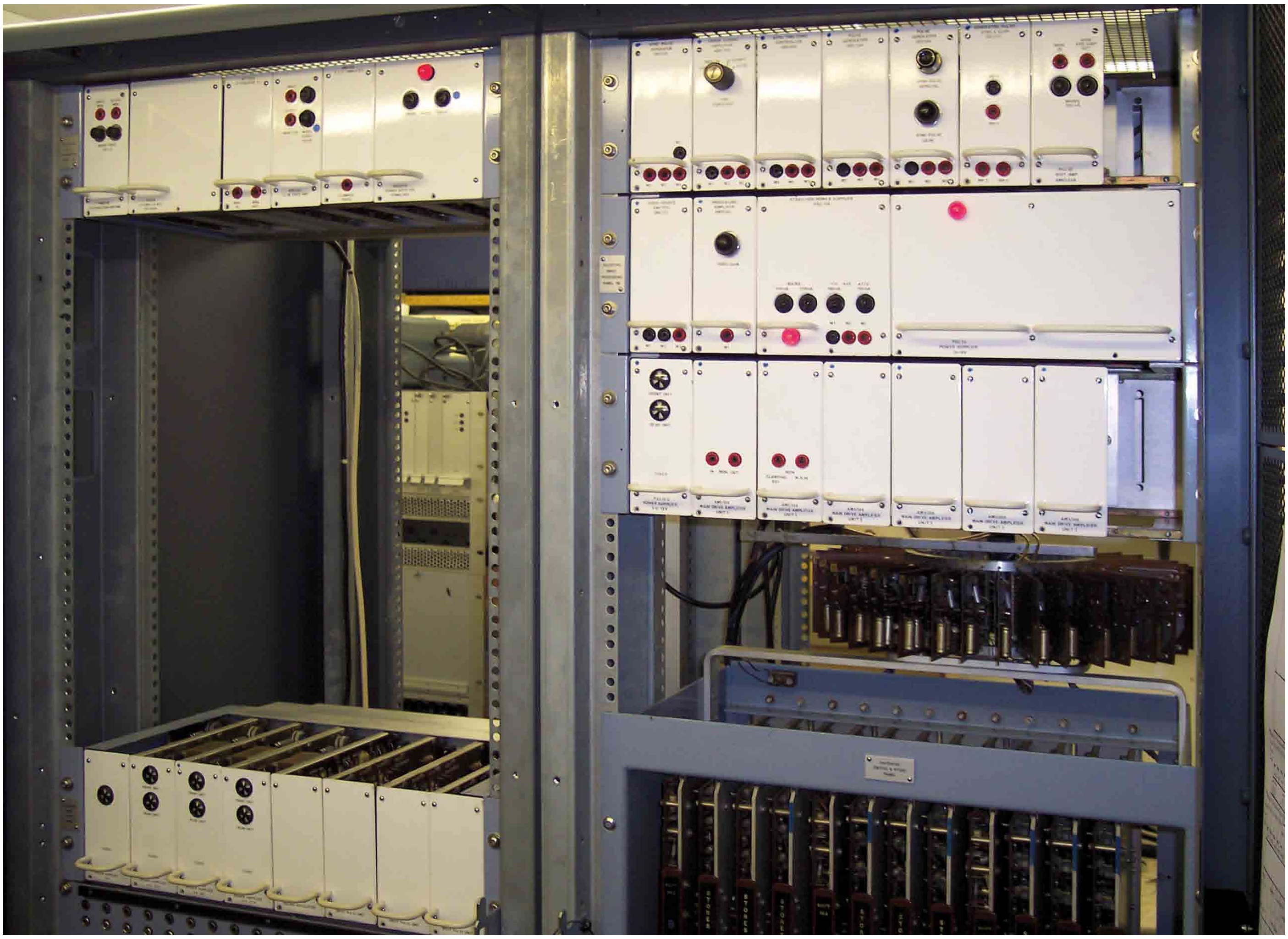
So you want to build a standards converter revisited. Again!

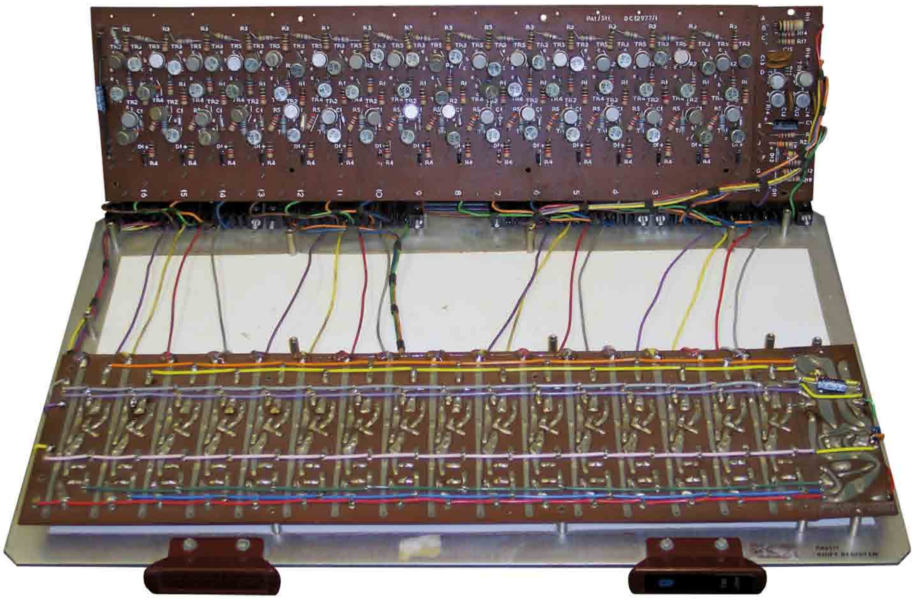
Yet more thoughts and reflections on generating signals for historic TVs. Jeffrey Borinsky FIEE CEng

It is 5 years since I last wrote about standards conversion. My articles in 2002 and 2006 summarised the state of art at those times. The main development since then is the dominance of Aurora converters.



Above: Malcolm's CO6/501 – General view

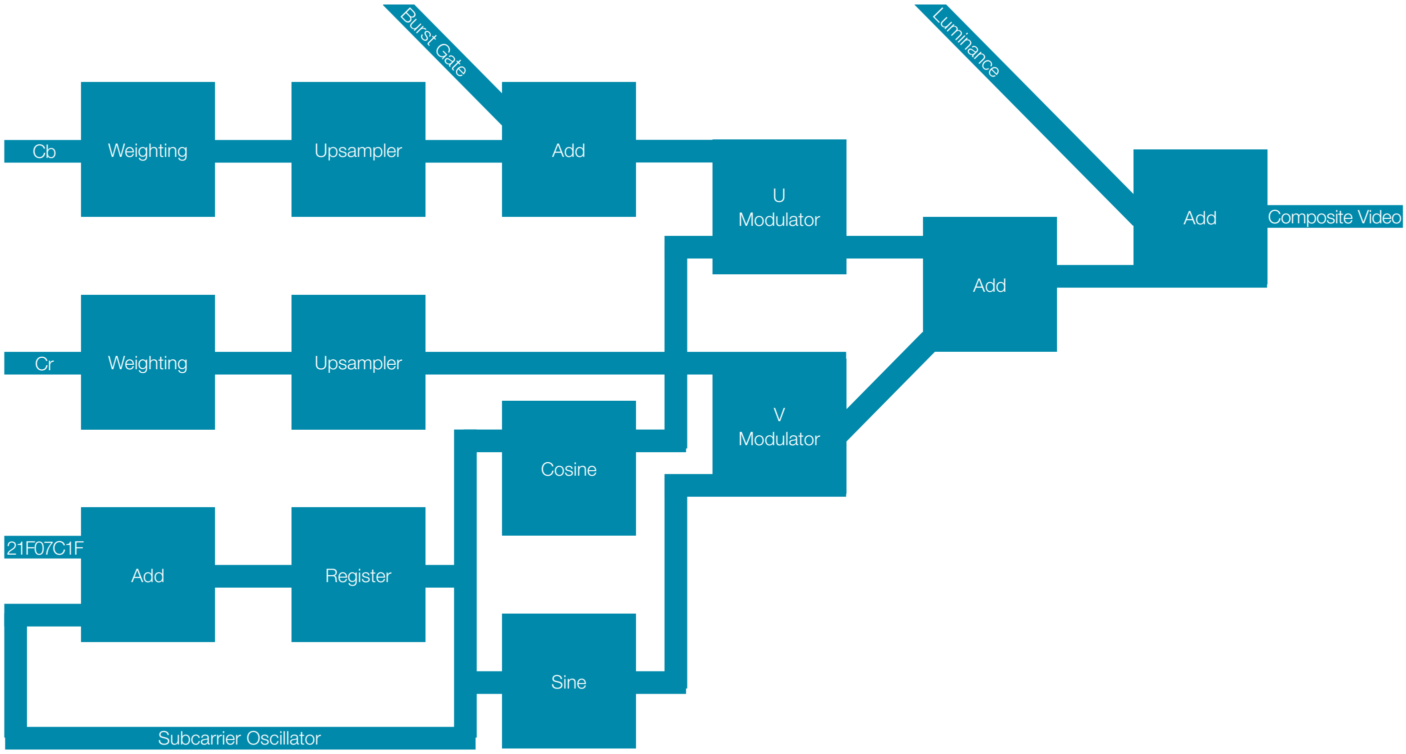
Below: Malcolm's CO6/501 – Low speed store



Aurora SCRF success

When Darryl Hock designed the diminutive Aurora SCRF converter I doubt he could have predicted its success. Not only does it give excellent picture quality, it is also exceptionally easy to use. Just connect it to a small power supply and it will deliver test card with tone to your vintage TV.

At the time of writing almost 500 of the single standard SCRF converters have been sold. The vast majority have been supplied to the UK for use with 405 line sets. A few have been supplied for 819, 441 and mechanical standards. At $235 + postage (currently around £165 plus typically £35 customs fees) the price was low enough to find a significant market. Quite a few enthusiasts have bought more than one, either for running individual TVs or perhaps to recreate a dual channel BBC/ ITV environment. Reliability is excellent with just a single reported failure in



NTSC coder block diagram

service. Actually it was dead on arrival, due to a soldering problem on the big Xilinx FPGA (Field Programmable Gate Array) chip.

There have been 3 iterations of the SCRF hardware, mainly to avoid the need for users to remove the cover to select certain functions.

I offer a Europe based support service for the SCRF. I have upgraded the firmware in a few, reprogrammed a couple to a different output standard and liaised with the British Heritage TV Group who needed a special RF channel 4A for their engineering trials. I hope these will have been successfully completed by the time you read this.

Aurora world converter

The SCRF has some limitations. The FPGA has a limited amount of memory within the chip, sufficient for several whole lines of video data but not whole frames. Hence it cannot change the frame rate, something that requires a much larger memory that can hold at least an entire frame. This means that the Baird 240 line 25 frame and RCA sequential colour standards are not feasible. To overcome this and also to provide the ultimate in flexible standards conversion Darryl designed the WC-01 World Converter. This will convert from 525 or 625 to any historic standard selected by simple user controls. It includes a universal RF modulator with settings for all historic channels. Low cost was not a priority for this product, it sells for over $900. This accounts for the limited sales. While it is undoubtedly a superb piece of engineering you can buy 4 SCRF converters for the price of a WC-01. It has been used in the UK to demonstrate 240 line pictures on a Marconiphone 702. The results were flickery as might be expected but entirely watchable.

405 NTSC colour

In my previous articles I said:

A clever approach would be to do the whole NTSC encoder digitally in programmable logic. I reckon this will need rather more programmable logic resource than the whole of the rest of the converter.

Darryl and I discussed this possibility in some detail and we think it feasible but he has not explored it in practice. For once I was right and we were sure that the coder would consume a lot of FPGA resources. There would be no hardware changes, purely new code for the FPGA. This would be a demonstration of the power and flexibility of using programmable logic.

Darryl succeeded again. The only hardware change is a larger FPGA which fortunately could be fitted on the existing PCB. Actually when you try to do it, a coder uses a lot of logic but isn't too hard to design in an FPGA. I've done a full broadcast grade PAL/NTSC coder for a client and the essential core of the coder was simpler than I expected. Let's have a look at how it's done. It's going to get rather technical in places so hang on for a bumpy ride. FPGAs are usually designed using a high level hardware description language, usually VHDL or Verilog. Both Darryl and I are familiar with VHDL, in particular as it is applied by the Xilinx tools for their FPGAs. The Xilinx tools take VHDL code and synthesise how the hardware is configured within the FPGA. This process is largely automatic though the designer can intervene in many ways to optimise the design.

These are the essential functions of an NTSC 405 coder. Apart from the 405 and sample rate conversions, exactly the same steps would be needed in a traditional analogue NTSC encoder.

- Convert the decoded colour difference (Cb and Cr) signals to 405
- Apply weighting factors to convert Cb to U and Cr to V
- Increase the sampling rate of the U and V colour difference signals
- Generate burst gate and add this to the U signal
- Generate quadrature subcarriers on U and V axes
- Modulate the colour difference signals on to the subcarriers
- Add modulated U to modulated V to make chroma
- Add chroma to luminance

Decoder chips, such as the TVP5150 used in the Aurora SCRF, give colour difference outputs as well as luminance. In most SCRF converters the Cb and Cr colour difference signals are ignored. In the NTSC 405 version they are converted to 405 in exactly the same way as luminance. No innovation needed, just duplicated line storage and interpolators.

The Cb and Cr signals cover the digital range 16 to 240, with 128 representing the central zero point. The U and V signals specified in the NTSC (or PAL) standards have a different range so they need to be multiplied by constants. Here's how it might be done in VHDL. You don't need to know VHDL to understand what's happening. The synthesis tools will look after the exact implementation. You only have to worry if FPGA resources are in short supply.

```
U <= Cb * Cb_to_U_WEIGHTING_FACTOR;

V <= Cr * Cr_to_V_WEIGHTING_FACTOR;
```

The Cb and Cr signals emerge from the decoder at 6.75MHz sampling rate. Weighting them to U and V leaves this unchanged. You can't do NTSC coding at this low sample rate because you can't represent 3.58MHz subcarrier with 6.75MHz sampling. Mr Nyquist's famous rule says this needs at least 7.16MHz. At some point the coded chroma will have to be added to the luminance so they will need to be at the same sample rate. Darryl already upsamples luminance from 13.5MHz to 27MHz to ease the analogue output filter so it makes sense to upsample U and V to 27MHz too. The simplest method is to repeat each sample 4 times but this is not very satisfactory. This is a job for a FIR or transversal filter. A really high quality filter needs lots of multipliers and adders. Fortunately the bandwidth of the signals is already limited by the original PAL 625 input to the decoder so only a modest filter is needed.

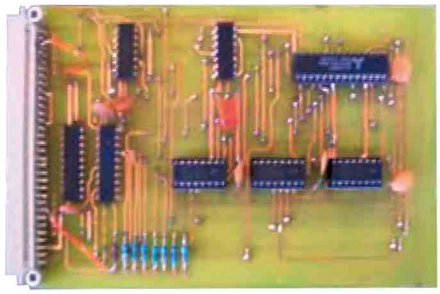
The burst gate is timed from the line sync datum. The only refinement is a small lookup table of values so that the burst edges are nicely shaped. This is then added to the U signal. In NTSC, unlike PAL, there is no burst on the V signal.

Subcarrier generation is a little more complex. A DTO (discrete time oscillator) is an adder/accumulator which can generate digital sawtooth waveforms at up to half the clock frequency. Typically we might use a 32 bit accumulator. For a clock frequency of 27MHz and subcarrier of 3.57945455MHz the coefficient is 2^32 * 3.57945455MHz/27MHz = 569408543 or 21F07C1F in hexadecimal. The sawtooth output of the DTO represents the phase of subcarrier. Sine and cosine waveforms are made from the phase data using lookup tables that reside in the RAM blocks found in the FPGA. You can do this the hard way using a spreadsheet to calculate all the values and declare the memory contents but Xilinx makes life easy for designers. Their tools include a facility called Coregen which automates the design of many useful functions which happen to include sine and cosine tables.

There is little point in observing the nicety of IQ axis modulation with narrow band Q which was specified in the original NTSC standard. As a result the modulators are very simple. Modern FPGAs include multiplier blocks. Even if they didn't, the VHDL synthesis tools would create multipliers from ordinary logic cells, albeit using rather a lot of cells. Here are the modulators and subsequent processing from my own coder design. This is only very slightly simplified from my own code. Again you don't need to understand VHDL to work out what's going on.

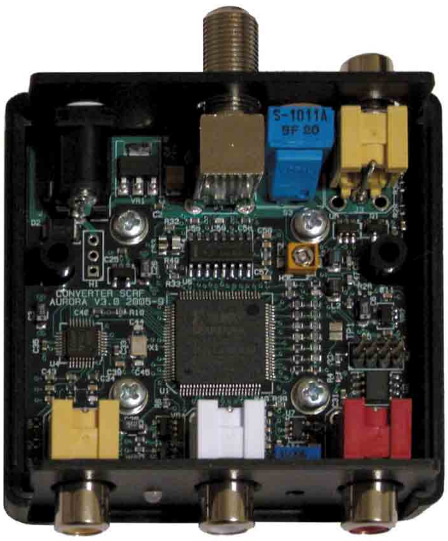
```
U_MODULATED <= (U + BURST) * U_SUBCARRIER;

V_MODULATED <=  V          * V_SUBCARRIER;

CHROMA <= U_MODULATED + V_MODULATED;

COMPOSITE_VIDEO <= LUMINANCE + CHROMINANCE;
```

As if by magic you now have a full NTSC signal. There are lots

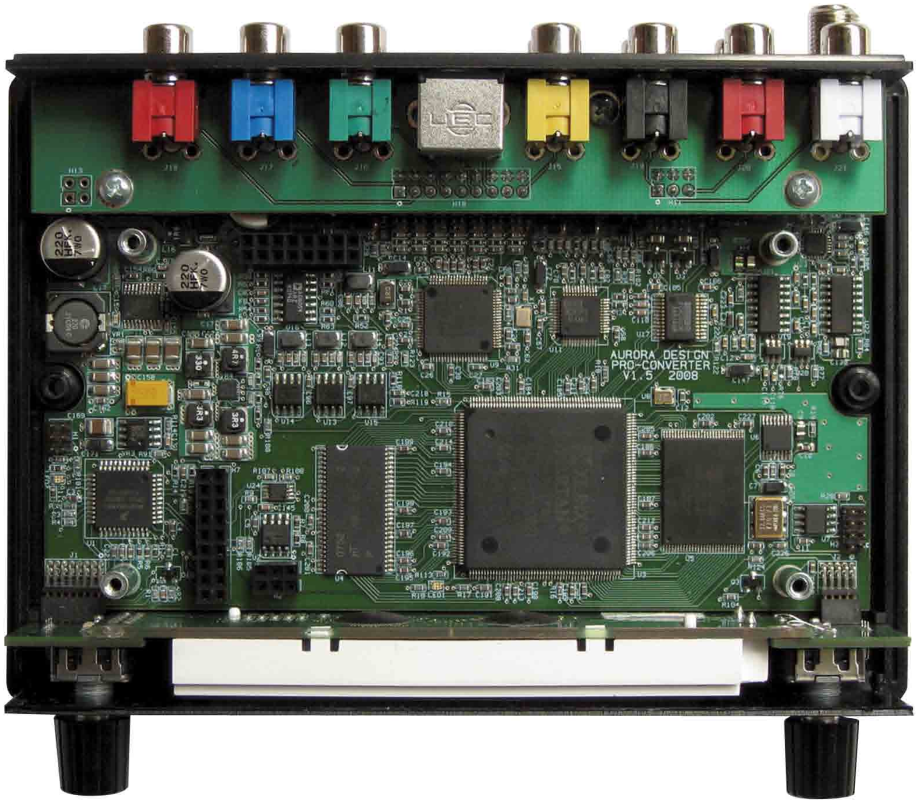


A line store from emerald48's converter

Aurora WC-01 World Converter



Aurora SCRF Converter



Aurora WC-01 World Converter inside

of details which would obscure this summary. Such as timing, word lengths and representation of signals but these are a normal part of programming an FPGA using VHDL rather than specific to an NTSC coder.

Looking forwards

Where will standards conversion be in a few years time? It's difficult to see how anyone could improve on the Aurora SCRF or make it much cheaper. The only way to do that is large scale production which just isn't going to happen. We will need to face the gradual decline of 625 and 525 systems. Analogue PAL and NTSC will be available from most video devices for some years but eventually they will die out. Then we will need a box to convert from HDMI, or whatever interconnect is then in use, to 405. It might be simplest to rely on HDMI to PAL/NTSC converters which will almost certainly be available for a long time to come. Conceptually it's not hard to design an HDMI to 405 converter but the Digital Rights Management associated with HDMI could make this unduly difficult.

Looking back

The world's first electronic standards converter was the BBC's CO6/501. Malcolm Everiss, well known for designing the Domino 625 to 405 converter, has restored one of these monsters to working order. One simple but lengthy and tedious job was replacing many hundreds of electrolytics. There were also lots of problems with old germanium transistors, notably the ASZ20 and OC140. The ASZ20 was very unreliable and used in great numbers so the only way was to find a suitable silicon replacement. The OC140 is a unique symmetric device where you can swap collector and emitter. There is no satisfactory replacement and even NOS devices don't always work. Malcolm says it's now about 95% working. Even when new, maintenance must have been difficult, so Malcolm has performed a herculean task to get it to work again. It's hardly surprising that the BBC designed the digital CO6/509 which is a fraction of the size, works better and is also a lot more reliable. Malcolm has restored one of those too.

What else

Just because an excellent converter is available at a reasonable price that's no reason for enthusiasts to stop experimenting. A man in France is taking his first steps to generate 819 line signals using FPGA methods. Another in Germany is attempting to build a copy of David Looser's early design which was based on ordinary TTL devices. You can learn a lot from such experiments even if the results don't quite justify the means. My warning from earlier articles still stands; it's not easy to build a standards converter.

Which leads me to a mystery. A man known only as emerald48 put a video on Youtube showing his own converter which he claimed was cheap and easy to design and build out of standard logic parts. All credit for his achievement but another video, now gone from Youtube, shows that it's not as simple as he claimed. There are about seven handmade Eurocard size PCBs, each with various chips. Mainly ordinary logic but also some memories and other devices. I would estimate the overall complexity as about equivalent to Dave Grant's Dinosaur. This sort of design is certainly not cheap. It's also quite complex, even if the principles are simple enough. I have managed a poor quality screen grab of one the five line store cards.

References

All my previous articles about converters and conversion can be seen on my website www.borinsky.co.uk Here are the references to those published in the BVWS Bulletin. Earlier articles from 405 Alive and Television can also be found on my website.

Borinsky, J.D., 2006. *So You Want to Build a Standards Converter Revisited: Some further thoughts and reflections on generating 405 line signals.* BVWS Bulletin,31 (3), pp.24-27.

Borinsky, J.D., 2006. *Aurora Standards Converter With RF Modulator: A review.* BVWS Bulletin,31 (2), pp.14-15,33.

Borinsky, J.D., 2005. *Aurora Standards Converter: A review.* BVWS Bulletin,30 (2), pp.32-34.

Borinsky, J.D., 2002. *So You Want to Build a Standards Converter: Some thoughts and reflections on generating 405 line signals.* BVWS Bulletin,27 (3), pp.18-24.

Borinsky, J.D., 2002. *Domino 625 To 405 Standards Converter.* BVWS Bulletin,27 (3), p.43.

Links

http://www.tech-retro.com/Aurora_Design/Home.html
Aurora standards converters

http://www.405-line.tv
The British Heritage TV Group aims to provide a 405 line broadcast service on Band I

www.bbc.co.uk/rd/index.shtml
Many of the BBC Research Department reports are available here including several from the 1960s and 1970s that are relevant to standards conversion.

www.vintage-radio.net
Latest news about standards converters is likely to appear here first

http://en.wikipedia.org/wiki/Upsampling
Further detail on upsampling digital signals

http://www.youtube.com/watch?v=RJVCA2OvQng
A video by Malcolm Everiss of his restored CO6/501

http://www.youtube.com/watch?v=w1DsM2_LApc
emerald48's somewhat mysterious converter in action