

# BI Technologies R2R Resistor Ladder Networks

8-Bit and 10-Bit R2R resistor ladder networks for DAC and ADC applications.

- Auto calibration circuits
- Slope generators
- Function generators
- Motor speed control



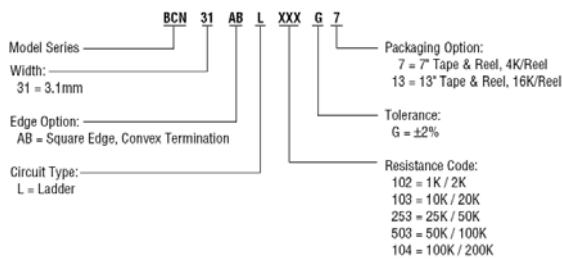
Model	BCN31Ladder	628 Ladder
<b>Body Style</b>	2512	SO-M
<b>Number of Leads / Terminals</b>	10 Terminal	16 Leads
<b>Resistance</b>		
Range, Ohms	1K to 100K	1K to 100K
Temp. Coefficient, ppm/°C	± 100	± 100
Operating Temperature Range °C	-40°C to +125°C	-55°C to +125°C
Ladder Accuracy	8 Bit: ± 1/2 LSB	8 Bit: ± 1/2 LSB
<b>Power Rating</b>		
Resistor Power	25mW	40mW
Package Power	400mW	640mW

8-Bit Ladder Networks in dual in line and single in line packages.

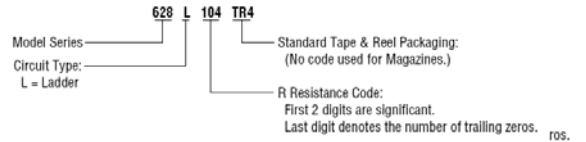
10-Bit Ladder Networks in dual in line, single in line and moulded surface mount packages. Please consult factory.

## Ordering Information

### BCN 31 Ladder

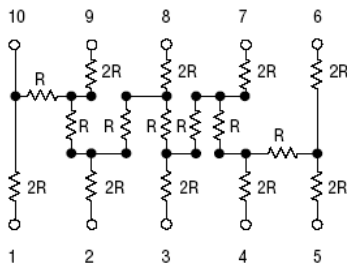


### 628 Ladder

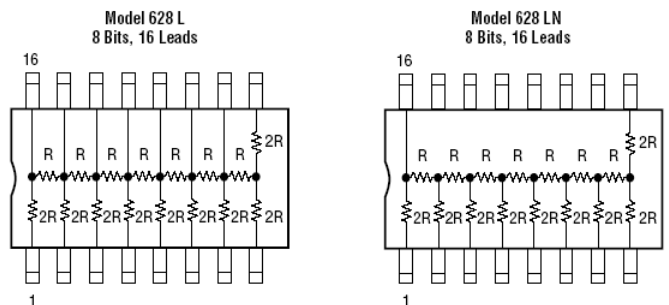


## Schematics

### BCN 31 Ladder



### 628 Ladder

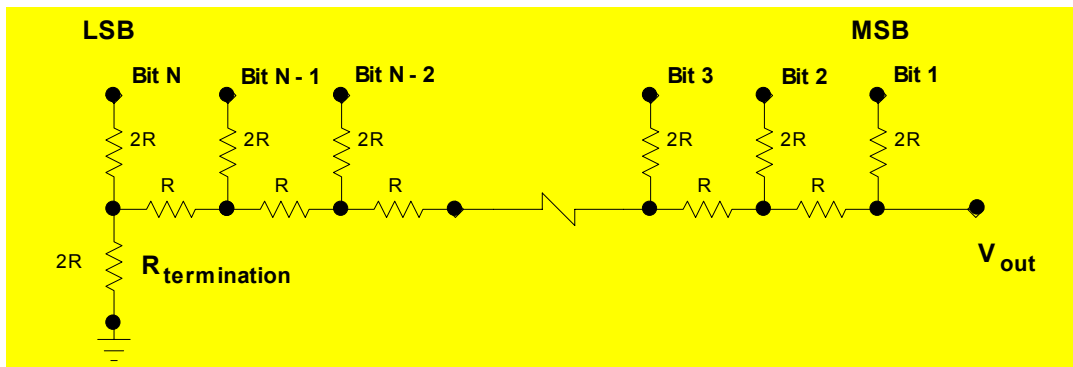


## Introduction

Real world signals are analogue. Digital systems that interface with the real world do so using analogue-to-digital converters (ADC). Conversion back to analogue is accomplished using digital-to-analogue converters (DAC). The R2R ladder network is commonly used for Digital to Analogue conversion and Analogue to Digital conversion by successive approximations. This application note discusses the important parameters that should be considered when implementing DAC designs using an R2R resistor ladder.

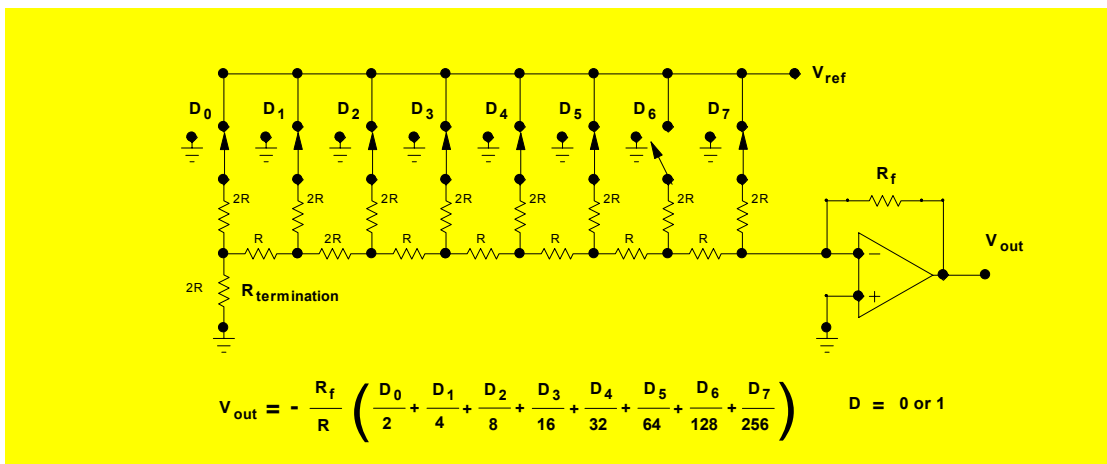
## R2R ladder functional description

A basic N bit R2R resistor ladder network is shown in Figure 1. The digital inputs or bits range from the most significant bit (MSB) to the least significant bit (LSB). The bits are switched between either 0V or  $V_{REF}$  and depending on the state and location of the bits  $V_{OUT}$  will vary between 0V and  $V_{REF}$ . The MSB causes the greatest change in output voltage and the LSB causes the smallest. The R2R ladder is inexpensive and relatively easy to manufacture since only two resistor values are required. It is fast and has fixed output impedance R. The R2R ladder operates as an array of voltage dividers whose output accuracy is solely dependent on how well each resistor is matched to the others. The resistors in the R2R network are printed directly onto a single substrate using a single film so they share similar electrical characteristics they are also laser trimmed to provide the necessary precision. These monolithic networks have an inherent accuracy advantage over discrete solutions because of the tight ratio tolerances and low temperature coefficient of resistance tracking.



*Figure 1.* N Bit R2R Resistor Ladder

The termination resistor is always connected to ground and insures that the Thevenin resistance of the network, as measured to ground looking towards the LSB (with all bits grounded), is R. The Thevenin resistance of an R/2R ladder is always R regardless of the number of bits in the ladder. Figure 2 shows a common implementation of the R2R resistor ladder network as a Digital to Analogue Converter using an op amp output. This type of DAC is known as a multiplying converter. The output voltage is linearly proportional to the digital input and the range can be adjusted by changing the reference voltage  $V_{REF}$ . The source impedance as seen by the op amp is always constant and equal to R regardless of the digital input. The value of R can be made low to charge up the op amp input capacitance quickly and achieve



*Figure 2.* Multiplying converter

the required bandwidth. As a general rule the op amp bandwidth should be as small as possible (i.e. a low pass filter) to pass only the expected changes in the digital input, any excess bandwidth only adds noise to the output. The op amp should have good stability against temperature changes and supply voltage variations.

The digital input is connected to the  $2R$  resistances sometimes by means of a high-speed analogue switch. The digital input voltage at  $D_7$  has twice the gain of the digital input at  $D_6$ , and so on. This can be demonstrated by using a repeated application of Thevenin's theorem as follows. Consider an input of 1 LSB that is  $D_7 D_6 D_5 D_4 D_3 D_2 D_1 D_0 = 00000001$  and  $V_{REF} = 5V$ . Neglecting the source resistance of the 5V input, Thevenin's theorem applied to the 5V source and the bottom two  $2R$  resistors replaces them with a 2.5V source in series with a single (Thevenin) resistance of  $R$  as shown in Figure 3. Repeated application of Thevenin's theorem yields the result. The 8-bit resistor ladder network used in this example has an output voltage of 0.0039V for a digital input of 1 LSB.

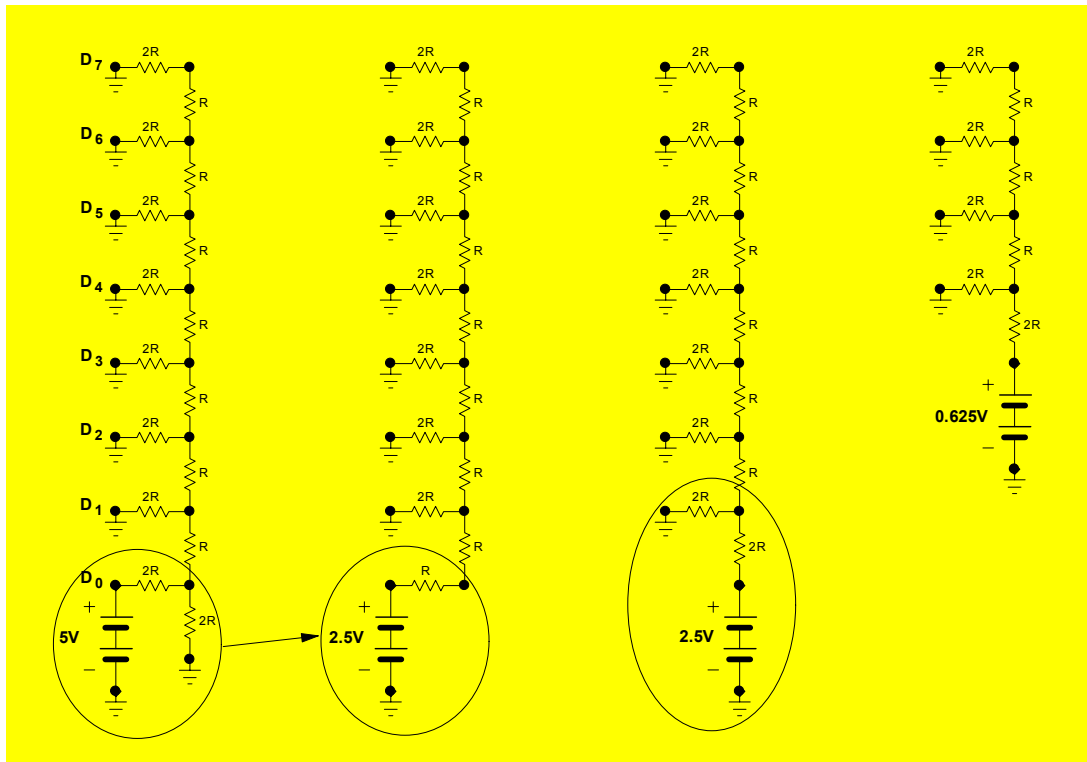


Figure 3. Repeated application of Thevenin's theorem

### Resolution

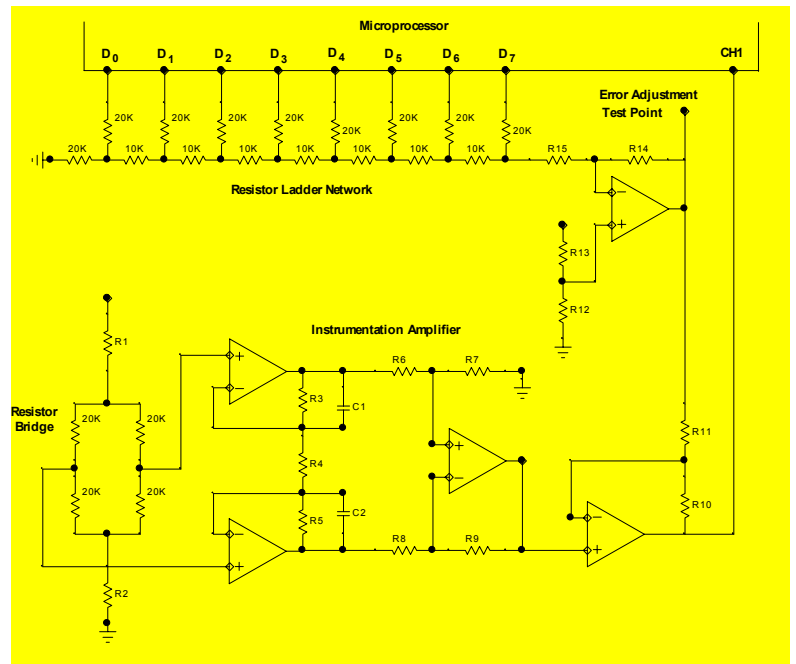
Resolution is the smallest standard incremental change in output voltage of a DAC. An  $n$ -bit DAC can decode 1 part in  $2^n$ , therefore the LSB carries a weight of  $2^{-n}$ . For example, a DAC with 10-bit resolution can resolve 1 part in  $2^{10}$  or 0.097% of the full-scale output voltage when the binary input code is incremented by one LSB.

### Accuracy

The accuracy of an R2R ladder is the percentage error in the output voltage and is usually expressed in terms of least significant bits. For example, a  $\pm 1/2$  LSB specification on an 8-bit ladder is the same as  $\pm 0.195\%$  full scale accuracy. We define output error as the deviation from an ideal output voltage that would be provided by a perfect reference and DAC. We address absolute accuracy in this application note, this means that everything is referenced to an ideal DAC output-voltage range. For example, a 10 bit DAC code 1023 should produce an output of 1.023V with a reference voltage of 1.024V and any deviation from this is an error.

## 1. Automatic Circuit Calibration DAC – Air pressure sensor

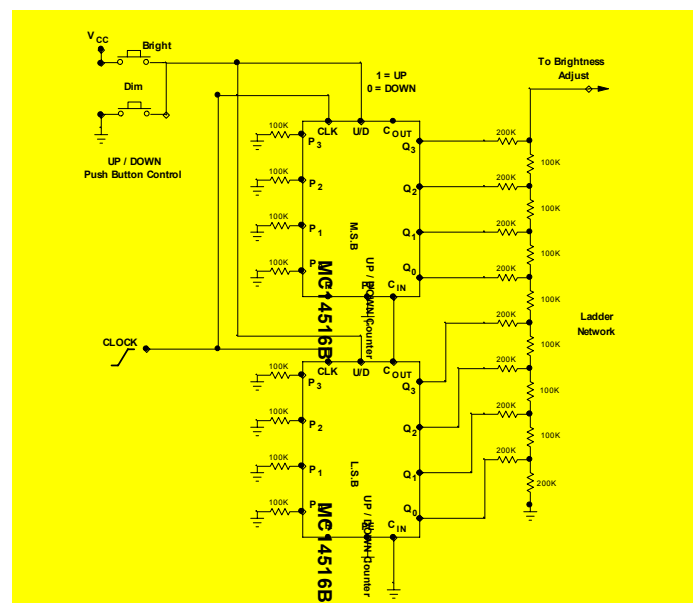
Electronic air pressure sensors are available at very reasonable cost and are used in numerous commercial applications. Air pressure sensors are sensitive strain gauges configured as resistor bridges. One leg of the bridge is a diaphragm that compresses and expands with fluctuations in air pressure resulting in small resistance changes. Since the resistance change is small the system is required to have a very large gain. For systems with a single power supply the instrumentation amplifier configuration provides good common-mode rejection ratio CMRR and minimises the number of passive components required to set the gain. The gain is set so that it provides maximum output voltage swing while avoiding amplifier saturation. System errors such as temperature drift and sensor offset can cause the output voltage to saturate and as a result it is necessary to provide a calibration mechanism. Calibration can be realised using potentiometers however they are undesirable in production designs. The part cost is higher than a fixed resistor and a pot requires human intervention thus it is preferable for adjustments to be made in software. Provided the current air pressure is known, then it is possible for the microprocessor to determine the calibration constants automatically and store them to memory. An R2R resistor ladder network controlled by the microprocessor forms a DAC that adjusts for the errors as shown in this example.



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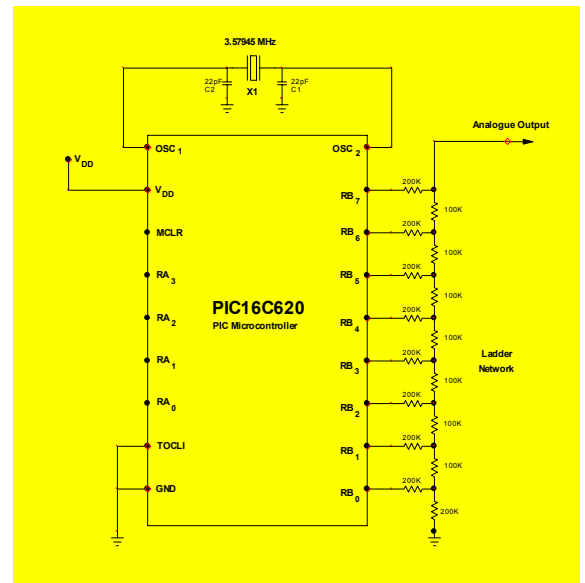
## 2. LCD Backlight Dimmer – Slope generator DAC

Backlighting is a key element in many liquid crystal display (LCD) applications. Due to the relatively low overall transmission of a typical LCD, the backlight is sometimes required to have extreme brightness. It should also possess a wide dimming range to facilitate use, depending on the amount of ambient light. LCD backlight controller IC's require a brightness adjustment signal in the form of a linear control voltage. There are several ways of generating the "Brightness Adjust" voltage. The simplest is by using a potentiometer. Another method, shown in this example, is by using a digital UP/DOWN counter. In this method two push button switches are used to generate a logic level 1 for an "UP count" and a logic level 0 for a "DOWN count". The UP/DOWN counters provide a digital output signal that is converted into an analogue signal using the R2R resistor ladder network. There are 256 brightness levels and setting the UP/DOWN counters pre-set inputs configures the brightness level at turn on.



### 3. Sine and DTMF Waveform Generation - Function generator DAC

Many embedded applications require the generation of analogue signals. For example the generation of multiplexed frequencies (DTMF) for telephone dialling, controlling the speed of a motor, the generation of sound and complex waveforms as well as the generation of variable voltages in power supplies. Although separate digital to analogue converter IC's exist the extra expense makes them prohibitive in cost sensitive designs. The example shown here demonstrates a DAC design using an R2R ladder and a microcontroller. To generate a single sine wave, the user creates a lookup table with the correct number of sample points. The software steps through each sample point and moves this value to the I/O port. The R2R ladder converts the digital signal to an analogue one. It is important that every sample point uses the same timing interval. Many telecomm applications, such as auto diallers, telephone keypads and security systems require DTMF for dialling and data transfer. Using the R2R ladder and seven sine lookup tables an entire 12-key keypad of DTMF patterns can be generated using a 3.579545 crystal.



### 4. Non-Linear Digital Dimmer - ADC

The digital dimmer box is intended for stage illumination in theatres. It is simple and inexpensive to implement using a microcontroller and an R2R ladder. It is compatible with older analogue dimmer boxes and supports 4400-Watt loads. In stage illumination, dimming of each incandescent lamp is controlled by an analogue voltage (ranging from 0 to 10 volts) and is supplied by a remote console. To achieve linear perception, a dimmer box should exhibit a non-linear response to the control voltage. Older dimmer boxes employ analogue processing for the task of compensation. The digital approach uses a simple software look-up table concept to implement response compensation. As a result, a dedicated external analogue circuit is not required. The system control uses a microcontroller running at 12MHz and an 8-bit R2R resistor ladder network on port 2 as a digital to analogue converter. The R2R output provides a reference voltage (pin 33) for the analogue comparator on port P3. The analogue control voltage is connected to another comparator input (pin 31) and the analogue to digital conversion is completed by software using a successive approximation technique. The counter/timer generates a time delay between the zero crossing of the line voltage and the TRIAC's trigger pulse. As a result, power is delivered to the load. At 12 MHz, it is possible to achieve delays from 0 to 8.33ms with the correct settings of the counter/timer prescaler, which corresponds to the phase-triggering range for an AC line frequency of 60Hz.

