



Magnetic Powder Cores

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THE MAGNETIC PRODUCTS GROUP OF **SPS**
TECHNOLOGIES

ARNOLD MAGNETICS LTD
Powder Core Division

Introduction

Arnold manufactures the world's largest selection of magnetic materials. We are magnetic specialists of both hard and soft magnetic materials. This product information guide is focused on our soft magnetic powder core products; Molybdenum Permalloy Powder, SUPER-MSS™, and HI-FLUX™.

Today, electrical design engineers need to identify and compare product capabilities, performance and effectiveness for high frequency power conversion inductors, noise filters and various tuned circuit applications to meet their design objectives. To assist in this selection process, we have included the following information:

- How to order parts
- Design information
- Formulas and definitions for design calculations
- Comparative magnetic curves for performance evaluation
- Electrical and physical specifications with part numbers
- "Q" curves for Molybdenum Permalloy Powder cores

In 1995 Arnold initiated a complete upgrade of our powder core manufacturing facility providing the most advanced equipment to process, control and monitor our products. The upgrade for Molybdenum Permalloy Powder (MPP) and HI-FLUX was completed in 1996. In early 1997 the Sendust (SUPER-MSS) upgrade was completed.

To further our commitment to Magnet Materials advancement, Arnold opened the Magnetics Technology Center (MTC) in 1996. This "state-of-the-art" magnetics development laboratory is used for new product and improved process development by Arnold and their customers.

Arnold's commitment to continuous improvement and customer satisfaction is best reflected in our commitment to excellence:

Our Commitment to Excellence

Arnold is committed to providing quality products and services that conform to our customers' requirements.

We will have an environment which encourages teamwork and in which each employee learns, understands, and practices quality conformance as an integral part of his or her job function. All departments will establish goals consistent with our commitment to continuous improvement.

We will judge our performance on how well we satisfy our customers' needs and be guided by the belief that our customers will ultimately determine how successful we will be.

We appreciate your selection of our products.

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Specifications and "Q" Curves

0.140" o.d.	22-23
0.155" o.d.	24-25
0.183" o.d.	26-27
0.250" o.d.	28-29
0.260" o.d. (i.d. 0.105/ht.0.100)	30-31
0.260" o.d. (i.d. 0.105/ht.0.188)	32-33
0.277" o.d.	34-35
0.310" o.d.	36-37
0.380" o.d. (i.d. 0.188/ht.0.125)	38-39
0.380" o.d. (i.d. 0.188/ht.0.156)	40-41
0.400" o.d.	42-43
0.440" o.d.	44-45
0.500" o.d.	46-47
0.655" o.d.	48-49
0.680" o.d.	50-51
0.800" o.d.	52-53
0.900" o.d.	54-55
0.928" o.d.	56-57
1.060" o.d. (i.d. 0.580/ht.0.340)	58-59
1.060" o.d. (i.d. 0.580/ht.0.440)	60-61
1.300" o.d. (i.d. 0.785/ht.0.345)	62-63
1.300" o.d. (i.d. 0.785/ht.0.420)	64-65
1.300" o.d. (i.d. 0.785/ht.0.440)	66-67
1.350" o.d.	68-69
1.410" o.d.	70-71
1.570" o.d.	72-73
1.840" o.d. (i.d. 0.950/ht.0.710)	74-75
1.840" o.d. (i.d. 1.130/ht.0.600)	76-77
2.000" o.d.	78-79
2.250" o.d. (i.d. 1.039/ht.0.600)	80-81
2.250" o.d. (i.d. 1.400/ht.0.550)	82-83
3.063" o.d. (i.d. 1.938/ht.0.500)	84-85
3.063" o.d. (i.d. 1.938/ht.0.625)	86-87
4.000" o.d. (i.d. 2.250/ht.0.535)	88-89
4.000" o.d. (i.d. 2.250/ht.0.650)	90-91
5.218" o.d. (i.d. 3.094/ht.0.800)	92-93
5.218" o.d. (i.d. 3.094/ht.1.000)	94-95
Index	96-98

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Molybdenum Permalloy, Hi-Flux and Super-MSS Powder cores are wound with magnet wire to make transformers or inductors. Maximum allowable energy dissipation for a given value of energy storage (inductance and current) or transformation (voltage and current), guide the selection of core material and size. Energy dissipation is usually specified in terms of maximum temperature rise, minimum efficiency or minimum Q value. (Q is 2π times the ratio of peak energy stored to energy dissipated during one period of current flow.) Consider the following when choosing a core material:

1. Molybdenum Permalloy Powder (MPP) cores provide the maximum Q and lowest core loss. MPP is the most stable core with respect to temperature and AC Flux. It has the widest range of permeabilities and is considered the premium material for direct current output inductors of Switched Mode Power Supplies. It is useful into the Megahertz range of frequencies. MPP cores are an excellent choice for precision audio frequency tuned circuits, High Q Filters, Loading Coils, RFI Filters and many other precision inductor applications.
2. Hi-Flux cores are a 50% Nickel 50% Iron distributed gapped powder core. HF has up to 15,000 Gauss saturation flux density and core losses significantly lower than iron powder cores. These cores are ideal for Switching Regulator Inductors, In Line Noise Filters, Pulse and Fly-Back Transformer applications. When used in applications with high dc current, HF cores can provide a reduction in inductor size as well as total cost.
3. Super-MSS is an improved Sendust material, originally developed by Arnold Engineering. It is designed to replace iron powder by offering much lower losses, with energy storage capability higher than MPP. Super-MSS cores are an excellent choice for energy storage and filter inductor applications in Switch Mode Power Supplies. The low loss properties of Super-MSS cores minimizes the temperature rise at power frequencies to well below that of a similar sized iron powder core. The DC Bias characteristics of Super-MSS are also excellent compared to iron powder of similar permeabilities and size.

For reference, some basic electromagnetic terms and relationships used to design with magnetic powder cores are defined, followed by graphs showing typical values for material characteristics essential to transformer and inductor design. The final section of this catalogue contains data for specific core sizes and Q curves for Molybdenum Permalloy Powder (MPP) cores.

Units of Measure

For historical reasons, the Centimeter-Gram-Second (CGS) system is used in this catalog. Conversion between the System International (SI) and CGS System is simplified using the following table.

Conversion Table

Quantity	To Convert		Multiply By
	From	To	
Magnetic Flux Density B	Gausses (CGS)	Teslas (SI)	10^{-4}
Magnetizing Force H	Oersteds (CGS)	Amperes per Meter (SI)	$1000/(4\pi)$

Also, free space permeability in the CGS System has a magnitude of 1 and no dimensions. Free space permeability is $4\pi \times 10^{-7}$ henries per meter in the System International.

Inductance

Inductance (L) is calculated using the inductance factor (A_L) listed for each core.

$$L = A_L N^2 \text{ nanohenries}$$

A_L = inductance factor in mH for 1000 turns.
N = number of turns.

Therefore,

$$N = \sqrt{\frac{L}{A_L}} \text{ turns}$$

where L is in nanohenries.

Inductance can also be determined from the relative permeability (referred to in this catalog as μ , "permeability" and "perm") and the effective core parameters shown in Figure 1.

$$L = \frac{4\pi\mu A_e}{l_e} N^2 \text{ nanohenries}$$

A_e = effective core area in square centimeters.
 l_e = effective magnetic path length in centimeters.
 μ = relative permeability (no dimensions).

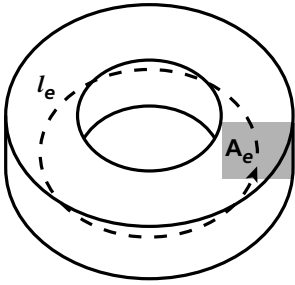


Figure 1.
Effective Core
Parameters

For toroidal powder cores, the effective area is the same as the cross sectional area. By definition and Ampere's Law, the effective magnetic path length is the ratio of winding ampere-turns (NI) to the average magnetizing force across the core area from inside diameter to outside diameter. Using Ampere's Law and averaging the magnetizing force gives the formula for effective path length.

$$l_e = \frac{\pi (O.D. - I.D.)}{\ln \left(\frac{O.D.}{I.D.} \right)}$$

O.D. = outside diameter of core.
I.D. = inside diameter of core.

Inductance factors are measured using a single layer winding with closely spaced turns. Flux densities and test frequencies are kept as low as practical, usually less than 40 gauss and 10 kHz or below. The "Normal Permeability versus Flux Density" and "Typical Permeability versus Frequency" graphs can be used as guides to define low-level test conditions for the various permeabilities and materials.

Permeability

The inductance factors listed for each core size are based on incremental relative permeabilities. With no direct current bias and at low flux densities, the normal and incremental permeabilities are the same. The incremental permeability decreases with direct current bias as indicated by Figure 2 and shown in the "Incremental Permeability versus DC Bias" graphs.

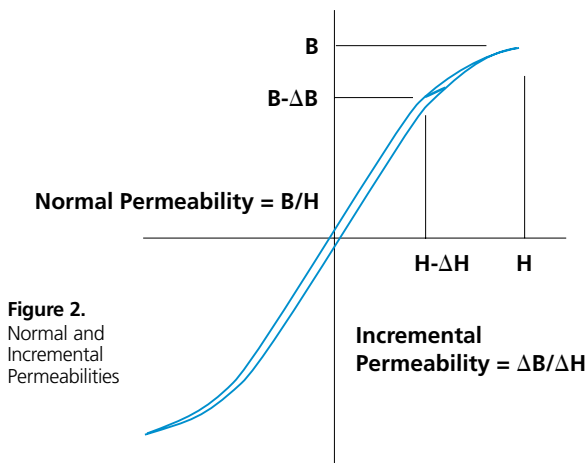


Figure 2.
Normal and
Incremental
Permeabilities

The "Normal Permeability versus Flux Density" graph shows normal permeability as a function of peak flux density, B.

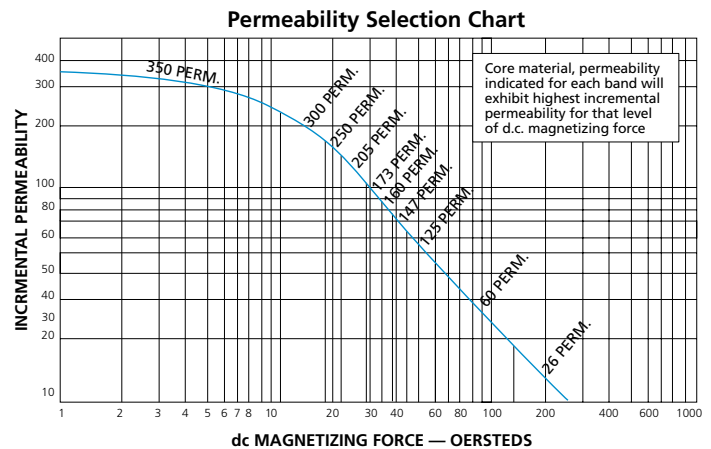
Most design procedures involve choosing a peak operating magnetic flux density to help determine the core size. Peak operating flux density is limited by the core material saturation flux density or by the core material loss. After choosing the material and operating flux density and determining the core size, Faraday's Law (discussed below) is then used to calculate the number of turns, N. Finally, a permeability is selected to provide the required inductance.

$$\mu = \frac{L l_e}{4 \pi A_e N^2}$$

L = inductance in nanohenries.
 l_e = effective magnetic path length in centimeters.
 A_e = effective core area in square centimeters.

A wide range of permeabilities are offered to satisfy various inductance requirements.

Ampere's Law (also discussed below) gives the peak value of magnetizing force, H, based on the number of turns, peak magnetizing current (the total current of an inductor and "no-load" current in a transformer primary) and core magnetic path length. As can be seen in Figure 2, selecting the permeability sets the peak magnetic flux density so it matches the value chosen at the beginning of the design procedure. Also, for Molybdenum Permalloy Powder (MPP), the following selection chart gives the permeability that yields maximum inductance for a given magnetizing force.



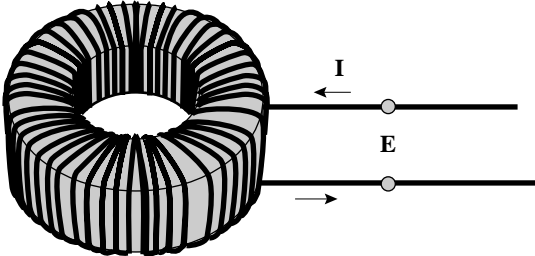
The "Normal Magnetization Curves" can be used with the "Typical Incremental Permeability versus DC Bias Curves" to estimate the direct current magnetic flux density for a chosen percentage of incremental permeability. For example, 125μ Molybdenum Permalloy Powder has 50% incremental permeability at just under 50 oersteds. The corresponding flux density is about 4500 gauss (0.45 tesla) according to the normal magnetization curve. Surveying the other permeabilities suggests that this could be used as an approximation of the DC flux density where Molybdenum Permalloy Powder has 50% of its original incremental permeability.

Magnetic Flux Density and Faraday's Law

The level of flux density (B) affects core loss and permeability. Unless otherwise noted, the data in this catalog is for sinusoidal waveforms and maximum (peak) magnetic flux densities. Using Faraday's Law:

$$B_{max} = \frac{E_{rms} 10^8}{NA_e \sqrt{2} \pi f}$$

- B_{max} = maximum (peak) flux density in gauss.
- E_{rms} = sinusoidal RMS voltage across winding (V rms).
- N = number of turns.
- A_e = effective core area in square centimeters.
- f = frequency of sinusoidal voltage in hertz.



The effective area is considered the total area of the core cross section as shown in Figure 1. The area occupied by magnetic alloy is less than this area and decreases with decreasing permeability. Catalog data for the different permeabilities include effects from the smaller magnetic alloy areas.

Also, B_{max} is an average maximum flux density value over the core cross section. The flux density is greater toward the inside diameter and smaller toward the outside diameter as shown by Ampere's Law and described in the following.

Magnetizing Force and Ampere's Law

Ampere's Law relates magnetizing force (H) to current, number of turns and magnetic path length.

$$H = \frac{0.4 \pi NI}{l}$$

- H = magnetizing force in oersteds.
- N = number of turns.
- I = current in amperes.
- l = magnetic path length in centimeters.

According to Ampere's Law, the magnetizing force is stronger toward the inside diameter (where l is shorter). The effective magnetic path length provides an average value of magnetizing force across the core cross section.

$$H_{average} = \frac{0.4 \pi NI}{l_e}$$

- H_{average} = the average magnetizing force across the core from inside to outside diameters in oersteds.
- l_e = effective magnetic path length as listed in the individual core specifications in centimeters. (See the section on inductance for the effective path length formula.)
- N = number of turns.
- I = current in amperes.

Average magnetizing force is used in this catalog unless noted otherwise.

The magnetizing force determines the estimate of magnetic flux density using the normal magnetization curves. See the above section on permeability. The relative permeability is, by definition:

$$\mu = \frac{B}{H}$$

- μ = relative permeability.
- B = magnetic flux density in gauss.
- H = magnetizing force in oersteds.

The d.c. winding resistance for an average winding can be calculated by:

$$R_{dc} = \frac{I_w N r}{12000}$$

I_w = mean length of turn (in.)

N = number of turns

r = resistance of wire in ohms per 1000 feet

(see wire table on page 8.)

In addition to the normal d.c. resistance of a winding, there exists an incremental change in the winding resistance due to the skin effects of a.c. current.* This can be approximated by:

$$\frac{R_{ac}}{R_{dc}} = .96 + .0035 x^2 - .000038 x^3$$

where $x = d \sqrt{\frac{f}{(1 + .00393 (\text{°C} - 20))}}$

d = wire diameter (inches)

f = frequency (HZ)

°C = operating temperature

Minimizing distributed capacitance is an important core winding consideration. A toroidal winding has an effective capacitance which may be considered to be in parallel with the inductance. This is the result of the summation of capacitances from turn to turn, layer to layer, and from parts of the winding to the core. (The effect of this capacitance on the Q and the inductance of the component is discussed in the section "Notes on

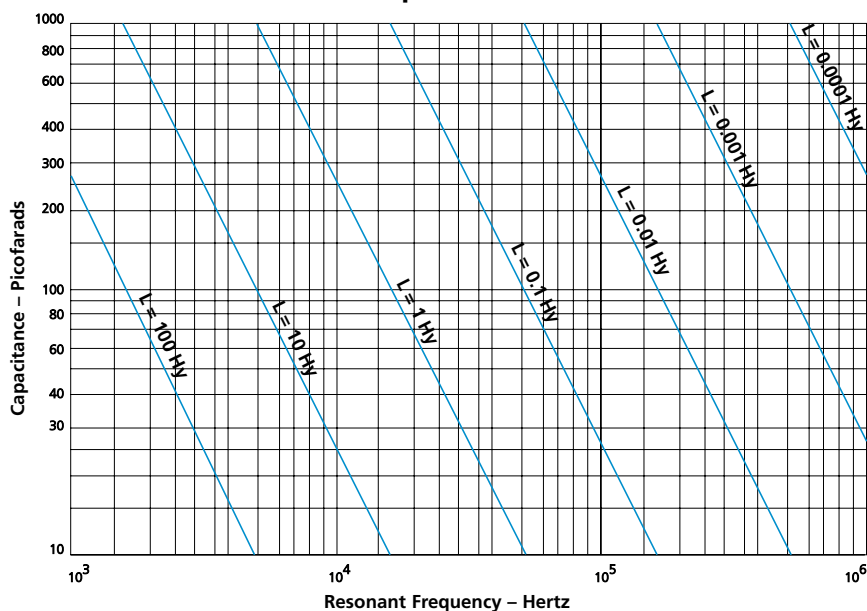
Molypermalloy Q Curves".) The graph below is useful for estimating self-resonant frequency. By selecting a winding technique which minimizes the voltage between turns, the distributed capacitance may be reduced. Several winding techniques are available. Dividing the winding into a number of sections, such as 2, 4, or more, or the use of a bankwound coil is effective in reducing the capacitance. In any case, the winding and inter-sector connecting technique should carefully avoid placing the first and last turns adjacent to each other - as they have the highest turn to turn potential, and thus contribute the most to the effective capacitance. Both the moisture content in the dielectric of the winding and the dielectric constant of potting and encapsulating materials increase the effective distributed capacitance.

Precision wound cores - stable with time and having reproducible temperature characteristics - must have winding strains relieved by temperature cycling. The wound cores must be cycled from room temperature to 125° C., repeating the cycle as many times as necessary to achieve reproducible results. At least one cycle should include a temperature lower than the wound core will be exposed to under operating conditions. This cycling will not only relieve strains, but also remove moisture that is present. Final adjustment of inductance value should be made after the temperature cycling process has been completed.

The wound cores should be kept dry until they are dipped, potted, or hermetically sealed. Potting and encapsulating compounds should be carefully selected as some may shrink with age or temperature change, and thus affect stability. Cushioning material on the wound cores can minimize this effect.

*Reference Data for Radio Engineers. ITT Corp. New York, NY, 4th Edition, 1956, pp. 128-132

Inductance - Capacitance Resonance Chart



Heavy Film Magnet Wire Table (Reference NEMA MW1000)

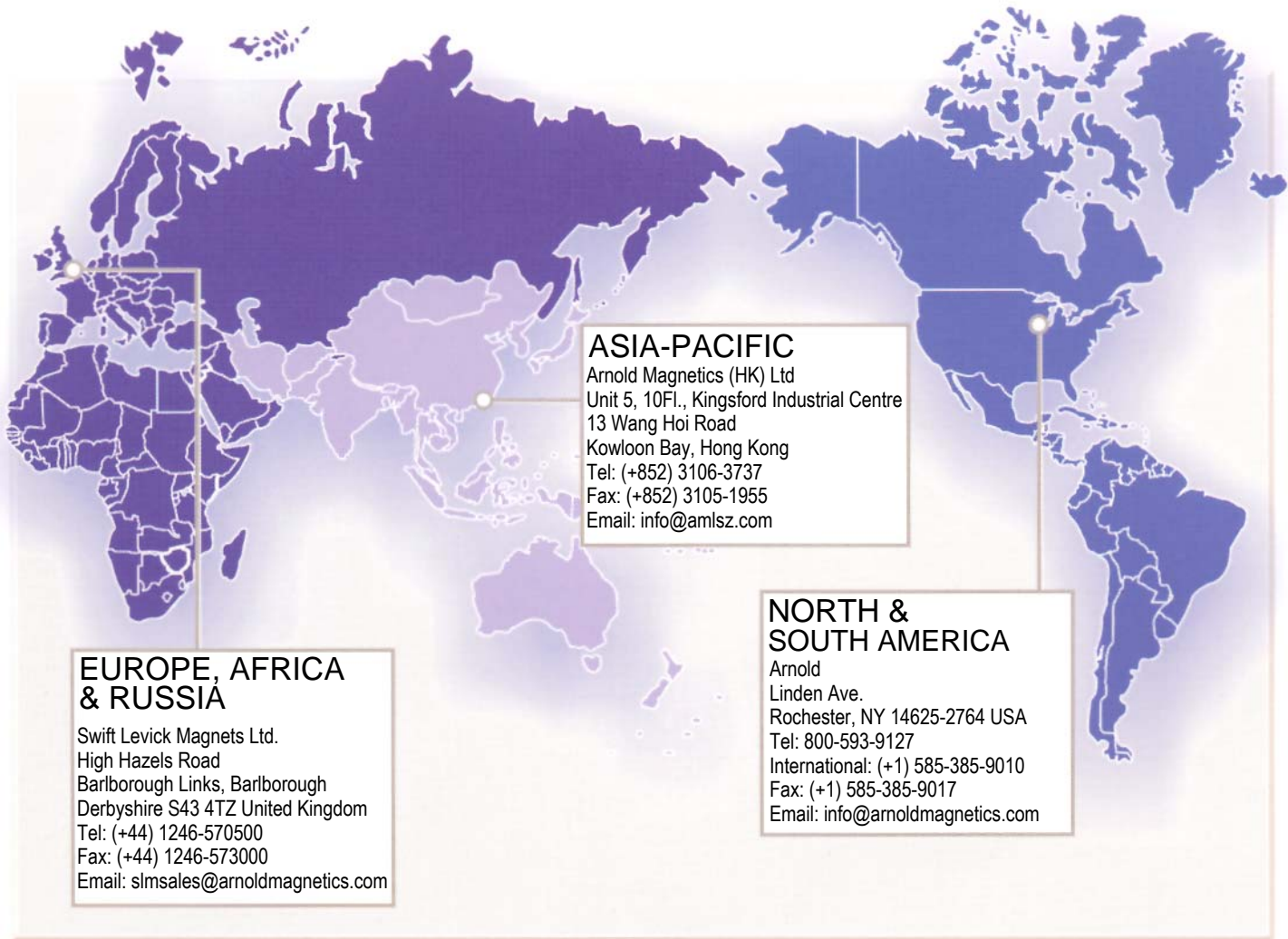
AWG Size	Maximum Outside Diameter Over Insulation in Inches	Nominal Resistance, Ω /1000 ft. at 20°C (68°F)	Nominal Bare Wire Diameter in Mils ¹	Nominal Bare Wire Cross Sectional Area in Circular Mils ²
10	0.1061	0.9988	101.9	10380
11	0.0948	1.26	90.7	8230
12	0.0847	1.59	80.8	6530
13	0.0757	2.00	72.0	5180
14	0.0682	2.52	64.1	4110
15	0.0609	3.18	57.1	3260
16	0.0545	4.02	50.8	2580
17	0.0488	5.05	45.3	2050
18	0.0437	6.39	40.3	1620
19	0.0391	8.05	35.9	1290
20	0.0351	10.1	32.0	1020
21	0.0314	12.8	28.5	812
22	0.0281	16.2	25.3	640
23	0.0253	20.3	22.6	511
24	0.0227	25.7	20.1	404
25	0.0203	32.4	17.9	320
26	0.0182	41.0	15.9	253
27	0.0164	51.4	14.2	202
28	0.0147	65.3	12.6	159
29	0.0133	81.2	11.3	128
30	0.0119	104	10.0	100
31	0.0108	131	8.9	79.2
32	0.0098	162	8.0	64.0
33	0.0088	206	7.1	50.4
34	0.0078	261	6.3	39.7
35	0.0070	331	5.6	31.4
36	0.0063	415	5.0	25.0
37	0.0057	512	4.5	20.2
38	0.0051	648	4.0	16.0
39	0.0045	847	3.5	12.2
40	0.0040	1080	3.1	9.61
41	0.0036	1320	2.8	7.84
42	0.0032	1660	2.5	6.25
43	0.0029	2140	2.2	4.84
44	0.0027	2590	2.0	4.00

¹A mil is 0.001 inch.
²A circular mil is the area of a circle which is 1 mil in diameter.

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