it is advisable to start any signal tracing with P1 set to minimum or nearly so.

The output of IC1a is fed to driver IC1b and output amplifier T1-T2, which drives loudspeaker LS1. Resistor R7 and capacitor C5 ensure adequate stability of the amplifier. Capacitor C6 prevents any residual direct voltage from reaching the loudspeaker. Resistor R8 makes the output short-circuit-proof. The peak power output is 100 mW.

**Construction**

Apart from the two transformers, on/off switch, fuse and LEDs, all components are conveniently housed on the printed-circuit board shown in Figure 3. This board is, however, not available ready made.

Voltage regulator IC2 is near the centre of the board and should be mounted on a heat sink.

Capacitor C8 is located as close as feasible to IC2 so as to suppress any interference pulses as effectively as possible.

The completed prototype board is shown in the photograph in Figure 4. The transformers and board should be housed in a suitable enclosure. The mains entry and fuse should be fitted at the rear, and the input and output terminals, the LEDs, and the on/off switch, at the front of the enclosure. The input and output terminals may be banana sockets, but the LF and HF inputs should be audio or BNC type sockets.

The outputs of the isolating transformer, that is, L' and N', should be accessible via a mains output socket at the front panel.

The wiring up is shown in Figure 1. Comparing this with Figure 3 shows that the terminals on the PCB are actually where they are shown.

Finally, make sure that the wiring of the mains leads is sound: well insulated cable and the use of strain relief bushes is sound practice!
### Command Codes for Specific System Addresses

#### Video Recorders (system address = 5)

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<tr>
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<th>Command Code</th>
<th>Symbol (IEC417)</th>
<th>Command Allocation</th>
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<td>- - -</td>
<td>search forward to next marker</td>
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<tr>
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<td>0 1 1 1 1 1</td>
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<td>search reverse to next marker</td>
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<tr>
<td>34</td>
<td>1 0 0 0 1 0</td>
<td>▼</td>
<td>picture slow run reverse</td>
</tr>
<tr>
<td>37</td>
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<td>picture frame by frame reverse</td>
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<td>1 0 0 1 1 0</td>
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<td>slow run forward</td>
</tr>
<tr>
<td>39</td>
<td>1 0 0 1 1 1</td>
<td>▲</td>
<td>slow run reverse</td>
</tr>
<tr>
<td>40</td>
<td>1 0 1 0 1 0</td>
<td>▼</td>
<td>picture slow run forward</td>
</tr>
<tr>
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<td>picture frame by frame forward</td>
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<td>picture fast run forward</td>
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<td>picture moderate run reverse</td>
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<td>eject</td>
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<td>46</td>
<td>1 0 1 1 1 0</td>
<td>▼</td>
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### RC-5 Command Allocations

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### Video Players (system address = 4)

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### Tuners (all) (system address = 8 and 17)

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