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

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In this issue

Technology Developed in GICE

Reconstruction of Multiport Scattering Matrix from One-port Measurements

from Electromagnetics Group

The scattering matrix (S-matrix) of a multiport network can be acquired from the direct measurement using a full-port vector network analyzer (VNA), or from multiple measurements with the use of a reduced-port VNA and proper reconstruction methods [1]-[3]. Port reduction method (PRM) [4] is an approach to reduce the number of measured ports by one by connecting a known termination to the unmeasured port. The n-port S-matrix is then reconstructed from a set of reduced (n-1)-port measured S-matrices. Basically, the minimum number of measured ports of device under test (DUT) is shown to be two. This method is further extended using auxiliary circuits until reaches the measured port being one which is the minimum number. It then provides a cost-effective approach to reconstruct the S-matrix of an n-port network using one-port VNA.

The reflection coefficient at port 1 of a two-port DUT by terminating its port 2 with Γ_2 is given by

$$S_{11}^{(2)} = S_{11} + \frac{S_{12}S_{21}\Gamma_2}{1-S_{22}\Gamma_2} \quad (1)$$

Similarly, by terminating port 1 with Γ1, one can obtain the following equation for port 2

$$S_{22}^{(2)} = S_{22} + \frac{S_{12}S_{21}\Gamma_1}{1-S_{11}\Gamma_1} \quad (2)$$

From (1) and (2), S11, S22, and the round trip path term S12S21≡RTP can be solved from three one-port measurements through the following matrix equation

$$\begin{bmatrix} 1 & S_{11}^{(2a)}\Gamma_{2a} & \Gamma_{2a} \\ 1 & S_{11}^{(2b)}\Gamma_{2b} & \Gamma_{2b} \\ S_{22}^{(1a)}\Gamma_{1a} & 1 & \Gamma_{1a} \end{bmatrix} \begin{bmatrix} S_{11} \\ S_{22} \\ RTP - S_{11}S_{22} \end{bmatrix} = \begin{bmatrix} S_{11}^{(2a)} \\ S_{11}^{(2b)} \\ S_{22}^{(1a)} \end{bmatrix} \quad (3)$$

Note the separation of S21 and S12 in the RTP term needs additional one-port measurements using an auxiliary circuit as shown in Fig.1.

In Fig. 1, the three ports of the auxiliary circuit are denoted as P1, P2, and P3. Its S-matrix is known and given by A whose elements are aij with i, j=1, 2, 3. Note that the auxiliary circuit needs advance characterization using a

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GICE Honors

The Chinese Institute of Electrical Engineering Graduate Student Thesis Contest

- **First Place**
  C.-F. Chou
  Advisor: Huei Wang

- **Second Place**
  1. Hsiang Hsu
     Advisor: Kwang-Cheng Chen
  2. J.-S. Liu
     Advisor: Homer H. Chen

- **Third Place**
  1. Yen-Ju Lin
     Advisor: Tzong-Lin Wu
  2. Kai-Cheng Hsu
     Advisor: Hung-Yu Wei

Message from the Director

Tzong-Lin Wu

Professor & GICE Director

As the leaves are tinged with red and brown by the cool weather, the year of 2016 is coming to an end. Take a look back at this year, which turned out to be one of our most impactful years ever!

In this Newsletter issue, we invite prof. Tah-Hsiung Chu and prof. See-May Phoong sharing their research.
The internationalization of higher education has become the trend of the world.To enhance the competitiveness of nurturing talents, promoting internationalization is one of the core focuses. Hence, GICE dedicates on expanding cooperation through visited prestigious university to developing further possibility of collaboration

Here's wishing you the Happiest New Year ever and enjoy the reading of GICE Newsletter!

Technology

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three-port VNA.

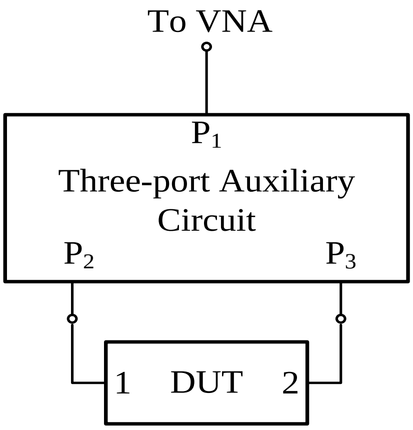

Fig. 1. Connection of a three-port auxiliary circuit and a two-port DUT.

The measured reflection coefficient Γ_m at port P1 through a one-port VNA is given as [5]

$$\Gamma_m = \boldsymbol{A_{II}} + \boldsymbol{A_{IJ}}\boldsymbol{S}[\boldsymbol{I} - \boldsymbol{A_{JJ}}\boldsymbol{S}]^{-1}\boldsymbol{A_{JI}} \quad (4)$$

In (4) S is a two-port S-matrix of the DUT, I is a unit matrix, and the remaining matrices related to the auxiliary circuit are given by

$$A = \begin{bmatrix} A_{II} & A_{IJ} \\ A_{JI} & A_{JJ} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \quad (5)$$

By substituting (5) into (4), it can be explicitly expressed as

$$\Gamma_m - a_{11} = \frac{N_0 + N_1 S_{12} + N_2 S_{21}}{D_0 + D_1 S_{12} + D_2 S_{21}} \equiv B \quad (6)$$

where No, N1, N2, Do, D1, and D2 are parameters of A, S11, S22, and RTP. One can further express S12 as S12=RTP/S21 and rewrite (6) as a quadratic equation of S21 given by

$$(N_2 - BD_2)S_{21}^2 + (N_0 - BD_0)S_{21} + (N_1 - BD_1)RTP = 0 \quad (7)$$

As the auxiliary circuit is properly characterized, all aij are known. By using the known aij and S11, S22 and RTP solved from (3), one can then solve S21. However, there are two solutions of S21 from (7). An additional one-port measurement with the use of another auxiliary circuit is needed to solve another set of two solutions of S21. These two sets then have the correct S21 in common. Once the correct S21 is found, S12 can be calculated.

As for an n-port DUT, one can utilize PRMs [4] along with the above approach to reconstruct the n-port S-matrix from a set of one-port measurements [6]. Specifically, one uses the above approach to acquire the two-port S-matrices of those (n-2)-port terminated DUTs required for PRMs. After that, PRMs are used to acquire the n-port S-matrix from those reconstructed two-port S-matrices.

The three-port DUT is a DITOM D3I2040 circulator and an Agilent 11667B power divider is used to be the auxiliary circuit. The DUT is firstly terminated at one port with three known terminations in sequence as three two-port circuits. The method developed above is then employed to reconstruct the S-matrices of these three two-port circuits from one-port measurements. Type-II PRM [4] is then used to reconstruct the S-matrix of the three-port DUT from the resulted three two-port S-matrices. Note because a one-port terminated DITOM D3I2040 circulator has distinguishable |S12| and |S21|, four one-port measurements are enough to solve (7). The one-port measurements are conducted at the port 1 of an Agilent N5222A four-port VNA. The reason to use a four-port VNA to perform one-port measurements is that it will also be used to directly measure the DUT full three-port S-matrix to verify the reconstructed results.

Table I shows the port arrangements for reconstructing the S-matrix of a three-port DUT from one-port measurements. Each notation in Table I represents an S-matrix. It is composed of two parts separated by an underline except for the one in the left column which is a three-port S-matrix. Note both DUT and auxiliary circuit are involved in the right column for one-port S-parameters. The left part with number or numbers indicates the port or ports to the corresponding DUT S-matrix. The left part with P1 indicates the measured port of auxiliary circuit. The right part describes the known

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terminations or ports of the auxiliary circuit connected to the rest port or ports of a three-port DUT. The two one-port S-matrices in the right column marked with * are duplicated ones.

Port of resulting three-port S-matrix	Port of intermediate two-port S-matrix	Port of measured one-port S-parameter
123	$13\Gamma_{2a}$	$1\_\Gamma_{2a}\Gamma_{3a}$
		$1\_\Gamma_{2a}\Gamma_{3b}$
		$3\_\Gamma_{1a}\Gamma_{2a}$
		$P_1\_P_2\Gamma_{2a}P_3$
	$13\Gamma_{2b}$	$1\_\Gamma_{2b}\Gamma_{3a}$
		$1\_\Gamma_{2b}\Gamma_{3b}$
		$3\_\Gamma_{1a}\Gamma_{2b}$
		$P_1\_P_2\Gamma_{2b}P_3$
	$12\Gamma_{3a}$	$1\_\Gamma_{2a}\Gamma_{3a}$*
		$1\_\Gamma_{2b}\Gamma_{3a}$ *
		$2\_\Gamma_{1b}\Gamma_{3a}$
		$P_1\_P_2\ P_3\Gamma_{3a}$

TABLE I Port description of the scattering matrices

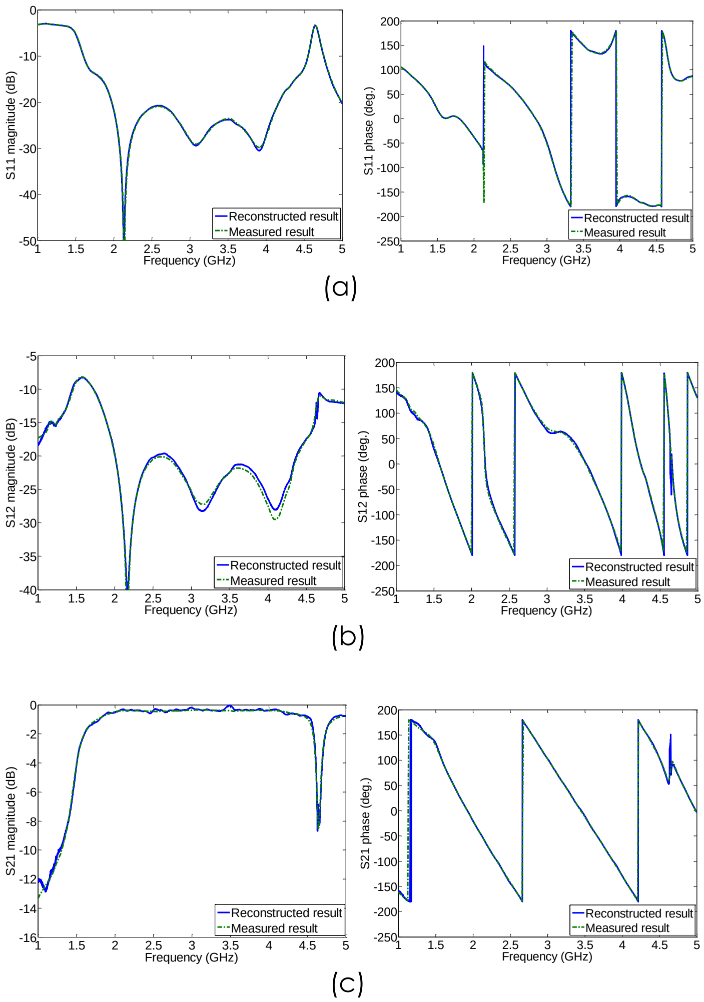

Fig. 2 Reconstructed results of (a) , (b) , and (c)   of a DITOM D3I2040 circulator.

There are a total of twelve one-port S-parameters as shown in the right column of Table I to give a total of ten one-port measurements accordingly. The reconstructed results are shown in Fig. 2. Note only three S-parameters are given and they are the worst cases in reflection coefficient, forward transmission coefficient and reverse transmission coefficient. The glitches around 1 GHz and 4.5 GHz are outside of the operation bandwidth. Most of the reconstructed results are shown in close agreement with the directly measured results except for the isolation response of S12. It is because |S12| is intrinsically small and a slight variation in the reconstructed result may result in a large error. Similarly, the difference of the reconstructed results from the directly measured results in |S21| of Fig. 2(c) is mainly caused by the cable-flex repeatability in one-port measurements.

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For more information please contact:
PHD Student: Yean-Chung Lin
Adviser: Professor Tah-Hsiung Chu
Email: thc@ntu.ee.edu.

Technology

Blind Channel Estimation in Two-Way Relay Networks

from Communication and Signal Processing Group

Relaying is an emerging technology in future generation networks due to its ability to improve the coverage and capacity of a cellular system [1]. In particular, the two-way relay network (TWRN) has drawn a lot of attention because its throughput advantage [2].

TWRN faces many challenges in terms of transceiver design, relay processing optimization, and transmission protocols development. Most existing designs on TWRN have assumed perfect channel state information at the terminals. While the traditional channel estimation methods can be applied to decode-and-forward TWRN, the channel estimation problem for amplify-and-forward TWRN is more challenging due to the self-interfering signals. In this article, we propose a simple blind algorithm for eliminating the self-interfering signals.

The self-interfering channel is estimated by the least-squares method and the cascaded channel from source to destination is estimated by the subspace method.

Figure 1 shows a TWRN with two terminal nodes and one relay node. The two terminals send data to each other with the assistance of the relay node. Due to symmetry, we only illustrate the processing at T1 below. Let $h_1 = g_1 * f_1$ and $h_2 = g_1 * f_2$ denote respectively the self-interfering channel and the cascaded channel from source to destination. Then the k-th received signal vector at T1 is given by

$$y_k = T(h_1)X_k^{(1)} + T(h_2)X_k^{(2)} + n_k, \quad (1)$$

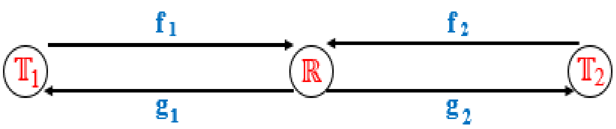

Fig. 1: System configuration for two-way relay network

Let $\hat{h}_1$ be an estimate of h_1. Since the vector $X_k^{(1)}$ is known, we can formulate the following cost function from the received vector y_k.

$$J(\hat{h}_1) = E\{ \| y_k - T(h_1)X_k \|^2 \} \quad (2)$$

It can be shown that this cost function is minimized if and only if $\hat{h}_1 = h_1$. The solution can be obtained by using the least-squares method and it is given in closed form.

In order to estimate h_2, we first remove the self-interfering signal from the received vector. Assume that the estimation of h_1 is perfect (i.e. $\hat{h}_1 = h_1$).

After eliminating the self-interfering signal in (1), we have

$$z_k = T(h_2)X_k^{(2)} + n_k. \quad (3)$$

The vector z_k is simply the received vector in an usual OFDM system with channel h_2 and transmitted vector $X_k^{(2)}$. Many blind estimation methods have been proposed for the estimation of h_2 from z_k. We can adopt the subspace based algorithm in [3].

Figures 2 and 3 show the performances on mean-squared error (MSE) and bit error rate (BER) respectively. We compare our results with [4]. Note that the method by [4] requires a non-unitary precoding matrix that depends on θ. The insertion of a non-unitary precoder at the transmitter not only modifies the structure, it also introduces severe noise amplification at the receiver. One can see from the figures that when θ increases from 0 to 1, the MSE in Liao's method decreases. However, larger θ does not necessarily yield smaller BER due to noise amplification.

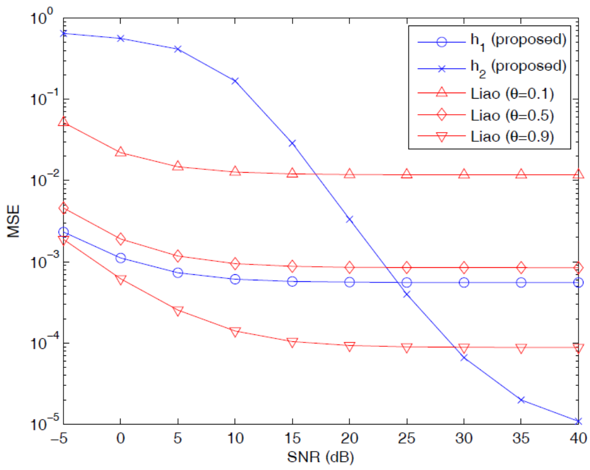

Fig. 2: Comparison of the MSE

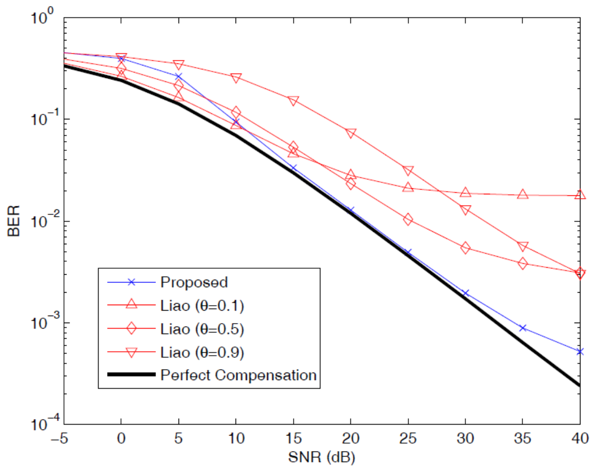

Fig. 3: Comparison of the BER

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From Fig. 3, we see that the proposed algorithm outperforms Liao's method, and the performance of our method is close to the perfect compensation.

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For more information please contact:
Professor: See-May Phoong
Email: smphoong@ntu.edu.tw

Activities

GICE Team Visited TU Dresden: Exploring Collaborations on Research with 5G Lab Germany and Double MS Degree Program

By Professor Shi-Chung Chang, Hsuan-Jung Su, Chun-Ting Chou, I-Hsiang Wang

Background on the 5G Lab Germany, TUD

The 5G Lab Germany in Technical University Dresden is one of the Excellence Initiative Centers not only in Germany but also in Europe Union. The 5G Lab is aimed at studying the disruptive changes and impacts that may be brought by the fifth generation (5G) of mobile communication systems. Its core theme is a holistic 5G view organized in four different technology tracks in network architecture, air interface, cloud systems and Tactile Internet applications. The 5G Lab Germany, TUD, has more than 20 faculty members, more than 600 researchers and industrial cooperation partners such as Vodafone, National Instrument, Rohde&Schwarz, Nokia, Ericsson, NEC, CLAAS, T-Mobile, IDT and BOSCH.

In view of the leading research in 5G theory, technologies and applications of 5G Lab Germany in Technical University Dresden, the NGMN-TW and MOST Licensed Shared Access project research team members contacted Professor Gerhard Fettweis for the visit on 7/19/2016. Dr. Pin-Hsun Lin, alumnus of GICE and EE Dept. of National Taiwan University and now a post-doc researcher in the Communications Theory Chair group of Professor Eduard Jorwieck, coordinated the detailed logistic arrangements on the TUD side and Prof. Chun-Ting Chou on the Taiwan side.

The visit consisted of two parts exploring collaboration one on wireless communication research and industry 4.0 progresses of TUD:

Agenda 1: Wireless Communications Research and Industry 4.0 Applications

Professor Eduard Jorwieck, Communications Theory Chair hosted the Presentations of 5G Lab research and Prof. Leon Urbas, Chair of Process Control System Engineering and Prof. Martin Wollschlaeger, Chair of Industrial Communications hosted the presentations of Industrial 4.0 Applications at TUD. There were two parts of presentations are organized as follows:

I. Wireless communications research (by Professor Eduard Jorwieck' Group)
   PHYSEC Research on physical layer security
   5G Waveform (GFDM)
II. Industry 4.0 Applications
   Process Industry (by Prof. Leon Urbas, Chair of Process Control System Engineering)
   Standardization (by Prof. Martin Wollschlaeger, Chiar of Industrial Communications)

We also visited 5G lab and the Modular Plant of the Automation Lab.

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Industry 4.0: Teaching through Research
(Source: BARTEC INSIGHT 2.2015 | 04 | QUESTION TIME)

Agenda 2: Double MS Degree and Internship programs

Professor Eduard Jorwieck hosted a discussion of mutual interest in and possible arrangements of double MS degree and internship programs between GICE, NTU and communications engineering related MS programs, TUD.

TU Dresden 5G Lab visit

Highlights of Visit

I. Double MS Degree and Internship programs between EECS, TUD and GICE, NTU

Based on the existing double MS Degree and Internship programs of GICE, NTU, Prof. Chun-Ting Chou and Shi-Chung Chang discussed with Prof. Eduard Jorwieck about double MS degree and internship programs with the EECS Dept., TUD. Prof. Eduard Jorwieck indicated very high interest and now proceeds to follow-up reviews of MOA template by TUD.

II. On TUD wireless communication related research

In general TUD is working on similar topics as NTU and other universities in Taiwan. However, their international visibility is much higher than universities in Taiwan. The 5G Lab in particular is considered the leading university team in the world, and is one of the schools which have prototypes and demonstration of 5G systems. The Communication Theory Lab has quite in-depth research on physical layer security.

III. On industry 4.0 related research

TUD has a quite mature team and study already.

<u>II.1 Train creative minds for digitalization to overcome the biggest hurdles in Industry 4.0 for SME</u>.

Prof. Leon Urbas, Chair of Process Control System Engineering, introduced his views and work on Process Industry 4.0. He considers that biggest hurdles are 1) Small and mid-sized companies (SMEs) do not have the workforce required to both understand and connect automation and information technology. 2) The the complexity of the new mechanisms of action.

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<u>II.2 Standardize digitalization for Industry 4.0 and 5G applications to industry communications</u>

Prof. Prof. Martin Wollschlaeger presented his leading activities in Standardization for Industry 4.0 by Germany in specific and by EU in general. As automation or intelligent manufacturing or industry have been evolving in the past 4 decades, the emphases are (1) to integrate or interface among legacy standards of different industries and (2) adaptation to the Internet technologies and standards and (3) adoption of emergent standards. Specific subjects Prof. Martin Wollschlaeger talked about include RAMI model, administration shell & things, IEC61360 (properties) 1st DB availability, and basic ontology. Prof. Wollschlaeger indicated Open Platform Communications Unified Architecture (OPC UA) as a candidate technology with 5G communications to facilitate vertical integration and flexible of reorganization.

IV. Possible research collaboration subjects

1. The 5G lab has significant research efforts on

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Activities *(Continued from page 6)*

Highly Adaptive Energy Efficient Computing (HAEC) and developing the corresponding system box, which are in quite synergy with the edge or FOG computing for 5G mobile communications that the NGMN-TW group is promoting and working on.

The 5G waveform research (GDFM) of TUD and the new waveform design research of our MOST project, entitled "Enabling Technologies and Operation Models for Licensed Shared Access by LTE Services," bear many common interests. Exchanges at both graduate students and faculty members level may expose NTU research capacity to international industry and allow students to access to communication-theoretic research beyond the application-centered environment.

5G and FOG computing for SME could be a win-win collaborative research topic.

V. Key takeaway and recommendations

From the discussion with TUD's Communication Theory Lab and 5G Lab, we learned that funding scale per project from the German government is not much higher than the MOST funding scale in Taiwan. However, the German government has separate funding to pay for the salaries of Ph.D. students and postdocs, and the salaries are much higher than what we pay in Taiwan. In addition, TUD completes for EU projects which provide much higher funding, and encourage both fundamental and applied researches. TUD's 5G Lab has also attracted large scale funding from the industry such as Vodafone which is collaborating with TUD and supports Ph.D. students and postdocs. As a result of higher funding and close collaboration with the industry, TUD has more in-depth research and international visibility. One clear example is that Dr. Pin-Hsun Lin obtained his Ph.D. from NTU GICE, and was also a postdoc for one year. His Ph.D. work was on physical layer security and got thesis awards. However, he could not find enough funding and motivated students in Taiwan to prosper his research. Instead, TUD provides him salary, funding and motivated students which enabled him to establish the physical layer security research in TUD and made him internationally renowned in that area. Our feeling is that if Taiwan keeps failing in encouraging advanced research through funding and policies, it will lose its talents to other countries.

GICE Team Visited ENSEEIHT and Paris-sud to further strengthen the international collaboration and recruit students

By Professor Shih-Yuan Chen

The École nationale supérieure d'électronique, d'électrotechnique, d'informatique, d'hydraulique et des télécommunications (ENSEEIHT) is a prestigious French engineering school in Toulouse and established a double degree program with NTU GICE (Graduate Institute of Communication Engineering) in 2014. Soon in the summer of 2015, an M1 student of ENSEEIHT, Mr. Robin Jeanty, joined this double degree program under the advisory of Prof. Shih-Yuan Chen. One year later, another student, Mr. Mathis Zamboni, joined the program under the advisory of Prof. Chun-Ting Chou. Meanwhile, two senior graduate students of NTU GICE joined the double degree program and started their study at ENSEEIHT in September 2016. To further strengthen the international collaboration and recruit more double degree students from ENSEEIHT, NTU delegates once again visited ENSEEIHT in October 2016. The NTU delegates include Professor Tzong-Lin Wu, Director of NTU GICE, Professor Huei Wang, Associate Dean of EECS College, and Professor Shih-Yuan Chen, Associate Chairperson of EE Department.

On October 7th 2016, NTU delegates visited ENSEEIHT to meet the professors and students. At the beginning, an introductory presentation was given by Prof. Huei Wang to provide an overview of NTU and NTU EECS. Prof. Tzong-Lin Wu then introduced NTU GICE and explained in detail the double degree program and the current status. Prof. Shih-Yuan Chen also introduced the most update research activities in the Electromagnetics Group of NTU GICE.

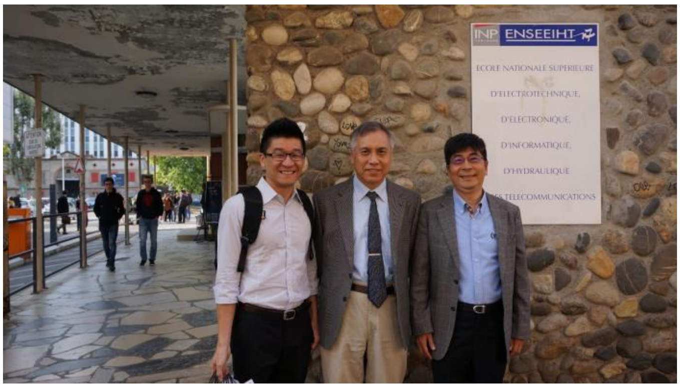

Figure 1. NTU delegates at the main gate of ENSEEIHT.

In the Q&A session, students asked questions regarding the courses, language, funding, research

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Activities

areas, etc. About 13 students attended this event, and several of them showed great interest in joining the double degree program or conducting research internship in NTU GICE. After the event, the NTU delegates were invited to have luncheon with professors of ENSEEIHT and also the two double degree students from NTU GICE.

Figure 2. Group photo after NTU-ENSEEIHT meeting between professors and students.

On October 11th 2016, NTU delegates visited University of Paris-Sud (Paris-Sud). Paris-Sud is merged from University of Paris XI and some other premier French engineering schools. In the near future, more prestigious universities and engineering schools will be further merged into a mega school, Universite Paris-Saclay. Prof. Said Zouhdi, Head of International Relations, invited us to participate in "International Day" of engineering school of Paris-Sud and hosted our visit again. Around 300 students attended this half-day event, which consists of two parts: oral presentation and country/university exhibition. Before the event, the NTU delegates first had a short discussion with the Vice President of Paris-Sud and Prof. Zouhdi on the promotion of the double degree program just signed by both sides.

Figure 3. Director Tzong-Lin Wu introduced GICE in Paris-Sud.

Then, in the first part of the event, an introductory presentation was given by Prof. Tzong-Lin Wu to provide overview of NTU EECS, NTU GICE, and the double degree program to all the students. In the second half, the NTU delegates setup a booth and explained the double degree program, exchange program, and also the research internship to students who are interested in studying in NTU and want to know more about the programs. More than 15 students showed great interest in visiting Taiwan for research internship and/or joining the double degree program. This visit has been a great success, and we will keep this momentum to establish a long-lasting and fruitful collaboration with the two universities.

Figure 5. Photos of the NTU booth in the exhibition of International Day at Paris-Sud.

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. Hung-Yu Wei

Editor
Chiao Yun Kang