

## On-chip Capacitances

### Problem Description

This report aims at describing technical characteristics of WIPL-D Software suite for analysis of self and mutual capacitances of pads and their connecting wires. Pads and wires are parts of relatively small chip (2-3 mm). Range of frequencies of interest is between 10 KHz and 10 MHz, which makes the problem to be extreme low frequency simulation. Even at 10 MHz, wavelength in air is 30 m. If chip was modeled with moderate details (1/10 of its size), size of model details would be 1/100,000 of wavelength. Since the requirements are such that chip device has significantly smaller details, EM simulation gets even more challenging.

WIPL-D Pro EM solver is typically used as high frequency simulator, which can simulate problems even in physical optics (PO) region. Nevertheless, it can be also used for simulations of low frequency problems if the analysis is performed carefully, in terms of modeling and setting the project parameters.

### Modelling

The chip geometry can be modelled in two ways. WIPL-D software suite comprises of two user interfaces (GUI) for creating projects. WIPL-D Pro is based on manual modelling and mesh of models. In that sense, models are built from plates and wires, but can also be made from built-in higher-level entities (objects).

WIPL-D Pro CAD offers automatic mesh of structures. Models in it can be made from numerous built-in primitives or models can be imported in popular CAD file formats. The geometry of the chip can vary for relatively simple generalized model to very complex model with all details so the better approach for this application would be to use WIPL-D Pro CAD.

Simplified chip model with two bond wires used for demonstration is shown in the figure below.

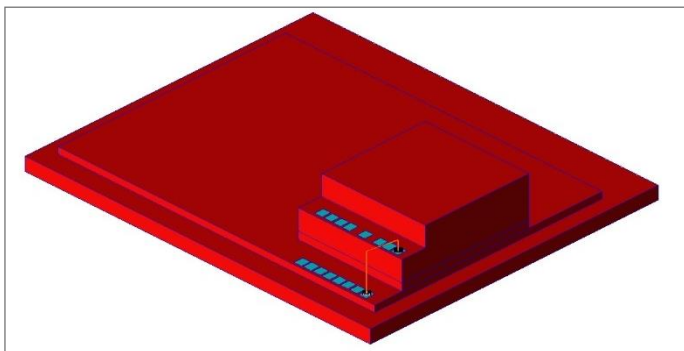


Figure 1. WIPL-D Pro CAD model.

Fig 2 shows meshed model used for simulations. The model is positioned so that two bond wires are displayed. One is on the bottom side where it serves as ports between pads while the second is on top side. In order to get the most stable model, its

best to choose mesh size such that meshed model has regular patches.

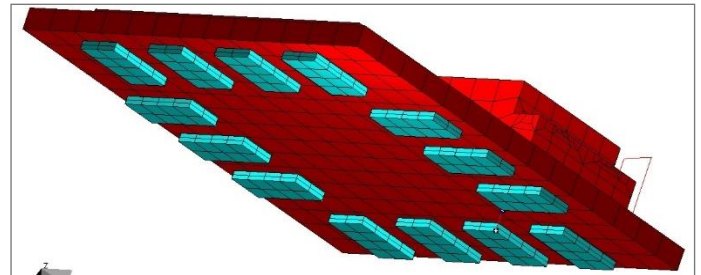


Figure 2. WIPL-D Pro model.

### Simulation

When it comes to simulation of extremely low frequency models, there are several requirements in order to ensure accuracy. WIPL-D can fill in elements of Method of Moments matrix in single or double precision. Double precision is needed for low frequency simulations. Also, the level of Integral Accuracy (IA) parameter should be increased until the results converge. If the results diverge with increasing IA level instead, then the simulation is not possible at such low frequency. For this specific simulation, it is recommended to perform simulations carefully and to start simulation of the model in higher frequency bands (GHz region). That way, we ensure results are consistent and we can slowly decrease simulation frequency band and increase IA level until results are stable. In the 1-10 GHz frequency band, recommended IA level is the default one: Normal, while under 1 GHz we recommend using Enhanced 2 level. Increasing this level slows down EM simulation. Simulation time at 1-10 GHz band is around 10 sec per frequency point while it is 252 sec in 100 KHz-1 GHz band. Number of unknowns is constant: 5,900. For EM simulations, we have used a regular desktop computer with 4 cores (8 threads) Intel Core i7-7700 at 3.60 GHz

Results indicate that self-admittances ( $y_{11}$ ,  $y_{22}$ ) are 2 orders of magnitude larger than mutual admittances ( $y_{21}$ ,  $y_{12}$ ). In that sense, mutual admittances may require Integral Accuracy set to Enhanced 3 and higher below 10 MHz.

In the entire simulation range, the behavior of the device is linearly proportional to frequency. It is the expectation of authors that such trend occurs at lower frequencies so low frequency behavior can be obtained by extrapolation of result at higher frequencies.

For example, coefficients of capacitance and coefficient of electrostatic induction can be calculated from:

$$y_{11} = j \cdot \omega \cdot c_{11}$$

$$y_{21} = j \cdot \omega \cdot c_{21}$$

If we use simulated values at several frequencies, we can obtain value of the capacitance:

| Frequency [MHz] | c22 [fF] | c21 [fF] |
|-----------------|----------|----------|
| 2000            | 19.118   | -0.1777  |
| 500             | 19.086   | -0.1779  |
| 200             | 19.088   | -0.1776  |
| 50              | 19.108   | -0.1789  |
| 20              | 19.175   | -0.1764  |

Note that positive values of coefficients of electrostatic induction (which correspond to mutual capacitance) can be obtained if we simply change the polarization of one of the two (or several) ports and run the simulation again.

So, we suggest to perform simulation at single frequency in the upper frequency bands and to assume that the same capacitance is preserved at lower frequencies due to the linear nature of the simulated result. Frequency should be high enough to ensure stable and accurate simulation but low enough not to interfere with high frequency behavior, which will be demonstrated later.

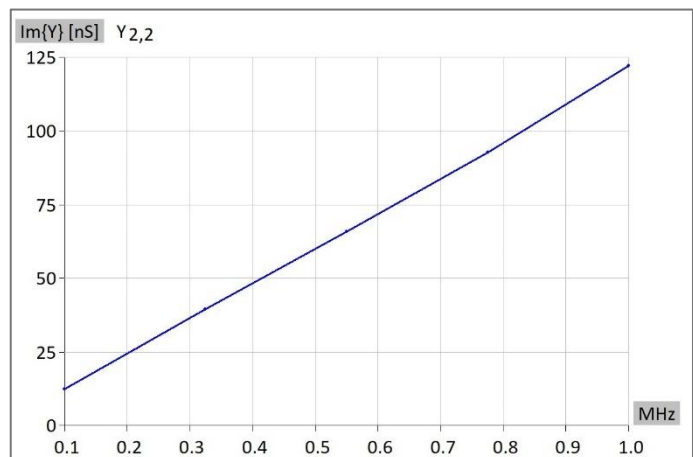
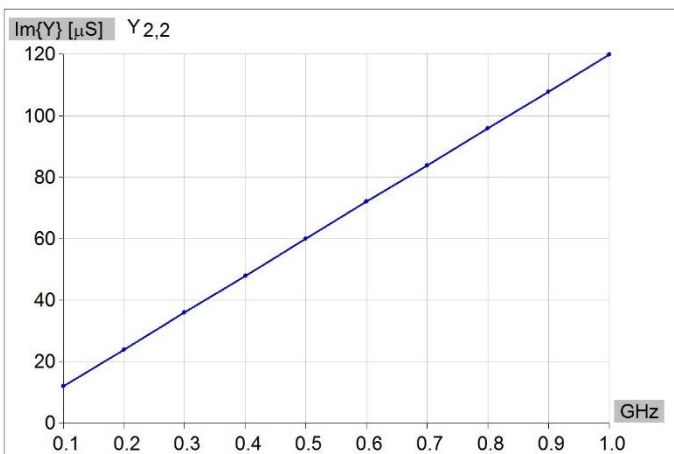
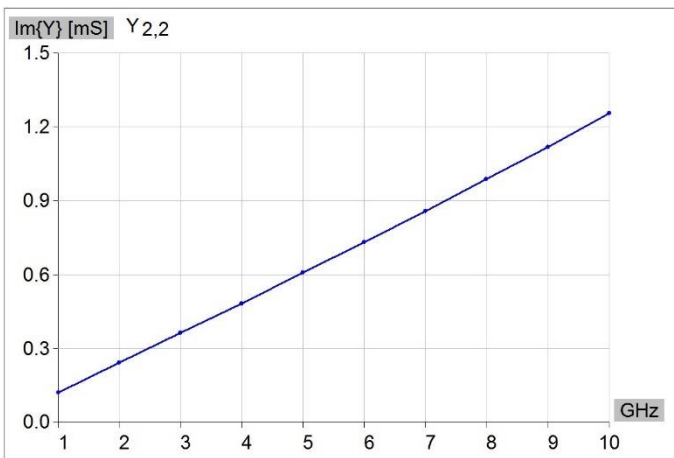
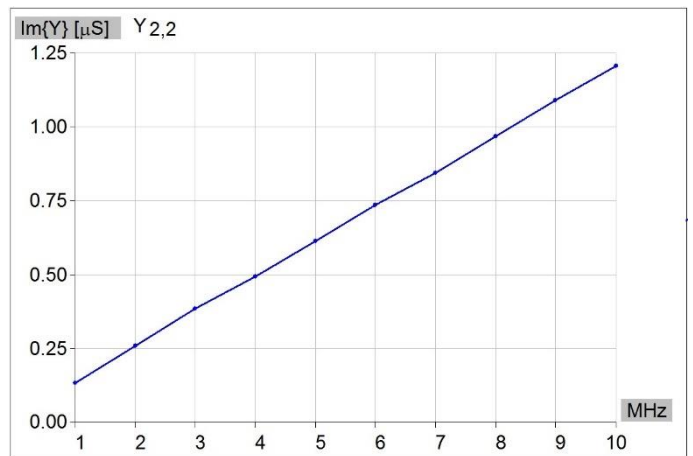
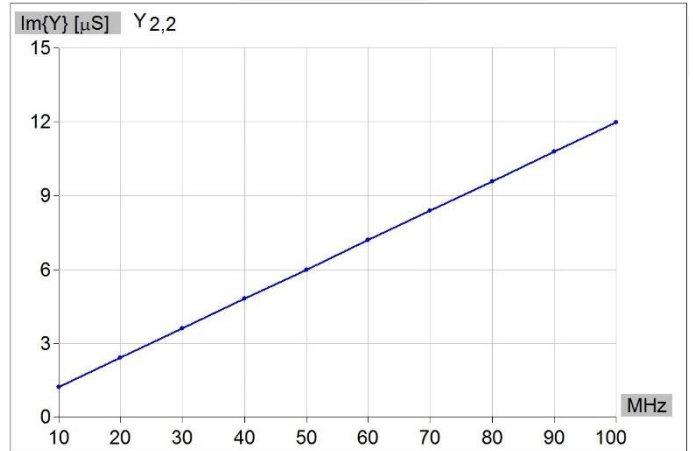
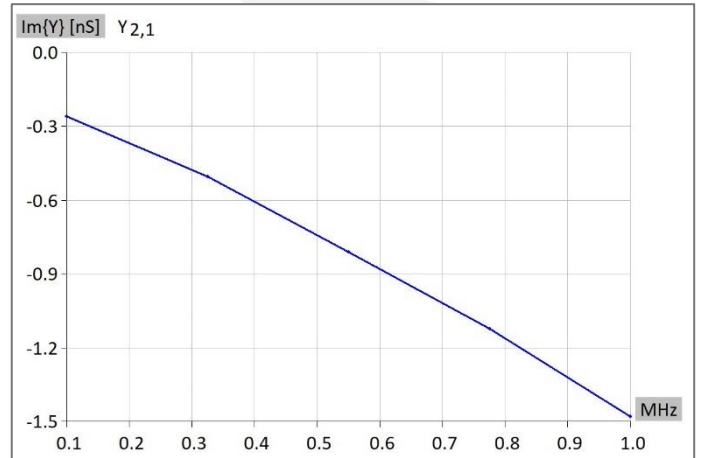
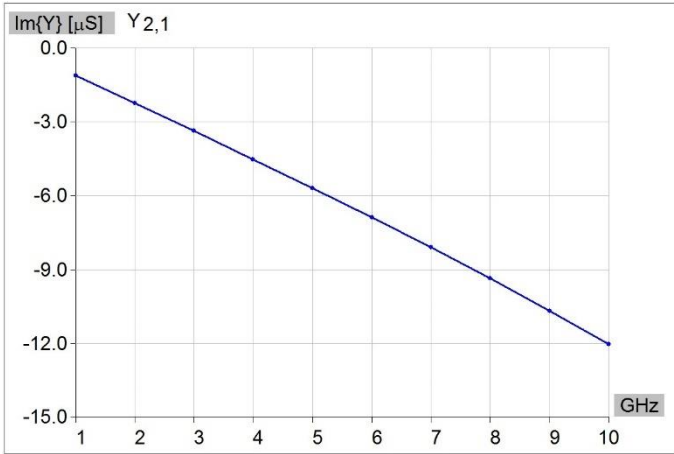
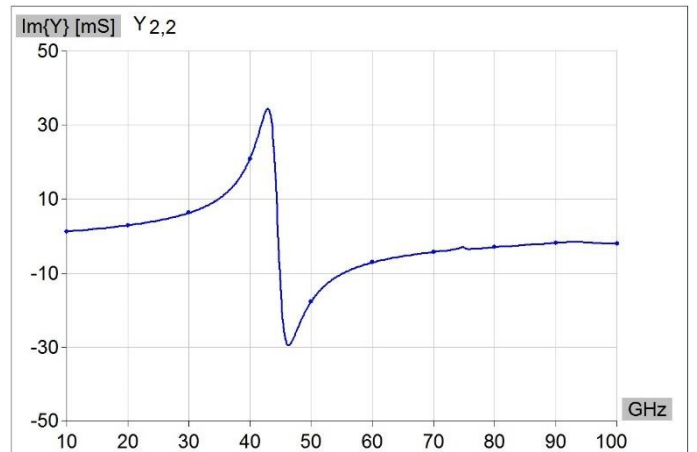
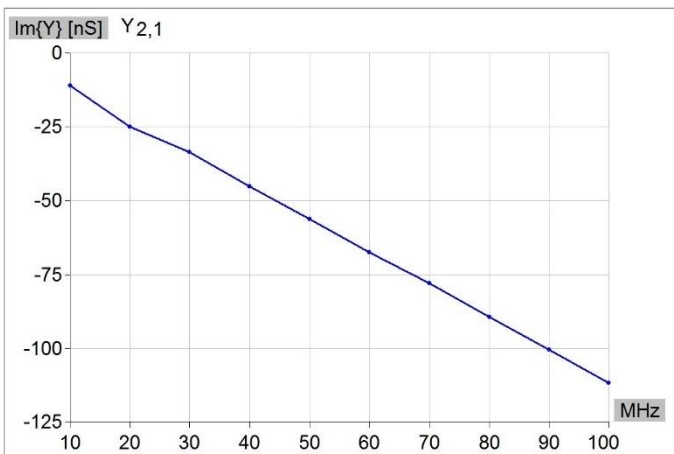
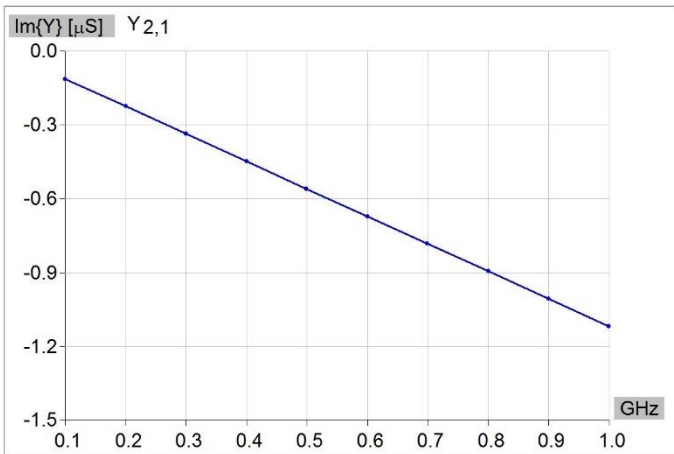


Figure 3. Self-capacitance in various frequency bands.



**Figure 4. Mutual-capacitance in various frequency bands.**

We have also simulated the frequency band 10-100 GHz to investigate the response and we found that linear behavior is no longer valid. In that sense we suggest using lower frequency bands (0.1-1 GHz for example).



**Figure 5. Self-capacitance in high frequency band.**