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Application Note
0.18µm Process Families

MIM capacitors:

Design Guidelines to help avoid Plasma Charging Damage

Version V2.0

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II. Document Revision History

Version	Date	Changes
V0.1	Sept. 2013	First draft
V1.0	May 2014	updates
V2.0	May 2016	Added in process family XS018, generalised and changes in notes for ease of applying in designs according to the guidelines.

III. Introduction

A MIM capacitor may be prone to hard dielectric breakdown due to Plasma Charging Damage (PCD) if its plates and associated connections are not well considered. Ultimately, such failure could impact product yield and/ or reliability.

The ratio of interconnect connected to the top and bottom plates (referred to as top antenna and bottom antenna, respectively – see Fig. 1), of the MIM capacitor, is identified as being the critical factor for the PCD failure mechanism.

As such, additional layout solutions are required to reduce such charging damage to the capacitor.

This document serves to provide these design guidelines.

Technology: XH018, XC018, XP018, XT018, XS018

Devices: single, double and triple MIM capacitors cmm#, cdmm#, ctmm#, cmmh#, cdmmh#, ctmmh#

(# denotes all derivatives of MIM capacitors with different metal options)

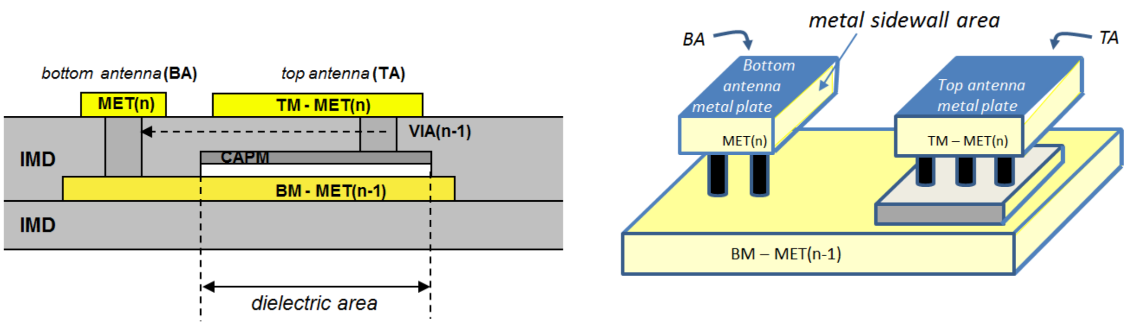


Fig. 1 *Schematic & 3-dimensional diagrams of X*018 process families primitive device: cmm# between MET(n) & MET(n-1 - single MIM capacitor (with top & bottom antenna metal plates)*

IV. Critical parameter in PCD-effect for MIM capacitors (Antenna ratio)

A balanced antenna ratio (AR) eliminates PCD. As there is no potential difference occurring to degrade the device through dielectric stresses, induced by the manufacturing process and circuit design.

The following antenna ratio term is considered and discussed, for floating MIM capacitor application.

Top antenna (T) to bottom antenna (B) ratio

$$AR_{(T/B)} = \frac{\text{sidewall area of top antenna}}{\text{sidewall area of bottom antenna}}$$

$AR_{(T/B)}$ is identified as the significant antenna ratio term.

PCD can be avoided by ensuring unity (i.e. with the same top and bottom antenna size – with the same metal layer), where practical. For normal size antenna, it must be considered that the larger the difference in top and bottom antenna, a greater probability of PCD failure will result. The effect from $AR_{(T/B)}$ is substantial as a large voltage potential difference will be generated with large $AR_{(T/B)}$.

As such, using metal bridge design solution (described in the later session, see Fig. 3) is possible.

Besides, a balanced $AR_{(T/B)}$ is in the range of 0.5 to 2.0 will minimize the chance of PCD occurring

In case of multiple metal antennas connected to the respective top and bottom capacitor plates as shown in Fig. 2, the total area of antenna will be the summation of all individual antennas.

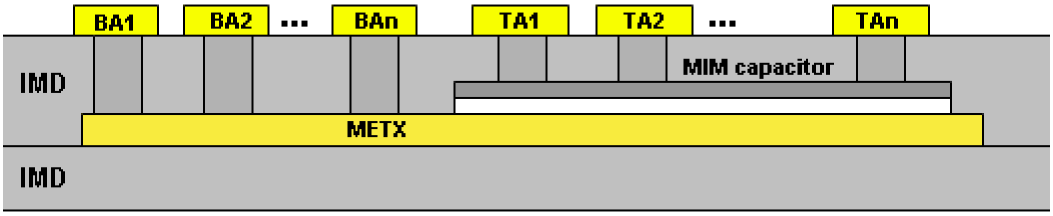


Fig. 2 *Multiple antennas connection to the respective top and bottom MIM capacitor plate.*
$AR_{(T/B)} = \sum$ *(sidewall area of TAi) /* $\sum$ *(sidewall area of BAi)*

V. Layout Guidelines

Ideally, antenna ratio ($AR_{(T/B)}$) would be in the range of 0.5 to 2. For those cases where the ratio of antennas cannot be adjusted to be within the range because of routing requirements, then there are effective ways to protect the floating MIM capacitors and compensate for PCD effects. These are to use:

1) metal bridges
2) connection to diffusion

Further details are given, as follows:

1) Use of metal bridges, to limit interconnection line that is connected to the floating MIM capacitor plates:

The introduction of metal bridges (i.e. by using a small bottom antenna metal area and reconnecting at a higher metal level, by keeping the MIM floating until topmost metallization level can help to eliminate most PCD effects encountered during manufacture.

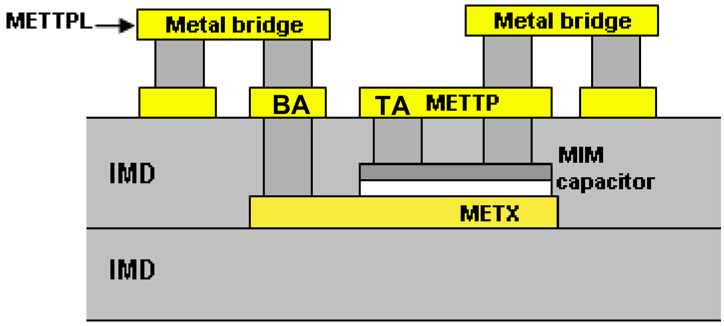


Fig. 3 *implement metal bridges to limit the connect pad or lines to the bottom plates.*

2) Connection to diffusion to drain the charges:

Both capacitor plates are connected to diffusion by the same metal layer. The charges collected on both plates can be discharged efficiently to the substrate through either direct connection to diffusion or by protection diodes. Thus, limiting potential build-up and preventing PCD to the dielectric. Please refer to the Fig. 4. In addition, the introduction of such protection diodes should be carefully considered not to jeopardize the parasitic capacitance, voltage dependence as well as quality factors of the floating MIM capacitors.

Note: For this method to work it must be ensured that:

a) connection to diffusion for both plates
b) and that these are connected using the same metal layer.

Failure to comply with the above requirements, for example by connection to diffusion on only one side, could lead to premature breakdown of the capacitor. This is because all the conductors connected to the diffusion will then act as an antenna of the connected plate, consequently, the antenna ratio ($AR_{(T/B)}$) could become very large and lead to a huge potential difference building up across the capacitor that leads to this breakdown.

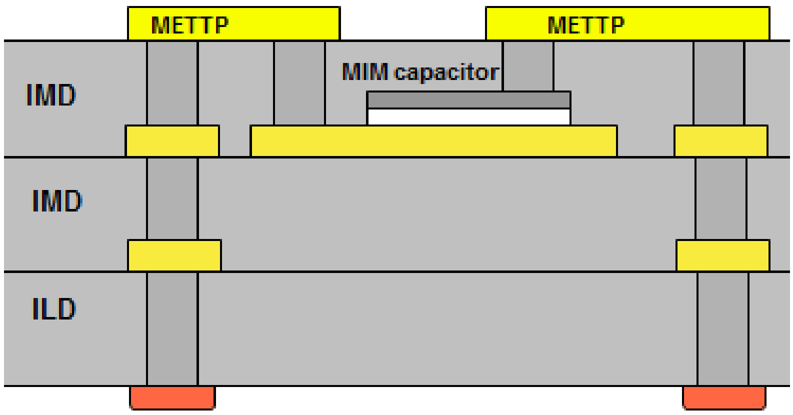


Fig. 4 *protection of the floating MIM by connections to diffusion from both top and bottom plates.*

In general, similar concept on design solution also applies to double and triple MIM stack devices.

Examples of good and poor designs:
NOT good: one side of capacitor connected to diffusion.

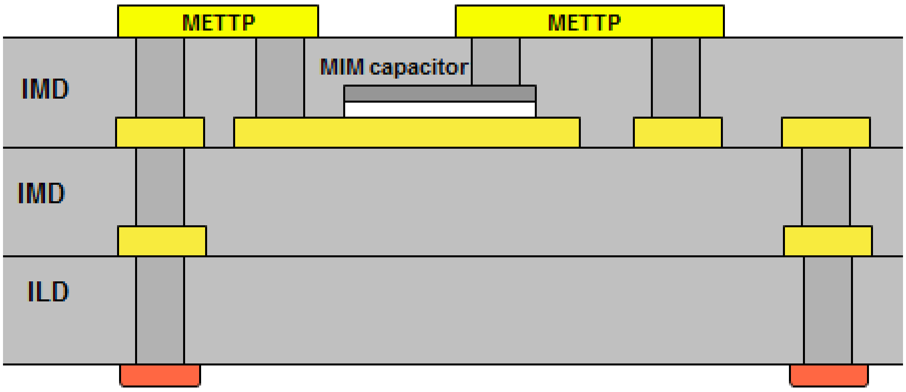


Fig. 5 *only one side of the capacitor was connected to diffusion.*

Good: as long as same metallization level connecting to the top and bottom capacitor plate both connection to diffusion; upper metal layers interconnect don't care.

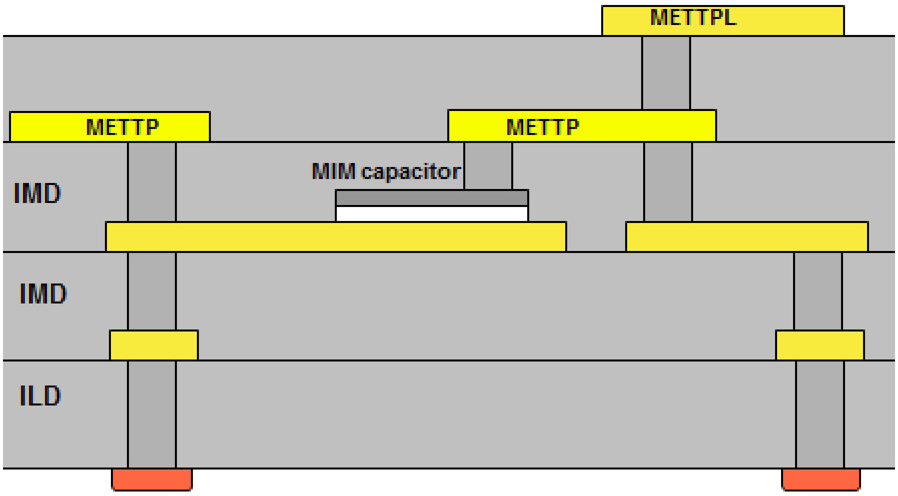


Fig. 6 *both sides were connected to diffusion through same metallization level.*

Following is a simple step-by-step procedure to achieve the goals to avoid PCD:
(1). Keep the AR(T/B) ratio between 0.5 and 2.0 at each current top metal until;
(2). Both sides of the capacitor can be connected to substrate or diffusion features at the using the same current top metal to accomplish this for both sides.

1. Proceed through the metal layers from bottom to top in this procedure.

2. The bottom plate of the capacitor cannot be connected to the substrate or a diffusion using the metal layer of the bottom plate or lower (e.g. for cmm3, MET2 and MET1 only).

3. At each current top metal starting with the second metal used in the capacitor (e.g. MET3 for the cmm3 device) check the $AR_{(T/B)}$ value to see if it is between 0.5 and 2. If it is move on to the next higher current top metal layer.

4. If the $AT_{(T/B)}$ is not within the 0.5 to 2 limits, one of two techniques can be used to correct the issue:

   a. If the current top metal antennas (top and bottom) are relatively small and there is sufficient room, add additional metal structures to the antenna with the smaller perimeter in the current top metal until the ratio is between 0.5 and 2.0.

   b. If one or both of the metal antennas are large or complex, break the connection between the capacitor and the large/complex antenna(s) such that the AR(T/B) is within the 0.5 to 2 limits. The bridge to reconnect the capacitor to the large/complex structure should be moved up into a higher metal layer.

   c. Move on to the next higher current top metal layer until the top metal layer is reached.

The same precautions in designs need to be taken into considerations for the case of double and triple MIM capacitors, in respective individual CM layers, that is breakdown into each single MIM layers to consider each capacitor's plasma effects. (see Fig. 7 and Fig. 8 for double and triple MIM respectively)

In particular, for the case of connecting devices to diffusion, for double and triple MIM; in general, one should make use of the topmost metal layer as the same metal level as connection, all the intermediate layers would maximize the plasma induced issue (with one side connect to diffusion while the other side not, similar to the case in Fig. 5).

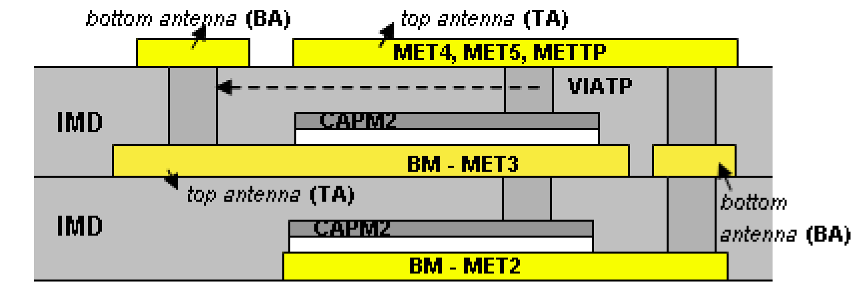


Fig. 7 *Schematic diagram of cdmm4t, cdmm4 - double MIM capacitor (with respective top & bottom antenna for each capacitor)*

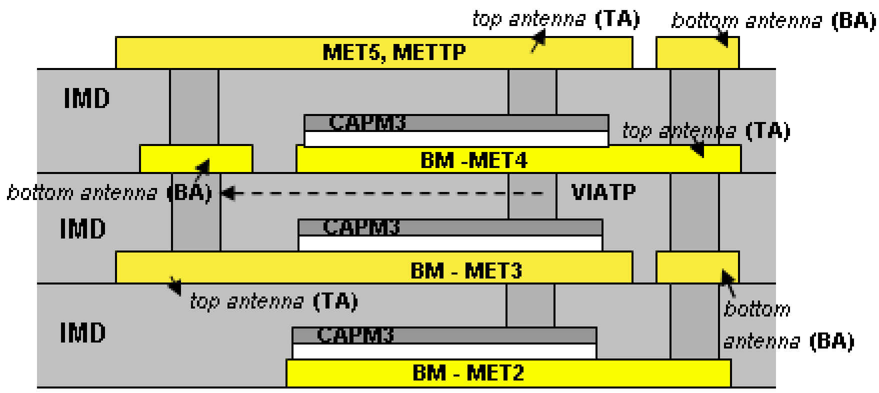


Fig. 8 *Schematic diagram of ctmm5t, ctmm5 - triple MIM capacitor (with respective top & bottom antenna for each capacitor)*

Avoid connect the intermediate metal layers inside double and triple MIM primitive devices to diffusion as it will exaggerate the plasma charging damage effect during process. The good design should be kept the capacitor floating during construction of double and triple MIM in process, not until upto the topmost metal can connect to devices to diffusion on the same metal level for both top and bottom antenna metal terminals. (as in Fig. 11), i.e. , for stack MIM, the diffusion connection should have been established after the stack MIM are built.

To further improve the antenna ratio to unity and eliminate the PCD effect, cross-coupling design concept can be applied for the case of double and triple MIM, that is to split the desired MIM into 2 (say a square shape design with size by a ratio of 1/√2, as such that the total capacitor area will be remained the same for 2 same capacitors); and the subsequent metal layers connection refers to respective top antenna / bottom antenna for each capacitor layer will have the same area, this will keep the antenna ratio to unity.

An example of same area used for each metal layers with the cross-coupling structures as illustrated in Fig. 9. Cross-coupling means for the two TMIM CAP1 and CAP2, top plate connect to bottom plate, and vice versa for each layer.

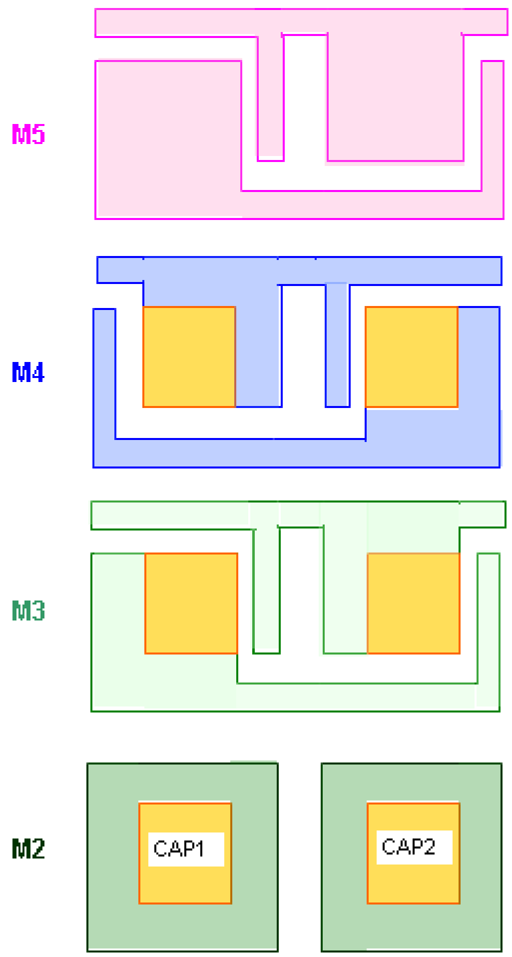


Fig. 9 *Sample Layout of a pair of cross-coupling TMIM CAPs – CAP1, CAP2 for M2, M3, M4, M5 layers.*

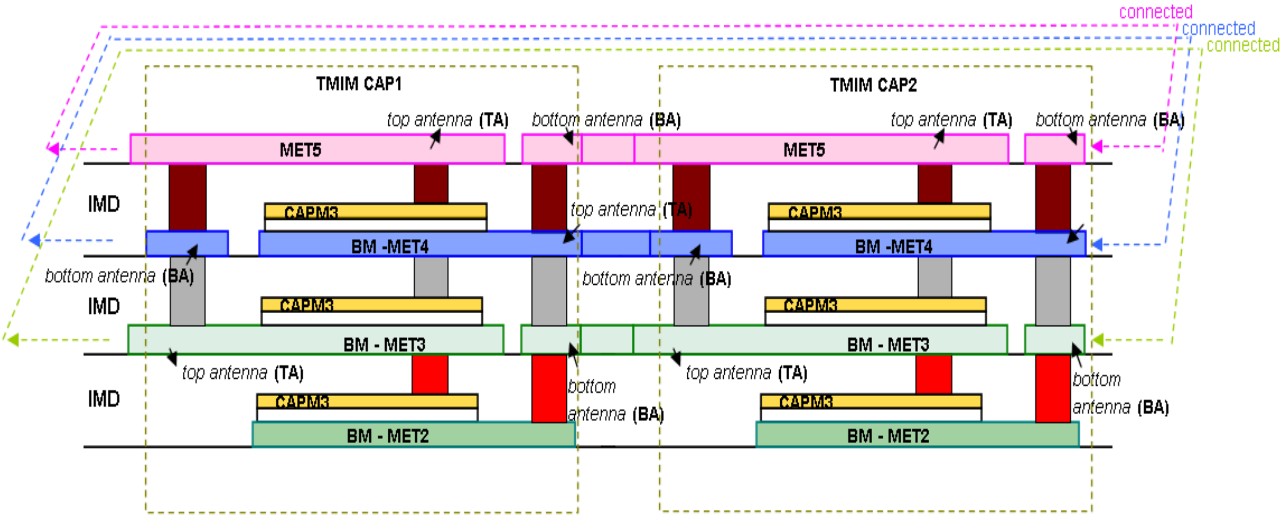


Fig. 10 *Corresponding schematic diagram of Fig. 9 for the 2 cross-coupling TMIM CAPs.*

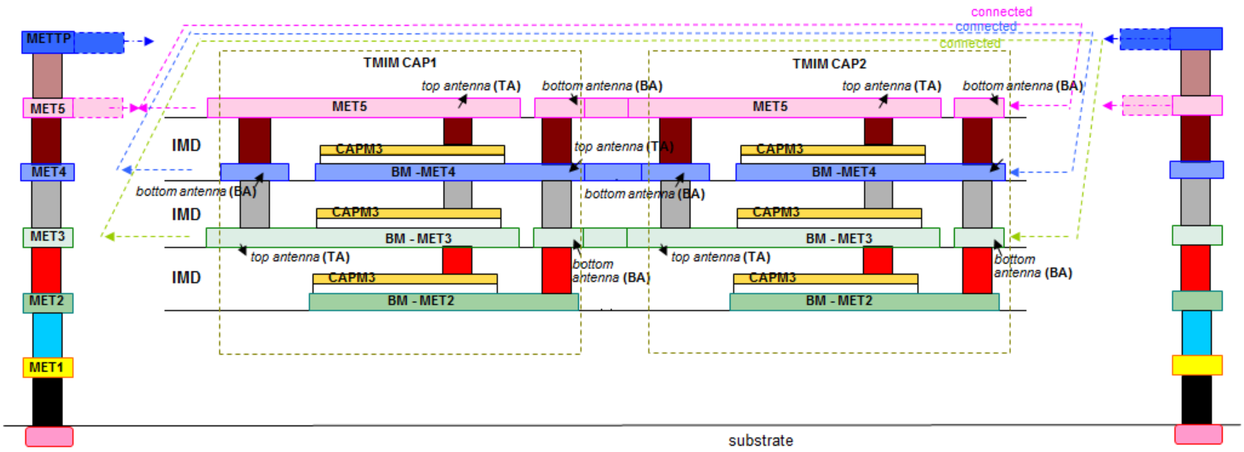
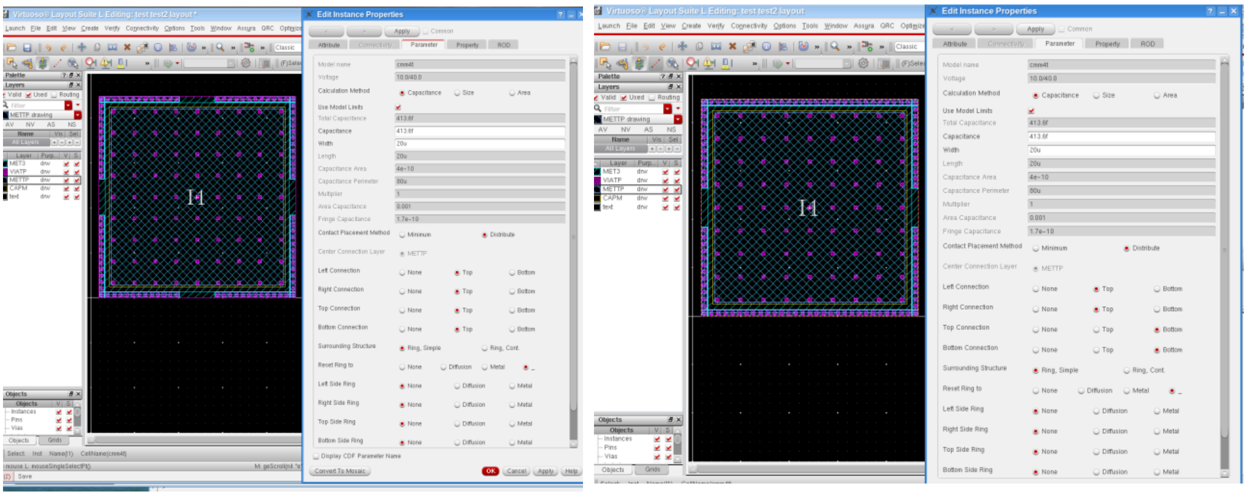


Fig. 11 *Correct connection from both sides to eliminate PCD effects connections to diffusion via the same topmost metal layers either MET5 or METTP metal layers. (same concept as described in Fig. 4)*

Besides, in our PDK Design kit, P-cells are provided by default with the minimum dimensions comply with the respective design rules, it is necessary for the designer to take special care to fulfil the above antenna rules and recommendations, e.g. using cross-coupling routing approach for stack MIMs, while in general the AR in the optimum range have to be fulfilled, …etc.



(a) (b)

Fig. 12 *Snaphot of P-cell with the "Parameter" window features. Selective options for desire dimensions and routing adjustment can be done accordingly. Example in cmm4t is shown here. Both cases (a) Set all Connection parameter in PCELL to "Top" (b) Set half of the Connection parameter in PCELL to "Top" and half to "bottom", the antenna ratio is between 0.5 to 2.*

Modifications of the routing connections is necessary in order to change the desire top and bottom antenna metal dimensions to fulfil antenna ratio/connections of both top and bottom plates to active substrate, such that the capacitors are protected against PCD

<u>Summary:</u>

Ratio of antenna top plate to bottom plate - $AR_{(T/B)}$ – is considered as a critical factor in avoiding Plasma Charging Damage (PCD), when designing in 'floating' MIM capacitors within layout design.

The following design guidelines have been advised to help avoid harmful amounts of PCD build-up.

- ✓ $AR_{(T/B)}$ should be kept in the range of 0.5 to 2.
- ✓ Avoid contacting only one of the floating MIM capacitor plates to diffusion.
- ✓ For floating MIM capacitors, make effective use of PCD compensation methods (as advised) by either:
    - a) applying 'small metal bridges'
    - b) connections to diffusion for both plates

Note: All the above design guidelines can be checked by a special MIM runset.