Creating your own Tower Module

Custom Relay Module Example

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The Tower System is a uniquely powerful modular development platform that offers endless possibilities for prototyping a microcontroller-based system. Freescale and its partners provide many Tower modules to prototype a system with; however, many applications require additional application-specific circuitry.

This application note presents an example of how to design and build a custom peripheral Tower module to complete your prototype system. Additionally, this application note provides helpful tips for both novice and expert hardware developers.

More information on the Tower System is available at http://www.freescale.com/tower.

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1 Overview

1.1 Why prototype with the Tower System?

Prototyping a microcontroller-based product with the Tower System lets you get started writing your software and evaluating microcontrollers and circuits while you plan and design your final product. This saves time, saves money, and helps you get to market faster. The flexibility of the Tower System allows you to build your system in various configurations. You can quickly swap out modules to try out different microcontrollers and features.

Prototyping with the Tower System:

- Enables flexible hardware changes
- Provides an expandable platform
- Is inexpensive
- Gets your product to market faster

1.2 Options for adding additional circuits to your Tower System

Extending your system is simple with the addition of a tower module containing the additional peripheral circuits that your system requires. Your module can contain specific circuits for your system, such as connectors, sensors, memories, buttons, relays, cameras, or many other components.

There are two main options for adding circuits to the Tower System.

- TWR-PROTO protoyping module

  Freescale offers the TWR-PROTO prototyping module, which is a very inexpensive module that plugs directly into the Tower System. The TWR-PROTO has a perfboard area that provides an easy way to hand-wire circuits to be interfaced to the Tower System.
- Build your own Tower module

  When the complexity of your circuits exceeds the capabilities of the TWR-PROTO module or you need to build more quantities than is feasible with the TWR-PROTO module, then you can build your own Tower module.

1.3 Why build your own Tower peripheral module?

Building a module is relatively easy, quick, and inexpensive. There are no expensive connectors to be sourced. You can design your schematic and layout yourself and get printed-circuit boards made and assembled in a matter of days. Building your own module allows you to create higher quantity/higher complexity prototype kits.

Building your own tower module:

- Is inexpensive (no costly connectors)
- Allows your module to be reused on other projects
- Allows you to produce higher quantity / higher complexity prototypes
- Allows your prototype features to be closer to your final product

2 Building your own Tower Peripheral Module

2.1 Resources available

2.1.1 Freescale Tower module design files

Freescale provides printed-circuit board design files for all Freescale Tower modules. These files can be helpful for an experienced board designer to use as examples when building a module. The files are provided in professional formats. Some or all of the following files may be available.

- LAY—Layout source (Cadence Allegro)
- GRB—Gerber files
- FAB—Fabrication document
- UNI—UniCAM file
- CEN—placement file
- BOM—Bill of Materials
- SCH—Schematic source (Cadence OrCad)
- SPF—Schematic PDF

2.1.2 Tower System mechanical drawing

Freescale also provides a mechanical specification that is critically important in ensuring mechanical compatibility with the Freescale Tower platform. See Section 6, "References," for information on how to find the mechanical specification and other files discussed in this application note.

2.1.3 Tower configuration tool

The Tower configuration tool is a Microsoft Excel-based tool created by Freescale that can be used to check compatibility between Tower modules. The signal connections to the Tower edge connectors on each Tower module are described in individual worksheets. Excel macros compare the connections of each tower module to warn of potential connection incompatibilities. Just choose the Tower module combinations that are relevant to your system and start the macro to check compatibility. A new worksheet can be created for any new Tower module. Thus, your new Tower module can be checked for compatibility with other available Tower modules. See Section 6, "References," for details.

2.1.4 Templates

This application note is accompanied by templates geared towards students, hobbyists, and customers with limited printed-circuit board design resources. The template formats include:

- Eagle (CadSoft)
- ExpressPCB (ExpressPCB)

2.1.5 Assistance from board manufacturers

Many board manufacturers provide assistance to help you achieve success with your board design. This may include design reviews and/or recommendations. These services may be free or come with a nominal cost.

2.1.6 Other resources

TowerGeeks (www.towergeeks.org) is an online community where Tower enthusiasts collaborate and share ideas and tips. Get connected on TowerGeeks to tap into the experiences of other fellow tower module builders.

2.2 What is needed to build a tower module?

Printed-circuit board experts can skip this section.

2.2.1 Prerequisite skills

Board design and assembly experience is required depending on the complexity of the module you are designing.

Some experience required in:

- Schematics
- Layout
- Soldering

2.2.2 Schematic and printed-circuit board layout tools

There is an abundance of schematic and layout tools available, including those that are free.

Tools discussed in this application note are:

- Cadence OrCAD / Allegro—Widely used industry formats used by professional board designers.
- CadSoft Eagle—Free version available under certain conditions. See Section 6, "References," for details. Many board manufacturers accept Eagle format. Popular with hobbyists.
- ExpressPCB—ExpressPCB provides free tools for designing printed-circuit boards to be submitted to them for fabrication. This format is not able to be converted to other formats or submitted to other manufacturers. However, their free tools are easy to learn and use. Also popular with hobbyists.

2.2.3 Component libraries

Depending on the component library available with your schematic and layout tools, you may not have a PCI Express x16 card edge component required for the Tower card edge. In this case you might have to build it yourself using the mechanical specification document or reach out for help from other users of your

tools. The templates accompanying this application note contain tower edge components compatible with Eagle and ExpressPCB formats.

3 Printed-Circuit Board Manufacturing

3.1 Board fabrication

3.1.1 Thickness

Board thickness is standard 0.062" (0.15748 cm) with a tolerance of +/- 0.005" (0.0127 cm).

3.1.2 Metal composition

Metal composition is an important factor affecting the reliability and longevity of boards. The cost, benefits, and availability of different board plating composition should be factored into the expected usage and lifetime of your board.

Specifically, the metal composition of the board plating that you choose will affect the number of reliable insertions that you can expect when your board is plugged into the tower elevator modules.

The PCI-Express connectors on the tower elevator modules have gold-plated wipes that make contact with the edge connector pads on the tower modules. The official recommended metal plating composition for PCI-Express edge connector pads is 15 or 30 micro-inches (μ") hard gold with an underlayer of 100–200 μ"of nickel. However, this is typically cost prohibitive for low-cost prototypes. Additionally, many prototype shops will not offer gold due to cost.

3.1.2.1 Gold

You will get the best connectivity and longevity with gold, but typical prototype applications do not require this level of durability and the cost may not be justifiable.

- Highest cost
- Highest reliability
- Highest resistance to corrosion
- May not be available by low-cost prototype shops
- Level of durability may be overkill for prototype applications

3.1.2.2 Lower-cost alternative metals

Alternative metal compositions are tin-lead, tin, silver, nickel, or other metal alloys. These metals provide significant cost savings; however, there are drawbacks with their usage.

The mating of these alternative metals to the gold-plated wipes of the PCI-Express connectors is not usually recommended due to the susceptibility to various problems such as corrosion, contamination, or metal migration. However, despite these warnings it is acceptable to use alternative metals in prototype

applications of short term use with a limited number of insertions. The low cost and availability makes the use of tin-lead, tin, or silver appealing, despite the limited capabilities.

- Restrict the number of insertions (less than 10–20)
- Restrict the board to a single slot in the Tower System to avoid cross-contamination with other tower modules.
- Limit use to environments with low humidity and low exposure to air pollution.
- For lead-free/RoHS compliant boards, do not use tin-lead. See Section 3.1.3, "Environmental safety/RoHS compliance" below.

3.1.3   Environmental safety/RoHS compliance

The Restriction of Hazardous Substances (RoHS) directive restricts the use of several hazardous materials in the manufacture of electronic components. Most notably is lead (Pb), which was widely used in board manufacturing. Most board manufacturers now offer lead-free (RoHS) compliant processes. Selecting a RoHS-compliant process is mandatory to ship boards into several countries including those in the European Union. Regardless of the specific governmental restrictions, lead-free (RoHS) boards are always recommended for environmental safety. Some low-cost board manufacturers may still offer boards that contain lead (non-RoHS). These may be acceptable for your needs if safe practices are used and proper disposal is done.

3.1.4   Solder type

Use your board manufacturer's recommendation for solder type. This recommendation will be based on the metal plating used in the board manufacturing process. For RoHS-compliant boards, use RoHS solder. Keep in mind that RoHS (lead-free) solder typically has a slightly higher melting point than non-RoHS (with lead).

3.1.5   Board size

Standard Tower modules are 3.543" x 3.174" (9.00 cm x 8.06 cm). This conveniently fits within the size limitations of the free version of CadSoft Eagle. See Section 6, "References," for details of other restrictions on the free version.

3.1.6   Number of layers

The number of layers depends on the complexity of your design. The use of power and ground plane layers is recommended for noise immunity. Filled planes of power and ground can be used in signal layers to provide a similar effect.

3.1.7   Silk-screen

Silk-screen is helpful to label components and board details. Some inexpensive prototypes will not include it.

3.1.8   Solder mask

Solder mask makes soldering easier by helping keep solder where it belongs. Some inexpensive prototypes will not include it.

3.1.9   Beveled edges

The card edges should ideally be beveled as described in the mechanical drawing. Otherwise they are difficult to insert into the Tower Elevator modules. Also, non-beveled edges may wear out the Tower Elevator module connectors faster. Many board manufactures will bevel the edges; however, some do not. Caution must be used to avoid contact with the signal traces if you bevel the edges yourself.
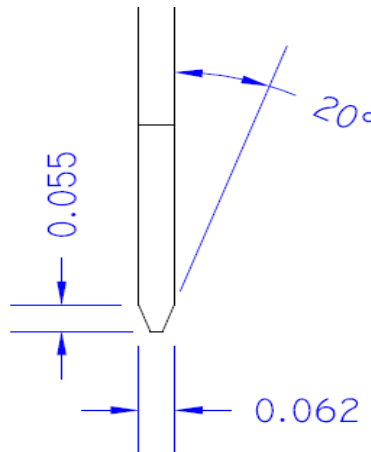
Figure 1. Tower card beveled edge

3.1.10   Board outline and notch width

The board outline must be drawn in the printed-circuit board layout tool. This is already done in the templates provided with this application note. Some board manufactures may not be able to create the notch on the board edges to the correct width due to the size of the router they use to create the board shape. In this case, the width can be slightly widened with no significant impact to the boards. The pads along the edge will be narrowed.

3.2   Assembly

Through-hole components are easiest for soldering the components by hand yourself. Otherwise surface-mount is cheaper and easier for a printed-circuit board manufacturer to assemble by machine. The type of components you choose depends on the complexity of your design, the number of boards you are building, and the capabilities of the available assembly methods.

3.3   Where to get boards manufactured?

Any printed-circuit board manufacturer that accepts a format that you are able to generate with your tools can manufacture your boards. Gerber files are an industry standard format used by most board manufacturers. The same manufacturer may provide board assembly services to solder the components. If not, you may need to arrange for a separate company to assemble the boards or put them together yourself.

4   Important Considerations

4.1   Signal quality

The PCI Express connectors used by the Tower System are capable of handling high speed signaling. However, to obtain clean signals at high speeds the source impedance should match the load impedance of the signal trace and the receiver. This can be balanced out using termination resistors. Also, depending on the complexity of the design, other signal integrity or emissions suppression techniques may be required. However, these techniques are beyond the scope this application note.

4.2   Rules of thumb

Printed-circuit board design techniques are abundant. Consult the many resources available.

Some important considerations:

- Trace Widths—To determine trace width, estimate the maximum current that will flow through the trace and choose a trace width size based on board manufacturer recommendations. In general, traces of around width 0.01" (0.0254cm) are good for standard digital signals.
- Space between components—Use manufacturer recommendations for the minimum space required between components to avoid metal migration.
- Planes—Use planes for improved noise immunity
- Route high speed signals with 45 degree angles.

4.3   Tower edges

4.3.1   Primary and secondary

The primary and secondary edges have a defined signal standard created by Freescale. The primary and secondary edge signals are different from one another. Many MCU modules only use the primary edge; however, MCUs with a greater number of pins will also use the secondary edge. The secondary edge provides extra signal connections that aren't available on the primary edge. Be sure to review the schematics for each MCU module you intend to use so you are aware of the signal connections the particular MCU modules make to the card edges.

4.3.2   A, B, C, and D sides

The top side of the primary card edge is labeled B.

The bottom side of the primary card edge is labeled A.

The top side of the secondary card edge is labeled D.

The bottom side of the secondary card edge is labeled C.

The connectors on the side of the elevator modules provide access to each signal on the tower edges. They are conveniently labeled A, B, C, or D and the positions match the position on the card edge. For example signal B80 on the elevator side connector is the signal B80 on the card edge.

4.4   General recommendations

- Review printed-circuit board design tips provided by the tools or manufacturer
- LEDs, switches, connectors, and anything that needs to be easily accessible should be placed along the sides. This allows for the flexibility of plugging in the module into the lower slots which are less accessible than the top slot.
- The maximum component height on the top side of the board is 0.591" (1.5 cm). If any of your components are taller, then plan for the board to go in the top slot. Additionally, the maximum component height on the bottom side of the board is 0.157" (0.4 cm).
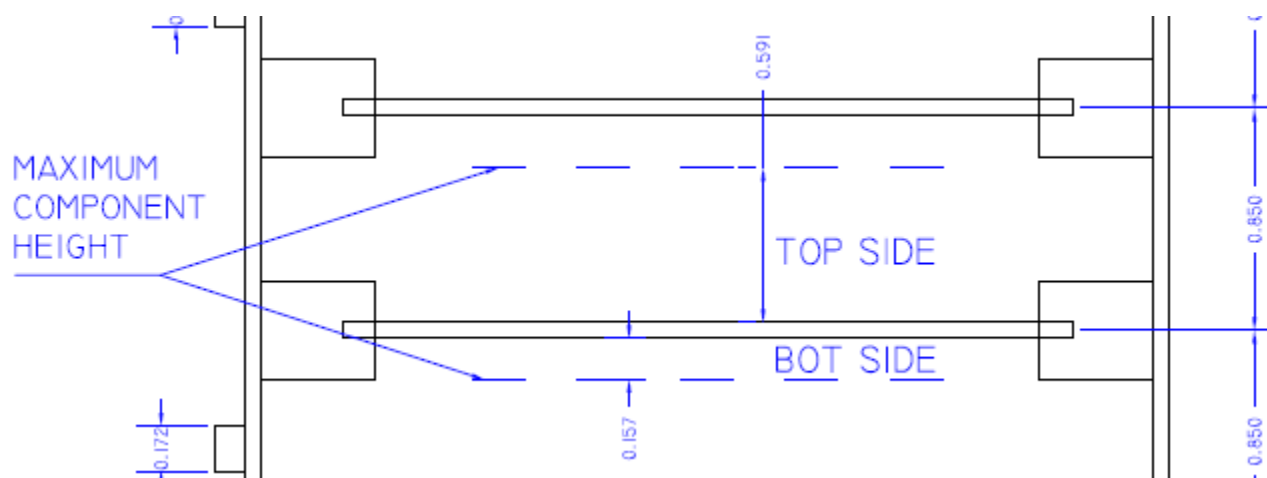
Figure 2. Maximum component height as shown on the mechanical drawing

4.5   Powering the Tower

In general, the power source for the Tower System can come from either the MCU module or Tower primary elevator. The tower has 5 V and 3.3 V power supply rails.

5 V power is typically straight from the source. However, 3.3 V or other power is regulated onboard. Typically a linear voltage regulator is used to step down the voltage.
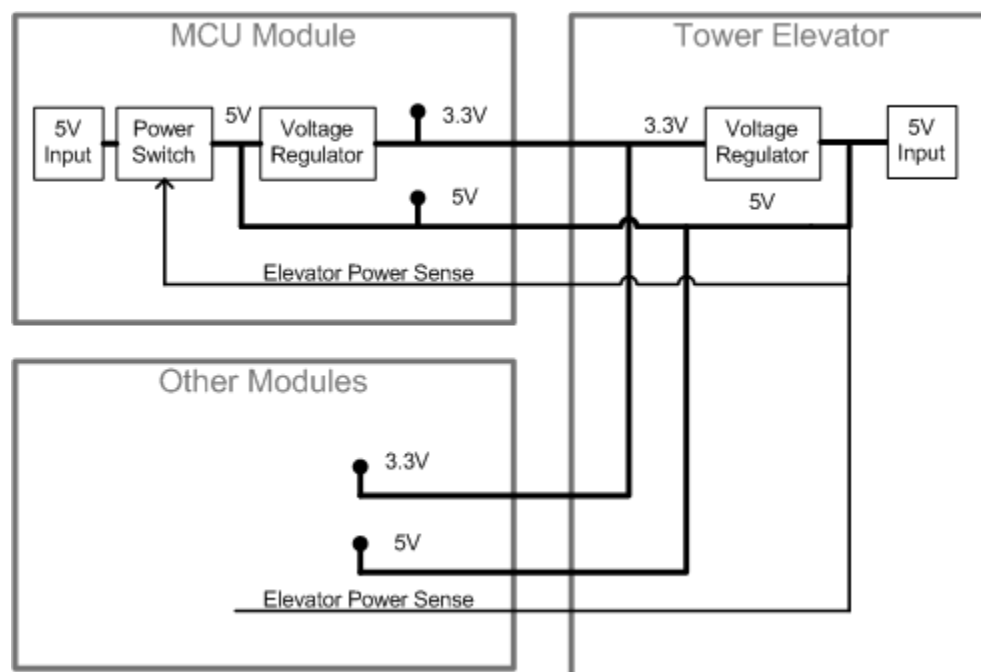
Figure 3. Simplified powering diagram

4.5.1   Power from the MCU module

MCU modules can typically get 5 V power from the USB connection for the embedded debug circuit (for example. OSBDM, OSJTAG). The 5 V will be regulated down to 3.3 V or another voltage for use in the system. Other power input sources may be available depending on the MCU module. Power from the MCU module will also go out through the edge connectors to the Tower elevator modules to power other tower modules in the system. However, if the MCU module detects that power is already on the elevators it will shut off its power output and accept power from the primary elevator.

4.5.2   Powering from the primary elevator

The primary elevator can get 5 V power from a USB cable or terminal block connector. It regulates the 5 V down to 3.3 V and sends the 5 V and 3.3 V supplies up through the elevator to the edge connectors. Also, the elevator module applies 5 V to the ELE_PS_SENSE to indicate to the MCU module that the elevator power is on. If the MCU module detects that the ELE_PS_SENSE signal is high, then it shuts off its power output to avoid contention on the elevator.

4.5.3   Limitation of USB power

USB hosts are only required to supply 500 mA of power.

A 5 V wall supply with USB connection may be used to get more power.

4.6 Strategies for a successful Tower design

- Pay careful attention that you don't short signals together on different modules you intend to use. In some cases, a signal from the microcontroller may be split and go to multiple locations and have different signal names on the schematic. See Section 4.6.1, "Be aware of multiplexed microcontroller signals."

- Review schematics for each microcontroller and other peripheral modules that you intend to use. Be aware that not all signals specified by the Tower edge standard may be available from each microcontroller module.

- Use the Tower configuration tool to check for compatibility issues with other modules. See Section 6, "References."

- Many unused signals from the microcontroller module can be used as general-purpose input/output (GPIO) signals. Review the documentation for the microcontroller(s) to be used with your module for details.

- Label the primary and secondary side Tower edges on the board silk-screen for easy reference when plugging the board into the Tower System.

- Be sure to connect your signals to the correct side of the card edge. Remember the "B" side is the top side of the primary edge and the "D" side is the top side of the secondary edge.

- Keep the signal connections flexible. Allow the ability to connect to multiple signals on the tower edge. This will make it easier for your module to be compatible with many MCU modules. Also, it will be more forgiving of mistakes.

4.6.1 Be aware of multiplexed microcontroller signals

In many cases, signals on microcontroller modules are used for multiple functions. In such cases there are three possibilities.

1. Signals from the microcontroller go to multiple locations.

    For example, a microcontroller signal that can be an IRQ or I2C signal may be routed to the Tower edge in two locations. Therefore, if you connect to one of the locations you must be aware of the other. Careful attention to the microcontroller module schematics is required to avoid problems.

2. Signals connected with a 0-ohm resistor that can be removed to disconnect the signals.

    Often signals in the above case can be isolated by removing a 0-ohm resistor on a signal trace on the microcontroller module. Choose the function you want use and remove the resistor. Alternatively, there may be a resistor that requires placing to connect a signal.

3. Signals connected via a jumper or shunt.

    Check your jumper settings to ensure the desired signals are connected and vice versa.

4.7 Summary of steps

- Plan your hardware/software
- Design your schematic
- Create your layout
- Tie your signals to your selected edge connector locations

- Order your parts
- Order boards
- Assemble and Test your boards

5 Tower Module Example: Custom Relay Module

A custom module was designed and built for a home irrigation (sprinkler) system prototype. The module holds relay circuits capable of switching the 24 V of AC power that is required by typical home irrigation systems. The relay circuits are controlled by general-purpose input/output (GPIO) signals on the microcontroller module. The GPIO signals pass from the microcontroller module down through the Tower elevator module to the relay module to control the relays.
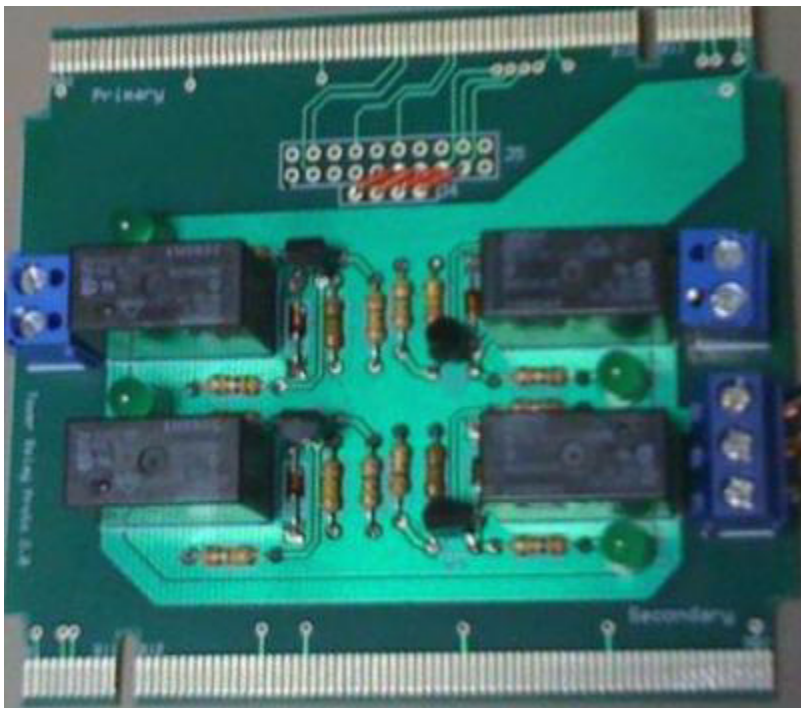
Figure 4. Relay Module

5.1 Module requirements

- Four relays to switch on 24 VAC power, controllable by GPIO signals from a Tower microcontroller module
- The ability to select from several GPIO signals to control the relays because different microcontroller modules may have different unused signals available to use as GPIO
- Capable of more than one relay module plugged into the system for 8 or more relays
- Low cost
  - Created with free schematic/layout tools
  - Inexpensive printed-circuit board manufacturing

— Minimal components

— Two layer board

- Small quantity capable of being assembled by hand

5.2　Module details

- Through-hole components used for easy hand soldering.

- Filled power and ground planes used in empty spaces for improved noise immunity.

- Many signals from the Tower primary edge routed to grid. Wires added to connect the relay control signals to the selected GPIO signals from the Tower edge.

- 3.3V level GPIO signals switch on the relays.

- The relays are powered by the 5V power available on the Tower primary edge.

- See schematics and layout.
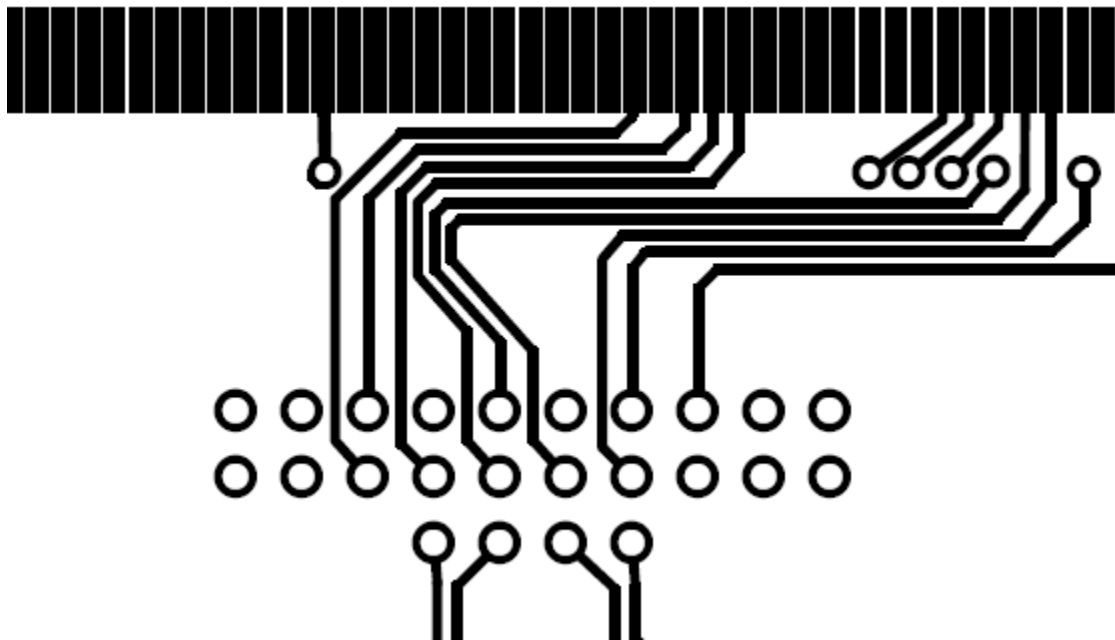
Figure 5. Signal connections to grid from Tower edge. Signals coming from relays

5.3　Designing and building the module

ExpressPCB was chosen as the board manufacturer because they provide free and easy-to-use tools online to design the board. The tools do not perform schematic capture or auto-routing; therefore, printed-circuit board layout was painstakingly done by hand. Even so, the process was relatively quick and easy.

The board design was submitted online through the board layout tool itself. It took 3–4 days from online order submission to receiving boards.

Initially, two boards were built to test the design, then additional quantities were purchased. The first two were manufactured in ExpressPCB's standard process. The standard process provides double-sided boards, plated with tin/lead, perimeter routed to shape, but with no silk-screen or solder mask layers.

Additional boards were manufactured in ExpressPCB's production lead-free process. The production process provides a lead-free plating option, silk-screen, and solder mask layers.
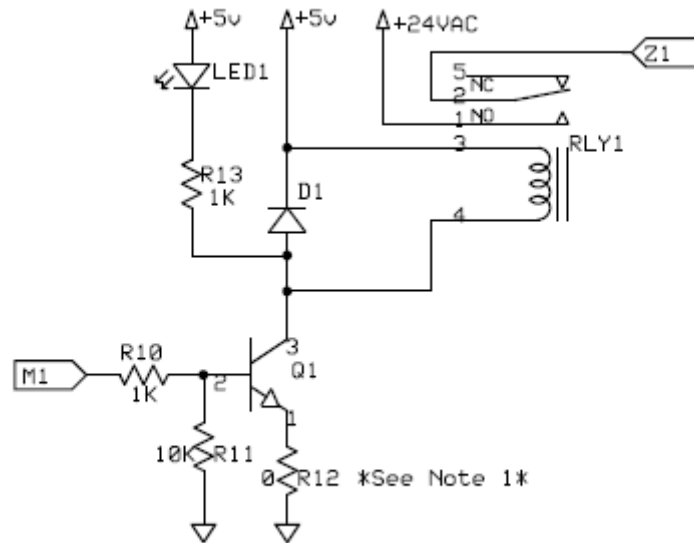
Figure 6. Schematic of single-relay circuit
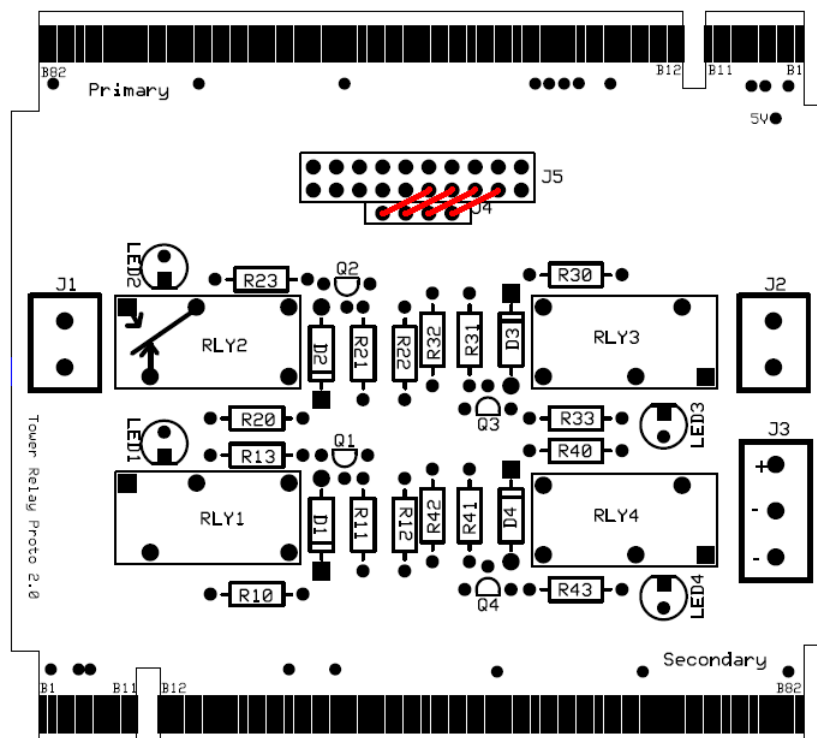
Figure 7. Top-level board image showing signal connections (red)

5.3.1 Cautions

The relay module was designed to switch 24 V of AC power. Although the relays themselves are rated for higher voltage, the board has not been rigorously evaluated and tested for safety at voltages above 24 V.

The use of a fuse on the power input is recommended for safety and preventing damage to the system.

6 References

6.1 Freescale resources

Freescale Tower Website: *www.freescale.com/tower*

Search *www.freescale.com* for keywords in **bold**.

TWR-K40X256-PWB: TWR-K40X256 Design Package. Example of design files from Freescale.

TOWER_CONFIG_TOOL: Tower Configuration Tool

900-76126_TWR-MECHDRW: Tower Mechanical Drawing

AN4346: Designing a Working Prototype Using MQX™ RTOS and Tower System for Kinetis Microcontrollers: Kinetis Intelligent Sprinkler System

AN4390_Files: Templates and relay module files associated with this application note.

6.2　Other references

ExpressPCB (*www.expresspcb.com*)

CadSoft Eagle (*www.cadsoftusa.com*)

CadSoft Eagle free version (EAGLE Light Edition) restrictions. See website for latest information.

- Board area is limited to 100×80 mm (4×3.2 inches)
- Only two signal layers
- Use is limited to nonprofit applications or evaluation purposes

7　Revision History

Table 1. Revision History

Rev. No.	Substantive Change(s)
0	Initial release.

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