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The Tower
Undergraduate Research Journal
at the Georgia Institute of Technology

Spring 2012, Volume 4
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Dear Reader,

I am proud to say that I have been the Editor of The Tower over these past two years, and even more proud to say that I have found lifelong friends working with the tremendously talented staff of The Tower. Just as The Tower has grown since the previous editor, Chu Yi, handed over the reins two years ago, I believe I have grown with The Tower. Working with the dedicated staff of The Tower, my fellow Editor-in-Chiefs at other student publications, and the Office of Student Media, I have not only learned how to manage an undergraduate research journal, but also learned a little more about myself. While college classes train you to largely work by yourself, I have found that The Tower has taught me how to work with others.

With the successful print of Volume IV of our journal, we at The Tower have achieved our long-term goal of publishing two volumes a year. The beauty, quality, and breadth of our journal are testaments to the value of working with others to achieve what individuals could never accomplish. The journal could not be possible without the dedicated work of our review staff, led by Mohamad Ali Najia, our production staff, led by Allison Dowell, and our business team, led by Michael Bonifacio. This year, we feature undergraduate research articles from the College of Engineering and the Ivan Allen College, as well as interviews with Chris Klaus and undergraduate researchers. We also have a new feature called Georgia Tech Science News in Review, where our reviewers write articles about undergraduate research news on campus.

If you have been following our journal throughout the years, you will notice the drastic changes in our journal layout. It is our philosophy that science and art should not be held as two mutually exclusive subjects. A famous professor once said that the key to being a successful scientist is to think like a poet but work like a bookkeeper. We at The Tower strongly believe that creativity and imagination is the key to a vibrant scientific community. Our journal’s design celebrates this philosophy, and I hope that the creativity our production staff demonstrates will continue to define The Tower in the coming years.

I have called The Tower my home for quite a while, and I know our next Editor-in-Chief, Tyler J. Kaplan, will find the same treasures I found while I managed The Tower. Over the past two years, Tyler and I have been in the trenches together trying to ensure a positive future for our journal. He has proven his dedication to The Tower by working incessantly to improve every aspect of The Tower. Tyler will be an excellent Editor, and I look forward to reading the many journals that Tyler and his staff will produce in the coming years.

I would like to thank Dr. Christopher Reaves, Marlene Beard-Smith, and Mac Pitts for the sweat and tears that they have given to The Tower. I would also like to thank Chris Klaus, Chun Yong, and Daniel McGrail for agreeing to let us share their thoughts in our journal, as well as all the authors who had their articles accepted in this volume of the journal. The authors of The Tower’s research articles are the undergraduates who make our journal possible. Finally, I would again like to thank our staff, whose work makes our mission of showcasing undergraduate research a reality.

Sincerely,

Michael Chen
Editor-in-Chief, 2010-2012
Dear Reader,

When I joined the Tower two short years ago, I had no idea that my journey with the organization would bring me to eventually become the Editor-in-Chief. I am both honored and humbled to be chosen for the position. Having worked with Michael Chen for two years, I know the large shoes that I have to fill, and will strive each and every day to make the work he has put in over the past years worthwhile as we move the journal forward.

As we transition into the new academic year, I am filled with a great sense of pride as I look at the many ways that the Tower has grown since Michael and I began working together. At the outset of my tenure as Business Manager, we were in a perpetual struggle to find reliable staff, and to build a cohesive team that could produce an effective journal. Now, I can say with confidence that we have put together a skilled, diverse Editorial Board that I believe will work together to produce a journal that positively represents both the Institute and the amazing undergraduate researchers that call it home.

Over the next year, we will continue to work towards diversifying the material that is printed in The Tower as we continue to cater towards a larger audience, both on and off of our campus. Be on the lookout for a stronger online presence, as we endeavor this year to expand the offerings on our website and the features of the online journal.

Additionally, I plan as Editor-in-Chief to pursue new initiatives throughout the year that will allow us to reach out to Tech’s campus through events that not only serve to promote research on campus, but allow us to showcase the work that goes on in our undergraduate labs throughout the year. The Undergraduate Research Kaleidoscope has been our flagship event over the past few years, and we plan to build on it this year so that we can become a more effective tool for communicating research to the greater Tech community.

The copy of the Tower that you are currently reading would have never been possible without the talents and devotion of our incredible staff of reviewers, production assistants, faculty supporters and of course, our editorial board. If you see them around campus, be sure to give them a pat on the back, and thank them for all that they do every day to keep undergraduate research a priority at Tech.

Finally, I want to take a moment to thank Michael Chen for the incredible work he has done for the journal over the past two years. Without his unwavering love and dedication to this journal, I would have never been inspired to become Editor-in-Chief. I wish him the very best in all that he pursues in life after Tech, and know that he will find incredible success wherever he goes.

Tyler J. Kaplan
Editor-in-Chief, 2012-2013
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Rising healthcare expenditures and the ever-aging United States population have made the healthcare industry an active sector for public policy debate. With many trying to find a political solution to this burgeoning problem, some such as Georgia Tech Professor and National Institute of Health Fellow Dr. Serhat Gul are approaching it from a scientific perspective by applying the field of operations research to tackle some of its most pressing issues. Dr. Gul’s research has evolved from tackling surgical scheduling issues at prominent hospitals to now advancing the nascent field of individualized medicine by helping create a template model through which unique treatment plans can be crafted for specific individuals.

With work experience in the Mayo Clinic and Center for Health Organization Transformation (a partnership between the National Science Foundation and leading national universities) in Boston, Dr. Gul has first-hand experience in the problems facing the healthcare industry. While at these hospitals, he worked to create modeling programs used in the industry to produce optimal surgery schedules that minimized surgeon overtime, appointment cancellation costs, appointment postponement costs, and preoperative wait time. The model took into account many operational variables including patient factors such as medical conditions and hospital factors such as operating room restrictions and patient treatment schedules. In fact, the Boston-based Beth Israel Hospital has started a pilot program using the insights from his research. After publishing a paper on the subject, Dr. Gul’s research interest began to shift towards the field of medical decision making. This paralleled his arrival at Georgia Tech in August 2011 to work with the Director of the Center for Operations Research in Medicine and HealthCare, Eva K. Lee in this field with funding from the NIH.

Dr. Gul’s new research focuses on a subset of the medical decision-making field called individualized treatment planning, which involves tailor-made treatment plans administered to patients that have two chronic diseases such as diabetes and various cancers. The major problem facing generic treatment plans for individuals with multiple diseases is many cases a treatment for one disease will have an adverse effect on the other. For example, patients that suffer from diabetes and breast cancer are given adjuvant chemotherapy less frequently due to the risk it poses in diabetes-related complications. To overcome this inherent complexity, Dr. Gul is designing a mathematical programming model for each disease that will determine how treatment for one disease affects the treatment for the other in that individual. His mathematical model will take into account risk factors specific to the patient such as initial blood sugar level, diabetes history, age, drug use, along with others as constraints in the model’s formulation of the treatment plan. His hope is that it will generate a plan that mixes treatments for a specific individual to minimize both risk factors and cost.

Dr. Gul is optimistic that his model will ensure manufactured treatment plans will maximize health outcomes and facilitate hospitals that service low-income families to provide wider health options at a fraction of present day costs.

Robot mapping applications, particularly those in harsh environments, benefit from the use of teams of robots. This provides increased reliability and coverage. In difficult exploration scenarios, such as search and rescue or surveillance and reconnaissance, the primary goal is to provide an accurate map of the operating environment. Moreover, multiple robots allow for a faster exploration than a single robot, but using multiple robots poses control challenges. The objective is to achieve scalability in computational costs and communication bandwidth, and robustness to node failure and to changes in network topology. As such, researchers in the field are interested in decentralized data fusion (DDF) systems consisting of a network of sensor nodes, each with its own processing facility, which together do not require any central communication facility. In such a system, since the data is decentralized, data loss due to node failure is eliminated.

Dr. Frank Dellaert, Associate Professor in the School of Interactive Computing, along with graduate students, Alexander Cunningham and Manohar Paluri, present a novel method for efficiently and robustly distributing map information across a team of robots. Their endeavors focus on developing algorithms for distributing simultaneous localizing and mapping (SLAM) across many robots, while remaining robust to communication and robot failure, and meeting limited computation and communication requirements. This lead the research team to develop an extended Smoothing and Mapping (SAM) approach to implement DDF, wherein a local optimization module executes single-robot SAM to condense a local graph; a communication module collects and propagates condensed local graphs to other robots; and a neighborhood graph optimizer module combines local graphs into maps describing the neighborhood of a robot.

One of the problems faced by the researchers has been to reduce data transfer by choosing the most informative features to transmit. The problem associated is the bookkeeping necessary to prevent double counting information. Thus, the proposed solution is augmenting SAM with Constrained Factor Graphs (CFG). The result will be an asynchronous distributed system resilient to robot failure and changing network topology scalable to large networks of robots. The general structure of the system allows for each robot to build a “local map.”

The research team has performed simulations to implement the algorithm using the Georgia Tech Smoothing and Mapping toolbox. It was done in a simulated scenario with a set of robots driving in circles to map out the area. On tabulating the results, they found that the time taken by the DDF-SAM method with CFG to condense the local maps into a neighborhood map was consistently faster than a comparable naive approach. The future of the research will deal with creating a fully distributed SLAM system and deploying this system in larger scenarios.

The tissue engineering and regenerative medicine fields are attempting to create biomaterials that will enable the body to heal itself more effectively when faced with serious defects and injuries. An approach currently being studied is the creation of tissue scaffolds which direct cell growth in the affected area. Researchers at the Parker H. Petit Institute for Bioengineering and Bioscience (IBB) from the School of Mechanical Engineering and the Department of Biomedical Engineering, in collaboration with researchers from Harvard University and Queensland University of Technology, have recently had success with an innovative and interdisciplinary technique called electrospinning. In electrospinning, an electrical gradient is used to spin nanofibers onto a collector, creating a mesh similar to a spider web. These nanofibers meshes can be used as tissue and membrane scaffolds. The meshes’ large surface area and size scale may improve attachment of cells to the tissue scaffolding surface and enhance function. Tubes of these nanofiber meshes can work as physical guides to direct cell growth in large bone defects. The research collaborative has also shown that a hybrid system incorporating different growth factors (chemicals that stimulate cellular growth) into the nanofiber mesh tubes through the use of a modified hydrogel stimulate bone growth and could lead to functional regeneration.

Dr. Robert Guldberg, Director of IBB and principle investigator of this research, notes that “nanofiber meshes effectively direct cell growth in a defect because they provide both physical and biochemical cues for cell growth along the mesh structure.” The system also provides living cells with a structure similar in dimension to structures within the body. The potency of this method is increased as the mesh facilitates spacio-temporal delivery of new regenerated tissues. Further research is being done to evaluate the efficacy of different meshes in promoting growth in rat bones.

Much of the funding for this research is provided by the military and the Department of Defense. Many soldiers are returning from combat with severe injuries to their limbs and extremities. In some cases, the injuries may be separating healthy, functioning parts of the body. Advances in regenerative medicine would greatly benefit these victims of such severe injuries and may be able to regain function in their injured limbs. The future plans for this project include scaling up experiments to human-scale systems in sheep and eventually clinical trials.


Radiographs of bone tissue grown with the direction of nanofiber mesh without growth factor, with growth factor, and with growth factor and perforations in the mesh tube. Although bone growth has occurred in all of these systems, III and IV show the most growth. Credit: Kolambkar et al, GT, and Biomaterials
In 2010, electricity consumption in the US alone totaled nearly 3884 billion kWh. Global trends indicate that electricity is at the highest demand than any other time in human history. Joint research by Dr. S. J. Deng from the School of Industrial and Systems Engineering at Georgia Tech, and Dr. S.S. Oren and Dr. Yumi Oum from the Department of Industrial Engineering and Operations Research at the University of California, Berkley aims to utilize derivatives for risk management in the energy market. In their paper, “Volumetric Hedging in electricity Procurement,” the researchers have identified methods to protect energy companies from risks associated with variable demand at regulated prices.

As a way to protect the market participants, particularly the load serving entities (LSEs) from price fluctuations, derivatives such as electricity futures, forwards and options are utilized. Futures and forward contracts obligate the party to buy or sell a certain quantity of electricity at a certain price and time in the future. However, the profit or loss from such a contract depends on the unknown price of electricity in the future. Options alleviate some financial risk in that they allow a party the right to buy a quantity of electricity at a certain price at a certain time in the future, for a small premium.

Although opportunities exist to mitigate risk, challenges such as the difficulty of storage and the unpredictability of demand still remain in hedging risks in electricity markets. For example, due to the strong correlation of demand with the temperature, the usage of weather derivatives such as Heating Degree Days (HDD) can hedge against sudden increases in demand caused by heat waves. However, the speculative image of these instruments makes them unsuitable due to opposition from regulators. Additionally, there is a strong correlation between the load and the price of electricity; such correlation makes volumetric hedging even more essential.

Dr. Deng and his collaborators have proposed an approach that uses standard forward electricity contracts and price-based power derivatives which exploits the correlation to create a volumetric hedge. The approach is a two-step process that involves first computing the optimal payoff function in terms of a spot price and then replicating it using standard instruments to arrive at the optimal number of contracts. As the standard method of using the no-arbitrage principle to hedge no longer holds when volumes vary, the researchers developed a methodology based on the utility of economic agents bearing risk that are not hedged by standard instruments. The specific utility is maximized over the LSEs profit to investigate price and quantity risks. To deal with the quantity-risk, the researchers borrowed concepts from agricultural literature to calculate the variance optimizing the hedge ratio of futures contracts. Their research shows that an optimal hedge portfolio also contains options of various strike prices, thus creating a more efficient market and precisely delivering supply that meets market demand.

Fluid mechanics, the study of fluid movement, is a fundamental and essential field in engineering. It describes everything from blood flow to geophysical convection. Thus, the applicability of the field is enabling researchers to understand the hemodynamics behind heart attacks, one of the United States’ leading clinical causes of death. Myocardial infarctions (heart attack) and cerebrovascular accidents (stroke) are due to atherosclerosis, the formation of plaque on arterial walls over several decades, restricting blood flow. The rupture of the plaque cap results in acute thrombotic occlusion, which is fatal. Clinically, however, atherosclerotic plaques are only specific to the coronary, carotid, and renal arteries. Mechanisms to prevent thrombotic occlusion in said arteries could provide means to reduce the chances of myocardial infarctions and cerebrovascular accidents.

David Ku, MD, PhD, professor in the George Woodruff School of Mechanical Engineering, and his lab in the Institute for Bioengineering and Bioscience (IBB) are keen on applying such principle engineering concepts to understanding arterial thrombosis. Current medical literature defines three factors that are thought to result in thrombosis: stasis of blood, endothelial disruption, and hypercoagulable blood. However, such criteria are paradoxical to the clinical presentation of arterial thrombosis. Previous scientific work in the field has focused on thrombus formation via the Virchow’s Triad; whereas, clinically, arterial thrombosis is due to high shear, exposed collagen, and normal circulating blood. Thus, other studies have yet to investigate high shear forces inducing massive arterial clotting, as occur in vivo.

The initial goal of Dr. Ku’s research was to recreate arterial thrombosis, showing occlusion under in vivo hemodynamics in a clinically observed duration of time (<30 minutes). Andrea Para, PhD candidate, was the lead graduate student on the project. An in vitro experiment was formulated to mimic in vivo arterial conditions. Porcine blood was pumped through a collagen coated glass tube with a stenosis until the tube was completely occluded. Histological sectioning of the thrombus indicated it was primarily comprised of platelets. Functional analysis revealed that the growth rate of the thrombus was shear dependent and platelets rapidly accumulated when the shear rate was greater than 1 000 s⁻¹. In fact, shear was calculated at peak stenosis to be 100X normal arterial shear (100 000 s⁻¹). Thrombus formation was rough and created disturbed blood flow downstream further increasing shear. Consequently, the velocity of the platelets traveling through the stenosis was calculated to be >2 m/s with a transit time past a point on the thrombus of <10 microseconds.

As such, the results imply that platelet aggregation is rapid with less than a 10 microsecond bonding time; the fastest bonding time to be reported in the scientific literature. At the nanometer scale, the platelet surface glycoprotein, GP1b adheres to the A1 domain of circulating Von Willebrand factor (vWF), causing platelet aggregation. The fluid mechanics of blood flow cause platelet margination to arterial walls allowing for increased platelet deposition at the stenosis. At high shear, the vWF glycoprotein unwinds increasing the bonding kinetics to the A1 bonding domains. However, in the in vitro experiment shear would reach a maximum of 200 000 s⁻¹, resulting in a platelet bonding force of >2 000 pN, which is 20X stronger than previously reported GP1b integrin bonds. Even though platelet accumulation is stimulated by shear, the bio-
physical mechanisms permitting such a high bonding force could not be explained by single bonds.

Multivalent bonding experiments involving varying the shear rate dependency elucidated the number of possible A1 domain bonding sites per shear rate. Additionally, vWF is thought to form mesh grids under a shear greater than 5 000 s\(^{-1}\). The geometry of vWF under high shear provided the appropriate bonding kinetics for platelet aggregation in 10 microseconds.

The implications of this work are vast. Platelets are commonly found in the blood, but are marginated to the arterial walls due to the fluid mechanics of blood flow. Platelets are captured and bond at very high velocity and shear. Progressive bonding results in higher platelet bond strength due to the shear induced elongation and unwinding of vWF. The capture and bonding of platelets occurs rapidly and can completely occlude specific arteries at stenoses. In order to inhibit platelet aggregation at high shear, the unfolding and release of vWF may be blocked. Currently, pharmaceuticals that prevent platelet activation may not consistently inhibit shear stimulated activation. However, new physics of arterial thrombosis may lead to new therapies to prevent myocardial infarctions and cerebrovascular accidents.


Breast cancer is a leading cause of cancer death for women in both the United States and abroad. The National Cancer Institute (NCI) estimates that 1 out of every 8 women will develop breast cancer within her lifetime. Implementation of early detection strategies is therefore critical for improved cancer prognosis and diagnosis, since it improves a patient’s chance of survival alongside reducing unnecessary invasive procedures like biopsies.

Currently, digital mammography is the principal early screening method used for detecting breast cancer, as it can identify microcalcifications abnormalities before symptoms arise. Cancerous cells typically cause microcalcifications that are usually very small, typically in the range of 0.1-1.0 mm, a major reason why 10-30% of the cancer cases go undetected. Thus, it is imperative that microcalcifications can be accurately identified in mammograms. Typically, the smaller microcalcifications are not easily distinguishable on mammograms and their shapes become distorted as the images are enlarged. Consequently, diagnosis of cancer is increasingly difficult.

Dr. Brani Vidakovic, Professor of Bioengineering Statistics in the Wallace H. Coulter Department of Biomedical Engineering, alongside graduate students, Erin Hamilton and Seonghye Jeon, in collaboration with Dr. Mary Newell, a radiologist at Emory University’s Winship Cancer Institute, are a team of researchers focused on solving this key issue with mammograms. The team has developed signal processing based methods to enhance the resolution of microcalcifications in digital mammograms. The technique works by taking a small portion of the initial image and storing it as a matrix of pixels. Utilizing wavelets, discrete mathematical functions that cut up data into different frequency components for signal processing, the pixel matrix is computationally transformed using a wavelet-transform algorithm. Wavelets are more precise with signal data than other common signal analysis techniques, such as Fourier, because the self-similarity of signal decompositions is preserved to build informative detail spaces. The wavelet-based interpolation of the digital mammogram signals results in a higher resolution image, allowing for a better visualization of smaller details.

Another screening strategy the team is investigating involves analyzing the background of digital mammograms for signs of cancer. Cancerous tissues typically exhibit a more innate regularity, while noncancerous tissues exhibit more irregularity. The regularity of a mammogram image is quantified through similar signal processing wavelet transforms of pixel matrices. This novel procedure is currently an unused yet promising diagnostic modality, since it is based on background

Continued on Page 21
Carbon Capture and Storage is Better Done “Virtually”
Hoki Tse

Due to fossil fuel burning and other human activities, anthropogenic carbon dioxide emissions are expected to double in the next 50 years. Carbon capture and storage (CCS) is one of the most popular paradigms proposed to stabilize and mitigate carbon dioxide concentrations. CCS involves sequestering carbon dioxide from industrial and power sources, then transporting and storing it underground indefinitely. But Georgia Tech Environmental Engineering researcher Costas Tsouris, his PhD student Douglas Aaron, and Oak Ridge National Laboratory researcher Kent Williams would rather redirect resources that would have been spent on CCS to alternative energy technologies, calling it “virtual CCS.”

Tsouris’ team performed a comparative analysis on cost and carbon avoidance between CCS and virtual CCS based on the famous “stabilization wedges” concept of Pacala and Socolow – dividing mitigation technologies into “wedges” to stabilize or even reduce carbon emissions over a period of 50 years. The total optimal cost of CCS investments to mitigate a single Pacala-Socolow wedge was estimated to be $5.1 trillion over 50 years. If that amount was spent on virtual CCS technologies such as windmills and nuclear power plants, how many “wedges” of carbon dioxide would be avoided?

Based on simulation models, both windmills and nuclear plants were found to be more efficient on avoiding carbon dioxide emissions than CCS, mitigating approximately twice and four times more, respectively. If CCS was to match the efficiency of virtual CCS, its cost would need to improve to $2.7 trillion to match windmills, and $1.2 trillion to match nuclear power plants. Moreover, they pointed out that virtual CCS investments would also make revenue via electricity sales during the lifetime of the establishments. Incomes of approximately $9 trillion and $22 trillion would be generated from windmills and nuclear power plants, respectively.

Tsouris’ team demonstrated that virtual CCS can avoid carbon dioxide emissions more efficiently than CCS, and make profits simultaneously. Investing on CCS would provide no benefits other than carbon dioxide avoidance. But then, why is CCS such a popular component of the CO2 mitigation strategy? They answered, “Perhaps because it would allow us to maintain our dependence on a source of energy with which we have considerable experience.”


A Modern Twist on Music
Michael Bonifacio

Each year the School of Music and Center for Music Technology hosts the Guthman Musical Instrument Competition. This event provides students with the opportunity to showcase new designs for instruments that blend the beauty of music with the intricacy of science and engineering. This year, more than 20 inventors came together to compete for a $5,000 dollar prize which is presented by Georgia Tech alumnus, Richard Guthman, in honor of his musician wife, Margaret.

Marco Donnarumma was selected to receive this prestigious award for his invention, Xth Sense. His design centers on the fundamental effects of muscle contractions. Just like a string on a guitar vibrates after being strung, a muscle fiber responds similarly when contracted. These small vibrations are impossible to notice without the aid of the device; however, with the help of an outfit that Donnarumma has designed to wear with sensors across the surface of one’s body, his invention reads the muscular contractions while moving and translates the motion into tones audible to humans.

One of the most fascinating aspects of his design was the invention’s coding. Because the sound originates in the muscle tissue and not the motion of the human, Xth Sense will create unique sounds with each new subject. The instrument uses pre-recorded sounds to form the base of the music, but the music is processed differently for each person because of the distinct oscillations of a person’s muscle. The fluidity in Donnarumma’s performance comes largely from the Xth Sense’s short lag time between the input and output.

Through his work with Dr. Martin Parker at the University of Edinburgh in the United Kingdom, Donnarumma was able to combine musical talent with ingenuity to create an amazing piece of machinery, labeling his invention the “world’s most innovative new musical instrument.” Donnarumma aimed at using the human body not as a vessel to play an instrument, but an instrument in and of itself.

http://www.gatech.edu/newsroom/release.html?nid=109781
Re-Hand Wins InVenture Prize
Mohamad Ali Najia

Re-Hand, a software-assisted home-use hand assessment and rehabilitation device, won the 2012 InVenture Prize in front of a live television audience at the Ferst Center for the Arts last night. “It was amazing,” said Re-Hand team member Daphne Vincent, who graduated in December of 2011 with a degree in biomedical engineering. “We are so excited. We now have our first investment and we will be able to get our invention into the hands of the people that really need it.” As the winner, Re-Hand received a cash prize of $15,000, a free U.S. patent filing by Georgia Tech’s Office of Technology Licensing (valued at approximately $20,000) and automatic acceptance to the 2012 class of Flashpoint, a Georgia Tech startup accelerator program.

Vincent’s team included three other biomedical engineering majors: Alkindi Kibria, Elizabeth LeMar and Kunal Dean MacDonald. “The competition was nerve-racking, exhilarating and thrilling,” said Vincent “We worked really hard over the last year and especially over the past two months. We have had so many crazy times and late nights, but it finally paid off.”

Matthew Stoddard, an industrial design major, and Christopher Vollo, an electrical engineering major, finished in second place with their invention Stylii, an extraordinarily precise and pressure-sensitive capacitive stylus designed for use on the iPad. Second place also receives a free U.S. patent filing by Georgia Tech, and automatic acceptance into Flashpoint, along with a $10,000 cash prize. “The patent will help us out so much and we’re excited about anything that will help us get this to market,” said Stoddard. “With the right connections and the right progress, it (the Stylii) will be on market by Christmas.”

CardiacTech, a chest retractor for bypass surgery, won the People’s Choice award, which comes with a $5,000 cash prize. Mechanical engineering students Benji Hoover and Josh DeVane and biomedical engineering students Kevin Parsons, Matthew Lee and Priya Patil made up the CardiacTech team. “Overall, we’re pretty happy with the People’s Choice Award,” said Hoover. “We would have loved to get a patent, but we are going to continue to work on getting our FDA clearance so we can get this thing into surgery.”
Interview: Christopher Klaus, Tech Alumnus
Written by Tyler Kaplan

This year, the Tower had the pleasure of interviewing Mr. Christopher Klaus, a Tech alumnus who has not only been extraordinarily successful in his respective field, but has taken the time to give back to the Institute which gave him so much. In 2000, he financed the new home of the College of Computing with a $15 million donation. When he made this donation at the age of 26, it was the fifth largest contribution in Tech’s history.

Klaus, who grew up in Sarasota, Florida, cites the unique internet presence of Tech as one of the major reasons he chose the Institute. “I had become aware of the internet before it became what is today, and Tech stood out because they were the only school I looked at that was actually on the internet already,” said Klaus. To him, this was a sign that Tech on the cutting edge of technology, and would best fit his desire to work in computing. Klaus spent one and a half years at Georgia Tech, during which time he dedicated himself to both his studies, and to developing the model for what would later become his first company, Internet Security Systems (ISS).

The original framework for the company began when Klaus participated in a summer internship at the Lawrence Livermore National Labs. Although they invited him back the next summer to be paid to develop the software, he is thankful that he did not, because it allowed him to continue developing the software without it becoming the intellectual property of the government. ISS continued to develop into his second year at Georgia Tech, when he decided to take a break from school to focus on the fledgling company. After raising significant capital in 1995 and 1996, ISS expanded its offices from his grandmother’s extra bedroom to Europe, Asia, and locations throughout the US. By 1998 the company went public and eight years later, in 2006, Klaus was ready to sell the company to IBM for a staggering $1.3 billion. ISS was not designed as a company that would be sold when the right offer came along, but was rather designed for investment and growth over time. Klaus cites this as one of the reasons for its magnificent success.

After completing the deal with IBM, Klaus began to devote himself to more completely to his next project, Kaneva. In stark contrast to his work with ISS, Kaneva is a company that seeks to facilitate the creation of massively multiplayer online games (MMOG) through user generated content (UGC). This means that Kaneva does the majority of the heavy lifting for game creation; game logic, hosting, and server maintenance, while the users are free to create and share 3D objects, accessories, sounds particle effects and animations.

Because the creation of computer games brings together all types of skills sets that are used in real life, they are incredibly complex and expensive. With Kaneva, Klaus said that he hopes to become disruptive by significantly lowering the cost to create an MMOG. Currently, it takes a company around two years and $250,000 to $2,000,000 to create such a game. Through the “ready out of the box” format that Kaneva is developing, Klaus estimates that it will take a group of one to two people about a weekend to create an MMOG.

Continued on Page 21
Daniel McGrail has presented his research seventeen times during his tenure in Michelle Dawson’s lab. From his experience, Daniel recommends that undergraduate researchers attend conferences for a deeper understanding of their projects. He says that these meetings have encouraged him to pause and think about the motivations and implications of his research. This challenge and also the anxiety that accompanies the preparation for the conference are rewarded by the deep sense of accomplishment that follows. At these conferences, Daniel stated that his colleagues treat him with respect and judge him based on the quality of his work instead of his young age. Daniel has been presenting his research accomplishments since 2009, most recently at the American Chemical Society meeting in 2012.

Daniel’s main drive is the desire to contribute to our society’s progress. He has dedicated more than three years to his research and has been awarded for his work multiple times. Currently a Petit Undergraduate Research Scholar, he was previously awarded the College of Engineering Outstanding Undergraduate Research award in 2011, and the President’s Undergraduate Research Award for the Spring and Summer of 2010 semesters. Daniel acknowledges that these awards provide crucial financial support for his research, and is delighted that his university is able to back him in his endeavors.

Upon reflection on his experience in Dr. Dawson’s lab, Daniel states that he is grateful that as an undergraduate researcher, he was not pressured by laboratory deadlines, and was able to learn at his own space. From this independent learning style, to his successes, it is evident that Daniel is a mature research scientist. His acclimation to the research culture of Georgia Tech was quick. He was one of Dr. Michelle Dawson’s first students, and as the lab started up was responsible for developing, optimizing, and debugging several laboratory protocols. Daniel states that this unique opportunity allowed him to strive in the laboratory, and being in a laboratory from the ground up is certainly rewarding. Not only was Daniel able to present his work at conferences, he is also working on his second publication demonstrating how cytoskeletal changes of human mesenchymal stem cells (MSCs) in long-term culture are a more effective predictor of therapeutic efficacy than current molecular assays. His first paper published in PLoS ONE describes Daniel’s work on how cells migrate towards tumors, utilizing mathematics and image processing in order to show that MSCs acquire a different mechanical phenotype than fibroblasts in response to soluble factors released by tumors, leading to increased migration. His current project in collaboration with the Griendling lab from Emory focuses on understanding how a novel NADPH oxidase regulator Poldip2 alters vascular

Continued on Page 21
In a recent interview, Chun Yong, a student of Biomedical Engineering, reflected on his undergraduate experience and stated that it was “all worth it.” He is, of course, referring to the demanding Georgia Tech curriculum and research culture. However onerous the coursework, it helped Chun with his research, especially on occasions when he needed to model structures, implement differential equations, or examine transport of glucose and insulin into cells. Chun’s hard work has been numerous recognized, including in a recent Senior Excellence Outstanding Research Award for his work with Type I-insulin-dependent diabetes. Chun’s role in the lab was to develop a delivery method for insulin-secreting cells for the treatment of Type I diabetes.

Chun was drawn to the lab of Dr. Sambanis because of its direct effect on society. Through this project, Chun recognized that the work of doctors and of researchers influences our society’s state of well-being. Perhaps this is one of the factors that can be attributed to his changing majors from Chemical Engineering, to Biomedical Engineering, and also continuing down a research path. After his initial work at the laboratory, Chun applied for a President’s Undergraduate Research Award (PURA) in the fall of 2009. He states that this stipend allowed him to continue to work at the laboratory, and encouraged him to strive for an even higher quality of work. Subsequently, he was awarded a Petit Undergraduate Research Scholarship in 2010. He stated that this year-long opportunity was a pleasant recognition for his efforts in the biomedical field. Chun is grateful for the stipend which allowed him to make substantial progress on his project while working full-time in the summer and part-time in the spring and fall. The work has culminated in two more PURA salary and two travel awards.

In addition to the PURA, Petit, and Outstanding Research Awards, Chun is also a 2011 Goldwater Scholar. When asked about this award, Chun expressed his gratitude to his professor, Dr. Newstetter who was the first to encourage him to pursue this award, and also to his mentor Dr. Sambanis who supported him throughout the process. When Chun was not initially selected in 2010, these professors inspired Chun to maintain his persistence and his hard work. The next year, the Goldwater committee rewarded Chun Yong and other exemplary students for their outstanding academic performance and a dedication to engineering.

Although he is still very attached to his research project, Chun did spend a summer at the Mayo Clinic, away from pancreatic cells. Surrounded by approximately one hundred students and outstanding faculty, Chun spent ten weeks in Rochester, MN as part of the Summer Undergraduate Research Fellowship program. The program taught him new ways to problem-solve, present his research, and improve his technical writing. Most importantly, it provided him with a plethora of wise advice for his future after graduation. Currently, his goals include continuing biomedical research in the industry and maintaining his commitment to diabetes research.
When asked what the key to his success is, Klaus talks about three keys to building a business: viral, retention and revenue. Once you find a concept that goes viral, and can find a way to retain those who use it, the revenue will come naturally. Even through all of his continued success, Klaus maintains that anyone who has a great idea should simply do one thing to ensure their success: Go for it!

smooth muscle cell motility. One of the most important lessons that Daniel is taking with him into his master’s project is how to approach a problem at hand and how to turn a research question into an experimental project. Daniel McGrail is graduating this summer and continuing in Dr. Dawson’s laboratory for a thesis-based master’s degree in Chemical and Biomolecular Engineering.

mathematics and image processing in order to analyze the viscoelasticity of the MSCs cytoskeleton. His current project focuses on the changes of MSCs in long-term culture, coupled with traction-force microscopy. One of the most important lessons that Daniel is taking with him into his master’s project is how to approach a problem at hand and how to turn a research question into an experimental project. Daniel McGrail is graduating this summer and continuing in Dr. Dawson’s laboratory for a thesis-based master’s degree in Chemical and Biomolecular Engineering.

rather than foreground features of a digital mammogram.

The procedure was implemented in the identification of 105 normal images and 98 cancerous images obtained from the University of South Florida’s Digital Database for Screening Mammography. A formidable 86% accuracy was achieved, compared to 55% accuracy from current visual inspections of mammogram images. The research is innovative, utilizing current diagnostic infrastructure and procedures, but improving upon diagnostic accuracy via easily implementable computational means. Hence, this research paves the way for non-invasive, early detection of pre-metastatic breast cancer and increasing patient prognosis.


The United States Trafficking Victims Protection Act and States’ Compliance: An Analysis

INTRODUCTION

The purpose of this paper is to examine what determines a state’s level of compliance with the United States Trafficking Victims Protection Act (TVPA). While there have been several studies on what causes human trafficking, and some analysis of the US State Department Trafficking in Persons Report, there is a remaining gap in the literature which this study seeks to fill. Those that do look at the TIP Report recognize a correlation between perceived level of corruption and TIP rankings (Lyday, 2000). However there are several cases to which this hypothesis does not apply, three of which will be examined here. These three states have relatively high levels of perceived corruption, yet were still ranked as Tier 1, which represents countries with the highest level of compliance, in the 2010 TIP report (Transparency International, 2010; US State Department, 2010). Therefore other factors will be proposed that could determine a state’s level of compliance in the prevention of human trafficking, as these cases do not support the aforementioned hypothesis. While these cases may simply be outliers to this theory, there indeed could be another reason that each of these countries were granted the highest level of compliance ranking, in spite of the corruption that hinders compliance.

1 This study was conducted as part of a research internship/directed study, under the direction of Dr. Esther Skelley Jordan. The purpose of this study is to contribute to Dr. Jordan’s research on global human trafficking, and is being published with her permission. Although the words here are my own, many of the ideas presented are the product of collaboration between myself and Dr. Jordan. Consequently, some of these ideas may appear in future publications in which she is the principal investigator.
This paper will explore three case studies of countries that received a Tier 1 ranking in the Trafficking in Persons Report: Nigeria, Colombia, and Georgia. Tier 1 indicates the highest level of compliance (out of three tiers) and is where most liberal democracies rank, including the United States. It is important to note that the TIP Report makes a clear connection between the level of both corruption in domestic governance and civil liberties in a country and the level of compliance with the TVPA’s minimum standards (US Congress, 2010). This, therefore, leads to a test of two our primary hypotheses: 1. A state’s level of corruption is negatively correlated with TVPA compliance; 2. Greater protection of civil liberties is positively correlated with TVPA compliance. For the purposes of this study, Transparency International’s Corruption Perceptions Index and Freedom House’s Freedom of Civil Liberties Score will be used to examine perceived corruption and freedom of civil liberties, respectively, in each case. It is not expected that the results of this study will support these hypotheses. Instead, the following examination of the cases of Nigeria, Colombia, and Georgia are expected to generate alternative hypotheses.

Nigeria is indeed a regional power in West Africa as the most populous country on the continent and the seventh most populous in the world (Odueme, 2011). It is also one of the world’s largest oil producers but, while the country’s rich oil reserves are lucrative and have potential to benefit the economy, any progress has been undermined by corruption and mismanagement. Instead, stolen oil has fueled violence and corruption in the Niger delta, which is home to the industry (BBC, 2010). The CPI ranges from 0-10 (10 being the least corrupt), and Nigeria has received a low ranking since the study’s beginning in 2001. The state climbed from a 1.0 on the CPI in 2001 and peaked in the year 2008 at a poor score of 2.7 (Transparency International, 2010). Nigeria received a Tier 1 ranking for the first time in the TIP’s history in 2009, and again in 2010, and its CPI score decreased from 2.5 to 2.4, meaning the perceived level of corruption increased, in that same timeframe (US Congress, 2010 and Transparency International, 2010).
Osita Agbu, who studied corruption and human trafficking specifically in Nigeria, writes: “It seems Nigeria’s laws cannot effectively control corruption for the simple reason that they were not designed for the kind of society existing now,” and notes Nigeria’s inadequate enforcement agencies (“Corruption and Human Trafficking: The Nigerian Case”, 9). Agbu also recognized that the Nigerian government was not enforcing the legal framework created to combat corruption (2003). Nigeria’s problems with corruption have only worsened since (Transparency International, 2010). As previously mentioned, the level of civil liberties in a country was also suggested in the TIP Report as a possible link to the level of compliance (US Congress, 2010). Nigeria’s level of civil liberties, according to Freedom House, has remained at a slightly below average score of 4 since the analysis began in 2002. The civil liberties scale ranges from 1-7, with the lower score meaning more civil liberties. The average civil liberties score of all of the other Tier 1 countries is a strong 1.2 (Freedom House, 2010). If strong civil liberties and limited corruption lead to greater compliance with the TVPA, as posited by the TIP report, then this case is puzzling (US State Department, 2010).

Table 1. This table shows the Corruption Perceptions Index (CPI) scores, Freedom House’s “Freedom in the World” civil liberties (CL) scores, and the TIP rankings for each of the three case studies.

<table>
<thead>
<tr>
<th>Countries of Interest</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>CPI</td>
<td>CL</td>
<td>TIP</td>
<td>CPI</td>
<td>CL</td>
</tr>
<tr>
<td>Colombia</td>
<td>3.8 n/a</td>
<td>n/a</td>
<td>3.6 4 Tier 1</td>
<td>3.7 4 Tier 1</td>
<td>3.8 4 Tier 1</td>
</tr>
<tr>
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<td>2.4 4 Tier 2</td>
<td>1.8 4 Tier 2*</td>
<td>2.0 4 Tier 2WL</td>
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<tr>
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<td>n/a</td>
<td>1.6 4 Tier 2</td>
<td>1.4 4 Tier 2</td>
<td>1.6 4 Tier 2WL</td>
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<td></td>
<td>CPI</td>
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<td>TIP</td>
<td>CPI</td>
<td>CL</td>
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<tr>
<td>Colombia</td>
<td>3.9 3 Tier 1</td>
<td>3.8 3 Tier 1</td>
<td>3.8 3 Tier 1</td>
<td>3.7 4 Tier 1</td>
<td>3.5 4 Tier 1</td>
</tr>
<tr>
<td>Georgia</td>
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<td>3.4 3 Tier 1</td>
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</tr>
<tr>
<td>Nigeria</td>
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<td>2.2 4 Tier 2</td>
<td>2.7 4 Tier 2</td>
<td>2.5 4 Tier 1</td>
<td>2.4 4 Tier 1</td>
</tr>
</tbody>
</table>

LEGEND
CPI= Corruption Perceptions Index (Transparency Int’l)
CL= Civil Liberties (Freedom House)
TIP= TIP ranking
CPI score - 1-10; the higher the number, the less corrupt
CL score - 1-7; the lower the number, the more liberty
TIP ranking - Tier 1, most compliance, Tier 3, least compliance
Colombia has received a Tier 1 ranking in the Trafficking in Persons Report since the Report was first published in the year 2000 (US Congress). As the fourth largest country in South America, with one of the largest populations on the continent, and the fourth largest economy in Latin America, Colombia is a powerful country in relation to other states in the region (BBC, 2010; Stokes, 2005). The country is also the home of substantial oil reserves as well as precious metals. However, Colombia has suffered from decades-long violent conflict involving drug cartels and human rights violations (BBC, 2010). According to Human Rights Watch, the government participates in illegal surveillance of those who are suspect of opposing it, including human rights workers (2010). Additionally, paramilitaries were recently demobilized but many returned to crime, and the law enforcement failed to investigate most of these (Human Rights Watch, 2010). Under this framework, it is not surprising that the level of perceived corruption and civil liberties are poor. Corruption in the country has been high for years, peaking at a below average score of 4.0 in year 2005, and declining (perceived corruption increasing) in the years since (Transparency International, 2010). The state has now reached a poor corruption score of 3.5 (Transparency International, 2010). Colombia, like Nigeria, has remained at a fairly steady below average score of 4 on Freedom House’s measure of civil liberties, with a peak period from 2006 to 2008 when the country received a score of three (Freedom House, 2010). Given Colombia’s mediocre at best corruption and civil liberties rankings, this case undermines the hypothesis that high levels of compliance with the TVPA are the result of protection of civil liberties and limited corruption. Something else must be explaining compliance.

Georgia’s Tier 1 ranking is puzzling as well. Although currently holding the highest CPI score (that is, lowest level of perceived corruption) of the three cases with a 3.8, Georgia has suffered from very high levels of corruption over the past decade (Transparency International, 2010). The state began the study in 2002 with a score of 2.4, but quickly fell to a 1.8 the next year (Transparency International, 2010). The perceived corruption was slightly yet steadily increasing each year, and achieved its highest (best) score yet in 2009 with a 4.1. In 2010 Georgia’s corruption score fell again to a 3.8 (Transparency International). Similar to Colombia, Georgia has remained at a fairly steady below average score of 4 on Freedom House’s measure of civil liberties, with a peak period from 2005 through 2007 when the country received a score of 3—still lower than most other countries that receive a Tier 1 TIP ranking (Freedom House, 2010; US State Department, 2010). It then declined to a score of 4 on the Freedom House scale in 2010. Again, Georgia is a case with mediocre levels of civil liberties and corruption; yet perfect compliance on preventing human trafficking.
What then, has led these countries to receive such a prestigious ranking in the U.S. Trafficking in Persons Report? It seems that following such guidelines outlined in the TVPA would be very difficult, if not nearly impossible, with the levels of corruption with which these three countries struggle. Transparency International defines corruption as “the abuse of entrusted power for private gain” (2010). It is surprising that a state with high corruption can rank so high in terms of human trafficking compliance. It is also feasible that corrupt officials may not only allow, but profit from, human trafficking by being compensated by traffickers for ignoring the crime. Alternatively, some possible factors that may explain what contributes to a state’s level of compliance with the TVPA are suggested here.

Gender inequality could potentially contribute to the level of compliance with the TVPA; it is feasible that an inferior role of women in society could have an effect on the amount of trafficking in women that takes place, and, more importantly for our study, on the motivation a government may have to take the measures to prevent the trafficking. The Victims of Trafficking and Violence Protection Act highlights the connection between gender inequality and the existence of human trafficking, and claims that “the low status of women in many parts of the world has contributed to a burgeoning of the trafficking industry.” (Trafficking Victims Protection Act of 2000, 1466) Although most victims of human trafficking are women and children, it must be noted that young men are also trafficked for agricultural labor, the sex trade, and by rebel armies for war within conflict-ridden countries (Lyday, 2000). Thus it is possible that the gender inequality could contribute to more trafficking in women, and then perhaps contribute to a less motivated government to stop this trafficking, but this factor does not explain a lack of compliance in fighting trafficking in males. Therefore, whatever effect gender inequality has on compliance with the TVPA seems to only apply to a fraction of the problem; that is, the governments that would lose motivation because of the inferior role of women. Theoretically these prevention standards should still be met to eliminate trafficking in males, but this is not the case and therefore this undermines the hypothesis that gender inequality is a primary driver of lack of compliance.

The level and accessibility of education in a society could also contribute to the level of compliance with the standards set by the TVPA. In a society that is more educated and has more access to education, it would be easier to make citizens aware of the problem and of ways to avoid becoming human trafficking victims. Lyday acknowledges that public enlightenment through schools and other institutions is one way of
combating trafficking, and promoting awareness is one element which the TVPA takes into consideration in ranking states (Lyday 2000; US State Department, 2010). Thus an advanced educational system would provide the means with which the government could educate their citizens on this issue, and consequently make it easier for states to meet TIP standards for efforts to promote awareness. According to the Human Development Index, which includes records of the gross enrollment ratio in education at all levels, Colombia and Georgia both have fairly high enrollment ratios of 79% and 76.7%, respectively (United Nations Development Program, 2010). Nigeria, however, has a low level of enrollment at only 53% (United Nations Development Program, 2010). This makes level of education seem like a possible, yet questionable, contributor to level of compliance.

**ECONOMIC INTERESTS DRIVE COMPLIANCE**

Foreign Direct Investment (FDI) seems the most credible contributor to compliance with the TVPA. FDI from the United States or other United Nations Security Council members could indeed contribute to a state’s level of compliance, as the incentive of receiving FDI could certainly persuade a country to comply with the standards established (Fredette, 2009). In fact, Kalen Fredette, in her study of the legislation of the UN Palermo Protocol (part of the United Nations Protocol to Prevent, Suppress and Punish Trafficking in Persons, Especially Women and Children, Supplementing the United Nations Convention Against Transnational Organized Crime), emphasizes that compliance is “best achieved by orchestrating economic incentive and sanction programs among Protocol Members” (“Revisiting the UN Protocol on Human Trafficking: Striking Balances For More Effective Legislation”, 133). FDI certainly seems like it could explain these three states’ high level of compliance, as they are all major recipients of FDI, particularly from the US, yet they theoretically are risky candidates for investment.

BBC describes Nigeria as “keen to attract foreign investment but [it] is hindered in this quest by security concerns as well as by shaky infrastructure troubled by power cuts” (2010). This statement shows how its compliance with the TVPA could be Nigeria’s attempt to be seen as a stable and strategically sound investment for donor states. A strong leader in the African Union (AU), Nigeria is a part of the New Partnership for Africa’s Development (NePAD), which the AU oversees. NePAD is an “anti-poverty blueprint which bargains with the West”, meaning promotion of good political and economic practice is exchanged for more foreign aid and investment (BBC, 2010). Perhaps Nigeria’s compliance with the TVPA is one of their efforts of good political practice.
It is feasible that Colombia, too, has deterred investors, as it is now one of the most violent countries in the world and could therefore be considered a risky investment (BBC, 2010). However the US remains the most influential foreign actor in Colombia; in 2009 alone the US gave $663 million to the Colombian government, the bulk of which went to military and police aid (Human Rights Watch, 2010). Human Rights Watch notes that US pressure is probably the main factor that has led the government to establish a specialized group of prosecutors to investigate trade unionist killings, which shows that the Colombian government could also be making an effort to reach the TVPA standards for the sake of aid in the same manner (Human Rights Watch, 2010).

The United States has significant strategic interest in Georgia; it has invested heavily in an oil pipeline from Azerbaijan via Georgia to Turkey (BBC, 2010). Both the US and the EU deepened their engagement and financial backing of Georgia in 2009 (Human Rights Watch, 2010). This seems like a similar exchange as that of NePAD in Nigeria. The US and Georgia signed a Charter on Strategic Partnership in January of 2009 envisaging increased cooperation. As a part of a US $1 billion pledge to support Georgia’s recovery following the 2008 war, the US gave $53.3 million (including $20 million for good governance, civic participation, and election and media reform) (Human Rights Watch, 2010). Therefore, it could be concluded that states comply with such standards as those set by the TVPA out of strategic interest due to potential gain from those in control of the ranking, in this case the US. This part of the theory describes recipient motivation.

**US MOTIVATION IS EQUALLY IMPORTANT**

In addition to the motivation described above, a causal link that goes both directions is suggested; that is, the inclusion of donor motivation. There has been debate over the motivation of the US in their TIP tier placement and enforcement. Hendrix notes how the US has seemingly dismissed some Tier 3 countries of the economic sanctions that should have been put in place according to the policies of the TVPA (Hendrix, 2010). According to the TVPA, the worst ranked countries are subject to non-humanitarian, non-trade related foreign assistance sanctions from the US (Hendrix, 2010). However, all unilateral economic sanctions by the US are subject to presidential waiver “based on a finding that certain circumstances exist, such as improved human rights conditions, ‘extraordinary circumstances’, or simply finding that waiver is in the US national security interests” (Hendrix, 2010, 196). It is this last reason to waive sanctions that seems to leave the US State Department the space to dissent from the set policy of the TVPA. US national security interests could be defined in a myriad
of ways and contexts, and perhaps some liberties have been taken when it comes to choosing which countries will suffer from sanctions and which will not. It is in this context that the credibility of the ranking and enforcement of the TIP Report is called into question, and therein lies what I believe to be the stronger argument for why these three states received the rankings they did.

Of the 14 countries ranked Tier 3 in 2008, only five of them were issued the sanctions stated in the TVPA (Hendrix, 2010). Hendrix explains: “critics say that instead of issuing blanket sanctions based on behavior, the US picks and chooses which countries to sanction, ignoring those that are strategically important to the US” (“Enforcing the U.S. Trafficking Victims Protection Act in Emerging Markets: The Challenge of Affecting Change in India and China”, 196). The US is accused of targeting those states where sanctions are already in place, or where there is little economic or security strategy involved (Hendrix, 2010). Additionally, according to Hendrix, there has been some debate over whether countries that should be given a Tier 3 ranking are placed instead in Tier 2 to fit US interests (2010). For example, India was placed on the Tier 2 Watch List in 2007, when it was argued that it should have received a Tier 3 ranking (Hendrix, 2010). CNN reported that “there was a heated debate between former Secretary of State Condoleezza Rice and former Deputy Secretary of State John Negroponte in which Rice overruled Negroponte’s wish to place them on the Tier 3 list due to ‘concern about alienating the Indian government.’” (“Enforcing the U.S. Trafficking Victims Protection Act in Emerging Markets: The Challenge of Affecting Change in India and China”, 196-197)

I argue that the same strategy is applied when the US is choosing how to rank countries of strategic interest. It is clear that this argument is not a new one; the TIP report is not outside the realm of US strategy. The US could argue that these rankings are what they are for security reasons (refer back to the economic sanctions’ waiver description—all unilateral economic sanctions by the US are subject to presidential waiver “based on...simply finding that waiver is in the US national security interests”) (Hendrix, 2010, 196). Rodrigo Pardo Garcia-Pena recognizes that “even the United States finds itself conditioned by what other countries and other actors do beyond the confines of North America” (The Issue of Drug Traffic in Colombian-US Relations: Cooperation As An Imperative, 103). This exemplifies the need for the US to cooperate with other states for their own security purposes; that is, the US is a state with vulnerabilities just like less developed nations, therefore the US must find ways to maintain and/or achieve security with other states as the world becomes more and more connected and interdependent. Robert Keohane puts it simply when he defines cooperation as “an instrument of foreign policy for countries that are involved in
matters which, by virtue of their global nature, require global treatment.” (Garcia-Pena, 1995, 103)

Human Rights Watch explains some possible reasons for the exemption of Nigeria in meeting the standards set by the US: “Because of Nigeria’s role as a regional power, leading oil exporter, and major contributor of troops to United Nations peacekeeping missions, foreign governments—including the United States and the United Kingdom—have been reluctant to publicly criticize Nigeria’s poor human rights record.” (2010) Human Rights Watch’s Annual World Report also notes that Secretary of State Hillary Clinton spoke out against the endemic corruption in the government of Nigeria, but was unwilling to publicly condemn serious abuses committed by Nigeria’s security forces (2010). And although foreign direct investment and aid is a large part of the cooperation between the West and Nigeria, in 2009 the UK provided £132 million in aid (including security aid) without demanding accountability (Human Rights Watch, 2010). This demonstrates the West’s lack of rigor in their demand for good political practice. The same goes for Colombia and Georgia, in that the US has significant strategic interest in both states, as explained above in discussing the proposed FDI theory.

I would like to stress that Tier 1 countries are those that are in full compliance with the minimum standards of the TVPA (Hendrix, 2010). Tier 2 countries are those whose governments are making significant efforts to comply; the extent to which human trafficking is a problem is considered, as well as the extent of noncompliance, resources and capabilities of the government (Hendrix, 2010). Given the circumstances I have explained regarding each country’s challenges in governance, these three states are cases that seem far too challenged in their capabilities to fully comply with the minimum standards stated in the TVPA. As recently as 2009, the Universal Periodic Review recommended that Nigeria “improve its legal framework…and reform the police and criminal justice sector” (Human Rights Watch, 2010). How can the TVPA standards be met without a sufficient, much less weak, police and criminal justice sector? The Palermo Protocol, while not the same as the TVPA but created with similar ideals, makes it very clear that the capacity to train government officials is crucial to the prevention (of trafficking), punishment (of perpetrators), and protection (of victims) needed in regards to human trafficking (2000). The corruption (and symptomatic lack of civil liberties) in all three cases undermines good governance—a strength that is clearly needed to fully enforce the required standards.
METHODOLOGY

The United States Victims of Trafficking and Violence Protection Act was created in 2000, “to combat trafficking in persons, a contemporary manifestation of slavery whose victims are predominantly women and children, to ensure just and effective punishment of traffickers, and to protect their victims.” (Trafficking Victims Protection Act, 2000, 1466).

The U.S. State Department Trafficking in Persons Report (TIP) is used in this study to operationalize states’ levels of compliance with the TVPA. The TIP Report was first published in 2000 and examines state governments’ efforts to achieve compliance with the Trafficking Victims Protection Act’s (TVPA) minimum standards for the elimination of human trafficking. This is an analysis that is focused on the level of government action to combat the problem of human trafficking rather than on the size of the problem itself (US Congress, 2000). The minimum standards for the elimination of human trafficking in the Trafficking Victims Protection Act mentioned above consist of the following:

<table>
<thead>
<tr>
<th>(1) “The government of the country should prohibit severe forms of trafficking in persons and punish acts of such trafficking.</th>
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<tbody>
<tr>
<td>(2) For the knowing commission of any act of sex trafficking involving force, fraud, coercion, or in which the victim of sex trafficking is a child incapable of giving meaningful consent, or of trafficking which includes rape or kidnapping or which causes a death, the government of the country should prescribe punishment commensurate with that for grave crimes, such as forcible sexual assault.</td>
</tr>
<tr>
<td>(3) For the knowing commission of any act of a severe form of trafficking in persons, the government of the country should prescribe punishment that is sufficiently stringent to deter and that adequately reflects the heinous nature of the offense.</td>
</tr>
<tr>
<td>(4) The government of the country should make serious and sustained efforts to eliminate severe forms of trafficking in persons.” (Trafficking Victims Protection Act of 2000, 1480)</td>
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These standards and this paper are both written using the TVPA’s definition of “severe forms of [human] trafficking” which is described as:

a. “sex trafficking in which a commercial sex act is induced by force, fraud, or coercion, or in which the person induced to perform such an act has not attained 18 years of age; or,

b. the recruitment, harboring, transportation, provision, or obtaining of a person for labor or services, through the use of force, fraud, or coercion for the purpose of subjection to involuntary servitude, peonage, debt bondage, or slavery.” (US Congress, 2000, 8)

Based on the TVPA’s minimum standards for the elimination of human trafficking, each state evaluated is placed into one of four categories: Tier 1 (the highest ranking, meaning full compliance), Tier 2, Tier 2 Watch Level, and Tier 3 (US Congress, 2000). The description of each category follows:

<table>
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<tr>
<th>A Tier 1 country has “acknowledged the existence of human trafficking, has made efforts to address the problem”, and fully comply with the TVPA’s minimum standards for the elimination of trafficking (US Congress, 2000, 20-22).</th>
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<tr>
<td>Tier 2 countries “governments do not fully comply with the TVPA’s minimum standards but are making significant efforts to bring themselves into compliance with those standards” (US Congress, 2000, 22).</td>
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| Tier 2 Watch List countries are those “whose governments do not fully comply with the TVPA’s minimum standards, but are making significant efforts to bring themselves into compliance with those standards AND:

a) the absolute number of victims of severe forms of trafficking is very significant or is significantly increasing;

b) there is a failure to provide evidence of increasing efforts to combat severe forms of trafficking in persons from the previous year, including increased investigations, prosecution, and convictions of trafficking crimes, increased assistance to victims, and decreasing evidence of complicity in severe forms of trafficking by government officials; or,

c) the determination that a country is making significant efforts to bring themselves into compliance with minimum standards was based on commitments by the country to take additional steps over the next year.” (US Congress, 2000, 22) |
| Tier 3 countries are those “whose governments do not fully comply with the minimum standards and are not making significant efforts to do so.” (US Congress, 2000, 22) |

Additionally, the perceived corruption and freedom of civil liberties are measured to test the primary hypothesis in each of the three case studies. For the purposes of this study, Transparency International’s Corruption Perceptions Index and Freedom House’s Civil Liberties Score were chosen to measure each factor, respectively.
As expected, these three cases fail to prove the primary hypotheses. Nigeria, Colombia, and Georgia all have an increasing amount of perceived corruption and below average level of civil liberties (Transparency International, 2010) (Freedom House, 2010). Alternatively, we see in all three cases the possibility of economic interest overpowering the corruption and civil liberties “obstacles”—meaning a state may see compliance as important and relevant enough to their economic interest to prioritize this goal and meet the TVPA’s requirements in spite of evident challenges. Hendrix notes in her study of the enforcement of the TVPA in emerging markets, that those countries “that received…more foreign investment were more responsive to shame” (Hendrix, 2010, 201-202). She also recognizes that reputational harm is more effective if it affects the country’s risk ratings for investment purposes (Hendrix, 2010). It is probable these three countries have made an effort to meet the TVPA standards as a defensive and preventative measure, for fear of receiving a low tier ranking and consequently losing FDI.

In addition to, or possibly in the place of, this motivation, US strategic interest from the other side—the “ranker”, as opposed to the “rankee”—is a factor in the process as well. Perhaps the US has potential to gain something from giving such states public praise; it is uncertain if the reward is in the form of security, possibly an economic agreement of some sort, or something altogether different. It is possible that these states are not actually in full compliance with the TVPA, but rather are making some effort worthy of such public praise as a TIP Tier 1 ranking (or perhaps no effort is being made at all, but the strategic interest is strong enough to award the state with the ranking regardless).

Suggested Further Research

An examination of a broader set of countries ranked in the Tier 1 category of the TIP Report is necessary. How many other cases suggest the theories proposed here? Perhaps the primary hypotheses put forth in this paper and in the TIP, that is, (1) that a state’s level of corruption is negatively correlated with TVPA compliance, and (2) that greater protection of civil liberties is positively correlated with TVPA compliance, is not accurate for many of the Tier 1 countries; in which case the validity of the TIP Report should be strongly questioned and the development of a new system may be necessary.
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Providing Georgia’s electric membership corporations with reliable electricity for more than 35 years

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Designing for Music Consumption in an Internet Age

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ABSTRACT

The music industry is a useful case study for a broad range of emerging digital products. Digital music can be stored and shared easily facilitating free distribution among listeners. Recording, selling, and marketing are more accessible, allowing artists to produce music independently. While these trends seem to suggest a decentralized model for music distribution, a few record labels continue to dominate the industry. In this study, we survey music consumers to better understand their needs and gauge their attitude about various aspects of the music industry. We use this information to outline the implications for the design of future music consumer products.
While demand for music remains strong, the value of the global recorded music industry shrunk by 31% from 2004 to 2010 [10]. The music industry is quick to blame this decline on piracy and has redirected a large portion of their resources towards lobbying for tighter intellectual property restrictions and increased policing [2]. Tactics used to prosecute intellectual property infringers risk alienating the new generation of music consumers [17]. While regulatory methods have been largely unsuccessful at stopping piracy and increasing profits, the music industry may consider developing different business models for music consumption in an Internet age.

Conditions confronting the music industry can be viewed from the perspective of other markets that have moved online. Infinite shelf space allows online retailers to carry a range of diverse items rather than just the top sellers. This has created what is known as long tail markets, characterized by having a vast amount of products that only appeal to a small number of people but together agree that the account for a large portion of the market [7,8]. In the music market, the long tail can be seen in the increased demand for less popular music [19] and experts agree that the cheaper costs of manufacturing and distribution associated with online markets have greatly advanced the development of independent music [15]. While many studies reveal the long tail effect in the music industry [7,8,19,14], the current structure of the established industry makes capitalizing on long tail markets difficult. Four record labels dominate the music market, representing 89% of the market share in album sales [13], and they are historically slow to adapt to technological change [15]. These labels continue to operate under the opposite assumption of the long tail: the superstar effect, which predicts that consumers will listen to the most popular artists in order to minimize search costs associated with finding music [1]. They concentrate their efforts on creating a few stars to appeal to mass audiences [3]. With the great costs expended on production and promotion, major labels only make money after the music that they produce reaches the top charts [15].

Amidst changing technology and overall industry confusion, we look to music consumers for insight. In this research project, we survey music consumers about the process of discovering, listening, and purchasing music. We seek to gain a better understanding of consumers’ needs and frustrations within this process and gauge their attitudes toward record labels and independent artists. We use this information to propose implications for designing better technology for music consumers.
Most of the current studies on music consumer behavior focus on music piracy. It has been shown that music consumers can be grouped into 5 categories based on downloading habits suggesting that pricing policies and promotion strategies can be targeted specifically to each group in order to increase profitability [12]. Another study looks at consumer behavior as it relates to seeking information about music and shows that consumers seek out public information like ratings, reviews, and contextual meta data such as associations with TV shows, commercials, or movies [11]. Both of these studies survey music consumers but use mostly quantitative data and focus on a narrow subject. We study music consumer behavior at a high level using a mix of quantitative and qualitative measures to identify what areas within the music industry need to be further adapted to online markets. We pay special attention to music consumers’ relationship with record labels and independent artists in order to inform decisions on the role that long tail music should play in future music services.

We chose to deploy an online survey to gain more insight about music consumers. The complete survey, which includes both multiple-choice and open-ended questions, is shown in Appendix 1. We piloted the survey with six Human-Computer Interaction researchers in order to refine the questions. Participants were recruited through posts on online music forums, Facebook, and email lists. In total, 91 people participated in the survey. Figure 1 shows the demographic information of the respondents. We performed a thematic analysis on the answers of the open-ended questions using qualitative research methods outlined by Strauss and Corbin [18]. This data was further supplemented by descriptive statistics calculated from the results of the multiple-choice questions. We report on both the responses to the closed survey questions and the qualitative responses from the open survey questions.

We first discuss what music our participants choose to listen to and why. We look specifically at their attitudes toward mainstream and independent music. Next, we explore how our participants find music and uncover many frustrations that they have in this area. Finally, we look at how our participants obtain music and explore their motivations, if any, for buying music.
The superstar effect

[1] predicts that consumers will stick to mainstream artists in order to minimize search costs; however, our data shows the opposite. When asked: “Is most of the music that you listen to considered mainstream?” 66% of the respondents said no. Participants said that mainstream music is “overplayed” (P5) and “not as authentic” (P71). In fact, some respondents like music more because it is unknown. For instance, a student from Atlanta, Georgia writes that it is “nice to listen to something most other people haven’t heard of” (P2). While participants self-reported that they avoid mainstream music, this was supported by assessing the popularity of their three favorite bands. To get an idea of each band’s popularity, we checked to see if they had a song in the Billboard “Hot 100” chart, the industry standard way of identifying the most popular songs based on radio play and sales. Since this chart is specific to domestic sales, responses from international participants were excluded from this analysis. For the purposes of this study, we considered respondents that listed 2 or more bands with “Hot 100” hits as mainstream. By this measure, 59% of the domestic respondents have obscure musical tastes, while only 41% have mainstream tastes. This data suggests that the superstar effect is not particularly helpful in predicting music choices.

Because major labels base their business in producing mainstream music, it is not surprising that we find their reputation damaged as consumers make more obscure music selections. Some participants have given up on them completely, citing that they like music that is “too obscure to be picked up by big labels” (p19). We also saw criticisms about what music labels chose to produce. A programmer from McDonough, Georgia thought that labels “make poor decisions in terms of variety and innovation” (p38).

For many of the same reasons for not liking big record labels, participants had a very positive impression of independent artists. They reported that independent artists have “unique” (p43, p90) music that is more “interesting” (p31, p79) to listen to. They also liked being able to talk to the artists and form a more intimate connection with them. On the other hand, some participants expressed wanting to listen to more independent music but they “don’t have time to explore independent artists” (p84). A designer from Brooklyn, New York says that he listens to independent artists “as much as possible, although they are more difficult to learn about” (p36). Similarly, an engineer in Cambridge, Massachusetts wrote: “I’d like to be more connected to indy music but don’t bother to spend time searching it out” (p33). These responses are more in line with the superstar effect, but they also show the desire to change the available techniques to create better ways to find music.
the fact that "computers have no souls" (p36) and, therefore, unable to accurately recommend music that he likes. These responses convey a complex and artful process behind choosing music.

Finding music can be a time-consuming process, especially if one listens to independent or "indy" music. We asked participants how much time they spend discovering new music each week. 84% of the survey respondents report to spend at least some time each week dedicated to this task while 43% of the respondents spend more than an hour. We also asked participants if they listen to independent music. Overall, 75% of the respondents said yes. Only 9% said no, while 16% did not know. We then compared the data of time spent discovering music to data about listening to independent music. As shown in Figure 3, the likelihood that respondents listen to independent music correlates positively with the time that they spend finding music. This further suggests how important the time component is to discovering independent music, perhaps because this music is not considered mainstream.

Finding music is further complicated because the criteria for choosing music differs from person to person. We have found that our respondents consider many factors when choosing music aside from what the music sounds like. For instance, we had participants mention everything from knowing a band’s influences and history to knowing the band’s “political aspirations” (p35) or if they “donate their profits to charity” (p62). Since there are many factors to consider when choosing music, we asked participants how they currently find music. Our participants also expressed dissatisfaction about the current recommendation systems such as the iTunes’ Genius feature, Pandora, or last.fm. For instance, a student from Columbia, South Carolina said: “even though I use last.fm, it rarely recommends music that I haven’t already heard or like” (p56). Similarly, the designer from Brooklyn said that he finds algorithmic methods lacking, predictable, and lame. He blames this on
The popularity of recommendations from friends testifies to the important social aspect in the process of finding music. Instead of websites that provide complex algorithms to recommend music, many of our participants expressed that they would rather have websites that would allow them to connect with other people to recommend music. For instance, a professor from Atlanta said: “I’d like to follow some of my friends music acquisitions as much as I follow their web bookmarks” (p27). Similarly, a student in Atlanta said that she wants browsers “to find people with similar tastes, make new friends, and find local concert buddies.”

The responses to the survey question: “What areas would you like music technology to be improved?” as shown in Figure 5 are consistent with the data we have presented so far, listing finding music as the number one response, followed by sharing music. Comments from participants suggest that the best way to improve ways to music is to improve ways to share music. Unfortunately, common ways to share music are subjected to increased criminalization following the decline of music sales. To examine this problem, we now look at our participants’ motivations for buying music.
As shown in Figure 6, most of the participants reported that they primarily buy digital music online, but an almost equal number reported that they find ways to obtain music for free. Of those that obtained music for free, 73% said that they do feel compelled to pay for some music. We asked these people what criteria they use to judge what music to pay for and why.

16 participants reported they buy music based on how much they listen to it and how much they like it. Most of all, we found that participants do not want to pay for uncertainty. For instance, a user experience researcher from Seattle, Washington said: “I’d like longer or better previews that make me sure I’m going to like something before I buy” (p39). If appropriate previews are not available, some of the respondents reported to find ways to self-preview. For example, a student from Atlanta, Georgia said: “I digitally download music for free and if it’s really good I’ll buy the record” (p69). Responses show that participants put great thought and care into deciding who gets their money. We found that respondents are more inclined to pay for bands that they feel need support, like upstarts and independent bands, rather than commercial artists. For example, a student from Atlanta said: “I tend to pay for Indie CDs because those bands are still getting started and I want them to succeed” (p23). Just as we saw in the previous section with deciding what music to listen to, many factors also play into what music participants chose to purchase.

We surveyed music consumers about how they discover, listen to, and purchase music. We found that the majority of participants are no longer drawn to mainstream music and show distaste for large record labels while admiring independent artists. Exploring music outside of the mainstream allows consumers to find music better suited to personal tastes but makes the task of finding this music highly time consuming. Participants find music most successfully by utilizing social mechanisms such as recommendations from friends or sharing. A large portion of participants do not pay for most of the music that they consume and hold high standards for the music that they do purchase. At the same time, participants show a strong desire to support upstart and independent musicians. While the results from this study do not arouse hope for the reemergence of the music industry by conventional means, they do elicit inspiration for new designs of better music services.
Our results show a backlash against mainstream music and record labels that support it but a desire for more independent music. We suggest improving ways for smaller artists to succeed without reliance on a major label. Already, artists can produce and distribute music without a record label thanks to technological advances. Yet other functions such as investment and promotion have not been completely realized outside record labels; however, the willingness of consumers to support independent artists indicates that these tasks can be solved with a fan-based approach. For example, a fan-based investment system could allow music fans to lend financial support to independent artists that they like. The ability to potentially earn returns would entice fans to make investments and also give them an extra incentive for promoting the band. For example, the online project-funding platform Kickstarter allows people to pledge money to support projects and receive gifts for certain pledge levels. This has become a popular place for bands to seek funding for recording new albums. Our findings suggest that the development of additional tools to support independent artists in this regard would be well received by music consumers.

In summary, technological changes have not only changed the medium in which we receive music, but also in the way that we fundamentally interact with music. We have discussed two implications for the development of new music services better adapted to these changes: 1) Create more fan-based alternatives to record label functions for independent artists and 2) Use social mechanisms over algorithmic methods for making music recommendations. These suggestions are based on the experience of music consumers. Future research could focus on how musicians interact with music technology to gain insights in creating new services that addresses the needs of the artists as well as the consumer.

The music industry is one of many industries struggling to adapt to the digital world. In this paper, we surveyed music consumers and observed the effects of the digital transition of music in consumer’s music tastes, ways for finding music, and spending habits. This research focused on music consumer technology, but these trends are applicable to other consumer goods that have made the digital transition like movies or books. We suggest two directions for future music services and encourage developers to take greater consideration of the demand of lesser-known artists in their designs.
Thank you to all of the participants in this study and also to (name removed for review process) for her valuable mentorship through this process. This work was supported by the President’s Undergraduate Research Award presented by the Undergraduate Research Opportunities Program at Georgia Tech.
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INTRODUCTION

As the world’s population continues to expand, resources must be managed more efficiently in order to conserve the limited quantities available. Innovations such as the smart grid and wireless sensor networks (WSN) are currently being researched and deployed in order to more effectively monitor energy consumption and production. These networks are capable of providing large amounts of information from spatially distributed sensors. Furthermore, these WSNs are used for monitoring ecosystems and water quality, and they have applications in healthcare, military, and security (Akyildiz, 2001). Radio-frequency identification (RFID) technology is an attractive option for use in WSNs because of simplicity, low-cost, and maintenance free operation (Finkenzeller, 2003).

RFID technology is currently used in a wide variety of applications including electronic vehicle registration, toll road payments, public transit payments, product tracking, animal identification, inventory systems, passports, and student IDs (Lee, 2010). These applications require exceedingly small amounts of power to operate because of the need to only transmit identification information. RFID tags can be either active, battery-assisted passive, or passive. Those that are active or battery-assisted passive require a battery to aid in power supply. However, a passive RFID tag harvests radio-frequency (RF) energy transmitted from an RFID reader to power itself and to communicate via backscatter radio communication (Dobkin, 2008). This energy harvesting involves connecting an antenna to a charge pump circuit. The antenna receives RF energy. The RF energy is then rectified into direct current (DC) power. After the conversion, the DC power can be used to operate a load. All of the components utilizing the DC power can be modeled together as one load at the charge pump’s output. This load affects the matching of the charge pump affecting the amount of power the charge pump is able to convert from RF into DC. Furthermore, the charge pump is not lossless due to its intrinsic inefficiency, parasitic and resistive losses in the diodes, and radiation. Characterization of charge pump circuits assists in the optimization for a given load and input power and leads to designing more efficient charge pumps. The measurement and characterization of a 4-stage Dickson charge pump is the main focus of this paper.
Passive RFID tags typically use some variant of the Dickson charge pump to increase voltage after harvesting RF energy (Trotter, 2009b). Power received by the RF tag’s antenna is coupled into a charge pump. There, the RF power is rectified by means of the first stage of the charge pump, the diode-capacitor couple D1 and C1, as shown in Figure 1. The stages are denoted by perpendicular diode-capacitor pairs. The diode acts as a gate allowing current to flow in the forward direction only.

Figure 1. Schematic of a Four-Stage AC-DC Dickson Charge Pump.

The charge pump’s operation can be analyzed by investigating when the input AC voltage is positive or negative. During the positive cycle of the AC voltage, diodes D2 and D4 turn on upon reaching the diode threshold voltage. This allows current to pass through the diodes and charge the capacitors. In the negative cycle, diodes D2 and D4 turn off, and diodes D1 and D3 turn on and continue to charge the capacitors. When parameters vary the following equation describes how the output voltage behaves.

\[
V_{out} = \frac{(N+1)(V_{in}-V_d)}{1 + \frac{1}{f C R_L}}
\]  

(1)

Where:

- \(N\) is the number of stages
- \(V_{in}\) is the input AC source
- \(V_d\) is the diode threshold voltage
- \(f\) is the frequency
- \(C\) is the stage’s capacitance
- \(R_L\) is the resistance lost (or transferred)

Equation 1 shows a non-linear relationship between the output power and the power the charge pump receives from the receiving antenna (Trotter, 2009a). This nonlinearity is due to the presence of diodes in the circuit, which are nonlinear elements as seen in the diode I-V curve in Figure 2. To further understand the non-linear relationship between input and output power and, thus, design better, more efficient charge pumps, it is necessary to obtain data from charge pumps with varying RF frequencies, loads, and input powers.
**Impedance Matching and Non-Linearity**

The inefficiency of the charge pump’s RF to DC power conversion results in a smaller output power for the given input power. One reason for the inefficiency is reflections of power due to mismatched impedances. A matched circuit, one without difference in impedances, will result in maximum power transfer and high efficiency. In linear circuits it is possible to design a matching network that will achieve complete matching at a certain frequency due to the impedance of its elements depending solely on frequency. Another contribution to the inefficiency of the charge pump’s power conversion is the impedance of a load once it is integrated with the entire circuit, changing the matching impedance.

Unlike the aforementioned linear circuits, charge pumps are nonlinear circuits due to the presence of diodes. Non-linear means complete matching only occurs at a certain input power and frequency since diode impedance depends on both factors. In practice, the input power for a charge pump will change depending on how much power the antenna is able to harvest, which varies constantly. As a consequence, the circuit’s impedance is unpredictable, and it is improbable to design a specific load to match it. Therefore, measuring the efficiency with respect to varying input power and frequency allows better characterization of the expected output power for a given resistive load. This is important since loads such as RFID tags require a certain minimum input to operate.

Figure 2 shows the current-voltage relationship, of a typical diode. This non-linear relationship means that the equivalent impedance of the diode changes as a function of voltage. Two other properties of the diode that may affect the functionality of the charge pump are its threshold voltage, $V_{th}$, and reverse breakdown voltage, $V_{br}$. Ideally, diodes do not allow current flow if the voltage across it is below the threshold voltage. However, if this voltage is below the reverse breakdown voltage, current flows in the opposite direction. Voltages in between $V_{br}$ and $V_{th}$ result in no current flow; therefore, they provide no power to the load.

An ideal scenario for a charge pump is one in which the receiving antenna is able to harvest enough energy to exceed the threshold voltage of the diodes and provide sufficient current to the load. The antenna’s ability to harvest energy is dependent on the antenna pattern, distance from the power source, and the strength of the signal.

Since the diode is a nonlinear element, its I-V curve is consequently nonlinear as shown in Figure 2. As stated previously this non-linearity changes the equivalent impedance of the diode, which, in turn, affects the matching in the charge pump. This impedance change occurs due to the change in slope of the diode I-V curve as voltage varies. Since the impedance of the diode is proportional to the inverse of the slope, a change in the position on the curve will lead to a change in the slope and, therefore, the impedance. If the charge pump is designed to achieve complete matching at a certain frequency and at a certain input power, any deviation of one or both of these values will contribute to the mismatching of the circuit. As previously stated, the system loses power due to the mismatching between source and charge pump and inefficiencies of the charge pump itself. This relationship can be expressed by Equation (2) below.

$$\eta_{CPT} = \eta_{Matching} \cdot \eta_{CP}$$  \hspace{1cm} (2)

Where:

- $\eta_{CPT}$ is the efficiency of the total charge pump system.
- $\eta_{Matching}$ is the ratio of the transmitted power into the charge pump to the total power.
- $\eta_{CP}$ is the efficiency of the charge pump itself.
MATERIALS AND METHODS

In order to characterize the charge pump, the charge pump output voltage and input voltage were measured as a function of transmitted power, frequency, and load impedance. The measurement system was composed of a signal generator (Model E8247C Agilent), a circulator (Model F2658-0600-67 Wentec), an RF power meter (Model E4418B Agilent), and a charge pump as shown in Figure 3. The charge pump was a Four-Stage Dickson Charge Pump containing Avago HSMS2862 diodes and 10 pF RF capacitors on a four layer FR-4 board with 50 Ω traces at 5.8 GHz.

Figure 3. Schematic of the test system.

As the charge pump was mismatched, some of the incident power was reflected. The circulator assists with measuring this reflected power. Circulators are passive, three port devices where the energy entering any one port is transferred to another port. Thus in Figure 3, the power from the signal generator enters port one and exits port two into the charge pump. Reflected energy from the charge pump enters the circulator’s port two and exits port three into the RF power meter. It was assumed that no power was reflected out of the RF power meter. Each time a signal passes through the circulator, it experiences loss since the circulator is a lossy device. Since the measured signal passes from the signal generator through the circulator to the charge pump and from the charge pump to the RF power meter, it experiences this loss term twice. Therefore, the power absorbed by the charge pump can be calculated by Equation 3:

\[
P_{\text{in}} = P_{\text{SigGen}} - 2L_{\text{circ}} - P_{\text{RfMeter}}
\]  

(3)

Where:

- \( P_{\text{in}} \) is the power absorbed by the charge pump.
- \( P_{\text{SigGen}} \) is the power generated by the signal generator.
- \( P_{\text{RfMeter}} \) is the power recorder by the RF power meter.
- \( L_{\text{circ}} \) is the loss inside the circulator, specified in the manufacturer datasheet to be 0.5 dB.

The charge pump efficiency was calculated by dividing the output power across the resistive load in the charge pump by the input power to the charge pump as in Equation 4 (Trotter, 2009a):

\[
\eta_{\text{CP}} = \frac{P_{\text{out}}}{P_{\text{in}}}
\]  

(4)
The charge pump output power was measured across the charge pump load with a voltmeter (Model 3441A Agilent). Once the output voltage was obtained, $P_{out}$ can be obtained from Equation 5:

$$P_{out} = \frac{|V_{out}|^2}{R_{load}}$$  \hspace{1cm} (5)

All instruments were remotely controlled using Standard Commands for Programmable Instruments (SCPI) through the programming language for technical computing MATLAB (Matrix Laboratory). The script commanded the signal generator to be set at a specified frequency, and then it was instructed to transmit signals with power ranging from -15 dBm to 16 dBm, in increments of 1 dBm. For each value of $P_{SigGen}$, a measurement of $V_{out}$ and $P_{RfMeter}$ is recorded. After the final value of 16 dBm was reached, the signal generator was set to a higher frequency and then it repeated the power emission. The frequency of operation spanned from 4.1 GHz to 7.5 GHz with a step size of 100 MHz. The charge pump under test was designed to work in the 5.8GHz Industrial Scientific and Medical (ISM) radio band. However, due to matching errors inherent to the charge pump, a wide range of frequency values were measured to observe performance both within and outside this band.

**RESULTS**

All efficiency results are shown in a dB scale. In this dB scale, -100 dB corresponds to a $10^{10}$ % efficiency, -20 dB to a 1 % efficiency, and 0 dB to 100 % efficiency, as shown in Equation 6:

$$\text{Percentage} = 10^{\frac{dB}{10}}$$  \hspace{1cm} (6)

Figures 4-7 represent plots of charge pump efficiency vs. frequency for different input powers with different resistive loads.

Figure 4. Efficiency vs. Frequency graph for four different input powers to the charge pump with a 100 Ω resistive load.

Figure 5. Efficiency vs. Frequency graph for four different input powers to the charge pump with a 1kΩ resistive load.

Figure 6. Efficiency vs. Frequency graph for four different input powers to the charge pump with a 20kΩ resistive load.
Figure 7. Efficiency vs. Frequency graph for four different input powers to the charge pump with a 500kΩ resistive load.

Figures 8-10 represent plots of charge pump efficiency vs. input power to charge pump for different resistive loads at different frequencies.

Figure 8. Efficiency vs. Power in Charge pump for various loads at 4.1 GHz

Figure 9. Efficiency vs. Power in Charge pump for various loads at 5.2 GHz
Figures 4-7 illustrate the optimal frequency of operation for different input powers. Frequencies between 6.0 GHz and 6.7 GHz produced the highest efficiencies for most resistive loads with the exception of the 20k Ω which yielded relatively higher efficiencies around 5.9 GHz. The maximum efficiency for each resistive load arises at these frequencies despite the charge pump being designed to operate at 5.8 GHz. In addition, as the input power increases resulting inefficiencies steadily increase with less erratic behavior.

Figures 8-10 show that the 1kΩ resistor yields maximum efficiency at higher powers for multiple frequencies. The absolute highest efficiency of 55.18 % was obtained at 6.0 GHz with a 1kΩ resistive load. The efficiency of the 1kΩ resistive load, however, does not remain superior as input power is decreased.

For input powers less than -5 dB, 75kΩ resistive load yields maximum efficiency. Unexpected behavior is observed between -5 and -10 dBm where, for some resistance values, the efficiency of the charge pump approaches zero for all tested frequencies.

**DISCUSSION**

The efficiencies of the charge pump systems partly depend on matching. Since the systems studied were nonlinear, matching depends on input power, frequency, and resistive load. Therefore, the differences in efficiencies between curves are due to varying the power, the frequency, or the load.

The charge pump circuit design, which has 50 Ω micro-strip traces at 5.8 GHz, was not best matched at 5.8 GHz. The observation that frequencies of 6.0 GHz and 6.7 GHz appear better matched than 5.8 GHz alludes to the influence of parasitic elements which affect the matching frequency of the circuit. Since parasitic elements change the equivalent impedance of the charge pump circuit elements, accounting for these parasitics more accurately will aid in creating a charge pump circuit that is best matched at 5.8 GHz. In addition, understanding the effects of parasitics will aid in better design methods for specific input powers.

As the input power increases over 5 dBm, the efficiencies saturate. It is hypothesized that the reason for this small increase in efficiency is due to a decrease in the slope’s rate of change of the diode’s I-V curve as voltage increases. Figure 2 shows that at higher voltages, the I-V curve approaches linearity. In other words, the slope changes less as voltage increases which implies that the equivalent impedance of the diode changes less. Therefore, a decreased change in efficiency is expected. At these higher input powers, the diode can be modeled as a linear element which implies that the impedance can be approximated as constant. Therefore, if the circuit becomes linear as input power increases, then only frequency should affect the matching of the circuit and not power. This independence of input power on matching at higher input powers implies that the matching efficiency of the circuit will not vary as input power increases and therefore the charge pump efficiency should reach a saturation limit.

The unexpected drop in efficiency that occurs between -5 dBm and -10 dBm in Figures 8-10 may be explained by the equivalent impedance of the diodes at these input powers. At low input powers, the slope of the diode’s I-V curve changes more rapidly than at high powers; resulting in a change in impedance. If this change in impedance diverges away from the matching impedance of the diode, then the efficiency of the charge pump significantly decreases. Another possibility is that parasitic capacitances and/or inductances of the diode are causing the dip. The equivalent impedance of the diode may be changing from capacitive to inductive as the input power decreases. This change from capacitive to inductive implies that at one particular input power, the equivalent impedance of the diode is purely resistive. At this resonant power, the capacitive and inductive parasitics of the diode cancel each other. This purely resistive equivalent impedance of the diode implies that maximum power loss occurs since all the energy-storage characteristics of the diode are absent at the resonant power. Non-reson-
ant input powers result in a diode whose equivalent impedance is not purely resistive. Therefore, it is expected that the dip only occurs when this resonant power is reached.

From characterizing the 5.8 GHz four-stage Dickson charge pumps, it can be determined what input values are necessary for obtaining certain efficiencies or certain output powers. Certain RFID tags, such as the UHF Symbol® Class 0, Gen 1 that operates at 915 MHz, require a minimum of -10 dBm to turn on (Banerjee, 2007). Therefore, since the RFID tag’s electronics represent a certain equivalent resistance, the charge pump must be designed to operate with this load impedance at the allotted frequency such that at least -10 dBm is produced to power this RFID tag.

**FUTURE WORK**

The current work has demonstrated a flexible system to characterize charge pumps. To understand how to design a more efficient charge pump, future work will involve the study of charge pumps with various stages, capacitances, diodes, and matching networks. To make these tests more modular, a board with multiple charge pumps will be constructed. Although there are many factors that contribute to the outcome, developing a mathematical model based on simulations to justify these results would aid in designing more efficient charge pumps.

Input powers higher than 16 dBm can be tested in order to verify the hypothesis that the charge pump efficiency reaches a saturation limit as input power increases. If the saturation occurs, it is most likely due to the diode entering the linear region of its I-V curve but further researching is needed to verify this.

To test the unexpected decrease in efficiency as shown in Figures 8-10, an appropriate model of the diodes in the four-stage Dickson charge pump that incorporates parasitic effects should be used. If this model is accurate enough, the resonant power at which the equivalent impedance of the diode becomes purely resistive can be determined. If this hypothesis is correct, a significant decrease in efficiency at this resonant power is expected.


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While much research has been done regarding the Civil Rights Movement and school desegregation in Atlanta and other major Southern cities, information regarding Chattanooga, TN has never been published. As a vibrant city with a large African American community and an interesting mix of both Southerners and former Yankees who emigrated after the Civil war, Chattanooga’s story is an important one to be told. This study covers the story of desegregation through a legal lens as a major lawsuit in Chattanooga was ultimately what brought about desegregation in the public school system. Through interviews, oral histories, and original legal documents from the case, the paper highlights the struggle between the African American community and the school board in the fight for equal education. A small group of African American parents stood up to the all-white board of education and demanded that their children be given full-time, equal education. Although many in the White community questioned the legality of the Supreme Court’s ruling in Brown v. Board of Education and later staunchly opposed desegregation, the lawsuit ultimately resulted in one of the most peaceful desegregation attempts made in the South. The case, entitled Mapp v. Board of Education resulted in a twenty-six year legal battle for equal rights, and school desegregation was only the beginning.

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AN IN-DEPTH LOOK AT THE DESEGREGATION OF CHATTANOOGA CITY SCHOOLS
INTRODUCTION

Prior to the desegregation and civil rights movements of the mid-20th century, Chattanooga looked like many other southern cities in regards to racial separation and discrimination. Although located in Tennessee, Chattanooga kept its eyes focused south on Atlanta throughout the 1950’s and 60’s watching the nearby, larger city’s attempt to understand and implement emerging policy decisions. This “wait and see” model allowed Chattanooga to have one of the most peaceful desegregation attempts in the South.

In the 1960’s the Tennessee Valley area was divided into two distinct schools systems, Chattanooga City Schools and Hamilton County Schools. For the purpose of this paper, the schools referred to will include only those found within the Chattanooga City School system. This paper will attempt to broadly trace the desegregation process within a legal framework, from the 1950’s to the 1980’s within the city limits.

DISCUSSION

The catalyst behind the beginning of school integration throughout the country was the Supreme Court decision of Brown v. Board of Education of Topeka, Kansas. Prior to this 1954 decision, schools had been segregated on the basis of “separate but equal,” a doctrine which originated out of a Supreme Court case in 1896, Plessy v. Ferguson. News of the ruling reached even the smallest communities; making the front page of the Chattanooga Times in Tennessee. For the most part, the civil rights era in Chattanooga, TN was characterized by its nonviolence; but that is not to say the city did not see its fair share of demonstrations and protests. Around the country, cities and school boards began to take action in order to comply with the Supreme Court’s interpretation of the Fourteenth Amendment. In Chattanooga, the local school board reacted quickly, and initially, it appeared that they would comply with the law. They voted unanimously to act on the mandate, issuing several public statements acknowledging the Supreme Court’s authority.
In a 1955 effort to involve local citizens, and possibly to placate the African American community, the school board created an Interracial Advisory Committee (IAC) made up of both Whites and African Americans who were charged with laying the foundation for a peaceful desegregation. Conversation at the first meeting of the IAC became heated as communist accusations flew at the board and people began chanting and yelling that the Tennessee constitution forbade racial mixing within schools. The meeting dissolved into chaos when a tear gas bomb was dropped. Fearing further community unrest and violence, the board decided to postpone the desegregation process interminably and embark on a process of elucidation and education.

In the five years that passed between the tear gas incident and the spring of 1960, racial tension seemed to abate. The board took this opportunity to move African American school construction projects to the top of its list, hoping to ameliorate overcrowding, the basis for much of the pressure to desegregate. However, the demonstrations and protests that began in 1960 brought Chattanooga’s attention to the issue of local race relations. In February, Chattanooga saw its first sit-in at a local lunch counter. Students at Howard High School passed out a list of rules to their fellow classmates that admonished cursing and encouraged small purchases during the demonstrations. The sit-ins were short, barely lasting over a week, and were overwhelmingly successful in desegregating the local lunch counters, but the protests also accomplished a much larger goal. By drawing the race issue to the forefront of the communities’ hearts and minds for the first time since 1954, the lunch counter demonstrations spurred local citizens to action and set the stage for the school desegregation attempt that would come within the next few years.

In April of 1960, James R. Mapp, a father of three young children, filed suit against the Chattanooga School Board in an effort to relocate his children to a closer, less-crowded all-White school. He intended to force the board to stop the operation of a compulsory bi-racial school system, but what he did not realize was that his complaint would launch a twenty-six year, exhaustive legal battle in Chattanooga for civil rights, equal opportunity, and racial justice.

TO HAVE ONE OF THE MOST PEACEFUL DESEGREGATION ATTEMPTS IN THE SOUTH.
Under district court orders in 1962, the school board began operating under a four-step timeline that would allow for complete school desegregation by 1968. This plan allowed for gradual desegregation within the school system beginning with the lower levels and proceeding upwards toward the 12th grade. By 1965, all elementary schools and the first year of junior high schools had been desegregated and yet the pace left the school system operating, in large part, on a bi-racial basis. Thus, an acceleration motion by the plaintiffs in the spring of 1965 was granted that would allow for complete dissolution of the dual school system by September of the same year. The motion for further relief requested complete desegregation of all grades along with all personnel, and the elimination of racial restrictions on extracurricular activities.

Portions of this request stemmed from the Civil Rights Act of 1964, which, "prohibited discrimination in public places, provided for the integration of schools and other public facilities, and made employment discrimination illegal." For many school systems, the most relevant portion of the Act denied federal funding to those who were not in compliance or who were not attempting to become in compliance. In Chattanooga, this meant that the board needed to demonstrate a good faith effort to attempt to desegregate or lose crucial government funding.

An acceleration of desegregation was granted and in the fall of 1965, the remaining levels of junior high school and high school were desegregated. Although the request to assign personnel without regard to race was denied, the board began assigning teachers across racial lines in 1966. By the Fall of 1967, a total of 115 teachers had been assigned across racial lines and only two schools’ faculty remained segregated.

By August of 1967, it became apparent both to James Mapp and to the city that regulated desegregation might not achieve the desired goals of integration within the city schools. Mapp attempted to combat this by filing a continuation of his original suit charging the city with deliberate slow-down of desegregation. He claimed that the ratios of students and teachers in formerly all-White and all-Negro schools was still overly skewed. Mapp further accused the board of “gerrymandering” school district lines to allow for continued segregation.

The broadening of the scope of the original lawsuit brought new arguments and ideas into Chattanooga’s desegregation discussions and ultimately revealed interesting in sights into cultural and race-based behavior. The school board maintained that although some instances of racial majorities still existed within the system, it was not its concern, stating, “…whatever racial segregation continues in the school system of Chattanooga today…is a result of what is referred to as ‘de facto’ segregation as contrasted with ‘de jure’ segregation. [It] is the result of factors and forces in the community, both in the past and in the present, over which the Chattanooga Board of Education has absolutely no control and thus, for which it has no legal responsibility.”

In May of 1971 the district court rejected this de facto argument as five formerly all-black schools in Chattanooga remained all-black, three had one White student, and six had less than ten White students resulting in a total of 9,223 Black students and 48 White students in formerly all-Black schools. In formerly all-White schools, three remained all-White and four had less than five Black students yielding a total of 13,250 White children and 3,446 Black children in formerly all-White schools.

In June of 1971 the board also provided a second plan for faculty desegregation that would create a 55% White – 45% Black ratio (plus or minus 10%). In the plan, teachers were given an opportunity to request up to four schools and were then transferred by lottery and seniority. This plan went into effect in August of 1971. From that summer of 1971 to June of 1973, the Board of Education of Chattanooga, TN attempted “to remove all vestigial remains of a dual school system, achieve maximum integration, and find a viable racial mix.”

Yet, the board found a 22% rejection rate by White parents whose children were placed in formerly all-Black schools. Additionally, as the percent of the Black student population approached 40%, a changeover to 100% African American occurred within three years. With this in mind, the board requested permission to proceed with an amended plan of desegregation that would increase the proportion of Whites to Blacks in the schools in order to minimize White withdrawal from the public schools.
On November 16, 1973 Judge Frank Wilson, who had presided over the case since 1961, ruled against the board’s amended plan for desegregation saying, “No plan of school desegregation can pass constitutional muster unless it is demonstrated that it does remove all residual consequences attributable to the fact that the system was one designed, built, located, structured, and operated as a dual school system.” Furthermore, “concern over ‘white-flight’ cannot become the higher value at the expense of rendering equal protection of the laws the lower value.” Thus, Judge Wilson ordered the school board to continue to attempt to achieve the original desired ratios of approximately 50-50.

The city pursued the mandated ratios through various constitutional and unconstitutional methods. However, many of the schools were still sub-par in terms of equality. The board attempted to bus students, but some of the transportation schedules for the African American students required 9 hours between pick-up and drop-off to base schools. In addition, the board attempted to meet ratios by mandating “in-tact transfers” or the, “moving of whole classrooms in-tact from one school to another.” Thus, classrooms remained segregated on an individual basis with, “the only contact made with students of the opposite race occurring at lunch time or in special classes.” These students were receiving similarly unequal education as they had in their previous classrooms. The facilities may have been better and closer but discrimination was still taking place.

When Judge Wilson’s deadline arrived in January of 1974, the racial ratios in many schools were nowhere near the intended outcome. The school board had gerrymandered the zones in an attempt to place 30% or more Blacks in formerly all-White high schools and 30% Whites in formerly all-Black high schools. “The result substantially desegregated the white schools but was a failure in the formerly all-Black schools with something like ten to fifteen White students remaining in each of the formerly all-Black high schools.” The school board maintained that “this effort was taken, and it failed, and with no responsibility attributable to the board for such failure, than the racial disproportion is now de facto and beyond the scope of the Fourteenth Amendment.”
Wilson decided that the school board had taken appropriate affirmative steps when it implemented zoning areas for the four city high schools that would have increased White enrollment at Riverside and Howard (the two formerly all-Black high schools) to 25%. However, Riverside and Howard remained more than 95% Black since the 1971-1972 school year, with nearly all of the White students zoned for attendance transferring to private/parochial schools or relocating to the suburbs. This is further evidenced by the fact that in the 1965-1966 school year, there were 14,144 White students in the Chattanooga School System but by 1973, there were only 8,125 White students left.

The annexation of several suburban White schools and the loss of many White students from inner-city schools further complicated the cities’ plan for ratios based on total percentages. Judge Wilson indicated that the board had no additional responsibility to increase the degree of desegregation in the annexed areas of Hillcrest and 10D. However, as Mapp and the NAACP pointed out, this opened the door for a “core city either all-Black or substantially all-Black with the suburbs substantially White with a minimum number of Black students.” They appealed this ruling to the Sixth Circuit, arguing both 10D and Hillcrest, as well as future annexations, must be included in the system’s plan of desegregation. “Plaintiffs were entitled to a system-wide remedy which would, at the time of its effectuation, extirpate the vestiges of segregation from all of Chattanooga’s schools.” Not involving the annexations in the desegregation plan “creates and insures the future creation and perpetuation of, a ring of suburban, heavily white, ‘neighborhood’ schools...the result being a built-in incentive toward resegregation.” Furthermore, “common sense alone should have told the District Court that exclusion of annexed areas from the operation of the plan would doom it.”

Attorney for the School Board, Raymond Witt countered, arguing that the racial composition could not have been the responsibility of the board and that the newly annexed schools should, “continue with the racial composition possessed by such schools at the time they became part of the Chattanooga system.”

It was during this same appeal in 1975, that the board first introduced the idea of termination of the litigation. The board acknowledged, with some hostility, the history of the litigation, accusing the plaintiffs of changing their interpretations of the constitutional requirements to the point of, “a 180
degreeturn in their theory moving from a demand that decisions be made without regard to race to a remedy requiring that decisions be made upon the basis of race.” The board claimed they had done everything within their power to desegregate the system, and that it was now, and had been since 1967, a unitary system. Ultimately, the Sixth Circuit upheld the orders of the District Court from 1973.

In April of 1976, Judge Frank Wilson denied further requests by the plaintiffs for a new desegregation plan for all Chattanooga schools, including annexed areas. He indicated that it would be, “appropriate to bring this litigation to an end.”

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AS OF 1977, ONLY 400 STUDENTS ATTENDED RIVERSIDE ON A DAILY BASIS, DOWN FROM NEARLY 1400 IN 1967.
By this time, the annexation included fifteen schools and 9,627 pupils, most of whom were White. With this ruling came a brief respite for both parties in Chattanooga. For the next several years, litigation remained minimal and the community seemed to come to terms with a somewhat desegregated system. In 1979 Riverside, one of the two formerly all-Black high schools closed due to low enrollment numbers. As of 1977, only 400 students attended Riverside on a daily basis, down from nearly 1400 in 1967.

Judge Wilson passed away in 1982 after seeing the case through more than twenty years of litigation. At that point, Judge R. Allen Edgar took over for Wilson. The next month, the board file-d a motion asking the court to find, “it has been in compliance with court orders on city school desegregation for 10 years and dismiss the board from the 24-year-old suit.”

In March of 1986, Edgar told the board that he would “consider the board’s request to dismiss Chattanooga’s 26-year-old desegregation case once the ratio of Black and White teachers and staff members at each school ‘approximately’ equals black-white percentages for the whole system.” Edgar indicated that his decision was based on Judge Wilson’s 1971 order and that while the board was technically in constitutional compliance in terms of students, the faculty ratios needed improvement. His order included the schools that had been annexed at any point throughout the desegregation proceedings but only in terms of teachers, not students.

In December of 1986, Judge R. Allen Edgar dismissed the 26-year-old case, James R. Mapp v. Board of Education of Chattanooga, TN. He announced the court-approved plan of 1971 was fully implemented and that there was, “no demonstrated need to further monitor compliance with orders of this court.”
FUTURE WORK

One of the most interesting aspects of the Chattanooga desegregation story is the way in which it is both similar to and different from other desegregation attempts around the country. My project was so focused on telling the unique and compelling story of my hometown that at times, I missed the forest for the trees. It would be fascinating to step back from the day-to-day happenings of the Chattanooga story and to put the process in the context of the larger movement around the country.

The Chattanooga desegregation litigation culminated with no real victor and severe inequality left in the system. While James Mapp was awarded attorney’s fees, which only the “prevailing party” is eligible for, both he and his attorneys felt that they had won some battles but lost the war. Mapp’s children, in whose names the original suit had been filed, had long since graduated by 1986 and their time in school had been fraught with harassment and bullying. On several occasions they had asked to be transferred back to their original majority-Black schools. In addition, Chattanooga was in the process of re-segregating itself. White families were fleeing to the suburbs leaving under-populated Black schools in the inner city with few resources. Despite busing, clustering, gerrymandering, and many other forms of relocation, the desired ratios mandated by Judge Wilson in 1971 were never achieved.

In more recent years, free magnet schools have sprung up in an effort to combat the educational inefficiencies of the Chattanooga City School System. Mr. Mapp continues to battle for racial equality and still runs the local NAACP chapter out of the back of his insurance office. Ultimately, his bravery and patience fundamentally changed the landscape of the Chattanooga system. It is rightfully so that he is still not satisfied and one can only hope that his example has instilled the same passion for equality and justice in future generations.

EPILOGUE

The Chattanooga desegregation litigation culminated with no real victor and severe inequality left in the system. While James Mapp was awarded attorney’s fees, which only the “prevailing party” is eligible for, both he and his attorneys felt that they had won some battles but lost the war. Mapp’s children, in whose names the original suit had been filed, had long since graduated by 1986 and their time in school had been fraught with harassment and bullying. On several occasions they had asked to be transferred back to their original majority-Black schools. In addition, Chattanooga was in the process of re-segregating itself. White families were fleeing to the suburbs leaving under-populated Black schools in the inner city with few resources. Despite busing, clustering, gerrymandering, and many other forms of relocation, the desired ratios mandated by Judge Wilson in 1971 were never achieved.

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... ONE CAN ONLY HOPE THAT [JAMES MAPP]’S EXAMPLE HAS INSTILLED THE SAME PASSION FOR EQUALITY & JUSTICE IN FUTURE GENERATIONS.
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SYNTHESIS AND TESTING OF POWER OPTIMIZED WAVEFORMS (POW) WITH FOCUS ON 1-POW AND SQUARE POW

ABSTRACT

Passive Radio Frequency Identification (RFID) tags are powered by energy-harvesting charge pumps through AC-to-DC rectification of the wireless RF signal: typically a pulse-interval encoded (PIE) continuous-waveform (CW). These charge pumps are comprised of capacitors and diodes, the latter being the leading barrier of passive tag operation. Specifically, the pump diode turn-on voltage is responsible for limited tag sensitivity, read range, and reliability. The Power Optimized Waveform (POW) is a new, non-invasive transmission signal that improves RFID tag sensitivity by providing higher peak voltages without exceeding Federal Communications Commission (FCC) output power regulations. Two POWs that are tested are the 1-POW, comprised of two sinusoids centered about a carrier signal frequency, and the Square POW, the product of a carrier signal and a voltage modulating square wave. A Dickson charge pump was used to measure the power gain of POW versus CW. Spectral efficiency and charge pump efficiency were calculated at different transmit powers and POW frequency spacing. Positive gain was achieved at low transmit powers (< ~4 dBm), and higher frequency spacing, making POW preferable over CW in low power applications.
I. INTRODUCTION

Power Optimized Waveforms within the Context of Radio Frequency Identification

Wireless power refers to the transmission of power from a source to a load without the use of wires. It is an emerging research field that has its roots in Radio Frequency Identification (RFID), where a passive tag with no local power source (i.e. no battery) must scavenge the power transmitted from a reader to turn itself on. Wireless power has many applications where limited power (e.g. no greater than a few milliwatts) is needed and a battery is either too large or too costly. Current applications include energy-harvesting devices such as sensors, personal area data devices, and other low-powered consumer electronics (Trotter, Griffin, & Durgin, 2009).

Devices that rely on wireless power, such as RFID tags, are characterized by their read range: the maximum distance a reader can be placed away from a tag while guaranteeing reliable reception of backscatter information. Conventional passive readers have a short read range (typically 2 to 10 m), which is related to their scavenging sensitivity. Ways to increase scavenging sensitivity include more sensitive circuit components, improving reader impedance matching, and switching to higher-gain antennas. Work in RF power harvesting has been done with power cycling of transmitter amplifiers to make signals such as a square waveform (Greene, Harrist, & McElhinny, 2008). However, this power cycling method does not optimize the bandwidth/Peak-to-Average-Power Ratio (PAPR) trade-off and it does not use the carrier as a full-duplex communications medium. Knowledge of this trade-off becomes especially useful when dealing with bandwidth limits such as those imposed by the Federal Communications Commission (FCC).

Transmitting Power Optimized Waveforms (POWs) is a new, non-invasive method for improving tag sensitivity (Trotter & Durgin, 2010a). A POW is specially designed to improve the power efficiency of the AC-to-DC power converter, known as a charge pump, when it is used as the input. The tag becomes more sensitive when its power efficiency increases.

This paper concentrates on the design, synthesis, and testing of two POWs: 1-POW and Square POW. The transmit power and subcarrier frequency spacing of each POW are varied and their performance assessed by comparing POW over continuous-waveform (CW) gain, spectral power efficiency, and charge pump efficiency. A discussion based on the relationships between POW subcarrier frequency spacing, peak power, average power, and PAPR, as developed by Trotter and Durgin (2010b), attempts to explain the experimental results and offers insight on potential applications for these particular POWs.
Passive RFID tags power themselves by rectifying the RF signal transmitted by a reader. A means of rectifying and boosting the RF power is through the inclusion of charge pumps in the tag. Specifically, the Dickson charge pump, which includes one or more serial stages of capacitors and diodes, is commonly used in RF-to-DC power conversion (Dickson, 1976). Charge pump diodes, however, introduce inefficiencies if the input RF voltage is not sufficiently large to trip the diodes.

A POW has a few basic properties when compared to the standard CW carrier used by RFID readers. Assuming the POW and CW carriers must have the same root mean square (RMS) voltage ensuring identical transmitted power, the POW has:

- Peak voltage that is much larger than its equivalent CW,
- Diode threshold voltages that are tripped more easily, and
- Capacitors that charge up to higher voltages (the key advantage of a POW over CW).

The POW period, which is closely related to the number of subcarrier frequencies and their separation, must not be too long or the charge pump capacitors will discharge and the tag will power off.

II. METHODS

POW Testbed

Two POW carriers were designed in MATLAB: a 1-POW and a Square POW. Each POW was synthesized by mixing the baseband frequencies with a 915 MHz local oscillator (L.O.) signal that was filtered to ensure a clean input signal. This signal was fed to an amplifier in series with a variable attenuator. The output from the variable attenuator was split and connected to a power meter and to the energy harvester’s charge pumps. The variable attenuator controlled the POW transmission power input to the energy harvester. The setup is illustrated in Figure 1.

Transmission power and frequency spacing were varied independently to assess the effect that each parameter had on the following performance metrics:

- POW gain,
- Spectral efficiency, and
- Charge pump efficiency.
In the first experiment, each carrier was fixed at a period of 1 μs. Spectral power efficiency and gain were measured at different transmission powers. In the second experiment, transmission power was fixed (first at 4 dBm and then at 7 dBm) and charge pump efficiency and gain were measured at various POW frequency spacings.

**Frequency and Time Domain Design of POWs**

Two classes of power-optimized waveforms were examined: N-POW and Square POW. Each POW spectrum can be defined by its baseband version upconverted to the passband. This section defines the POW based on its parameters and presents the Peak-to-Average-Power Ratio (PAPR). The PAPR is a useful metric that describes the POW’s ability to focus its power (Trotter, Hässig, & Durgin, 2010).

### A. N-POW

The N-POW class comprises N equally spaced baseband subcarrier frequencies. The N-POW’s baseband time-domain and power spectral density (PSD) equations are defined for N>0:

\[
V_{\text{POW}}(t) = \frac{1}{\sqrt{N}} \sum_{k=1}^{N} \cos(2\pi k\Delta f t)
\]

\[
PSD_{\text{POW}}(f) = \frac{1}{2N} \sum_{k=1}^{N} [\delta(f - k\Delta f) + \delta(f + k\Delta f)]
\]

The simple case of the 0-POW is equivalent to the CW signal as it only has one frequency carrier (generally 915 MHz in the case of RFID). The upconverted 1-POW turns a baseband cosine waveform into a waveform of two cosines centered about the carrier frequency. The general N-POW is defined in Eq. 1. The equations for N-POW peak power, average power, and PAPR are:

\[
\text{peak power} = 2N \left(V^2\right)
\]

\[
\text{average power} = \frac{1}{2} \left(V^2\right)
\]

\[
\text{PAPR} = 4N
\]

For the N-POW, peak power is directly proportional to the number of subcarriers, while the average power remains the same. As a result, PAPR is also proportional to the number of subcarrier frequencies.

In the case of the 1-POW, the difference in subcarrier frequencies equals the POW frequency, \(\Delta f\), and period, \(1/\Delta f\). In the general case of N subcarriers, the POW frequency is equal to the lowest common multiplier of the differences between subcarrier frequencies. The downside of increasing the number of POW subcarriers, assuming that the bandwidth is held constant, is an increase in the POW period. The greater the POW period, the lower the frequency of POW peak voltage arrivals and therefore the longer the discharge time of the pump capacitors, which may adversely affect POW efficiency. Conversely, increasing spacing between subcarrier frequencies will result in bandwidth increase and a POW period decrease. One period of the 1-POW is illustrated in Figure 2(a). The relative difference in PSD between CW and 1-POW is illustrated in Figure 2(b).
B. Square POW

The Square POW is created by multiplying a 915 MHz sine wave with a square wave envelope or, alternatively, convolving a sinc wave with an impulse at 915 MHz. A Square POW characterized by a high voltage ($V_{\text{high}}$), low voltage ($V_{\text{low}}$), period ($T_{\text{POW}}$), and duty cycle ($D$) is defined by the following time-domain and PSD equations:

$$V_{\text{POW}}(t) = V_{\text{low}} + \sum_{k=-\infty}^{\infty} (V_{\text{high}} - V_{\text{low}}) \text{rect}\left(\frac{t - k T_{\text{POW}}}{D T_{\text{POW}}}\right)(6)$$

$$PSD_{\text{POW}}(f) = V_{\text{low}}^2 \delta(f) + (V_{\text{high}} - V_{\text{low}})^2 \left(\frac{D}{T_{\text{POW}}}\right)^2 \text{sinc}^2\left(\frac{D}{T_{\text{POW}}}f\right) \sum_{k=-\infty}^{\infty} \delta(t - k \Delta f)(7)$$

While the Square POW’s longer peak voltages facilitate envelope detection, the sharp corners and flat edges in the time-domain result in large bandwidth (Trotter & Durbin, 2010b). The Square POW peak power, average power, and PAPR are:

$$\text{peak power} = V_{\text{high}}^2 \quad (V^2)(8)$$

$$\text{average power} = V_{\text{high}}^2 D + V_{\text{low}}^2 (1 - D) \quad (V^2) (9)$$

$$\text{PAPR} = \frac{1}{D + V_{\text{low}}/V_{\text{high}}(1-D)} (10)$$

Peak power is directly proportional to the square wave’s high voltage, $V_{\text{high}}$. For large duty cycles, $D$, the average power will approximately equal the peak power yielding a low PAPR and ineffective POW. One period of the Square POW’s equivalent time-domain representation is illustrated in Figure 2(c). The Square POW’s PSD is illustrated in Figure 2(d).

C. POW Gain Over a Charge Pump Network

Passive RFID tags are self-powered by rectifying the RF input and multiplying the voltage through a charge pump network. A limiting factor of charge pump efficiency is the turn-on voltage of the pump’s diodes. As a consequence, the DC output voltage of a Dickson charge pump is largely dependent on the maximum instantaneous voltage ($V_i$) of the input waveform. The POW Gain ($G_{\text{POW}}$) is defined as the ratio of DC power output of a POW input ($P_{\text{out,POW}}$) to DC power output of a CW input ($P_{\text{out,CW}}$). An approximate model that relates POW Gain to Peak-to-Average-Power Ratio (PAPR), peak voltage ($V_i$), and transmit power ($P_t$) is:

$$G_{\text{POW}} = \frac{P_{\text{out,POW}}}{P_{\text{out,CW}}} = \left(\frac{\sqrt{\text{PAPR}} - V_i/\sqrt{2}}{\sqrt{2} - V_i/\sqrt{2}}\right)^2 (11)$$

This model applies only in the operating region where the diodes are forward-biased. This condition is met when $V_{\text{ON}} \leq V < V_b$, where $V_{\text{ON}}$ is the diode turn-on voltage and $V_b$ is the diode breakdown voltage. As the transmit power is increased, Eq. 11 tends toward PAPR/2, the empirical POW gain limit. In subsequent work, Trotter further develops and discusses a more holistic POW gain model comprised of 4-input power regions (2010).
III. RESULTS

The Square POW and the 1-POW were compared along four dimensions:

- Gain versus transmit power
- Spectral power efficiency versus transmit power
- Gain versus POW frequency spacing
- Charge pump efficiency versus POW frequency spacing

Based on these parameters, the Square POW yielded an overall superior performance to the 1-POW.

The Square POW produced greater gain than the 1-POW at all transmit powers below 6.0 dBm. Within transmit powers of -5.0 dBm – 4.0 dBm, the Square POW averaged 1.13 dB gain over the 1-POW. As illustrated in Figure 3, the Square and 1-POW yielded negative gains beyond 5.5 dBm and 4.5 dBm, respectively. Saturation of the charge pumps for both POWs may account for the decaying gain as transmit power was increased.

Charge pump saturation might also explain the 0.78 dB and 0.45 dB drop in gains (Figure 4) for the Square POW and 1-POW, respectively, when transmit power was increased from 4 dBm to 7 dBm. Despite these drops in gain, Figure 4 illustrates a positive trend in POW gains as frequency spacing was increased. The Square POW yielded the greatest gains across the entire tested frequency spacing range of 250 kHz – 3 MHz.

The spectral power efficiency was calculated by holding the POW frequency constant and measuring the output voltage over a transmission power range of -5 dBm – 7.5 dBm. Since the POW bandwidth was kept constant, then the spectral power efficiency was expected to increase so long as output power increased. Figure 5 confirms that transmit power is proportional to spectral power efficiency.

Charge pump efficiency was calculated by holding the POW transmit power constant and measuring the output gain over a frequency spacing range of 250 kHz – 3 MHz. Each POW was tested at transmit powers of 4 dBm and 7 dBm. As illustrated in Figure 6, increasing frequency spacing resulted in higher POW gain regardless of transmit power. The Square POW exhibited 8.97% improvement in charge pump efficiency when transmit power was increased from 4 dBm to 7 dBm. The 1-POW exhibited a comparable improvement of 8.94% for the same increase in transmit power. At best, the Square POW yielded a marginally greater charge pump efficiency than the 1-POW; the more significant advantage of the Square POW was seen in gain over fixed frequency spacing at variable transmit powers (refer to Figure 3). The POW gain over the measured transmit power range is summarized in Table I.
IV. DISCUSSION

Improving the read range of passive RFID tags is advantageous in low-power applications \((P_t < 5 \text{ dBm})\). The Square and 1-POW provide strictly positive gains at transmit powers of up to 5.5 \(\text{dBm}\) and 4.5 \(\text{dBm}\), respectively. For applications operating under these transmit powers, both POWs yield greater read ranges than the CW signal. Furthermore, the Square POW produces higher gain at a majority of the tested transmit powers (refer to Figure 3). If the objective is to maximize read range at transmit powers beyond 5.5 \(\text{dBm}\), alternative modulation schemes are necessary.

As observed in Figure 4, lower transmit powers yield positive POW gains over CW if the frequency spacing is sufficiently large. The Square POW, transmitting at 4 \(\text{dBm}\), achieves positive gain when subcarrier frequency spacing is greater than 657 kHz. At 7 \(\text{dBm}\), the frequency spacing needs to exceed 2.06 MHz in order to achieve positive gains. The 1-POW transmitting at a power of 4 \(\text{dBm}\) achieves positive gain if frequency spacing exceeds 917 kHz (260 kHz greater than the Square POW) but yields strictly negative gains at any frequency spacing below 3 MHz when transmitting at a power of 7 \(\text{dBm}\). This helps confirm that a lower frequency spacing, or larger POW period, effectively reduces the frequency of POW peak voltage arrivals and therefore the energy harvesting charge pumps discharge for longer periods of time, resulting in reduced gains. Conversely, greater frequency spacing produces lower POW periods and higher frequency of peak voltage arrivals at the charge pumps. The flattening trends in Figure 4, however, suggest decreasing marginal gain with increasing frequency spacing. In light of the fact that the Federal Communications Commission (FCC) regulates RFID UHF bandwidth and limits its range in North America to 902 MHz – 928 MHz, a spectrally efficient POW should be designed with a frequency spacing that operates at positive gain over CW and still meets governmental restriction on signal bandwidth (Trotter & Durgin, 2010b).

While the current testbed measurements confirm some of the performance expectations for the 1-POW and the Square POW, some changes are suggested in future POW testing. The analytical derivation of the relation between frequency spacing and POW gain should be tested by extending the frequency spacing range beyond 3 MHz and confirming the theoretical POW gain limit, \((\text{PAPR}/2)\). Another concern is that increased transmit powers yield improved charge pump efficiency despite reduced POW gains (Figure 6). A possible explanation is reflections at the charge pump input power interface which were unaccounted for. Therefore, the testbed should also incorporate a power coupler and power meter at the interface to account for reflection losses.

![Table I](image)

**Table I**

<table>
<thead>
<tr>
<th>Measured POW Gain</th>
<th>(\text{Square POW})</th>
<th>(\text{1-POW})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{Positive} , (+))</td>
<td>(-5.0 &lt; P_t \leq 5.5 \text{ dBm})</td>
<td>(-5 &lt; P_t \leq 4.5 \text{ dBm})</td>
</tr>
<tr>
<td>(\text{Negative} , (-))</td>
<td>(5.5 &lt; P_t \leq 7.5 \text{ dBm})</td>
<td>(4.5 &lt; P_t \leq 7.5 \text{ dBm})</td>
</tr>
</tbody>
</table>
V. CONCLUSION

Dickson charge pumps see increased DC output when powered by Power Optimized Waveforms (POWs). The experimental 1-POW and Square POW at transmit powers under 5 dBm yield a positive gain over conventional CW. The DC output power harvested by the Dickson charge pumps can be used to power passive tags such as those commonly found in RFID. The additional DC power extracted from POW at low transmit powers translates to greater transmission distances between RF transmitters and tags. The added efficiency makes this signal transmission method more desirable for its power-harvesting advantages in low-power RFID applications that can range from personal wireless battery chargers to communications and powering in industrial settings.
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