Experimental Determination of On–Chip Interconnect Capacitances

SEMATECH Agreement #34015300

IC TEST DESIGN REPORT–REVISED
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Michael B. Steer, Paul D. Franzon, Alan W. Glaser

Electronics Research Laboratory
Department of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27695-7911

Phil Russell, Gordon Shedd

Department of Materials Science and Engineering
North Carolina State University
Raleigh, NC 27695

Project Director: M. Steer — (919) 515-5191
email: mbs@ncsu.edu

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NCSU-ERL-95-27

This document replaces NCSU-ERL-95-27, dated April 7, 1995 and June 8, 1995.

Contents

3.1 Introduction

This design report describes the test structures to be used in electrically characterizing on-chip interconnects.

The aims of the project are as follows:

1. Develop benchmark capacitance and resistance measurements of on-chip interconnect structures.
2. Determine dimensions of interconnect structures. This will facilitate the determination of the effects of geometric assumptions made by capacitance extraction tools.
3. Experimentally determine properties of state-of-the-art structures.
4. Characterize on-chip transmission lines at frequencies up to 20 GHz.

Transmission lines will be characterized using a Hewlett Packard network analyzer. Capacitances will be determined using conventional capacitance meter techniques and a new Atomic Force Capacitance Meter. The Atomic Force Capacitance Meter will be used to measure very small capacitances.

3.2 Processing Requirements

In order to successfully complete the planned characterization of the proposed structures, the following processing should be done:

1. **Passivation thickness should be no more than 1μm, preferably less.** This is so we can minimize the required pad size for ACM probing while still maintaining enough clearance for the probe to enter the passivation window.
2. **Structures to be measured using ACM are in the center of the test coupon.** Since our test structures are only half of the total chip, we would like the structures to be measured with ACM as near to the center of the chip as possible, so as to minimize processing gradients in that area. Currently, we have placed the ACM structures in the left center of our chip area.
3. **The design will be stepped such that each chip will see similar surrounding regions.** (Instead of using it as a test plug which occupies a few isolated sites surrounded by other circuits.)

3.3 Layers

The IC has three metallization layers as shown in Figure 1.

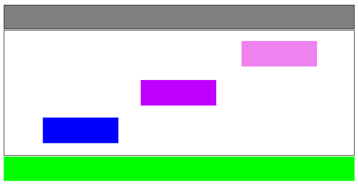


Figure 1: Cross-section of test IC showing three metallization layers.

3.4 Standard Dimensions

Dimensions are mostly indicated symbolically. Actual dimensions will be assigned based on the design rules and after consultation with the SEMATECH processing group.

SYMBOL	DESCRIPTION	DIMENSION μm
W_V	Very tiny line width	0.25
W_T	Tiny line width	0.35
W_S	Small line width	0.45
W_M	Medium line width	0.5
W_X	Experimental line width	0.6
W_W	Wide line width	0.7
S_S	Small line–to–line separation	0.45
S_M	Medium line–to–line separation	0.5
S_X	Experimental line–to–line separation	0.6
S_W	Wide line–to–line separation	0.7
L_S	Short layout length	400
L_M	Medium layout length	800
L_L	Long layout length	6400

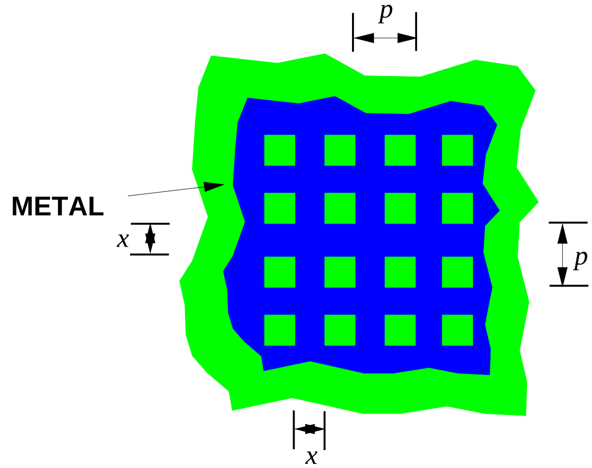


Figure 2: Gridded ground plane dimensions, x — width, p — pitch.

3.5 Measurements

The measurements to be performed are capacitance and resistance measurements and microwave transmission line characterization.

3.5.1 Capacitance and Dielectric Constant Measurement

There are two approaches which we plan to employ in measuring capacitances.

1. **Conventional Capacitance Measurement** using conventional contacting is shown in Figure 3. There are two probes shown here; each has three contacts—a signal contact and two guard contacts. We use coaxial probes (GGB model 40 picoprobes) which continue the coaxial probe to within 1 mm of the final test fingers. The guard contacts are extensions of the outer conductor of the coaxial line. On the chip, a set of three probe pads (Figure 3(b)) are contacted. The minimum dimension of the probe pads are 50 μm on one side with the outer pads typically connected to the chip ground. Sub-picofarad capacitance measurements require a balanced probe system, but the electrical balance must, of course, be disturbed at the probe, resulting in a residual capacitance. The residual capacitance of the microprobe and the probe pad is approximately 70 fF; this must be subtracted out of the measurements. This establishes a resolution of 4 fF. Thus the resolution of the capacitance measurement is independent of that of the capacitance meter provided that the meter's resolution is 1 fF or less.

2. **Atomic Capacitance Microscopy** (ACM) utilizing an atomic force microscope is shown in Figure 5. Atomic capacitance microscopy is an extension of atomic force microscopy. What is novel about our work is that we are not interested in the total capacitance measured but in a derived capacitance—the capacitance of the interconnect structure itself. Referring to the capacitance diagram in Figure 5, the technique can be described as follows. An alternating voltage signal is applied between the probe tips with one of the tips in contact with metallization. The electromechanical force on the other probe tip is measured via a piezoelectric stack from which C_{TOTAL} is derived. C_{PROBE} is determined from a through calibration and the capacitance of the interconnect structure C_X is determined. The system has a measurement resolution of 10^{-21} F.
   As an example of how the capacitance matrix can be derived from measurement, we present a method for obtaining the matrix using six independent test structures. These structures are shown in Figure 4 (note that we assume that the capacitance matrix is symmetric.) We will measure seven different equivalent capacitances, but only six are required for the derivation (the seventh will be for verification purposes). The relationships between the measured capacitances and the capacitance matrix elements (as shown in Figure 4) can be written as a matrix equation:

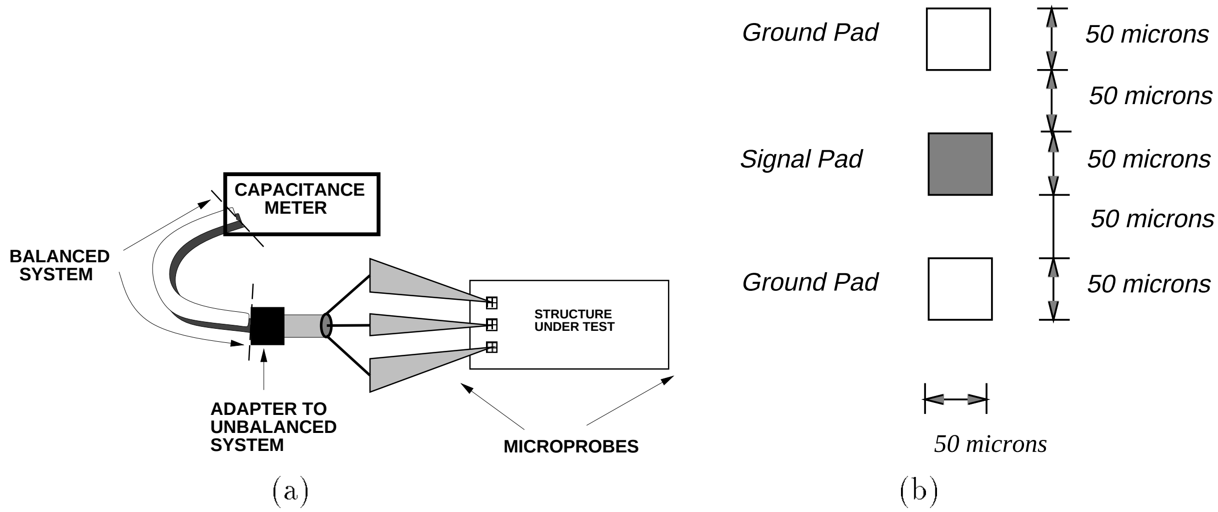


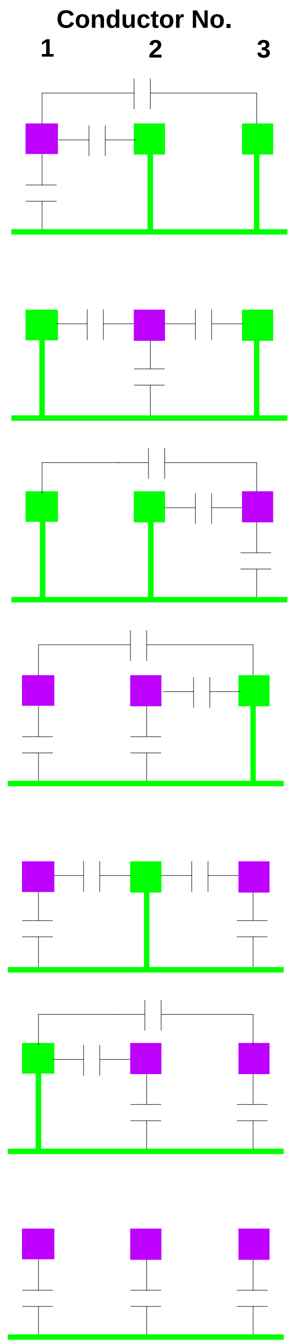
Figure 3: Conventional contact probing. (a) using shielded microprobes from GGB industries; (b) detail of contact pads.

$$\begin{bmatrix} C_A \\ C_B \\ C_C \\ C_D \\ C_E \\ C_G \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{12} \\ C_{13} \\ C_{22} \\ C_{23} \\ C_{33} \end{bmatrix}$$

If the coefficient matrix is invertible, then we can find the capacitance matrix elements by taking the inverse of the coefficient matrix and multiplying by the measured values vector:

$$\begin{bmatrix} C_{11} \\ C_{12} \\ C_{13} \\ C_{22} \\ C_{23} \\ C_{33} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} C_A \\ C_B \\ C_C \\ C_D \\ C_E \\ C_G \end{bmatrix}$$

The above coefficient matrix is in fact invertible; thus our measurement set will suffice for the derivation of the capacitance matrix.
Similar techniques must be used to find the crossover and via capacitances.



$$C_A = C_{11} + C_{12} + C_{13}$$

$$C_B = C_{22} + C_{12} + C_{23}$$

$$C_C = C_{33} + C_{13} + C_{23}$$

$$C_D = C_{11} + C_{13} + C_{22} + C_{23}$$

$$C_E = C_{11} + C_{12} + C_{33} + C_{23}$$

$$C_F = C_{22} + C_{12} + C_{33} + C_{13}$$

$$C_G = C_{11} + C_{22} + C_{33}$$

Figure 4: Three–line structures for capacitance matrix measurement. Structures in green are connected to the substrate and are thus grounded; structures in purple are electrically connected (connections not shown) so that they are at the same potential.

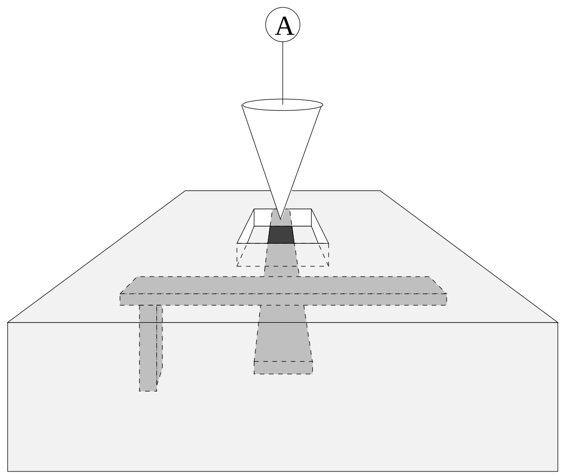
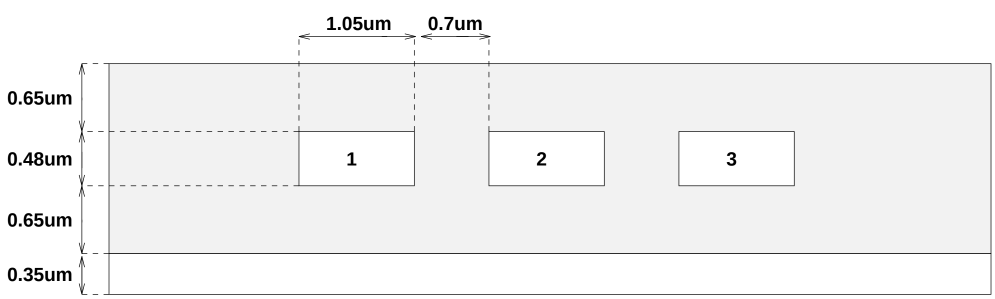


Figure 5: Capacitance of small structures using atomic force capacitance microscopy. Probe A is an ACM probe. The horizontal wire is connected to ground through a via.



$$C = \begin{bmatrix} 215.4 & -24.4 & -0.2 \\ -24.4 & 219.9 & -24.4 \\ -0.2 & -24.4 & 215.4 \end{bmatrix} \text{ fF/mm}$$

Figure 6: Assumed minimum design rule metallization cross-section of SEMATECH's 0.35 μm process. The actual dimensions are available on a need-to-know basis only. Also shown is the calculated capacitance matrix.

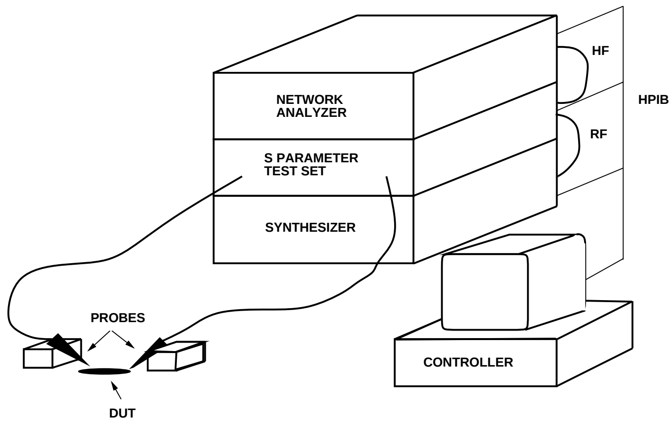


Figure 7: Measurement setup for microwave transmission line characterization.

3.5.2 Atomic Force Microscopy

Capacitance measurements of 3-D micron-sized interconnect structures will be carried out using an Atomic Force Capacitance Microscope located at North Carolina State University. The Atomic Force Microscope has a resolution of 2×10^{-22} F and can be used with structures of 50s of nm on a side or greater.

However, this microscope can only be used for relative capacitance measurements and thus needs a separately characterized reference structure for comparison (in order to produce absolute measurements). In our Electronics Research Laboratory we have a HP 4275 A Multi-Frequency LCR Meter that when combined with the Model 40 GGB probe and an appropriate parasitic de-embedding procedure will give us 1 fF measurement accuracy. If three capacitors of different sizes are built alongside the three-dimensional structures to be tested, then we can use the LCR meter to *obtain the dielectric constant* and to provide a reference capacitance. Each parallel plate capacitor will have a 50 μm wide grounded guard band around it to enable us to account for the fringing fields in a predictable manner.

3.5.3 Expected Capacitance Values

The expected capacitance values for the test chip are shown in Figure 6 for coupled lines. The expected capacitance for the crossover shown in Figure 5 is approximately 1 aF. The conclusion is that the conventional contact capacitance technique can be used with uncoupled and coupled line structures but atomic capacitance microscopy is required for small structures such as cross-overs.

3.5.4 Transmission Line Characterization

Standard transmission line characterization will be performed using a microwave network analyzer and microprobes, as in Figure 7.

3.5.5 Physical Cross-Section Measurements

Conventional scanning electron microscopy will be used to obtain most dimensional information. Focused Ion Beam Milling (FIB) will be used to produce windows in the passivation layer and through dielectrics for probing. FIB will also be used to obtain dimensional information on 3D structures that are not amenable to cross-sectional SEM. Cross-sectional information will be obtained to a resolution of 50 nm.

3.5.6 Dielectric Measurements

Performance specification: 3%

This will be similar to the conventional capacitance measurement performance but the structure will be fairly large so that the fixed error is minimized.

3.5.7 Loss Measurements

The minimum loss that can be measured is determined by the impedance error. Since most of the impedance of an interconnect is capacitive the capacitance measurement performance establishes the impedance error. Thus loss tangents less than 0.03 cannot be measured directly using an LCR meter. Lower loss tangents will be measured using microwave measurement techniques.

3.5.8 Transmission Line Characterization

The propagation constant and characteristic impedance errors are 5%.

For simple simulation purposes the R, L, G and C parameters versus frequency up to 20 GHz will be obtained. As these are derived quantities and use assumptions (such as the frequency behavior of G) that cannot be verified, the error in the quantities cannot be determined. However, what is important in transmission line simulation is the value of characteristic impedance and propagation constant that can be calculated using the measured parameters.

3.5.9 Measurement Fixture

Passive measurements will be made using a Cascade Microprober, see Figure 8, and a Hewlett Packard Automatic Network Analyzer (ANA) HP8510B connected to a HP workstation for data retrieval. There are two types of fixtures: a microstrip fixture, Figure 9(a), and a coupled fixture, Figure 9(b). The microstrip and coupled fixtures are identical except for added repetition.

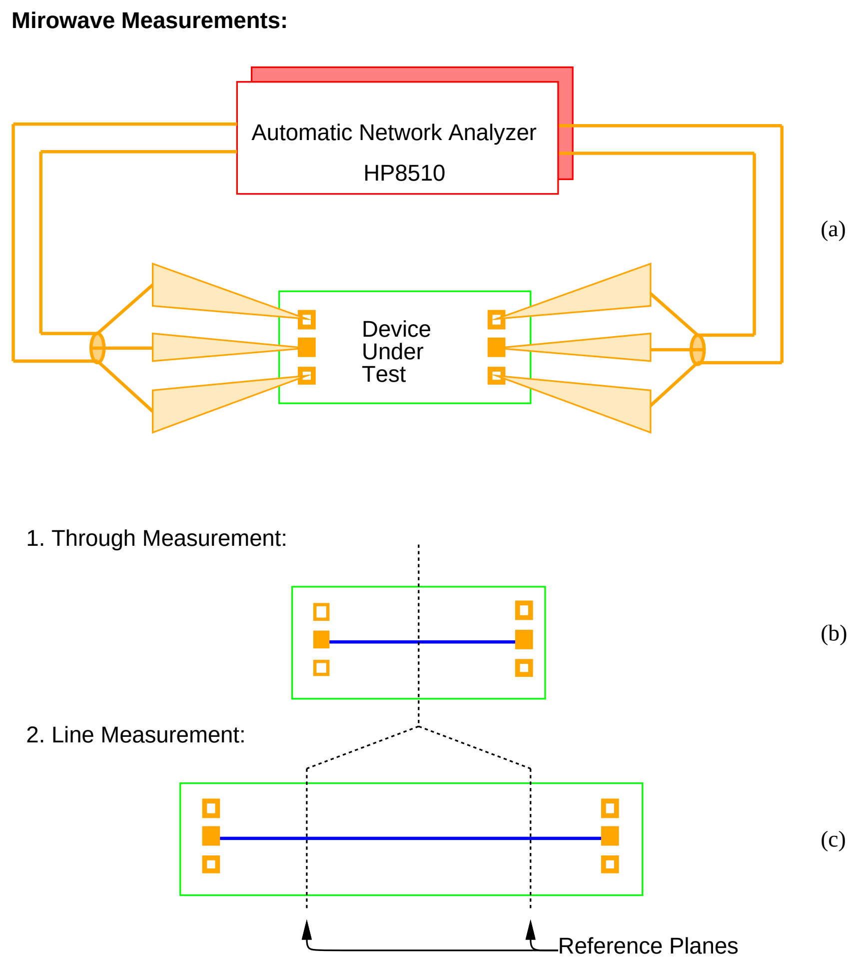


Figure 8: Set-up for microwave measurements: (a) test set-up using a Cascade Microtech probe station and picoprobes from GGB industries.

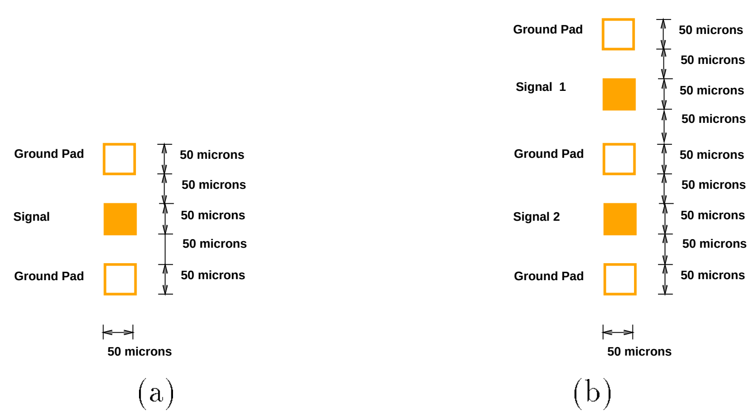


Figure 9: Fixture layout: (a) one signal version; (b) two signal version.

3.6 General Guidelines

1. SEMATECH's 0.35 μm 3 metal layer process with CMP for ILD planarization will be used to fabricate the test chip. An area of 1 cm by 2 cm has been allocated.

2. Metal resistances will be measured for most structures.

3. All structures will be cross-sectioned.

4. Frequency range

    4.1 Low frequency measurements will be made at 10 MHz.

    4.2 The measurement range in task 3.7.2 will be 100 kHz to 10 MHz using direct capacitance measurements. Network analyzer impedance measurements will be used in the range 10 MHz to 100 MHz.

    4.3 High frequency 2-parameter measurements will be in the range 45 MHz to 20 GHz.

5. An independent way of cross-checking the results of the capacitance measurements will be devised. For structures with uniform cross-sections, field solvers will be used. For representative structures, measurements using two capacitance measurement techniques will used. Measurements will also be verified through time-domain measurements performed on an interconnect network. A voltage contrast scanning electron microscope and Tektronix TK1180 TDR unit will be used. This system has a 20 ps timing resolution.

6. All measurements will have error estimates.

7. Calibration structures will be used to remove the effect of parasitics.

8. There are no active devices. This eliminates many reticles and holds down costs.

9. Structures submitted by member companies have been incorporated.

3.7 Facilities Description

Equipment from the electronics research laboratory to be used in this project include

- Microwave network analyzer system:
  HP8510 network analyzer, synthesizer, Cascade Microtech Probe Station, LABView measurement control software. S-parameter measurements from 45 MHz to 26.5 GHz are supported.

- HP4275A LCR meter. Provides capacitance measurements from 100 kHz to 10 MHz. A resolution of 4 fF can be obtained using probe pads on the chip surface and shielded probes.

- Capacitance and microwave shielded probing will be via GGB model 40 picoprobes with ground-signal-ground and ground-signal$_1$-signal$_2$-ground configurations.

- Focused Ion Beam Work Station FEI Model 610 (Ga LMIS, 280 Å beam, 5-30 kV, chemically enhanced selective etching, selective deposition of platinum). Used to cut through devices to permit in-wafer, cross-sectional SEM imaging, and to prepare selected regions for cross-sectional TEM (lattice imaging demonstrated).

- Low Voltage Field Emission Scanning Electron Microscope model JEOL JSM-6400F (15 Åresolution at 30 kV; 70 Å image resolution at 1 kV; 0.5-30 kV) with a Raith ELPHY E-beam lithography system (< 0.1 μm capability).

- JEOL JSM-6400F (15 Å resolution at 30 kV; 70 Å image resolution at 1 kV; 0.5-30 kV) with a Link Pentafet (energy dispersive x-ray analysis system).

- Scanned Probe Microscopes Digital Instruments Nanoscope III (STM, Multi-mode system including Tapping-Mode and Contact-Mode Atomic Force Microscopy; Magnetic Force Microscopy; Electrostatic Force Imaging (Surface Potential Imaging to be added for project); scan ranges to 150x150 μm).

- 2 Digital Instruments Nanoscope II's (STM, Contact-Mode AFM; scan ranges to 150x150 μm).

- JEOL Ultra-High Vacuum STM (Nanoscope compatible; atomic resolution semiconductor imaging).

- Secondary Ion Mass Spectrometer (AIF) Cameca IMS-3f (>1 μm mass-selected imaging resolution; mass resolution (M/dM) of 10,000; detection limit of, for example, 1014 cm $^{-3}$ for boron).

- High Resolution Scanning Auger Microprobe (AIF) JEOL JAMP-30 (LaB6 SEM: 500 Å Auger probe) with a CMA (electron energy spectrometer: 0.3-1.0% energy resolution)

- High Resolution Transmission Electron Microscope for Elemental Analysis (AIF) Topcon 002B (TEM: 2.4 Å point-to-point resolution, 1.4 Å lattice resolution; 20kV - 200kV) with a Noran Voyager II (energy dispersive x-ray analysis system).

- Ultra High Resolution Transmission Electron Microscope (AIF) Topcon 002B (TEM: 1.8 Å point-to-point resolution, 1.4 Å lattice resolution; 20 kV - 200 kV)

- Scanning Transmission Electron Microscope for Elemental Analysis (AIF) Hitachi H-800 (STEM: 2.05 Å Resolution, 75–200 kV) with a Noran Series II (energy dispersive x-ray analysis system)

- Electron Beam/IC Test Instrument (AIF) Advantest E1231 Electron Beam Test System — stroboscopic imaging, quantitative waveform measurements, 0.1 μm spatial resolution, 10 mV voltage resolution, 10 ps time resolution (research demonstration).

- An Atomic Force Microscope has been developed which enables capacitance of structures to be determined for nanometer scale structures.

3.8 Test Structure Assignment

Important considerations are

- **Lengths**
  Each transmission line structure is repeated three times at different lengths.

- **Area Budget**
  - The total die area is 1.6 cm $\times$ 2.0 cm, including Process Control Monitors.
  - The working size is 0.9 cm $\times$ 1.9 cm.
  - A unit is 100 μm^2.
  - The working area is 1,710,000 units.
  - Each pad shown in Figures 9 (a) and (b) is 25 units.

3.9 Details of Structures: Conventional Fixturing

This section details the structures that will be measured using conventional mechanical probing techniques. There will be more structures than can be measured using conventional fixture probes, because we are area–limited by the size of the probe pads (50 μm on a side). We should be able to fit all of the structures on the chip if we eliminate the large probe pads (as we will be able to do in the ACM measurements). The tradeoff is that we will not be able to make as many ACM measurements, as they are very time-intensive.

Each structure will be completely surrounded by guardbanding to insure that it is well–isolated from other structures. The guardbanding will consist of a ring of metal on each metallization layer; these rings will then be attached to each other and to the substrate using enough vias to guarantee a "good" ground.

Some structures will be laid out at three different lengths; this is required for microwave measurement calibration. Layout lengths are indicated in the description of each structure, if applicable.

Some structures will be laid out at various widths; this is to test an idea for a table–lookup model of interconnect characteristics, and to test the minimum allowed feature size of the process. We intend to use parameters measured from three widths to calibrate a quasi–analytic transmission line model; a fourth width is required to validate the model. There will also be two small widths for feature–size testing. Note that different widths are identified in separate structure descriptions.

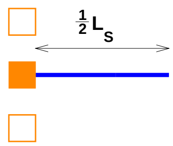
The structure descriptions contain the following information:

- **Index** provides a unique identifier for each structure.
- **Description** gives a short text description of the structure.
- **Dimensions** gives (where applicable) the length and width of the structure under test. Note that these dimensions do not include guardbanding or pad connections.
- **Measurement Plan** indicates the proposed measurement technique(s).
- **Plan View** shows schematic view of object from above. Not to scale.
- **Cross-Section** shows schematic view of object in cross-section. Not to scale.
- **Instances** graphically enumerates all layouts of the proposed structures. Not to scale.

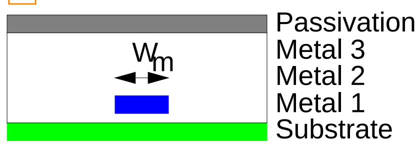
3.9.1 Fixture/Process Calibration Structures

Index:	CAL(1, 2, 3)
Description:	Fixture calibration structure, straight, metal 1, 2, 3.
Dimensions:	$L = \frac{1}{2}L_S$, $W = W_M$
Measurement Plan:	microwave transmission line parameters

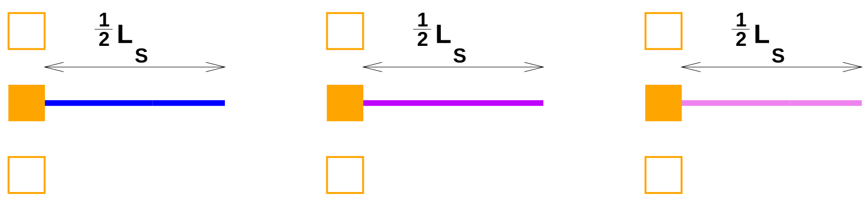
Plan View:



Cross-Section:

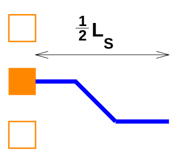


Instances:

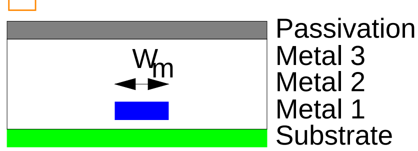


Index:	CALB(1, 2, 3)
Description:	Fixture calibration structure with bend, metal 1, 2, 3.
Dimensions:	$L = \frac{1}{2}L_S$, $W = W_M$
Measurement Plan:	microwave transmission line parameters

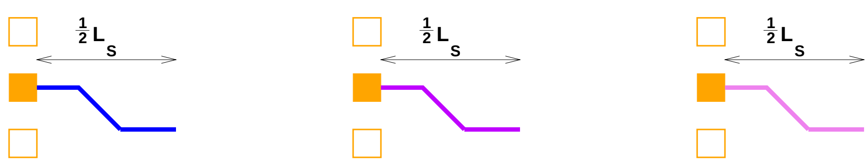
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

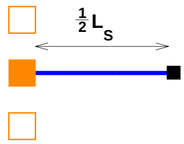
Index: CS(1, 2, 3)

Description: Fixture calibration structure, straight, metal 1, 2, 3. Grounded to epi (small ground connection).

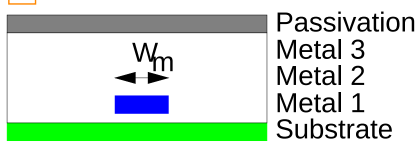
Dimensions: $L = \frac{1}{2}L_S$, $W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



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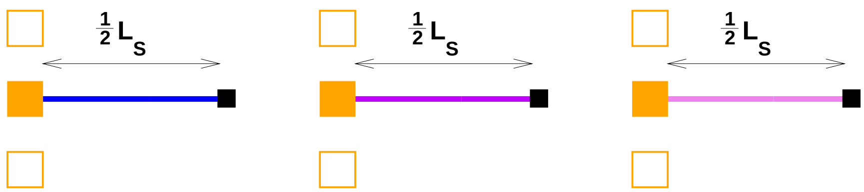


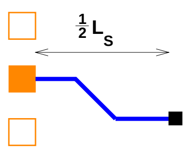
Index: CBS(1, 2, 3)

Description: Fixture calibration structure with bend, metal 1, 2, 3. Grounded to epi (small ground connection).

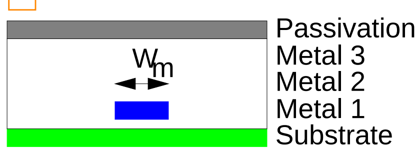
Dimensions: $L = \frac{1}{2}L_S$, $W = W_M$

Measurement Plan: microwave transmission line parameters

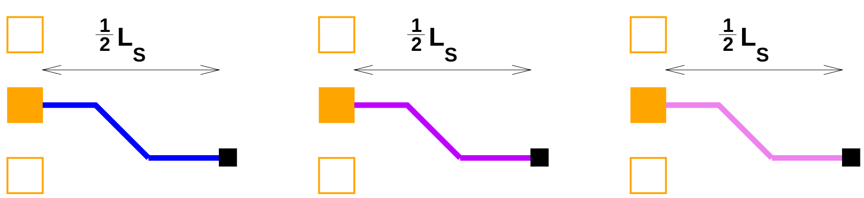
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

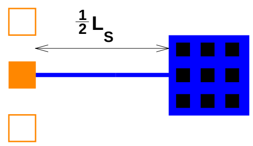
Index: CAL(1, 2, 3)

Description: Fixture calibration structure, straight, metal 1, 2, 3. Grounded to epi (large ground connection).

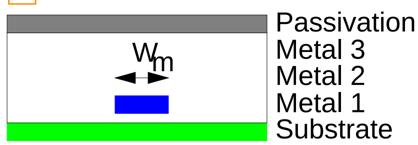
Dimensions: $L = \frac{1}{2} L_S$, $W = W_M$

Measurement Plan: microwave transmission line parameters

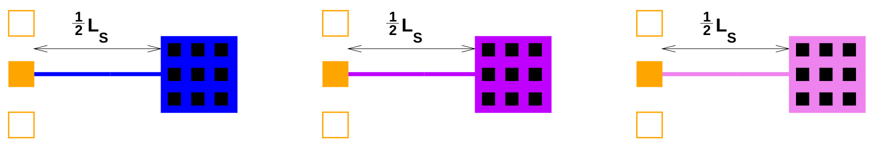
Plan View:



Cross-Section:



Instances:



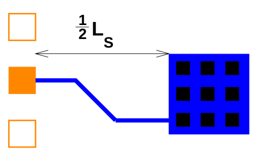
Index: CAL(1, 2, 3)

Description: Fixture calibration structure with bend, metal 1, 2, 3. Grounded to epi (large ground connection).

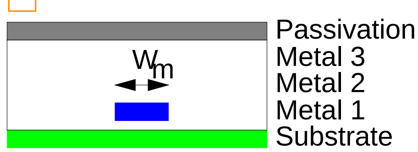
Dimensions: $L = \frac{1}{2} L_S$, $W = W_M$

Measurement Plan: microwave transmission line parameters

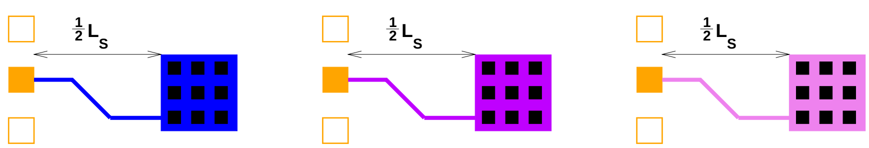
Plan View:



Cross-Section:



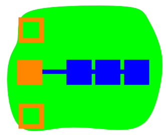
Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

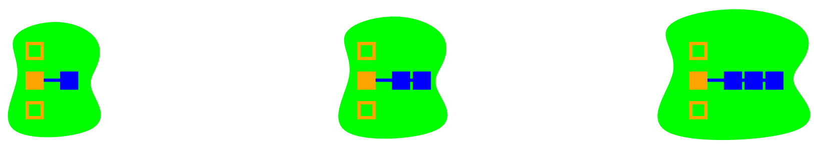
Index: P1S(A, B, C)
Description: Metal 1 to substrate capacitance
Dimensions: $L = 50\mu\text{m}$, $W = 50\mu\text{m}$ (per pad; A=60, B=100, C=160 pads)
Measurement Plan: conventional capacitance

Plan View:



Cross-Section:

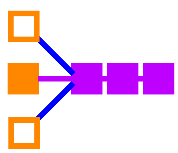
Instances:



Note: Actual number of 50um x 50um blocks will vary.

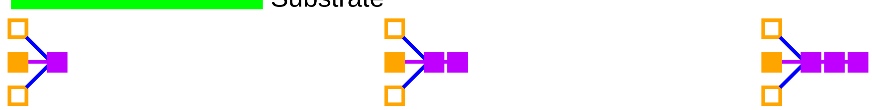
Index: P21(A, B, C)
Description: Metal 1 to metal 2 capacitance
Dimensions: $L = 50\mu\text{m}$, $W = 50\mu\text{m}$ (per pad; A=60, B=100, C=160 pads)
Measurement Plan: conventional capacitance

Plan View:



Cross-Section:

Instances:

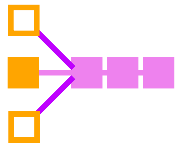


Note: Actual number of 50um x 50um blocks will vary.

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

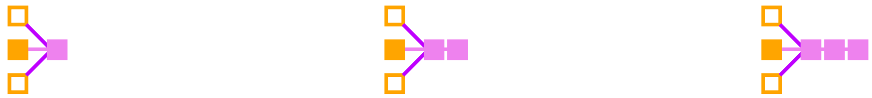
Index: P32(A, B, C)
Description: Metal 2 to metal 3 capacitance
Dimensions: $L = 50\mu\text{m}$, $W = 50\mu\text{m}$ (per pad; A=60, B=100, C=160 pads)
Measurement Plan: conventional capacitance

Plan View:



Cross-Section:

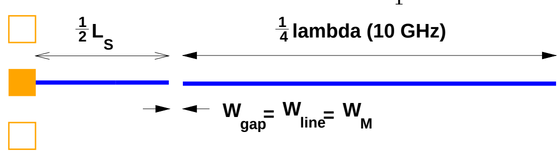
Instances:



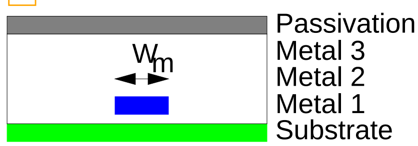
Note: Actual number of 50um x 50um blocks will vary.

Index: RES(1, 3)
Description: Weakly coupled $\lambda/4$ resonator.
Dimensions: $L = \frac{\lambda}{4}$ at 10 GHz ($3799.5\mu\text{m}$), $W = W_M$, $W_{gap} = W_M$
Measurement Plan: microwave transmission line parameters

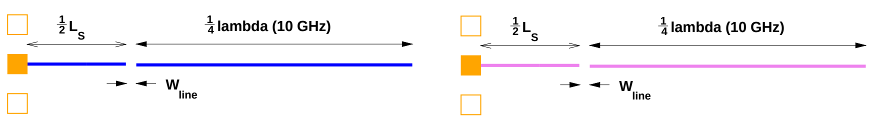
Plan View:



Cross-Section:



Instances:



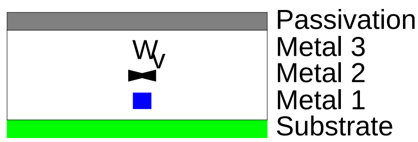
$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

3.9.2 Strip Line

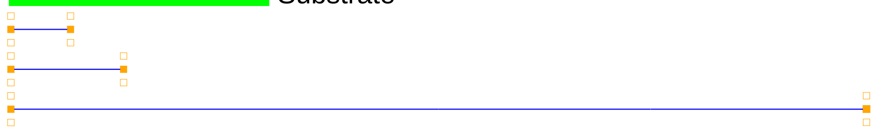
Index:	U1V(S, M, L)
Description:	Very tiny width microstrip line, metal 1.
Dimensions:	$L = L_S, L_M, L_L$; $W = W_V$
Measurement Plan:	microwave transmission line parameters

Plan View:

Cross-Section:



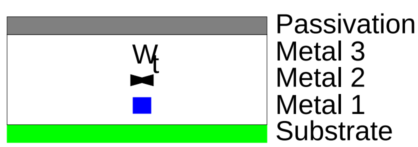
Instances:



Index:	U1T(S, M, L)
Description:	Tiny width microstrip line, metal 1.
Dimensions:	$L = L_S, L_M, L_L$; $W = W_T$
Measurement Plan:	microwave transmission line parameters

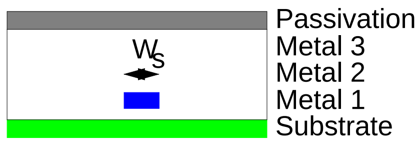
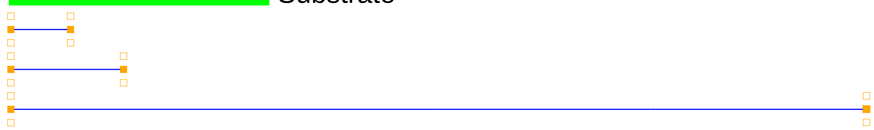
Plan View:

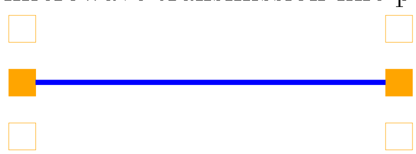
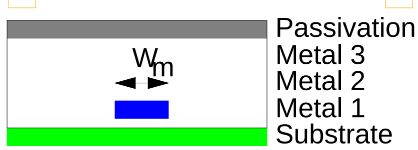
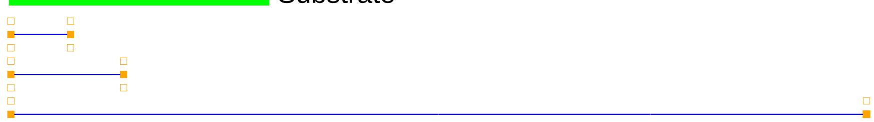
Cross-Section:



Instances:

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index:	U1S(S, M, L)
Description:	Small width microstrip line, metal 1.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_S$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

Index:	U1M(S, M, L)
Description:	Medium width microstrip line, metal 1.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index: U1X(S, M, L)

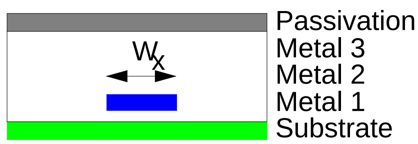
Description: Experimental width microstrip line, metal 1.

Dimensions: $L = L_S, L_M, L_L; W = W_X$

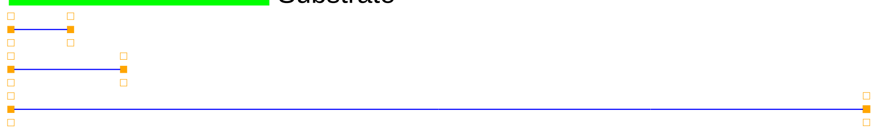
Measurement Plan: microwave transmission line parameters

Plan View:

Cross-Section:



Instances:



Index: U1W(S, M, L)

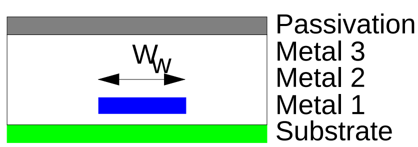
Description: Wide width microstrip line, metal 1.

Dimensions: $L = L_S, L_M, L_L; W = W_W$

Measurement Plan: microwave transmission line parameters

Plan View:

Cross-Section:



Instances:

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

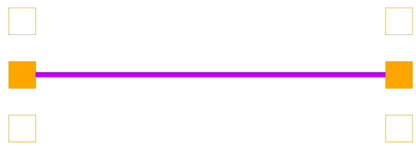
Index: U2V(S, M, L)

Description: Very tiny width microstrip line, metal 2.

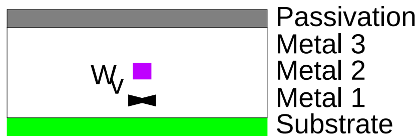
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_V$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

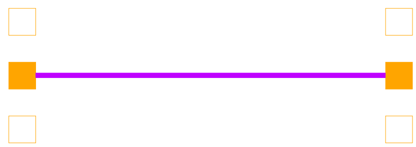
Index: U2T(S, M, L)

Description: Tiny width microstrip line, metal 2.

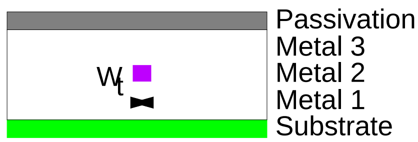
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_T$

Measurement Plan: microwave transmission line parameters

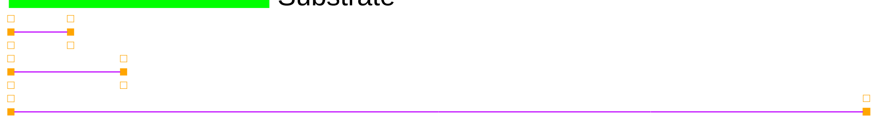
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu$m $W_T = 0.35\mu$m $W_S = 0.45\mu$m $W_M = 0.5\mu$m $W_X = 0.6\mu$m $W_W = 0.7\mu$m
$S_S = 0.45\mu$m $S_M = 0.5\mu$m $S_X = 0.6\mu$m $S_W = 0.7\mu$m
$L_S = 400\mu$m $L_M = 800\mu$m $L_L = 6400\mu$m

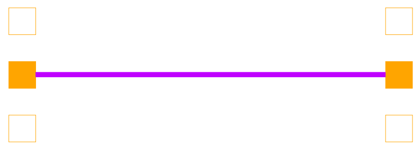
Index: U2S(S, M, L)

Description: Small width microstrip line, metal 2.

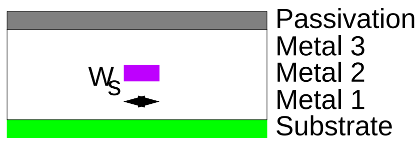
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_S$

Measurement Plan: microwave transmission line parameters

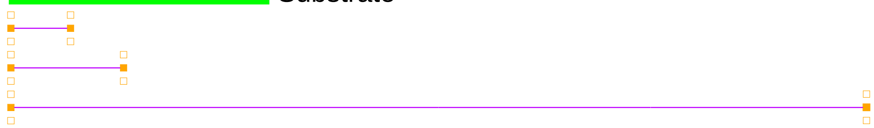
Plan View:



Cross-Section:



Instances:



Index: U2M(S, M, L)

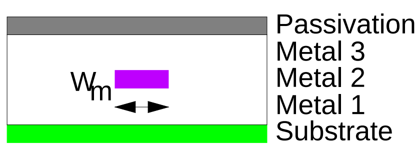
Description: Medium width microstrip line, metal 2.

Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:

Cross-Section:



Instances:

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index: U2X(S, M, L)

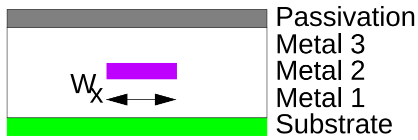
Description: Experimental width microstrip line, metal 2.

Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_X$

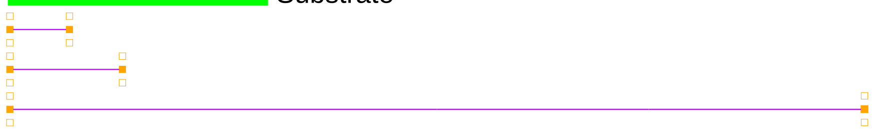
Measurement Plan: microwave transmission line parameters

Plan View:

Cross-Section:



Instances:



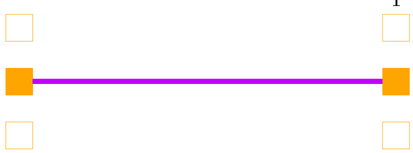
Index: U2W(S, M, L)

Description: Wide width microstrip line, metal 2.

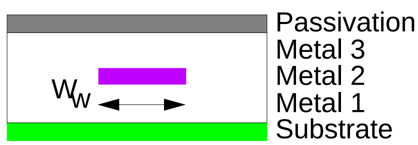
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_W$

Measurement Plan: microwave transmission line parameters

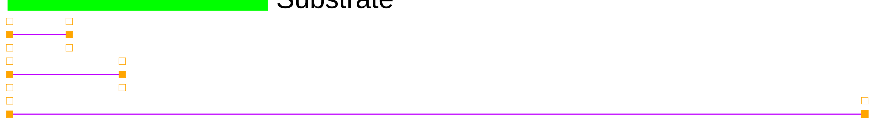
Plan View:



Cross-Section:



Instances:

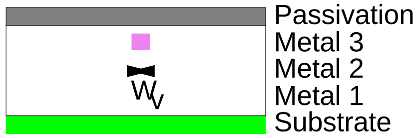


$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

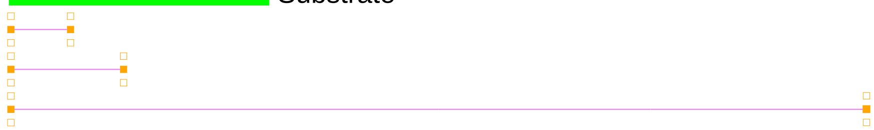
Index: U3V(S, M, L)
Description: Very tiny width microstrip line, metal 3.
Dimensions: $L = L_S, L_M, L_L; W = W_V$
Measurement Plan: microwave transmission line parameters

Plan View:

Cross-Section:

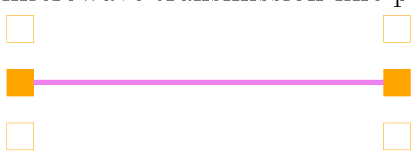


Instances:

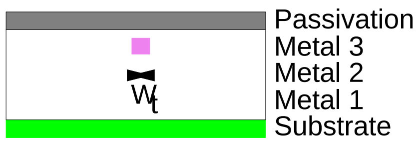


Index: U3T(S, M, L)
Description: Tiny width microstrip line, metal 3.
Dimensions: $L = L_S, L_M, L_L; W = W_T$
Measurement Plan: microwave transmission line parameters

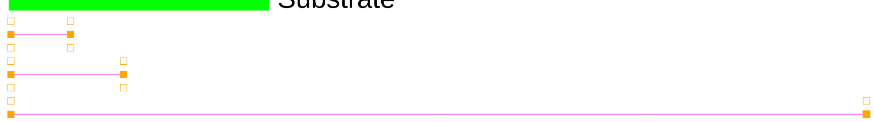
Plan View:



Cross-Section:



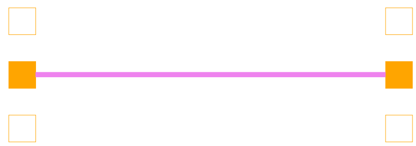
Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

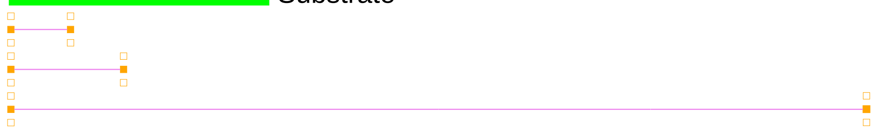
Index: U3S(S, M, L)
Description: Small width microstrip line, metal 3.
Dimensions: $L = L_S, L_M, L_L; W = W_S$
Measurement Plan: microwave transmission line parameters

Plan View:



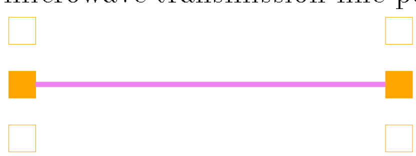
Cross-Section:

Instances:

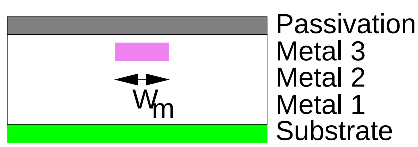


Index: U3M(S, M, L)
Description: Medium width microstrip line, metal 3.
Dimensions: $L = L_S, L_M, L_L; W = W_M$
Measurement Plan: microwave transmission line parameters

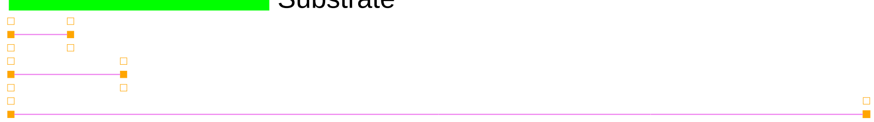
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

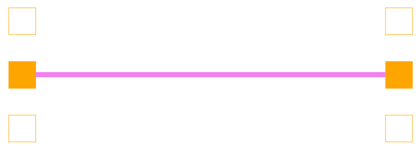
Index: U3X(S, M, L)

Description: Experimental width microstrip line, metal 3.

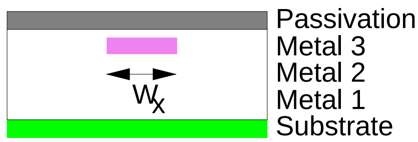
Dimensions: $L = L_S, L_M, L_L; W = W_X$

Measurement Plan: microwave transmission line parameters

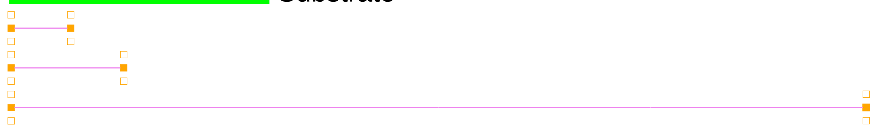
Plan View:



Cross-Section:



Instances:



Index: U3W(S, M, L)

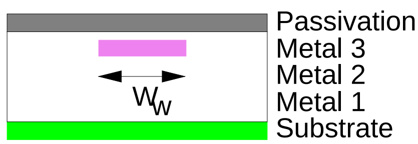
Description: Wide width microstrip line, metal 3.

Dimensions: $L = L_S, L_M, L_L; W = W_W$

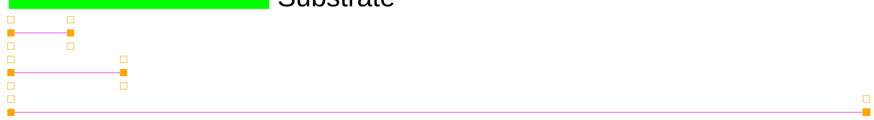
Measurement Plan: microwave transmission line parameters

Plan View:

Cross-Section:

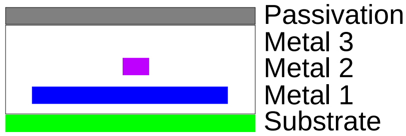
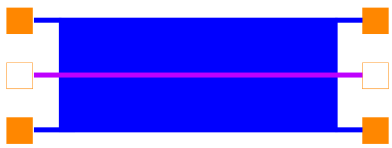


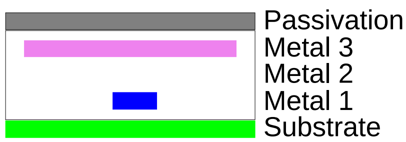
Instances:



$W_V = 0.25\mu$m $W_T = 0.35\mu$m $W_S = 0.45\mu$m $W_M = 0.5\mu$m $W_X = 0.6\mu$m $W_W = 0.7\mu$m
$S_S = 0.45\mu$m $S_M = 0.5\mu$m $S_X = 0.6\mu$m $S_W = 0.7\mu$m
$L_S = 400\mu$m $L_M = 800\mu$m $L_L = 6400\mu$m

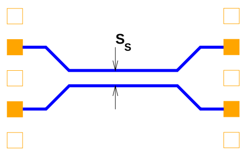
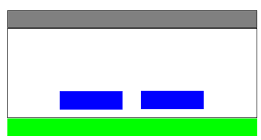
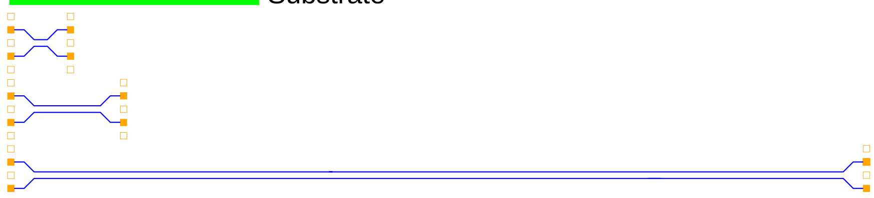
3.9.3 Single Line with Ground Plane

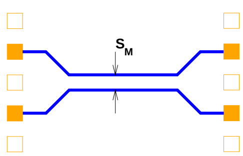
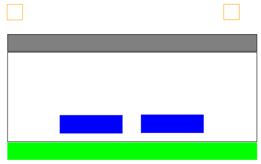
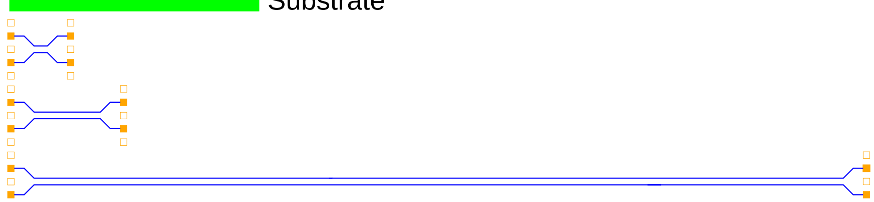
Index:	2OG(S, M, L)
Description:	M2 line over M1 ground plane.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

Index:	1UG(S, M, L)
Description:	M1 line under M3 ground plane.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

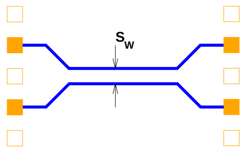
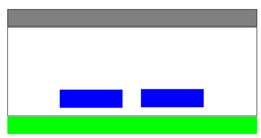
$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

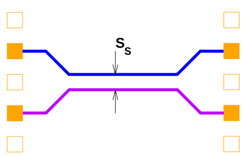
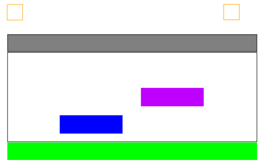
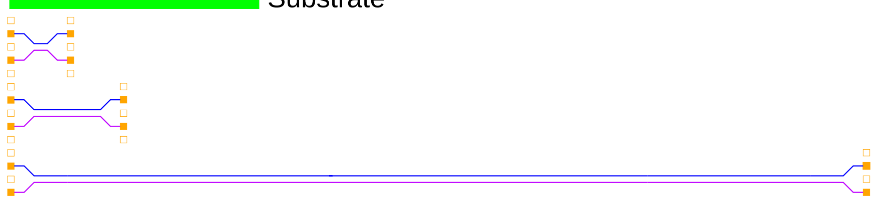
3.9.4 Two Coupled Strip Lines

Index:	C11S(S, M, L)
Description:	Parallel lines, metal 1 to metal 1, small separation.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

Index:	C11M(S, M, L)
Description:	Parallel lines, metal 1 to metal 1, medium separation.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index:	C11W(S, M, L)
Description:	Parallel lines, metal 1 to metal 1, wide separation.
Dimensions:	$L = L_S, L_M, L_L$; $W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

Index:	C12S(S, M, L)
Description:	Parallel lines, metal 1 to metal 2, small separation.
Dimensions:	$L = L_S, L_M, L_L$; $W = W_M$
Measurement Plan:	microwave transmission line parameters
Plan View:	
Cross-Section:	
Instances:	

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

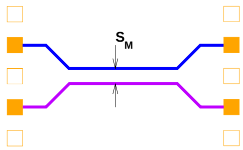
Index: C12M(S, M, L)

Description: Parallel lines, metal 1 to metal 2, medium separation.

Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:

Instances:

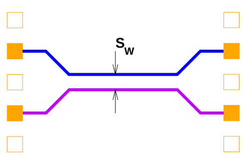
Index: C12W(S, M, L)

Description: Parallel lines, metal 1 to metal 2, wide separation.

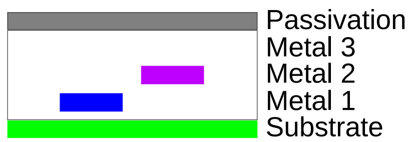
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

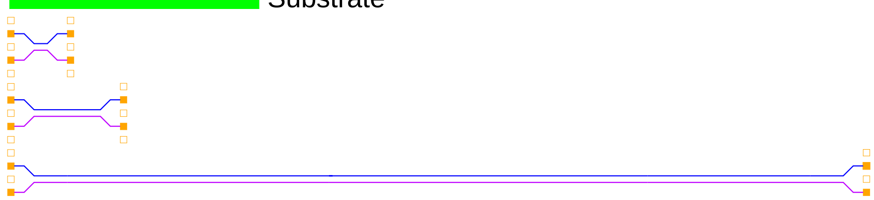
Plan View:



Cross-Section:



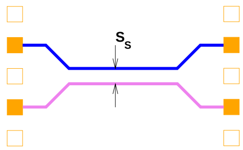
Instances:



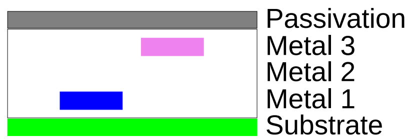
$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index: C13S(S, M, L)
Description: Parallel lines, metal 1 to metal 3, small separation.
Dimensions: $L = L_S, L_M, L_L; W = W_M$
Measurement Plan: microwave transmission line parameters

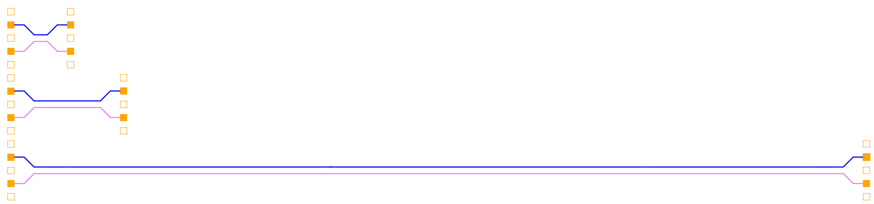
Plan View:



Cross-Section:

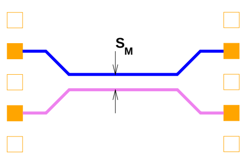


Instances:



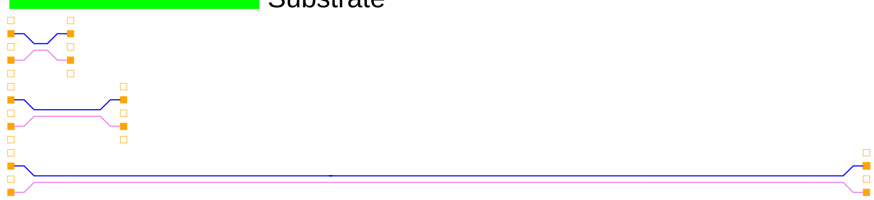
Index: C13M(S, M, L)
Description: Parallel lines, metal 1 to metal 3, medium separation.
Dimensions: $L = L_S, L_M, L_L; W = W_M$
Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:

Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

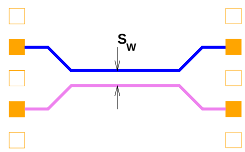
Index: C13W(S, M, L)

Description: Parallel lines, metal 1 to metal 3, wide separation.

Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

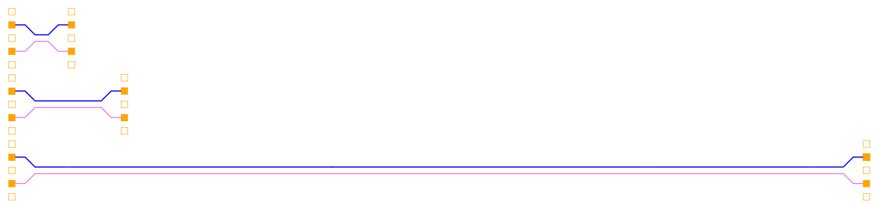
Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:

Instances:



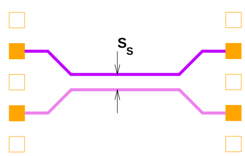
Index: C23S(S, M, L)

Description: Parallel lines, metal 2 to metal 3, small separation.

Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

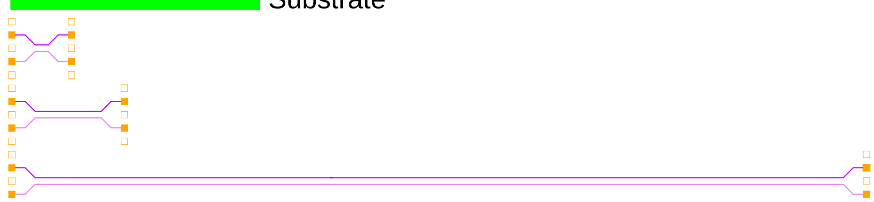
Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:

Instances:



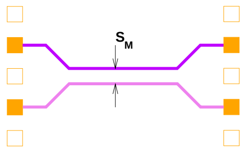
$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$

$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$

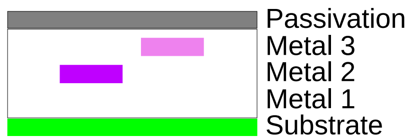
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index: C23M(S, M, L)
Description: Parallel lines, metal 2 to metal 3, medium separation.
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan: microwave transmission line parameters

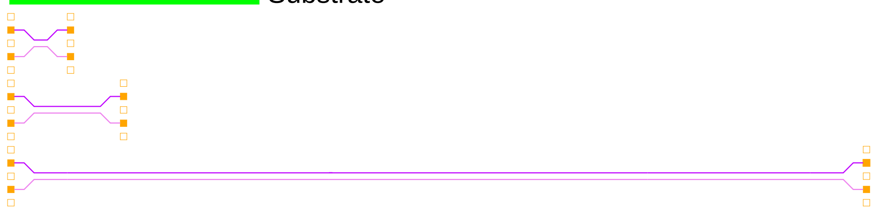
Plan View:



Cross-Section:

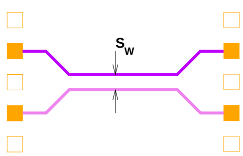


Instances:



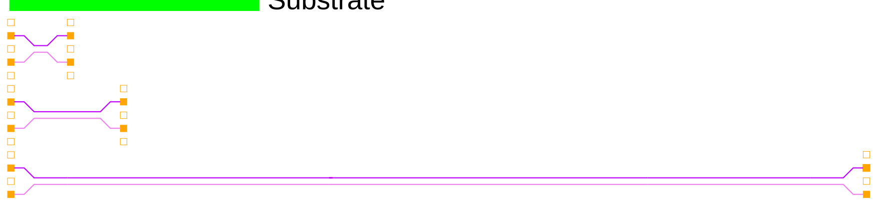
Index: C23W(S, M, L)
Description: Parallel lines, metal 2 to metal 3, wide separation.
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:

Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

3.9.5 Three Coupled Strip Lines

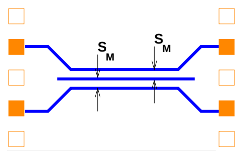
Index: 3CC(S, M, L)

Description: Three parallel lines, metal 1, medium separation, center conductor grounded.

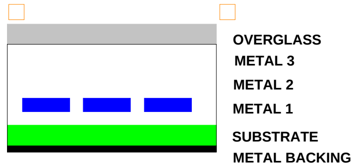
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

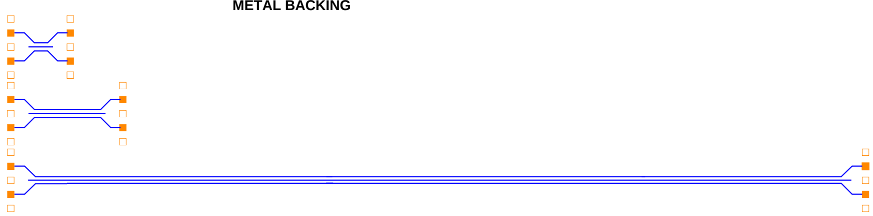
Plan View:



Cross-Section:



Instances:



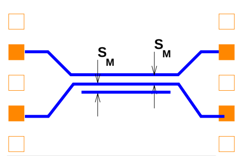
Index: 3CO(S, M, L)

Description: Three parallel lines, metal 1, medium separation, outside conductor grounded.

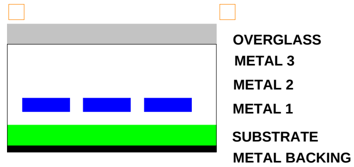
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

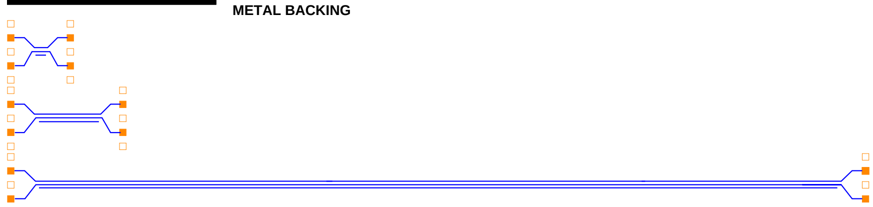
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu\text{m}\ W_T = 0.35\mu\text{m}\ W_S = 0.45\mu\text{m}\ W_M = 0.5\mu\text{m}\ W_X = 0.6\mu\text{m}\ W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}\ S_M = 0.5\mu\text{m}\ S_X = 0.6\mu\text{m}\ S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}\ L_M = 800\mu\text{m}\ L_L = 6400\mu\text{m}$

3.9.6 Other Coupled Strip Line Structures

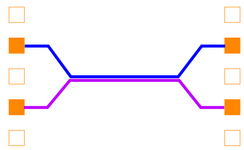
Index: 12ABT(S, M, L)

Description: Abutting lines, metal 1 to metal 2.

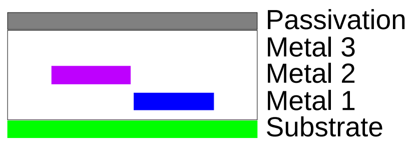
Dimensions: $L = L_S, L_M, L_L; W = W_M$

Measurement Plan: microwave transmission line parameters

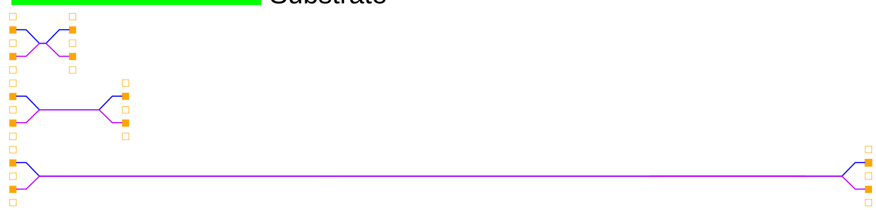
Plan View:



Cross-Section:



Instances:



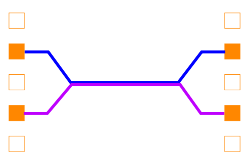
Index: 12OVL(S, M, L)

Description: Partially overlapped lines, metal 1 to metal 2.

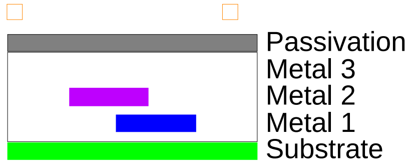
Dimensions: $L = L_S, L_M, L_L; W = W_M$

Measurement Plan: microwave transmission line parameters

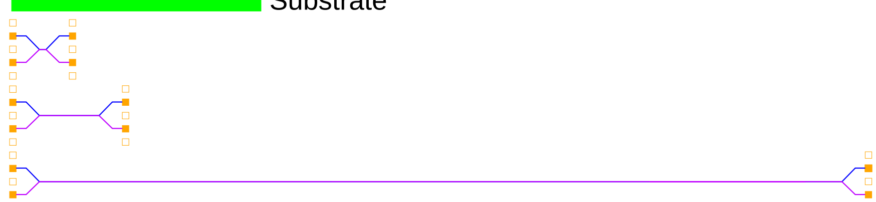
Plan View:



Cross-Section:



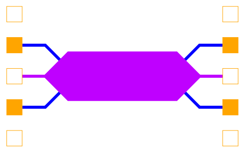
Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index:	11UG(S, M, L)
Description:	Coupled lines under metal ground plane.
Dimensions:	$L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan:	microwave transmission line parameters

Plan View:



Cross-Section:

Instances:

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

3.9.7 Gridded Ground Plane Structures

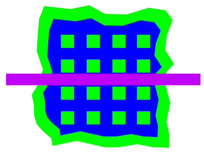
Index: UGP(S, M, L)

Description: Single line over gridded ground plane.

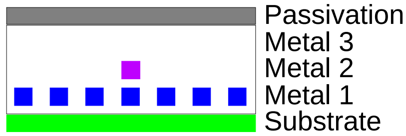
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

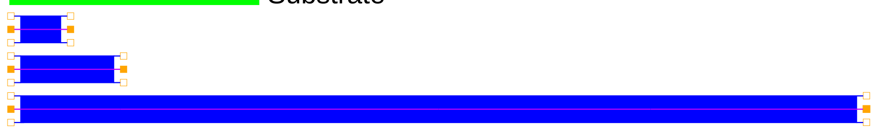
Plan View:



Cross-Section:



Instances:



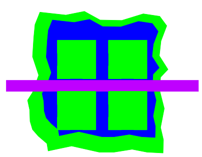
Index: UGPW(S, M, L)

Description: Single line over gridded ground plane, wide pitch.

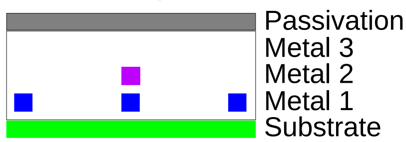
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

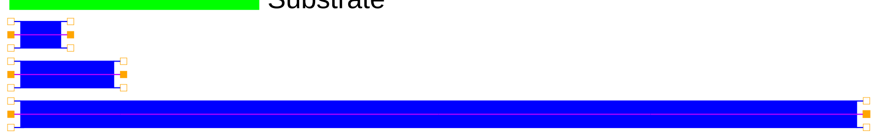
Plan View:



Cross-Section:



Instances:



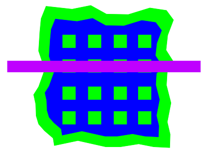
$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$

$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$

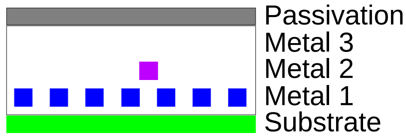
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index: UOGP(S, M, L)
Description: Offset line over gridded ground plane.
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan: microwave transmission line parameters

Plan View:



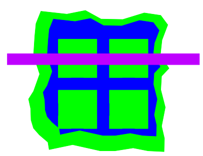
Cross-Section:



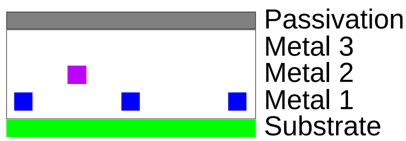
Instances:

Index: UOGPW(S, M, L)
Description: Offset line over gridded ground plane, wide pitch.
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$
Measurement Plan: microwave transmission line parameters

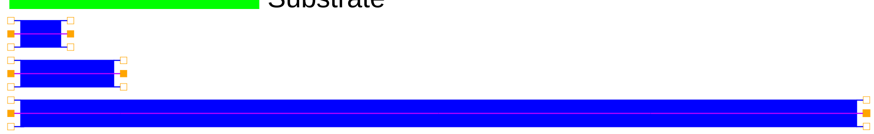
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

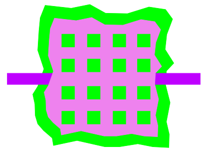
Index: UBGP(S, M, L)

Description: Single line between gridded ground planes.

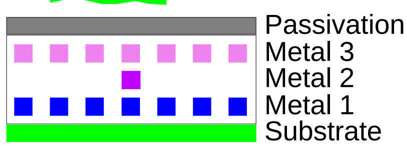
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

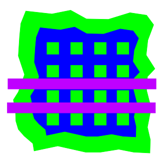
Index: CGP(S, M, L)

Description: Coupled lines over gridded ground plane.

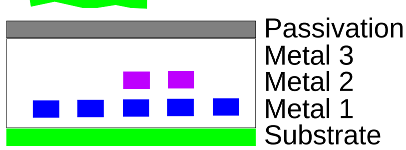
Dimensions: $L = L_S,\ L_M,\ L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

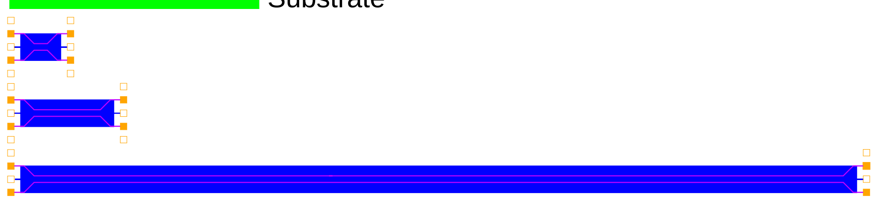
Plan View:



Cross-Section:



Instances:



$W_V = 0.25\mu\text{m}\ W_T = 0.35\mu\text{m}\ W_S = 0.45\mu\text{m}\ W_M = 0.5\mu\text{m}\ W_X = 0.6\mu\text{m}\ W_W = 0.7\mu\text{m}$

$S_S = 0.45\mu\text{m}\ S_M = 0.5\mu\text{m}\ S_X = 0.6\mu\text{m}\ S_W = 0.7\mu\text{m}$

$L_S = 400\mu\text{m}\ L_M = 800\mu\text{m}\ L_L = 6400\mu\text{m}$

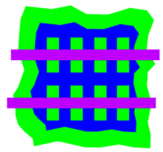
Index: CGPW(S, M, L)

Description: Coupled lines over gridded ground plane, wide separation.

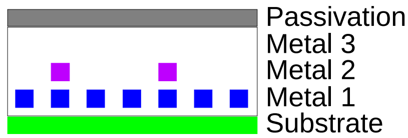
Dimensions: $L = L_S, L_M, L_L$; $W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

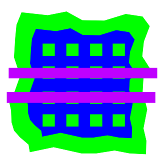
Index: COGP(S, M, L)

Description: Offset coupled lines over gridded ground plane.

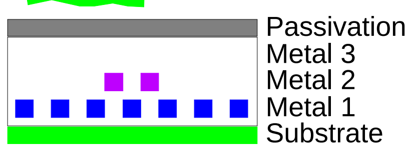
Dimensions: $L = L_S, L_M, L_L$; $W = W_M$

Measurement Plan: microwave transmission line parameters

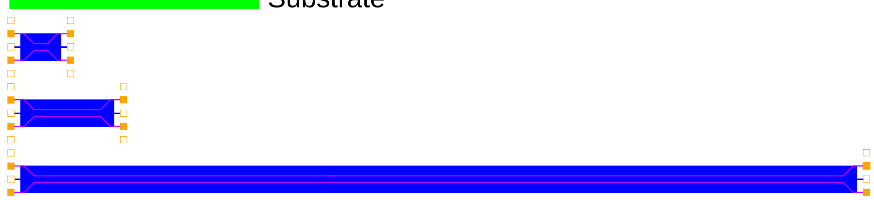
Plan View:



Cross-Section:



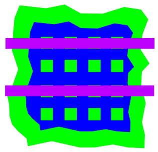
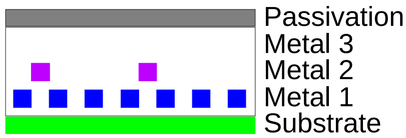
Instances:



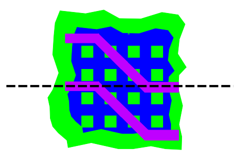
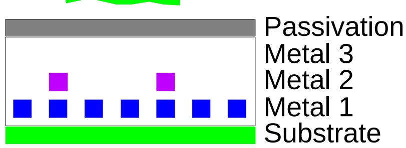
$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$

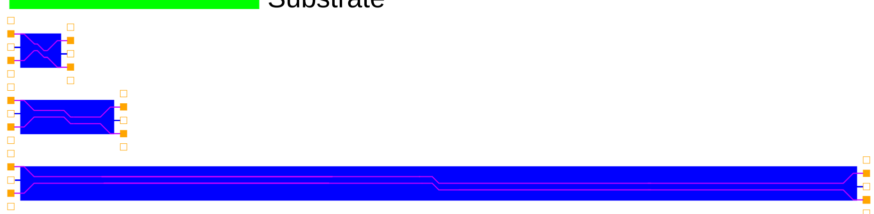
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$

$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

Index: COGPW(S, M, L)
Description: Offset coupled lines over gridded ground plane, wide separation.
Dimensions: $L = L_S, L_M, L_L$; $W = W_M$
Measurement Plan: microwave transmission line parameters
Plan View:

Cross-Section:


Instances:


Index: CJGP(S, M, L)
Description: Coupled lines with jog over gridded ground plane.
Dimensions: $L = L_S, L_M, L_L$; $W = W_M$
Measurement Plan: microwave transmission line parameters
Plan View:

Cross-Section:


Instances:


$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

3.9.8 Simulated Bus Structures (Crossovers)

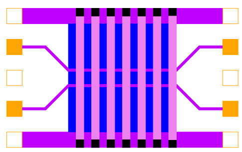
Index: XLL(S, M, L)

Description: Coupled lines with orthogonal loading above and below, between parallel busses.

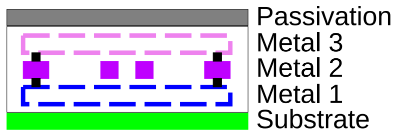
Dimensions: $L = L_S, L_M, L_L$; $W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

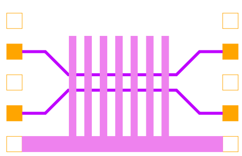
Index: XBUS(S, M, L)

Description: Coupled lines with orthogonal bus-like loading above.

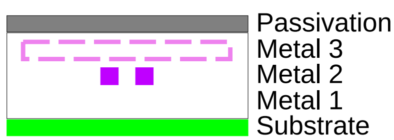
Dimensions: $L = L_S, L_M, L_L$; $W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

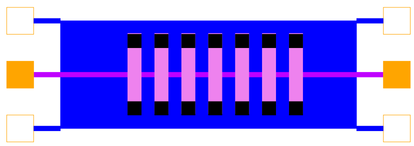
Index: XWL(S, M, L)

Description: Single line over wide line with orthogonal loading above.

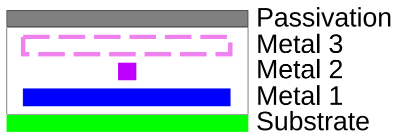
Dimensions: $L = L_S, L_M, L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

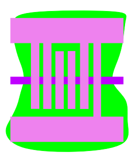
Index: XRND(S, M, L)

Description: Single line with random orthogonal loading above.

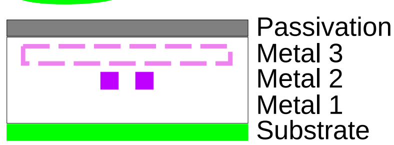
Dimensions: $L = L_S, L_M, L_L;\ W = W_M$

Measurement Plan: microwave transmission line parameters

Plan View:



Cross-Section:



Instances:

$W_V = 0.25\mu\text{m}$ $W_T = 0.35\mu\text{m}$ $W_S = 0.45\mu\text{m}$ $W_M = 0.5\mu\text{m}$ $W_X = 0.6\mu\text{m}$ $W_W = 0.7\mu\text{m}$
$S_S = 0.45\mu\text{m}$ $S_M = 0.5\mu\text{m}$ $S_X = 0.6\mu\text{m}$ $S_W = 0.7\mu\text{m}$
$L_S = 400\mu\text{m}$ $L_M = 800\mu\text{m}$ $L_L = 6400\mu\text{m}$

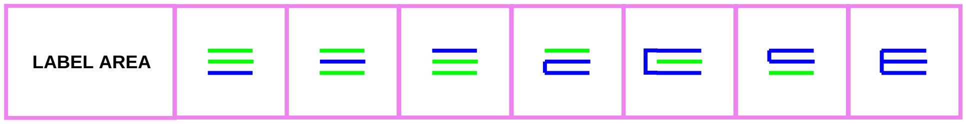


Figure 10: Schematic view of required signal/ground permutations for three–conductor networks. Blue denotes the line to be measured, green denotes a grounded line. Note also the guardbanding around each structure (not to scale—the guardbanding boxes will be 50μm$\times$50μm for each structure, while the label area will be 100μm$\times$50μm).

3.10 Details of Structures: ACM Fixturing

ACM is required for those structures which are not amenable to conventional probing (usually because the capacitances in question are too small to resolve with standard techniques). Previously we showed methods to derive desired capacitance values from measured values. In that discussion, it was noted that measuring parameters for three-line structures requires seven different signal/ground permutations per three-line system. Similarly, a two-line system (e.g. crossovers and layer changes) requires three different signal/ground permutations per structure. Because of the physical characteristics of the ACM, measurement time will be minimized by laying out these structures in a line. A schematic example of what this will look like (including guardbanding and label) is shown in Figure 10.

Note also that we have provided at least two copies of each structure. One of the copies has a 2μm$\times$2μm probing pad (and associated passivation window) attached; the other copy does not. Some of the structures which do not have the pad structure attached will be processed using FIB milling to open a passivation window for ACM probing.

Because of the sheer number of structures listed, we will not show graphically every structure to be built; rather, we will provide a schematic view of the structure, and then list all structures based on the schematic, giving index number and a short description. The structure descriptions contain the following information:

- **General Description** gives a short text description of the structure.
- **Plan View** shows schematic view of object from above. Not to scale.
- **Cross-Section** shows schematic view of object in cross-section. Not to scale.
- **Instances** lists all layouts of the proposed structures, including index names. Note that each item listed here will have a layout instance similar to that shown in Figure 10. Note also that if a structure is to be laid out at different lengths, the lengths will follow the index name and will be parenthesized.
- **Ordering** shows how the layouts will be grouped.

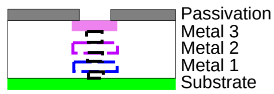
Note that the **Measurement Plan** for all structures in this section is ACM.

3.10.1 Fixture Calibration Structures

Description: Structures for de–embedding fixture parasitics

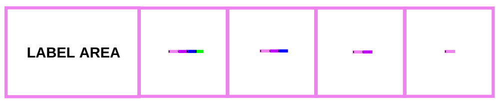
Plan View:

Cross-Section:



Instances: F: Fixture pads to M1, M2, M3, short to substrate

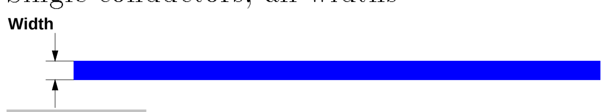
Ordering:



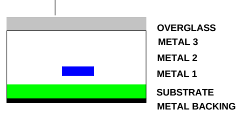
3.10.2 Single Conductors

Description: Single conductors, all widths

Plan View:



Cross-Section:



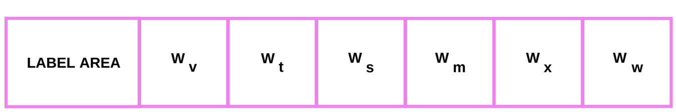
Instances:

UA1(A, B): M1, all widths

UA2(A, B): M2, all widths

UA3(A, B): M3, all widths

Ordering:

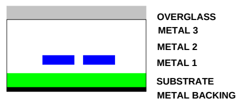


3.10.3 Two Coplanar Conductors

Description: Two coplanar conductors

Plan View:

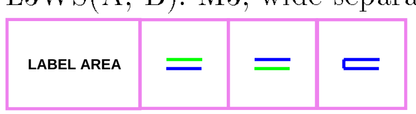
Cross-Section:



Instances:

L1SS(A, B): M1, small separation, small width
L1MS(A, B): M1, medium separation, small width
L1MM(A, B): M1, medium separation, medium width
L1MX(A, B): M1, medium separation, experimental width
L1MW(A, B): M1, medium separation, wide with
L1XS(A, B): M1, experimental separation, small width
L1WS(A, B): M1, wide separation, small width
L2SS(A, B): M2, small separation, small width
L2MS(A, b): M2, medium separation, small width
L2MM(A, B): M2, medium separation, medium width
L2MX(A, B): M2, medium separation, experimental width
L2MW(A, B): M2, medium separation, wide with
L2XS(A, B): M2, experimental separation, small width
L2WS(A, B): M2, wide separation, small width
L3SS(A, B): M3, small separation, small width
L3MS(A, B): M3, medium separation, small width
L3MM(A, B): M3, medium separation, medium width
L3MX(A, B): M3, medium separation, experimental width
L3MW(A, B): M3, medium separation, wide with
L3XS(A, B): M3, experimental separation, small width
L3WS(A, B): M3, wide separation, small width

Ordering:

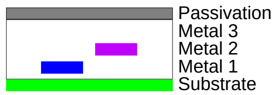


3.10.4 Two Non–Coplanar Conductors

Description: Two non-coplanar conductors

Plan View:

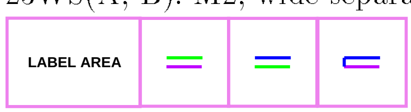
Cross-Section:



Instances:

12SS(A, B): M1 to M2, small separation, small width
12MS(A, B): M1 to M2, medium separation, small width
12MM(A, B): M1 to M2, medium separation, medium width
12MX(A, B): M1 to M2, medium separation, experimental width
12MW(A, B): M1 to M2, medium separation, wide with
12XS(A, B): M1 to M2, experimental separation, small width
12WS(A, B): M1 to M2, wide separation, small width
13SS(A, B): M1 to M3, small separation, small width
13MS(A, B): M1 to M3, medium separation, small width
13MM(A, B): M1 to M3, medium separation, medium width
13MX(A, B): M1 to M3, medium separation, experimental width
13MW(A, B): M1 to M3, medium separation, wide with
13XS(A, B): M1 to M3, experimental separation, small width
13WS(A, B): M1 to M3, wide separation, small width
23SS(A, B): M2, small separation, small width
23MS(A, b): M2, medium separation, small width
23MM(A, B): M2, medium separation, medium width
23MX(A, B): M2, medium separation, experimental width
23MW(A, B): M2, medium separation, wide with
23XS(A, B): M2, experimental separation, small width
23WS(A, B): M2, wide separation, small width

Ordering:

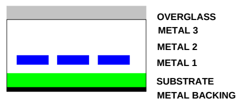


3.10.5 Three Coplanar Conductors

Description: Three coplanar conductors

Plan View:

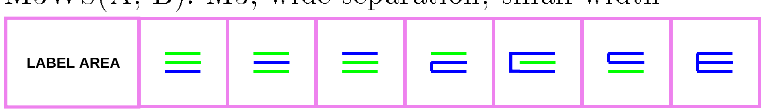
Cross-Section:



Instances:

M1SS(A, B): M1, small separation, small width
M1MS(A, B): M1, medium separation, small width
M1MM(A, B): M1, medium separation, medium width
M1MX(A, B): M1, medium separation, experimental width
M1MW(A, B): M1, medium separation, wide with
M1XS(A, B): M1, experimental separation, small width
M1WS(A, B): M1, wide separation, small width
M2SS(A, B): M2, small separation, small width
M2MS(A, B): M2, medium separation, small width
M2MM(A, B): M2, medium separation, medium width
M2MX(A, B): M2, medium separation, experimental width
M2MW(A, B): M2, medium separation, wide with
M2XS(A, B): M2, experimental separation, small width
M2WS(A, B): M2, wide separation, small width
M3SS(A, B): M3, small separation, small width
M3MS(A, B): M3, medium separation, small width
M3MM(A, B): M3, medium separation, medium width
M3MX(A, B): M3, medium separation, experimental width
M3MW(A, B): M3, medium separation, wide with
M3XS(A, B): M3, experimental separation, small width
M3WS(A, B): M3, wide separation, small width

Ordering:

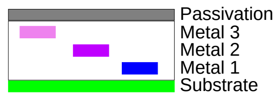


3.10.6 Three Non–Coplanar Conductors

Description: Staircase of lines

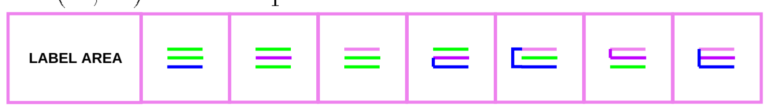
Plan View:

Cross-Section:



Instances:
SS(A, B): Small separation
SM(A, B): Medium separation
SX(A, B): Experimental separation
SW(A, B): Wide separation

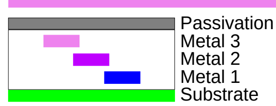
Ordering:



Description: Overlapping staircase of lines

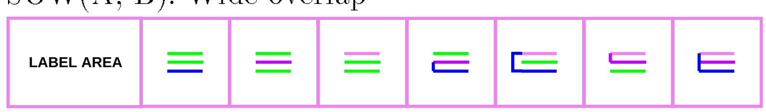
Plan View:

Cross-Section:



Instances:
SOS(A, B): Small overlap
SOM(A, B): Medium overlap
SOX(A, B): Experimental overlap
SOW(A, B): Wide overlap

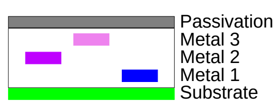
Ordering:



Description: Inverted V

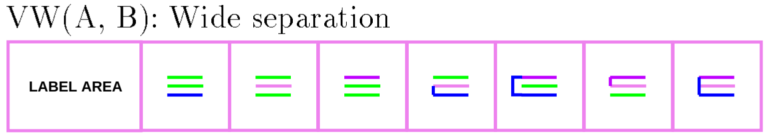
Plan View:

Cross-Section:



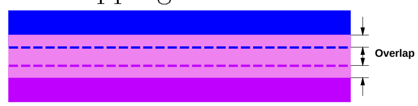
Instances:
VS(A, B): Small separation
VM(A, B): Medium separation
VX(A, B): Experimental separation
VW(A, B): Wide separation

Ordering:

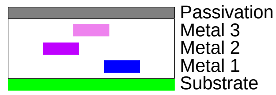


Description: Overlapping inverted V

Plan View:

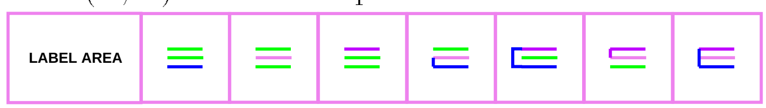


Cross-Section:



Instances: VOS(A, B): Small overlap
VOM(A, B): Medium overlap
VOX(A, B): Experimental overlap
VOW(A, B): Wide overlap

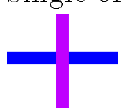
Ordering:



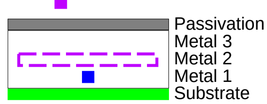
3.10.7 Crossovers

Description: Single orthogonal crossover

Plan View:

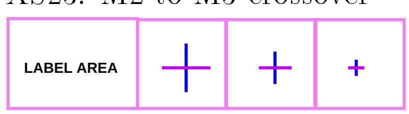


Cross-Section:



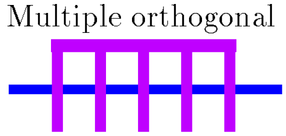
Instances: XS12: M1 to M2 crossover
XS13: M1 to M3 crossover
XS23: M2 to M3 crossover

Ordering:



Description: Multiple orthogonal crossovers

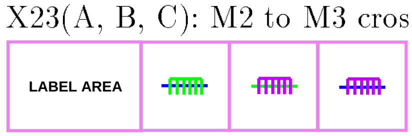
Plan View:



Cross-Section:

Instances: X12(A, B, C): M1 to M2 crossover, 3 lengths
X13(A, B, C): M1 to M3 crossover, 3 lengths
X23(A, B, C): M2 to M3 crossover, 3 lengths

Ordering:

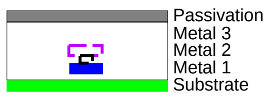


3.10.8 Vias

Description: Single via

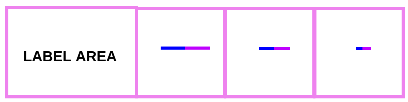
Plan View:

Cross-Section:



Instances: VS12: M1 to M2 via
VS23: M2 to M3 via

Ordering:



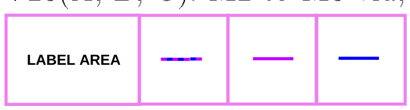
Description: Multiple vias

Plan View:

Cross-Section:

Instances: V12(A, B, C): M1 to M2 via, 3 lengths
V23(A, B, C): M2 to M3 via, 3 lengths

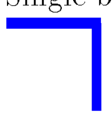
Ordering:



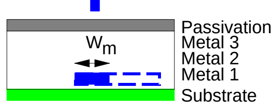
3.10.9 Bends

Description: Single bends

Plan View:

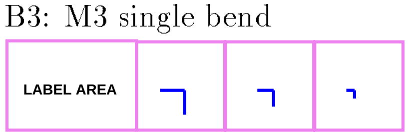


Cross-Section:



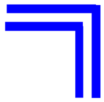
Instances: B1: M1 single bend
B2: M2 single bend
B3: M3 single bend

Ordering:

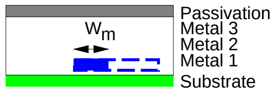


Description: Coupled bends

Plan View:

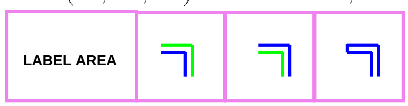


Cross-Section:



Instances:
CB1(A, B, C): M1 bends, 3 lengths
CB2(A, B, C): M2 bends, 3 lengths
CB3(A, B, C): M3 bends, 3 lengths

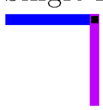
Ordering:



3.10.10 Layer Changes

Description: Single layer change

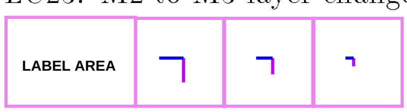
Plan View:



Cross-Section:

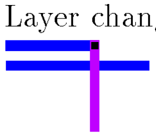
Instances:
LC12: M1 to M2 layer change
LC23: M2 to M3 layer change

Ordering:

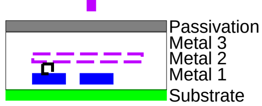


Description: Layer change with crossover

Plan View:

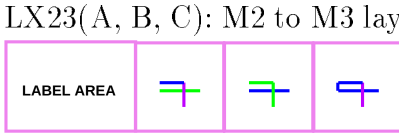


Cross-Section:

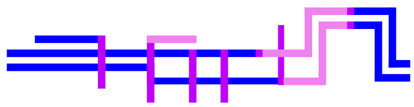


Instances:
LX12(A, B, C): M1 to M2 layer change with crossover, 3 lengths
LX23(A, B, C): M2 to M3 layer change with crossover, 3 lengths

Ordering:



3.10.11 Verification Structure

Description:	ACM verification structure. Note that only the plan view is shown.
Plan View:	
Instances:	VERA: Bottom line grounded. VERB: Top line grounded. VERC: Top and bottom lines connected.

3.11 Contact Points

Mark Basel	Integrated Silicon Systems Manager, Extraction Group email: mark@isscad.com
Ed Buturla	SEMATECH, TCAD group email: Ed.Buturla@sematech.org
Michael (Sean) Casey	Intel Corporation, MS: RN2-40 P.O. Box 58119 2200 Mission College Blvd. Santa Clara, CA 95052-8119 phone: 408-765-9383 fax: 408-765-9322 email: casey@td2cad.intel.com
Aykut Dengi	SEMATECH, TCAD group ECAD Engineer email: aykut.dengi@iambic.eng.sematech.org phone: 512-356-3174 fax: 512-356-7668
John Ellis–Monaghan	IBM, Dept. M65/972-1 1000 River Rd. Essex Jct., VT 05452 email: jjem@vnet.ibm.com phone: 802-769-8627 fax: 802-769-9659
Paul Franzon	Department of Electrical and Computer Engineering North Carolina State University Box 7911 Raleigh, NC 27695-7911 phone: 919-515-7351 fax: 919-515-5523 email: paulf@ncsu.edu

Alan Glaser
Department of Electrical and Computer Engineering
North Carolina State University
Box 7911
Raleigh, NC 27695-7911
phone: 919-515-3947
email: awglaser@eos.ncsu.edu

Dan Hahn
SEMATECH
Provided Opus/Technology file
email: hahnd@shatter.eng.sematech.org

Mark Harward
Testchip Technologies Inc.
P.O. Box 821614
Dallas, TX 75382
phone 214-348-5875
fax: 214-348-8180
email: mharward@testchip.com

Asim Husain
SEMATECH
2706 Montopolis Drive
Austin, Texas 78741
phone: 512-356-7545
fax: 512-356-3083
email: Asim.Husain@sematech.org
Principal Investigator — SEMATECH

Peter Lloyd
SEMATECH, TCAD group
email: Peter.Lloyd@sematech.org

Soo–Young Oh
Hewlett Packard
phone: 415-857-5291
fax: 415-857-5839
email: oh@hpctgjm.hpl.hp.com

Kartik Raol
DEC, TCAD group, ULSI group
email: raol@supac.enet.dec.com

Phil Russell
Department of Materials Science and Engineering
North Carolina State University
Raleigh, NC 27695
phone: 919-515-7501
email: phil_russell@qm.aif.ncsu.edu

Gordon Shedd
Department of Materials Science and Engineering
North Carolina State University
Raleigh, NC 27695
phone: 919-515-3096
email: gordon_shedd@qm.aif.ncsu.edu

Mark Sheedy
SEMATECH
2706 Montopolis Drive
Austin, Texas 78741
phone: 512-356-7041
fax: 512-356-3110
email:mark.sheedy@sematech.org
Contract Manager — SEMATECH

Michael Steer
Department of Electrical and Computer Engineering
North Carolina State University
Box 7911
Raleigh, NC 27695-7911
phone: 919-515-5191
fax: 919-515-3027
email: mbs@ncsu.edu
Principal Investigator — NCSU

Marcel Terbeek
SEMATECH, TCAD group
email: Marcel.Terbeek@sematech.org

P.K. Vasudev
SEMATECH, TCAD group
email: P.K.Vasudev@sematech.org
phone: 512-356-3341
fax: 512-356-3083

Bin Zhao
SEMATECH, TCAD group
Project Leader, Interconnect Simplification
email: Bin.Zhao@sematech.org

SEMATECH's mailing address:
2706 Montopolis Drive
Austin, Texas 78741-6499