

eling-wave formalism developed by Pierce, but did not consider the available gain to be of any practical significance.

Stimulated Compton scattering is similar to stimulated bremsstrahlung, when viewed in the electron rest frame. As early as 1928, Peter Kapitza and P. A. M. Dirac² had considered stimulated Compton scattering. More recently, H. Dreicer (Los Alamos) calculated³ the gain for thermal electrons, and R. H. Pantell, G. Soncini and H. E. Puthoff (Stanford electrical engineering department) calculated⁴ the gain for relativistic electrons. A related group of devices⁵ developed mainly at the Naval Research Lab is based on yet another variation, relativistic electrons in a longitudinal magnetic field. These devices operate at lower frequencies than the transverse field devices, but are quite promising for high-power millimeter-wave and microwave radiation.

Madey's calculations for stimulated magnetic bremsstrahlung emission are based on the analogy to stimulated inverse Compton scattering.⁶ His results show that amplification is possible because stimulated emission occurs at a slightly longer wavelength than does absorption (inverse bremsstrahlung). The wavelength for stimulated emission varies with the electron energy, as well as with the magnet period and field. The tests of this theory at Stanford involved three main components: the superconducting electron accelerator to supply the relativistic electrons; a superconducting right-hand double helix wound around the interaction region to provide the magnetic field and a pulsed carbon-dioxide laser to act as a master oscillator.

The theory for stimulated bremsstrahlung predicts a correlation between the lineshape for spontaneous radiation on the one hand and the gain on the other; both of these were measured. For the spontaneous-emission measurements, the electron beam alone was fed into the magnetic field, bunched at the 1.3-GHz accelerator operating frequency, and the angular distribution, polarization and spectrum were noted. For the gain measurements, 10.6-micron radiation from the carbon-dioxide laser was sent through the interaction region in a beam parallel to the bunched electron beam. The interaction between the bunched electrons and the infrared radiation modulates the infrared radiation at 1.3 GHz: The percentage modulation is equal to the gain per pass. The magnet used during the tests had a 3.2-cm period and was 5.2-meters long; the tube enclosing the interaction region had an inner diameter of 10.2 mm, and the magnetic field was 2.4 kG. The electron energy was varied about 2% in the vicinity of 24 MeV.

The results appear to bear out the theory. For spontaneous emission, the observed linewidth is 0.4%, close to the theoretical homogeneously broadened width of 0.3%. The instantaneous peak gain per pass reached 7% at an instantaneous peak current of 70 milliamps. Correlation between gain and spontaneous-emission lineshape was as predicted, with net gain on the long-wavelength side and net absorption on the short-wavelength side of the lineshape for spontaneous emission. Gain varied linearly with electron current over the 5 mA–70 mA range, and the magnitude of the gain as well as its dependence on electron energy were independent of optical power density in the entire observed range (100 watts/cm² through 1.4×10^5 watts/cm²). The maximum stimulated power was 4×10^3 watts; this power is 10^9 times larger than the spontaneous power with the same electron current.

Madey is particularly pleased about the lack of saturation observed; this factor was the one least amenable to prediction. Now, he explained to us, there is a good likelihood of producing a powerful tunable laser for such large-scale processes as, say, laser-induced isotope separation or industrial photochemical synthesis. The next step is to build a laser oscillator; that is, to enclose the

interaction region in an optical resonator and to obtain sufficient electron current so that the gain per pass exceeds the resonator losses. If these tests, scheduled to end this October, are successful, the group would like to rebuild the electron storage ring originally built at Stanford in the 1960's, with a periodic magnet in one arm of the storage ring. As in a conventional storage ring, an rf cavity within the ring would maintain the steady-state energy of the circulating electrons. But in this case high-power coherent radiation would result from stimulated emission within the periodic magnet.

—MSR

References

1. H. Motz, Jour. Appl. Phys. **22**, 527 (1951).
2. P. L. Kapitza, P. A. M. Dirac, Proc. Cambridge Philosophical Soc. **29**, 297 (1933).
3. H. Dreicer, Phys. Fluids **7**, 735 (1964).
4. R. H. Pantell, G. Soncini, H. E. Puthoff, IEEE Jour. Quantum Electronics **4**, 905 (1968).
5. J. L. Hirshfield, I. B. Bernstein, A. M. Wachtel, IEEE Jour. Quantum Electronics **1**, 237 (1965). V. L. Granatstein, M. Herndon, R. K. Harper, P. Sprangle, IEEE Jour. Quantum Electronics **10**, 651 (1974). P. Sprangle, V. L. Granatstein, Appl. Phys. Lett. **25**, 377 (1974).
6. J. M. J. Madey, Jour. Appl. Phys. **42**, 1906 (1971).

Progress report on the VLA

Work goes on at the Very Large Array telescope project's site on the arid Plains of San Augustin, fifty miles west of Socorro, New Mexico. A \$2.9-million subcontract for the third phase of construction of the giant radio telescope has been awarded to the Burn Construction Company.

The VLA telescope, which is expected to be fully in operation some time in 1981 (see PHYSICS TODAY, May 1972, page 17), had its origin in studies initiated in the early 1960's to improve the performance of radioastronomy instruments in general. The essential concepts and design of the facility now under construction were developed between 1964 and 1971. Design and construction of the array is the province of Associated Universities Inc., the non-profit corporation of nine universities that operates the National Radio Astronomy Observatory under contract to the National Science Foundation. AUI also operates Brookhaven National Laboratory.

When it is completed, at an estimated cost of \$76 million, the telescope will consist of 27 fully steerable dish-shaped antennas, 82 feet in diameter and 90 feet tall, distributed along three sets of railroad tracks arranged in an equian-gular Y configuration. The northward

arm will stretch 11.8 miles across the plain, and the others will extend for 13 miles southeast and southwest.

Phase three in the project's construction consists of ten miles of railroad embankment to be prepared, 8.1 miles of double trackage to be laid, 49 radio-telescope antenna foundations to be built, and the installation of railroad switchings and turnouts, as well as an underground electrical system. The Burn company had previously been awarded, in June, 1974, a \$605 000 contract for the first phase of the construction. This phase, which involved the setting up of one mile of trackage and six foundations, plus assorted site services, was successfully completed in Spring 1975. Phase two construction consisted of the permanent buildings, site work, and utilities; it has been undertaken by the George A. Rutherford Construction Company for about \$2.4 million. Launched in December, 1974, this second stage is about three-quarters finished.

When the Burn company wraps up its work, there will be nine miles of double railroad trackage and 55 antenna bases ready for use. The Very Large Array is scheduled to begin functioning as an instrument for serious scientific work in late 1977, when its first ten antennas



Second antenna in the Very Large Array is outfitted with electronics. By 1981 there will be 27 such 200-ton antennas, 82 feet in diameter, arranged in a Y shape with 13-mile branches.

will already have made it one of the most powerful tools for radioastronomy in the world. The facility's nearest competitors will be the six-element array at Cambridge, England, and the 12-element system in the Netherlands, at Westerbork. Both will be kept busy even after the VLA is in operation.

Resolving power for the completed VLA will be equivalent to that of a conventional radio telescope consisting of a steerable paraboloidal dish 17 miles in diameter. Such a Brobdignagian antenna would be unwieldy, difficult to situate, exceedingly vulnerable to disturbed weather conditions, and incredibly costly; in addition, it would be quite unnecessary. Aperture synthesis, the principle on which all such arrays as the one taking shape in New Mexico are based, was developed conceptually in the late 1950's to obviate the need for such monsters. Martin Ryle won a Nobel prize for this and other contributions to the field of radioastronomy.

The VLA radio telescope employs ordinary aperture synthesis techniques as follows: Signals received at each of the 27 antennas are to be relayed to a central control building, where a computer will combine each message from any given antenna with each of the other antennas' signals. The first antenna has already been successfully used to send signals from a radio source to the computer. A final total of 351 interfering antenna pairs distributed over the Y

of the tracks will generate a radio map of any portion of the sky. Moreover, the rotation of the Earth will steadily move these 351 interferometers to new points while the same patch of sky is under observation, a refinement known as "supersynthesis."

The result will be highly detailed radio "pictures" produced in times from a few minutes up to 12 hours. Typical resolutions for areas several arc-minutes across will be 0.6 seconds of arc at an observing wavelength of six cm, or 2.1 seconds of arc at 21 cm, the well-known neutral hydrogen wavelength. At first only four observing wavelengths will be available, but these will be broadly representative of the radio spectrum: 18–21 cm, 6 cm, 2 cm, and 1.3 cm. The resolving power of the Very Large Array at these bands will make the facility comparable in the sharpness of its results to the 200-inch optical telescope on Mount Palomar. Plans among other nations for building VLA-scale radio telescopes are unknown, but the US facility will be available to qualified foreign users. —FCB

TTF-TCNQ

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search Center (Baden, Switzerland), Orsay and Karlsruhe reported (PHYSICS TODAY, September 1973, page 17) seeing a Peierls instability in a plati-

num salt (KCP) that they felt was much closer to being a one-dimensional electronic system than the TCNQ salts.

Although the Peierls effect was proposed for TTF-TCNQ three years ago, the structural aspects of the transition have only recently been demonstrated experimentally. Last year observation of an incommensurate superlattice and one-dimensional diffuse scattering in TTF-TCNQ at low temperature were reported in x-ray studies carried out² by Robert Comès and Francoise Denoyer (Orsay) in collaboration with Garito and Heeger. Their observations were independently confirmed³ by S. Kagoshima and his collaborators (Electrotechnical Laboratory, Tokyo).

Paris and Tokyo. At the San Juan conference two groups—Comès, Denoyer, Garito and Heeger, and Kagoshima and H. Anzai of the Electrotechnical Laboratory, Tokyo—reported their independent x-ray observations of a Kohn anomaly and a Peierls transition in TTF-TCNQ. They reported finding a Peierls period in TTF-TCNQ at room temperature and below. This periodicity, unlike the lattice periodicity, is determined by the Fermi momentum of the electron gas in the metal. Seeing the Peierls period might mean that part of each branch of the material had developed a charge-density wave and had become semiconducting, even at room temperature.

At low temperatures, the x-ray scattering was made more difficult because of the need to surround the apparatus with cryogenics. Although many solid-state workers had been thinking mostly of structure along the TTF-TCNQ chains, both experimental groups found that the low-temperature phase transitions were not taking place solely along the chains. A periodicity develops perpendicular to the chains at 54 K and changes at 38 K.

With the vectors **a**, **b** and **c** of the high-temperature lattice as reference, the structural rearrangement found consisted of a doubling of the periodicity in the **a** direction without change in the periodicity along the **c** direction. In the **b** direction (the chain direction), it was found that there is a periodicity modulation of 3.4 **b**, up to at least 100 K, in accord with a Peierls mechanism. Thus the structural phase transitions at low temperatures have approximately a three-dimensional character. Kagoshima and his colleagues also observed an anomaly in their intensity at 34 K.

Brookhaven-Orsay-Penn. In two separate papers at the San Juan conference Gen Shirane (Brookhaven) and Comès discussed neutron-scattering experiments carried out in collaboration with Steven M. Shapiro (Brookhaven) and Garito and Heeger. As they cooled the sample below 54 K a peak appeared in the neutron-diffraction pattern indicat-