Engineers set new world record in generation of high-frequency submillimeter waves

Researchers at the UCLA Henry Samueli School of Engineering and Applied Science have achieved a new world record in high-frequency submillimeter waves. The record-setting 324-gigahertz frequency was accomplished using a voltage-controlled oscillator in a 90-nanometer complementary metal-oxide semiconductor (CMOS) integrated circuit, a technology used in chips such as microprocessors.

The signal generator, which produces frequencies nearly 70 percent faster than other CMOS oscillators, paves the way for a new generation of submillimeter devices that could someday be used in high-resolution sensors on spacecraft, and here on Earth in a new class of highly integrated and lightweight imagers that could literally cut through fog and see through clothing fabrics. And because frequency ultimately means bandwidth, "the higher frequency increases the available bandwidth," said M.C. Frank Chang, UCLA professor of electrical engineering, who leads the research team. That greater bandwidth translates into faster communication speeds.

With traditional 90-nanometer CMOS circuit approaches, it is virtually impossible to generate usable submillimeter signals with a frequency higher than about 190 GHz. That's because conventional oscillator circuits are nonlinear systems in which increases in frequency are accompanied by a corresponding loss in gain or efficiency and an increase in noise, making them unsuitable for practical applications.

Chang, who also is director of UCLA Engineering's High Speed Electronics Laboratory, and researchers Daquan Huang and Tim LaRocca skirted the issues using a technological sleight of hand — and some unique analog signal processing.

The researchers first generated a voltage-controlled CMOS oscillator, or CMOS VCO, operating at a fundamental frequency of 81GHz with phase-shifted outputs at 0, 90, 180 and 270 degrees, respectively. By linearly superimposing these four (or quadruple) rectified phase-shifted outputs in real time, they ultimately generated a waveform with a resultant oscillation frequency that is four times the fundamental frequency, or 324 GHz. This new frequency generation method, in principle, has high DC-to-RF conversion efficiency (up to 8 percent) and has low phase noise, comparable to that of the constituent fundamental oscillation signal.

"When you go back to the fundamental math and physics, you find that you can do this and not pay much of a price. That's the beauty of it," Chang said. "If you use digital signal processing, you can synthesize this and synthesize that, but you pay the price for it with a loss of energy."

The measurement test of the 324-GHz signal was conducted by engineers Lorene Samoska and Andy Fung of NASA's Jet Propulsion Laboratory in Pasadena, which has facilities to test these high-frequency ranges. JPL and NASA are particularly interested in submillimeter technology because submillimeter-range wavelengths are ideal for deep-space remote sensing — there is no atmosphere in space to dampen the signals. Higher frequency signals, in turn, produce higher resolution images. "You can see better," Chang said.

Chang and Huang, in collaboration with JPL colleagues, have jointly applied for government grants to use the technology to design lightweight, low-power and highly integrated signal generators that can produce signals at frequencies up to 600 GHz. Applications for these high-frequency VCOs include imaging systems for both commercial and future space missions.

Creating 600-GHz signals requires a relatively straightforward modification of the circuit — either by increasing the fundamental frequency of the VCO or increasing the number of superimposed oscillator outputs (using eight or 16 instead of four).

"Because the algorithm has been validated, we know that we can achieve these frequencies," Chang says.

For example, if quadruple 85-GHz VCO outputs are used, the resulting output frequency would be 340 GHz. That frequency is something of a Holy Grail to the commercial aerospace industry and the military because it represents a "window" in our atmosphere where there is very little attenuation of submillimeter signals. (Essentially, they are invisible to the air.)

Normally, millimeter-range waves excite the atomic and molecular bonds in water, oxygen, carbon dioxide and other molecules in the atmosphere, and the gases absorb the waves. Signals at 340 GHz, however, "sneak through," Chang said, and can propagate long distances.

"One result is that waves of these frequencies can see through the fog, which is of interest to commercial aerospace companies," he said. Chang estimates that he and his colleagues will be able to produce the 340-GHz signals within the next six months

Another application of the high-frequency CMOS VCOs of interest to the United States military is in submillimeter wavelength imaging.

"Because the wavelength is submillimeter, you may image through people's clothing," Chang said. "For example, it would be possible to remotely view if some civilian walking up to you has plastic explosives hidden under his coat."

CMOS technology makes future submillimeter-wave devices easily integrated with advanced microprocessors on-chip and can be very lightweight, so these sensors would be portable. "Foot soldiers could backpack them into the battle zone," Chang said.

Source: University of California - Los Angeles