Informes Técnicos Ciemat 1266
Octubre, 2012

UOA1: Hardware Manual

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Catálogo general de publicaciones oficiales
http://www.060.es

Depósito Legal: M -26385-2011
ISSN: 1135 - 9420
NIPO: 721-12-048-6

Editorial CIEMAT

CLASIFICACIÓN DOE Y DESCRIPTORES

S70
ELECTRIC POTENTIAL; FRECUENCY CONVERTERS; FRECUENCY DEPENDENCE; ANALOG-TO-DIGITAL CONVERTERS; ELECTRONIC CIRCUITS ; SIGNALS; OPTICAL FIBERS; OPTICAL SYSTEMS

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Wolfers, G.; Sánchez, E.
32 pp. 11 figs. 4 tables

Abstract:
The UOA1 is a versatile printed circuit board which can be configured to accommodate up to four analogue signal channels of either electrical to optical or optical to electrical converters. A charge-balance voltage to frequency technique is used for the conversion. The board can be adapted to different electrical input or output range and the full scale frequency can be adjusted to provide the best accuracy-tobandwidth compromise for each application.

UOA1: Manual de Usuario

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Resumen:
El circuito impreso UOA1 permite configurar hasta cuatro canales analógicos de conversión eléctrica óptica como también de conversión óptica eléctrica. Se utiliza la técnica de tensión frecuencia basada en el método del balance de la carga para la conversión. Las entradas y salidas eléctricas pueden adaptarse a distintos niveles de tensión y se puede ajustar la frecuencia máxima del conversor para conseguir según permite cada aplicación el mejor compromiso entre ancho de banda y precisión.

Contents

Tables and Drawings

1. Introduction

1.1. Scope of Document

This document provides a technical description of the UOA1 hardware. It is intended to provide the necessary information for people devising configuration for the module. It is specifically not a manual for end users, although it may provide them with useful background information, and help them resolve hardware problems.

1.2. Background to the UOA1

In an experimental system such as the Neutral Beam Injection (NBI) at the stellarator TJ-II in CIEMAT, many analogue signals generated from the experiment need to be transferred to a control room in order to control and monitor the installation. As a general rule in Fusion experiments signals cannot simply be transferred through copper cables but have to be isolated and transmitted via optical fibres instead. The obvious case is for those signals that are raised to High Voltage (HV) potential but it is also generally imposed to either comply with safety standards or to solve ground loop issues.

To date in the NBI system two converter models are being used. The first one was inherited from the Oak Ridge National Laboratories. It uses a pair of voltage-to-frequency (V/F) and frequency-to-voltage (F/V) converters, locally called EVF0 for the emitter and EFV0 for the receptor, to transmit the signal. Although quite robust, those converters have been working for more than 30 years, they are now outdated and becoming costly to maintain too because of their distinct physical form which requires special racks and power supplies. They can only transmit unipolar signals and their bandwidth is limited to 5 kHz.

The second model used in our system was designed on site and documented[1] 15 years ago. It also uses a V/F emitter (EMI001/95) and an F/V receptor (REC001/95) for the transmission. They can cope with bipolar signals and have a 0 to 100 kHz bandwidth but they are prone to offset changes and, as a result, are not supported anymore.

As a substitute was becoming badly needed a number of off-the-shelf solutions were evaluated. There was little offer on the market and probably the best commercial option, the AFL300[2] converter, was quite expensive, had only a 0 to 5 kHz bandwidth and a physical form that could not easily be integrated in our system.

When it became clear that a new design would be required, other ways of transmitting analogue signals via optical fibres, like the analogue-to-digital and digital-to-analogue conversion, were explored but it soon appeared that the cost per channel would be much higher than the cost of a V/F channel and that the required development effort was a lot greater too. In the end we settled for a new design based on the V/F F/V conversion technique that would have to match, as a minimum, the existing converter characteristics and improve them whenever possible.

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[1] Analogue Signal Transmission Of Up To 100 kHz Through Optical Fibre. A. López, A. Montoro. ITC 813 Decembre 1996.
[2] AFL-300 Fibre Optic Link. www.lab-systems.com.

1.3. Requirements

The following specification has been laid down because it is compatible with all our current requirements. Better values can be achieved, sometimes by accepting a trade-off with other parameters. This is discussed in more detail in section 4.

1.3.1. Physical Form

- Size: 160 mm x 100 mm Eurocard.
- Width: 4HP, 6HP with metallic frame.
- Supply connector: DIN41612 "H11" plug at rear.
- Electrical signal connector: RJ45 socket on front panel.
- Optical signal connector: 4 x ST type on front panel, 62.5/125 μm multi-mode fibre compatible.

1.3.2. Organisation

- Channels: 4.
- Input voltage range (V/F): +/- 10 V standard, +/- 250 mV optional.
- Input impedance (V/F): 1 Mohm.
- Output voltage range (F/V): +/- 10 V.

1.3.3. Electrical Isolation

- To ground: 1.5 kV peak (150 V peak on versions prior to MK1-2).
- Between channels: 650 V peak (320 V peak on versions prior to MK1-2).

1.3.4. Performance

- Linearity: 0.02% typical.
- Frequency response: DC to 100 kHz @ -3 dB.
- Gain accuracy: better than 1%.
- Transmission range: 800 m minimum.

1.3.5. Power

- Supply voltage: 24 V_{DC} @ 300 mA (V/F) and 250 mA (F/V).
- Supply voltage tolerance: operating 18 to 36 V_{DC}.

1.4. Concepts

See Drawing D1

The simplified Block Diagram shows the different stages involved in both V/F and F/V conversions. For the V/F conversion an input stage is used to raise the circuit's input impedance and optionally amplify the input signal. It is followed by an offset generator that shifts and scales the input signal dynamic range to the V/F converter input range. The converter frequency output is buffered in order to drive the large current that feeds the optical fibre transmitter.

For the F/V conversion the optical signal from the fibre connector is shaped through the digital buffer to make it compatible with the converter's frequency input specification. A compensation stage is used to remove the offset from the converter's analogue output and a low-pass filter stage attenuates the residual ripple voltage originating from the F/V conversion. Finally the output stage is used to amplify the filtered signal and provides low output impedance.

Each channel is powered by two isolated DC/DC converters. The first one supplies the analogue components and the other the digital parts.

1.4.1. V/F F/V Converter

The V/F F/V conversion is relying on the VFC110[3] integrated circuit (IC) from Texas Instruments. The IC was chosen because it was readily available and had much better electrical characteristics than its competitors. Among others its full scale frequency, an important parameter since it conditions the maximum analogue signal bandwidth that can be transmitted, was twice as high as the next option. It also includes an onboard precision 5 V_{DC} reference that can conveniently be used for offsetting the converter transfer function. And last but not least it can perform both V/F and F/V conversions.

1.4.2. PCB Layout

While the electrical circuit was being laid down it became apparent that most stages of the V/F conversion were also required to perform the F/V conversion. This is roughly shown on the block diagram where it can be seen that the input circuit for the V/F conversion can be used as the output circuit for the F/V conversion and that the offset generator can be re-configured as well to remove the offset from the F/V conversion. Likewise, with only a few connection changes, the converter can perform either as V/F or as F/V and the LED circuitry is the same for both circuits. As a result, and in order to optimize production costs, it was decided that only one printed circuit board (PCB) layout, capable of performing both functions, would be produced.

To avoid ground loop related problems it was decided that each channel would be isolated from the others and with respect to ground as well.

1.4.3. Conversion Performance

Other important points taken into consideration when designing the converter were the linearity, the accuracy, the frequency response and the temperature stability. All those parameters are mainly dependent on the converter's full scale frequency setup. Lowering the frequency improves the converter's linearity and reduces the temperature gain drift and frequency jitter. It does however reduce the analogue signal bandwidth that can be transmitted

[3] VFC110 High-Frequency Voltage-to-Frequency Converter, Texas Instruments, SBVS021A Revised April 2007.

and therefore a compromise between accuracy and frequency response ought to be made.

Here the full scale frequency has been lowered from 4 to 2 MHz because it substantially improves the converter performances without sacrificing too much the transmitted signal bandwidth. Other applications may of course require other settings and provision is made in the design to easily permit changing the full scale frequency.

1.4.4. Transfer Function Offset

Although the converter's output frequency dynamic range goes from 0 Hz to full scale it is not practical to use the low frequency values either. This is because there should be a reasonable gap between the maximum frequency of the analogue signal and the lower frequency of the F/V converter for the voltage ripple to be efficiently filtered out. The original 0 V lower end converter input can be raised to increase the transmissible signal bandwidth at the cost of a reduced signal dynamic range. Given the selected low-pass filter, which is detailed below, a good compromise was found for the current design by limiting the converter dynamic range to 2 to 10 V. With the full scale frequency set to 2 MHz the lowest ripple frequency that has to be filtered is 400 kHz.

1.4.5. Low-Pass Filter

The filter selection is directly related to how large the gap can be between the signal frequency bandwidth to be transmitted and the lowest F/V converter frequency. Since this parameter is largely dependent on each particular application a flexible filter topology has been chosen. It is based on two UAF42[4] ICs cascaded to form a fourth-order active low-pass filter. Higher order filter were considered but the extra cost was not justified. The three most commonly-used active filter types, Butterworth, Chebyshev and Bessel can easily be implemented by changing a few resistor values on the board. Texas Instruments provides a computer-aided programme that automatically calculates the relevant component values.

A Butterworth type filter has been chosen by default for the design. It has a flat pass-band and a fairly sharp cut-off profile which gives a minimum 40 dB ripple attenuation at 400 kHz with a cut-off frequency set to 128 kHz.

1.4.6. Calibration

The converter was designed having in mind that the calibration process should be straightforward and that it should not be affected by temperature variation. Both the universal active filter and the voltage-to-frequency converter ICs have good temperature stability and, in order not to spoil this, care has been taken to select most components with low temperature dependence. All gain related components have tight tolerances which allow each channel to be calibrated with a single trimming potentiometer to better than 1% accuracy. The calibration process relies on adjusting the converter frequency to the theoretical calculated value at a given voltage setting. F/V

[4] UAF42 Universal Active Filter, Texas Instruments, SBFS002B Revised October 2010.

converters are therefore independent from the V/F converters which make swapping matching modules a simple procedure.

1.4.7. Test Facility

An integrated test facility was envisaged to help checking the channels calibration in-situ but the idea was finally dropped because there was no cheap and simple way to achieve this. There were however some unused gates available from the optical connector buffer section and these were exploited to develop a LED indicator circuit. It produces a pseudo analogue LED indicator which intensity is proportional to the converter's channel frequency. In many occasions, troubleshooting downtime can greatly be reduced thanks to this type of diagnostics.

2. Circuit Description

2.1. Component and Channel Numbering

The circuit diagram is organised with a common section on Drawing D2 which shows the connections between each channel and the shared back and front electrical connectors and four identical channels, CH1 to CH4.

Component designators are numbered from 1 to 9 for the common parts, 101 to 199 for channel 1, 201 to 299 for channel 2 and so on. Equivalent components in the different channels have the same designator except for the first digit. In the following description the first digit will be replaced by x as shown on Drawing D3.

2.2. External Connections

See Drawing D2

To maintain compatibility with the previous converter model the board is powered through the back DIN41612 "H11" plug BC1. Capacitors C1 and C2 provide local supply filtering.

For the analogue inputs or outputs a shielded RJ45 connector FC1 has been chosen. Although traditionally used in digital applications the Cat 5e shielded version is specified to carry analogue video signal as well. It has been selected here for its compact form and efficient locking system. It is very cheap too and being directly soldered onto the PCB simplifies the module assembly.

Standard footprints for optional common mode rejection filters Lx have been placed in line with each analogue connection. The PCB short circuit tracks that link the two positive pads together and the two negative ones should be cut open if they were to be fitted.

2.3. Power Supply

See Drawing D3

The Power Supply section is common to both V/F and F/V configurations. Each channel has its own isolated supplies provided by two SIL DC/DC converters Ux07 and Ux01 that feed on one hand the analogue components with +/- 15 V_{DC} and on the other the digital components with +5 V_{DC}. The DC/DC converters input are rated at 24 V_{DC} but they can work from 9 to 36 V_{DC}. A resettable fuse F1, rated at about twice the nominal current consumption, protects the board against short circuits. The backplane subrack 24 V_{DC} supply is routed to the converters by making the link 1-2 of header JP1. Note that, for historical reasons, provision was made for powering the board from an auxiliary 5 V_{DC} supply and in that case the link 2-3 of header JP1 should be made instead. Obviously the DC/DC converters would have to be replaced with 5 V input models if this was to be done.

It was hoped that the V/F converter would work with the analogue supply isolated from the digital supply. Tests carried out during the prototype validation showed that this was not the best option and that the 0 Ohm resistor Rx26 should be fitted to connect both analogue and digital grounds together.

Low output ripple DC/DC converters have been chosen. Capacitors Cx13, Cx15, Cx17 and Cx21 contribute to attenuating the switching noise from their outputs but it was found that the most effective way of filtering that noise down was to place capacitors Cx14, Cx16, Cx18 and Cx22 between the output and input grounds. The drawback of that solution is a reduced isolation to ground rating which is then limited to whatever those capacitors can take.

For good measure 100 nF decoupling capacitors have been placed next to all IC supply pins.

2.4. Voltage to Frequency Configuration

See Drawing D4

2.4.1. Input Stage

The input signal from connector FC1 is routed to the input stage of the channel by making the link 1-2 of header JPx03. The input impedance is fixed by Rx22 while Rx38 limits the current that can flow into the positive input of Ux06 when the board is not powered. Only the uncommitted op-amp of the UAF42 universal active filter Ux06 is used. It is configured as a noninverting amplifier which gain is set up by Rx32 and Rx37. The gain is 1 when Rx37 is omitted and the input voltage ranges from -10 to +10 V. Rx37 can be calculated and installed to increase the gain and reduce the input range proportionally.

The uncommitted op-amp of the second UAF42 Ux05 is configured as a summing amplifier and adds the Vref signal to offset the buffered input signal. Values of Rx31 and Rx36 are chosen in relation with Rx29 to convert the bipolar input into a unipolar signal compatible with the V/F converter input. The summing op-amp output signal is negative and has to be inverted, using the high-pass op-amp of the universal active filter, before it can be fed to the converter. Note that two 1k resistors Rx14 and Rx18 have to be placed in parallel with the capacitors of both universal filter's integrators to let the high-pass op-amp work as an inverter.

With the values shown in the schematic a –10 to +10 V input signal is converted into a +2 to +10 V signal at the high-pass output of IC Ux05.

2.4.2. V/F Conversion

The link 1-2 of header JPx02 is made to configure the VFC110 integrated circuit Ux04 as a V/F converter. The analogue signal enters the converter through Rx28 and trimming potentiometer Rx02. As described in the manufacturer document capacitors Cx05 and Cx08 can be fitted to lower the full scale frequency (f_{FS}) of the converter. A low f_{FS} improves the converter's linearity but reduces the signal bandwidth that can be transmitted. Here the f_{FS} is set to 2 MHz with a 56 pF capacitor mounted in Cx05. As recommended, a ceramic capacitor with a low capacitance versus temperature dependence (C0G type) is fitted. Likewise the input resistance Rx28 is chosen with a low temperature coefficient to maintain the converter output frequency (f_{OUT}) stability. Potentiometer Rx02 is used to adjust f_{OUT} with respect to the converter input. For example, with the values shown in the schematic, when the input is shorted 6 V reaches the V/F converter and the potentiometer should be tuned to get a 1.2 MHz frequency signal at the f_{OUT} output.

2.4.3. Optical Output interface

The frequency signal is routed to one driver of IC SN75452 Ux03 by making the link 1-2 of header JPx04. The driver output is connected to the HFBR-1412 optical transmitter OCx01 as suggested by the optoelectronic manufacturer[5]. Rx04 limits the current flowing into the transmitter diode. The proposed 180 Ohm value gives a 62.5/125 μm fibre link distance of 2 km at 25 ºC and 800 m for the worst case scenario which is more that sufficient for most of our applications. Rx04 value can be lowered to increase the maximum distance if required.

2.5. Frequency to Voltage Configuration

See Drawing D5

2.5.1. Optical Input Interface

Here again the optical receiver OCx01 is connected as recommended by Avago with a decoupling capacitor Cx01 between supply and ground and a fairly low value for the pull-up resistor Rx05 to ensure the signal returns quickly to a high level when the open collector output is turned off. The JPx01 link 2-3 is made to route the HFBR-2412 receiver output to the inputs of IC Ux02. Note that link 2-3 of JPx04 has to be made too to force the Ux03 driver 1 open collector transistor into high impedance. The 74AS02 2-input NOR gates are arranged to produce a sharp negative going pulse each time a high to low

[5] Low Cost, Miniature Fiber Optic Components with ST®, SMA, SC and FC Ports, Avago Technologies, AV02-0525EN June 2007.

transition is detected from the optical receiver output. Note that the pulse width is very important. It is used to reset the F/V comparator and should not be superior to 1/10 of the full scale period. At a 4 MHz full scale frequency the width of the pulse should not be superior to 25 ns. The minimum pulse width is defined by the high-to-low propagation delay of the first gate. The Transistor-transistor Logic (TTL) technology used has to be significantly faster than the width of the pulse to be generated. TTL technologies like the Fast (F) and the Advanced-Schottky (AS) are known to be fast enough but the Low-power (L) and the Low-power Schottky (LS) are not. According to the chosen technology the width of the pulse can be adjusted with capacitor Cx19 and optional resistor Rx09. Resistors Rx11 and Rx12 shift the TTL level pulse to a zero crossing signal.

2.5.2. F/V Conversion

Link 2-3 of header JPx02 is made to route the zero crossing pulse to the comparator input of the F/V converter Ux04. In this case the VFC110 is configured to generate an analogue signal which average is proportional to the zero crossing pulse frequency. Potentiometer Rx01 and resistor Rx28 together with optional capacitors Cx05 and Cx08 are chosen to set up the converter full scale frequency. Since we want the F/V converter to work with the V/F converter described in section 2.4.2 the chosen f_{FS} is set to 2 MHz with a 56 pF C0G ceramic capacitor placed in Cx05. Potentiometer Rx01 is used to calibrate the converter output with respect to the input frequency. With the values shown on the schematic, and assuming a 1.2 MHz frequency signal is being received on the optical connector, Rx01 is trimmed to obtain a 6 V averaged signal at the converter's analogue output.

2.5.3. Output Stage

The analogue output of the F/V converter is fed to the uncommitted op-amp of IC UAF42 Ux05. The op-amp is configured as a differential amplifier to subtract the 6 V offset from the analogue signal.

Voltage ripple with a frequency equal to the input is still present at the differential amplifier output. The UAF42 universal active filters Ux05 and Ux06 are cascaded to form a fourth order low-pass filter. As explained in the Texas Instruments' document the filter is based on the classic state-variable analogue architecture with an inverting amplifier and two integrators. Only a few external resistors are required to configure many kinds of active filters such as Butterworth, Bessel or Chebyshev. In our particular case the Butterworth type filter has been implemented with a Q of 0.54 for the first filter pair and a Q of 1.3 for the second respectively set by Rx16, Rx17, Rx35 and Rx21, Rx23, Rx25. Resistors Rx13, Rx19, Rx20 and Rx24 adjust the -3 dB cut-off frequency to 128 kHz to ensure a minimum of 40 dB attenuation of the ripple voltage at 400 kHz, the lower end of our dynamic range.

Once the ripple voltage has been filtered out, the signal is amplified using the uncommitted op-amp of Ux06 and the restored analogue voltage is routed to the RJ45 front connector FC1 by making the link 2-3 on header JPx03. The gain of the last amplifier is set by adjusting Rx37 with respect to Rx32. With the values of the schematic, a +2 to +10 V signal with ripple would output the

VFC110 converter and be shifted to a -4 to +4 V signal at output pin 6 of Ux05 then have the ripple attenuated at output pin 1 of Ux06 and finally be amplified to -10 to +10 V at pin 6 of Ux06.

2.6. LED Indicator

See Drawing D3

The second driver of Ux03 and NOR gate 0 of Ux02 are used to provide a simple monitoring system. The frequency signal from either V/F or F/V converters toggles the state of driver 2 which then toggles gate 0 to generate a square wave that turns the green LED LDx01 on and off. Capacitor Cx20 and resistors Rx07 and Rx08 adjust the time the LED is turned on each period. Since the turned on time is constant the LED is slightly on at low frequencies and is hard on at 4 MHz. The LED remains off when no frequency is detected. Resistors Rx06 and Rx27 limit the current that flows into the LED and into the gate's output.

3. Assembling and Testing

3.1. Default Board Layout

The board is a standard 3U size Eurocard, 100mm by 160mm and 1.6mm thick. A 4-layer construction was chosen with two signal layers on the outside and power and ground layers on the inside. The PCB complies with Class 4 Standard specifications and is made of grade FR4 fibreglass reinforced epoxy. All layers have 35μm thick copper tracks. Both sides are finished with green solder mask and white silk screen to permit easy identification of the components (see Drawings D7 and D8).

The board layout and routing was done on site. Each channel's components were placed in line starting from the back of the board with the DC/DC converters and ending at the front with the optical connector. Each channel is identical to the others. The only two exceptions to this are, one, the position of the optical connectors and associated components that had to be slightly squeezed between the RJ45 connector and the module's handle, and second, the position of components that are common to all four channels and appear on Drawing D2. Analogue components were grouped together and placed to avoid as much as possible noise pickup from the digital components.

Each channel is isolated with respect to ground and with respect to the others. Note that isolation is only provided to help resolve ground loop related problems. There is a minimum gap of 0.4 mm between the common board supply and any channel. The theoretical breakdown voltage for that gap is 640 V peak but this should be decreased accordingly if any noise cancelling capacitors are to be fitted between the DC/DC converters' grounds. The minimum gap between channels is 0.2 mm which should withstand up to 320 V peak.

3.2. Assembling

Gerber files are made available to the manufacturers to produce the PCB and to assemble those default components (see Drawing D6 and Table T11) common to both V/F and F/V configurations. The remaining components to be mounted depend on the required configuration. Table T12 shows the component list that would have to be fitted in order to configure the board with four V/F channels as described in section 2.4 and Table T13 shows the component list for four F/V channels as described in point 2.5.

All ICs are common to both configurations but it was chosen not to fit them by default to keep the cost of configuring only one out of the four channels low. Dual-In-Line (DIL) ICs are mounted on sockets to facilitate the configuration process.

With the exception of JP1 which always should be set to link 1-2 for a standard 24 V_{DC} board supply, all the other jumpers are either placed to short 1-2 for the V/F channel option or to short 2-3 for the F/V version.

The board can be used stand alone but our preferred format is fitted inside a 6HP, 3U Eurocard metal frame. Then the front panel should be mechanised as shown on Drawing D9 and the front serigraphy shown on Drawing D10 should be printed onto a transparent sticker and applied on top of the front panel.

3.3. Board Testing

First a 24 V supply should be applied to the UOA1 and the current consumption monitored. When fully populated the UOA1 should draw about 280 mA. Anything largely above that should be considered suspicious.

When powered the V/F channels should have their associated LED indicators switched on straight away. Then the frequency signal should be checked with a scope to confirm that it is stable when a fixed voltage or a short circuit is applied to the converter input and that it varies accordingly when the input value is changed. If this is not the case the fault should normally easily be traced down by checking whether the signals at each of the converter output stage comply with the theoretical values.

An optical frequency signal generated by a V/F channel can be used to test the F/V channels. The F/V channel LED should switch on when the optical fibre is inserted into its optical connector. Likewise the value of the output voltage should change proportionally with the frequency. Again if this is not the case each output stage trace should be checked and compared to the theoretical expectation to pinpoint which part of the circuit is faulty.

3.4. Calibration

Calibration is dependent on the chosen configuration but the procedure should be roughly the same for all of them. It is based on the principle that for a given voltage all compatible channels should be working at the same frequency. Modules can then be swapped without having to recalibrate the converters. The module should be left to warm up about 15 minutes before any calibration procedure is carried out.

In the case of a V/F converter the electrical input should be shorted and the channel frequency monitored. Rx02 should then be adjusted until the frequency matches within the error margin the theoretical frequency value for zero volt input. In our particular case a shorted input should proportionate 6 V_{DC} at the VFC110 input and since we want the converter full scale frequency to be 2 MHz at 10 V_{DC} the potentiometer should be trimmed to set the frequency output to 1.2 MHz.

Note that the frequency of the V/F converter may slightly be altered when measurements are carried out directly to the channel's ICs. This is known to happen when a test clip is fitted on top of the VFC110 chip or when an oscilloscope probe is placed between the f_{OUT} signal and DGnd of a +/- 250 mV input channel. To avoid problems during calibration it is recommended that the frequency measurement be made onto an F/V channel IC instead.

In the case of F/V converter a precise frequency light signal should be sent to the channel's optical input connector. Rx01 should then be adjusted until the measured F/V converter output voltage matches within the error margin the theoretical value. In our particular example we would set the potentiometer to obtain 0 V_{DC} when a 1.2 MHz frequency signal is received on the optical input.

3.5. Experimental Results

Experimental traces obtained from prototype boards are shown on Sheet S14. Step, sine and ramp responses are compared for the Bessel, Butterworth and Chebyshev low-pass output filter configurations. The filters' theoretical cut-off frequencies are set to achieve a minimum of 40 dB attenuation at 400 kHz. It can be seen that there is no perfect filter and that the choice of one or the other may depend on each application. Resistor values which are shown on drawing D5 configure the UAF42 universal filters as a 128 kHz 4th-order Butterworth low-pass filter.

3.6. Resolved Problems

Tests performed with the MK1 prototype boards showed that the analogue signal was quite sensitive to the +/- 15 V_{DC} DC/DC converter Ux07 ripple voltage and that fitting a converter with low ripple helped to keep the noise down. Part of that noise could significantly be removed by fitting capacitors between the power supply ground and the analogue ground or by shorting those grounds together if isolation is not required. With 1 μF across the grounds and a TMR3-2423E DC/DC converter the noise could be contained to about 40 mVp-p. Most of that noise had a high frequency component which could be filtered efficiently to less than 10 mVp-p with an oscilloscope 20 MHz low-pass filter.

Common mode rejection filter footprints were added as a precaution to the MK1-1 production board between the analogue connector FC1 and each channel. In case they would be inefficient discreet components could be mounted in those footprints to form RC or LC passive low pass filters. Surface mounted (smd) capacitor footprints Cx14, Cx16, Cx18 and Cx22 were added too to allow capacitors to be fitted between the DC/DC converters grounds. And finally the MK1-1 board was to be fitted with the "WI" version of the TMR3 because it would theoretically improve ripple voltage performance compared with the “E” version.

Unfortunately the tests carried out on the MK1-1 board showed that the “WI” version of the TMR3-2423 converter was not giving the expected result and ended up being noisier than the “E” version. It appeared however that the noise could drastically be reduced for both models by inserting common mode chokes between the 24 V_{DC} supply and the DC/DC converters. This could be achieved (just) by mounting the DC/DC converters high on the MK1-1 board making use of the converter package extra pin length and inserting an smd choke between the pcb contacts and the bended supply pins of the converter. With the choke installed the value of the capacitor across the DC/DC converter grounds could be lowered to a few nano farads. At this value, some smd size 1210 capacitors are rated to 1.5 kV ore more and can be fitted without having to downgrade the original DC/DC input output isolation. The other problem raised by using the “WI” version was its higher current consumption. With no load the “WI” model requires twice as much current as the “E” model and gets so hot that using it inside an enclosed metallic frame with no forced cooling is somewhat marginal.

As a result only the use of the TMR3 “E” model is foreseen for the MK1-2 board version. Cx16 and Cx22 have been removed to make room for the common mode rejection filter footprints Lx01 and Lx02. Copper gaps have been increased to take full advantage of the available isolation. Between supply power ground and channel ground the limitation is fixed by the DC/DC converter to 1.5 kV. Between the channel grounds however the limitation is mainly due to the FC1 RJ45 connector connections where gaps of more than 650 V cannot be achieved.

4. Application

See Drawing D3

Some thoughts about variations that could fairly easily be implemented on the UOA1 board are gathered here.

4.1. V/F Input Configuration

Standard inputs in the NBI system are +/- 10 V with Rx37 omitted and +/- 250 mV with 1 kohm in Rx37. Other input ranges can be configured by changing the gain of the input op-amp. For example changing resistor Rx37 to 39 kohm would set the input range to +/- 5 V.

The input impedance is fixed by Rx22. Standard value is 1 Mohm but other values can be mounted to suit other applications. Rx22 can be used to adapt the input to current signal. A 500 Ohm resistor would ideally convert a 4-20 mA current signal into a + 2 to + 10 V voltage signal. With the input op-amp configured as follower this range is directly compatible with the V/F converter and no offset is required, nor is any attenuation. This means that resistor Rx31 would have to match the feedback resistor Rx29 and Rx36 would not be fitted.

Other applications may require a higher input range. This could be accommodated by using the common mode rejection filter footprint Lx to place resistors and form a voltage divider with Rx22. The 17 mil minimum gap maintained between the pcb traces that link the RJ45 connector to the channels would withstand up to 680 V so the input voltage is more likely to be limited by the components fitted in the Lx footprints. Size 0805 thin film chip resistors are only specified up to 100 V. Care should be taken to provide proper safety standard if any voltage above 25 V_{RMS} or 60 V_{DC} is to be used.

4.2. Full Scale Frequency Selection

Looking at the VFC110 datasheet it is obvious that the converters linearity is inversely proportional to the full scale frequency. Applications that do not require a high bandwidth would gain precision with a lower f_{FS} setting. As explained in the datasheet three components are determining the converter f_{FS}, the integrator input resistor Rx02 in series with Rx28 for the V/F version or Rx01 plus Rx28 for the F/V, the integrator capacitor Cx08 and the one-shot capacitor Cx05. Texas Instruments provides a table of values for seven different f_{FS} ranging from 10 kHz to 4 MHz. All those components can easily be modified on the UOA1 board to provide the best accuracy-to-bandwidth compromise for each application.

4.3. Optical Connectors

Standard ST type connectors OCx01 are fitted on the board. If required the SMA version has the same footprint and can easily be mounted instead.

4.4. F/V Low Pass Filter Configuration

A fourth-order Butterworth low-pass filter has been chosen by default to remove the residual F/V converter ripple voltage from the transferred signal. It is a good compromise between the Bessel filter which has a good step response but a flatter cut-off frequency and the Chebyshev filter which has a sharp cut-off frequency but a pour step response and some ripple in the pass-band. All three filter configurations can easily be implemented with the UAF42 IC by changing the value of only a few resistors. Texas Instruments provides a programme that calculates the values of resistors Rx13, Rx16, Rx17, Rx19, Rx20, Rx21, Rx23, Rx24, Rx25 and Rx35 for a given filter profile and cut-off frequency. Analog Devices provides an internet tool[6] as well which has a better graphical interface and gives a better feedback when components are not exactly matching the calculated values.

Higher order filters have been evaluated but were finally discarded mainly because the bandwidth benefit that they provide is at the cost of a poorer step response. And it was thought that, if any application would require this anyway, a special configuration would be created by cascading additional UAF42s from “sacrificed” juxtaposed channels. With only a few extra links made on the board 8^{th}-order, 12^{th}-order and 16^{th}-order filters could fairly easily be achieved.

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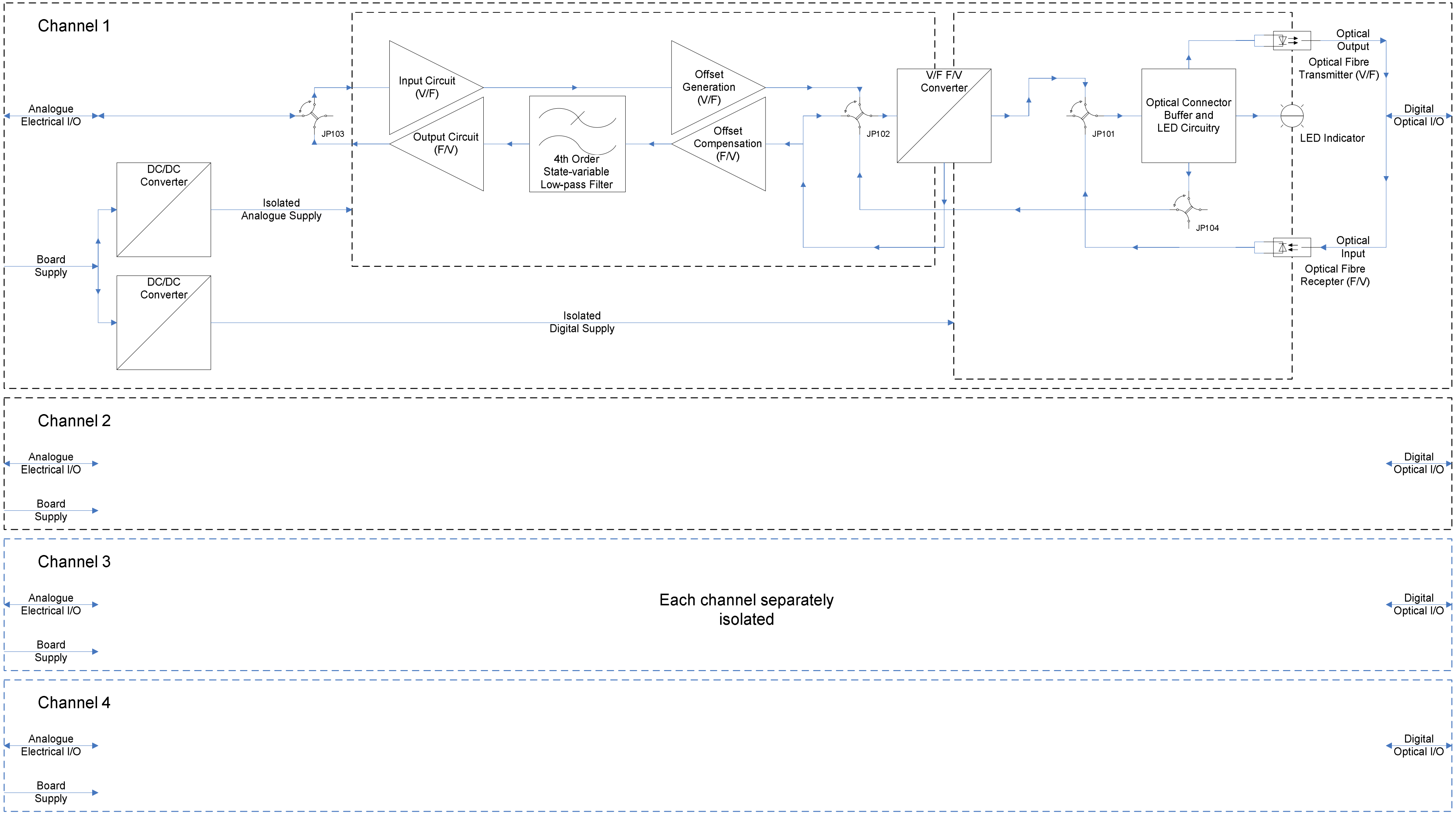
[6] Analog Devices Analog Filter Wizard™ v1.0, http://designtools.analog.com/dt/filter/filterW.html

4.5. F/V Output Configuration

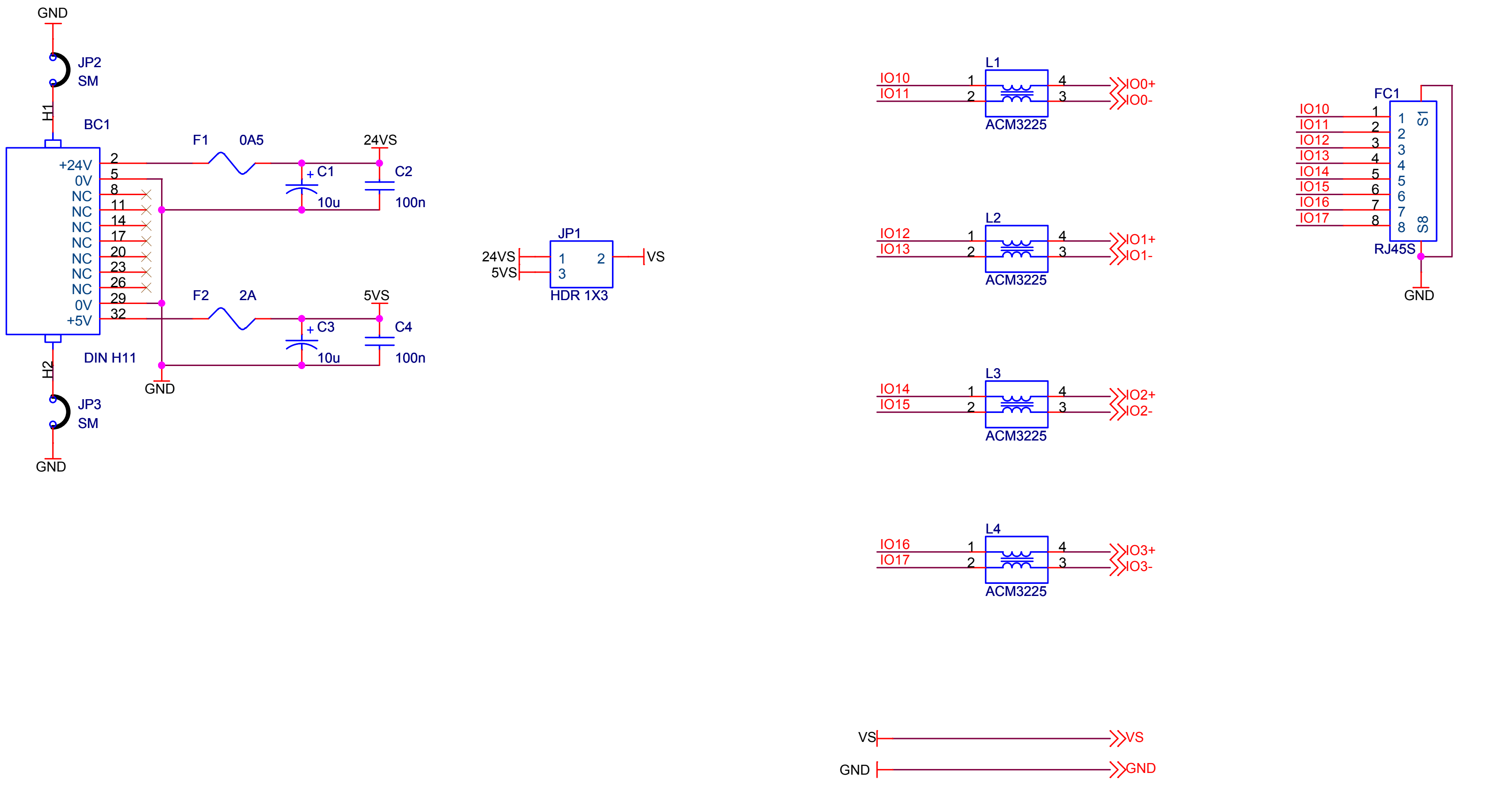
Standard output is +/- 10 V. Smaller output ranges can be configured by changing the resistors values of the differential op-amp or the gain of the output stage. For example replacing Rx30 with 100 kohm would change the output range to +/- 5 V and if Rx37 is omitted as well the range would drop to +/- 2 V.



NOTE:
This is a simplified block diagram.
Jumpers position shown for V/F
configuration. Rotate all four of
them 90º for F/V configuration.

UOA1 Block Diagram					
Asociación Euratom-Ciemat Grupo NBI Avenida Complutense 40 E-28040 Madrid					
TAMAÑO	NOMBRE DE ARCHIVO		Nº DIBUJO		REV.
A4P	UOA1-BD.VSD		NBD00339		A
ESCALA	1:1	G. Wolfers	HOJA	D1	

DIBUJADO POR	FECHA
G. Wolfers	06/02/2012



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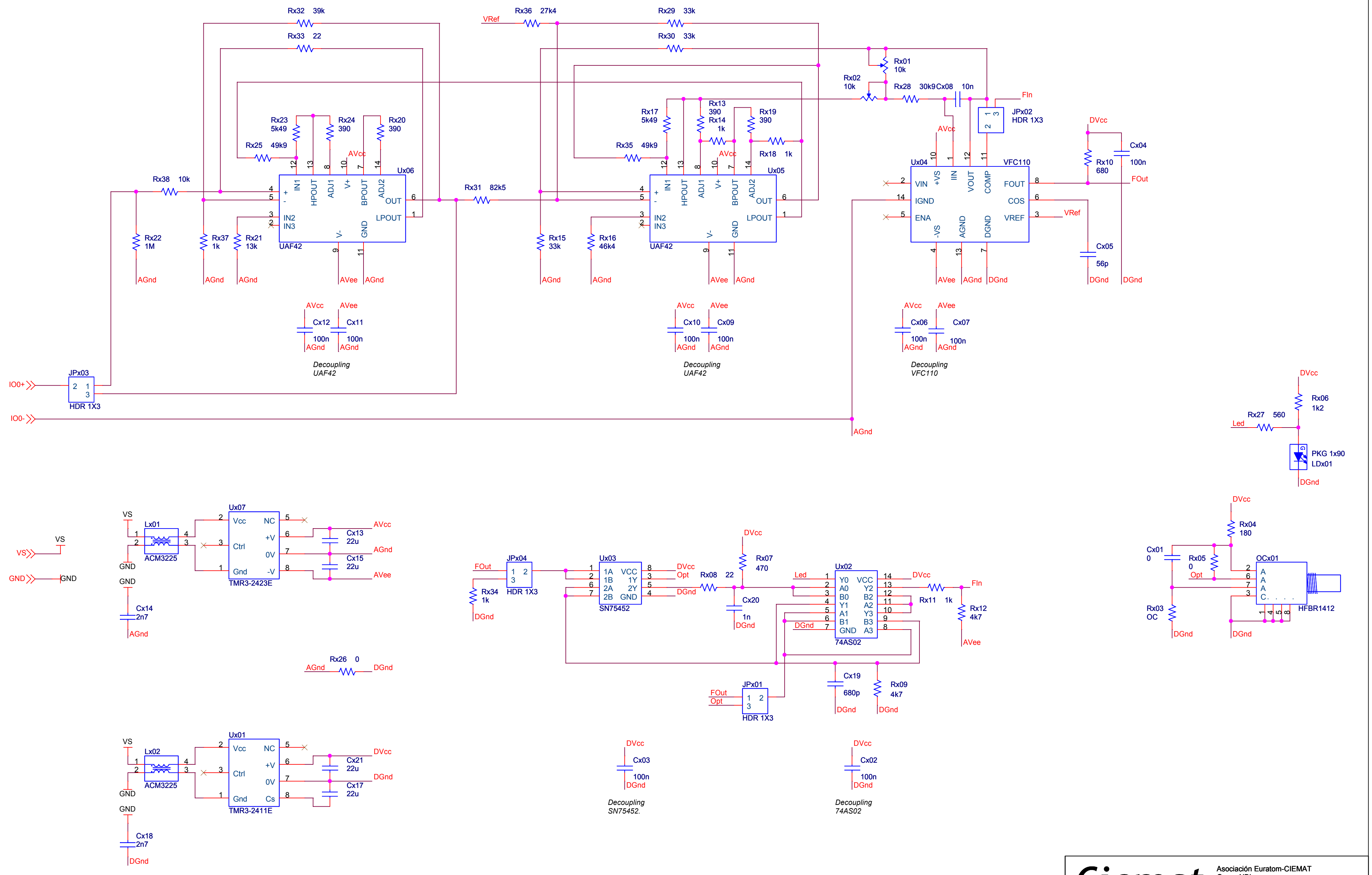
Grupo NBI
Av. Complutense, 40
E-28040 Madrid

Title	D2: UOA1 Circuit Diagram, Connectors	G Wolfers
Size A4	Design Filename and Document Number UOA1.DSN NBD00328	Rev A
Date:	Friday, August 10, 2012	Sheet D2 of



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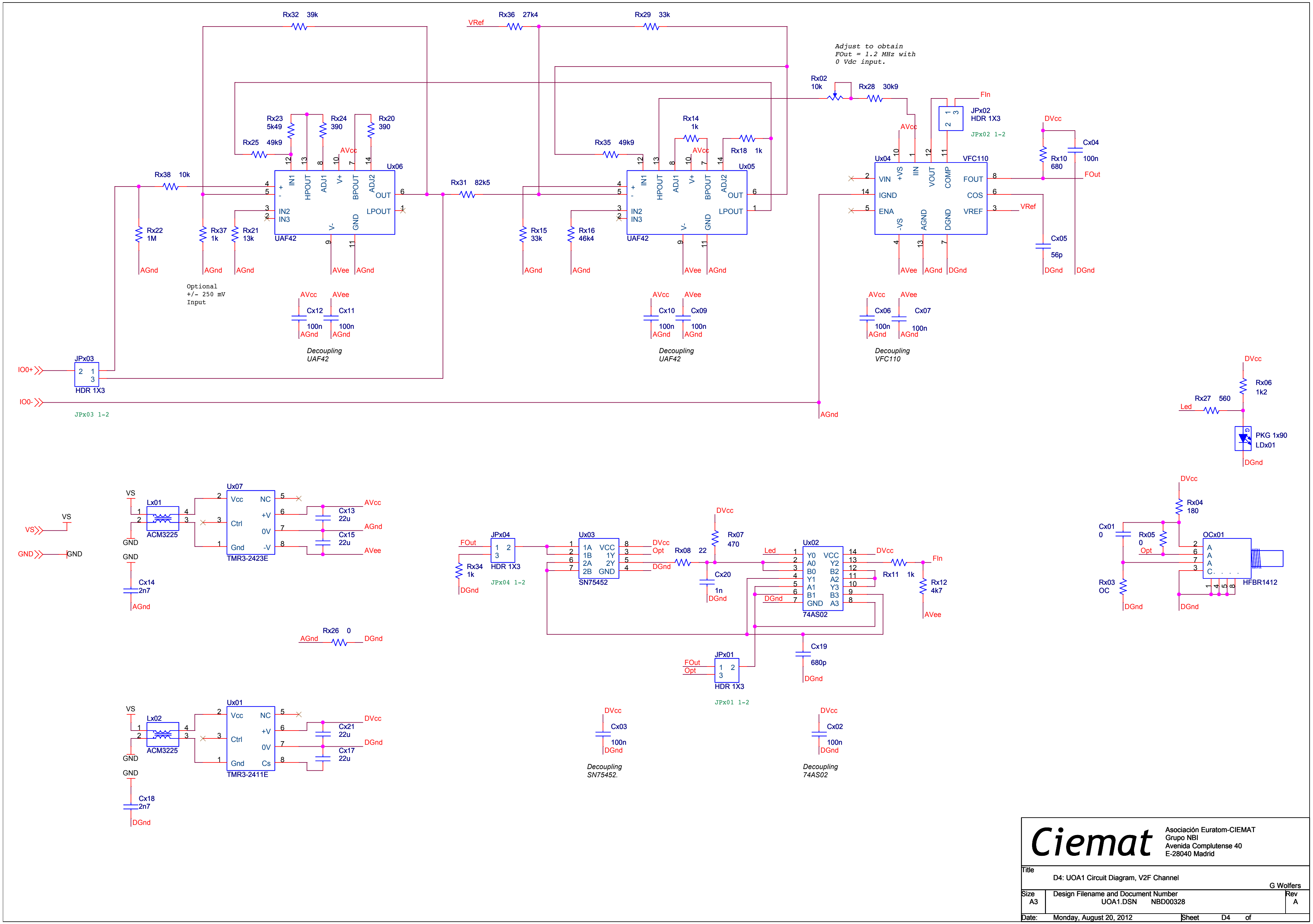
Grupo NBI
Avenida Complutense 40
E-28040 Madrid

Title	D3: UOA1 Circuit Diagram, Channel x	G Wolfers
Size A3	Design Filename and Document Number UOA1.DSN NBD00328	Rev A
Date: Monday, August 20, 2012	Sheet D3 of	



Adjust to obtain
FOut = 1.2 MHz with
0 Vdc input.
Rx32 39k
Rx36 27k4
Rx29 33k
VRef
Rx02 10k
Rx28 30k9
FIn
JPx02 HDR 1X3
JPx02 1-2
Rx23 5k49
Rx24 390
Rx20 390
Rx25 49k9
Rx38 10k
Ux06
UAF42
Rx31 82k5
Rx14 1k
Rx35 49k9
Rx18 1k
Ux05
UAF42
Ux04
VFC110
DVcc
Cx04 100n
Rx10 680
FOut
Cx05 56p
Rx22 1M
Rx37 1k
Rx21 13k
Rx15 33k
Rx16 46k4
AGnd
AVee
AVcc
DGnd
Optional
+/- 250 mV
Input
Cx12 100n
Cx11 100n
Decoupling
UAF42
Cx10 100n
Cx09 100n
Decoupling
UAF42
Cx06 100n
Cx07 100n
Decoupling
VFC110
JPx03
HDR 1X3
JPx03 1-2
IO0+
IO0-
Rx06 1k2
Rx27 560
Led
PKG 1x90
LDx01
VS
GND
Lx01
ACM3225
Ux07
TMR3-2423E
Cx13 22u
Cx15 22u
Cx14 2n7
Rx26 0
JPx04
HDR 1X3
JPx04 1-2
Rx34 1k
Ux03
SN75452
Opt
Rx08 22
Rx07 470
Cx20 1n
Ux02
74AS02
Rx11 1k
Rx12 4k7
Cx19 680p
JPx01
HDR 1X3
JPx01 1-2
Rx04 180
Cx01 0
Rx05 0
Rx03 OC
OCx01
HFBR1412
Lx02
ACM3225
Ux01
TMR3-2411E
Cx21 22u
Cx17 22u
Cx18 2n7
Cx03 100n
Decoupling
SN75452.
Cx02 100n
Decoupling
74AS02
Ciemat
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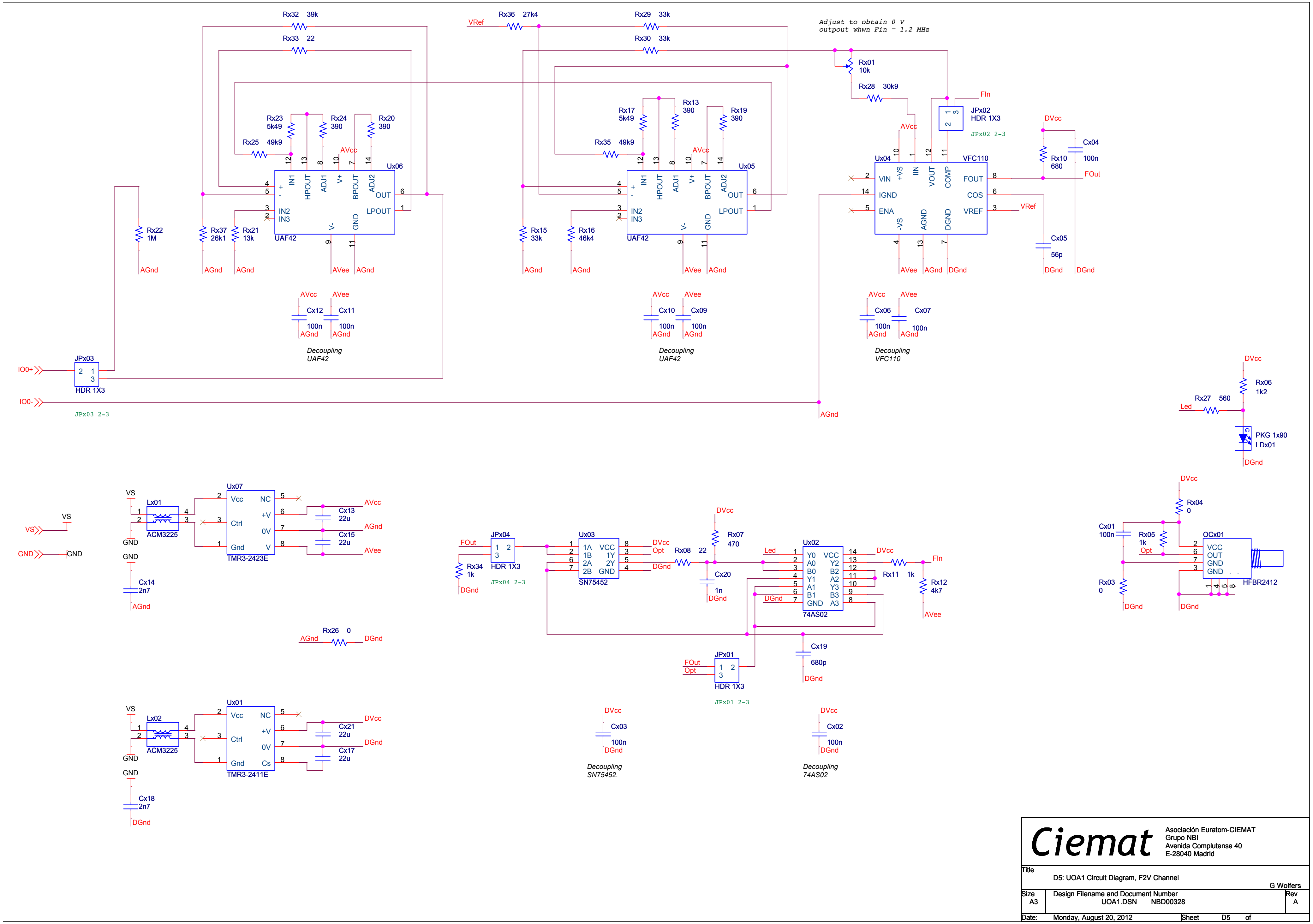
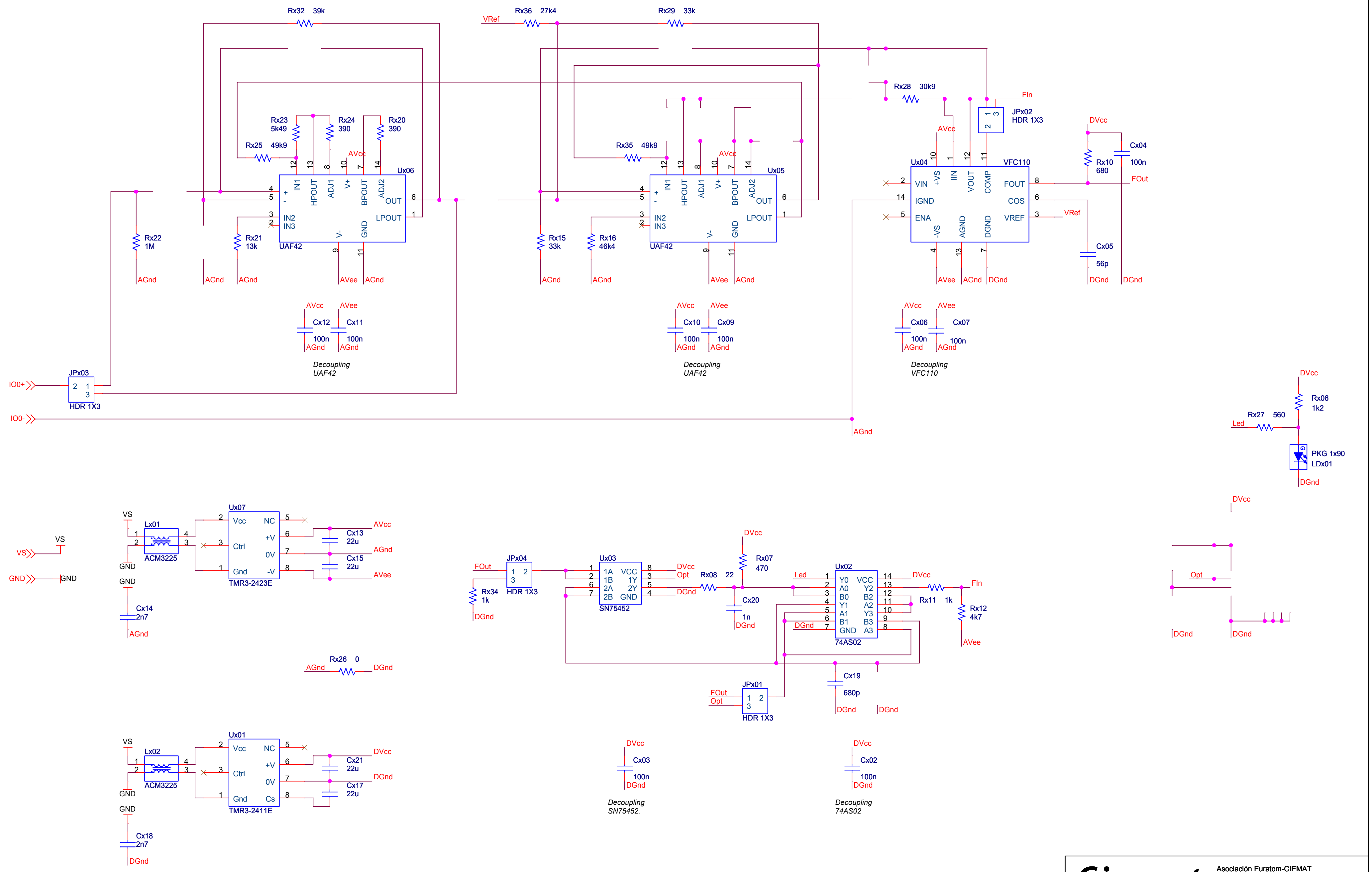
Grupo NBI
Avenida Complutense 40
E-28040 Madrid
Title
D4: UOA1 Circuit Diagram, V2F Channel
G Wolfers
Size A3
Design Filename and Document Number
UOA1.DSN NBD00328
Rev A
Date: Monday, August 20, 2012
Sheet D4 of


Rx32 39k
Rx33 22
VRef
Rx36 27k4
Rx29 33k
Rx30 33k
Adjust to obtain 0 V
output whwn Fin = 1.2 MHz
Rx01
10k
Rx28 30k9
FIn
JPx02
HDR 1X3
JPx02 2-3
Rx23
5k49
Rx24
390
Rx20
390
Rx25 49k9
AVcc
Ux06
IN1
HPOUT
ADJ1
V+
BPOUT
ADJ2
OUT
LPOUT
IN2
IN3
V-
GND
UAF42
Rx17
5k49
Rx13
390
Rx19
390
Rx35 49k9
Ux05
Ux04
VFC110
VIN
IGND
ENA
+VS
IIN
VOUT
COMP
FOUT
COS
VREF
-VS
AGND
DGND
DVcc
Rx10
680
Cx04
100n
FOut
Cx05
56p
Rx22
1M
Rx37
26k1
Rx21
13k
Rx15
33k
Rx16
46k4
AGnd
AVee
DGnd
Cx12
100n
Cx11
100n
Decoupling
UAF42
Cx10
100n
Cx09
100n
Decoupling
UAF42
Cx06
100n
Cx07
100n
Decoupling
VFC110
IO0+
JPx03
HDR 1X3
IO0-
JPx03 2-3
Rx06
1k2
Rx27 560
Led
PKG 1x90
LDx01
VS
GND
Lx01
ACM3225
Ux07
Vcc
Ctrl
Gnd
NC
+V
0V
-V
TMR3-2423E
Cx13
22u
Cx15
22u
Cx14
2n7
Rx26 0
Lx02
Ux01
Cs
TMR3-2411E
Cx21
22u
Cx17
22u
Cx18
2n7
FOut
JPx04
HDR 1X3
JPx04 2-3
Rx34
1k
Ux03
1A
1B
2A
2B
VCC
1Y
2Y
GND
SN75452
Opt
Rx07
470
Rx08 22
Cx20
1n
Ux02
Y0
A0
B0
Y1
A1
B1
VCC
Y2
B2
A2
Y3
B3
A3
74AS02
Rx11 1k
Rx12
4k7
Cx19
680p
JPx01
HDR 1X3
JPx01 2-3
Cx03
100n
Decoupling
SN75452.
Cx02
100n
Decoupling
74AS02
Rx04
0
Cx01
100n
Rx05
1k
OCx01
VCC
OUT
GND
HFBR2412
Rx03
0
Ciemat
Asociación Euratom-CIEMAT
Grupo NBI
Avenida Complutense 40
E-28040 Madrid
Title
D5: UOA1 Circuit Diagram, F2V Channel
G Wolfers
Size
A3
Design Filename and Document Number
UOA1.DSN NBD00328
Rev
A
Date: Monday, August 20, 2012
Sheet D5 of



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Grupo NBI
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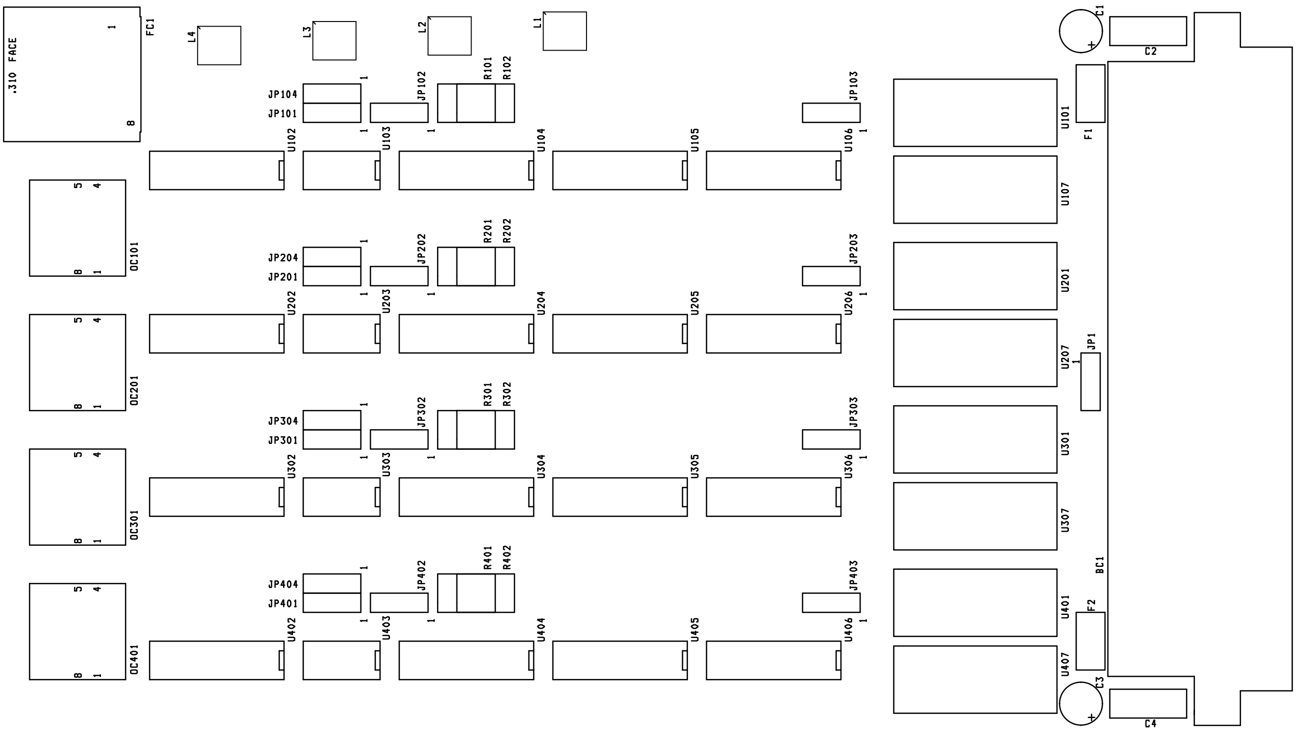
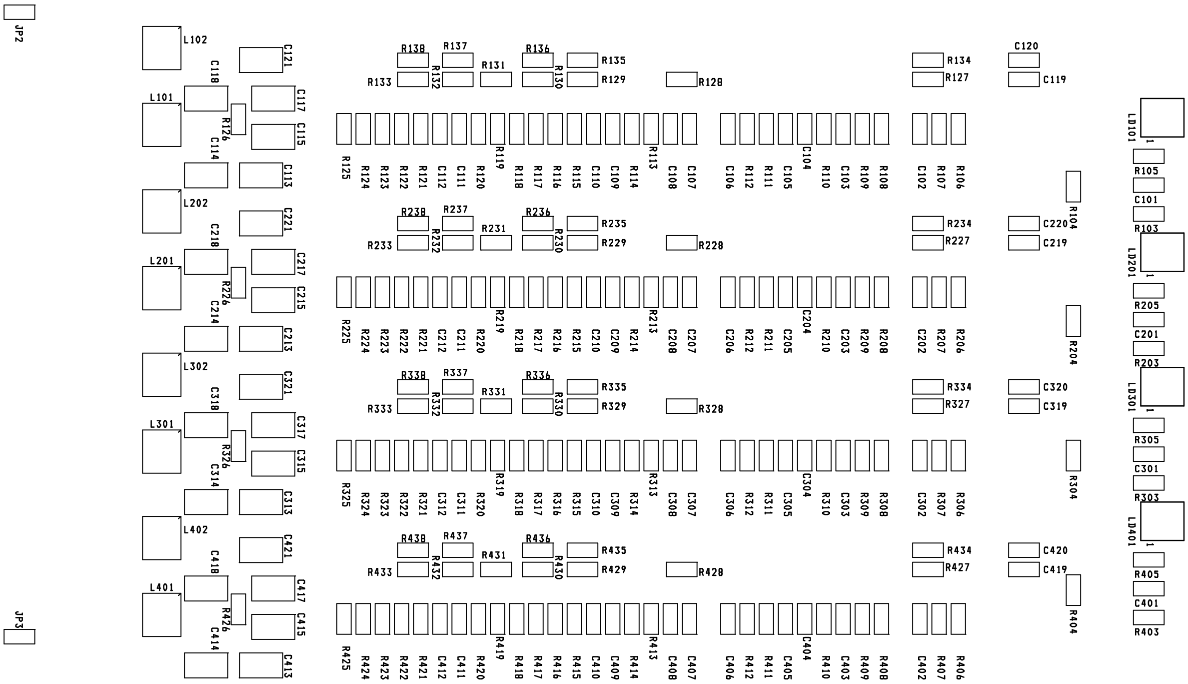
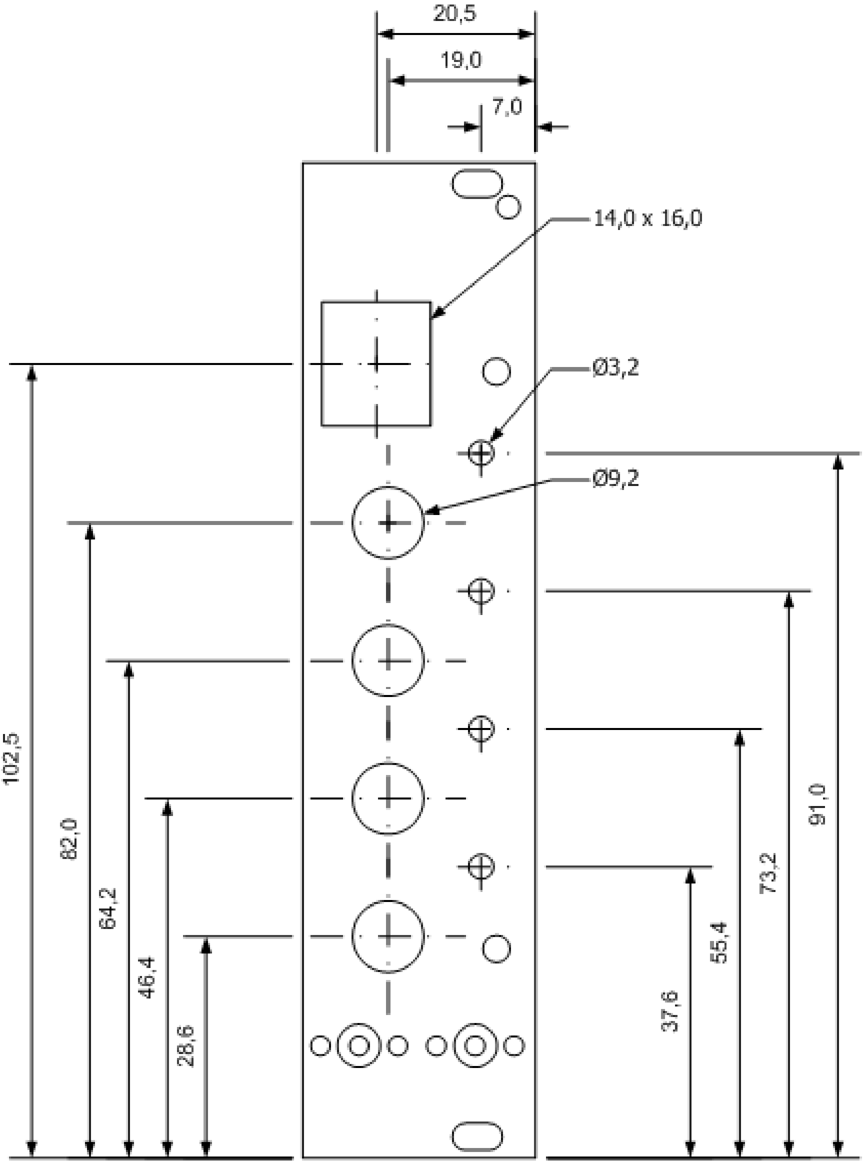
E-28040 Madrid

Title	D6: UOA1 Circuit Diagram, Default Components	G Wolfers
Size A3	Design Filename and Document Number UOA1.DSN NBD00328	Rev A
Date: Monday, August 20, 2012	Sheet D6 of	



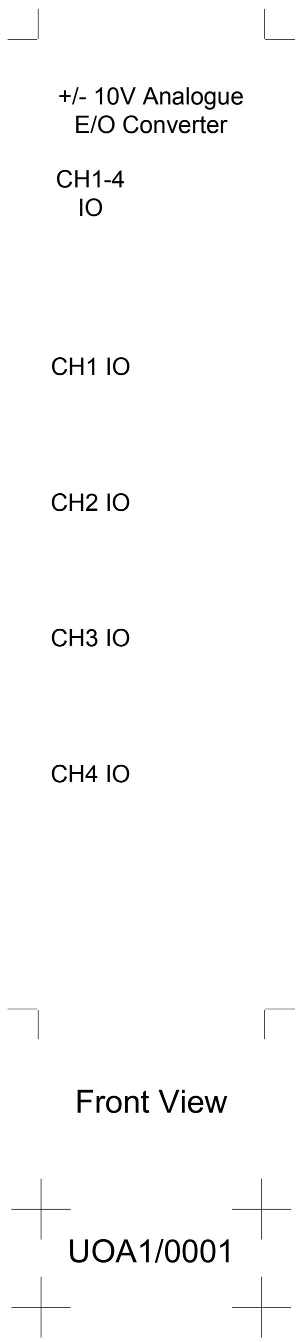
J10 FACE
FC1
L4
L3
L2
L1
C1
C2
JP104
JP101
JP102
R101
R102
JP103
U101
F1
U102
U103
U104
U105
U106
U107
OC101
JP204
JP201
JP202
R201
R202
JP203
U201
U202
U203
U204
U205
U206
U207
JP1
OC201
JP304
JP301
JP302
R301
R302
JP303
U301
U302
U303
U304
U305
U306
U307
OC301
BC1
JP404
JP401
JP402
R401
R402
JP403
U401
F2
U402
U403
U404
U405
U406
U407
OC401
C3
C4





Rear View

	UOA1 Front Panel				
	Asociación Euratom-Ciemat Grupo NBI Avenida Complutense 40 E-28040 Madrid				
	TAMAÑO A4P	NOMBRE DE ARCHIVO UOA1.VSD	Nº DIBUJO NBD00329		REV. B
DIBUJADO POR G. Wolfers	FECHA 20/06/2012	ESCALA	1:1	G. Wolfers	HOJA D9



		UOA1 Front Panel Label					
		Asociación Euratom-Ciemat Grupo NBI Avenida Complutense 40 E-28040 Madrid					
		TAMAÑO A4P	NOMBRE DE ARCHIVO UOA1.VSD		Nº DIBUJO NBD00329		REV. A
DIBUJADO POR G. Wolfers	FECHA 15/09/2011	ESCALA	1:1	G. Wolfers	HOJA	D10	

T11 Default Component List

Item	Quantity	Reference	Part	VNom	Tolerance	Description	Distributor	Order #
1	1	BC1	DIN H11			Conector DIN 41612 tipo H11 macho 90?para PCB	RS Amidata	433-236
2	1	C1	10u	35 Vdc	20%	2.54 mm radial electrolitic capacitor	RS Amidata	228-6717
3	2	C2	100n	50 Vdc	10%	5.08 mm radial ceramic capacitor	RS Amidata	653-0153
6	36	C102	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C103	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C104	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C106	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C107	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C109	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C110	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C111	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C112	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C202	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C203	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C204	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C206	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C207	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C209	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C210	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C211	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C212	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C302	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C303	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C304	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C306	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C307	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C309	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C310	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C311	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C312	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C402	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C403	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C404	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C406	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C407	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C409	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C410	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C411	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
		C412	100n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	264-4416
7	4	C105	56p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6313
		C205	56p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6313
		C305	56p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6313
		C405	56p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6313
9	16	C113	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C115	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C117	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C121	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C213	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C215	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C217	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C221	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C313	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C315	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C317	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C321	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C413	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C415	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C417	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
		C421	22u	16 Vdc	10%	1210 X5R ceramic capacitor	RS Amidata	698-3816
10	8	C114	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C118	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C214	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C218	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C314	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C318	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C414	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
		C418	2n7	1k5 Vdc	20%	1210 X7R ceramic capacitor	RS Amidata	698-2894
11	4	C119	680p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6423
		C219	680p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6423
		C319	680p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6423
		C419	680p	50 Vdc	5%	0805 COG ceramic capacitor	RS Amidata	723-6423
12	4	C120	1n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	723-6149
		C220	1n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	723-6149
		C320	1n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	723-6149
		C420	1n	50 Vdc	10%	0805 X7R ceramic capacitor	RS Amidata	723-6149
13	1	FC1	RJ45S			Shielded 90?pcb mounted RJ45 female connector	RS Amidata	331-6443
14	1	F1	0A5			5.08 mm radial resettable fuse	RS Amidata	517-6635
16	17	JP1	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP101	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP102	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP103	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP104	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP201	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP202	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP203	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP204	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP301	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP302	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP303	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP304	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP401	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP402	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP403	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
		JP404	HDR 1X3			2.54 mm 1x3 SIL header	RS Amidata	1/12 547-3150
17	2	JP2	SM			SMD jumper	RS Amidata	
		JP3	SM			SMD jumper	RS Amidata	
19	12	L1	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L2	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L3	ACM3225			Common mode rejection filter	RS Amidata	547-4787

T11 Default Component List

Item	Quantity	Reference	Part	VNom	Tolerance	Description	Distributor	Order #
		L4	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L101	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L102	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L201	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L202	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L301	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L302	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L401	ACM3225			Common mode rejection filter	RS Amidata	547-4787
		L402	ACM3225			Common mode rejection filter	RS Amidata	547-4787
26	4	R106	1k2		1%	0805 thick film resistor	RS Amidata	223-0433
		R206	1k2		1%	0805 thick film resistor	RS Amidata	223-0433
		R306	1k2		1%	0805 thick film resistor	RS Amidata	223-0433
		R406	1k2		1%	0805 thick film resistor	RS Amidata	223-0433
27	4	R107	470		1%	0805 thick film resistor	RS Amidata	223-0376
		R207	470		1%	0805 thick film resistor	RS Amidata	223-0376
		R307	470		1%	0805 thick film resistor	RS Amidata	223-0376
		R407	470		1%	0805 thick film resistor	RS Amidata	223-0376
28	4	R108	22		1%	0805 thick film resistor	RS Amidata	223-0203
		R208	22		1%	0805 thick film resistor	RS Amidata	223-0203
		R308	22		1%	0805 thick film resistor	RS Amidata	223-0203
		R408	22		1%	0805 thick film resistor	RS Amidata	223-0203
30	4	R110	680		1%	0805 thick film resistor	RS Amidata	679-1614
		R210	680		1%	0805 thick film resistor	RS Amidata	679-1614
		R310	680		1%	0805 thick film resistor	RS Amidata	679-1614
		R410	680		1%	0805 thick film resistor	RS Amidata	679-1614
31	8	R111	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R134	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R211	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R234	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R311	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R334	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R411	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R434	1k		1%	0805 thick film resistor	RS Amidata	223-0427
32	4	R112	4k7		1%	0805 thick film resistor	RS Amidata	223-0528
		R212	4k7		1%	0805 thick film resistor	RS Amidata	223-0528
		R312	4k7		1%	0805 thick film resistor	RS Amidata	223-0528
		R412	4k7		1%	0805 thick film resistor	RS Amidata	223-0528
35	8	R115	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R129	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R215	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R229	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R315	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R329	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R415	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R429	33k		0%1	0805 metal film resistor	RS Amidata	566-187
36	4	R116	46k4		1%	0805 thick film resistor	RS Amidata	679-1421
		R216	46k4		1%	0805 thick film resistor	RS Amidata	679-1421
		R316	46k4		1%	0805 thick film resistor	RS Amidata	679-1421
		R416	46k4		1%	0805 thick film resistor	RS Amidata	679-1421
38	8	R120	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R124	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R220	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R224	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R320	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R324	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R420	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R424	390		1%	0805 thick film resistor	RS Amidata	223-0360
39	4	R121	13k		1%	0805 thick film resistor	RS Amidata	679-0881
		R221	13k		1%	0805 thick film resistor	RS Amidata	679-0881
		R321	13k		1%	0805 thick film resistor	RS Amidata	679-0881
		R421	13k		1%	0805 thick film resistor	RS Amidata	679-0881
40	4	R122	1M		1%	0805 thick film resistor	RS Amidata	223-0821
		R222	1M		1%	0805 thick film resistor	RS Amidata	223-0821
		R322	1M		1%	0805 thick film resistor	RS Amidata	223-0821
		R422	1M		1%	0805 thick film resistor	RS Amidata	223-0821
41	4	R123	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
		R223	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
		R323	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
		R423	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
42	8	R125	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R135	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R225	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R235	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R325	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R335	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R425	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
		R435	49k9		0%1	0805 metal film resistor	RS Amidata	708-6632
43	4	R126	0			0805 thick film resistor	RS Amidata	223-0146
		R226	0			0805 thick film resistor	RS Amidata	223-0146
		R326	0			0805 thick film resistor	RS Amidata	223-0146
		R426	0			0805 thick film resistor	RS Amidata	223-0146
44	4	R127	560		1%	0805 thick film resistor	RS Amidata	223-0382
		R227	560		1%	0805 thick film resistor	RS Amidata	223-0382
		R327	560		1%	0805 thick film resistor	RS Amidata	223-0382
		R427	560		1%	0805 thick film resistor	RS Amidata	223-0382
45	4	R128	30k9		0%1	0805 metal film resistor	RS Amidata	708-6578
		R228	30k9		0%1	0805 metal film resistor	RS Amidata	708-6578
		R328	30k9		0%1	0805 metal film resistor	RS Amidata	708-6578
		R428	30k9		0%1	0805 metal film resistor	RS Amidata	708-6578
48	4	R132	39k		0%1	0805 metal film resistor	RS Amidata	565-904
		R232	39k		0%1	0805 metal film resistor	RS Amidata	565-904
		R332	39k		0%1	0805 metal film resistor	RS Amidata	565-904
		R432	39k		0%1	0805 metal film resistor	RS Amidata	565-904
50	4	R136	27k4		0%1	0805 metal film resistor	RS Amidata	708-6559
		R236	27k4		0%1	0805 metal film resistor	RS Amidata	708-6559
		R336	27k4		0%1	0805 metal film resistor	RS Amidata	708-6559
		R436	27k4		0%1	0805 metal film resistor	RS Amidata	708-6559

T12 V-F Component List

Item	Quantity	Reference	Part	VNom	Tolerance	Description	Distributor	Order #
5	4	C101	0			0805 thick film resistor	RS Amidata	223-0146
		C201	0			0805 thick film resistor	RS Amidata	223-0146
		C301	0			0805 thick film resistor	RS Amidata	223-0146
		C401	0			0805 thick film resistor	RS Amidata	223-0146
18	4	LD101	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
		LD201	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
		LD301	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
		LD401	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
20	4	OC101	HFBR1412			ST transmitter optical connector	RS Amidata	240-7021
		OC201	HFBR1412			ST transmitter optical connector	RS Amidata	240-7021
		OC301	HFBR1412			ST transmitter optical connector	RS Amidata	240-7021
		OC401	HFBR1412			ST transmitter optical connector	RS Amidata	240-7021
22	4	R102	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
		R202	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
		R302	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
		R402	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
24	4	R104	180		1%	0805 thick film resistor	RS Amidata	679-0942
		R204	180		1%	0805 thick film resistor	RS Amidata	679-0942
		R304	180		1%	0805 thick film resistor	RS Amidata	679-0942
		R404	180		1%	0805 thick film resistor	RS Amidata	679-0942
25	4	R105	0			0805 thick film resistor	RS Amidata	223-0146
		R205	0			0805 thick film resistor	RS Amidata	223-0146
		R305	0			0805 thick film resistor	RS Amidata	223-0146
		R405	0			0805 thick film resistor	RS Amidata	223-0146
34	8	R114	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R118	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R214	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R218	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R314	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R318	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R414	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R418	1k		1%	0805 thick film resistor	RS Amidata	223-0427
47	4	R131	82k5		0%1	0805 metal film resistor	RS Amidata	708-6701
		R231	82k5		0%1	0805 metal film resistor	RS Amidata	708-6701
		R331	82k5		0%1	0805 metal film resistor	RS Amidata	708-6701
		R431	82k5		0%1	0805 metal film resistor	RS Amidata	708-6701
52	4	R138	10k		1%	0805 thick film resistor	RS Amidata	223-0562
		R238	10k		1%	0805 thick film resistor	RS Amidata	223-0562
		R338	10k		1%	0805 thick film resistor	RS Amidata	223-0562
		R438	10k		1%	0805 thick film resistor	RS Amidata	223-0562
53	4	U101	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
		U201	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
		U301	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
		U401	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
54	4	U102	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
		U202	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
		U302	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
		U402	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
55	4	U103	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
		U203	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
		U303	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
		U403	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
56	4	U104	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
		U204	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
		U304	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
		U404	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
57	8	U105	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U106	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U205	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U206	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U305	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U306	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U405	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U406	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
58	4	U107	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623
		U207	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623
		U307	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623
		U407	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623

T13 F-V Component List

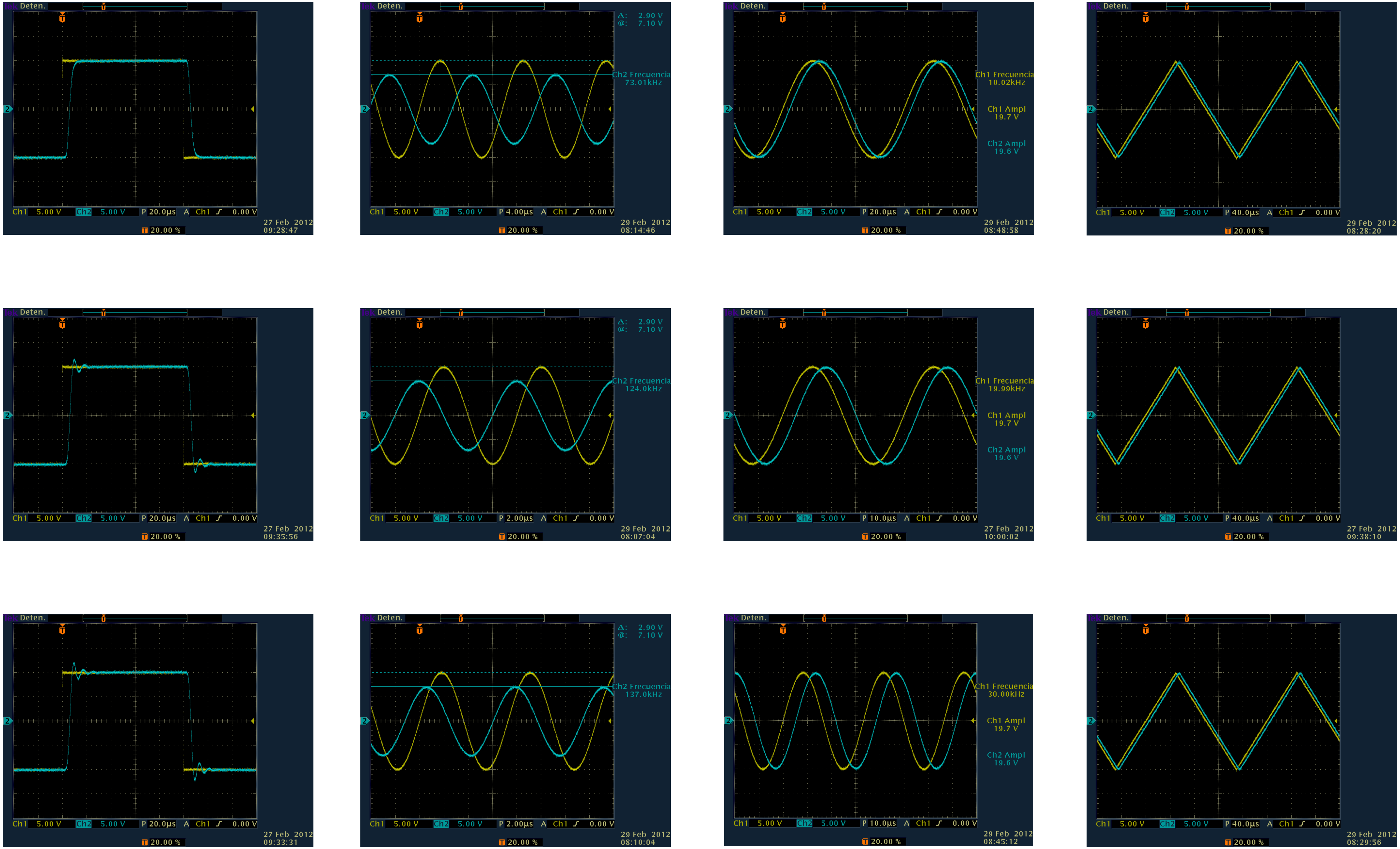
Item	Quantity	Reference	Part	VNom	Tolerance	Description	Distributor	Order #
5	4	C101	100n	50 Vdc	10%	X7R ceramic 0805 capacitor	RS Amidata	264-4416
		C201	100n	50 Vdc	10%	X7R ceramic 0805 capacitor	RS Amidata	264-4417
		C301	100n	50 Vdc	10%	X7R ceramic 0805 capacitor	RS Amidata	264-4418
		C401	100n	50 Vdc	10%	X7R ceramic 0805 capacitor	RS Amidata	264-4419
18	4	LD101	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
		LD201	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
		LD301	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
		LD401	PKG 1x90			Low current 90º pcb mounted green 3 mm LED	RS Amidata	546-0479
20	4	OC101	HFBR2412			ST receiver optical connector	RS Amidata	450-727
		OC201	HFBR2412			ST receiver optical connector	RS Amidata	450-727
		OC301	HFBR2412			ST receiver optical connector	RS Amidata	450-727
		OC401	HFBR2412			ST receiver optical connector	RS Amidata	450-727
21	4	R101	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
		R201	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
		R301	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
		R401	10k		10%	6 mm 0W25 vertical multiturn potentiometer	RS Amidata	521-9192
23	4	R103	0			0805 thick film resistor	RS Amidata	223-0146
		R203	0			0805 thick film resistor	RS Amidata	223-0146
		R303	0			0805 thick film resistor	RS Amidata	223-0146
		R403	0			0805 thick film resistor	RS Amidata	223-0146
24	4	R104	0			0805 thick film resistor	RS Amidata	223-0146
		R204	0			0805 thick film resistor	RS Amidata	223-0146
		R304	0			0805 thick film resistor	RS Amidata	223-0146
		R404	0			0805 thick film resistor	RS Amidata	223-0146
25	4	R105	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R205	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R305	1k		1%	0805 thick film resistor	RS Amidata	223-0427
		R405	1k		1%	0805 thick film resistor	RS Amidata	223-0427
33	8	R113	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R119	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R213	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R219	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R313	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R319	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R413	390		1%	0805 thick film resistor	RS Amidata	223-0360
		R419	390		1%	0805 thick film resistor	RS Amidata	223-0360
37	4	R117	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
		R217	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
		R317	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
		R417	5k49		1%	0805 thick film resistor	RS Amidata	708-6354
46	4	R130	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R230	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R330	33k		0%1	0805 metal film resistor	RS Amidata	566-187
		R430	33k		0%1	0805 metal film resistor	RS Amidata	566-187
49	4	R133	22		1%	0805 thick film resistor	RS Amidata	223-0203
		R233	22		1%	0805 thick film resistor	RS Amidata	223-0203
		R333	22		1%	0805 thick film resistor	RS Amidata	223-0203
		R433	22		1%	0805 thick film resistor	RS Amidata	223-0203
51	4	R137	26k1		0%1	0805 metal film resistor	RS Amidata	708-6547
		R237	26k1		0%1	0805 metal film resistor	RS Amidata	708-6547
		R337	26k1		0%1	0805 metal film resistor	RS Amidata	708-6547
		R437	26k1		0%1	0805 metal film resistor	RS Amidata	708-6547
53	4	U101	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
		U201	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
		U301	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
		U401	TMR3-2411E			8-pin SIL 5 Vout 3 W DC/DC converter	RS Amidata	733-1594
54	4	U102	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
		U202	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
		U302	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
		U402	74AS02			14-pin DIL quad 2-input fast TTL NOR gate	RS Amidata	663-1590
55	4	U103	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
		U203	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
		U303	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
		U403	SN75452			8-pin DIL dual peripheral NAND driver	RS Amidata	649-302
56	4	U104	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
		U204	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
		U304	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
		U404	VFC110			14-pin DIL 4 MHz voltage to frequency converter	RS Amidata	660-4535
57	8	U105	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U106	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U205	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U206	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U305	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U306	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U405	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
		U406	UAF42			14-pin DIL universal active filter	RS Amidata	311-580
58	4	U107	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623
		U207	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623
		U307	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623
		U407	TMR3-2423E			8-pin SIL +/- 15 Vout 3 W DC/DC converter	RS Amidata	733-1623

Step | Sine (-3 dB) | Sine (-0.1 dB) | Ramp

77 kHz 4th-order Bessel

128 kHz 4th-order Butterworth

0.1 dB 150 kHz 4th-order Chebyshev



Yellow Traces: V/F Input Signal
Blue Traces: F/V Output Signal

1135- 9420