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In this issue

Technology Developed in GICE

High Gain Multi-Beam Metallic Antennas for 5G Communications

from Electromagnetics Group

INTRODUCTION

The onset of fifth generation (5G) mobile communications has posed many challenges for antenna researchers. To achieve larger bandwidth and higher data speed, millimeter wave (mmW) frequency spectrum is considered for 5G communications. However, energy loss during propagation is a major concern at mmW frequency. Also, simultaneous use of several mobile systems is required to reduce both cost and inter system interferences. This increases the complexity of base station antennas (BSAs). Hence, for 5G communications high gain multi-beam antennas with even beam squints are more appropriate.

To realize the required radiation characteristics, conventional BSAs employ PCB based phased array antennas. However, at mmW frequencies, these antennas along with suffering from severe energy loss inside dielectrics, exhibit uneven beam squints and large deviation from beam-widths. To counter these problems, a larger antenna is required to achieve the desired gain. Metallic antenna arrays could be potential alternatives to the conventional phased arrays as they provide high energy efficiency, broad bandwidth of radiation, inexpensive and compact design. In this report, metallic reflectarray and transmitarray antenna with multi-beam capability are discussed. Both the type of antennas belongs to the high gain antenna group. They avoid complex beam forming networks by employing space feeding technique. In reflectarray antennas the entire incident wave is reflected back whereas in transmitarray antenna it is desired to transmit most of the

(Continued on page 2)

GICE Honors

Prof. Hung-yi Lee

Won the champion in Formosa Grand Challenge (FGC) competition, held by MoST

Prof. Ai-Chun Pang

「108 MoST Outstanding Research Award」

Message from the Director

Hsuan-Jung Su

Professor & GICE Director

As the weather is getting hotter, we also have hot news for NTU GICE to share with you. Congratulations to Prof. Ai-Chun Pang for winning the 2019 MOST Outstanding Research Award! This is a major achievement for Prof. Pang and for NTU GICE. We would also like to congratulate Prof. Hung-Yi Lee and students of NTU GICE for their year-long devotion to the MOST Formosa Grand Challenge (FGC) and winning the competition by beating the other 142 teams. The MOST FGC is the world's first competition for listening comprehension for machines. It is our outstanding faculty and students who make the NTU GICE flourish. The NTU GICE will continue to provide a healthy and dynamic environment to encourage creativity and innovation.
In this issue, we invite Prof. His-Tseng Chou to share his research progress on High Gain Multi-Beam Metallic Antennas for 5G Communications. Prof. I-Hsiang Wang also presents his information theoretic results on Degrees of Freedom of the Bursty MIMO X Channel without Feedback. In the Corner of Student News, Matteo Zecchin, who is a double-degree student of NTU GICE and University of Padova, Italy, tells us about his life and study at NTU. Please have a coffee and enjoy reading this issue.

Technology *(Continued from page 1)*

incident electromagnetic energy to the radiation aperture.

Reflectarray Antenna

Reflectarray antennas are an array of periodically placed carefully designed elements on a reflecting surface. In this study, convex non-resonant elements are used. The elemental radiation pattern for every element in the surface is assumed to be identical except for the phase variations caused by their position and height of the element. This relative phase shift of the element can be calculated with respect to the incident and scattering angles by applying GO theory. An initial set of required heights that produces orthogonal beams in a range of scan angles can be calculated using this analysis. It is found from the radiation pattern plot that; the directivity of the beams tends to decrease away from the boresight direction. An optimization method is used to get an even directivity distribution over the entire scan range.
A steepest descent method (SDM) based numerical synthesis is then developed to model the radiation of reflectarray antennas and synthesize the reflecting elements for the multi-beam radiation with optimized gain to achieve the desired directivity over the entire scan range. Each beam is considered independently by using an integrated cost function to optimize the multi-beam radiation. This SDM-based procedure results in closed-form formulations to update the geometries of the reflecting elements. In this case, the heights of the reflecting elements are optimized to produce beams with uniform directivity over the entire scan range. Using these optimized heights, a reflectarray structure is designed and its di

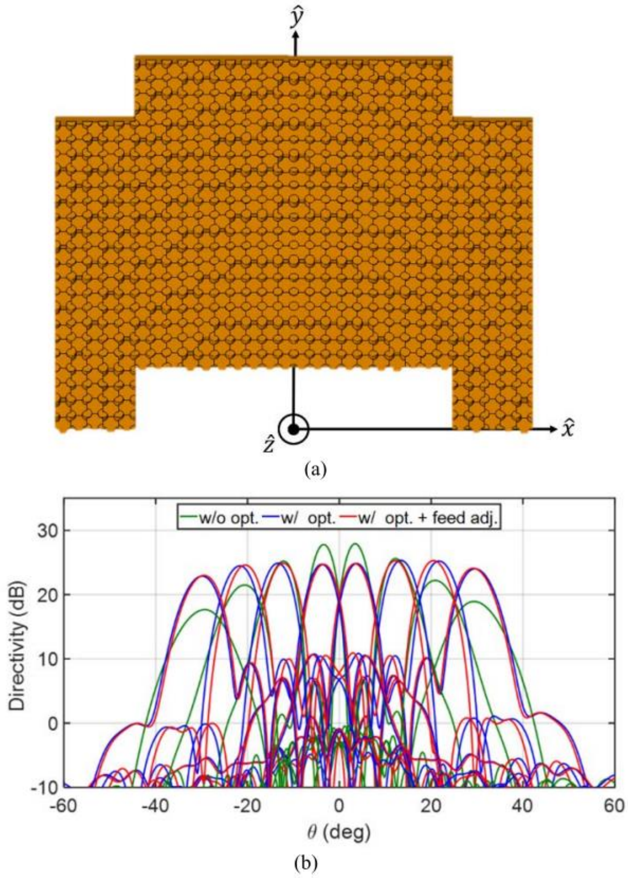


Fig.1. (a) Structure and (b) Simulated directivity of the reflectarray

Transmitarray Antenna

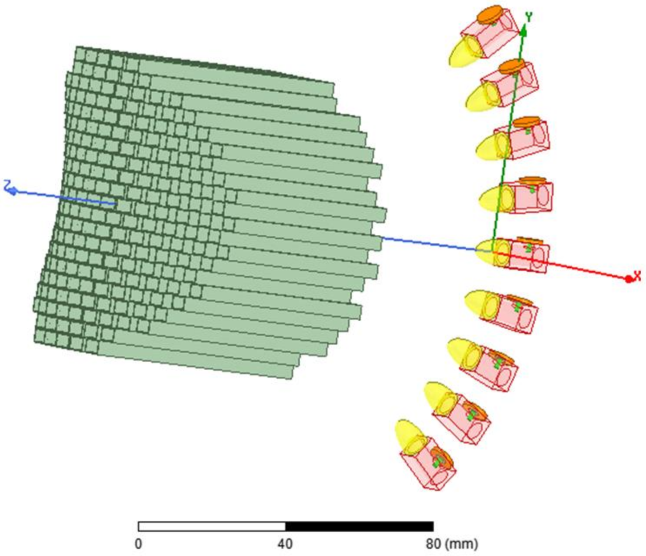
The basic operating principle of transmitarray antenna is similar to reflectarray antenna except for transmitarray antenna, the radiation and illumination aperture are separate unlike reflectarray antenna. Transmitarray antennas combine the advantage of both array theory and optic theory as it is comprised of an illuminating source and a transmission layer. The transmission layer is an array of elements and situated at the far-

(Continued on page 3)

Technology *(Continued from page 2)*

field of the illuminating source. The incident electromagnetic wave propagates through these phase transforming array elements to produce a focused radiation in far-field.

In this study, rectangular waveguide elements operating in their fundamental mode are considered as array elements. The relative phase shifts in this case are obtained by altering position, length and dimension of the waveguide elements. For the fundamental mode in waveguide, the change in dimension alters the refractive index. Hence, mathematical expression for the illumination surface, radiation surface and refractive index is derived first by comparing electrical path lengths for various scan angles. Using these expressions, a structure for the transmission layer is designed. To achieve multi-beam capability, a cluster of feeds can be placed at the focal arc of the antenna. For the example shown in Fig. 2, 9 sources are placed in the focal arc to produce multiple beams in E-plane.



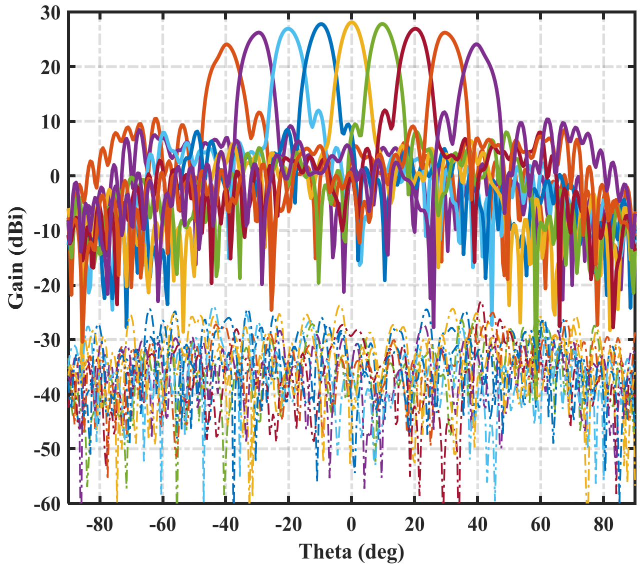


Fig. 2 (a) Structure and (b) radiation pattern of the transmitarray antenna

Conclusion

A brief description of research in metallic array antennas for 5G communications is given in this report. High gain multi-beam antennas are required to compensate for the high propagation loss and inter systems interference at mmW frequencies. Metallic array antennas can meet these requirements as they are energy efficient. In particular, both the reflectarrays and transmitarray antenna could be potential alternative to the PCB based antennas because of their inexpensive and simple designs. Multi-beam capability can be incorporated by placing a cluster of feed sources at the focal arc for both the antennas.

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Technology

Degrees of Freedom of the Bursty MIMO X Channel without Feedback

from Communication and Signal Processing Group

INTRODUCTION

Wireless communication has brought about great convenience in our daily life and led to an ever-increasing demand of higher rates of communication. A simple and effective way to provide higher rates in wireless communication systems is to employ multiple antennas at the transmitters and the receivers, resulting in the so-called mulitple-input and mulitple-output (MIMO) systems. Despite its convenience, wireless communication is very susceptible to interference. For example, consider a wireless network where two pairs of users are communicating with three antennas at each node. When the two communication links interfere with each other, we have an Interference Channel (IC) whose the degrees of freedom (DoF) are only 3, instead of 6 when there is no interference. (In comparison, a single-antenna Gaussian channel has 1 DoF.) The X channel offers a simply ready and boosts the DoF from 3 to 4, by allowing each transmitter to send messages to both receivers. Another important problem faced by wireless networks is the fluctuation in the communication links. Deep shadowing or strong co-channel interference, for instance, can make the link between a transmitter and a receiver virtually unavailable occasionally. Other factors, such as machine-type communication envisioned in 5G systems which interrupts regular traffic, can also lead to bursty links in a network.

The Bursty MIMO X Channel

We investigate how the burstiness of channel impacts the degrees of freedom (DoF) of the MIMO X channel, when the channel topology is known to the receivers, but not to the transmitters, as illustrated in Figure 1. Each transmitter has M antennas, and each receiver has N antennas. Each of the four Tx-Rx links can be intermittently on-and-off (S_{ij} = 1 : the link is on, $i, j \in$ {1, 2},) governed by four Bernoulli random sequences which can be arbitrarily correlated at each time instant, subject to the following channel symmetry assumption: The direct-links (i.e. Tx1 to Rx1 and Tx2 to Rx2) have the same level of burstiness, modeled by Ber(p_d), and so do the cross-links, modeled by Ber(p_c), and the direct-links also have the same level of conditional burstiness, i.e. $\mathcal{P}(S_{11} = 1 | S_{12} = 1) = \mathcal{P}(S_{22} = 1 | S_{21} = 1) = p_{d|c}$.

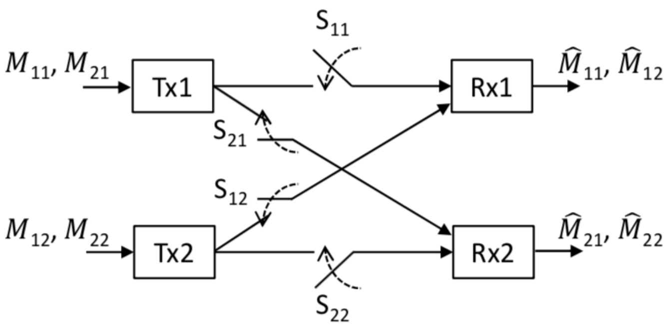

Figure 1: Bursty MIMO X Channel (M_ji: message from Txi to RxJ, M ̂ji: decoded message)

How Burstiness Impacts the DoF

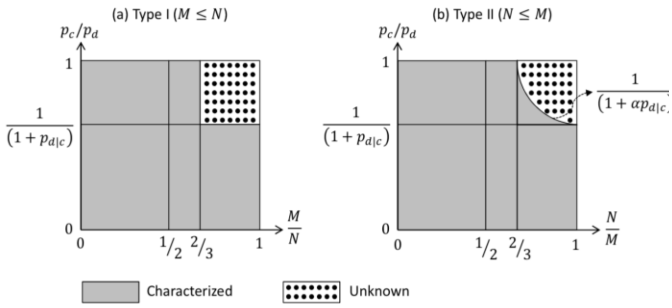

Figure 1: Status of sum DoF Characterization $\left(\alpha = \frac{3N-2M}{2N-M}\right)$

We partially characterize the sum DoF (η) of this channel as shown in Figure 2, where two types of channel are distinguished: Type I has $M \le N$ and Type II has $N \le M$. We highlight that burstiness of the channel disrupts the networking topology, turning the MIMO X channel into a new network with 16 time-varying topologies. This fundamental difference causes the bursty MIMO X channel to differ greatly from the non-bursty channel, in both DoF and achievability schemes.

Interference alignment can be suboptimal:

First of all, various interference alignment (IA) schemes that achieve the DoF of the non-bursty MIMO X channel become suboptimal on the bursty channel. We discover that a

(Continued on page 5)

Technology *(Continued from page 4)*

combination of the Han-Kobayashi strategy and interference alignment can achieve strictly higher DoF than interference alignment alone. Specifically, we introduce the HKIA scheme, where we send private messages with the usual interference alignment, but overlay public messages on top of them. The DoF achieved by IA and HKIA on a 3x2 bursty MIMO X channel is compared in Figure 3.

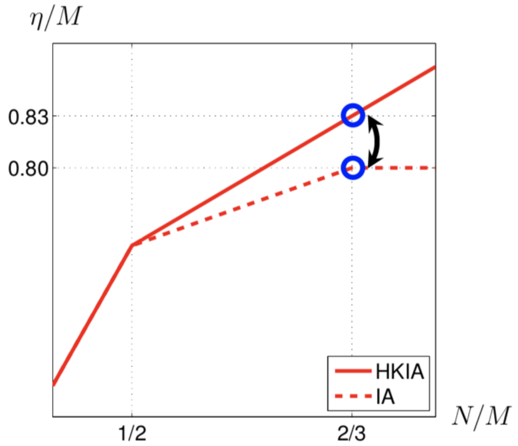

Figure 2: DoF achieved by IA and HKIA on the 3x2 bursty X channel with $p_d = 0.7$, $p_c = 0.5$, and $p_{d|c} = 0.9$.

DoF curves look very different

In addition, the reciprocity between the transmit antennas and receive antennas is lost, and the sum DoF of the channel does not saturate when the ratio between the transmit antennas and receive antennas (the lesser over the larger) exceeds 2/3. This is illustrated in Figure 4, where we see that the Type II channel has higher DoF than Type I, and the DoF keeps increasing when the antenna ratio is greater than 2/3.

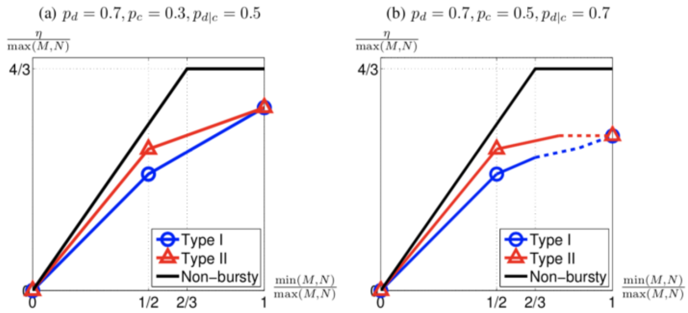

Figure 4: Example DoF plots (Dashed lies: lower bounds)

Interference alignment is still important:

Somewhat surprisingly, however, we also find that interference alignment still plays a crucial role on the bursty MIMO X channel. Specifically, interference alignment still achieves optimal sum DoF when $p_c/p_d \leq 1/(1+\alpha p_d)$ or $M/N < 2/3$ or $N/M < 1/2$, albeit being more involved. In the remaining regimes, it can be combined with the Han-Kobayashi scheme to achieve optimal sum DoF or the best known lower bound.

Conclusion

The bursty MIMO X channel is fundamentally different from the non-bursty MIMO X channel. New coding schemes, such as HKIA, are needed to achieve optimal DoF. The DoF curves also differ substantially from those of the non-bursty channel. Remarkably, interference alignment still plays an important role on the bursty MIMO X channel.

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Activity

The professor and students of GICE won the champion of Formosa Grand Challenge

Human language technology is the core of AI. To encourage the development of the related AI technology, the Ministry of Science and Technology of Taiwan (MOST) held the 1st Formosa Grand Challenge (FGC) competition. It is the world's first listening comprehension test for machine. The competition started at March, 2018, and ended at March, 2019, which is one year in length. 143 teams (700 participants) participated in the competition. Prof. Hung-yi Lee (professor of GICE) and Prof. Yun-Nung Chen led the students winning the competition.

FGC includes six preliminary competitions, semi-final competition and final competition. In all the competitions, the AIs developed by the participants have to listen to spoken content (for example, conversation between two speakers, broadcast news, etc.), and then answer the questions based on the spoken content. In the competitions, AI needs as least two abilities: Speech Recognition and Language Understanding. AI first transcribes the spoken content into text by speech recognition module, and then language understanding module processes the recognition results and find the answers of questions.

For the speech recognition part, although there is lots of speech recognizers developed by the large industry freely available online, the team of Prof. Lee developed their own speech recognizer. With the speech recognizer customized for the competition, they can obtain recognition accuracy higher than the commercial systems in the competition. Their language understanding module is completely based on deep learning. The module takes the transcriptions of speech recognition system and questions as input and outputs the answers directly. Eventually, their AI obtained 53.7% accuracy in the end, and won the champion in the final competition.

Prof. Lee and his research team have been working on machine comprehension of spoken content. They developed the world's first deep learning based spoken question-answering (QA) system and benchmark corpus [1]. They also developed the world's first spoken language understanding system that can take TOEFL Listening Comprehension Test [2], and the system achieved 55% accuracy on the test [3].

Reference:

[1] Chia-Hsuan Li, Szu-Lin Wu, Chi-Liang Liu, Hung-yi Lee, "Spoken SQuAD: A Study of Mitigating the Impact of Speech Recognition Errors on Listening Comprehension", Annual Conference of the International Speech Communication Association (INTERSPEECH), India, Sept. 2018, pp. 3459-3463, ISSN 1990-9772

[2] Bo-Hsiang Tseng, Sheng-syun Shen, Hung-Yi Lee, Lin-Shan Lee, "Towards Machine Comprehension of Spoken Content: Initial TOEFL Listening Comprehension Test by Machine", Annual Conference of the International Speech Communication Association (INTERSPEECH), San Francisco, Sept. 2016, pp. 2731 – 2735, ISBN 978-1-510833-13-5

[3] Yu-An Chung, Hung-Yi Lee, James Glass, "Supervised and Unsupervised Transfer Learning for Question Answering", Annual Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies (NAACL-HLT), New Orleans, June 2018, pp. 1585-1594, ISBN 978-1-948087-27-8

Fig. 1: The team won the champion in FGC. (Source of image: Project office of Formosa Grand Challenge)

Fig. 2: The spoken content and question. The content and question are provided to machine in audio. The text transcriptions shown on the screen are for human reading. (Source of image: Project office of Formosa Grand Challenge)

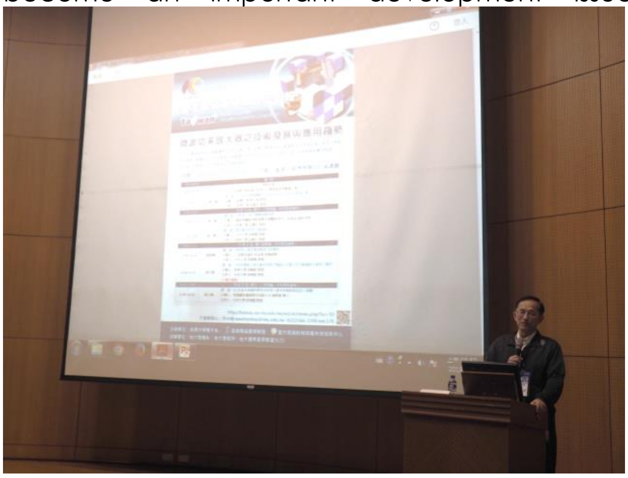
Activity

The 2019 1st Semiannual Report of Taiwan Electromagnetic Industry-Academia Consortium: Microwave power amplifier Technical Development and Trends Symposium

The European Microwave Week, held in Spain Sep. 23~28, 2018, in which the European Microwave Integrated Circuit Conference focused on microwave and millimeter wave power amplifier design, which shows the importance of the power amplifier research. We expect Taiwan to have a leading role in the microwave power amplifier related industry, but there are still many challenges to be faced in terms of technology and application. Therefore, the Taiwan Electromagnetic Industry-Academia Consortium has specially held a symposium on the development and application of microwave power amplifier technology, on 3rd of May, 2019, at the Barry Lam Hall, National Taiwan University (NTU) in Taipei, Taiwan, so that experts in the field of microwave power amplifiers can exchange their ideas and discuss future research trends. The symposium was organized by the Department of Electronics Engineering, Chang Gung University (CGU), Taiwan Electromagnetic Industry-Academia Consortium, High-Speed RF and mm-Wave Technology Center, and co-organized by the Department of Electrical Engineering, NTU, Graduate Institute of Communication Engineering, NTU, and Industry Liaison Office, NTU.

In this event, the organizers invited six speakers: Prof. Tian-Wei Huang from National Taiwan University, Shaw-Guann Lin, Associate Research Fellow from Taiwan Semiconductor Research Institute, Prof. Hwann-Kaeo Chiou from National Central University, Yue-Lin Tsai, Deputy Technical Manager from Industrial Technology Research Institute, Prof. Hsien-Chin Chiu from Chang Gung University, Dr. Chun-Hsien Lien, Region Technical Manager from National Instruments, to share their research and experience for the microwave power amplifier techniques. The speakers share their experience in technology development and research in microwave power amplifiers. The content is given from the perspective of system, process, and industry development, including relevant CMOS and GaN power amplifier design, engineering application problems, measurement requirements and software design practice examples. The agenda is wonderful and substantial.

Prof. Ruey-Beei Wu from National Taiwan University first explained that the popular electronics industry includes 5G, IoT, and automotive electronics. Various wireless communication systems, advanced driver assistance systems, and radar systems need to transmit microwave and millimeter wave signals. The most important component is the power amplifier (PA). The 5G module consists of three parts, the RF front-end module, the RF transceiver module, and the baseband signal processor. The fastest growing is the RF front-end (RFFE) module. Previously, the cost of 4G RFFE averaged 10 US dollars, and the market estimates that 5G would reach 50 US dollars. The front-end module of the mobile phone will reach a market size of about 35 billion US dollars in 2023. However, the power amplifier in the RFFE module is the most power-consuming component. In the future, the power saving and heat-saving will become an important development issue.



Professor Ruey-Beei Wu, NTU

The topics discussed at this meeting include: the 5G mmW broad linear 28nm/65nm CMOS PA, modulation signal measurement for power amplifier, designs of GaN/Sin MMIC power amplifiers, application of power amplifier in microwave annealing, Novel Gam HEMT based power amplifier on 6-inch Si wafer for 5G microcell basestation applications, and design challenge of power amplifier and front-end for 5G millimeter-wave cellular communication. The report is quite in-depth and rich. The number of applicants for the event was 125, which was quite enthusiastic. There were about 70 students and teachers, and the rest were from the industry. Through the exchange of microwave power amplifier trends, the main purpose of this conference is also to explore the key and opportunities for Taiwan's technology development in power amplifiers.

Professor Tian-Wei Huang, NTU

Corner of student news

Matteo Zecchin came from Italy and he got his Master Degree by joining double degree program via a collaboration agreement signed by NTUGICE and University of PODOVA.

Pages and pages could be written on the differences and similarities between Italy and Taiwan, what would you expect from two countries with completely backgrounds and 10000km apart?

However, in this article I would rather share with you what made my last year unforgettable and how this experience has positively and deeply affected me!

The first impact with Taiwan was rough, collecting all the necessary things for the room, get all the paperwork done and catch up with the fast pace of Taipei was a real challenge, especially when you are not used to the hot and humid climate of Taiwan. Fortunately, all things are difficult before they become easy and my Taiwanese life was not an exception.

That anonymous room in the Prince House dormitory slowly start becoming my dwelling and the dorm life has revealed all its pros. I made new friends from all over the world and we began exploring the enormous city of Taipei that, I must admit, at the beginning was intimidating.

When we were not cruising around the streets of Taipei with our bikes, heading to night-markets or visiting parks and temples, I was focused on my studies.

The academic life was fantastic, I had the chance to experience a school system that is completely different from the one that we have in Italy. Here, to the students is given the possibility to freely explore the subject and delve into new topics, this helped me to define my interests and to further develop my intellectual autonomy.

I have also joined the Network and Communication Theory Lab of professor I-Hsiang Wang. Under his supervision I have deepen my knowledge on distributed computing and network information theory. In this context I had the chance to meet a lot of talented people that stimulated in me new research interests; hopefully I had the same effect on them.

Even if my campus life was predominantly devoted to study I couldn't refrain from joining some of the of the countless recreational activities held at NTU. I have always loved swimming and then I decided to try joining the NTU swimming team. I trained with the NTU swimmers for a couple of months, but I didn't manage to fill the gap between me and these formidable athletes (university sport is a serious thing here in Taiwan!).Nevertheless, I enjoy the beautiful sport facilities of NTU as an amateur swimmer and I love playing basketball with my friends during weekends at the University's courts.

Concluding, I think that visiting a country as a student is, literally and figuratively, a once in a life-time experience that I sincerely suggest to any reader in the position of doing so.

Hike at the Teapot Mountain (I am the one in the upper right corner, grey shirt)

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