## 3. Categorized Summary of Research Outcomes

(The criteria for top conferences and journals are listed in Appendix II)

Major research outcomes are summarized in the following respectively for each subproject.

### 3.1 Subproject 1 (SP1)

A website http://emgroup.ee.ntu.edu.tw in English has been setup to introduce the team and report the research achievements of the Advanced Microwave and RF-SoP Integration subproject. It describes in details the laboratory equipments, team members, research results, etc. Some of the research outcomes are summarized here.

Task 1: Advanced MMIC Technologies

- CMOS ring-based multiple-push VCO chips with the world record tuning are developed, including a 0.2-34-GHz VCO in 0.13 μm CMOS, and a 0.1–65.8-GHz VCO in 90 nm CMOS.
- CMOS PA chips with the worldwide highest output power in the operating frequencies, including a 60-GHz 18-dBm DAT (Distributed Active Transformer) PA, a V-band 18-dBm PA, a 90-100 GHz 12-dBm balanced PA, and a 24-GHz 22-dBm PA, are developed.
- The multicascode configuration with noise reduction topology were proposed, analyzed and applied to implement two low power miniature CMOS LNAs. One with cascode device was designed at V-band in 65-nm process, having the advantages of better noise figure and lower power consumption. The other with triple-cascode structure was fabricated at Q-band in 0.13- m technology, feathuring higher gain performance with a compact size.
- A simple analysis and design methodology of the reduced-size Marchand rat-race hybrid is presented. A $180^{o}$ single-balance gate-pumped mixer and a single-balance diode mixer fabricated in a bulk 130-nm CMOS process have been designed at 60 GHz to verify the design methodology. The hybrid makes the singly balanced mixers achieve LO-to-RF isolation better than 33 dB, which is comparable to most reported doubly balanced mixers.
- A low-voltage and low-power 60 GHz LNA using 90 nm standard MS/RF CMOS technology is developed. Operating at 0.7 V supply voltage and 4.9 mW dc power only while maintaining a peak gain of 13 dB at 55 GHz and 12.6 dB at 60 GHz with a compact size of 0.351 $mm^2$, this MMIC demonstrates the lowest supply-voltage among published LNAs around 60 GHz.
- Two world widest input locking range, without any tuning range mechanisms, frequency dividers demonstrate high potential for integration in a wideband mmW PLL using 90nm CMOS technology and the dual-mixing technique. Both the divide-by-2 and divide-by-4 ILFDs have demonstrated a locking range of 51–74 GHz and 82.5–90 GHz. The power consumption is only 3 mW for both ILFDs, from a 0.5 V supply.

- An amplitude-shift-keying (ASK) demodulator for the RFID tags which can be embedded on panel displays was demonstrated for the first time. Implemented in 3-μm LTPS TFT technology with circuit size of 500 μm × 450 μm, it has incorporated a novel full-wave demodulator circuit to resolve the issue of high threshold voltage and reduce the ripples of the demodulated envelope.

- An ultra-broadband 0.8-77.5-GHz distributed mixer as a single down-converter was developed to cover most wireless applications, including Cellular/ WLAN/ WiMAX/ Satellite/ 60GHz.

- A 65-nm CMOS chip set including an LNA, a down-conversion, an up-conversion mixer and a medium PA for 71-76 GHz wireless communication applications is designed, fabricated, and measured. The measurement results show that the 65-nm CMOS technology is suitable for the design of RF front-end circuits to operate in E-band.

- The first CMOS LNA with RF electrostatic discharge (ESD) protection in the mmW regime and has the highest operation frequency reported to date is demonstrated. Using an impedance isolation method to minimize the RF performance degradation, it sustains 6.5-kV voltage level of the human body model on the diode and 1.5 kV on the core circuit, which is much higher than that without ESD protection (350 V).

- A K-band distributed frequency doubler using current-reuse technique is developed in 0.18 m CMOS technology. The high-pass drain line and high-pass inter-stage matching network are used to obtain a good fundamental rejection. A measured conversion gain of better than -12.3 dB is obtained, and the fundamental rejection is better than 30 dB for the output frequency between 18 and 26 GHz.

- An ultra-low-power VCO based on the complementary cross-coupled structure with the three- coil transformer feedback is proposed and realized in 0.18 μm CMOS. This VCO has a 1 MHz offset phase noise of -118.5 dBc/Hz and consumes only 0.66 mW dc consumption.

- A low-power 13.5-30.5-GHz 7.3mW divide-by-four frequency divider with 77.3% locking range is presented, using the cascoded integration of injection-locked frequency divider (ILFD) core and a divide-by-two source-injection current mode logic (SICML) divider to removal the transconductance and parasites. This world-record divide-by-four frequency divider has three times wider locking range than other published divide-by-four dividers.

- A CMOS frequency divider operating at an input frequency in the vicinity of the transistor's cutoff frequency is presented. By optimizing the value of the series inductance at the injector, an enhanced input locking range is exhibited for divide-by-4 frequency division.

- A novel circuit topology for a CMOS mmW LNA is presented. With the proposed gain-boosting technique, the LNA which is fabricated in a standard 0.18-μm CMOS process exhibits 15-dB gain at 40 GHz.

- A compact 0.18-μm CMOS wideband gain-flattened LNA is developed. The gain flatness is enhanced by the gate-inductive gain-peaking technique, further resulting in

better wideband noise canceling and quick gain roll-off outside the desired signal band to reject interference. Without using any passive inductor, the core size of the fully-integrated CMOS LNA circuit is only 145μm × 247μm.

- A power-level tracking PA with reduced spurious emission was developed by utilizing a DC-DC converter with frequency-hopping capability. Measured results show a two times improvement in average efficiency while negligible spectral degradation for the W-CDMA standard at 836.5 MHz. For the EDGE standard, the efficiency was also improved by two. Moreover, the spurious emissions were improved by up to 4.5 dB.

Task 2: Chip Scale Packages and Modeling Techniques

- A fast and accurate thermal-wake aware R model for integrated microchannel 3D ICs is presented, with 400X speed up and only 2.0% error from commercial tool. Use of the proposed model for thermal optimization during the IC placement stage is also demonstrated, resulting in up to 25˚C peak temperature reduction according to the experiments. The paper titled "Thermal modeling for 3D-ICs with integrated microchannel cooling" was nominated as a candidate for the best paper award at *2009 IEEE/ACM Int. Conf.Computer-Aided Design*.

- An MPML2 system targeting for cost-effective manufacturing at the 32nm node and beyond is proposed, with key structure of a beamlet array cells (BACs). Hundreds of BACs are packaged and uniformly arranged over the whole wafer area, while each has a data processor and an array of beamlets, each consisting of an electron-beam source, a source controller, a set of electron lenses, a blanker, a deflector, and an electron detector. Integration using 3D and MEMS technologies increases the density of beamlets and reduce the system cost. The proposed MPML2 can achieve 10 wafers per hour throughput for 300mm-wafer systems.

- A world first 0.18- m CMOS monopulse transceiver for X-band FMCW radar applications is implemented. It integrates 16 building blocks by incorporating innovative synthetic trans- mission line, with a reduced chip area of 2.6 mm × 3.3 mm. The measurements show excellent performances: total power consumption 0.35W, transmitter output power 1 dBm with a 35-dB $2^{nd}$ harmonic suppression, on-chip isolations between T/R more than 60 dB, receiver gain -4.5 dB, NF 11.5 dB, and the obtained I/Q signals imbalance 0.6-dB in amplitude and 7° in phase.

- A new coupling structure for inductive coupling in 3D IC vertical interconnect is proposed. With this new structure, the coupling coefficient can be improved by 6dB which leads to lower power consumption for each bit transmitted.

- A synthesis and optimization tool for spiral inuductor in LTCC is developled. It needs only about 1/100 of the simulation time in commercial EM software, thus capable of fast optimization for inductor layout.

Task 3: SOP Integration and EMC Design

- Bandpass filters with double-folded substrate integrated waveguide (SIW) resonators using multilayer LTCC technology are proposed. They have compact sizes and good frequency responses, demonstrating 74%-88% size reduction as compared with planar waveguide filters.
- A new design method of dual-band SIW filters is proposed by taking advantage of the existence of multiple cavity modes. By using LTCC technology, the SIW resonators are vertically stacked to minimize filter size. Two dual-band filters at Ka band are demonstrated, one has 3$^{rd}$ order tri-section response at 30 and 34.5 GHz with size 5 x 4 x 0.65 mm$^3$ and the other has quasi-elliptic response at 30 and 39 GHz with size 4.12 x 3.92 x 0.83 mm$^3$.
- A new design method for tri-band filters with the most flexible band allocation capability is proposed. For the bands assigned to adjacent frequency regions, transmission zeros are introduced to split one of the single bands into two. For the separately assigned band, different modes of stepped-impedance resonators (SIRs) are used to realize different passbands.
- A tri-band LTCC filters with minimum number of resonators using the concept of modal orthogonality is presented. Taking advantage of the multiple modes inside one SIW cavity, the coupling mechanisms for different pass bands can be selectively controlled by the modal field distributions. Thus, a tri-band filter of four-pole quasi-elliptic response can be realized by four resonators only, and has been verified at Ka-band.
- A laminated waveguide magic-T with imbedded Chebyshev filter response is developed in a multilayer LTCC technology by vertically stacked SIW resonators with highly symmetric coupling structures. A third-order bandpass magic-T is designed and fabricated to operate at 24 GHz with 6% fractional bandwidth. Its highly symmetric structure provides a low in-band magnitude imbalance (±0.25 dB), phase imbalance (0°~6°), and 30 dB isolation between the sum and difference ports.
- An X-band FMCW radar transceiver module, which includes filter, rat-race coupler, duplex circular high gain circular-polarized antenna, and transceiver IC, has been designed and taped out on LTCC substrate, demonstrating the RF-SOP integration.
- A wide-band microstrip-to-microstrip via transition proposed for connecting an IC chip and an antenna array on the opposite sides of a multi-layered LTCC is implemented. It demonstrated overall return loss of 20 dB and insertion loss of 0.48dB over 57-67 GHz.
- An analytical mode analysis of vias in the multi-layered PCB periphery is developed to suppress the EM radiation induced by ground bounce. A systematic approach to achieve the optimum suppression design is thus developed for the various geometry parameters of the shorting vias, including the pitch, radius, and distance to the board edge.
- A novel common-mode filter design based on the concept of an effective negative permittivity metamaterial transmission line is patented and licensed by King Core Inc. (a listed company in Taiwan) with the license fee of NT$ 3.3 million. Based on the LTCC fabrication, the size of the filter is only 1.2 mm x 1.0 mm with good signal integrity of

differential signals up to 10 GHz and wide-band suppression of fractional bandwidth over 100%. It is smallest common- mode suppression circuit that needs no ferrite materials in the literatures. It is expected to be in mass production in two years and delivery 50 million pieces in next 5 years.

- A model and application of the power bus with multiple via ground surface perturbation lattice (MV-GSPL) is investigated. A 1-D model is proposed and based on which, a MV-GSPL power/ground pair is designed for an RF-SiP package. Both the chip-package co-simulation and experimental results show its excellent power noise isolation capability.
- A novel miniaturized forward-wave directional coupler with periodical mushroom-shaped ground plane is proposed. A 0 dB coupler with the length about 1.28 $\lambda g$ is designed, and 1.0 dB coupling is measured at 2.9 GHz due to the loss. Comparing with previously works, the proposed coupler can attain the highest coupling level with a smaller size.
- A novel EBG structure is proposed for broadband suppression of GHz simultaneous switching noise, composing of three-dimensional interdigital capacitors (3D-IDC) and series U-shaped transmission lines periodically. A prototype is implemented using LTCC, demonstrating the rejection band from 2 to 5.5 GHz and over 45 dB noise reduction in the stop band.
- By symmetrically placing a pair of open-stub resonators on the slotted reference plane, the radiated emission induced by common-mode noise crossing the slot can be effectively suppressed, at least 5 dB from 2.16 to 3.44 GHz by the ground resonators.

Task 4: Advanced Antenna Technologies

- A leakage-reduced CB-CPW transmission line is proposed, which possesses good insertion/ return loss responses, low loss factor, and flat group delay characteristics. Using the proposed structures as feed lines could not only improve the antenna efficiency but also lower the cross polarization levels of the coplanar patch antenna.
- An efficiency-enhanced (80.8% at 5.05 GHz using FR4 substrate) and size-reduced coupled twin-slot antenna fed by a CB-CPW is proposed. By using a capacitive feed with a T-match stub, the lengths of the twin slots can be optimized for highest efficiency, and the impedance matching can be accomplished by adjusting the parameters of the T-match stub.
- The effect of parasitic slots on the radiation patterns of the first harmonic mode of a CPW-fed slot dipole antenna is presented. By adding four parasitic slots, two on each of the two arms of the slot dipole, the radiation patterns of the first harmonic and fundamental modes can be made similar, while performance retained. Therefore, the antenna can operate at dual bands.
- A simple mathematical formula is proposed for computing the coupling coefficient between two arbitrary antennas that are placed within the other's near-field region. The

information required by this expression consists of the associated normalized vector far-field patterns, their relative orientations, and the antenna spacing.

- A uniplanar and compact bow-tie slot antenna capable of tri-band operation is proposed. Its size is determined by the upper resonant frequency and thus compact in nature. The middle and lower operating frequencies are obtained by inserting two metal strip pairs near the ends of the bow-tie slot without increasing the overall antenna area.

- A novel miniaturized design of microstrip-fed slot antenna is proposed. By properly loading a pair of C-shaped rings inside a half-wavelength slot, an optimized prototype with 50% size reduction was fabricated and measured, keeping nominal radiation patterns of slot antennas.

- A compact sequential-phase feed for CP sequential-rotation arrays is presented, which employs only a single-stage transition and hence the layout is compact and neat. Two miniature square feeds of sizes $\lambda_g/4$ and $3\lambda_g/8$ are given and compared, which can be extended to $2^N \times 2^N$ feeding networks, very suitable for large-scale printed CP arrays.

- An isosceles triangular slot antenna for broadband dual polarization applications is proposed. Good isolation between the two input ports ($|S_{21}| < -30$ dB) and low cross-polarization radiation level (<–15 dB) are achieved, and the antenna gains radiated from the two diversity ports are almost equal and stable over the entire operating band.

- An integrated dual planar inverted-F antenna (PIFA) with enhanced isolation is proposed, composing of two PIFAs merged together through a common metallic strip and a via connected to the ground plane. Good impedance matching and high isolation are obtained within its operating frequency band.

- A novel broadband CP antenna using traveling wave excitation is investigated and developed. The 3-dB axial ratio bandwidth of 25% for single antenna and 50% for 2x2 arrays is achieved. It has a planar structure performing much wider bandwidth than patch antenna, while a simple outer-feed scheme leading to manufacturing advantage over spiral antenna.

- An on-board folded dipole antenna is developed to work with a low-power fully integrated 60 GHz transceiver. High data rate and low power consumption are demonstrated.

- A tri-band aperture-coupled slot dipole antenna fed by a CPW has been proposed to exhibit satisfactory and stable radiation characteristics within each band. The flexible and nearly independent allocation of the three operating frequencies makes the proposed antenna more suitable for practical multi-frequency applications.

- A novel wideband (FBW=50%) quasi-Yagi antenna fed by a balun bandpass filter has been proposed, capable of providing better output balanced signals as well as retaining bandpass response. Compared with conventional quasi-Yagi antenna, it shows improvements in maintaining stable co-polarized radiation patterns, low cross-polarized radiation patterns, and a well-defined return-loss response throughout the operating bandwidth.

### 3.2 Subproject 2 (SP2)

- A new approach of organizing the course lectures (as spoken documents) for efficient learning was developed. In this approach, we automatically divide the course lectures by the slides used. We derive the core content of the slides by automatically extracting the key terms, and then construct the semantic relationships among slides by a key term graph. In this way, all slides are given its length, timing information in the course, automatically produced summary, key terms, related key terms and related slides based on the key term graph, in order to help the learner to decide whether to choose to listen to it or not. Spoken segment retrieval is also developed, and the retrieved spoken segments also include all above information about the slides they belong to to help the user in browsing. In this way, the user can easily develop his own plan of learning what he needs considering his available time and his background knowledge, based on the semantic structure provided by the system. A preliminary prototype system for an experimental course has been successfully developed with encouraging initial test results.

- A Chinese pronunciation learning software called NTU Chinese was successfully developed. It gives the students opportunities to practice their listening and speaking skills anytime and anywhere. This software is able to evaluate the utterance produced by an individual learner from four different aspects: pronunciation, pitch, timing and emphasis. For those phonemes with scores below a threshold, a 3-dimensional video will show on the screen to demonstrate the actions of the vocal tract shape, including the relative positions among the lip, tongue and other articulators. The scoring algorithm was trained with the scores given by real professional Chinese teachers over a corpus produced by a group of real learners whose mother tongues are not Chinese.

- Documents discussing public affairs, common themes, interesting products, and other topics are reported and distributed on the Web via various platforms such as review sites, forum, discussion groups, blogs, microblogs, news, etc. Watching specific information sources and summarizing the newly discovered opinions are important for governments to improve their services, companies to market their products, and customers to purchase their objects. Our research outcomens in opinion mining include NTU sentiment dictionary (NTUSD), opinion mining testbeds (MOAT), and various algorithms on sentiment word mining, opinionated sentence extraction, opinionated document extraction, opinion summarization, opinion tracking, and opinionated question answering. The results are distributed by free downloading (e.g., NTUSD and MOAT) and presented in top conferences such as ACM SIGIR 2005, ACL 2007*2, ACM SIGIR 2007, ACM WI 2007, EMNLP 2008, ACM WI 2008, ACM WI 2009, EMNLP 2009, and AAAI 2010.

- We propose a novel method for acquisition, modeling, compression, and synthesis of realistic facial deformations using polynomial displacement maps. This work was accepted as a full paper and then presented in ACM SIGGRAPH ASIA 2008. Our method consists of an analysis phase where the relationship between motion capture markers and detailed facial geometry is inferred, and a synthesis phase where novel detailed animated facial geometry is driven solely by a sparse set of motion capture

markers. For analysis, we record the actor wearing facial markers while performing a set of training expression clips. We capture real-time high-resolution facial deformations, including dynamic wrinkle and pore detail, using interleaved structured light 3D scanning and photometric stereo. Next, we compute displacements between a neutral mesh driven by the motion capture markers and the high-resolution captured expressions. These geometric displacements are stored in a polynomial displacement map which is parameterized according to the local deformations of the motion capture dots. For synthesis, we drive the polynomial displacement map with new motion capture data. This allows the recreation of large-scale muscle deformation, medium and fine wrinkles, and dynamic skin pore detail. Applications include the compression of existing performance data and the synthesis of new performances. Our technique is independent of the underlying geometry capture system and can be used to automatically generate high-frequency wrinkle and pore details on top of many existing facial animation systems.

- Interactive 3D content on Internet has yet become popular due to its typically large volume and the limited network bandwidth. Progressive content transmission, or 3D streaming, thus is necessary to enable real-time content interactions. However, the heavy data and processing requirements of 3D streaming challenge the scalability of client-server delivery methods. We propose the use of peer-to-peer (P2P) networks for 3D streaming, and argue that due to the non-linear access patterns of 3D content, P2P 3D streaming is a new class of applications apart from existing media streaming and requires new investigations. We also present FLoD, the first P2P 3D streaming framework that allows clients of 3D virtual globe or virtual environment (VE) applications to obtain relevant data from other clients while minimizing server resource usage. To demonstrate how FLoD applies to real-world scenarios, we build a prototype system that adapts JPEG 2000-based 3D mesh streaming for P2P delivery. Experiments show that server-side bandwidth usage can thus be reduced, while simulations indicate that P2P 3D streaming is fundamentally more scalable than client-server approaches. This work has been published in IEEE Internet Computing and was presented in IEEE INFOCOM 2008.

- We have developed methods for overcoming artifacts due to handshakes. Handshakes when taking photographs or videos often result in annoying artifacts, such as blur in photographs and jitter in videos. We have proposed a technique for reconstructing a high-quality high dynamic range (HDR) image from a set of differently exposed and possibly blurred images taken with a hand-held camera. To overcome the problem with blurred long-exposed photographs, we use Bayesian framework to formulate the problem and apply a maximum likelihood approach to iteratively perform blur kernel estimation, HDR image reconstruction and camera curve recovery. When convergence, we simultaneously obtain an HDR image with rich and clear structures, the camera response curve and blur kernels. It was published in CVPR 2009 as an oral paper. We have also proposed an approach for video stabilization by directly stabilizing a video without explicitly estimating camera motion. The method first extracts robust feature trajectories from the input video. Optimization is performed to find a set of transformations to smooth out these trajectories and stabilize the video. In addition, the optimization also considers quality of the stabilized video and selects a video with not only smooth camera

motion but also less unfilled area after stabilization. The work was published in ICCV 2009.

- We propose a novel personalized ranking system for amateur photographs. This work was accepted as a full paper and then presented in ACM SIGMM 2010. Although some of the features used in our system are similar to previous work, new features, such as texture, RGB color, portrait (through face detection), and black-and-white, are included for individual preferences. Our goal of automatically ranking photographs is not intended for award-wining professional photographs but for photographs taken by amateurs, especially when individual preference is taken into account. The performance of our system in terms of precision-recall diagram and binary classification accuracy (93%) is close to the best results to date for both overall system and individual features. Two personalized ranking user interfaces are provided: one is feature-based and the other is example-based. Although both interfaces are effective in providing personalized preferences, our user study showed that example-based was preferred by twice as many people as feature-based.

- Realistic rendering of participating media is one of the major subjects in computer graphics. Monte Carlo techniques are widely used for realistic rendering because they provide unbiased solutions, which converge to exact solutions. Methods based on Monte Carlo techniques generate a number of light paths, each of which consists of a set of randomly selected scattering events. Finding a new scattering event requires free path sampling to determine the distance from the previous scattering event, and is usually a time-consuming process for inhomogeneous participating media. To address this problem, we propose an adaptive and unbiased sampling technique using kd-tree based space partitioning. A key contribution of our method is an automatic scheme that partitions the spatial domain into sub-spaces (partitions) based on a cost model that evaluates the expected sampling cost. The magnitude of performance gain obtained by our method becomes larger for more inhomogeneous media, and rises to two orders compared to traditional free path sampling techniques. This approach has been published in ACM Transactions on Graphics and was presented in ACM SIGGRAPH Asia 2010.

- Wedding is one of the most important ceremonies in our lives. It symbolizes the birth and creation of a new family. Hence, we present a system for automatically segmenting a wedding ceremony video into a sequence of recognizable wedding events, e.g. the couple's wedding kiss. Our goal is to develop an automatic tool that helps users to efficiently organize, search, and retrieve his/her treasured wedding memories. Furthermore, the obtained event descriptions could benefit and complement the current research in semantic video understanding. Based on the knowledge of wedding customs, a set of audiovisual features, relating to the wedding contexts of speech/music types, applause activities, picture-taking activities, and leading roles, are exploited to build statistical models for each wedding event. Thirteen wedding events are then recognized by a hidden-Markov model, which takes into account both the fitness of observed features and the temporal rationality of event ordering to improve the segmentation accuracy. We conducted experiments on a collection of wedding videos and the promising results demonstrate the effectiveness of our approach. Comparisons with conditional random fields show that the proposed approach is more effective in this

application domain. This system has been published in IEEE Transactions on Circuits and Systems for Video Technology.

- Image formation is traditionally described by a number of individual models, one for each specific effect in the image formation process. However, it is difficult to aggregate the effects by concatenating such individual models. To address this issue, we apply light transport analysis to derive a unified image formation model that represents the radiance along a light ray as a 4-D light field signal and physical phenomena such as lens refraction and blocking as linear transformations or modulations of the light field. This unified mathematical framework allows the entire image formation process to be elegantly described by a single equation. It also allows most geometric and photometric effects of imaging, including perspective transformation, defocus blur, and vignetting, to be represented in both 4-D primal and dual domains. Because the proposed framework covers the complete light transport process and the functionality of each element of the imaging system, it can be easily applied to other imaging systems. We submitted our paper directly to a journal without conference publication. The paper appeared in IEEE Trans. Image Processing, Feb. 2011.

### 3.3 Subproject 3 (SP3)

- The video processing SoC team has implemented several chips. In this year, we designed the first quad HDTV H.264 encoder and HD multi-view video encoder for 3D video applications in a single chip. The throughput is 212MPixels/s. It can support real-time video coding for 4096x2160p single-view video or 1920x1080p three-view video. Moreover, In order to support video analysis applications with higher throughput requirements, a tera-scale performance image stream processor and machine learning SoC is developed. One image stream processor and one feature stream processor are integrated to support various low-level feature extraction and K-NN/K-means classifiers, and the top performance is 1.3 TOPS. Furthermore, a new programmable processor architecture---configurable filtering unit (CFU)---is also proposed in this year for graphics processing units or stream processors. It is proved that it can replace the conventional texturing unit and further accelerate the performance of filtering based operations with the hardware cost overhead of only 7.85%.

- We designed a multi-function decoder to support high-definition applications, including multiview 3DTV, quad full-HDTV, and the video streaming. It can achieve 4096x2160p@24fps real-time video decoding in only 59.5mW. For further supporting various video analysis applications, a Semantic Analysis SoC (SASoC) is designed with high power efficiency of 671 GOPS/W achieved with power-aware frequency scaling technique. Moreover, a machine learning engine is developed in to support various state-of-the-arts algorithms, which is the first work reported in literatures.

- Our software-defined-radio SoC team has presented several key components for the software-defined radio transmitter/receiver to meet the demands for different applications, especially on RF digital-to-analog converter (RFDAC), all-digital frequency synthesizer, analog-to-digital converter (ADC), and continuous-time

delta-sigma modulator (CTDSM). In the transmitter, the RFDAC is proposed since the impedance matching problem is relaxed compared with a traditional transmitter. A digital pre-distortion for memory-less non-linear power amplifiers has been developed and a clipping technique for crest factor reduction which improves the out-of-band signal power has also been demonstrated. An all-digital frequency synthesizer using embedded FIR noise filtering technique is realized and demonstrated. Also, an area/power-efficiency Nyquist-rate ADC architecture , suitable for digital IF wireless receivers. Furthermore, a design methodology, including peripheral circuits, such as PGA and reference buffer design, achieves better power optimization in the perspective of analog baseband circuits. A CTDSM that supports multi-standard application is also realized. It incorporates a proposed quadrature mismatch scrambler (QMS) to mitigate the mismatch between the I/Q multi-bit DACs. Experimental results demonstrated that this versatile CTDSM is suitable for low-IF or zero-IF receivers, which is the key to a high-performance software-defined radio.

- The broadband wireless communication SoC team investigated circuit designtechniques beyond 60 GHz using advanced 65nm, 90nm and 130nm CMOS technologies. The goal of the previous year research was to exploit the limits of CMOS technology. On the system side, a fully-integrated 77GHz FMCW Radar system including antenna assembly and analog signal processing has been demonstrated. Other blocks such as a 200GHz CMOS injection-locked frequency divider, several 77GHz high PAE power amplifier circuits, and500Mps 12 bit analog-to-digital convertor were designed and implemented. In order to operate beyond the ft of the CMOS technology, some circuit techniques that were proposed to maximize the fmax of a CMOS transistor were proposed.

- We worked on design issues on real-time and/or energy-aware task scheduling in the past year. The work is motivated by the strong demand of the industry in green computing and the energy-consumption constraint for mobile devices. In particular, we work on the decoding of H.264 video streams over multi-DSP and showed how effectively the energy consumption could be saved by dynamic voltage scaling techniques. In the research work, we also considered the resource contention issue of multi-core System-on-Chip (SoC) in real-time task scheduling. The objective is to tackle the communication problem among tasks with performance requirements and precedence constraints. A polynomial-time optimal algorithm is proposed for a restricted case in which one multi-layer bus, unit execution time, and chain-based precedence constraints are considered. The results are then extended as a pseudo-polynomial-time optimal algorithm for more general cases.

- We have been working on multicore architecture research. This project aims to design a retargetable dynamic binary translation framework by which binary translators from arbitrary guest ISA to host ISA can be developed with ease. We will carefully identify ISA-dependent and ISA-independent functionalities in the proposed binary translation framework and clearly define the interfaces between them. As a result we can isolate the ISA-dependent functionalities, and develop binary translators from different ISA's by implementing ISA-dependent functionalities within the framework.

- We study an optimization problem for multi-hop link scheduling with bandwidth and

delay guarantees over WRNs. Through our theoretical analysis, the intractability and inapproximability of the optimization problem are shown. Due to the intractable computational complexity, we present efficient algorithms to provide a reasonable small approximation factor against any optimal solution even for a worst-case input. Furthermore, some experimental results indicate that our algorithms yield near-optimal performance in the average case. We also propose an adaptive contention control strategy (ACCS) to solve the problem of transmission efficiency in IEEE 802.15.4. ACCS can be implemented in the IEEE 802.15.4 medium access control (MAC) protocol standard adding no new message type. An analytic model and a simulation model are developed to evaluate the performance of IEEE 802.15.4 and ACCS. The simulation results demonstrate that the proposed scheme significantly improves goodput, average queuing delay, average MAC delay, and energy consumption.

- We presented the first optimal dynamic-priority on-line scheduling algorithm for uniform multiprocessors and an improved optimal scheduling algorithm with the times of rescheduling decreased dramatically. We believe the results provide the fundamental real-time scheduling theory for multiprocessors and it might be applicable to state-of-the-art asymmetric multi-core platforms of similar uniform multiprocessors, where it is the focus on Taiwan SoC industry. We also invent the novel Batch-Pipelining technology to improve the performance tuning for multi-core applications such as H.264 decoder.

- We developed a very useful binomial-trinomial tree for efficient derivatives pricing under the standard Black-Scholes model and the more general jump-diffusion models. We also derived a general integral formula for calculating first and higher-order differentiations without finite differences for a very broad class of derivative securities, hence avoiding the so-called curse of differentiation. Finally, we designed an optimal bivariate tree algorithm under stochastic interest rates, remedying a grave error in the literature.

- We proposed a run-time memory thread throttling framework based on the idea of restricting the number of concurrent memory tasks to reduce the interference among memory requests and improve system performance on multi-core architecture. The proposed framework can detect phase change in applications and intelligently select adequate scheduling policy for each phase to tackle the memory wall problem. This work has been published in the premier conference IEEE/ACM International Symposium on Microarchitecture (MICRO 2010).

- We proposed an efficient encoding scheme for dual-diagonal LDPC codes is proposed. Our two-way parity bit correction algorithm breaks up the data dependency within the encoding process to achieve higher throughput, lower latency and better hardware utilization. The proposed scheme can be directly applied to dual-diagonal codes without matrix modifications. FPGA encoder prototypes are implemented for IEEE 802.11n and 802.16e codes. Results show that the proposed architecture outperforms in terms of throughput and throughput/area ratio. This work is published in IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences. Our work in low power LDPC decoder algorithms also have been recommended for publication in

International Journal of Communication Systems.

- We studied an optimization problem for interference-aware link scheduling with QoS guarantee over wireless relay networks (WRNs). To the best of our knowledge, this work is one of very first attempts at the studying of interference-aware link scheduling problem based on explicit bandwidth and delay requirements of WRNs. The contributions are described as follows. (1) Explicit QoS guarantee: We present efficient link scheduling algorithms to provide bandwidth and delay guarantees for WRNs over arbitrary routing; (2) Flexible performance metric: The performance metrics (e.g., throughput, capacity) can be specified by service providers; (3) Appropriate system model: We assume that a link scheduler has the information of service flows instead of the information of links. Although the link information could be measured, the measurement requires substantial efforts and extra overheads, and the measured results may be highly inaccurate; (4) Worst-case performance bound: The worst-case performance of the presented polynomial-time algorithms is proven to be within a reasonably small factor of the optimal algorithm.

- The indoor femtocell technology (known as femto BSs) with low power and low cost is proposed to provide comprehensive indoor wireless converge of macro BSs, which is known as the femtocell network. The Location Area ID for a femtocell is different from that for the macrocell that covers the femtocell, which results in frequent location update procedure (i.e., the location update cost increases) when the Mobile Station has a significant level of mobility between femtocells and macrocells. We propose the Cell Priority Transition (CPT) mechanism to reduce the location update cost for the femtocell network. The simulation experiments and analysis are conducted to investigate the performance of the CPT mechanism. Our study shows that the proposed CPT mechanism significantly reduces the location update cost for femtocell networks. This research result is published in Vehicular Technology Conference (VTC2010-Fall).

- We developed middlewares on client-side virtualization for x86 and ARM platforms based on Xen. The applications of VM, such as 3D game, on x86 can perform close to on bare machine. All the paravirtualization drivers for devices are supported. We also port Xen and Android to ARM emulator and develop a new paravirtualization technique called inline emulation, which can perform up to 7 times better on the codes for virtualization.

### 3.4 Subproject 4 (SP4)

- We have studied a multi-radio multi-channel Fast ARQ (MF ARQ) scheme and an MF HARQ scheme for delay-sensitive flows in a multi-channel environment. The optimized MF ARQ/HARQ schemes are shown able to achieve better effective throughput than those of similar multi-channel ARQ/HARQ schemes in various Nakagami-m fading environments.

- We have investigated the performance improvement for spectrum sharing among two cellular operators. We successfully derived the mathematical model and predict the performance improvement in call blocking probability and utilization for UMTS and

WiMAX operators.

- We developed a technology for improving the capacity of wireless backhauls transmitting packets with small payloads, such as VoIP. We propose a scheduler that concatenates small packets into large frames and sends them through multiple parallel channels with an intelligent channel selection algorithm. Significant capacity and re-sequencing delay improvements is achieved.

- With the concept of distributed video coding, our implementation results demonstrate that, although the appended metadata is less than 8% of the total transmitted data, it improves the quality of the upsampled video significantly. Meanwhile, the computation time of our project is close to that of bilinear upsampling algorithms implemented on mobile devices.

- In two-tier networks consisting of a macrocell overlaid with femtocells in co-channel deployment and closed-access policy, spatial reuse is achieved at the price of severe cross-tier interference from concurrent transmissions. The lack of direct coordination between the macro and femtocells makes interference control as a challenging issue. Cognitive radio (CR) becomes a promising solution, where femtocells with cognitive information accomplish concurrent transmissions while meeting a per-tier outage constraint. SBy employing stochastic geometry model, bounds on the distribution of aggregated interference from two-tier spatial point processes are successfully analyzed. The maximum number of simultaneously transmitting femtocells and overall downlink capacity of two-tier networks meeting a per-tier outage requirement in each approach are theoretically derived.

- To successfully deploy femtocells overlaying the Macrocell as a two-tier that had been shown greatly benefiting communications quality in various manners, it requires to mitigate cross-tier interference between the Macrocell and femtocells, and intra-tier interference among femtocells, as well as to provide Quality-of-Service guarantees. Considering the infeasibility of imposing any modification on existing infrastructures, we leverage the cognitive radio technology to propose the cognitive radio resource management scheme for femtocells to mitigate cross-tier interference. Under such cognitive framework, a strategic game is further developed for the intra-tier interference mitigation. Through the concept of effective capacity, proposed radio resource management schemes are appropriately controlled to achieve required statistical delay guarantees while yielding efficient radio resource utilization in femtocells.

- We have developed a universal software radio (USRP)-based platform that implements the feature detection of DVB-T signal using our novel distributed coordination of quiet periods. Our platform demonstrates the practicality of DSA and its potential for provide ubiquitous wireless broadband access.

- We developed a coordinated sensing scheme by which secondary devices using dynamic spectrum access can have interference-free quiet periods to detect DVB-T signal in bounded time. This scheme ensures returning license devices (such as DVB-T broadcasted) to be detected in a timely manner so as to meet the regulatory requirements.

- We have proposed a cooperative location estimation scheme. From the encounter history

of a specific user meeting other users and the location estimation results of other users, the user is able to further improve the accuracy of its location estimation. The cooperative algorithm provides a significant gain over the non-cooperative scheme and the location estimation accuracy increases with the number of users involved in cooperation.

- We have designed an adaptive precoder selection scheme for applications using MBSs in 4G networks. We considered a typical MIMO-OFDMA cellular system in a SFN. By utilizing the common feedback channels in MBSs, we proposed an effective adaptive precoder adaptation scheme with low complexity based on precoder training and user feedback.

- The multicast/broadcast service (MBS) has emerged as a key technology for delivering multimedia contents in 4G networks. The development of OFDMA and MIMO has provided a high-throughput air interface for delivering the multimedia contents in MBSs. To further improve the spectral efficiency for MIMO communications, the technique of precoding can be applied to tailor the signals to the current downlink channel quality. In this project, we propose an effective adaptive precoder selection scheme with low complexity based on precoder training and user feedback. The proposed scheme effectively improves the performance of received SINR measured at the mobile stations (MSs).

- The technique of spectral precoding is successfully applied to both orthogonal frequency-division multiplexing with cyclic prefix (CP-OFDM) and CP-OFDM multiple access (CP-OFDMA) systems with unconstrained guard ratios and arbitrary input data statistics. The developed spectrally precoded CP-OFDM and CP-OFDMA signals are shown to provide very small power spectral sidelobes decaying asymptotically as $f^{-2L-2}$ with L an adjustable precoding order.

- We have proposed extended hierarchical finite-state machines (HFSMs) to solve the synthesis problem and a set of HFSM templates are proposed and used as the elementary components of a hardware design. A guideline on the refinement of a C program is proposed and the refined C functions are compiled into HFSMs that in turn generate synthesizable hardware description language (HDL) code as the final design.

- Interdisciplinary research that applying game theory to solve practical wireless networking problems (e.g. femtocell resource allocation and co-existence of TV white space network)

- Localization is a fundamental task in a number of applications. State-of-the-arts often rely on the static world assumption. However, the real environment is typically dynamic. We propose the feasibility grids to facilitate the representation of both the static scene and the moving objects. Given that an observation can be decomposed into stationary objects and moving objects, incorporating the feasibility grids in localization yields performance improvements over the occupancy grids, particularly in highly dynamic environments. The experimental results show that the feasibility grid is capable of rapid convergence and robust performance in localization by taking into account moving

object information. A root mean squares accuracy of within 50cm is achieved, without the aid of GPS, which is sufficient for autonomous navigation in crowded urban scenes. Inaddition, we have demonstated that cooperative localization and tracking is superior than self-localization and cooperative localization in challenging scenarios. Localization and moving object tracking are mutually beneficial. The proposed approach is evaluated using humanoid robots in the RoboCup environment in which only uncertain data from onboard cameras and odometry are used. Ample experimental results with ground truthing from laser scanners demonstrate the accuracy and feasibility of the proposed vision-based cooperative simultaneous localization and tracking algorithm.

- While significant progress has been made in building large common sense knowledge bases, they are intrinsically incomplete and inconsistent. We try to answer queries based on knowledge collected from multiple sources without a common ontology. New assertions are found by computing graph similarity with principle component analysis to draw analogies across multiple knowledge bases. Experiments are designed to find new assertions for a Chinese commonsense knowledge base using the OMCS ConceptNet and similarly for WordNet. The assertions are voted by online users to verify that 75.77% / 77.59% for Chinese ConceptNet / WordNet respectively are good, despite the low overlap in coverage among the knowledge bases.

- Existing quality of experience assessment methods, subjective or objective, suffer from either or both problems of inaccurate experiment tools and expensive personnel cost. The panacea for them, as we have come to realize, lies in the joint application of paired comparison and crowdsourcing, the latter being a Web 2.0 practice of organizations asking ordinary unspecific Internet users to carry out internal tasks. We present Quadrant of Euphoria, a user-friendly web-based platform facilitating QoE assessments in network and multimedia studies, which features low cost, participant diversity, meaningful and interpretable QoE scores, subject consistency assurance, and a burdenless experiment process.

- We have built an integrated OSGi-based platform in order to provide infrastructural supports for the applications in smart environments. In the core of this platform is a message bus that is responsible for exchanging messages between devices. Platform Adapter converts sensed events to messages, and then publishes them to channels in the bus. Based on this platform, we have implemented multiple enhanced Bayesian classifiers, each of which represents an activity to be recognized; furthermore, we enhanced each classifier by incorporating both ranking features and reliability factors to detect interleaving/concurrent activities and unexpected malfunction respectively. In addition, we also proposed a concept called ambient-intelligence compliant object (AICO) to facilitate context-aware service provision in a smart home; An AICO has the potential to be responsive, sensitive, interconnected, contextualized, transparent, and intelligent such that it can be moved from a living lab into the real world.

- We propose an in-place search algorithm for computing the exact solutions to the resource constrained scheduling problem in high-level synthesis. As opposed to existing search-based scheduling techniques whose space complexity is squared or exponential in the search depth, our approach requires only a constant storage space during the traversal

of the search tree. The low space complexity is accomplished by using a combination-generating algorithm, which leads our approach to visit search nodes in such a way that each one is obtained by making only a small change to its sibling without keeping any parent nodes in memory. Experimental results on several well known benchmarks with varying resource constraints show the effectiveness of the proposed algorithm.

- We have developed the Playful Bottle system. The Playful Bottle explores the use of a mobile phone, when attached to an everyday object used by an everyday behavior, becomes a tool to sense and influence that behavior. This mobile persuasion system, called Playful Bottle system, makes use of a mobile phone attached to an everyday drinking mug and motivates office workers to drink healthy quantities of water. A camera and accelerometer sensors in the phone are used to build a vision/motion-based water intake tracker to detect the amount and regularity of water consumed by the user. Additionally, the phone includes hydration games in which natural drinking actions are used as game input. Two hydration games are developed: a single-user TreeGame with automated computer reminders and a multi-user ForestGame with computer-mediated social reminders from members of the group playing the game.

- We have proposed a reliable service management framework by formally defining a Message-Oriented service application model and protocols that facilitate autonomous composition, failure detection and recovery of services. Based on this framework, we devise a robust location-aware activity recognition approach for establishing ambient intelligence applications (especially for healthcare) in a smart home. The approach infers a single resident's interleaving/concurrent activities by utilizing a generalized and enhanced Bayesian Network fusion engine with inputs from a set of the most informative features. Each feature in this work reckons its corresponding reliability to control its contribution in cases of possible device failure, therefore making the system more tolerant to inevitable device failure or interference commonly encountered in a wireless sensor network, and thus improving overall robustness.

- Achieved new world records in solving SVP (**http://www.latticechallenge.org/svp-challenge/**): The problem of finding short vectors in high-dimensional Euclidean lattices is an NP-hard problem that is important both in its own right and in determining the security of a wide variety of cryptographic algorithms. We have developed and implemented the state-of-the-art SVP solvers on Cloud Computing and established several new world records on the most reputed SVP Challenge website. This represents a major progress in understanding the strength and limitation of lattice-based cryptography.

- We developmented a telehealthcare platform integrated with the electrical medical recode of NTUH and some case managers of NTUH have used it to execute telehealthcare for more than 100 cases. Moreover, the care service models include home care, community care and rural area care.

### 3.5 Subproject 5 (SP5)

- A room-temperature, continuous-wave $Cr^{4+}$:YAG double-clad crystal fiber laser grown by the co-drawing laser heated pedestal growth method was demonstrated. The threshold is below 100 mW, which is a factor of 4 lower than previously reported $Cr^{4+}$ doped lasers. A slope efficiency of 6.9% was obtained, and is in good agreement with the numerical simulation. In additional to small core diameter, the low-threshold lasing is made possible by the low propagation loss of 0.08 dB/cm and the high crystallinity of the core.

- A 24-pair Si-rich $SiN_x/SiO_x$ based distributed Bragg reflector (DBR) in-situ doped with Si nanocrystals is demonstrated to show self-photoluminescence (PL) with narrow-linewidth green-color emission pattern.The PL linewithof the Si-nc-doped DBRmirror shrinks to 10nm by blocking UV and blue luminescence at 400–510 nm.In addition, the gain of Si-ncdoped$SiO_2/SiO_x/SiO_2$strip-loadedwaveguide amplifier on Si substrate with amplified spontaneous emission (ASE)at 750-850 nm is observed.Net modal gain and losscoefficients of85.7 $cm^{-1}$ and 21 $cm^{-1}$, respectively, are determined by 785-nm laser diode injection,and a small-signal power gain of 13.5 decibel (dB) with a saturation power at 1.1 nWis obtained. The fitting of power-dependent gain withagain-saturated amplifier model reveals a peak gain of 35 dB.

- We also present a method for fabricating deep Si trenches with only a wet chemical etching process. A typical photolithography process was used to define the etching area. Aqueous $HF/AgNO_3$ solution and aqueous $HF/H_2O_2$ solution were applied to etch silicon nanowire (SiNW) structures in the selected domains. This method exhibits high anisotropy and is capable of etching deep Si trenches with depths of about 50 μm without an additional etching mask. It effectively minimizes instrument costs and reveals the potential of large-area fabrication.

- A cantilever-based optical gauging system is used as a surface tension and concentration gauge that requires only 0.5 μL of solution. NaCl-water solution and alcohol-water mixture are tested. A micro spherical reflecting mirror-integrated cantilever is first set above a droplet carried by a glass substrate, and then the droplet is moved up gradually. Once they touch, the cantilever is pulled and bent down as the droplet reshapes. The cantilever deformation amount is related to the solution's surface tension, which is a function of the concentration, and can therefore be used to determine the two physical quantities of interest.

- By using a 200GHz AWG channelized ASE source in connection with a saturable semiconductor optical amplifier (SOA) based noise blocker as the injecting source at the remote node in front of the local optical network units (ONUs), we demonstrate the spectrum-sliced ASE transmitter with greatly suppressed intensity noise performance in WDM-PON network. Such channelized SOA filtering technique effectively reduces the relative intensity noise of the ASE sourcea and improves its extinction-ratio (ER) and signal-to-noise ratio.

- Plasma power controlled PECVD of $SiO_x$ under $SiH_4/N_2O$ gas mixture with manipulated Si quantum dot (Si-QD) size for tailoring photoluminescent (PL) wavelength is demonstrated. The incomplete decomposition of $N_2O$ at high plasma power facilitates

Si-rich $SiO_x$ deposition to enlarge O/Si composition ratio and to shrink Si-QD size. As RF plasma power increases from 20 to 70 W, the O/Si ratio is increased from 1 to 1.6 and the average Si-QD size is reduced from 4.5 to 1.7, which increases Si-QD density from $3.2 \times 10^{17}$ to $3.02 \times 10^{18}$ $cm^{-3}$ and blue-shifts PL wavelength from 780 to 380 nm.

- The Si nanopillars with high aspect ratio were fabricated by dry-etching the thin $SiO_2$-covered Si substrate with a rapidly self-assembled Ni nanodot patterned mask. The Si nanopillars induce an ultra-low reflectance and refractive index of 0.88% and 1.12, respectively, at 435 nm due to the air/Si mixed structure and highly roughened surface. Lengthening the Si nanopillars from 150 ± 15 to 230 ± 20 nm further results in a decreasing reflectance, corresponding to a reduction in refractive index by $\Delta n/n = 18\%$ in the visible and near-infrared wavelength region. After dry etching Si wafer into Si nano-pillars, the weak blue-green luminescence with double consecutive peaks at 418-451 nm is attributed to the oxygen defect ($O^{2-}$) induced radiation, which reveals less relevance with the ultra-low-reflective Si nano-pillar surface.

- We report on the transport properties of single ZnO nanowires (NW) measured as a function of the length/square of radius ratio via transmission line method (TLM). The specific contact resistance of the FIB Pt contacts to the ZnO NWs is determined as low as $1.1\times10^{-5}$ $\Omega cm^2$. The resistivity of the ZnO NWs is measured to be $2.2\times10^{-2}$ $\Omega cm$. ZnO NW-based UV photodetectors contacted by the FIB-Pt with the photoconductive gain as high as $\sim10^8$ have been fabricated and characterized.

- We achieved a new roll-to-roll method to fabricate visible light transparent microlens arrays on a glass substrate by using soft and cost-effective polydimethylsiloxane (PDMS) molds. First, we fabricated microlens arrays master molds by photoresist thermal reflow processes on silicon substrates. We then transferred the pattern to PDMS molds by spin coater. After making the PDMS molds, we used a two-wheel roll-to-roll printing machine to replicate ultraviolet resin microlens arrays on glass substrates. The PDMS molds can be made easily at a low cost compared with traditional electroplating metal molds. This work was published in Journal of Micromechanics and Microengineering and was invited to be presented in SPIE Photonics West 2011.

- Along with the progress of image sensors in recent years, fix-focus cameras on mobile electronic devices do not fulfill consumer needs. With the size of mobile devices getting smaller and smaller, the displacement-to-thickness ratio is getting larger, and that makes mechanical motor systems difficult to be packaged inside cameras to achieve autofocus function. We propose a design using micromachined fluoropolymer deformable mirrors rather than traditional mechanical motor. With low color dispersion and adjustable power range of 20-diopter, deformable mirrors can be integrated into optical module and are well suitable for miniature optical auto-focus camera.

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range of 20-diopter, deformable mirrors can be integrated into optical module and are well suitable for miniature optical auto-focus camera.

- We develop the antireflection (AR) coatings with nanowire arrays (NWAs) since the ability to suppress the reflection over a broad range of wavelengths and incident angles plays an important role in the performance of optoelectronic devices, such as photodetectors, light-emitting diodes, optical components, or photovoltaic systems. Superior AR characteristics of NWAs, including polarization-insensitivity, omnidirectionality, and broadband working ranges are demonstrated.

- Pt contact on p-Si nanowires (NWs) using Ga ion-induced deposition by focused ion beam was formed with specific contact resistance ($\rho_c$) of 1.54×10-6 Ωcm2. Ohmic behavior is caused by Ga ion-induced amorphization of Si NWs underneath Pt contact. Very low Schottky barrier height associated with interface states raised from Pt-amorphized Si junction and with image force induced by applied bias can be implemented to elucidate ultra low $\rho_c$. The value of $\rho_c$ lower than that of any known contact to Si NWs demonstrates a practical method for integrating NWs in devices and circuits.

- A technique applying the slot waveguide concept on the SOI platform to manipulate the polarization dependence of straight channels and dual-channel directional coupler sections. By optimizing the geometry and length of each section, the polarization dependence can be minimized or maximized for certain applications. With such a technique, the polarization-mode-dispersion-less feature in a race-track ring resonator over a wide spectral range can be achieved.

- A hexagonal nanostructure formed by seven core shell nanocylinders filled with different dielectric cores is investigated. The surface plasmon resonance in such a hexagonal nanostructure under conditions of different illumination wavelengths, dielectric cores, angles of incidence, and thicknesses of silver shells is studied by use of the finite element method. Simulation results show that the resonant wavelength is redshifted as the dielectric constant and the size of the core increase. The peak resonant wavelength and the local field enhancement are approximately proportional to the radius of the dielectric core.

- A rigorous electromagnetic analysis for spontaneous emission in grating-assissted microcavities is developed. The simulation tool is efficient and can be carried out in a laptop. Power distribution of air, substrate, waveguide and surface plasmon modes is analyzed. The far field radiation pattern is also calculated. The developed tool is used to analyze OLED lighting devices in an academia-industry cooperation project with a display company. We also licensed a CAD tool to the display.

- We proposed a novel technique to systematically derive the continuity of field derivatives at a slab interface up to arbitrary orders. The derived interface conditions can combine directly with Taylor series expansion to build finite-difference formulation for Helmholtz equation. We apply the proposed finite-difference formulation to the analysis

of simple slab waveguides and multiple quantum waveguides. It can significantly reduce the computation time and memory. The ultimate accuracy is also lower due to smaller round-off error. The formulation can also be directly applied to beam propagation analysis.

- A wide-angle formulation for the simulation of beam propagation is proposed. In stead of using single reference index for the whole computation domain as in conventional formulation, we use different local reference indices region by region. Therefore, the "contrast ratio" of accurately modeled propagation constants is much larger as in the liquid crystal displays with local-dimming technology. The formulation is applied to both two- and three-dimensional simulations, which shows the proposed scheme works very well and gives better results than the conventional.

- Three numerical techniques are developed for the analysis of optical devices. A novel beam propagation method based on local reference indices is developed for efficient analysis of wave propagation in guided and un-guided propagating waves. A grating analysis tool based on the pseudospectral method is developed for efficient calculation of highly conducting gratings. A generalized relation of higher-derivatives across abrupt interfaces is derived, which can be applied in waveguide analysis.

- In order to study eigenmode characteristics of optical waveguides with high accuracy, as demanded in the study of plasmonic waveguides, 2D waveguide mode solver is developed with new electromagnetic formulations that combine Maxwell's curl and divergence equations to derive the eigenvalue problem. New penalty-type boundary conditions are derived to work with new formulations, and the pseudo-spectral Legendre method is adopted to perform spatial discretization for its accurate approximation property. For a square dielectric waveguide, the calculated modal index is seen to converge to the order of 10−11.

- To effectively investigate the fundamental characteristics of two-dimensional (2D) photonic crystals (PCs) with arbitrary 3D material anisotropy under the out-of-plane wave propagation, we establish a full-vectorial finite element method based eigenvalue algorithm to perform related analysis correctly. The band edge diagrams can be conveniently constructed from the band structures of varied propagation constants obtained from the algorithm, which is helpful for the analysis and design of photonic band gap (PBG) fibers.