Ultra-Wide-Band (UWB) Band-Pass-Filter Using Integrated Passive Device (IPD) Technology for Wireless Applications

June 17, 2009
Agenda

- Introduction
- Design and characterization for flip-chip IPD
- Design and characterization for Wire bonding IPD
- The simple triple wire-bond and philips/TU Delgt tripe wire-bond inductance model
- Conclusions
Introduction

• Most common applications of Integrated passives devices (IPDs) are in the front-end of wireless systems, between the antenna and transceiver.

• Integrated passives devices (IPDs) based on semiconductor processes offer the advantage of excellent parameter control, and allow simplified and compact module design.

• IPD processes can be used to make high density capacitors, high Q inductors and large value resistors.

• The Ultra Wide Band (UWB) band-pass-filter developed in this paper has the smallest size while achieving equivalent electrical performance.

• In this paper, an UWB Band-pass-filter is made using lumped integrated passive devise technology on a silicon substrate for wireless applications.
The technology of UWB

- UWB offers great potentials for home networking, wireless sensors, and location aware system.

- UWB Characteristics and signal.
  - Low power
  - High data rate
  - Bandwidth (BW) calculation:
    \[ BW = \frac{f_H - f_L}{f_c} = \frac{2(f_H - f_L)}{f_H + f_L} \]
  - Narrowband: BW < 1%
  - Wideband: 1% < BW < 20%
  - Ultra-Wide-Band: BW > 20%

![UWB technology diagram](image)
Integrated Passive Device Process Description

- In the STATS ChipPAC’s silicon process, a specially treated silicon substrate is used to grow dielectric layer and metal layer.

- Capacitors: < 100pF, inductors: 20nH (Q 25-45), Resistors: < 100K Ohm.

Figure 1: Thin film Integrated Passive Device (IPD) structure (not in scale).
RF Product Design Examples

- GSM LPF, Balun.
- DCS LPF, Balun.
- 11b/g BPF, Balun.
- 11a BPF, Balun.
- WiMax BPF, Balun.
- Diplexers: GSM/DCS, 11b/a, WiMax.
- Compact designs: Balanced filter, Balanced diplexers.
- RF Modules (CSMP) and RF SiP.

IPD on wafer being probed

IPD on substrate
IPD RF Applications (side by side with a die)

SC1-301W (Wirebond)  SC1-301F (Flip Chip)
SC1-302W (Wirebond)  SC1-302F (Flip Chip)
SC1-303W (Wirebond)  SC1-303F (Flip Chip)
SC1-101W (Wirebond)  SC1-101F (Flip Chip)

IPD product databook available from the website.

IMS2008, Atlanta
UWB Band-Pass-Filter for Flip-Chip IPD

- Figure 2 shows a circuit topology for the band-pass filter.
- Flip-chip IPD layout of the UWB band-pass-filter for EM simulation.
  - Two bumps are for UWB band-pass-filter input and output.
  - Four bumps are just for electrical ground.
  - The UWB band-pass-filter of flip-chip die has a size of 1.4mm x 1.2mm x 0.40mm (including bump height).

Figure 2: Circuit topology for UWB band-pass-filter (BPF).

Figure 3: Flip-chip IPD layout of the UWB band-pass-filter for EM simulation.
UWB Band-Pass-Filter for Flip-Chip IPD

• To meet electrical performance and size target a general design methodology (Figure 4) was followed.

Step: 1) Create circuit model for IPD
Step: 2) Generate physical layout to fit available space, and perform EM simulation
Step: 3) Optimize as required to meet specifications.

Figure 4: Design methodology of integrated passives.
UWB Band-Pass-Filter for Flip-Chip IPD

- The simulated characteristics of the UWB band-pass-filter are shown in Figure 5.

- The insertion loss from 7GHz to 9GHz is 1.8dB and the return loss is greater than 15dB in EM-simulation.

![Figure 5: S₁₁ and S₂₁ parameters for the UWB band-pass-filter in simulation.](image)
Fabrication

- Passive integration on silicon substrate.
- Low insertion loss in pass band.
- Eutectic Sn/Pb or lead-free solder bump.
- Low profile, 0.40mm height.
- Directly flipped on PCB.
- Operating temperature: -40 to +85°C.
- Storage temperature: -40 to +85°C.

Figure 6: UWB band-pass-filter flip-chip die.
Wafer Level Test

- Membrane probes for non-destructive wafer-level test.
- PCM for line width, leakage current, capacitance, inductor Q, etc.
- Ensure yield before wafers/dies shipped out.
Characterization on Laminate Board

- S-Parameters were measured with wire bonding IPD die through probing on the G-S-G patterns on the test board.
  - Verify the response in package.
  - Temperature controller used for IPD temp characterization.
UWB Band-Pass-Filter Results for Flip-Chip IPD

- Typical characteristics of the manufactured UWB band-pass-filter are shown in Figure 7.
- The insertion loss is 1.7dB (minimum) and return loss is 15dB.
- The manufactured UWB band-pass-filter has low pass-band insertion loss and small size.

Figure 7: Typical characteristics of the manufactured UWB band-pass-filter.
UWB Band-Pass-Filter Results for Flip-Chip IPD

- Typical characteristics for the flip-chip UWB band-pass filter.
- In high frequency applications, our simulation scheme is very suitable for designing IPD products.

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UWB Band-Pass-Filter for Wire Bonding IPD

- The circuit design and fabrication of the wire-bond UWB band-pass-filter IPD are similar to those described above for the flip-chip device.
- The device can be mounted directly on a PCB or laminate substrate using conventional wire-bonding techniques.
- The UWB band-pass-filter of wire-bonding die has a size of 1.2mm x 1.0mm x 0.25mm.

Figure 8: Wire bonding IPD layout of the UWB band-pass-filter for EM simulation.
The circuit-level simulation was done using a simple inductance model (0.35nH) for each of the triple wire-bonds.

### Table 2: Typical characteristics for the UWB band-pass filter.

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**Figure 9:** $S_{11}$ and $S_{21}$ parameter for UWB band-pass-filter in simulation.
Fabrication

- The device can be mounted directly on a PCB or laminate substrate using conventional wire-bonding techniques.
- RF test board layout shows an UWB band-pass-filter with 3 wires to input pad (#3) and output pad (#6).
- The four ground pads (#1, #2, #4, #5) are also connected with triple wire bonds pads.

Figure 10: UWB band-pass-filter wire-bond die and RF test board layout.
UWB Band-Pass-Filter for Wire Bonding IPD

- The characteristics of the UWB band-pass-filter of wire bonding die are shown in Figure 11.
  - The insertion loss is 2.4dB (Minimum) and the return loss is 7dB.
- Compared to the results for the flip chip UWB filter, these results are much worse than expected.

Figure 11: Measured characteristics of the UWB band-pass-filter of wire bonding die.
Tripe wire-bond inductance model

- Figure 12 shows a comparison of the simulated result versus measurement using the simple triple wire bond inductance model.

- The simple model does not account for mutual interactions between the wire bonds, which become more important at higher frequencies.

> It can be seen that the agreement between the two is poor. Because of the good agreement in the flip-chip case, it was suspected the cause of the discrepancy was in the simple inductance model used for the wire bonds.

Figure 12: Measurement versus simulation using the simple triple wire-bond inductance models for wire-bonding IPD.
Wire-bond shape model

BONDW Shape
Shape1
Rw=12.5 um
Gap=700 um
StartH=250 um
MaxH=350 um
Tilt=50 um
Stretch=100 um
StopH=0 um
FlipX=1

• StartH is 250um (top of IPD)
• StopH is 0 (plane of the test board)
• Gap is 700um (total length of the wire bond in the x-y plane)
• MaxH is 350um (a 100um loop height – typical.)
• Tilt and stretch are chosen to give the wire bond a reasonable shape.
Simulation setup

- This is the same as the simple model, but the wire-bond inductors have been replaced by the ADS WIRESET model.
Tripe wire-bond inductance model

- An improved circuit-level simulation was done using the Philips /TU Delft wire-bond models in ADS.
- These account for a more detailed shape of the wire bond and also account for mutual inductances between all of the wires.
- The comparison between the IPD characteristics using the simple triple wire bond model and the more accurate Philips/TU Delft model is shown in Figure 13.

![Figure 13: Simulation using the simple triple wire-bond inductance model versus simulation using the Philips/TU Delft triple wire bond inductance models.](image)
Tripe wire-bond inductance model

- Figure 14 shows a comparison of the measured data versus simulation using the Philips TU/Delft wire-bond inductance model for wire-bond IPD. With the more accurate wire-bond models, the agreement is much better.
- At these high frequencies, the simple wire-bond models are not sufficiently accurate.

Figure 14: Measurement versus simulation using the Philips/TU Delft triple wire-bond inductance models.
Conclusions

• The design and implementation of a silicon based band-pass-filter for Ultra Wide Band applications have been presented.

• Excellent filter properties are obtained from the UWB band-pass-filter of flip-chip die.

• For wire bondable IPDs working at high frequencies (such as this UWB filter), simple inductance model for multiple wires is not good enough for designs.

• More advanced coupled-wire models in ADS have shown better predictions of the wire behaviors.

• The IPD technology is especially well suited for UWB applications because of its excellent parameter control and enabling smaller form-factors.