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The DUR]IP funding has been used by the University of Nevada at Reno to acquire a high performance radiofrequency (RE) /nhicrowave (MW) signal generator, a high power broadband amplifier, a broadband horn antenna, high power cables, and a high-end computer that is interfaced with the signal generator and amplifier via a LabVIEW program. This equipment will be used to support an AFOSRfunded research project to investigate the feasibility of designing novel non-lethal radiofrequency (RE) stunning weapons based on eluddation of non-thermal hiomolecular effects of pulsed and continuous wave (CW) RE exposure on neurotransmifter release. It will also support a DEPSCoR-funded program that extends those studies to include microwave frequencies and to explore the effect of pulsed and CW RE/microwave exposure on skclctal muscle contractility. All projects incorporate Basic Science Electrical and Biomedical Engineering graduate students, as well as undergraduate students majoring in the basic sciences into various aspects of the research.

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FINAL REPORT

EXPANDING CURRENT RESEARCH CAPABILITIES FOR INVESTIGATING RF/MICROWAVE BIOEFFECTS

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Submitted to the Air Force Office of Scientific Research
DURIP (Defense University Research Instrumentation Program)

July 14, 2004

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SUMMARY

The DURIP funding has been used to acquire a high performance radiofrequency (RF) /microwave (MW) signal generator, a high power broadband amplifier, a broadband horn antenna, high power cables, and a high-end computer that is interfaced with the signal generator and amplifier via a LabVIEW program. This equipment will be used to support two Department of Defense (DoD) research projects. The first project, currently funded by the Air Force Office of Scientific Research (AFOSR), is to investigate the feasibility of designing novel non-lethal radiofrequency (RF) stunning weapons based on elucidation of non-thermal biomolecular effects of pulsed and continuous wave (CW) RF exposure on neurotransmitter release. The second project, funded under the DEPSCoR program involves broadening of the scope of the AFOSR project by extending our studies to include microwave frequencies and by exploring the effect of pulsed and CW RF/microwave exposure on skeletal muscle contractility, thus enabling us to investigate another strategy for designing non-lethal immobilizing weaponry. With the acquisition of the equipment under the DURIP, our laboratory is now equipped with signal generators and amplifiers in the range 0.75 – 6 GHz with both CW and pulse modulation capabilities. All projects incorporate Basic Science, Electrical and Biomedical Engineering graduate students, as well as undergraduate students majoring in the basic sciences into various aspects of the research.

In order to sustain the growth and development of our DoD-related research, it is crucial to set up an exposure facility in a physical space that is easily accessible to all faculty and graduate students involved in our research. Therefore, the equipment forms a fundamental part of a free-space *in vitro* cell/tissue RF/microwave exposure facility that has been assembled in a state-of-the-art anechoic chamber and adjacent screen room that exists in the Microwave Engineering Research Laboratory located in the Harry Reid Engineering Laboratory building on the campus of the University of Nevada, Reno. The anechoic chamber/screen room has been made available for our use, free of charge, by the Department of Electrical Engineering. This chamber is equipped with an automated antenna gain/pattern measurement system that includes an antenna mounting stand (called the "tower") and turntable that are computer-controlled. The horn antenna is mounted on the tower and the turntable is used to focus the RF/microwave beam on the cell samples. The whole set-up can also be monitored remotely by the person running the experiment using a video camera installed in the anechoic chamber and monitor that is placed in the screen room.

DESCRIPTION OF EQUIPMENT PURCHASED

Item	Cost	Source
1. Agilent Technologies 8665B High Performance Signal Generator with optional pulse modulation	$44,476.32 (includes a 20% educational discount as well as a 5% price increase)	Agilent Technologies, Englewood, CO
2. Instruments for Industry TD 81-250 (1 – 8 GHz) 250 Pulsed/CW High Power Broadband Amplifier	$89,250 (includes a 15% educational discount)	Instruments for Industry, Ronkonkoma, NY
3. Model AH81-400 Horn antenna	$4,250 (includes a 15% educational discount)	Instruments for Industry, Ronkonkoma, NY
4. Model HPFC-3M and Model HPFC-10M High Power Coaxial test cables	$1,275 + 1,530 = $2,805 (includes a 15% educational discount)	Instruments for Industry, Ronkonkoma, NY
5. A high-end Personal Computer	$3703	Technology Center, Reno, NV

1. The ***Agilent Technologies 8665B High-Performance Signal Generator, with optional pulse modulation capable of generating variable pulse widths and delays,*** has a frequency range of 100 kHz to 6 GHz, thus giving coverage of many communications systems and most surveillance and avionics radars. With the optional pulse modulation capability, pulse widths from 50 ns to 999 ms, less than 5 ns rise/fall times, as well as variable pulse delay can be obtained. This signal generator, in conjunction with the broadband power amplifier described below, will enable us not only to extend our research (described below) into the microwave range using CW radiation but also allow us to investigate bioeffects due to fast rise/fall time and narrow pulse width RF/microwave radiation. The instrument comes with a 1-year warranty from the manufacturer.

3. The ***Instruments for Industry (IFI) TD 81-250 High Power Pulsed/CW TWT (Traveling Wave Tube) Broadband Amplifier*** will be used in conjunction with the Agilent 8665B signal generator to supply variable power to the *in-vitro* cell and tissue exposure systems that will be used in the research projects. The frequency range of the amplifier is 1 – 8 GHz, the rated power is 250 Watts CW and typical power is 300W. The amplifier comes with complete TWT protection, including VSWR (voltage standing wave ratio) reflected power protection, thus eliminating the need to incorporate a circulator and dummy load into the exposure set-up. In addition to other standard features, the front panel LCD Back-lit display includes forward and reflected power metering. The instrument comes with a 3-year warranty from the manufacturer.

4. A ***high-end personal computer*** to interface with the Agilent 8665B signal generator and IFI power amplifier and with other equipment used in the exposure experiments. This computer will also be used to interface with the electrochemical detector and force transducer recording unit to collect data in real-time during the experiments. Moreover, the experiments will be performed using different types of exposures that will incorporate variations of several RF/microwave parameters: frequency, intensity, amplitude and frequency modulation, pulse modulation with varying pulse widths, rise/fall times, and pulse delays, and times of exposure. Hence, it is critical to the success of our research projects to completely automate the exposure protocols. We are using the program LabVIEW to perform the interface. The College of Engineering, University of Nevada, Reno, has a site license for LabVIEW that is available for use on all the projects.

5. To perform free-space irradiation of the excitable cell preparations and tissue samples, a ***broadband horn antenna*** will be used for the frequency range 1 – 6 GHz. The Model AH81-400 horn antenna, rated for a power of 400 W, has been purchased from IFI as a package together with the amplifier.

6. One 10-meter long high power ***flexible coaxial cable*** (Model HPFC-10M) will be required to connect the horn antenna to the jack in the wall between the anechoic chamber and screen room. Also, one 3-meter long high power flexible coaxial cable (Model HPFC-3M) will be required to connect the jack to the amplifier placed in the screen room. These have been purchased as part of the package from IFI.

STATUS OF INSTALLATION AND TESTING OF THE EQUIPMENT

The RF/MW signal generator and power amplifier have been installed in the screen room adjacent to the anechoic chamber. They have been connected via the high-power cables to the IFI horn antenna that has been mounted on the tower in the anechoic chamber. For measurement of the radiation pattern of the horn antenna, we are using another broadband horn (Qpar Angus Ltd, U.K.) antenna available in our laboratory as the receiving horn. This receiving horn is connected to a network analyzer (model HP70205A) placed in the screen room. All measurements are completely automated.

Figures 1 and 2 respectively show the IFI horn antenna installed in the anechoic chamber and the instrumentation including the signal generator, amplifier and computer in the screen room. Figure 3 shows a close-up of the signal generator and amplifier.

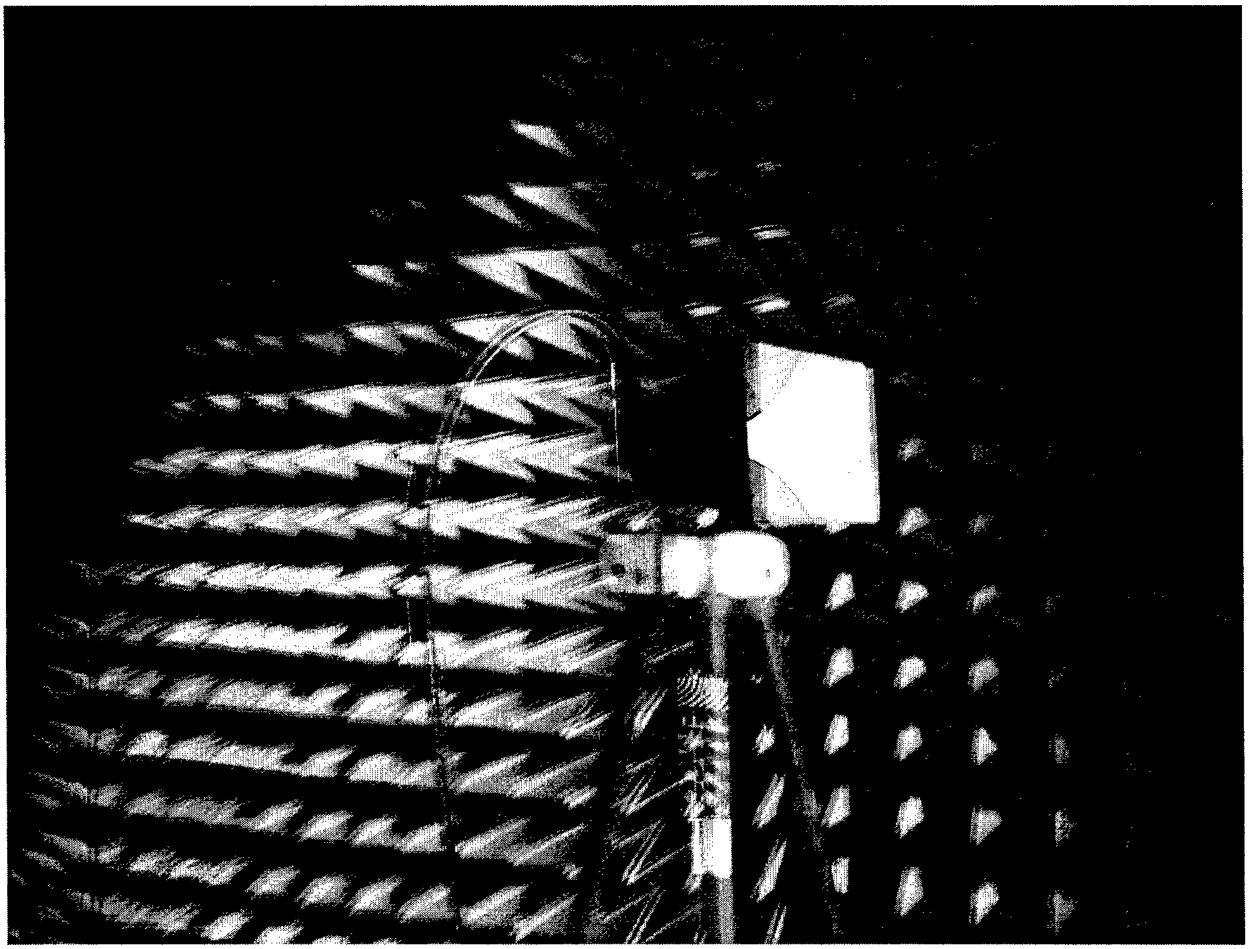

Figure 1: Photograph of the IFI horn antenna within the anechoic chamber.

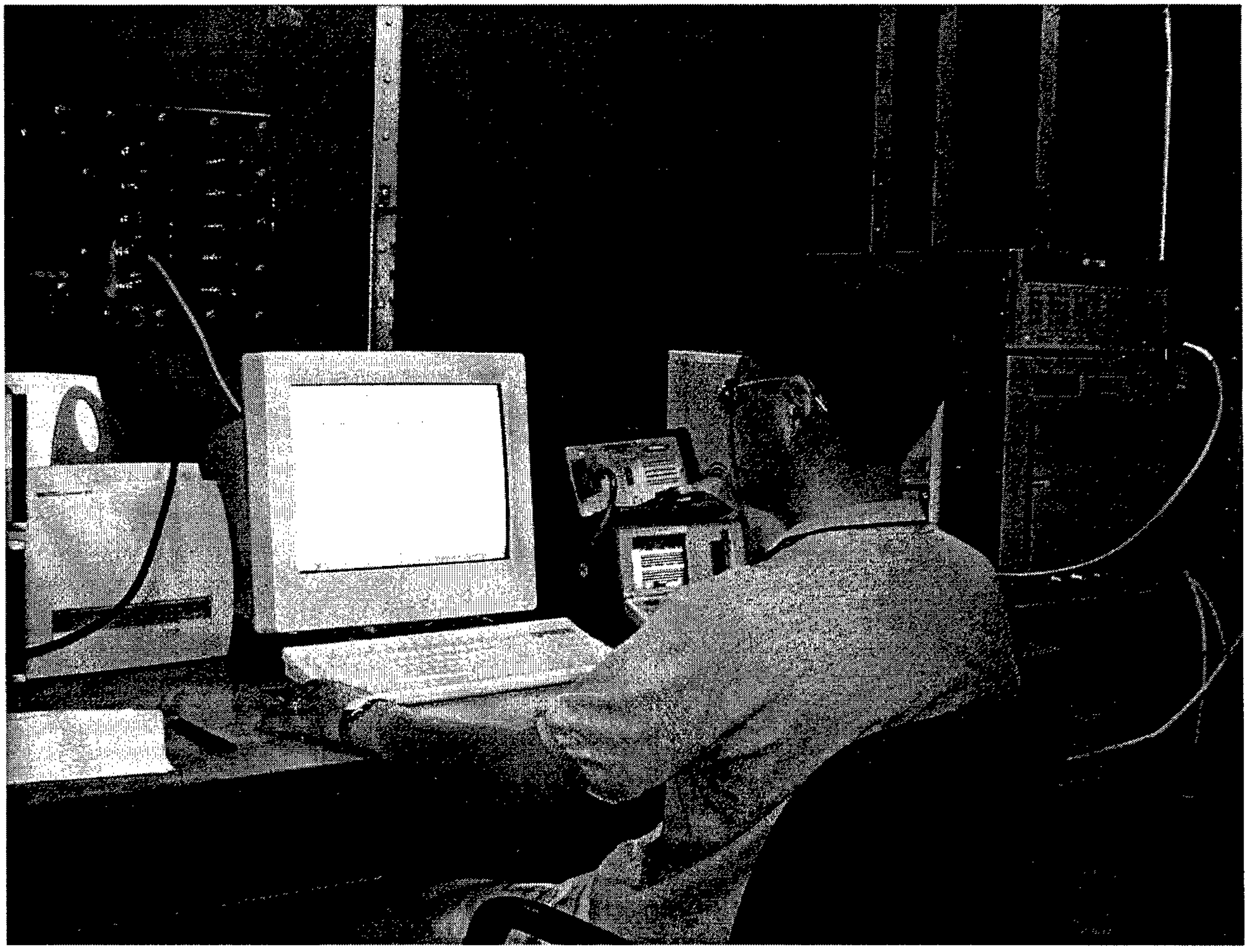

Figure 2: Photograph of graduate student Jihwan Yoon working in the screen room on measurement of the radiation pattern of the horn antenna – the signal generator and amplifier are on the extreme right of the picture.

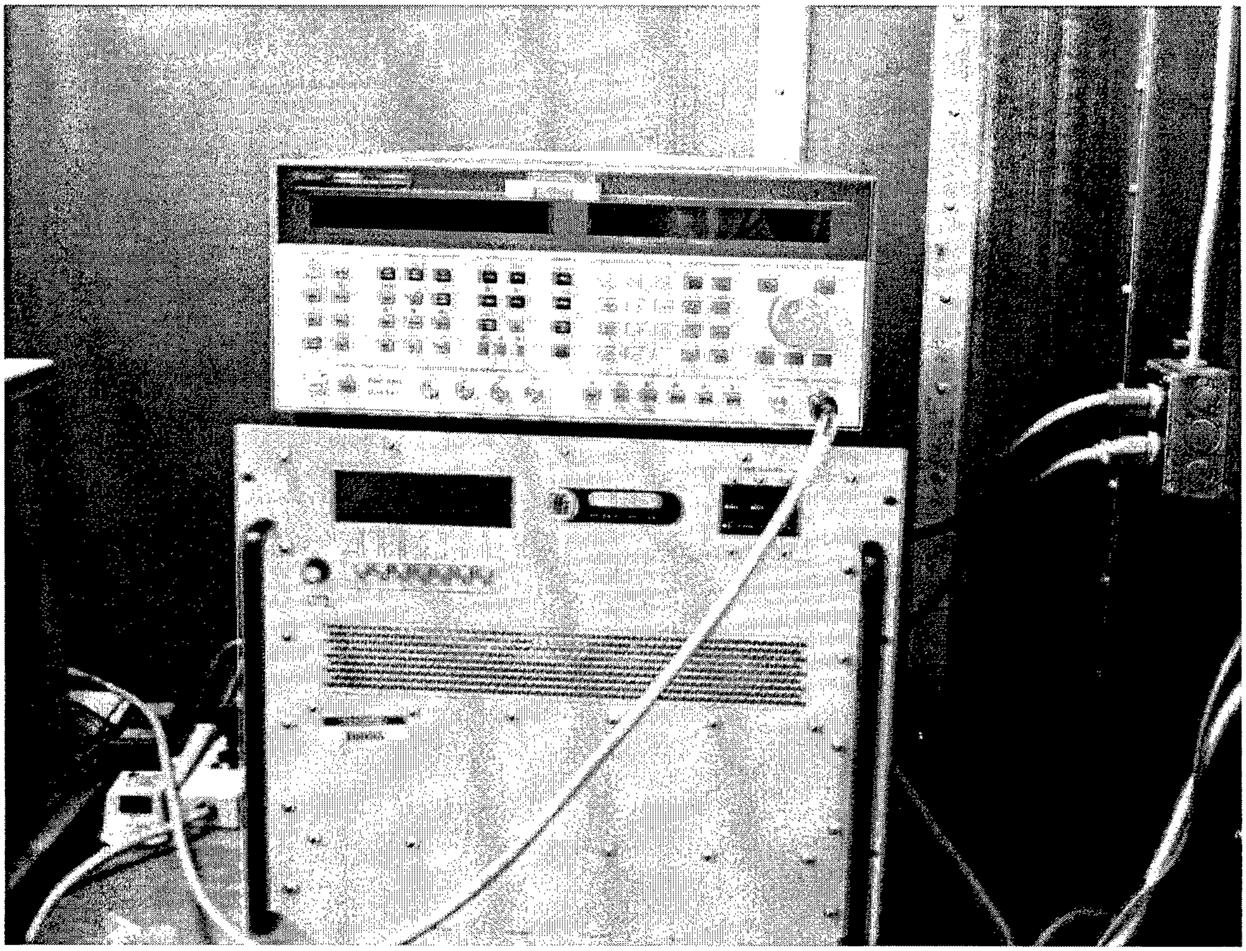

Figure 3: Close-up photograph of the signal generator and amplifier within the screen room.

Jihwan Yoon, an electrical engineering Ph.D. student who is currently working on this project, has performed the interfacing of the turntable and tower to the computer and is in the process of measuring detailed radiation patterns of the IFI horn antenna over the frequency band 1 – 6 GHz. He is also designing a chamber that will contain the exposure systems for the biological cells and skeletal muscle samples. This chamber will be placed within the main anechoic chamber in the far-field of the horn antenna and will provide not only the proper electromagnetic environment for the cells but also will protect the other equipment that will be placed within the anechoic chamber (the electrochemical detector that measures the amount of catecholamine release from the cells, and pump that superfuses the cells with balanced salt solution, the force transducer and bridge amplifier for measuring muscle contractility, etc.). The design is being performed using state-of-the-art Finite-Difference Time-Domain software XFDTD from Remcom, Inc.

The research described below, encompassing two Department of Defense projects, deals with investigations of non-thermal effects of CW and pulsed RF/microwave radiation. The primary goal of the research overall is to (1) identify bioeffects that can be triggered in excitable cells by RF/microwave radiation, and (2) determine the specific RF/microwave exposure parameters that are capable of triggering the bioeffects.

Our research focus fits into the current interest of the Department of Defense in non-lethal weaponry and antiterrorism, in that war fighters may in the future have the capability of using weapons that will be effective in stunning/immobilizing the enemy but not causing permanent harm.

The scope and interdisciplinary nature of the research will make an important contribution towards the training of future engineers and scientists in the United States in areas of interest to the Department of Defense. Already we have found that our undergraduate and graduate students are very excited to be part of a research thrust that not only is highly relevant and important for the defense of our country, but also because of its potential for resulting in therapeutic breakthroughs in the form of non-invasive treatment methods based on specific cellular and sub-cellular effects of RF/microwave radiation.

SUPPORTING INFORMATION

Research projects that will benefit from the acquired instrumentation

The instrumentation that has been purchased will greatly expand the capabilities of two Department of Defense research projects:

Project 1: The first research project entitled "Sensitivity of neurotransmitter release to radiofrequency fields" is currently funded in the amount $357,652 by the AFOSR (Program Manager: Dr. Robert Barker, Physics and Electronics division) for a three-year time period (6/1/02 – 5/31/05). The Principal Investigator of this project is Dr. Gale Craviso and the Co-Principal Investigator is Dr. Indira Chatterjee.

The instrumentation acquired under the DURIP will allow us to extend our research into higher frequency bands in which there are substantial communications as well as surveillance, avionics and missile-range precision instrumentation radar equipment in the L-band (ITU (International Telecommunications Union) assignment: 1.215 – 1.4 GHz), S-band (ITU assignments: 2.3 – 2.5 GHz, 2.7 – 3.7 GHz) and C-band (ITU assignment: 5.25 – 5.925 GHz).. This will be important because if our research shows that non-thermal bioeffects exist in the form of altered neurotransmitter secretion for a specific set of RF/microwave parameters, then applying already well-developed and advanced RF/microwave technology in a novel way to develop immobilizing weaponry would be an achievable goal.

Project 2: The second project entitled "Exploring non-thermal RF radiation bioeffects for novel military applications" is funded by the Department of Defense EPSCoR program in the amount of $500,000 (with $250,000 additional matching from the University of Nevada, Reno). The program manager is Dr. Robert Barker, Physics and Electronics Division of the AFOSR. The Principal Investigator is Dr. Gale Craviso and Co-Principal Investigator Dr. Indira Chatterjee. The project is for a three-year period starting 6/1/03. The project addresses the long-term goals set in Project 1 funded by the AFOSR, i.e. investigating the feasibility of designing novel non-lethal stunning/immobilizing weapons based on non-thermal effects of RF/microwave radiation on neurotransmitter release from chromaffin cells. It extends the scope of Project 1 by proposing to conduct exposures at low levels of microwave radiation, as well as by using another type of excitable cell i.e. skeletal muscle cells, to investigate whether RF/microwave radiation will produce non-thermal effects on muscle contraction, thereby providing another strategy to design novel immobilizing weaponry. As for the studies in Project 1, biomolecules that are able to sense the RF/microwave radiation and cause the bioeffect will be identified and future studies directed at determining how the exposure alters the function of the biomolecules.

The acquired equipment will not only enable us to extend the research into the range 1 – 6 GHz but also, because of the options for exposing the cells to pulsed radiation having quick rise/fall time (< 5 ns) and varying pulse widths (50 ns – 999 ms) and delays, provide tremendous opportunities for realizing the goals of the research.