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Newsletter

Graduate Institute of Communication Engineering, National Taiwan University

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GICE Honors

Outstanding Young Scholar

the Foundation for the Advancement of Outstanding Scholarship (FAOS)

Prof. Yu-Chiang Frank Wang

This award is selected for those who are researchers or faculty members in Taiwan with age below 45 and have remarkable research achievements and impacts.

IPPR Award

Merit Award for Doctoral Thesis at 16th Master's and Doctoral Thesis Award

Ph.D. graduate student : Fu-En Yang (Advisor : Prof. Yu-Chiang Frank Wang)

Merit Award for Doctoral Thesis at 16th Master's and Doctoral Thesis Award from The Chinese Image Processing and Pattern Recognition Society (IPPR)
Ph.D. dissertation title: Visual Understanding with Knowledge Transfer

IPPR Award

Excellent Master Thesis Award at 16th Master's and Doctoral Thesis Award

M.S. degree program student : Yuan-Yi Hsu (Advisor : Prof. Yu-Chiang Frank Wang)

Excellent Master Thesis Award at 16th Master's and Doctoral Thesis Award from The Chinese Image Processing and Pattern Recognition Society (IPPR)
Master's thesis title: Bias-Eliminating Augmentation Learning for Debiased Federated Learning

GICE Outstanding Doctoral Dissertation Award

EM Group / Dr. Hsu-Wei Liu (Advisor : Prof. Tzong-Lin Wu)

Hsu-Wei Liu received the M.S. degree in electrical engineering from National Chung Cheng University in 2010 and received the Ph.D. degree from Graduate Institute of Communication Engineering, National Taiwan University in 2022. He is currently a Technical Manager with Mediatek, Inc., Hsinchu, Taiwan.

GICE Outstanding Doctoral Dissertation Award

DS Group / Dr. I-Chan Lo (Advisor : Prof. Homer H. Chen)

I-Chan Lo received the Ph.D. degree from Graduate Institute of Communication Engineering, National Taiwan University in 2022. He is currently with PetaRay Inc. His research interests include image processing, computer vision, computational photography and computational VR/AR/MR displays.

GICE Outstanding Doctoral Dissertation Award

Design of Single-Cell Absorption Common-Mode Filters

Dr. Hsu-Wei Liu

Ph.D. degree from Graduate Institute of Communication Engineering, National Taiwan University in 2022.

I. INTRODUCTION

Nowadays, digital input/output interfaces demand high-speed data transmission to fulfill the requirements from up-to-date applications. A technique called differential signaling is widely employed to provide a remarkable immunity to a discontinuous ground plane and significantly reduce the radiation. Nevertheless, an asymmetrical routing of a differential pair, a mismatch in signal phases/amplitudes, and the fiber-weave effect result in differential-mode (DM) signals converting into unwanted common-mode (CM) noise. CM noise can lead to radiation problems and then cause the sensitivity degradation of wireless systems.

To eliminate CM noise, CM filters (CMFs) have been widely developed in the past few years. By considering different ways to deal with CM noise, there are two main categories of CMFs, reflection CMFs and absorption CMFs (A-CMFs). In contrast to reflecting CM noise, A-CMFs are designed to absorb CM noise by introducing resistive elements, which absorb CM noise at certain frequencies.

In the literature, one can observe that all the A-CMFs are synthesized based on a design concept of multiple stages or cells. By following this design concept, the synthesized multi-stage A-CMFs have limits on size and maintaining DM signal integrity with data rate higher than 10 Gb/s; in other words, they may not be able to be applied in high-speed transmission systems. The author is devoted to developing single-cell A-CMFs in two-layer PCBs using patterned ground structure (PGS). The proposed works can be applied to high data rate transmission and feature outstanding DM performance, compact size, and high cost-efficiency.

II. PROPOSED CIRCUITS AND MEASUREMENT

Based on two mirror symmetry planes, a novel single-cell circuit featuring bidirectional CM noise absorption is proposed in Fig. 1 [1]. Analytical design formulas are found through even-even and even-odd mode techniques and can be used to determine circuit parameters for bidirectional CM noise absorption. They include two cases of $\theta_{1,e}$ and θ_2; to obtain an excellent DM performance, $\theta_{1,e}$ and θ_2 are chosen as 90° and 270° at 2.45 GHz, respectively. Besides, $Z_{1,e}$ is a free variable to determine R_e and Z_2. According to circuit simulation results, there is a tradeoff between the CM absorption bandwidth and dimension for different values of $Z_{1,e}$.

In this case, $Z_{1,e}$ is set the same as the even-mode port impedance Z_e of 60 Ω; both Z_2 and R_e are 120 Ω. The measured S-parameters are presented in Fig. 2. $|S_{cc21}| < -10$ dB holds from 2.37 to 2.76 GHz, and $|S_{cc11}| < -10$ dB holds from 2.15 to 2.86 GHz. Thus, the CM noise absorption band can be obtained from 2.37 to 2.76 GHz. The -3 dB bandwidth of $|S_{dd21}|$ can reach 7.83 GHz. This work shows that bidirectional A-CMFs can be achieved using the design concept of single-cell circuit.

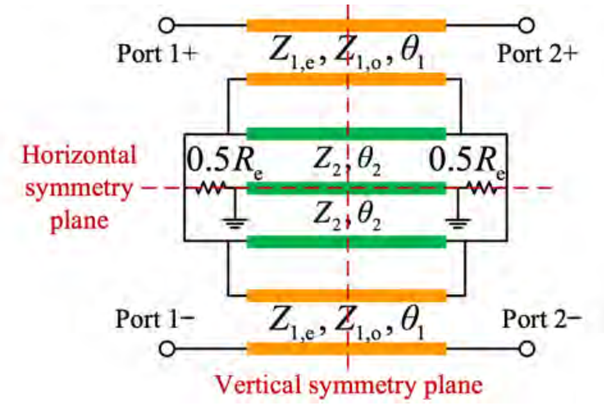

Fig. 1. Proposed full circuit composed of two coupled differential lines (colored in brass) cascoded with the other two transmission lines (colored in green).

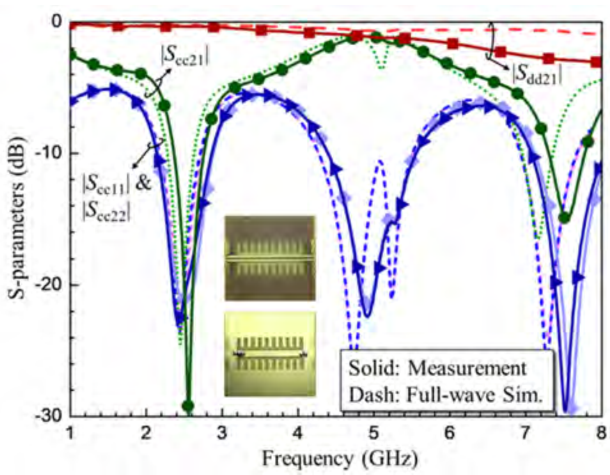

Fig. 2. Frequency responses in the measurement and full-wave simulation.

Although the first proposed single-cell bidirectional A-CMF features a compact size and great DM performance, the size and DM performance can still be further improved. The first proposed and conventional A-CMFs using PGSs are designed with shunt lumped elements placed across slots. Inspired by asymmetrical coplanar strip (ACPS), the author proposes a novel PGS containing shunt and series lumped elements (SSLEs) [2]. The SSLE PGS can significantly increase design flexibility for synthesizing CMFs.

The proposed circuit architecture of bidirectional A-CMFs is shown in Fig. 3. It consists of two coupled transmission lines (colored in brass) and a cascode network. In this example, two shunt resistors R are designed on the horizontal symmetry plane. Besides, the resistors are connected to a "black box," a full lossless network, which is implemented using SSLE PGS and can be formed with series, shunt, and distributed elements. The designed architecture, including the full lossless network, must have mirror symmetry with respect to the horizontal symmetry plane to avoid mode conversion. One of the possible even-mode half circuits is shown in Fig. 4.

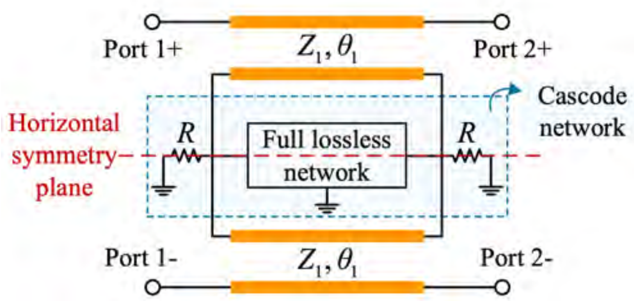

Fig. 3. Proposed circuit architecture.

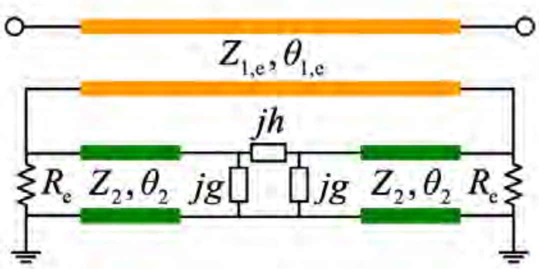

Fig. 4. Proposed example of even-mode half circuit with the π network.

From the proposed even-mode half circuit, the circuit parameters are derived, and the values of jg and jh are obtained. The impedances of jg, and jh can be realized by either inductors or capacitors, depending on the signs of the reactances. Based on the derived results, the minimum value of $\theta_{1,e}$ is 90°. θ_2 is determined as 65°. By setting $Z_e = Z_{1,e}$ = 60 Ω, R_e is equal to 120 Ω. To achieve a compact size, one can set both strip and slot widths of the ACPS as small as 0.1 mm, where the ACPS is used to implement the transmission line (Z_2, θ_2). Thus, Z_2 can be directly obtained as 140.6 Ω using an analytical expression [3]. The corresponding R, L, and C values are calculated as 60 Ω, 7.4 nH, and 1 pF, respectively.

In Fig. 5, the measurement results show that $|S_{cc21}| < -10$ dB holds from 2.29 to 2.58 GHz, and $|S_{cc11}| < -10$ dB is from 1.61 to 2.57 GHz. Therefore, the CM absorption band can be obtained from 2.29 to 2.57 GHz. In DM, the measured −3 dB cutoff frequency of $|S_{dd21}|$ is up to 16.3 GHz. In Fig. 6, the measured eye diagrams show that the performance degradation of the proposed A-CMF is under 6.7% compared to the reference board; that is, with the proposed PGS, the bidirectional A-CMF can still have the capability to be applied in an ultra-high-speed digital transmission with data rates of up to 20 Gb/s. Moreover, the size of this work is smaller than the first work than 55%.

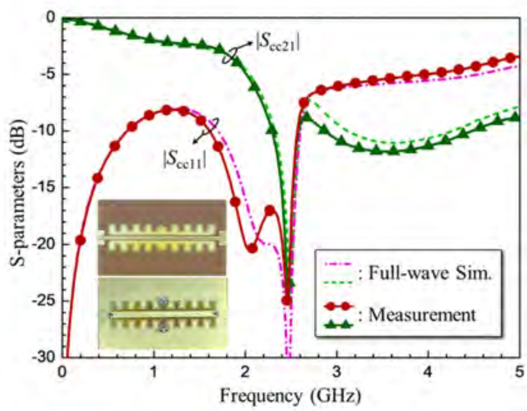

Fig. 5. CM frequency responses in the measurement and full-wave simulation.

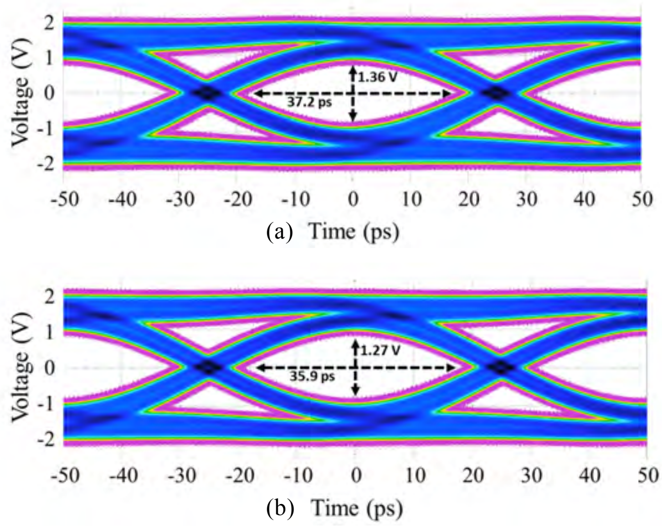

Fig. 6. Measured eye diagrams with 20-Gb/s PRBS. (a) Reference board with a solid ground plane and (b) proposed A-CMF.

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GICE Outstanding Doctoral Dissertation Award

360° Light Field Construction for the Metaverse

Ph.D. I-Chan Lo

I-Chan Lo received the Ph.D. degree from Graduate Institute of Communication Engineering, National Taiwan University in 2022.

I. INTRODUCTION

Human eyes, through evolutionary processes, have adapted to maintain consistent vergence and accommodation. However, most state-of-the-art AR/VR devices rely on stereoscopic displays, leading to a vergence-accommodation conflict (VAC) that can easily cause visual discomfort to users [1]. These displays offer 3D perception by presenting two images with disparity, a principle that has driven 3D display designs for the past two centuries. However, these systems struggle to provide correct accommodation cues, because the images are projected at a fixed focal distance. This mismatch, termed VAC, can result in eye strain, headaches, or even a loss of depth perception, making it a significant challenge in the development of metaverse display devices.

Light field display (see, for example, Figure 1) is a promising technology that can correctly render focus cues for 3D scene and is free from the VAC, thereby providing a more natural visual experience. To harness the potential of this technology, we propose a system for constructing a 360° light field using a dual-fisheye camera. The system comprises a light field generation module that creates a 360° light field from a series of dual-fisheye images, and a resampling module that generates the display sub-light field based on a specified view angle or trajectory. The ultimate goal is to leverage this technology to provide immersive visual experiences for users in the realm of the metaverse.

Figure 1: An in-house developed near-eye light field AR display, offering a depth of field ranging from 25 cm to infinity, and enabling users to focus freely on objects within the range [2].

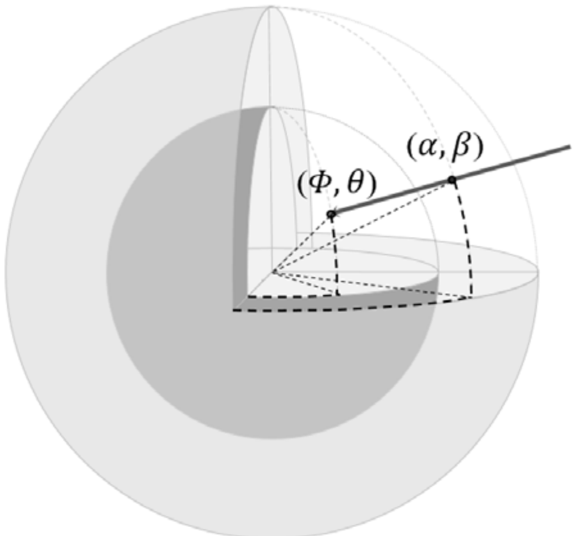

Figure 2: Two-sphere representation of a light ray in 3-D space.

II. 360° LIGHT FIELD REPRESENTATION

A light field samples the radiance of light rays emitted from the scene along different directions. The 360° representation of a 4D light field requires two parameters to describe the position of a light ray and another two parameters to describe the orientation of the light ray. A 360° image serves as a 2D slice of the 4D light field, and creating a 360° light field from a set of 360° images involves describing each image as a 2D slice of the 360° light field representation.

Similar to the two-plane representation of a 4D light field, a 360° representation of the light field can be achieved by using two concentric spheres, one for describing spatial coordinates and the other for angular coordinates, as shown in Figure 2. Interpretation of the two-sphere representation is straightforward. For example, we can use $(\Phi, \theta, \alpha, \beta)$ to represent a light ray, where the angular coordinates (α, β) denote the intersection point on the first sphere, and the spatial coordinates (Φ, θ) denote the other intersection point on the second sphere.

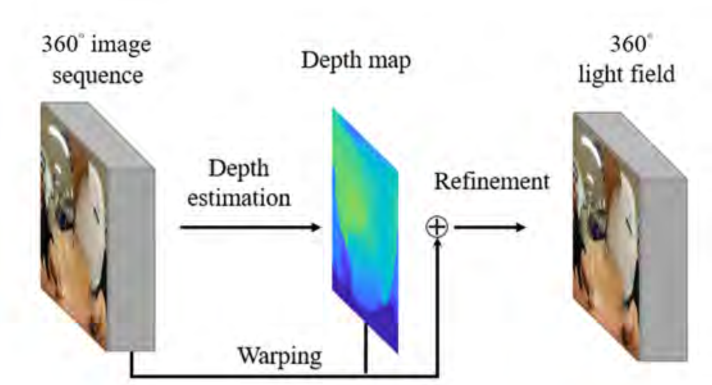

Figure 3: A flowchart for 360° light field construction.

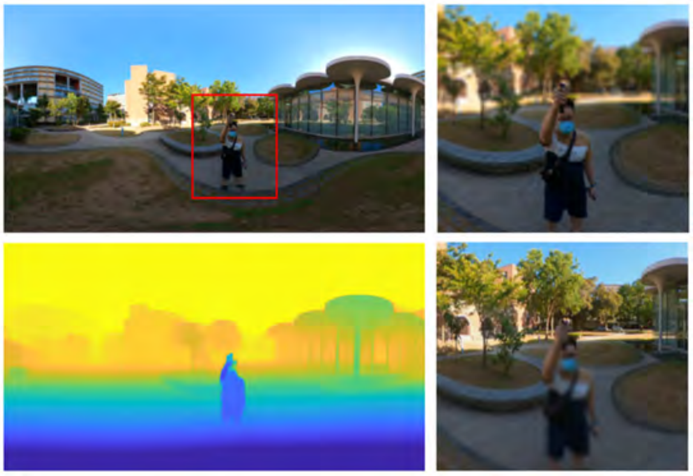

Figure 4: An exterior test scene. The left column is the 360° reference image and the corresponding depth map; the top (bottom) image in the right column is the refocused image of the scene enclosed by the red box in the top-left image on a near (far) focal plane.

III. 360° LIGHT FIELD CONSTRUCTION

We propose an efficient system to construct a 360° light field using a dual-fisheye camera and to resample the 360° light field for piecewise displaying the light field on a near-eye light field display.

We gather a sequence of fisheye image pairs, each of which is merged to form a 360° image using our developed algorithm [3]. We then calculate the depth map by applying dense feature matching to adjacent 360° images. Then, the depth information is applied to warp image pixels at new angular coordinates to construct a 360° light field [4]. The processing flowchart is shown in Figure 3.

Figure 5: Captures of a sub-light field of an interior test scene displayed on a near-eye light field display. The left image corresponds to a near focal plane, while the right image corresponds to a far focal plane.

To generate the visual content compliant with the light field display, we design a resample module based on proximal interpolation that creates new views for the specified viewpoint and field of view. The viewpoint represents the position and orientation of the viewer's eye. The field of view is the intrinsic parameter of a light field display.

IV. EVALUATION

Using our proposed system, we construct a 360° light field, shown in Figure 4. The depth map's contour visibly aligns with the scene's geometry, producing visually pleasing refocused images of the sub-light field, resampled from the 360° light field. This is evidenced by the clear image of a person when the focal plane is up front, and the distinct images of background trees when the focal plane shifts to the back. Furthermore, we place a camera at the eye position to capture the sub-light field displayed on the near-eye light field display. As shown in Figure 5, adjusting the camera's focal distance brings the near or far object into sharp focus. The results suggest that users can freely adjust their focus on the virtual content, facilitating a natural and comfortable visual experience.

V. CONCLUSION

We propose a system that efficiently constructs a high-quality 360° light field for applications to metaverse with a near-eye light field display. The results produced by our system are well-suited for use on real-world light field displays.

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實驗室(MPAC LAB&Petaray)合照

5G Empowering Ambulance Services and Potential Role of ML-based 5G Network Slice Management

Prof. Haibin Zhang

Visiting professor,
Graduate Institute Communication Engineering,
National Taiwan University

I. INTRODUCTION

One key pain point of ambulance services nowadays is high number of over-triaged cases, where the patients are brought to hospital while treatment in situ would suffice, leading to unnecessarily high operational costs in order to ensure healthcare quality in emergencies.

The technical limit behind this is identified as follows: the Chief Medical Officer (CMO) of an ambulance service may be remotely consulted for decision-making in difficult emergency situations. This is now only possible via an audio connection (telephone) or through a dedicated communication channel via the dispatcher. The CMO has thus no visual feed of the patient information for more effective assessment, often leading to conservative decisions of the ambulance crew (over-triage).

5G has potential to resolve this key pain point by enabling real-time video communication between ambulance paramedic and the CMO. Furthermore, 5G may facilitate ambulance to real-timely request and obtain priority when passing road junctions, in order to reach the scene or deliver the patient as quickly as possible.
This short article addresses these 5G potentials by summarizing the major findings of the following R&D activities as part of the European Horizon 2020 5G-HEART project [1]:

- Trials, using 5G standalone (SA) test networks, involving ambulance professionals.
- Research on how ML-based 5G network slice management my ensure QoS provisioning to ambulance services (and other emergency scenarios), with dynamically varying traffics.

II. OBSERVATION FROM TRIALS

A first group of trials aimed to investigate how 5G-enabled video-audio and vital patient data monitoring can benefit remote patient assessment and what are the potential implementation constraints. An indoor 5G SA test network was used for this purpose. **It was verified that the decision making was quicker and more accurate when the remotely based CMO received real-time video-audio complemented with vital patient data (e.g. electrocardiogram) from the paramedic** (see Figure 1). This meant that the pre-hospital triage was significantly improved, accelerating patient treatment and avoiding unnecessary conveyance to the hospital. Readers may refer to [2] for detailed description of the trials.

Figure 1 A paramedic examined patient (left), a remote CMO received video and patient data (right)

A second group of trials aimed to investigate how 5G network slicing may ensure performance of multiple time-critical services (i.e. video for remote patient monitoring, traffic priority request and feedback). An outdoor 5G SA test network was used along a highway in the Netherlands. **It was verified that 5G network slicing was able to guarantee sufficient radio resource for the delivery of mission-critical services even in competition with general purpose data traffic** (see Figure 2). Readers may refer to [3] for detailed description of the trials.

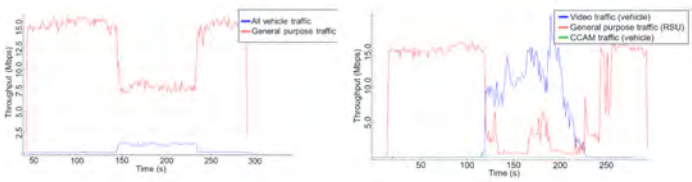


Figure 2: Performance of time-critical services in competition with general purpose data traffic: without network slicing (left, where the "All vehicle traffic" includes both video and traffic priority request services), with network slicing (right, where the "CCAM traffic" refers to traffic priority request services). Note: the amount of " CCAM traffic" is low so that video is dominating in the "All vehicle traffic"

III. POTENTIAL ML-BASED IMPROVEMENT

This research focused on how ML-based 5G network slice management my ensure QoS provisioning to ambulance services (and other emergency scenarios), with dynamically varying traffics.

A two-step ML-based multi-slice radio resource allocation framework has been proposed for 5G networks (see Figure 3), specifically for emergency scenarios and featuring a good trade-off between complexity and performance.

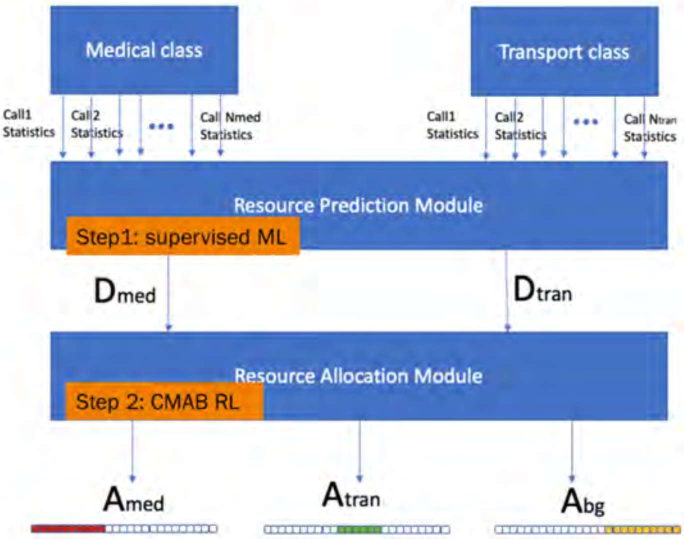
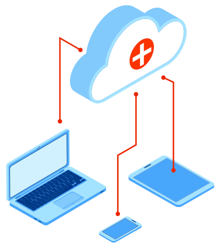


Figure 3: Proposed two-step ML-based multi-slice radio resource allocation framework. In the shown example (ambulance services), emergency traffic is grouped into two priority classes: "Medical class (med)" and "Transport class (tran)", co-existing with general purpose/background ("bg") traffic. In the shown example, three network slices may be configured corresponding to the three different classes of the traffic

In the first step, call-level resource demands are predicted using supervised ML, which are then aggregated to predict slice-specific resource demands. An innovative method is included in this step to ensure the collection of representative training data for the supervised ML. In the second step, a contextual multi-armed bandit (CMAB) reinforcement learning (RL) model is applied to derive the resource allocation among the slices based on the slice-specific resource demand predictions. **The simulation results showed that the proposed framework outperforms alternative solutions in the defined utility values for priority emergency traffic at the cost of modest performance sacrifice of the background traffic.** Readers may refer to [4] for detailed description of the study.

Figure 4: Group photo: the "5G Wireless Access Technology" course of Prof. Zhang during his visit to NTU in Mar-Apr. 2023



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BIOGRAPHY – Prof. Haibin Zhang

· Senior scientist, TNO, The Netherlands

· Visiting professor, Graduate Institute of Communication Engineering, National Taiwan University

· Management Committee Member, European COST INTERACT

· Technical Manager, (previous) H2020 EU-Taiwan Clear5G project

Major Research Areas:

B5G/6G radio technologies, B5G/6G for vertical applications, network sustainability.

Abstract：

Prof. Zhang is senior scientist and strategist at TNO - Netherlands Organisation for Applied Scientific Research. He is visiting professor at National Taiwan University. He was co-chair of the mobile group of GreenTouch, and technical manager of (previous) H2020 Clear5G project. He is/has been management committee member of COST IC1004, COST IRACON and COST INTERACT, and serves in the Expert Advisory Group of the European NetWorld2020 organization.

Vol. 14, No. 2 Sep. 2023

Broadband CMOS RFICs for Astronomic Observation

Author

Wei-Chieh, Ma

Master student of Graduate Institute of Communication Engineering, National Taiwan University

Research topic: monolithic microwave integrated circuit (MMIC) modeling and design

I. A HIGH LO-TO-RF ISOLATION E-BAND MIXER WITH 30 GHZ INSTANTANEOUS IF BANDWIDTH IN 90NM CMOS

To increase instantaneous bandwidth, a modified cascode mixer using a CS amplifier transistor and a cold-biased (Vds=0) mixing transistor was proposed, as shown in Fig. 1. The CS transistor increases conversion gain without considerably degrading IP1dB, while the cold-biased mixing transistor achieves wide IF bandwidth. Additionally, the LO-to-RF isolation is improved by two pairs of LC resonators.

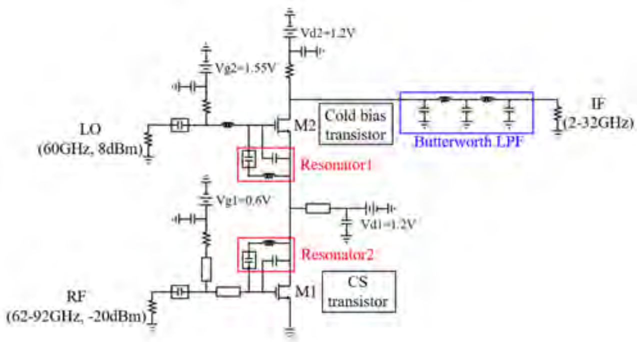

Fig. 1. Circuit schematic of the broadband mixer

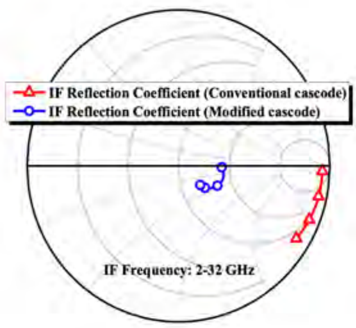

Fig. 2. The reflection coefficient at IF port of cold-biased schematic

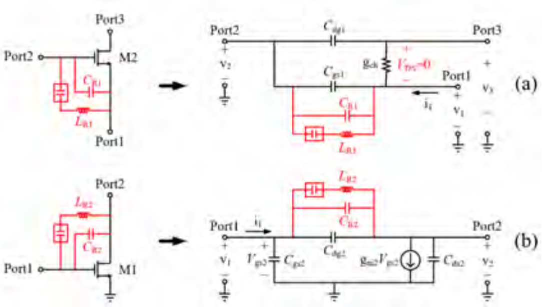

Fig. 3. The small signal equivalent circuit of (a) resonator in mixing stage; (b) resonator in gm stage.

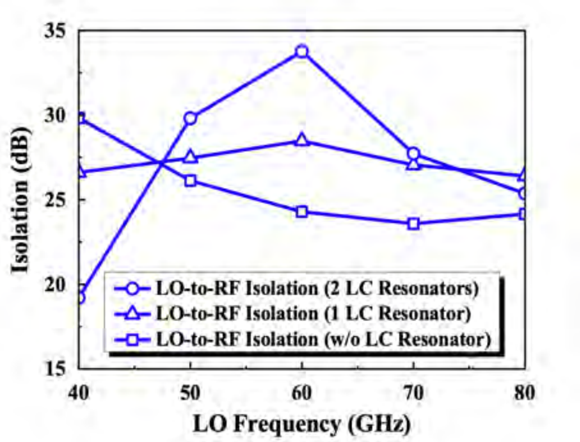

Fig. 4. Simulated LO-to-RF isolation with different number of resonators

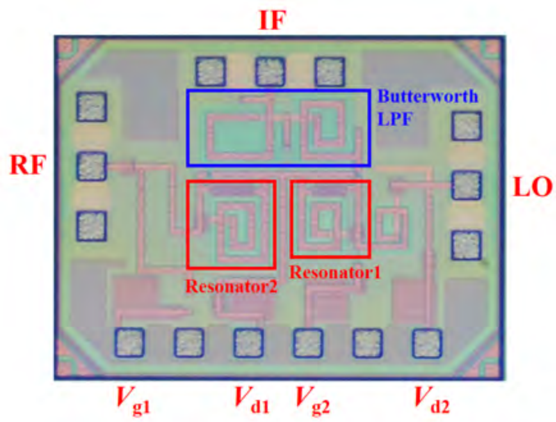

Fig. 5. Chip photo of wide IF bandwidth mixer

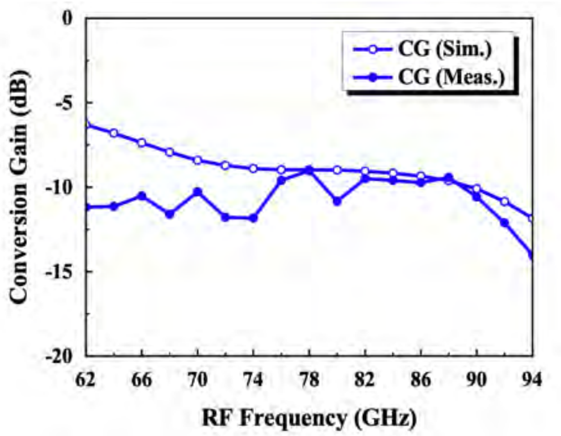

Fig. 6. Simulated and measured conversion gain

III. CIRCUIT DESIGN

A. Wide Band Design

For the design of a mixer with a wide IF bandwidth, modified cascode topology was proposed [5]. It is able to independently adjust the bias condition of two transistors by connecting an ac-short stub to the interstage. The cold-bias criterion is satisfied by biasing the mixing transistor's drain and source with the same voltage, 1.2 V. The mixing transistor, which therefore functions as a voltage-controlled resistor, has an output impedance that is equal to its channel resistance. As a result, the output impedance of a modified cascode mixer is lower and less frequency-variable than that of a conventional cascode mixer.

To obtain a 50 ohm output impedance with wide IF bandwidth, the size of the mixing transistor was specified. The modified cascode exhibits IF port reflection coefficients that are less frequency-dependent and closer to the center of the Smith chart than a conventional cascode does, as shown in Fig. 2. This makes designing a wideband output matching network easier. High-frequency RF and LO signals are blocked from the IF port using a shunt-first Butterworth low-pass filter (LPF) without drastically lowering bandwidth.

B. LO-to-RF Isolation Improvement

The isolation of single-ended mixers is typically poor. The high-frequency RF and LO signals are blocked from the IF port by the LPF. However, because of the closeness of the LO and RF frequencies, the matching network is unable to sufficiently isolate the LO and RF ports. Hence, LC resonators are required to improve LO-to-RF isolation [7].

Fig. 3 depicts the circuit for two pairs of LC resonators. The mixer operates at 60 GHz LO signal. Thus, the admittance between two ends of the resonators at 60 GHz needs to be as low as possible to reject the LO signal from entering to the RF port. The simulated LO-to-RF isolation for a 40-80 GHz LO signal is shown in Fig. 4. Without LC resonators, the mixer provides a 24 dB LO-to-RF isolation, which is too low for system use. After utilizing two LC resonators, the LO-to-RF isolation with a improved to an outstanding level of 34 dB.

IV. MEASUREMENT

Fig.5 shows the chip photograph of the proposed mixer. When pumping by an 8-dBm LO power at 60-GHz, the mixer exhibits 30 GHz IF bandwidth. Over the full E-band, the conversion loss is between 9 and 12 dB, as shown in Fig. 6. The measured LO-to-RF isolation is 40.8 dB, while the RF-to-IF isolation is better than 38 dB. The IP1dB ranges from -2 to 4 dBm in the full RF band.

Fig. 7 Professor Wang and members in MMIC laboratory

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Wei-Chieh, Ma

Master student of Graduate Institute of Communication Engineering, National Taiwan University

Research topic:
monolithic microwave integrated circuit (MMIC) modeling and design

Huei Wang

IEEE Fellow,
Professor of Graduate Institute of Communication Engineering, National Taiwan University

The 2023 1st Semi-annual Workshop of Taiwan Electromagnetic Industry-Academia Consortium: Development and Technology of Low-Orbit Satellites

6G communication will start commercial use in 2030, and it is characterized by the integration of satellite communication and mobile communication standards. Therefore, the world has begun to pay attention to low-earth-orbit (LEO) satellite technology. Since the communication frequency band of LEO satellites partially overlaps with 5G millimeter waves, the current experiences and technologies of Taiwan's industry in 5G manufacturing, research, and development can be extended to LEO satellites. According to TrendForce statistics, the global satellite manufacturing industry will create an output value of about US$234 billion by 2030, and Taiwan's Ministry of Digital Development has opened the door for telecom manufacturers to apply for radio segments for LEO satellites by the end of December 2022. Therefore, the theme in the first semi-annual workshop in 2023 of Taiwan Electromagnetic Industry-Academia Consortium is the development and technology of LEO satellites, which was held in June 5. This workshop invited six experts and scholars from the industry and academia to conduct in-depth discussions on the development and application of LEO satellites to the integration of antennas and radio frequency systems.

Fig. 1. TEMIAC held a Development and Technology of LEO Satellites workshop at National Changhua Normal University

Fig. 2. Professor Ruey-Beei Wu gave a welcome speech

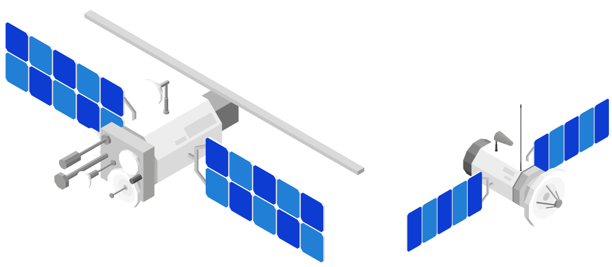
Fig. 3. Guests from industry, academia, and research institutes listened to the speeches.

The workshop was held at National Changhua Normal University, with about 200 attendees. The meeting kicked off with speeches by Professor Ming-Fei Chen, President of Changhua University of Education, and Professor Ruey-Beei Wu, Coordinator of Taiwan Electromagnetic Industry-Academia Consortium, followed by six insightful speeches, each about 40 minutes including 5-minutes Q & A. In addition, Microelectronics Technology, Inc. also held a talent recruitment briefing at noon that day, attracting many students to participate. This workshop not only provides an opportunity for the industry and academia to communicate with each other, but also allows students to understand the development prospects of LEO satellites. These will help Taiwan's future R&D synergy in LEO satellite-related technologies, so that Taiwan can become one of the important settlements for components, subsystems, and related services of the global satellite industry before 2030.

Fig. 4. Shung-Yuan Wang, manager of Microelectronics Technology Inc. (MTI), delivered a talk on LEO Satellite Development and User Terminal Technology Introduction

Fig. 5. Professor Hsi-Tseng Chou, Director of Graduate Institute of Communication Engineering, NTU

Fig. 6. Larry Hung, executive assistant to general manager of Pyras Technology Inc.



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Workshop on the annual report of Program for Key Technologies Research on Next Generation Communication Systems and Program for 6G Advanced Research

On July 18-19, 2023, a two-day workshop on the annual report of "Program for Key Technologies Research on Next Generation Communication Systems" and "Program for 6G Advanced Research" took place at National Taiwan University in Taipei City, Taiwan. The event saw participation from esteemed individuals including Professor Tzong-Lin Wu, Associate Dean of the College of Electrical Engineering and Computer Science at National Taiwan University, and Professor Guu-Chang Yang, Dean of the College of Electrical Engineering and Computer Science at National Chung Hsing University. These experts, along with other prominent figures from academia and industry in the communication and networking field, engaged in discussions and shared their invaluable insights on evolving communication technologies.

The opening was conducted by Professor Zsehong Tsai, who serves as the Director of the Office of the S&T Policy Expert Consultation Board. He emphasized Taiwan's pursuit of greater international collaboration. While Taiwan has already made a substantial mark on the global semiconductor industry, there remains untapped potential within the telecommunications sector. Professor Tsai highlighted that 6G encompasses more than mere technological advancements; it presents an opportunity for Taiwan to establish stronger international connections. Subsequently, Professor Tzong-Lin Wu delivered a concise welcome speech and inaugurated the two-day event.

The workshop was divided into two main segments: technical presentations and booth demonstrations. In the technical presentations section, a total of 13 talks were delivered by research teams from various universities in Taiwan. The topics of these talks encompassed a broad spectrum, including sub-THz transceiver design, sub-THz sensing radar, open network architecture, upper-middle band MIMO systems, reconfigurable intelligent surfaces, and non-terrestrial networks. These presentations facilitated the exchange of experiences and viewpoints among research teams and experts, exploring further possibilities in these cutting-edge communication technologies.

In addition to the enlightening technical presentations, the research teams also showcased their remarkable project outcomes at dedicated booths. This interactive platform provided them with an opportunity to offer more immersive insights into their work. Some teams ingeniously set up live experiment environments, enabling attendees to witness firsthand the tangible results of their innovative designs. Utilizing videos and remote connections, others skillfully connected back to their laboratories, effectively extending the workshop's reach beyond the confines of the event space. This dynamic approach not only facilitated deeper discussions but also fostered collaborative exploration, allowing visitors to delve into the intricacies of the showcased testbeds and gain a comprehensive understanding of the cutting-edge advancements.

The two-day workshop dedicated to the annual report served as an excellent platform for the exchange of perspectives and the establishment of connections among the various research teams. This inclusive environment offers both industry and academia an enhanced opportunity to foster collaborations. Looking ahead, this workshop also holds significant potential for inviting international partners who are engaged in cooperative efforts with Taiwan's research teams. As the event continues to evolve, it stands poised to become an even more robust conduit for global cooperation and knowledge exchange.

Fig. 1 Group photo of specialists from academia, industry, and research institutes in the telecommunications field.

Fig. 2 Professor Zsehong Tsai, Director of the Office of the S&T Policy Expert Consultation Board, delivered an opening speech to emphasize the significance of the 6G development in Taiwan.

Fig. 3 Professor Tzong-Lin Wu, Associate Dean of the College of Electrical Engineering and Computer Science at NTU, delivered a welcome speech for the workshop.

Fig. 4 The research teams of the two 6G research programs showcased their technological breakthroughs at their booths.

Fig. 5 Group photo of the Principal Investigators (PIs) and Co-PIs from the two 6G research programs and 6G Program Office.

National Taiwan University
Graduate Institute of Communication Engineering

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

Editor in Chief
Prof. Shih-Chun Lin

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

E-mail
ntugice@ntu.edu.tw