

Mixed Mode: More than Analog and Digital

Roberto S. Murphy, Reydezel Torres
Instituto Nacional de Astrofísica, Óptica y Electrónica
Tonantzintla, Puebla, México
rmurphy@icee.org

SUMMARY

In its origin, the term “Mixed Mode” referred to integrated circuits (ICs) made from digital and analog components. Mixing these types of circuits opened the field of IC design to include a vast scope of functionalities, paving the way for versatile circuits including system on chip (SoC), and lab on chip (LoC), amongst many more.

Nowadays, due to the evolution of technologies, manufacturing processes including transistors than reach cut-off frequencies in the hundreds of GHz range are readily available, providing sophisticated bases for the design and development of a slew of wireless circuits impacting telecommunications, the Internet of Things (IoT), industrial and medical applications, and many more.

All these wireless circuits require, besides transistors, resistors and capacitors, inductors, transmission lines on chip, through silicon vias (TSVs) for 3D integration, and antennas to transmit and receive all sorts of data. Hence, mixed mode circuitry includes many passive devices working together with active ones to be able to meet the stringent requirements imposed on these types of circuits.

Inductors, for instance, are mandatory in RF circuits as impedance matchers, filters of all kinds, resonant circuits, and transformers. And even though inductors have a resonant frequency, they are present in the chip, representing parasitic components at different frequency ranges. An example of an integrated inductor is shown in Fig 1, showing two different shielding platforms.

Transmission lines and coplanar waveguides are other fundamental elements of RF circuits. Stages in the same chip

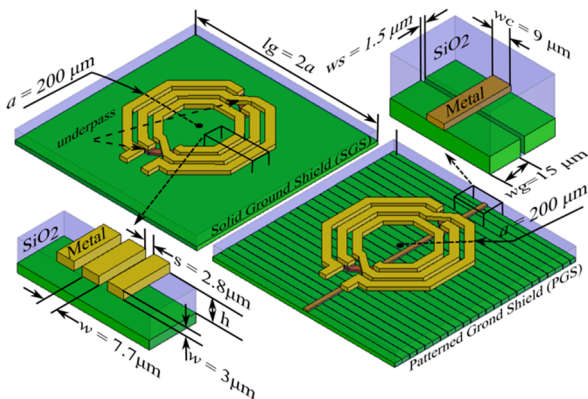


Fig. 1. Integrated inductors with a solid ground shield and a patterned ground shield.

have to be connected to others, and eventually to the chip package. The impedance between stages has to be matched, and therefore, these structures have to be fully characterized and modeled in order to design interconnects adequately.

Three D integration has become common in recent years, since it is a convenient and direct form to create complex systems on-chip while reducing losses and interconnect delays. This requires conducting lines from the active part of the chip to the bas of the wafer, Through Silicon Vias (TSVs), which have to be manufactured with reliability and efficiency in mind. Hence, accurate models for TSVs are also needed to design ICs for 3D integration.

As technology evolves, the cut-off frequency that active devices can attain is ever increasing, reaching now values of the order of several hundreds of GHz. This has made the inclusion of antennas in the same IC possible, notwithstanding all the limitations that are encountered in the process. Nevertheless, research on integrated antennas has been a very active field in recent times, and it will surely continue to be so.

To characterize and model devices for RF ICs, the measurement set-up has to be calibrated and the data must be subsequently de-embedded. As the frequency of operation increases, this is not straightforward, and some additional procedures must be carried out to model the actual behavior of the device. For instance, when measuring an integrated transmission line, the model shown in Fig. 2 has to be taken into account.

This talk will present the efforts that the High-Frequency Group at the *Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE: National Institute for Research on Astrophysics, Optics and Electronics)* has undertaken in the last 35 years, covering different aspects of active device modeling, inductors, transmission lines, coplanar waveguides, TSVs and antennas. Some aspects regarding measurements, calibration and de-embedding will be also highlighted, as they are ever present in the characterization of devices in the high-frequency regime.

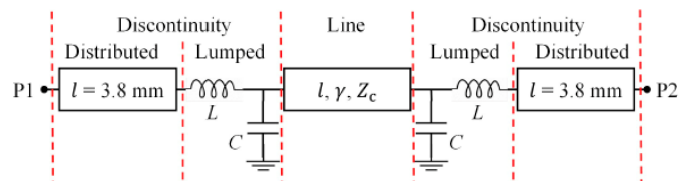


Fig. 2. Model for an IC transmission line.