NTU GICE Newsletter
Graduate Institute of Communication Engineering, National Taiwan University

Vol. 10, No.4 NOV. 2019 https://comm.ntu.edu.tw/ gicenewsletter@ntu.edu.tw

In this issue

Technology Developed in GICE

Optimization of Precoding-Based Waveforms for 5G New Radios

from Communication and Signal Processing Group

INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) and orthogonal frequency division multiple access (OFDMA) have been the basis of the physical-layer frame structure in many modern communication systems including 4G LTE. However, OFDM/OFDMA suffers from a number of drawbacks such as sensitivity to frequency offset and high peak-to-average power ratio which seriously affect their performance in some 5G scenarios. In 5G, demands arising from low-latency applications, energy efficiency, support of multiple numerologies, relaxation of synchronization, etc., impose constraints on a transmission waveform such as low out-of-band emission (OOBE) and low peak-to-average power ratio (PAPR) on which OFDM/OFDMA generally does not perform well. Several waveforms alternative to OFDM have been proposed and studied, including filter-bank multicarrier (FBMC), universal-filtered multicarrier (UFMC), generalized frequency division multiplexing (GFDM), etc. Many of these waveforms call for advantages such as spectral containment and power amplifier efficiency and have been proposed for 3GPP's consideration as the waveforms for New Radio (NR).

In this article, we introduce our own waveform proposal for 5G new radio based on an efficient precoding and devise an optimization scheme of the waveform precoding coefficients which prove to outperform all existing waveforms in terms of a low OOBE and a low PAPR. The

(Continued on page 2)

GICE Honors

Prof. Chun-Ting Chou
Pan Wen Yuan Foundation
「Innovation Awards in IOT Application」

Prof. Ai-Chun Pang
Pan Wen Yuan Foundation
「Innovation Awards in IOT Application」

Message from the Director

Hsuan-Jung Su

Professor & GICE Director

Congratulations to Prof. Chun-Ting Chou and Prof. Ai-Chun Pang for receiving the "Innovation Awards in IoT Application" from the Pan Wen Yuan Foundation! We are happy to see them recognized for their hard work in the IoT field. Nice job! We would also like to congratulate Prof. Homer Chen for his great success in hosting IEEE ICIP 2019, the world's leading image and video processing conference, in Taipei on September 22-25.

In this issue, we invite Prof. Borching Su to share his research results on Optimization of Precoding-Based Waveforms for 5G New Radios, which is a critical element of the 5G wireless communications, and Prof. Hsin-Chia Lu to share the results of on-chip antenna integrated with voltage controlled oscillator in 40nm CMOS process at 140GHz, which is a key element for applications such as security screening. Please enjoy reading their research works!

Technology *(Continued from page 1)*

proposed waveform is named circularly pulse-shaped (CPS) precoding OFDM where the columns of the precoding matrix **P** are circularly shifted versions of a prototype vector.

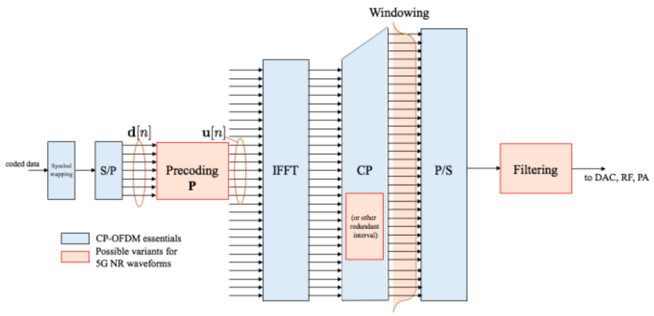


Figure 1: Transmitter structures for OFDM-based Waveforms with additional processing

More specifically, the CPS precoding matrix is designed as **P** = **W**$_S$ **A**, where **W**$_S$ is an S-point normalized DFT matrix and **A** is an *S* x *S* GFDM modulation matrix with the (*kM* + *m*)th column vector $\mathbf{a}_{k,m}$ derived from an *S* x 1 prototype pulse vector $\mathbf{a}_{0,0}$, i.e., $[\mathbf{a}_{k,m}]_s = [\mathbf{a}_{0,0}]_{(s-mK) \bmod S}\, e^{j2pks/K}$. The precoder design inherits some benefits of GFDM but possesses a greater advantage to fit in a subband-based frequency resource block allocation in 5G NR as depicted in Figure 1. The precoding characterized by an *S* x *S* matrix multiplication can be efficiently implemented in the order of *O*(*S* log *S*) [1].

Optimization of Prototype Vector of The CPS Precoder

We formulate an optimization problem to find a suitable prototype vector **p** = $\mathbf{a}_{0,0}$, such that the overall transmitted waveform has the desired properties. The problem is formulated as

$$\begin{aligned} &\underset{\mathbf{p}}{\text{minimize}} && \bar{\sigma}_x^2(\mathbf{p}) && \text{(1a)}\\ &\text{subject to} && \gamma_x(\mathbf{p}) \le U && \text{(1b)}\\ & && \zeta(p) \le (1+\epsilon)\frac{S^2}{\rho} && \text{(1c)}\\ & && ||\mathbf{p}||_2^2 = \rho. && \text{(1d)} \end{aligned}$$

The objective function

$$\bar{\sigma}_x^2 = \frac{1}{N}\sum_{n=0}^{N-1}\mathbb{E}\left\{\left[|x_n[b]|^2-\bar{\mu}_x\right]^2\right\} = \frac{1}{N}\sum_{n=0}^{N-1}\mathbb{E}\left\{|x_n[b]|^4\right\}-\bar{\mu}_x^2,$$

is to minimize the variance of instantaneous power (VIP) of baseband CPS-OFDM signals so as to reduce the impact caused by PA nonlinearity. The constraint (1b) dictates that the out of subband emission power (OSBEP) of baseband CPS-OFDM transmission, defined as $\gamma_x = \int_{\omega\in\mathcal{F}_{\text{OSB}}} S_x\left(e^{j\omega}\right)\frac{d\omega}{2\pi}.$, must be less than a predefined upper bound U. The constraint (1c) requires that the noise enhancement factor at the receiver caused by the equalization of the precoder not to exceed $1+\epsilon$ where ϵ is a predetermined. It can be shown that when $\epsilon = 0$ is chosen, the precoder **P** would be a unitary matrix. The last constraint (1d) is a power constraint. All the above functions can be parameterized by **p**, the first column of the precoding matrix **P**. Readers interested in details of the derivations are referred to reference [1].

Solving the problem (1) directly is generally considered NP-hard and difficult to be analyzed since the VIP function $\bar{\sigma}_x^2(\mathbf{p})$ is a fourth-order polynomial of **p** [1]. In [1], we proposed a semi-definite relaxation and a majorization-minimization technique [2] to handle the problem.

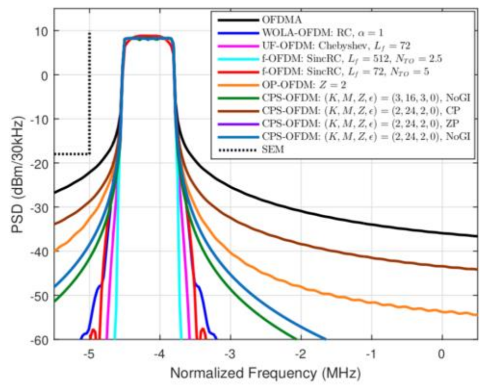
Performance Evaluation and Comparison with Other Waveforms in the Literature

We evaluate the performance of the proposed waveform and compare it against other existing contenders in the literature. The system parameters are chosen according to the agreements in the 3GPP

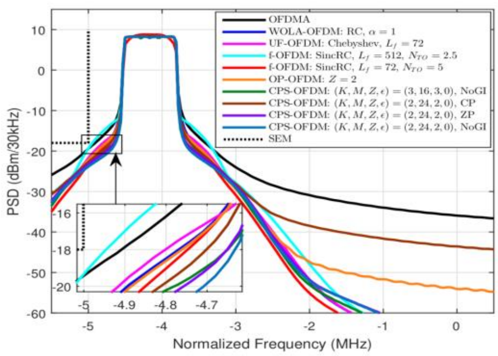
(Continued on page 3)

Technology *(Continued from page 2)*

standardization meetings for 5G NR waveform evaluation [3]. In Fig. 2(a), we can see that the proposed waveform has a lower OSBE than OFDMA. Although candidates like f-OFDM, UF-OFDM have an even lower OSBE, they suffer from a high PAPR and when the practical PA nonlinearity is considered, the corresponding effects of spectral regrowth can be observed in Fig. 2(b). CPS-OFDM leads to the lowest amount of OSBE in adjacent bands. Fig. 3(a) shows the advantage of CPS-OFDM in terms of PAPR and Fig. 3(b) demonstrates the bit error rate (BER) performance of the proposal is comparable to other alternatives.

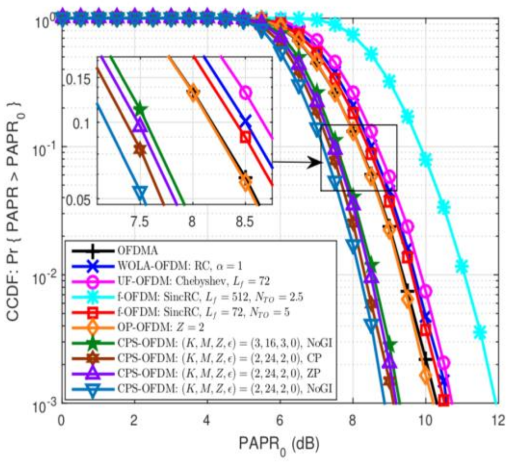


(a)

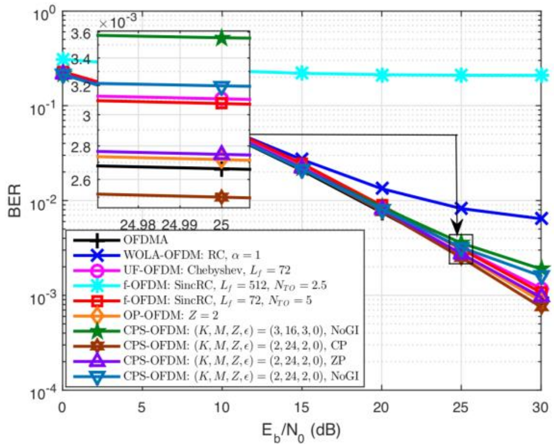


(b)

Fig.2 (a) Simulated PSD results of low-OSBE waveforms in absence of PA nonlinearity; (b) Simulated PSD results of the same waveforms in presence of PA nonlinearity.



(a)



(b)

Fig. 3 (a) PAPR performance results for low-OSBE waveforms; (b) Single user detection performance results.

Conclusions

In conclusion, we introduced the CPS-OFDM new waveform proposed for 5G New Radio (NR). It possesses advantages of both low out-of-subband emission (OSBE) and low peak-to-average power ratio (PAPR) that are critical to physical layer signal requirements for 5G NR. An optimization problem is formulated and solved for waveform prototype design, and simulation results clearly demonstrate the performance advantages against other existing alternatives.

References

[1] Y. Huang and B. Su, "Circularly Pulse-Shaped Precoding for OFDM: A New Waveform and Its Optimiza- tion Design for 5G New Radio," IEEE Access, vol. 6, pp. 44129-44146, August 2018.

[2] Y. Sun, P. Babu, and D. P. Palomar, "Majorization-minimization algorithms in signal processing, com- munications, and machine learning," IEEE Trans. on Signal Processing, vol. 65, no. 3, pp. 794-816, Feb. 2017.

[3] 3GPP, "Study on New Radio access technology physical layer aspects," Technical Report (TR) 38.802, V14.2.0, Sep. 2017.

For more information please contact:
Professor: Borching Su
Email:borching@ntu.edu.tw

Technology

On-chip Slot Ring Antenna Integrated with Wide Tunign Range Voltage Controlled Oscillator at 140 GHz in 40nm CMOS Technology

from Electromagnetics Group

INTRODUCTION

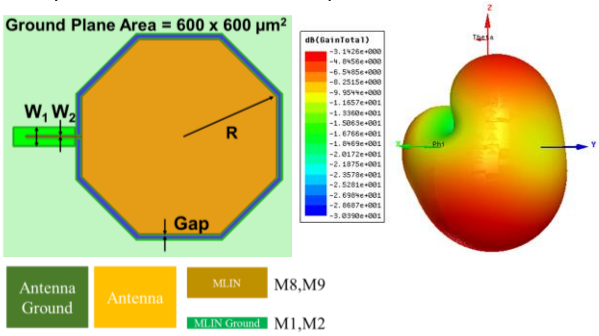
The 140 GHz millimeter wave signal has low propagation attenuation, short wavelength, and high resolution. Unlike X-ray, the millimeter wave is non-ionizing radiation. Thus, millimeter waves are safer to the human body. It also has better penetration capability than infrared light. These features make millimeter wave an ideal candidate for detecting concealed hand-held metal objects in security screening. This report will present an on-chip antenna integrated with a wide tuning range voltage controlled oscillator (VCO) in standard 40nm CMOS process at 140GHz.

Antennas are usually realized in the printed circuit board or integrate the antenna in the package (*AIP*). Both approaches need bond-wire or flip-chip interconnect to route millimeter wave signal from chip to antenna. As frequency goes higher, the loss due to these interconnect increases dramatically. But as wavelength is reduced, it becomes feasible to use on-chip antenna to integrated with active source into a single die. However, there remain some difficulties for on-chip antenna at millimeter wave band. The first issue is the lossy Si substrate under on-chip antenna will reduce antenna efficiency and the second issue is the stringent metal filling density requirement in modern CMOS process. Some papers add resonator with high dielectric constant to improve the upward radiation efficiency. For the second issue, dipole and patch antenna are no longer good candidates as large area without or full of metal does not comply design rules. Slot antenna provides a suitable radiating element to comply with design rule requirement. Since current only exists at edge of slot, we can therefore adjust the metal density in region slight away from slot to satisfy design rule requirements.

In this report, we will present a microstrip line fed slot ring antenna at 140GHz. To enhance downward gain and efficiency of this on-chip antenna, backside Si lens is also used. The input matching measurement results of this antenna and its radiated power pattern combined with an active VCO and Si lens will also be presented.

ANTENNA DESIGN

The layout of the slot ring antenna and the substrate stacking in the CMOS process in shown in Fig. 1(a). Microstrip line at left hand side feeds the slot ring antenna at right hand side. The microstrip line has signal trace at M8 and M9 with width W0 of 2μm while ground is at M1 and M2. To comply with design rule, metal at M3~M9 as ground is also added at both sides of the microstrip line. The separation W1 between two metal ground is 30μm. EM simulation shows these ground has no effect on the microstrip line. The center metal and outer ground of slot ring antenna are formed by combining metal from M1~M9. The slot ring antenna has gap at 10 μm and radius R at 158 μm to yield input matching at 140GHz and optimal efficiency. The die has lossy Si substrate at 300μm in thickness.



(a) (b)

Fig. 1. Microstrip line fed slot ring antenna (a) layout, substrate layer stacking and (b) simulated radiation pattern.

Fig 1(b) shows the simulated radiation pattern of the on-chip slot ring antenna. We can see it has peak gain at -3dB point downward but with about 0dB front-to-back ratio. This is due to the large mismatch between Si substrate and air around the antenna die. To enhance the efficiency of the on-chip antenna, a hyper-hemispherical type Si lens using high resistivity (HR) Si is added at back side of the chip. The cross section of the whole assembly is shown in Fig. 2(b). We select the lens diameter at 8mm get highest gain at 20dB at 140GHz. The 3dB beam widths are 8° and 9° at E-plane and H-plane.

(Continued on page 5)

Technology *(Continued from page 4)*

IMPLEMENTATION AND MEASUREMENT RESULTS

The chip includes the VCO and the on-chip slot ring antenna is fabricated in TSMC 40nm CMOS. The die photo is shown in Fig. 2(a).

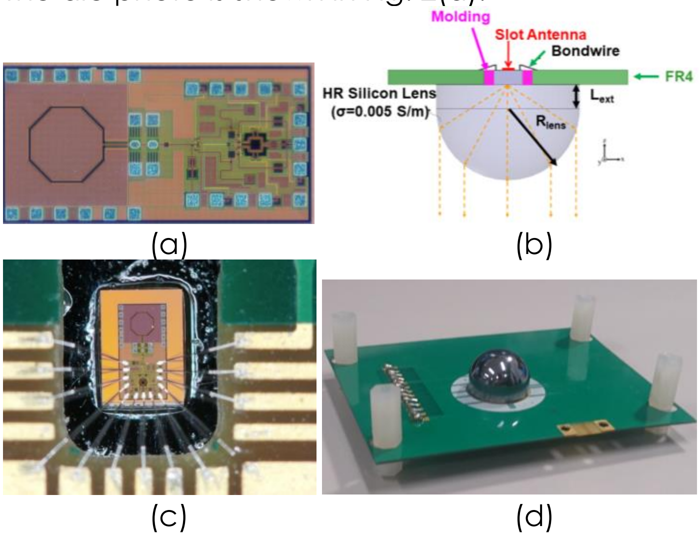


Fig. 2. (a) Die photo (size: 0.67x1.36mm2), (b) cross section of final assembly, (c) chip side photo after bondwire and (d) Si lens side photo after assemble.

We have two GSG probe pads for antenna and VCO respectively in the center of the die. These two pads are connected by a short microstrip line. If the microstrip line is not burnt out by laser, the VCO is connected to antenna. If it is cut by laser, we can measure VCO and antenna separately. The VCO is measured separately with tunable frequency from 122.9 to 142.9 GHz with peak output power at -2dBm at 143GHz. Before the die is mounted on the high resistivity (HR) Si lens, we can measure its input matching. If we directly place the chip on metal chuck in a probe station, the antenna will see the reflection from the metal chuck resulting an erroneous reflection coefficient. To emulate an infinite large Si substrate in the simulation, we mount the chip on a lossy Si wafer with thickness of 670µm as shown in Fig. 3(a) and place them on the metal chuck. As the energy radiated by the slot ring antenna is absorbed by the lossy Si substrate, EM simulation shows the input matching in this setting is almost identical to the input matching when the slot ring antenna is placed on an HR infinite Si substrate. The measured input reflection coefficient is shown in Fig. 3(b). The frequency range of the VNA is 140GHz~220GHz, so we can only get results from 140GHz. We can see the frequency with minimum reflection coefficient is shifted upward to 160GHz. But we still can get -15dB reflection coefficient at 140GHz.

The chip is then attached on a hyper-hemispherical silicon lens with 8mm diameter and subsequently wired-bonded to a FR4 PCB as shown in Fig. 2(b). The die side photo after wire bonding is shown in Fig. 2(c) and the lens side photo of the whole assembly is shown in Fig. 2(d). With the DC power from PCB, the chip with lens can radiate energy into free space.

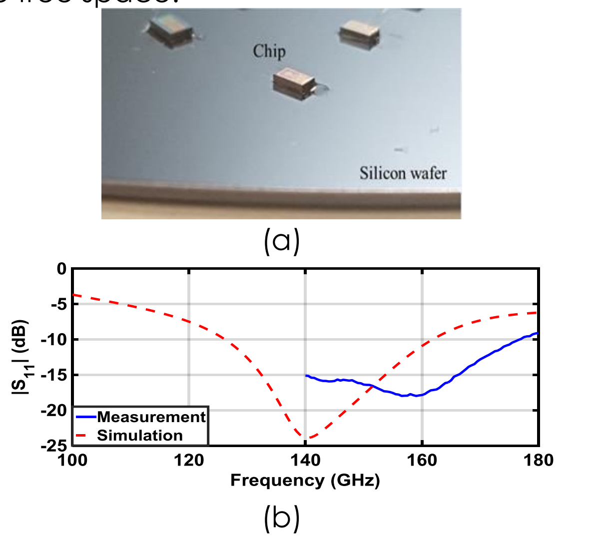
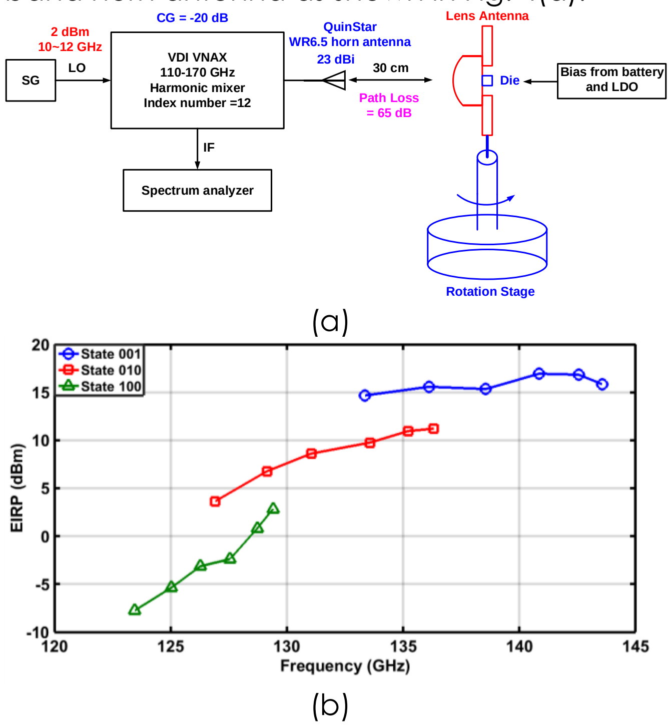


Fig. 3. (a) Chip mounted on lossy Si wafer to input matching measurement. (b) Measured and simulated input reflection coefficients of on-chip slot ring antenna.

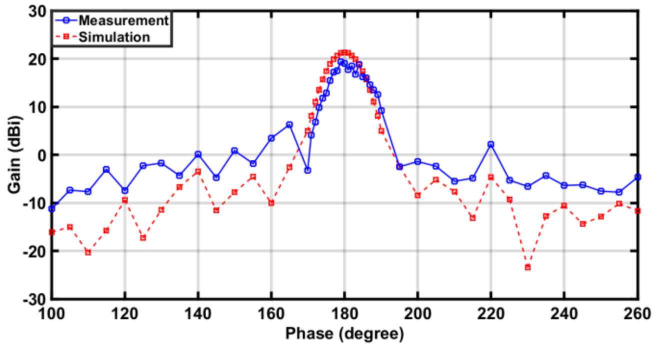
The output power is then characterized through a spectrum analyzer that receives down-converted D-band signal to IF frequencies by using a VDI VNAX WR6.5 110~170GHz harmonic mixer aided with a D-band horn antenna as shown in Fig. 4(a).



(Continued on page 6)

Technology

(Continued from page 5)



(c)

Fig. 4. (a) Gain and antenna pattern measurement setup. (b) Measured EIRP under different VCO frequency. (c) Measured and simulated E-plane pattern of radiator including on-chip antenna and Si lens.

With known power from VCO, horn antenna horn gain, conversion loss of the mixer and the distance between source and receiving horn antenna, we can calculate the EIRP and gain of the lens integrated on-chip antenna using Friis equation. The measured EIRP is shown in Fig. 4(b). The measured gain pattern in E-plane cut of the radiator is shown in Fig. 4(c). It has peak gain at 20dB at 143GHz with beam width of 8°. The simulated pattern has beam width at 8° and peak gain at 20dB.

CONCLUSION

This report presents a microstrip line fed on-chip slot ring antenna integrated with a 140 GHz CMOS voltage controlled oscillator. Slot ring antenna design can easily comply with stringent design rule requirements at standard CMOS process. Measurement results of input matching and radiated power pattern have good agreement with simulation.

For more information please contact:
Professor: Hsin-Chia Lu
Email: leonardo@ntu.edu.tw

Activities

Taiwan hosted IEEE ICIP 2019—the world's leading image and video processing conference

The IEEE International Conference on Image Processing (ICIP 2019) was successfully held on September 22-25 at Taipei International Convention Center (TICC), in Taipei, Taiwan. ICIP is one of the IEEE Signal Processing Society flagship conferences and has served as a premier forum for researchers and practitioners across academia and industry for the exchange of fundamental research results and technological advances in the field of image processing since 1994.

ICIP 2019 was organized by Prof. Homer H. Chen, from National Taiwan University, Prof. Hsueh-Ming Hang, from National Chiao Tung University, and Prof. C.-C. Jay Kuo, from the University of Southern California. ICIP 2019 successfully attracted 2,067 paper submissions from all over the world and accepted 940 papers in total with an acceptance rate of 45.5%. The technical program of ICIP 2019 features three excellent plenary talks, given by Edward Y. Chang, from HTC Research & Healthcare, on the topic "Advancing Healthcare with AI, VR, and Blockchain, Pierre Vandergheynst, from Ecole Polytechnique Fédérale de Lausanne, on the topic "Signal processing on graphs. Past. Present. Future?", ACM Turing Award Laureate Yann LeCun, from Facebook AI Research & New York University, on the topic "Self-Supervised Learning: The Future of Signal Understanding?". The technical program of ICIP 2019 also includes 14 special sessions covering timely and important image and video processing technologies.

In the four-day technical program, ICIP 2019 gathered more than 1,600 technical professionals and top technology companies (such as Google, Facebook, Qualcomm, Tencent, and Microsoft) from

(Continued on page 7)

Activities

(Continued from page 6)

around the globe, shared and advanced the state-of-the-art technologies in image/video processing, image/video analysis, image/video communications, computer vision, computational imaging, and visual technologies based applications.
One of the highlights of the conference was the revolution of poster presentation by large LCD screens—first ever in the history of ICIP. It won the praise from all participants.

The success of ICIP 2019 was due in part to the generous support of the Platinum Patrons (Qualcomm, Kuishou, Google, Facebook, Tencent, Microsoft, Quanta Computer, and AmTran), Gold Patron (ELAN Microelectronics), Silver Patrons (Sinica IIS, MediaTek, and HTC) and Bronze Patrons (JD AI, Top Taiwan Venture Capital Group, Osparks AMG, Sinica CITI, Mitsubishi Electric, and InterDigital), and in part to the support from the Ministry of Science and Technology, the Bureau of Foreign Trade of the Ministry of Economic Affairs and the National Science Foundation of United States.

2019 IEEE ICIP

2019 IEEE ICIP

Corner of Student News

Hsinju Chen is pursuing Master degree in the supervision of Prof. Shih Yuan Chen at Graduate Institute of Communication Engineering, NTU.

During the 2018-19 academic year, I flew to the University of Illinois at Urbana-Champaign (UIUC) with the consent and blessings of my master's advisor Professor Shih-Yuan Chen and spent 9 months amid the serene cornfields in Central Illinois. Eager to maximize my study abroad experience, I immediately sought mentorship from Professor Jennifer T. Bernhard of Electromagnetics Laboratory to continue with my research, signed up for a variety of lectures, and joined a few student organizations to better understand local culture and connect with people. My research on mutual coupling with Professor Bernhard was an extension of my antenna element design during my first year at GICE. With literature survey and verification in the design process, I was able to understand more about array design and also fortunate enough to present my findings at 2019 AP-S/URSI. At the newly built Electrical & Computer Engineering (ECE) Building, which was recently awarded LEED Platinum certification, I took Advanced Digital Communication and RFIC & System Design, learning more about communication systems while gaining hands-on experience in receiver design. Since I was in the States, the opportunity of taking English literature classes was too good to pass up, and my course schedule ended up being a colorful mix of classes in ECE, English, and Theatre. The very different classroom environments and fields of study helped me retain an intellectually balanced life. I participated in proactive discussions in class and learned from my fellow classmates that no one should be fearful of asking questions or expressing their thoughts in safe classroom settings. I often went to office hours to get acquainted with professors and instructors and learn more about course materials as well as their academic life stories. They were always incredibly friendly and helpful. Not only did I get to personally know more academic professionals, I also met many graduate students of different disciplines from all over the world who were willing to share their stories with me, and I find each and every one of them intriguing and informative. Staying in a dorm was one of the best decisions I had made prior to arriving on campus. In the many dorm organizations and events I had participated, I learned a lot about social issues from my peers and became more conscious of the world around us. I made a few good friends there and we often shared stories of our lives and perspectives on current affairs, providing each other glimpses into different cultures. In addition to taking acting classes, I also spent a good amount of time at Krannert Center for the Performance Arts to enjoy all the wonderful programs being held there. During the many breaks throughout the school year, I traveled across North America, visiting cities while meeting more people along the way.

Last year at UIUC had been very fruitful not only academically but also socially, and I am thankful for the experience to learn and grow as a person. As of now, I am focused on finishing my master's studies and excited about my next chapter in life.

Late Night Snack after a Book Club Movie Outing

National Taiwan University Graduate Institute of Communication Engineering

No.1, Sec.4, Roosevelt Road, Taipei 10617, Taiwan

Phone
+886-2-3366-3075

Fax
+886-2-2368-3824

E-mail
gicenewsletter@ntu.edu.tw

Visit us at:
http://www.comm.ntu.edu.tw

Editor in Chief
Prof. Borching Su

Editor
Chiao Yun Kang