Speed 3:
World's shortest burst of microwave radiation detected in California

by Greg Smestad

If someone told you that ultrafast microwave bursts were detected in L.A., you might think that they were signals from extraterrestrial civilizations or the basis for next disaster movie from Hollywood. But researchers from two southern California universities have combined electrostatics and relativity to produce pulses of microwave radiation that are in the range of 6 to 50 GHz in frequency, which corresponds to 5-cm to 6-mm wavelengths. This would not be noteworthy, except that the pulses are approximately 6 cycles long and the bandwidth-limited measured pulse duration was less than 750 ps. Using their new results, the researchers hope to sharpen the view produced by radar systems as well as to explore the processes occurring in supernovae.

The microwave band radiation is produced from what is called a dc to ac radiation Converter, or DARC. "A relativistic ionization front passing through a capacitor array with a period of 1-cm produces tunable radiation in the Ka band in an organic gas," explains Patrick Muggli, a researcher at the Univ. of Southern California (USC) in Los Angeles. Together with Tom Katsouleas, Roland Liou, Peter Lai, and Jerry Hoffman of USC, and John Dawson, Warren Mori, Chan Joshi, and Robert Brogle at the University of California Los Angeles (UCLA), the team has also proven that big-budget physics is not the only way to be on the cutting edge of science. In contrast to visible laser systems that may use a Ti:sapphire laser in a self-mode-locking operation to produce 6.5-fs pulses,[1] the new microwave laser system uses an optical switch provided by a organic gas plasma. The device, first conceived by Dawson, Mori, and Katsouleas, operates in fundamentally new ways compared to conventional ultrafast systems.

The heart of the device is a six-in.-long torpedo-shaped microwave cavity sectioned into separate capacitor plates. Each set of plates is biased with a polarity opposite that of its neighboring plates. The organic gas within the cavity is then ionized by frequency-quadrupled YAG laser pulses (266-nm wavelength, 50 ps in duration) to form a plasma. Contrary to what one might initially think, the excitation and energy source is not the incoming YAG laser beam, which serves only to rapidly ionize the gas to form a plasma. The energy instead comes from the dc power source feeding the capacitors, which operates at between 100 and 1000 v. The organic gas is a photoconductor that switches from an insulator (before the laser radiation reaches it) to a conductor as the laser pulse creates the plasma. The static long wavelength electric field, which exists within the cavity before the laser pulse, is altered by the rapid production of plasma and converted into a microwave pulse.

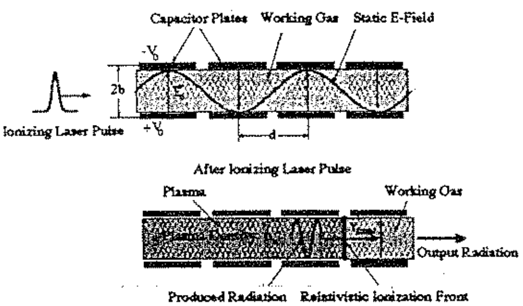

Figure 1. DARC schematic.

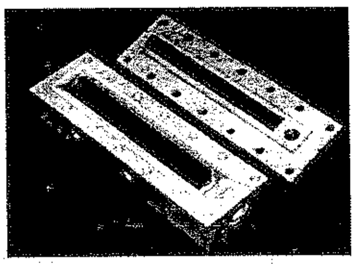

Figure 2. Ka-band device used for short pulse and spectra measurements, with capacitor (left, above quarter) for another Ka-band structure. The structure is placed in a glass tube that serves as vacuum chamber (as in Figure 2). The laser pulse comes from the right, or bottom, and the microwave exits into the Ka-band waveguide. There is a thin window guide; red and black wires are high votage wires.

As the ultraviolet laser beam travels along the axis of the cavity, a half-cycle microwave pulse is generated within the first capacitor. This pulse lags slightly behind the laser pulse at velocities close to the speed of light. As the laser pulse travels within the cavity, microwave half cycles of opposite phase are generated by the subsequent capacitors and are added together (superimposed) to create an output microwave pulse that is compressed compared with the static field. James Glanz, writing for *Science,*[2] likened the process to a musician's accordion. The radiation slows down due to the presence of the plasma similar to the way that light is slowed down when it passes from air to a medium of higher refractive index such as glass or water. The waves then look foreshortened to an observer at rest with respect to one traveling with the output beam. It is this relativistic aspect that allowed the team first to calculate that short bursts of radiation could be produced this way.[3] The researchers then went on to verify their predictions[4] and to build an apparatus from 12 pairs of copper electrodes embedded in a high-dielectric-strength kel-F plastic material, and later from a Ka-band waveguide (see Fig. 1).

The ionized gas [for example, azulene, or tetrakis(dimethylamino)ethylene, TMAE] is stopped by a glass barrier, but the microwave radiation is guided out of the capacitor array to be detected. In the Ka-band case, a diffraction grating (with centimeter-spaced lines) then separates the frequencies of the pulse so that a diode detector can analyze the signal. The pulses exhibit a discrete frequency (noncontinuous) spectrum. The gas pressure controls and tunes the frequency, and the number of cycles can be changed by increasing or decreasing the number of plates. Tom Katsouleas explained that by controlling the distance between the plates and the applied voltage, "designer radiation" pulses can be produced and tailored temporally as well as in the frequency domain (chirp).

Because some of the work is funded by the U.S. Air Force Office of Scientific Research and DOE, it is hoped this aspect will lead to short-burst coded military communications that are more difficult to jam. "The cost of the cavity was a mere $100, with the picosecond laser ionizer bringing up the cost by approximately $100,000," explains Katsouleas. The whole system is small enough to fit on a lab bench and it is hoped that the decreasing cost of ultrafast visible laser systems will allow the DARC to find numerous applications.

Future applications include pulsed radar with which it is hoped that one could image gold or other valuable minerals within a host rock material. Because the pulses occupy 1 in. in space, they can be used in precise time-of-flight measurements to do remote sensing. Other applications of the theory that led to the device include studies of plasma physics. Plasma is the fourth state of matter, along with liquid, gas, solid, and the most abundant form of matter in the universe, yet it is poorly understood. It is thought that radiation sources working on the same principle as DARC could exist in the chaotic gases surrounding supernovae bathed in cosmic background radiation.

As for future breakthroughs, it is hoped that the wavelengths and not the pulse duration can be improved. Because the measured pulse is less than 750 ps and the frequency is 50 GHz ± 15-percent bandwidth, the pulse is said to be transform limited and governed by the Heisenberg uncertainty principle from quantum mechanics. Although the device operates near the limit of what is possible in terms of time compression, the goal is now to extend the wavelength range available to include the infrared (Teraherz or THz), opening up applications in material characterization. **With all these applications, it is no wonder that when Tom Katsouleas is asked if he is busy, he replies, that like the microwave burst, his time is compressed.**

References

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