Presented at IPC Printed Circuits Expo®
SMEMA Council APEX®
Designers Summit 04

PCB Design Using the Metric System

Andrew Kowalewski
SyChip, Inc.
Plano, TX

There are many ways of specifying units for many different measurements, and over the years they have developed a life of their own. For example, length was once measured with glorious imprecision. In 100AD King Edgar of Saxony defined the yard as the distance from the tip of the his nose to the end of his outstretched thumb. Useful measure that. Can you imagine asking the King to "Come over here, I want to make sure this length of timber is one yard"? Or how about a "perch"? Originally defined as "the total length of the left feet of the first sixteen men to leave church on Sunday morning". Very useful – Not! Then we have the roofing industry giving us copper thicknesses in ounces per square foot. How useful is that?

These days we are doing much better. Apart from some obscure methods of measuring various parameters, we find the most universal systems are based on the pound, the inch and the second ("English" system) and the meter, gram and second, known universally as the metric system and more specifically as the SI system for **Systeme International d'Unites**, originally the system developed in France and adopted by Europe. Notice that time units are the same in both – a sign that convergence is possible.

Today, most of the world is using the metric system for their measurements. The metric system has quickly become accepted worldwide, with accuracy of measurements improving over the years as new and more accurate measurement technologies became available. Many countries have switched from imperial to metric measurements to further standardise units of measurement around the world. Notable exceptions to metric standardisation remain America and some Third world African countries. Despite a commitment for converting to the metric system by Thomas Jefferson, Abraham Lincoln, Franklin Roosevelt and Jimmy Carter, America remains (almost) firmly entrenched with the imperial system.

In 1968, Congress adopted an act requiring the United States to study the metric system and make recommendations for adoption. This study recommended that the United States make a deliberate but careful change to the SI system of units. Not much of a practical nature has happened in the US since then, apart from the Metric Conversion Act of 1975 which explains the improvements and values of using the metric system in different industries.

Why should anyone change to a common system of measurement? Many reasons exist, but the most spectacular one would have to be the foul-up which occurred when a British team working with the US space program forwarded data to an American team in metric units, and the American team assumed the units were English. The resultant mess crashed the Mars Lander on the surface of Mars, destroying many millions of dollars of experiments and setting the Mars exploration program back many years.

Enough said. If you want a cogent explanation as to why metrication is a good thing, have a look at http://lamar.colostate.edu/~hillger/qanda.htm - they give a lot of good reasons for going metric.

Let's look at the basic metric system. It is founded on a base of ten – all units relate to each other through powers of ten. A system of prefixes allows supersets and subsets of the basic units – the meter, the gram and the second. The most common prefixes are:

- Mega means millions of basic units (Megawatts or MW)
- Kilo (pronounced "kee-low"or "ky-low") is one thousand basic units (kilometres or km)
- Deca (pronounced "deck-ah") is ten basic units
- Deci (pronounced "dess-ee") means tenths (decimetre or dm – not a common measurement)
- Centi (pronounced "sent-ee") means hundredths (centimetre or cm)
- Milli (pronounced "mill-ee") means thousandths (millimeter or mm)
- Micro means millionths (microsecond or uS)
- Nano means thousandths of millionths (nanosecond or nS)
- Pico means millionths of millionths (picosecond or pS)

The common units a board designer is likely to encounter are:

- Millimeter – one thousandth of a meter
- Centimetre – one hundredth of a meter
- Micrometer – one millionth of a meter and also known as a "micron" often abbreviated to "um" or just "u".

- Gram – weight, where 28 grams is close to one ounce
- Kilogram – one thousand grams and about 2.2 pounds
- Microsecond – one millionth of a second
- Nanosecond – one thousand millionth of a second

Temperature will also be affected by metrication. The US system of measuring temperature in degrees Fahrenheit will eventually be replaced with degrees Celsius. In fact, most of our industry already uses degrees Celsius so that's not so much an issue for us right now.

You will also find some differences in the spelling. Europe and most other countries spell the meter as "metre" from the original French. We spell it "meter" and I guess standardising the units globally is one thing, but standardising the spelling also will probably take a lot more effort and will no doubt need a future generation to address.

In our industry, the urgent need for standardising units globally comes from the globalisation of the economy and the global supply of components that we need to live with. Many of the parts we put on circuit boards these days come from overseas, or from American companies who want to trade globally and have converted their units to the most common global system – the metric system. Working with dual units in board design can be a pain, especially when we rely on a grid of one system or the other and components are used with base units from either. Continuously converting between the two systems for library parts, design rules and documentation adds extra work, takes more time, and might give rise to conversion and rounding errors that can seriously jeopardise a design, especially at the leading edge of the design business where we have to squeeze and squeeze to fit components in, with tight track and spacing requirements.

Some CAD systems have excellent techniques for working between the two types of units, while others are only marginally helpful. Library parts built in metric for example can sometimes be a mil or so out if the database does not have the resolution to handle sub-mil parameters. Of course, using so-called gridless routing techniques overcomes some of these issues, but a common unit system for all applications is always easier to use.

US fabricators too are very much familiar with mils and ounces and might have little idea of the alternative system. Even if they do, familiarity with one system of units is a powerful reason to not change. Even today some shops in the US will not accept metric data.

Assemblers have it a little better. A lot of the assembly machinery originated in Europe and Japan and so is built from the ground up to accommodate both imperial and metric inputs.

Many of the newer components being designed in the US are strictly metric. It is much easier to use the metric system when feature sizes get smaller and smaller. Sub-mil units make it tricky when components span more than one inch and the position of the decimal point becomes an issue. Then standards bodies like JEDEC and IPC have converted or are in the process of totally converting their standards documents to metric measurements, an acknowledgement of the globalisation of our industry and their desire to stay in tune with the rest of the world.

In other words, the world is changing and we need to change with it - this is one of the few times the US is playing catch-up with the rest of the world in the electronics industry instead of being a major leader.

Australia in its wisdom decided that the country was going to convert to the metric system by mandate in 1971. In the beginning, tradesmen like carpenters and plumbers were up in arms but quickly found that once they became familiar with measurements like "50x100" instead of "2x4" then the metric system suited them much better, mainly because the metric system made it much easier to divide measurements instead of converting yards, feet, inches and fractions of an inch into a common unit of measurement before dividing. They are now staunch supporters of metrication and would not dream of reverting to English measurements.

Years ago all boards were designed in English measurements. The ubiquitous DIP with its legs on 100 mil centers was king. Axial resistor and capacitor pitches were usually 400 mils and everything was right with the world. Then around 1987 we started seeing board designs with surface mount components which were made in Asia and were basically metric components but the units were easily converted to mils and so their impact wasn't so great. A 1206 is 125 mils by 62 mils and that came easily from the metric size which was 3.2mm by 1.6mm, known in the metric system as "3216". Usually a five mil routing grid worked with these components, but the writing was on the wall.

Then there was a flood of active SMT parts such as the SO series that were based on 50 mil pitches. These were ok too for the English grids of the day, but there were also more and more parts coming from Asia that used metric pitches, and suddenly neither grid was very helpful. Getting a track between two pins on a metric pitch like 1mm was very difficult when you were using a 25 mil grid. Even a five mil grid wasn't very helpful in centering a trace between pins, and we had to keep zooming in and out and changing grids to suit.

I went through the pain of conversion about seven years ago, and I remember it well. Building library parts in metric units was not at all intuitive. All the mil measurements I was used to had to be translated into their metric equivalents for things like pin pitches, padstack hole sizes, rectangular pad dimensions and silkscreen text heights, thicknesses and printable line widths. I remember a lot of initial frustration because nothing was simple and everything took longer than it needed. Of course schedules and delivery dates didn't change, and I was tempted many times to revert to the units I was most familiar with.

Then gradually things became much easier. Line widths and spaces became familiar again, inch to metric conversion became a snap (as happens when you do something often enough), metric grids became embedded in the psyche, and I found that I was back up to full speed and suddenly enjoying life again.

Looking back, I remember that the few metric parts I needed to convert to English units suddenly became an issue of having a lot of English parts to convert to metric units. More work, more time needed. Then over the years parts data sheets and part dimensions with metric units became more and more common to the point that these days metric parts are by far the most common and English parts are relatively rare. And all that fits nicely with being familiar with metric design rules today. In fact, if memory serves me correctly it took me about four board designs before I felt reasonably comfortable with the new metric units. There seemed to be a lot of pain in the process at the time, but looking back now it wasn't so bad, it didn't last very long, and it was very much well worth the effort.

So let me give you some tips to help you on the road to metric design Nirvana.

Like the meaning of life, there is one major conversion factor to remember – 39.37 is the universal number. This is derived from having 25.4mm to the inch in turn leading to having 39.37 mils in a millimetre, and I found that if I forgot inches and worked directly from mils to millimeters, I wasn't confused by separate mil and inch conversions. Set your calculator's constant to 39.37 and do the following:

Divide mils by 39.37 to get millimeters, and multiply millimeters by 39.37 to get mils.

What could be simpler than that?

Then there are rough rules of thumb that can give you rough conversions done in the head. For non-critical conversions (like short distances) or to get a rough idea of the size of something during the transition period, use four mils to 0.1 millimeter. That has worked well for me, as the error is very small. Of course don't use this conversion for things like multiple pin pitches. The additive error could cause the last pin in a long row to be dangling in mid air, and that will never be a good thing. It could lead you to change to a janitorial career.

Common discrete components convert this way:

- 0201 (20 x 10 mils) converts to a 0603 (0.6 x 0.3mm)
- 0402 (40 x 20 mils) converts to a 1005 (1 x 0.5mm)
- 0603 (60 x 30 mils) converts to a 1608 (1.6 x 0.8mm)
- 0805 (80 x 50 mils) converts to a 2012 (2 x 1.2mm)
- 1206 (120 x 60 mils) converts to a 3216 (3.2 x 1.6mm)
- 1210 (125 x 100 mils) converts to a 3225 (3.2 x 2.5mm)
- 1825 (180 x 125 mils) converts to a 4632 (4.6 x 3.2mm)
- 2010 (200 x 100 mils) converts to a 5025 (5.0 x 2.5mm)
- 2220 (220 x 200 mils) converts to a 5651 (5.6 x 5.1mm)
- 2512 (250 x 125 mils) converts to a 6432 (6.4 x 3.2mm)

The metric 0603 can be confused with the English 0603 – the only time where there is a component size common to both but of course very different in size physically.

There are a number of standard conversions that will become as automatic as breathing:

- 100 mils is 2.54mm
- 200 mils is 5.08mm
- 300 mils is 7.62mm

- 600 mils is 15.24mm
- 1mm is about 40 mils
- 5mm is about 200 mils
- 10mm is about 400 mils
- 25mm is about an inch
- 50mm is about 2 inches
- 100mm is about 4 inches
- 150mm is about 6 inches
- 200mm is about 8 inches

One quarter of an inch becomes 6.35mm
One half an inch becomes 12.7mm
Three quarters of an inch becomes 19.05mm
One inch becomes 25.4mm
One foot becomes 305mm

Half ounce copper at 0.7 mils thickness becomes 0.017mm or 17u
One ounce copper at 1.4 mils thickness becomes 0.035mm or 35u
Two ounce copper at 2.8 mils thickness becomes 0.07mm or 70u.

A 40 mil drilled hole becomes 1.00mm (close enough – hole size tolerances are such that specifying a drilled hole of 1.016mm is totally fruitless)
Drilled hole sizes step in increments of 0.05mm, or 50u

A 3 mil trace and space becomes 0.075mm
A 4 mil trace and space becomes 0.1mm
A 5 mil trace and space becomes 0.125mm
A 6 mil trace and space becomes 0.15mm
An 8 mil trace and space becomes 0.2mm
A 10 mil trace and space becomes 0.25mm

A 2 mil clearance becomes 0.05mm, or 50u.

Nowadays we are using ever finer traces, spaces, pads and drilled holes, and I find it much easier to slip down into microns for a basic unit. That eliminates the decimal point from my millimeter measurements and gives me more manageable steps as traces become thinner. For example a 0.1mm trace (4 mils) becomes 100 microns (100um) and as I get thinner lines I can go to a 75um trace, and that's easier to handle than a 0.07mm trace when it comes to working out tracking densities and clearances to adjacent pads or traces.

Guess what? That is starting to sound like the IC business; they have been using microns for many years now and I'm sure that soon they will slip down into nanometer units; today's fine line technology of 0.18u converts well into 180nm and is easier to manipulate.

Solder mask clearances are easy too. Screened epoxy masks with 5 mil clearances become 0.12mm or 120u, and a photoimagable mask with 2 mil clearance becomes a clearance of 0.05mm or 50u. Solder mask thicknesses measured in microns rather than microinches or mils is also easier to handle.

Same with plating specs. Microns are very handy for specifying gold, nickel, copper and solder plating thicknesses. Once you get familiar with the new measurements they will become just as natural as what you use now.

Complex board stackups are also easier to handle in microns when working out copper and dielectric thicknesses. Half, one and two once copper thicknesses convert well to 17, 35 and 70 microns, while dielectric thicknesses for stackups don't need shuffling of the decimal point when adding layers with varying thicknesses.

So once you have made your commitment to going metric, start a program of converting your library parts to metric units, though I can hear you groaning when I suggest that. Who wants to begin what might be a mammoth task on thousands of parts? Maybe start branch libraries and convert only those parts you need for your immediate jobs, and of course all new parts will be done in metric.

Then grit your teeth and start getting used to metric board sizes, drill sizes, component sizes, component clearances, tracks widths and spaces, dielectric and copper thicknesses etc etc and etc. Keep in mind that it is better to start 'thinking metric' as soon as possible rather than 'thinking English' and converting all the time. Nevertheless, expect teeth-grinding frustration for a little while, but hang in there – there's Nirvana ahead.

Start generating outputs in metric units, and stick to your guns when your fabricator or assembler complains. Drill coordinates usually take the form "3+3" allowing a 999.999mm board with micron resolution. Gerber data is the same, giving as much size and resolution as we are likely to need for the foreseeable future.

You should base your board features like outlines and cutouts on two decimal points of millimetres – that gives a resolution of 10 microns and is more than adequate for even the most demanding applications. For example, specifying a board size of "38.375mm" is ludicrous – routing tolerances of +/- 0.1mm make that demand for micron resolution totally meaningless.

It's always tempting to go back to imperial units because it causes less pain, but the reality is that the pain is much worse but is stretched out over time. You'll know what I'm talking about when you will one day stand back and say to yourself, or anyone else within earshot "Boy this metric stuff is just so much easier. I wish I'd done this a long time ago".

Reference

And if you have a continuing interest in the subject, check out these websites:
http://users.vnet.net/cmstone/metric/index.htm Civil engineering and metrication
http://www.metricusa.com/ - All you ever wanted to know, with links to conversion calculators
http://anduin.eldar.org/~ben/convert.html - Useful links to conversion programs
http://lamar.colostate.edu/~hillger/ Home page for the US Metric Association, formed in **1916** to convert US to metric!
http://lamar.colostate.edu/~hillger/qanda.htm - good reasons for going metric, mainly for export industries

PCB Design

in Metric Units

Andy Kowalewski

February 24th, 2004

andyk_01@swbell.net

Introduction

- Measurement was an inaccurate art
  - Yard
  - Perch
- Advancing technology improved precision and resolution

Current systems of measurement

World now has two main systems

English, also called “Imperial”

Yard, pound, second

Metric, also called “SI system”

Meter, gram, second

Current systems in use

English system

- Some Third World countries
- United States

Metric system

- Everybody else

Progress in the US

Commitments from

Thomas Jefferson
Abraham Lincoln
Franklin Roosevelt
Jimmy Carter

Congress recommended study in 1968
Study recommended deliberate change to Metric

Congress passed Metric Conversion Act in 1975

In general, not much has happened since

Why convert?

Globalisation of trade

Globalisation of economies

Global teamwork

Look at http://lamar.colostate.edu/~hillger/qanda.htm

Metric system – Based on powers of ten

Prefixes

Mega	Meg-ah	Millions	Megawatts, MW
Kilo	Kee-low, ki-low	Thousands	Kilowatts, KW
Deca	Deck-ah	Tens	Decawatts, DW
Deci	Dess-ee	Tenths	Decimeters, dm
Centi	Sent-ee	Hundredths	Centimeters, cm
Milli	Mill-ee	Thousandths	Millimeters. mm
Micro	Mike-row	Millionths	microseconds, uS
Nano	Nan-oh	Thousandth of millions	Nanoseconds, nS
Pico	Pee-koh	Millionths of millionths	Picoseconds, pS

Need for change in electronics

Global supply of components

Dual units lead to -

- Misunderstandings
- Conversion and rounding errors
- Extra work

Most new components are metric based

- IPC and JEDEC switched to metric

Sub mil units cause confusion in tight designs

Tracking midway between
Metric pins on an imperial grid
(or imperial pins on a metric grid)
is very difficult

Resistance to change in electronics

- Lack of familiarity
  - Lines and spaces
  - Padstack pad and hole sizes
  - Text heights, thicknesses
- CAD systems don’t usually handle dual units well
- Some Fab shops refuse metric databases

Conversion pain, anguish and suffering

Translating mils to millimeters is a pain

Nothing is intuitive

Nothing is simple, everything takes too long

- Schedules don’t change

Temptation to revert to inches

Four reasonable designs lead to more comfort

Conversion process – length, width, thickness

39.37

Divide mils by 39.37 to get millimeters

Multiply millimeters by 39.37 to get mils

Work in mils for conversions exclusively, not inches

Common PCB units

Millimeter	One thousandth of a meter
Centimeter	One hundredth of a meter
Micrometer	One millionth of a meter Also “micron”, or “um”
Gram	Weight, 28 grams close to 1 ounce
Kilogram	One thousand grams and about 2.2 pounds
Microsecond	One millionth of a second
Nanosecond	One thousandth millionth of a second
Temperature	Celsius, Centigrade Vs Fahrenheit
Spelling	Metre Vs meter

Common measurements

100 mils is 2.54mm
200 mils is 5.08mm
300 mils is 7.62mm
600 mils is 15.24mm
1/4 inch is 6.35mm
1/2 inch is 12.7mm
3/4 inch is 19.05mm
1 inch is 25.4mm
1 foot is 304.80mm

1.0mm is 39.37 mils
5.0mm is 196.85 mils
10.0mm is 393.7 mils
25.0mm is 984.25 mils

Half ounce copper at 0.7 mil thickness is 0.017mm or 17u
One ounce copper at 1.4 mil thickness is 0.035mm or 35u
Two ounce copper at 2.8 mil thickness is 0.07mm or 70u
40 mil drilled hole becomes 1.016mm

Drill step size 0.05mm (50u)

Useful approximations

25mm is about 1 inch
50mm is about 2 inches
75mm is about 3 inches
100mm is about 4 inches
150mm is about 6 inches
200mm is about 8 inches

4 mils is about 0.1mm
1 mil is about 0.025mm
=25um

A 3 mil trace/space becomes 0.075mm, or 75u
A 4 mil trace/space becomes 0.1mm, or 100u
A 5 mil trace/space becomes 0.125mm, or 125u
A 6 mil trace/space becomes 0.15mm, or 150u
An 8 mil trace/space becomes 0.2mm, or 200u
A 10 mil trace/space becomes 0.25mm, or 250u

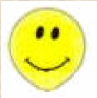
A 2 mil clearance becomes 0.05mm, or 50u

Plan the conversion process

Plan library conversion

- Use separate libraries –
  - New parts & new jobs - metric
  - Old parts & new jobs – convert imperial to metric

Bite the bullet and design in metric

Grit your teeth  Don’t revert

- Board sizes
- Drill sizes
- Component sizes and clearances
- Trace widths and spaces
- Dielectric and copper thicknesses
- Etc Etc & Etc

Common discrete components

0201 (20 x 10 mils) converts to an 0603 (0.6 x 0.3 mm)

0402 (40 x 20 mils) converts to a 1005 (1.0 x 0.5 mm)

0603 (60 x 30 mils) converts to a 1608 (1.6 x 0.8 mm)

0805 (80 x 50 mils) converts to a 2012 (2.0 x 1.2 mm)

1206 (120 x 60 mils) converts to a 3216 (3.2 x 1.6 mm)

1210 (125 x 100 mils) converts to a 3225 (3.2 x 2.5 mm)

1825 (180 x 125 mils) converts to a 4632 (4.6 x 3.2 mm)

2010 (200 x 100 mils) converts to a 5025 (5.0 x 2.5 mm)

2220 (220 x 200 mils) converts to a 5651 (5.6 x 5.1 mm)

2512 (250 x 125 mils) converts to a 6432 (6.4 x 3.2 mm)

PCB design outputs

Start generating outputs in metric units

- Drill coordinates 3+3
- Gerber data 3+3

Fab drawings

- Metric, of course – resist dual units
- Dimensions to two decimal places

Fabricators and assemblers may complain

Conversion attitude

“Think Metric” as soon as possible -

Concentrate

Persist

Expect teeth grinding frustration for a while

Finally

Metric units become intuitive

Converting metric to imperial for the unconverted becomes a pain

You say to anyone who will listen
"Boy, this metric stuff is just so much easier.
I wish I'd done this a long time ago".

Life is sweet again

?