RF Application Case Study

Exploring the Outer Limits of High-Frequency CMOS Circuitry

About Omeed Momeni

Professor Momeni is a member of the faculty of the Electrical and Computer Engineering Department at University of California, Davis. His research interests include mmW and terahertz integrated circuits and systems. Prior to his position at UC Davis, he was with NASA and the Jet Propulsion Laboratory. Momeni is the recipient of the National Science Foundation CAREER award in 2015 and was named Professor of the Year 2014 by IEEE.

Dr. Omeed Momeni has a long-term goal to push CMOS-based circuitry to its theoretical limits in the 700 GHz range. To test those limits he designed and fabricated a voltage-controlled oscillator targeted at a 130 nm BiCMOS process. To verify this circuit, he assembled a test and measurement system that included a Cascade EPS150RF probe system in combination with Infinity Probe® to contact the on-chip output pads connected to the VCO circuitry. His research team was able to verify the operation of the circuit and make progress toward the integration of radio frequency (RF) circuitry onto relatively low-cost semiconductors.

Numerous technologies, such as radar, imaging and spectroscopy, require the generation of signals that range into the millimeter-wave (mmW) region and beyond into the terahertz range. In response, researchers are actively developing RF circuitry implemented at the chip level, where substantial size and cost benefits can be realized.

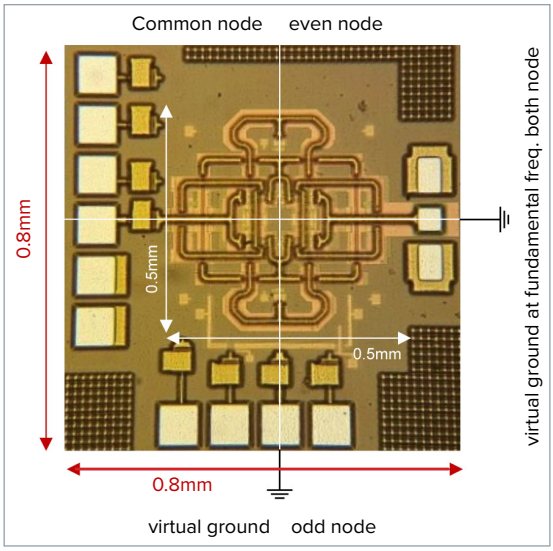

Figure 1: A BiCMOS process with a 135 nm feature size was used to fabricate the VCO. The pads on the left and bottom were wirebonded to a mounting board to provide power supplies and control voltages. The two pads on the right were the oscillator output and the targets of the Infinity Probes.

One such group includes Dr. Omeed Momeni and his colleagues at the University of California Davis. Their long-term goal is to push CMOS-based circuitry to its theoretical limits in the 700 GHz range. In pursuit of this vision, they recently focused on the design of a voltage-controlled oscillator (VCO) targeted at a 130 nm BiCMOS process. In a paper

“The Infinity Probe provided low, stable contact resistance required for consistent, accurate measurements at the RF frequencies.”

delivered at the 2016 International Solid State Conference, Dr. Momeni and his colleague Rouzbeh Kananizadeh reported successful operation of this on-chip VCO at frequencies up to 190 GHz with a tuning range of 20.7% and a maximum power output of -2.1 dBm.

To verify this circuit, they assembled a test and measurement system that included a Cascade 150 mm probe station to contact the on-chip output pads connected to the VCO circuitry. The EPS150RF probe station’s compact architecture occupied a minimum of valuable lab space, and FormFactor minimized the team’s startup time by completing the initial system assembly.

The fabricated VCO circuit (Figure 1) was delivered to the lab in the form of individual die each containing a single copy of the circuit. Consequently, Dr. Momeni’s team configured the EPS150RF for probing by mounting each die on its own board, which was then vacuum-sealed onto the probe station’s chuck for probing operations. Each board included wire bonding to deliver various DC voltages and ground connections to the chip, which also contained two additional pads that were probed to capture the VCO’s output.

The RF output frequencies of the VCO required exceptional probe performance to deliver accurate, repeatable results, and FormFactor met this challenge with its Infinity Probe, which delivers dependable results into the 500 GHz range and beyond. It minimizes probe loss while substantially reducing unwanted coupling and transmission modes.

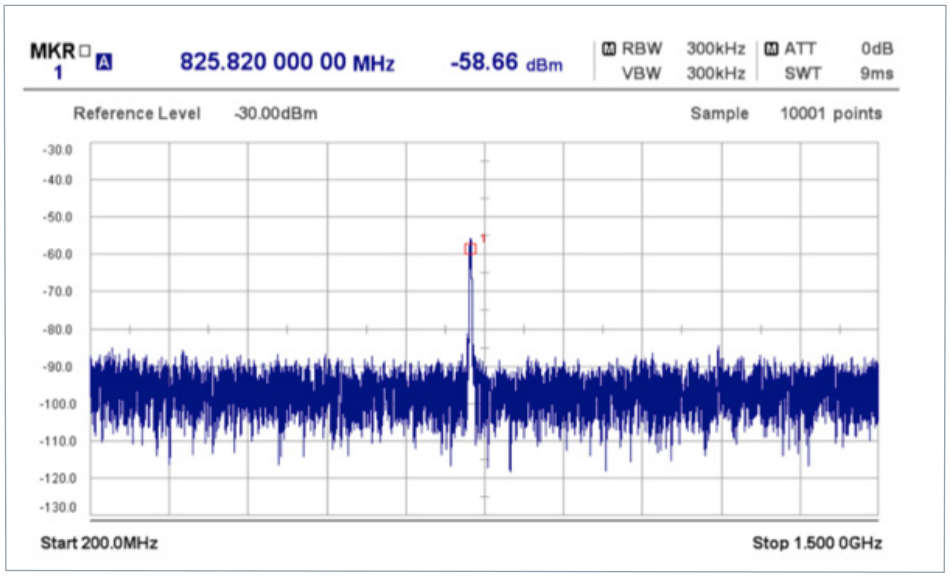

Figure 2: A series of precision measurements confirmed the VCO’s output across a tuning range of 20.7% with a center frequency of 190.5 GHz. This particular display shows a spectrum analyzer measurement taken at a 210.1 GHz output.

“The ease of use and accuracy operating with WinCalXE is really impressive.”

In this particular application, the Infinity Probe’s waveguide was coupled with a harmonic mixer to complete the signal path to a spectrum analyzer, which conducted the frequency measurements. It verified a tuning range of 20.7% at a center frequency of 190.5 GHz. Figure 2 shows one of multiple measurements made across the tunable spectrum, this particular measurement at 825 MHz.

The power output of the VCO was verified with a similar probe setup which created a signal path from the chip’s output pads to a power meter. In this case, a waveguide attachment with a 90 degree E-bend helped position the Infinity Probe in acceptable physical proximity to the power meter. It verified a maximum output power of -2.1 dBm. In all cases, EPS150RF and its Infinity Probe provided the low, stable contact resistance required for consistent, accurate measurements at the RF frequencies produced by the VCO.

Photo: Dr. Momeni Omeed working with his EPS150RF probe system.

For Dr. Momeni and his colleague on this project, Rouzbeh Kananizadeh, the successful fabrication and operation of this BiCMOS circuit represents a significant performance milestone in progress toward the integration of RF circuitry onto relatively low-cost semiconductors. FormFactor is proud to have played a part in their research. We view this kind of close collaboration with the academic community as a fundamental part of our commitment to progress across all of the physical sciences.

The EPS150RF Probe System Meets Your Lab Requirements

"EPS150RF provides the highest accuracy with shortest time to measurement."

Our EPS150RF enables exploration up to the terahertz range with the ability to probe pads as small as 25 µm x 35 µm and beyond.

WinCalXE software, the industry leading on-wafer RF calibration is comprehensive and intuitive and includes:

/ Exclusive 1-, 2-, 3-, and 4-port calibration algorithms
/ Immediate and live data measurement and viewing
/ LRRM, LRM+, SOLT-LRRM hybrid and NIST-style multi-line TRL calibrations
/ Error Set Management capability for data comparison and augmentation

Reliable and repeatable measurement results with a uniform contact performance and consistent overtravel allowed

/ RF positioner with a resolution of 100 TPI
/ Chuck surface planarity of ± ≤3 µm
/ A unique 200 µm platen contact stroke with ± ≤1 µm accuracy

The choice of the probe technologies up to 67 GHz gives this probe system the widest application spectrum

/ |Z| Probe®: best in lifetime
/ ACP Probe: best for discrete devices
/ Infinity Probe: best for characterization

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