Call Sign: WI2XVX
File No. 0131-EX-CM-2019
Applicant: Brown University
FRN: 0003-5995-37

EXPERIMENTAL DESCRIPTION

Purpose of Application

The purpose of this application is to change emission designators to show modulation of the signal as data at 1 Gbps.

A duplicate line on the existing license which shows the same make and model of transmitter twice is deleted, as there is only one transmitter at this time.

No changes in frequencies, power, locations, or other operating parameters are proposed.

Contact Information

The STOP BUZZER contact remains Daniel Mittleman, Professor of Engineering, at 713-992-4137, daniel_mittleman@brown.edu.

Any questions about this application should be directed to Dr. Michael Marcus, Consultant to Brown University, at 301-229-7714, mjmarcus@marcus-spectrum.com.

Ongoing Experimental Program

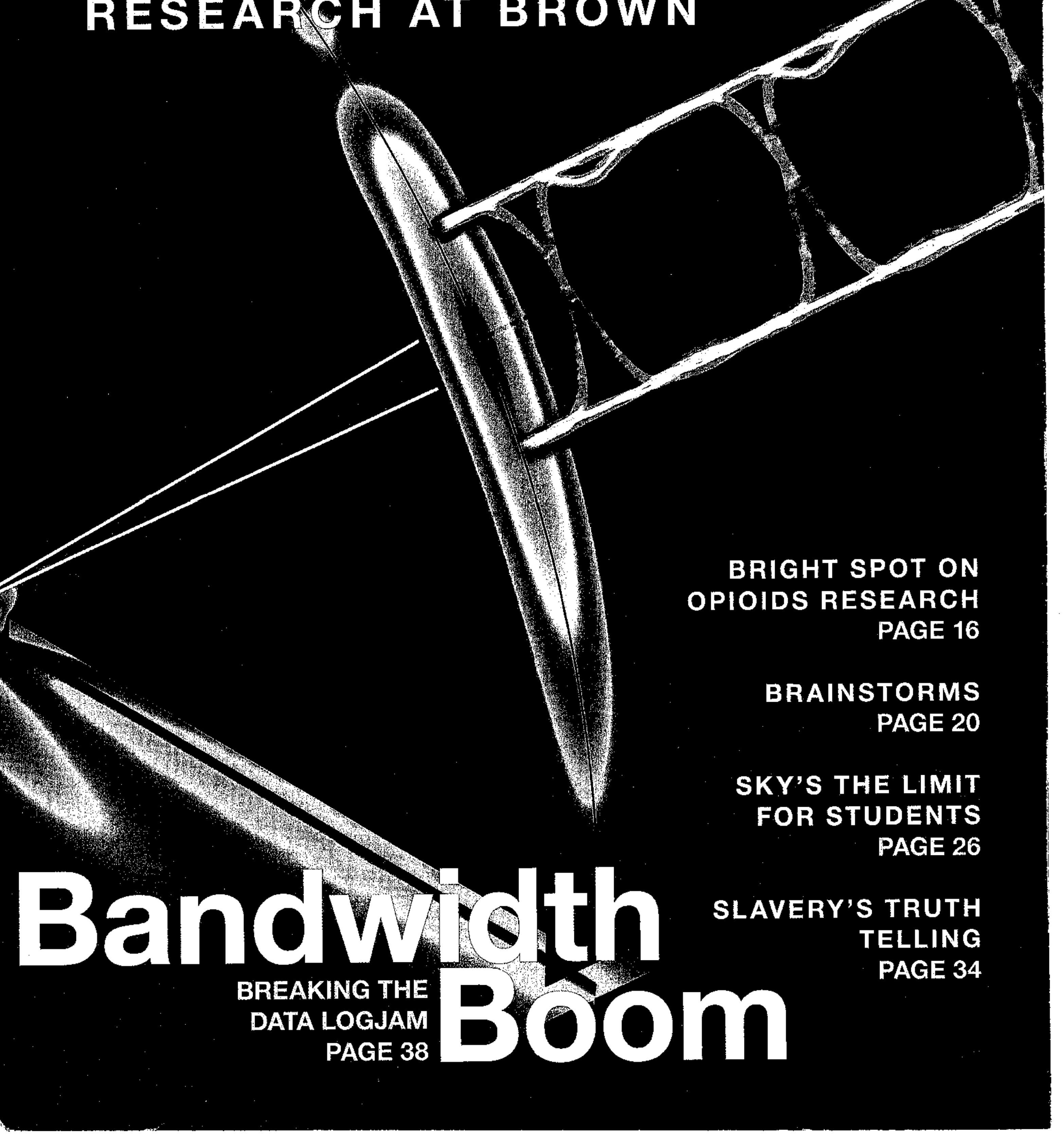
This license will continue to be used by Daniel Mittleman, Professor of Engineering at Brown University, for propagation measurement experiments on the Brown campus in Providence RI. Prof. Mittleman is a qualified researcher in this field, who has written extensively on the subject of TeraHertz propagation. The purpose of the experiment is to gather measurement data with respect to propagation in a complex environment at frequencies of approximately 100, 200, 300 and 400 GHz.

Prof. Mittleman participated in ET Docket No. 18-21, the Spectrum Horizons rulemaking. Attached is a recently published article describing his work using this experimental license.

IMPACT

2019

RESEARCH AT BROWN



BRIGHT SPOT ON OPIOIDS RESEARCH
PAGE 16

BRAINSTORMS
PAGE 20

SKY'S THE LIMIT FOR STUDENTS
PAGE 26

SLAVERY'S TRUTH TELLING
PAGE 34

Bandwidth Boom

BREAKING THE DATA LOGJAM
PAGE 38

STARTING OFF

Welcome to the second annual issue of *Impact: Research at Brown*, and to the many stories of outstanding work by Brown faculty and students. We are building on many fronts in our research, in bricks-and-mortar structures and even more in relationships, and there is much exciting news to share.

Let's start in downtown Providence, where Brown is investing in a newly thriving entrepreneurial and research-intensive ecosystem that is supporting the University's ambitions in translational medical research, forging new industry partnerships, and much more.

It is home to the Warren Alpert Medical School, flourishing medical/biology labs, the School of Public Health, the Institute for Computational and Experimental Research in Mathematics, and, most recently, the South Street Landing building, which is inspiring collaboration between my office and hundreds of other key administrative staff consolidated there. Later this year, our growing School of Professional Studies will join the Jewelry District's new Innovation Center in a building developed by Wexford Science & Technology.

On College Hill, we dedicated the Engineering Research Center last May. This three-story, 80,000-square-foot structure has specialized research laboratories and collaborative spaces for biomedical engineering, advanced materials, environmental engineering, and other programs. In December, the Watson Institute for International and Public Affairs opened the doors to Stephen Robert Hall, an expansion designed to fuel an expanding community of scholars working on global policy issues.

The latest research hub is at 164 Angell Street, the state-of-the-art collaborative home of the Data Science Initiative, the Center for Computational Molecular Biology, the Carney Institute for Brain Science, and the Annenberg Institute for School Reform.

In this year's *Impact*, you'll read about research made possible by these Brown investments and by funding from federal agencies and foundations. The Carney Institute, newly named by an extraordinarily generous gift, is on the leading edge of advancing research in brain science toward cures and treatments for ALS, Parkinson's, and other neurological disorders and diseases. Continuing a proud tradition of excellence in particle physics, Brown researchers continue to make discoveries contributing to our understanding of the universe, and play leading roles in the multinational upgrade of the particle collider in Europe. The Center for the Study of Slavery and Justice marks its fifth year with an ambitious agenda. And our undergraduates are engaging in remarkable research projects, including creating EQUiSat, a small satellite deployed in July by astronauts on the International Space Station.

I hope that you enjoy this year's selection of stories and this glimpse of the depth and breadth of research and scholarship at Brown.

Jill Pipher
Vice President for Research
Elisha Benjamin Andrews Professor of Mathematics

RESEARCH AT BROWN

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On the Cover: A simulation of radiation emerging from a terahertz multiplexer. Terahertz is high-frequency radiation that could enable the next generation of ultra-high-bandwidth networks to handle more data. (Mittleman lab/Brown University/Ducournau Lab/CNRS/University of Lille)

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NICK DENTAMARO

FOCUS

A CLOSER LOOK AT RESEARCHERS AND PROJECTS GAINING WIDER INFLUENCE

Information Ultra-Highway

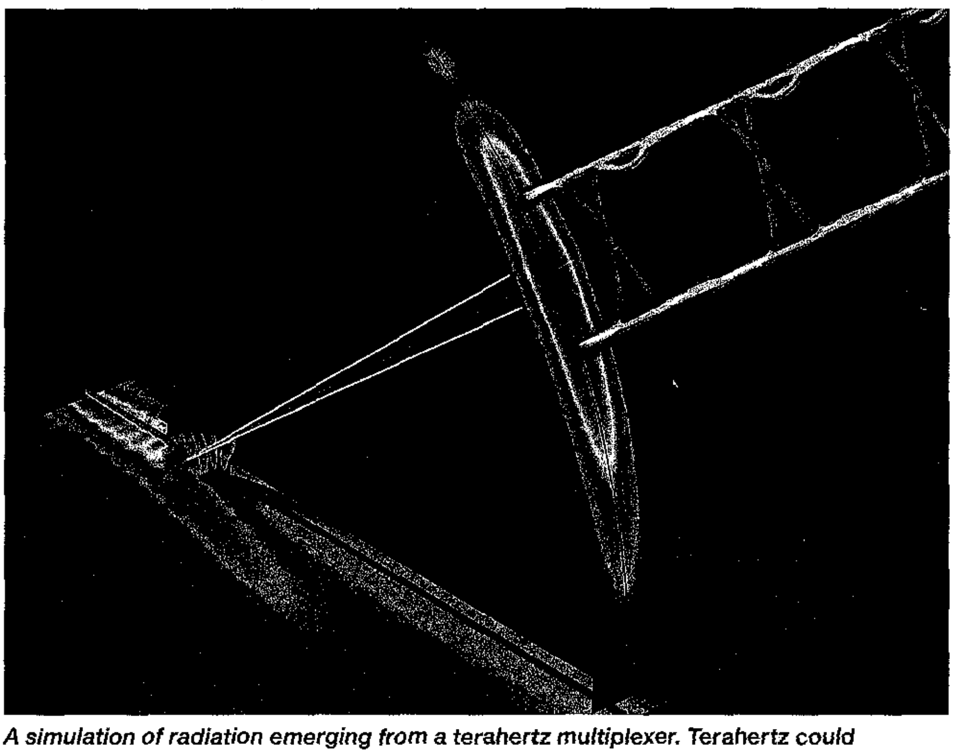
Transmitting data via terahertz waves shows promise in unclogging the data logjam.

BY KEVIN STACEY AND NOEL RUBINTON '77

When Alexander Graham Bell transformed communications with the telephone in the 1870s, he had an assist from two Brown professors—Eli Whitney Blake and John Peirce—whose work on a phone receiver was ultimately adopted by Bell.

With the revolution in communications now going at speeds that Bell could never have imagined, another Brown professor—Daniel Mittleman in the School of Engineering—is working with colleagues to find a way to solve a critical logjam on the modern-day information superhighway.

Today's cellular networks and Wi-Fi systems rely on microwave radiation to carry data, but the demand for more and more bandwidth is rapidly becoming more than microwaves can handle. That has researchers thinking about transmitting data on higher-frequency terahertz waves, which have as much as 100 times the data-carrying capacity of microwaves.

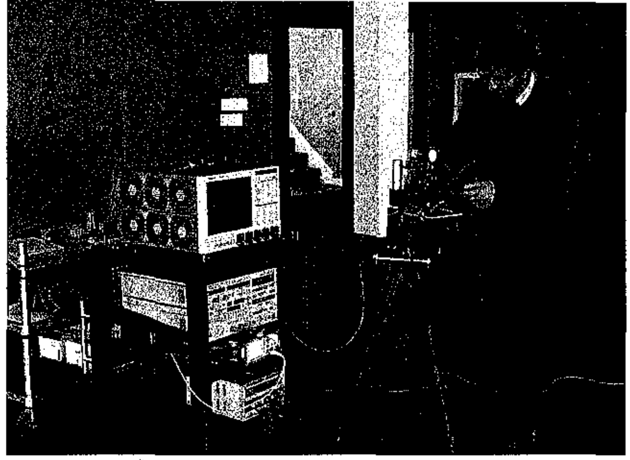


A simulation of radiation emerging from a terahertz multiplexer. Terahertz could enable the next generation of ultra-high-bandwidth networks to handle more data.

MITTLEMAN LAB/BROWN UNIVERSITY/DUCOURNAU LAB/CNRS/UNIVERSITY OF LILLE

Mittleman is at the forefront of those exploring the field of terahertz technology. Though terahertz transmission remains in an early stage, with much basic research to be done and plenty of challenges to overcome, Mittleman is leading many key avenues of investigation. He and his colleagues are working to develop the basic components and techniques needed to make terahertz communications a reality.

Multiplexing, the ability to send multiple signals through a single channel, is a fundamental feature of any voice or data communication system. An international research team led by Mittleman has demonstrated for the first time



Brown graduate student Rabi Shrestha works on terahertz testing equipment.

MITTLEMAN LAB/BROWN UNIVERSITY

a method for multiplexing data carried on terahertz waves, which may enable the next generation of ultra-high-bandwidth wireless networks.

"The terahertz range is often called the 'last frontier' of the electromagnetic spectrum, since it is the least well explored range of the spectrum," Mittleman said. "There's a good reason for this: everything is more challenging in this range, including generating the radiation, manipulating it, and detecting it. But, with these challenges, there are also tremendous opportunities for new science and new technologies."

In the journal *Nature Communications*, Mittleman and his team reported the transmission of two real-time video signals through a terahertz multiplexer at an aggregate data rate of 50 gigabits per second, approximately 100 times the optimal data rate of today's fastest cellular network. "We showed that we can transmit separate data streams on terahertz waves at very high speeds and with very low error rates," Mittleman said.

Mittleman and his team have even made the streets of Providence near their Barus & Holley offices a literal living laboratory. They have conducted measurements under the first license from the Federal Communications Commission to perform outdoor tests of data transmission in several frequency bands in the terahertz range. "These kinds of outdoor tests will be important for understanding what's possible in terahertz communication," Mittleman said.

The first outdoor tests have proven promising, in some cases easing concerns about the versatility of terahertz links. For example, it's long been assumed that terahertz links would require a direct line of sight between receiver and transmitter. But Mittleman and his team showed that non-line-of-sight terahertz data links are possible because the waves can bounce off of walls and other obstacles without losing too much data. Mittleman and his colleagues bounced terahertz waves at four different frequencies off of a variety of objects—mirrors, metal doors, cinderblock walls, and others—and measured the error rate of the data on the wave after the bounces. They showed that acceptable error rates were achievable with modest increases in signal power.

"There are also tremendous opportunities for new science, and new technologies."

—Daniel Mittleman

The researchers also looked at what's known as multipath interference. When a signal is transmitted over long distances, the waves fan out, forming an ever-widening cone. As a result of that fanning out, a portion of waves will bounce off the ground before reaching the receiver. That reflected radiation can interfere with the main signal unless a decoder compensates for it. It's a well-understood phenomenon in microwave transmission, and Mittleman and his colleagues wanted to test it in the terahertz range.

They showed that this kind of interference occurs in terahertz waves but to a lesser degree over grass compared to concrete. That's likely because grass contains a lot of water, which tends to absorb terahertz waves. Over grass, the reflected beam is absorbed to a greater degree than over concrete, leaving less of it to interfere with the main beam. That means that terahertz links over grass can be longer than those over concrete because there's less interference to deal with, Mittleman said.

There's also an upside to that kind of interference with the ground. "You can imagine that if your line-of-site path is blocked," Mittleman said, "you could think about bouncing it off the ground to get there."

In other terahertz work, Mittleman and others, including Masaya Nagai, an academic colleague in Japan, have developed a new method of manipulating the polarization of light at terahertz frequencies.

The technique, outlined in a paper in the journal *Scientific Reports*, uses stacks of carefully spaced metal plates to make a polarizing beamsplitter, a device that splits a beam of light by its differing polarization states, sending vertically polarized light in one direction and horizontally polarized light in another. Such a beamsplitter could be useful in a wide variety of systems that make use of terahertz radiation, from imaging systems to future communications networks.

Terahertz radiation is a hot area of study, and the work isn't limited to data transmission. Mittleman and Professor Vicki Colvin from Brown's chemistry department are heading a team that has improved the resolution of terahertz emission spectroscopy—a technique used to study a wide variety of materials—by a thousandfold, making the technique useful at the nanoscale. Laser terahertz emission microscopy is a burgeoning means of characterizing the performance of solar cells, integrated circuits, and other systems and materials.

The researchers believe their new technique could be broadly useful in characterizing the electrical properties of materials in unprecedented detail.

"Terahertz emission has been used to study different materials—semiconductors, superconductors, wide-bandgap insulators, integrated circuits, and others," Mittleman said. "Being able to do this down to the level of individual nanostructures is a big deal." ■