ohmcraft WHITE PAPER

High Voltage Chip Resistors

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Many component engineers are faced with a circuit requirement calling for resistors having voltage ratings well above that associated with surface mount chip resistors, but below the level of conventional high voltage resistors which are generally available in sizes large enough to handle tens of kilovolts. The resistors discussed in this paper are particularly attractive as an alternative to carbon composition resistors for higher voltage applications. Fine line direct write thick film technologies allow the manufacture resistors which are physically small, yet capable of handling voltage effectively in the 500-5000 volt range, and are supplied in either surface mount or leaded format. The use of software tooling permits the design and fabrication of custom values and circuit configurations rapidly. This paper will discuss chip resistors ranging in size from 0805 with a rating of 500 volts to 2512 with a rating of 2500 volts. The technologies compress extended voltage ratings into minimum format, covering voltage ranges not normally associated with surface mounted resistors. Chip resistors with voltage ratings up to 2500 volts are now available. In addition, these chip resistors are available in extremely high values, exhibit lower noise, lower voltage coefficient, tighter tolerances, better ESD resistance, and offer stability which is superior to what is conventionally available.

Within the past few years, manufactures of power and high voltage electronics have been contemplating the use of SMT components in designs. The reasons for this trend are well documented. While there are many applications for high voltage SMT, such as the high voltage power supply in copiers, these applications have not experienced wide spread use of SMT partially due to the non-availability of chip resistors with adequate voltage ratings. Until now, chip resistors capable of handling voltages higher than about 200 volts have not been generally available. Other market needs center on the general availability, until now, of the traditional carbon composition resistor. Designers accustomed to dealing with traditional leaded carbon composition had plenty of leeway when it came to voltage limitations and power surge tolerance. This latitude has largely been lost however with conventional surface mount chip resistors. In addition, a large class of applications requiring high value (up to 100G) was addressed by carbon composition resistors. All these dilemmas are heightened with the impending shut down of the last remaining carbon composition resistor operation. Fortunately, a new type of surface mount chip resistor has been developed which restores high voltage ratings along with providing improvement in most other characteristics.

The application of a new thick film, fine- line technology to resistor manufacturing has resulted in the commercial introduction of a unique group of high voltage chip resistors. These resistors possess voltage ratings five to ten times greater than conventional chip resistors, along with lower noise, reduced voltage coefficient, tighter tolerances, better ESD resistance, and the availability of high values. This article describes the technical principles employed upon which these improvements are based: the methodology of precision, fine-line direct writing for producing the parts, and the resulting performance data, characteristics and benefits achieved.

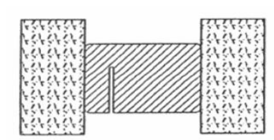
The technical challenge of producing a chip resistor with a higher voltage rating centers on their generally small size and their relatively simple resistive element designs. Table 1 shows a conventional 0805 thick film chip resistor with its resistive element being only about 50 mils in length. This length is the reason the voltage rating is low. Most thick film materials begin to experience serious degradation when subjected to internal electric fields much greater than one or two volts per mils. This places an upper limit on the voltage rating of this size chip to 50 volts at most. This is well below the ratings carried by traditional leaded styles. For example, the 1/8-watt size which had a rating of about 200 volts. Another technology, sputtered thin film, does not fare much better. Potential breakdown across the very narrow interline spaces found in the fine serpentine patterns results in similarly low ratings.

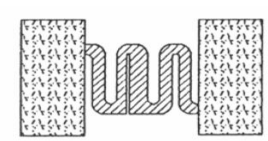
New High Voltage Chip Resistors

The solution to the above dilemma is found in a new type of thick film chip resistor made with the same thick film materials, but deposited in a fine line serpentine pattern. This fine line manufacturing technology is the key as one is able to increase length of the resistive trace many fold with a proportional decrease in the internal electric field experienced, for a given external applied voltage. Comparison between conventional and fine line thick film chip resistors is shown in Table 1 for the 0805 style. In this case, the resistive element trace is lengthened by a factor of six, lowering the internal electric field by the same factor and permitting the assignment of a proportionately higher voltage rating.

Conventional **Fine Line**

Resistor Design





			Fine line difference
Trace width {w} mils	50	4	12X narrower
Trace length {l} mils	50	300	6X longer
Aspect ratio {l/w} unit squares	1.2	75	60X higher
Internal electric field volts/mil	V÷50	V÷300	6X lower
Voltage rating (volts)	50	600	12X higher

Table 1

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A Comparison of 0805 case size Thick Film Chip Resistors made by Conventional VS. Fine Line Direct Write Technology

Serpentine patterns such as that shown in Table 1 feature a trace width of 4 mils and an inter-line spacing of 2 mils. This fine geometry can not easily be produced by screen printing. They are, however, readily manufactured using high speed, precision direct-write techniques.

Figure 1
Compact designs having narrow line and even narrower spaces are easily implemented using high speed precision direct write deposition.

A microphotograph of an array of chip resistors produced in this manner prior to singulation is shown in Figure 2. The precise definition of resistive traces deposited using direct- write techniques, is clearly evident.

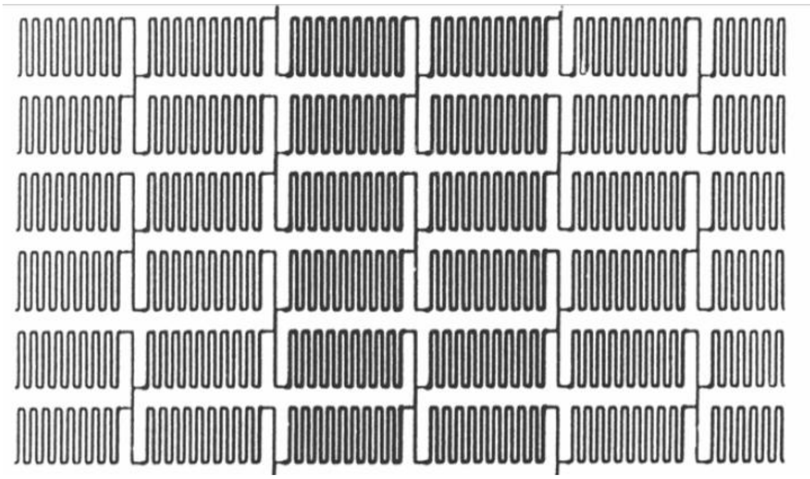

Figure 2
Photograph of part of an array of fine-line serpentine 0805 chip resistors prior to singulation

Voltage Rating Improvement

Table 2 and figure 3 outlines the improvements when direct write design and manufacturing techniques are applied to various size chips. Although the improvement in voltage rating is sizeable in every case, it is greatest with larger sizes. For chip resistors manufactured using direct write techniques, the real limiting factor is the spacing between the conductor pads. Conventional chips are limited because of excessive electric field.

Chip	Trace Dimensions (mils)		Voltage Rating (volts)	
Size	Conventional	Fine Line	Conventional	Fine Line
0502	15 x 30	4 x 120	30	300
0603	25 x 40	4 x 160	40	400
0805	40 x 50	4 x 240	50	600
1206	50 x 100	4 x 1000	100	1000
2512	50 x 230	4 x 2600	100	2500

Table 2
Voltage Rating Improvement for Different Chip Sizes

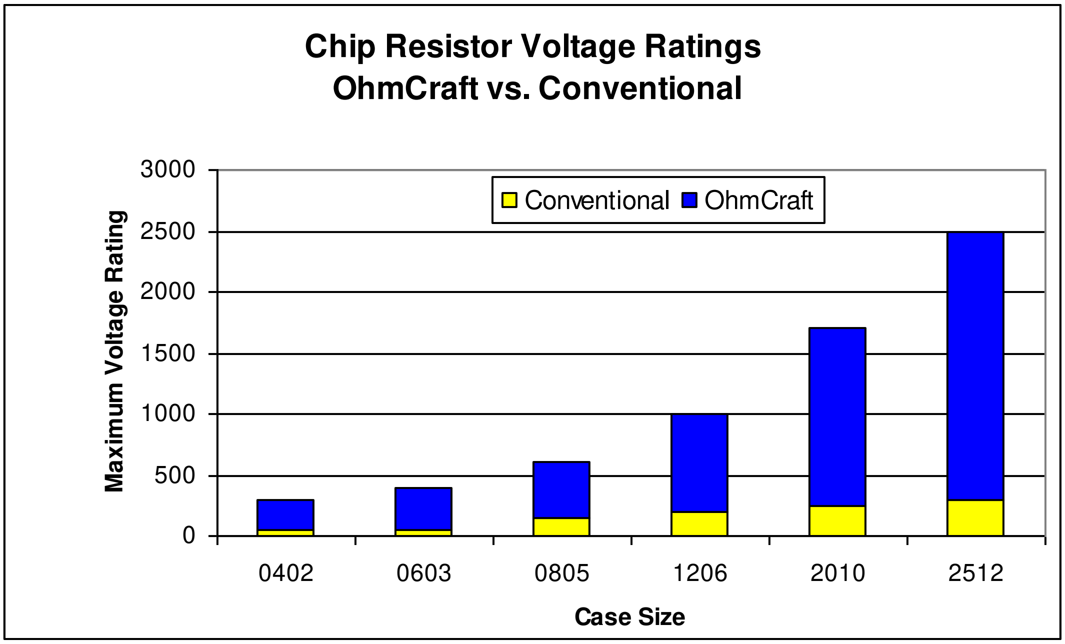

Figure 3
Voltage Ratings for different Case Sizes

Short Time Overload (STO)

The validity of these enhanced voltage ratings are easily tested by means of the short-time overload test. Results obtained on several resistor values in different sizes are shown in Table 3.

Chip Size	Improved Voltage Rating	Resistor Value	STO* Δr/r (%)
0502	300	1025MΩ	<%1.0
0603	400	1.6MΩ	<%1.0
0805	600	1.25MΩ	<%1.0
1206	1000	3.03MΩ	<%1.0
2512	2500	3.125MΩ	<%1.0

*__STO__ is maximum voltage for 5 seconds

Table 3
Short Time Overload Tests on High Voltage Chip Resistors

Critical Resistance Value

The maximum voltage which can safely be applied to a resistor applies to ohmic values above a critical resistance value. Below that ohmic value, a de-rated voltage must be used consistent with the rated power. Complete voltage de-rating curves are shown in figure 4 for chips of different size power ratings. The effect of carrying a higher voltage rating is seen to raise the critical value. The critical resistance value in the resistance at which both rated voltage and rated power apply. Below that ohmic value, the power rating governs, while above that value the voltage rating is the controlling parameter.

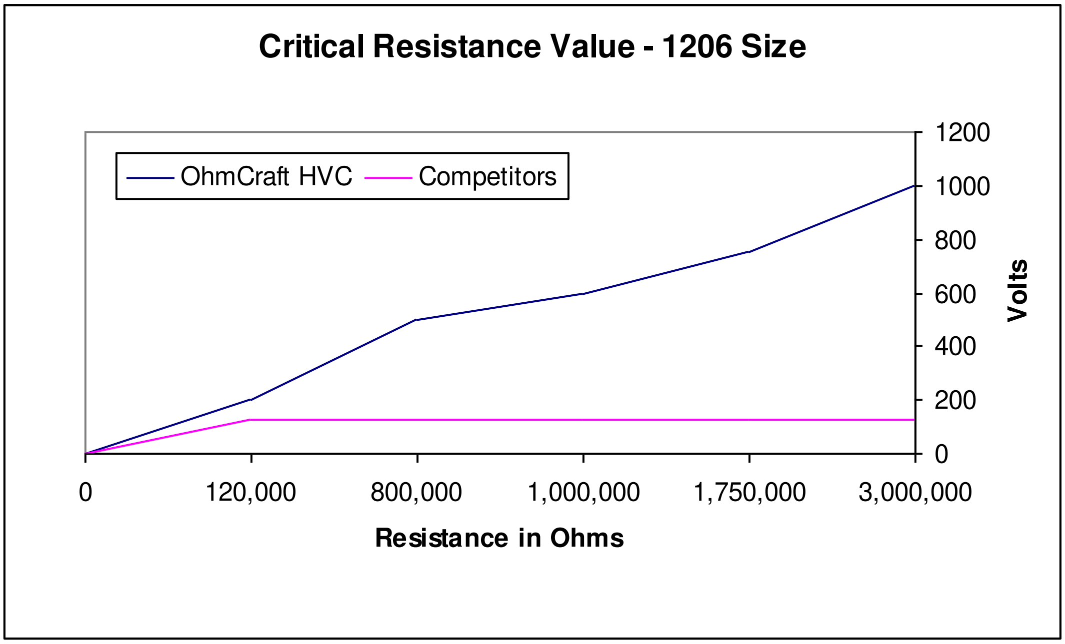

Figure 4
Critical Resistance Value for 1206

The use of fine-line serpentine designs provides several other improvements in chip resistor performance. These performance improvements are related to these factors:

- For given resistance value, the higher aspect ratio (i.e. number of unit square areas in series) of the serpentine pattern requires the use of film compositions having much lower specific resistivity (ohms/unit square) which generally have superior characteristics.
- The use of longer trace reduces detrimental resistor termination effects.

These improved characteristics are summarized in Table 4.

◘ Higher voltage rating	◘ Higher values
◘ Lower current noise	◘ Smaller voltage coefficient
◘ Better ESD tolerance	◘ Closer resistance tolerances
◘ Better load-life stability	

Table 4
Performance Improvements Resulting From Fine-Line Configuration

Achieve High Ohmic Value using Lower ohms per square resistivity

The ability to achieve significantly higher resistive values, with a given film composition in a given area, is greatly enhanced by fine-line design methodology. This principle was illustrated in Table 1 and is also illustrated in figure 5. Assuming a film composition for both cases of 1M ohm/square, it can be seen in the conventionally screened resistor shown on the left that its R value would be 1 megohm, while the resistor on the right, made by fine-line technology would have an R value of 60 megohms by virtue of its longer trace.

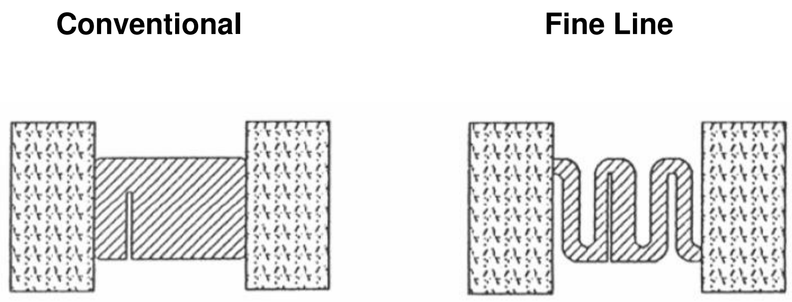

Figure 5
Fine Line Technology enables higher square count for a given resistor area

Low Noise Characteristics

For a given resistance value, if one uses lower ohms per square ink, the result is a lower noise resistor. Figure 6 compares the noise level of conventional thick film, thin film, and fine line thick film. Note that the fine line thick film resistor is similar to the thin film resistor. A closely related characteristic, the voltage coefficient of resistance, also decreases significantly.

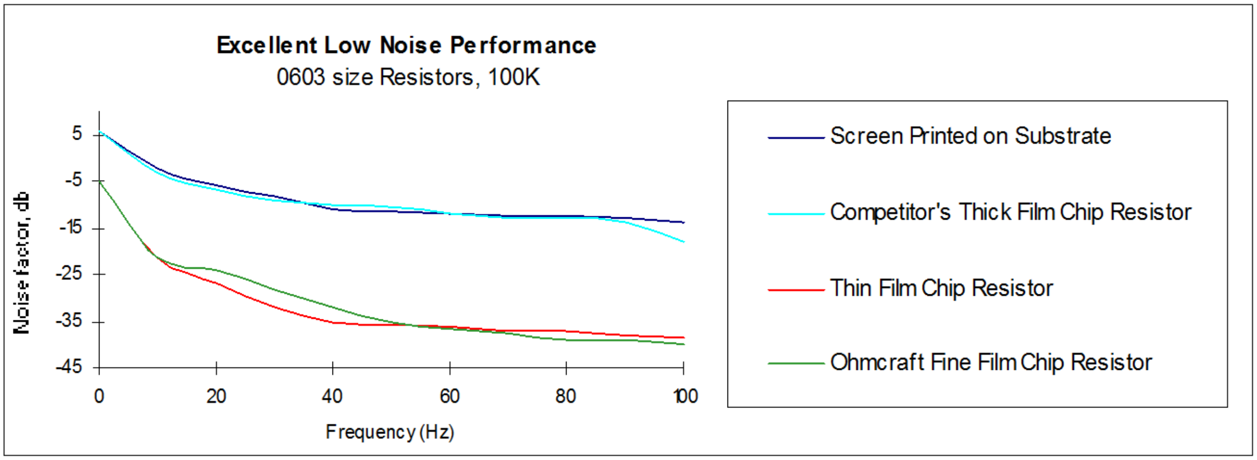

Figure 6
Comparison of noise characteristics

HVC trimming advantages

The fine-line serpentine pattern conventionally allows for a top-hat segment for laser trimming purposes. Such a trim feature displays much better post-trim stability than the plunge cuts employed with conventional one-square designs allowing adjustment to resistance tolerance of 0.1% meaningful. Figure 7 demonstrates this improvement.

Conventional **Fine Line**

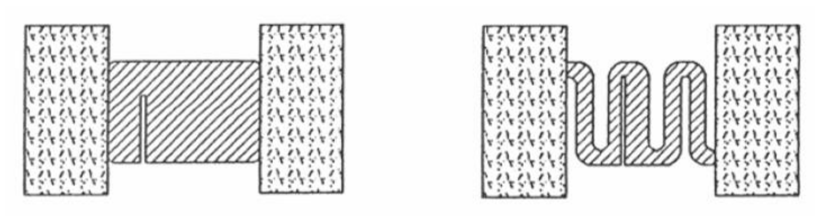

Figure 7
Serpentine pattern enables trimming to tighter initial tolerances without post trim shifts.

Of course, the serpentine pattern retains the non-inductive feature associated with conventional design. All these improvements are obtained regardless of form of the chip termination construction. All of these performance improvements have been demonstrated convincingly in flip-chip, wire-bondable and wrap-around formats.

Conclusions

A new type of surface mount chip resistor has become available, which carries much higher voltage ratings. Additionally, many other important characteristics have been enhanced. All these advances open up new chip resistor and SMT applications.