MotionC-P™

C/C++ Programmable, Standalone, DSP 4-axis Servo or Stepper Motion Controller with Opto-couplers, Solid State Relays, ADC, DAC, and high voltage I/Os

Technical Manual

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Temperature readings for controllers are based on the results of limited sample tests; they are provided for design reference use only.

Chapter 1: Introduction

1.1 Functional Description

Features:

- 4.55 x 5.3", 200 mA at 12V
- C/C++ programmable, with remote debugger IDE, and samples
- Driven by **A-Engine™, A-Engine86™, R-Engine80™, i386-Engine™, or 586-Engine™**
- **MC25x0:** 4 axis stepping open-loop control with pulse, direction
- Stall detection with 4 quadrature encoder inputs
- **MC2140S/2120S:** 4 or 2-axis closed-loop servo control
- 7 solenoid drivers, 40+ TTL I/Os, 2 RS232, 1 RS485
- 32 Opto-couplers for home, limit,capture, and fault switches
- 16 opto isolated Solid State Relays (SSR) for AC or DC loads
- 32-bit registers for position, velocity, acceleration, and jerk
- S-curve, trapezoidal, velocity-contour, and electronic gearing
- 5 MHz pulse rate, 100 μs programmable loop rate, and 8 ADCs

The **MotionC-P™ (MCP)** is a low-cost, high-performance, standalone, C/C++ programmable industrial controller for up to 4-axis motion control. The **MCP** uses a DSP chipset (**MC2140/2120/2540/2520**, PMD) with build in sophisticated field proven control firmware. The **MCP** is driven by a host ("host" will now automatically imply all TERN controllers listed above) C/C++ programmable TERN controller. User only needs to define parameters for PID algorithm and trajectory profile. The DSP calculates velocity, position and stabilizes the motor output, while the host controller interfaces with user, interfaces with a PC, monitors I/Os, reads ADCs, computes or pre-loads a new set of parameters.

The host controller interfaces to the DSP chipset via high-speed data bus. User can easy develop application C/C++ program on a PC, download, and debug via serial link. The host writes pre-defined motion commands to the DSP, and the DSP can interrupt the host at any time.

The **MCP** provides a total of 32 opto-couplers for home switches, limit switches, fault switches and other user inputs. Seven solenoid drivers are capable of sinking up to 350 mA at 50 V. Eight opto-isolated Solid State Relays (SSR) can switch 100 mA AC or DC loads upto 230V. Two PPI (82C55) chips provide 48 I/O lines. Two RS-232 and one RS-485 drivers can be installed. The **MCP** also supports a 16-bit parallel-word input mechanism, such as ADC, which can be used as position feedback instead of normal incremental quadrature encoder. Expansion headers are available for 8 10-bit ADC inputs, PWM output and trace memory expansion.

Additional I/Os, memory, ADC, and DAC can be provided by the host. The technical manual of the respective host provides additional information.

The **MCP2140** supports up to 4-axis closed-loop digital servo control for a variety of servo motors. It uses incremental quadrature encoders for position feedback and high speed 12-bit DACs for ±10V servo control voltage output. Each axis contains sophisticated trajectory profile and digital servo capabilities, allowing very low position and velocity tracking errors. The 4-axis operation can be programmed either independently or in synchrony to allow advanced multi-axis motion such as circular and continuous-path profiles. It provides electronic gearing, PID/PI control, a choice of S-curve, trapezoidal, or contoured velocity profile modes, 1/T counter for stable low-velocity motion, automatic motor error shutdown, monitoring travel limit switches, home switches, capture switches, and fault switches. **MCP2120** is a 2-axis version

The **MCP2540** is a 4-axis open-loop stepping motor controller. It supports sophisticated trajectory generation and synchronization features, allowing the creation of complex motion sequences. It provides up to 3 MHz pulse and direction signals for driving step motor systems. Each axis has a quadrature decoder input which can be read by the host. It includes the same protected position inputs for home, limit, and fault as the **MCP2140**.

*MotionC*2140 provides:

- Electronic gearing
- PID or PI control
- Choice of S-curve, trapezoidal, or contoured velocity profile modes
- 1/T counter for stable low velocity motion
- Automatic motor error shutdown
- Monitoring travel limit switches
- Home switches, capture switches, and fault switches

The host x-*Engine* provides many options. See x-*Engine* manual for details.

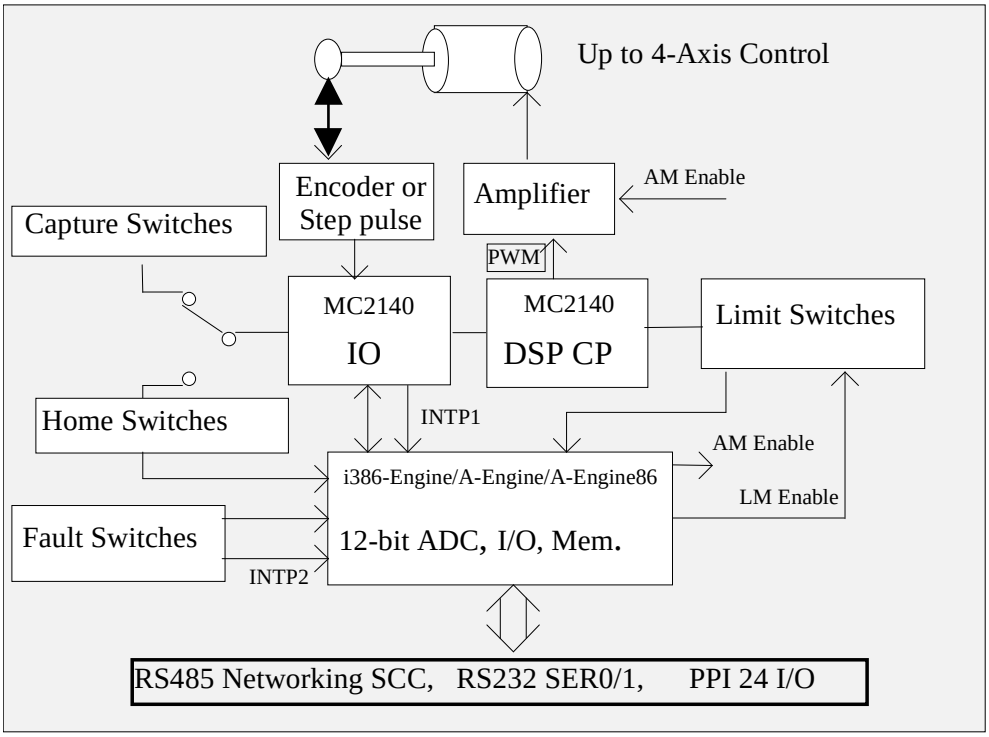


Figure 1.1 Funcitonal block diagram of the *MotionC*2140

Standard Features:

- Dimensions: 4.65 x 3.75 inches (MC2140, 40 MHz)
- Driven by an *i386-Engine*/*A-Engine*/*A-Engine86* (C/C++ programmable)
- Power consumption: 200 mA at 12V
- Temperature range: -40°C to +80°C
- *MC*2140/*MC*1401: Up to 4-axis closed-loop servo control
- 7 solenoid drivers, 24+ TTL I/Os
- 2 RS-232 drivers, 1 RS-485 driver

- Protected switches for position, velocity, acceleration and jerk
- 32-bit registers for position, velocity, acceleration and jerk
- S-curve, trapezoidal, or contoured velocity profile modes
- Electronic gearing for multi-axis
- 1/T counter for stable low velocity motion
- PID or PI control, Programmable loop rate to 100 μs

1.2 Physical Description

The physical layout of the *MotionC*2140 is shown in Figure 1.2.

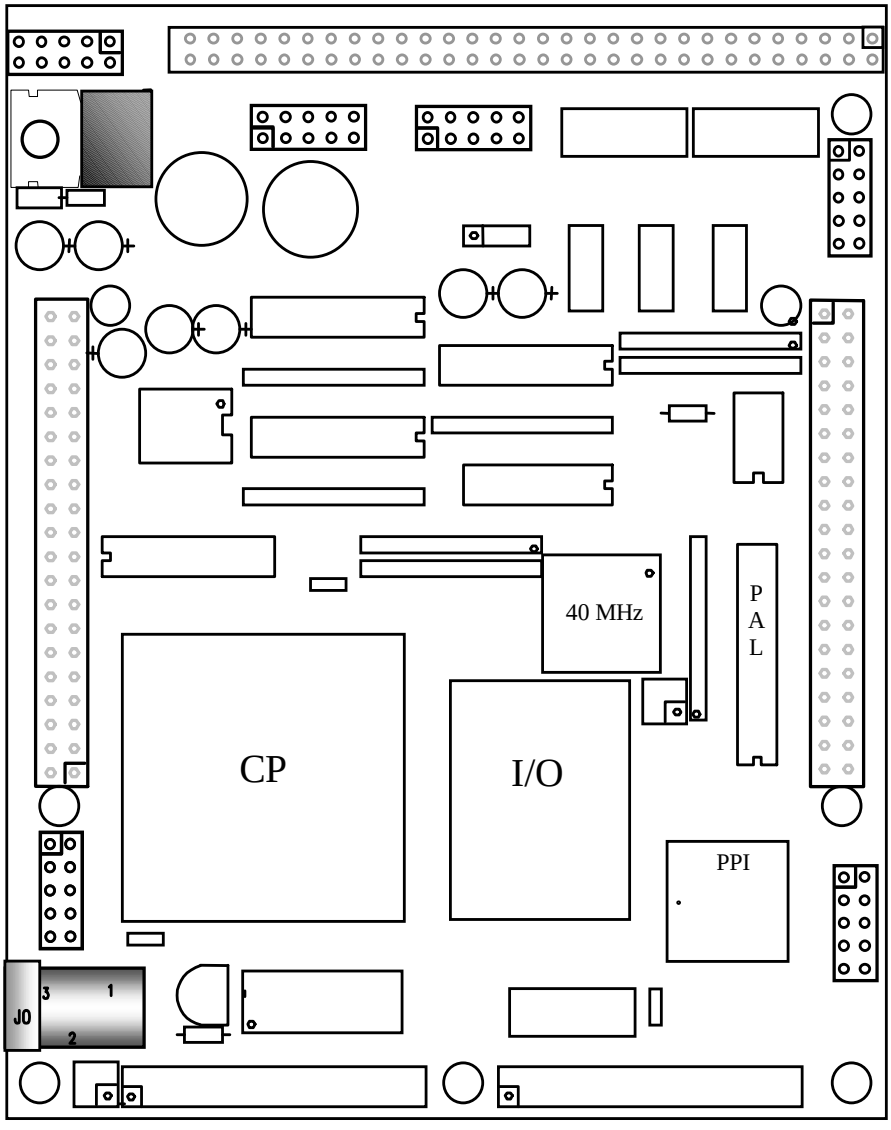
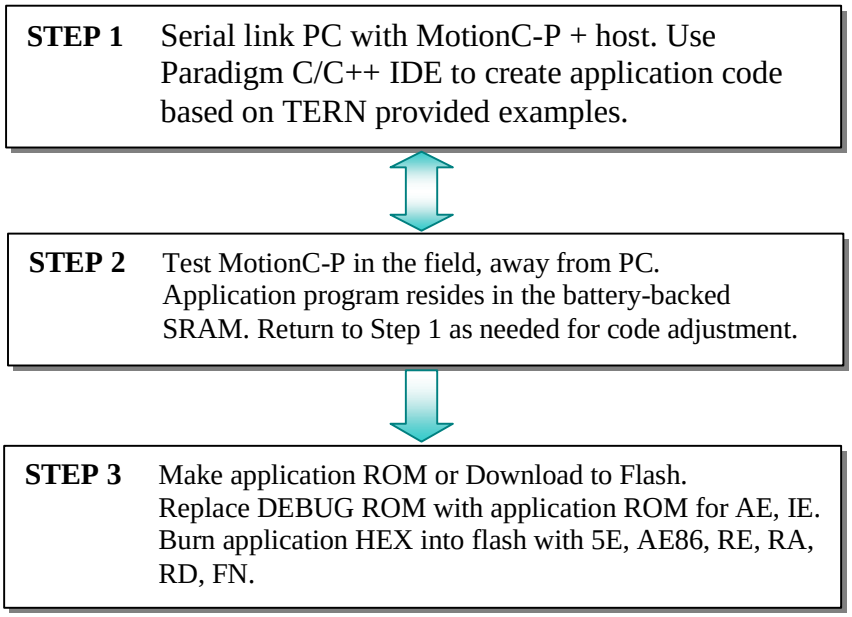


Figure 1.2 Physical layout of the *MotionC*2140

1.3 *MotionC*2140 Programming Overview

Development of application software for the *MotionC*2140 consists of three easy steps, as shown in the block diagram below.



There are three possible steps in the development of a C/C++ application program. These steps are explained thoroughly in the Technical Manuals for the *A-Engine/A-Engine86/i386-Engine*. The **EV** Kit is capable of completeing Step 1 and Step 2. The **EV** Kit cannot perform Step 3. Step 3 allows you to generate a HEX or BIN file and allows you to produce your own ROM/Flash chip. User will need the **DV** Kit for Step 3. Please refer to the Tutorial section in the Technical Manuals for the **EV-P/DV-P** Kit to obtain further details on programming the MotionC-P and host.

1.3.1 Minimum Hardware Requirements

- PC or PC-compatible computer with serial COMx port that supports 115,200 baud
- **MotionC-P**
- x-*Engine* controller:
  586-Engine, A-Engine, A-Engine86, FlashCore-N, R-Engine, R-Engine-A, R-Engine-D, i386-Enginef
- Debug serial cable (RS-232; DB9 connector for PC COM port and IDE 2x5 connector for controller)
- Center negative wall transformer (+9V 500 mA), a 1A transformer may be reuired, to satisfy current needs.

1.3.2 Minimum Software Requirements

- TERN **EV-P/DV-P** Kit installation diskettes
- PC software environment: Windows 95/98/2000/ME/NT/XP

Chapter 2: Installation

2.1 Software Installation

Please refer to the Technical manual for the "C/C++ Development Kit and Evaluation Kit for TERN Embedded Microcontrollers" for installing software.

The README.TXT file on the TERN installation CD contains important information about the installation and evaluation of TERN controllers.

Also refer to the technical manual for your host controller.

2.2 Hardware Installation

Hardware installation for the MotionC-P consists primarily of connecting the microcontroller to your PC.

Overview

- Install host controller to the MotionC-P.
- Connect PC to the MotionC-P/Host using the Debug serial cable.
- Connect 9V wall transformer to DC power jack on MotionC-P.
- Begin application development.

2.2.1 Connecting the MotionC-P to the host controller

To install the host controller onto the MotionC-P, align the J1 and J2 pin headers of the host with the J1 and J2 20x2 sockets of the MotionC-P. The J1 and J2 headers/sockets are identified by the white “J1” and “J2” markings on each PCB. Pin 1 of the J1 and J2 socket of the MotionC-P are shown below.

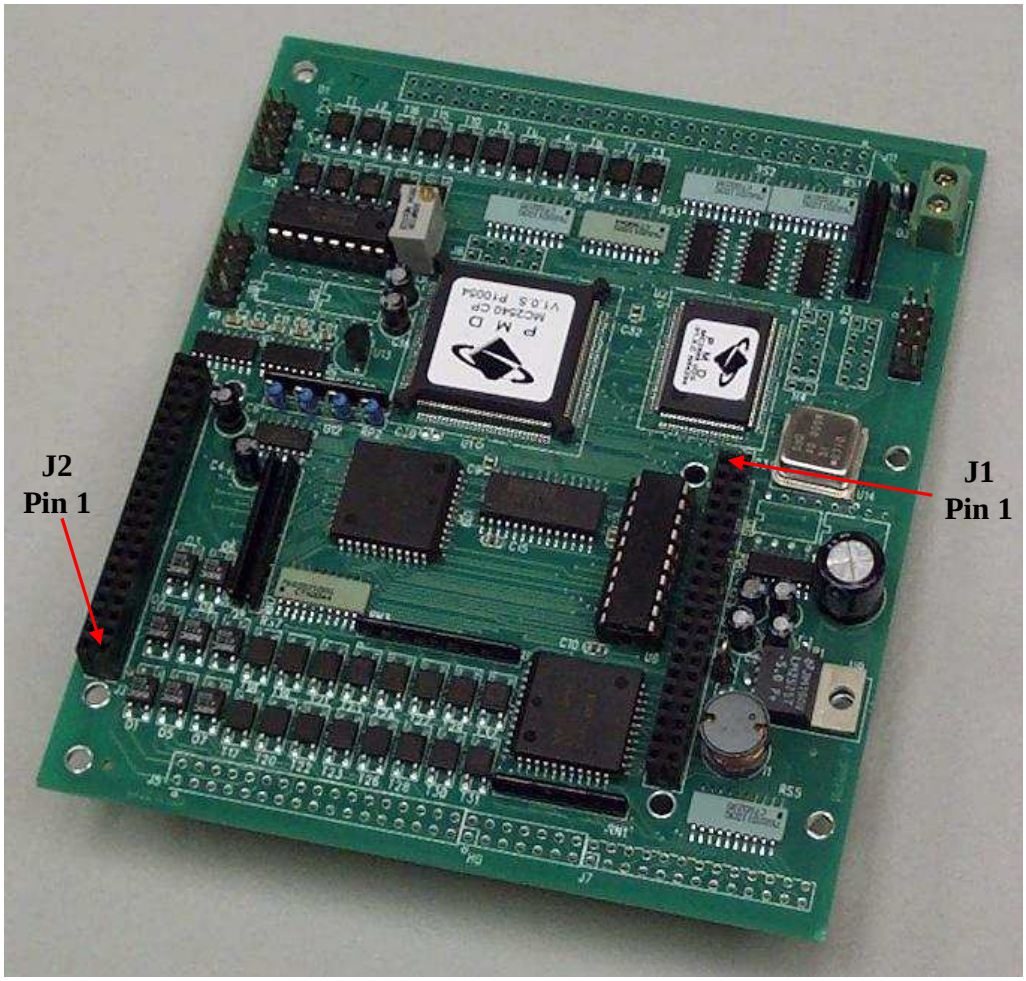


Figure 2.1 Before installing the *Engine* controller on the *MotionC*2140

2.2.2 Connecting the MotionC-P to PC and power

Install the 5x2 IDE connector of the debug serial cable onto the H1 header of the MotionC-P. Be sure to align the red edge of the cable with pin of the H1 header. Pin 1 of the H1 header is the pin nearest the “H1” label on the PCB itself. Connect the DB9 connector to your PCs open COMx port. The default COM port used by Paradigm C/C++ is COM1, but can be changed at any time. Refer to the following picture to confirm cable orientation.

Next, install the power jack adapter in the 2-pin screw terminal on the MotionC-P. Note that the output of the wall transformer is center-negative. An ohm-meter can be used to confirm polarity on the screw terminal. In addition, the following picture confirms the correct orientation of the power jack adapter.

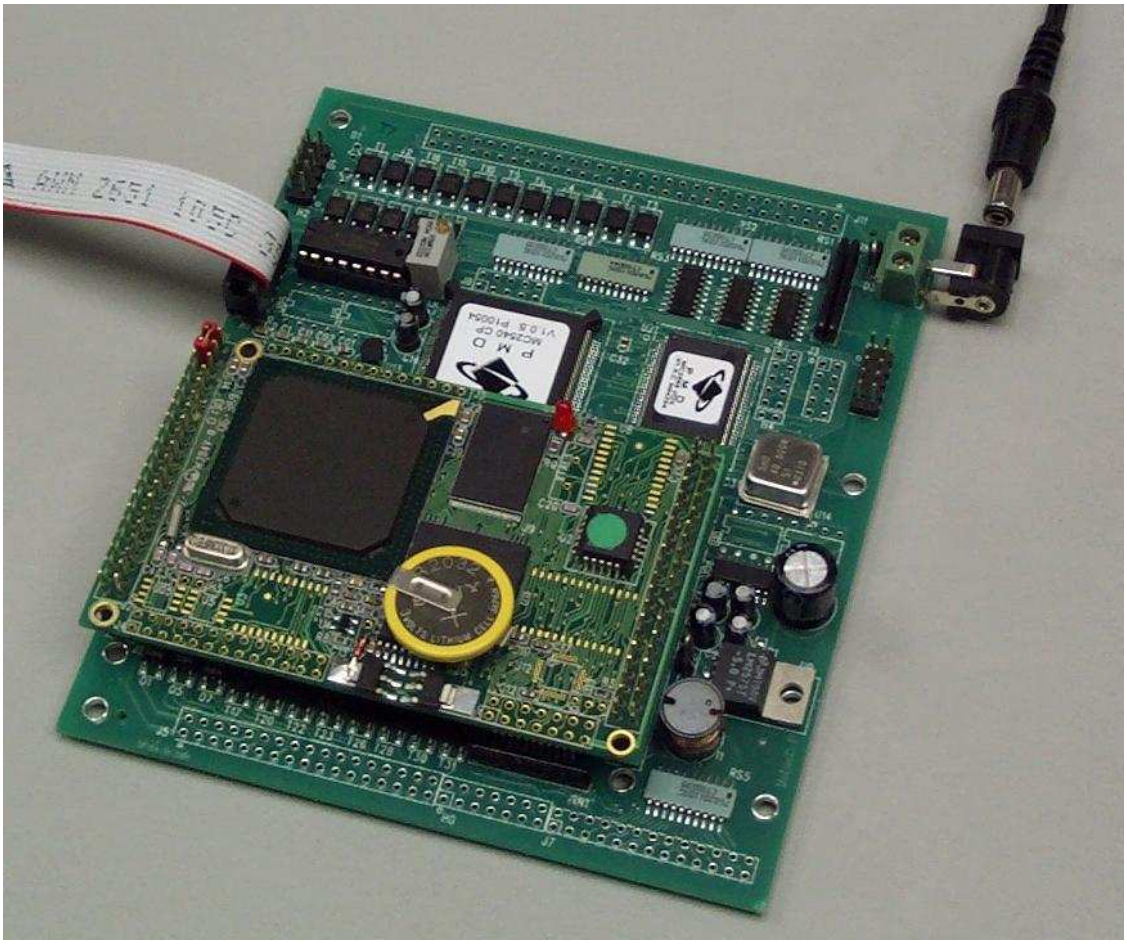


Figure 2.2 Connecting the MotionC-P and Host controller to power and PC

Chapter 3: Hardware

3.1 Host Controllers

The MotionC-P must be driven by a host microprocessor core controller. This includes TERN's A-Engine, A-Engine86, R-Engine, R-Engine-A, R-Engine-D, FlashCore-N, i386-Engine, i386-Engine-L or 586-Engine. Please refer to the corresponding Technical Manual for more information on each available host controller.

3.2 Interface with PMD MC2140/MC2540 DSP chipset

The MotionC-P can be configured with four different DSP chipsets: MC2120, MC2140, MC2520, or MC2540. The MC2120/MC2140 offers 2/4 channels closed-loop digital servo control, while the MC2520/MC2540 offers 2/4 channels open-loop stepping motor control. Each DSP chipset is packaged in two surface mount chips, "CP" and "I/O". The chipset is driven by its host via an 8-bit, bi-directional port. Communication to and from the chipset consist of packet-oriented messages. An interrupt line /HINT, from the "CP" pin 98, to an external interrupt on the host controller (see host controller for details), so the chipset can signal the host when special conditions occur, such as receiving an encoder index pulse. The host writes commands/reads data to and from the MCP chipset. Each command consists of a 16-bit word, with a command code value defined in the MC2140 manual (DSP chipset manuals for both MC21, tern_docs\parts\mc2100ts.pdf, series and MC25, tern_dcos\parts\mc2500ts.pdf series). Data is transmitted to and from the chipset in 16-bit words. TERN written "C" Functions are available in **mc21.lib** (the mc21.lib is used for both the MC21 and MC25 chipsets) and prototypes are listed in mc21.h file. Sample code and demos are available in the **samples** directory of its respective host controller.

void mc21_host_dat_wr(unsigned int dat); // host Engine writes 16-bit dat to MC
void mc21_host_cmd_wr(unsigned char cmd); // host Engine writes 16-bit cmd to MC
unsigned int mc21_host_dat_rd(void); // host Engine reads 16-bit dat from MC
char mc21_host_rdy(void); //return 0 for "I/O" pin 8, HRDY low, indicating busy

3.3 MotionC-P I/O Map

The following table lists the I/O addresses of the MCP, together with their Data Bits, Chip-Select Symbol and Functions. Addresses may vary by host controller.

Base I/O Address	Data Bits	Select Symbol	Function
0xD0	D0-D7	/MC	Read/Write D0-7 from/to DSP "I/O" chip (U2)
0xB0	D0-D7	/PPI	Read/Write D0-7 from/to PPI 82c55 I/O chip (U18)
0xA0	D0-D7	/PP	Read/Write D0-7 from/to PPI 82c55 I/O chip (U19)
0xC0	D0	/RST1	Hardware reset "CP".

3.4 Quadrature Encoder Inputs

The MCP supports up to 4 channels of Incremental Encoder inputs for motor position information. Each quadrature encoder channel consists of a square wave, offset 90-degree from the other. For every channel, four position inputs and control signals are supported:

A channel pulses (QDAx)
B channel pulses (QDBx)
Index pulse
Home switches signal

Differential line drivers (75173) are used to support differential quadrature inputs. The quadrature encoder inputs are not optically isolated from digital ground (GND). The differential line drivers are located at positions U15, U16, and U17. All differential signals are pulled-up via 10Kohm resistor. If only single ended quadrature inputs are used, allow unused inputs to remain high. The differential line drivers buffer the A/B channel inputs and well as the Index input for each channel. The Home input for each channel are buffered by opto-couplers. See Section 3.6 for additional details on opto-couplers.

3.5 MCP DAC Servo Analog Outputs (MC2140 only)

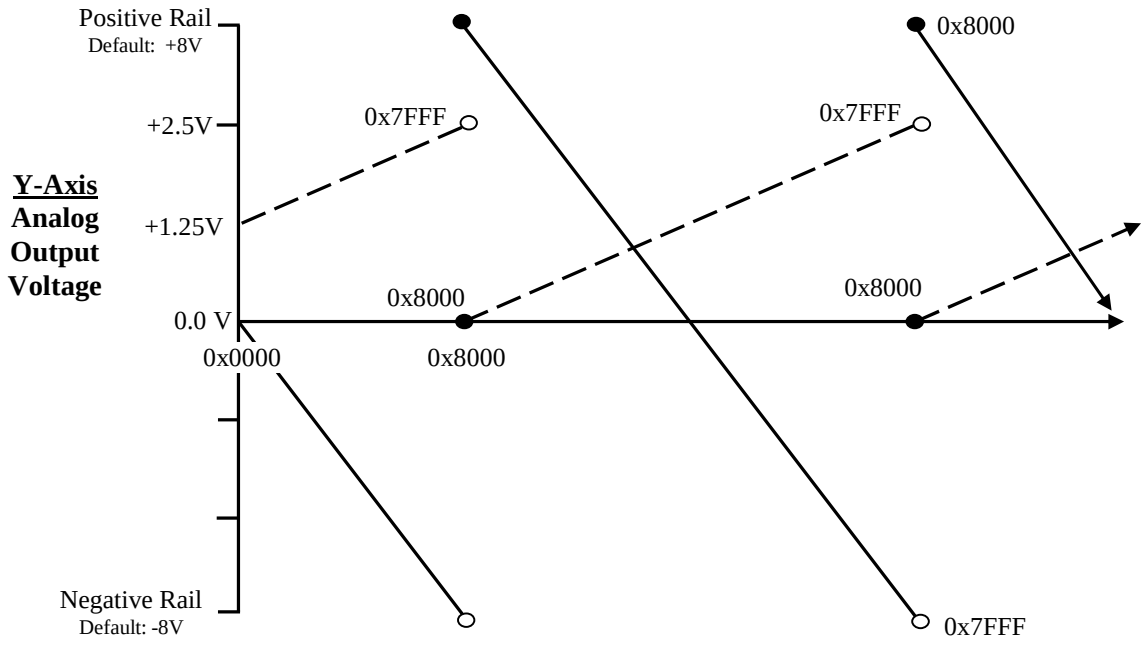
When the MCP is configured with the MC2120/MC2140 DSP chipset, it offers +- 10V analog servo motor control. The MC2120/MC2140 supports both DAC and PWM output mode for external servo motor amplifier. The MC2140 uses a quad 12-bit voltage output DAC converter (DAC7625, tern_docs\parts\da7625.pdf). While the 16-bit DAC output mode is used, the 12-bit DAC only uses the upper 12 bits (CPD15- CPD4) from the CP chip.

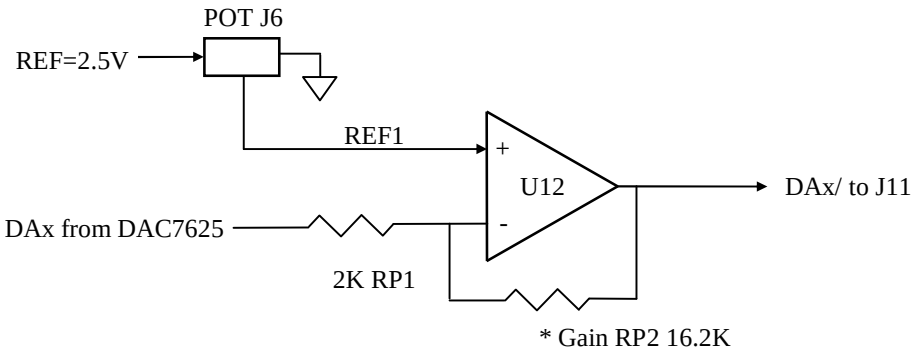
The DAC7625 contains four precision output buffer amplifiers, providing full 12-bit performance at 1LSB total unadjusted error. The DAC7625 has a typical 3µs output setting time and outputs 0 to 2.5V with an external 2.5V precision reference. A quad amplifier buffer (LM324, http://www.national.com/ds/LM/LM124.pdf) with adjustable gain and offset supports 4 channels of default ±10V analog servo control signals at header J11 (DA1/-DA4/), supporting a variety of motor amplifier interfaces.

A resistor pot is installed in J6 provides the offset voltage. User may replace default 16K gain resistors in RP2 to setup necessary gains. The DA1/(J11.45), DA2/(J11.46), DA3/(J11.31), and DA4/(J11.32) provide buffered output voltage from the operational amplifier (U12), capable up to 20 mA. The MC2140 outputs a 16-bit data word as an unsigned 16-bit number with a range of 0-65535. Please see sample program **mc21_dac.c** for additional details.

Output Value from DSP	Output of DAC (Volts)
0	DAC outputs 0 volts
32768	DAC outputs 1.25 volts
65536	DAC outputs 2.5 volts

The following graph shows the DAC output and the corresponding amplifier output as a function of DAC input from DSP chipset. Axes are not to scale. Solid line represents output from amplifier and dashed line represents output from DAC.





3.6 Open-loop stepping outputs (MC2540 only)

With the MCP configured with the MC2520/MC2540 chipset it provides 2/4 channels of stepping output with direction signal for stepping motors. Signal are routed to the J4 header. These signals are tied directly to the DSP chipset with no protection for the chipset and are 5V signals only. Any out-of-range voltage will certainly damaged the DSP. Step outputs can achieve pulses up to 3MHz and offer S-curve, trapezoidal, velocity-countouring, and electronic gearing profiles. See the technical specifications for the MC2500 family, tern_docs\parts\mc2500ts.pdf.

3.7 Limit, Home, and Fault Switches

There are 2 limit switch inputs for each axis: +L1 and –L1. There are a total of 8 limit switch inputs (+L1-4, and –L1-4). There are also 4 home switch inputs: HOM1-4 and 4 fault switch inputs: FLT1-4. All switch inputs are routed to J11 and protected by opto-couplers (**tern_docs\parts\ps2701.pdf**). All switch inputs are default high by external pull-up resistor packs, with the corresponding input to the DSP chipset high also. Each input switch can be activated with a valid logic low with the corresponding input to the DSP chipset pulled low also. See sample programs: **mcp_h_i.c** and **mcp_sta.c** in the corresponding **samples** directory for details.

3.8 Power Amplifier Control, Solenoids and Solid-State Relays

Seven lines of high voltage driver outputs (U11, ULN2003, tern_docs\parts\uln2003a.pdf) are designed to sink up to 350 mA at 50V. These lines can be used to enable external power amplifiers to drive DC motors, or drive solenoids. The power amplifier enable signals, are buffered from digital circuits.

Four channels of high voltage drivers are driven by the DSP chipset (O1-4). Three lines OU1-3 are driven by the host via J2 pin 11, 18, and 20. See sample program **mcp_hvo.c**.
Eight solid-state relays are installed on the MCP (tern_docs\parts\ps2701.pdf). They have a zero ohm contact while enabled and open contacts while disabled (disable by hardware default). The SSRs are installed at positions O1-O8. Contacts are routed to J5 pins 1-16.

3.9 Power Supplies

The MCP offers a number of power supply configurations. Refer to the MCP schematic for exact pin details/locations (tern_docs\schs\mcp1.pdf, tern_docs\schs\mcp2.pdf).

All on-board devices require +5V. In addition, all pull resistor packs are tied to VCC. This allows the user to supply a REGULATED +5V DC to any VCC signal to power the MCP. The on-board RS-232 can generate +-8V which are tied to the power supply of the operational amplifier (with the MCP2120/MCP2140). The amplifier outputs will then be limited by the supply voltage generated by the on-board RS-232. Typically, users do not require max servo output, making +-8V satisfactory.

The MCP by default is installed with a linear voltage regulator which will supply +5V DC to power the MCP. In this configuration, the user can supply an unregulated +12V at the 2-pin screw terminal, J0. In, addition, diodes D1 and D3 can be installed which connect a clean +-12 volts to the operational amplifiers. A full ouput range of +-10 volts is now supported on the analog servo outputs DA1/ - DA4/.

A third configuration uses the optional switching voltage regulator. The MCP can then accept up to +24V unregulated DC at the 2-pin screw terminal, J0. With this configuration, the diodes D1 and D3 CANNOT be installed or the RS-232 will be damaged. In this configuration, the operational amplifier is then powered by the +-8V generated by the RS-232, and thus the analog servo output is limited to +-8V.

3.10 PPI – 24x2 TTL level I/Os

There are 24 bi-directional user programmable TTL level I/O lines at J7 header (U18, uPD71055, or 85C55, tern_docs\parts\85c55.pdf). These 24 TTL level I/O pins can be used to interface to with LCDs, Keypads, or power relay drivers.

The U19 PPI should be configured to support 8 outputs (B20-B27) for the O1-O8 SSRs, and 16 inputs (B00-07, B10-B17) for the opto-couplers (tern_docs\parts\ps2701.pdf) T17- T32. These signals are routed to the J5 header.

See sample program **mcp_ppi.c** for details.

3.11 RS-232 and RS-485

Two channels of RS-232 serial ports are available on the MCP.

- H1 SER0 for debugging
- H2 SER1 for application.

An RS-485 driver and header H3 supports the optional SCC2691 UART from the host controller.

See sample code for the host controller for details on serial ports, **s0_echo.c**, **s1_echo.c**, and **ae_scc.c** (if your host controller is the i386-Engine, see ie_scc.c, etc.).

3.12 DSP Ready Signal to the Host

The DSP IO chip pin 8 (HRDY) is a hardware ready signal that indicates the DSP is busy while it is low. The MCP routes HRDY signal to J2 pin 12. See the schematic for the host controller to determine the corresponding signal on J2 pin 12.

Chapter 4: Software

Please refer to the Technical Manual for the "C/C++ Development Kit for TERN 16-bit Embedded Microcontrollers" on debugging and programming tools. For software information related to your host controller, please refer to the respective manual.

4.1 Functions in MC21.LIB

void ***mc21_host_dat_wr***(unsigned int dat); // host A-Engine writes 16-bit dat to MC21

void ***mc21_host_cmd_wr***(unsigned int cmd); // host A-Engine writes 16-bit cmd to MC21

unsigned int ***mc21_host_dat_rd***(void); // host A-Engine reads 16-bit dat from MC21

char ***mc21_host_rdy***(void); // return 0 for MC IO pin 8 low, indicating host port busy

```
/* return 16 bits of the status register of DSP chipset. */
unsigned int mc21_host_status_rd(void);

/* Issue a hardware reset to the DSP chipset */
void mc21_hard_reset(void);

/* reads 10-bit ADC from DSP, ch=0-7 for AN1-8 at header J8 */
unsigned int mc21_adc_rd(char ch);
```

4.2 Sample Programs

The sample programs are organized by chipset family and PCB version.

The following sample programs apply to the MCP with either DSP chipset:

samples\mc21\mc21_ver.c

samples\mcp\mcp_ppi.c

samples\mcp\mcp_hvo.c

samples\mcp\mcp_sta.c

samples\mcp\mc25_pos.c

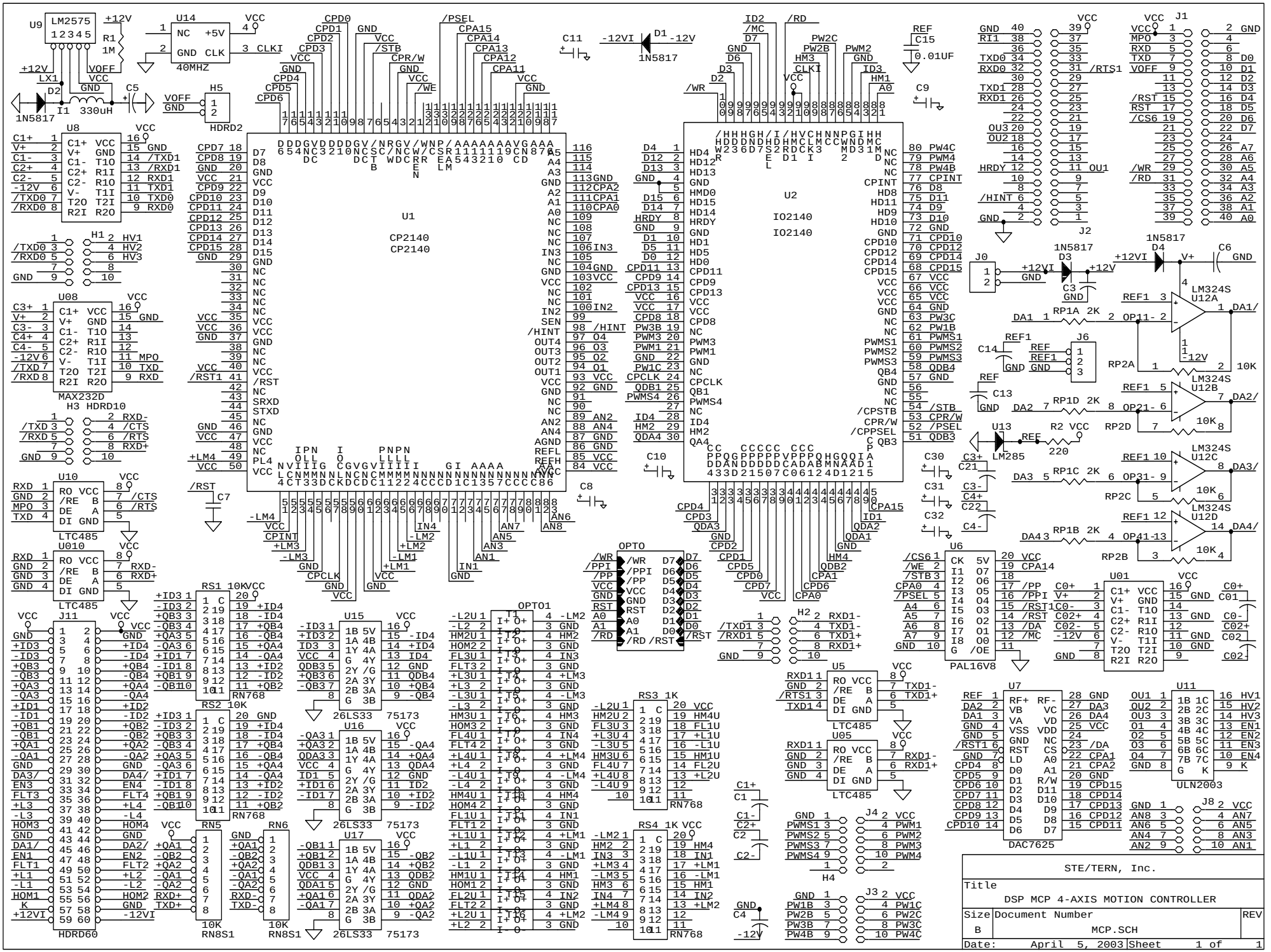
samples\mcp\mcp_h_i.c

If the MC2120/MC2140 is installed:

samples\mc21\mc21_dac.c

If the MC2120/MC2140 is installed:

samples\mcp\mc25_stp.c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DSP MCP 4-AXIS MOTION CONTROLLER
Size B
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Date: April 5, 2003
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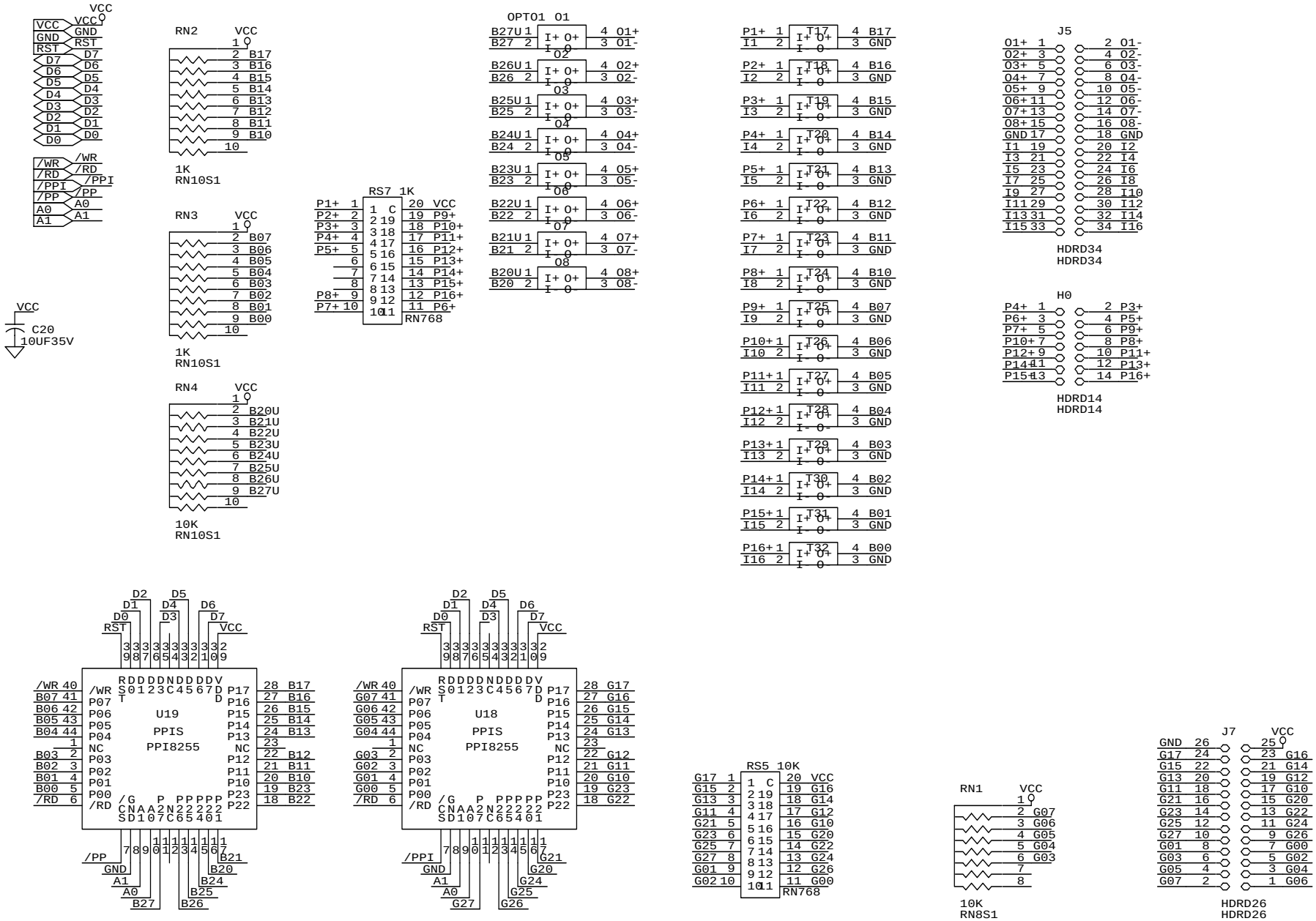

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