IEEE RFIC Symposium

25th Anniversary

RFIC Symposium's 25th Anniversary

In 1997, the **IEEE Microwave and Millimeter-Wave Monolithic Circuits (MMWMC) Symposium** was turned into the **IEEE RFIC Symposium** with an expanded focus into silicon-based circuits.

2021 was our 25th symposium and 2022 marks 25 years from our first symposium, coincidentally also held in Denver.

Happy Anniversary, RFIC!!

First RFIC Symposium in 1997

Louis Liu

Message in Printed Digest from 1997 General Chair, Louis C.T. Liu

On behalf of the Steering Committee, I would like to welcome you to the 1997 IEEE Radio Frequency Integrated Circuits (RFIC) Symposium. This new and exciting Symposium expands from our previous Microwave & Millimeter-wave Monolithic Circuits (MMWMC) Symposium. The MMWMC Symposium was created in 1982 to provide focused forum for emerging MMIC technology. For the past 15 years, this Symposium encouraged the rapid advancement of the technology and facilitated its application in DoD and commercial systems. Today, approximately half of all papers presented during Microwave Week are related to the monolithic technology. We are very pleased that the MMWMC Symposium has served our society and membership well and has made significant impact on our technology development.

After observing the technology and business changes in the wireless industry and the high-volume production community, the Steering Committee began to implement the re-focus of the Symposium two years ago. The feedback we received from previous attendees and our membership is that there is a need for more emphasis on Si and GaAs RFICs for commercial applications. With all of this input taken into account, we decided to expand the MMWMC Symposium in several ways: to cover both Si ad GaAs technology instead of GaAs only, to provide the high volume and low-cost technique emphasis, and to include both R&D and production development.

To reflect this expansion of the Symposium's scope, we changed the symposium name to Radio Frequency Integrated Circuits (RFIC) Symposium. We expect to bring you the newest developments in highly integrated ICs; ICs for wireless communications, GPS and automotive radars; Si bipolar, CMOS, BiCMOS and GaAs design techniques; design for manufacturability and RFIC packaging.

This is the first year of the RFIC Symposium. I hope that you will hear the presentations of many interesting papers and learn new technology from the technical sessions, Sunday Workshop and Monday Panel Session. I also hope that you will meet many new friends. To ensure the continued success of the symposium, I would like to receive your feedback on areas that we can improve. If you like this Symposium, please tell your colleagues and invite them to attend and submit a paper. I look forward to seeing you in Denver.

RFIC Symposium's Beginnings


Vijay Nair

<u>Background</u>: The predecessor to RFIC conference was MMWMC. This conference attendees and papers presented were mostly from defense-related institutions, DOD, NRL, etc. I have been a member of the TPC/steering committee of this conference since late 1980. As the DOD funding decreased, the paper submissions and attendance decreased year over year. The attendance number was stagnant around 400 for several years.

I personally was researching/publishing in low power RFIC circuits (based on GaAs , InP etc.) At the same time, I have been monitoring the advancement of Silicon technologies. Silicon IC designers started moving from digital/analog designs to RF IC designs and their paper submissions were mostly to ISSSC. The number of silicon RF papers were increasing in ISSSC over the years. This bothered me since I considered MTT was the home of RF, microwave, and mmWave. The word 'monolithic' was not as impactful as integrated circuits.

Since I was slated to be the TPC chair in 1997, I made a presentation to 1996 ADCOM proposing to change the name and focus on RF integrated circuits. The presentation included the data showing the decreasing numbers in papers/attendance to MMWMC and increasing submissions of RF IC papers to ISSCC. I argued that this area should be under the MTT Charter. The time was ripe and if we did not act, we were likely to lose it forever. There were discussions on pros and cons and about merging to IMS to have just one conference. I again pointed out that Silicon designers usually do not submit papers to IMS since it has NO focus on RF silicon ICs. If merged with IMS, it would lose the focus on this emerging technology.

ADCOM approved to change of focus and the name in June 1996 meeting. For me RFIC name made the most sense.

<u>The Launch of RFIC</u> : Since I was the only one in the steering committee from a commercial company (Motorola), I took the lead in this new endeavor. Dr. Mahesh Kumar and Dr. Luis Lu were from DOD related companies. I invited a few RFIC leaders like Sayfe Kiaei and Natalino Camilleri to join the TPC/steering committee. Louis designed the RFIC Logo. We solicited a few invited speakers from the RFIC field who did not attend IMS. We aggressively pushed the RFIC call for papers to technologists beyond the usual database IMS had. **The positive response we received was astonishing!** The attendance doubled in 1997 (from 350 or so in 1996 to over 700 in 1997).

<u>The 'rest is history'</u> : In my opinion, this conference has been a huge success! It attracted more RFICs designers to participate and present papers at this conference. Lot of commercial companies from US and abroad started participating in the conference and in the exhibits. I thank the steering committee from 1997 to the present for making this conference an excellent one.

About the Name and Logo

Who came up with the acronym for RFIC?

“I made a presentation to 1996 ADCOM proposing to change the name and focus on RF integrated circuits. ADCOM approved to change the focus and the name in June 1996. The word ‘monolithic’ was not as impactful as ‘integrated circuits. For me, the RFIC name made the most sense.” [Vijay Nair]


Vijay Nair

“The ‘RFIC’ division was started at Motorola in 1990. People like Vijay and Lovelace were on the committee when the change was made, and this is why I attribute the name to come from Motorola.” [Natalino Camilleri]

What was the thought process in designing the original RFIC logo?

“We wanted the new RFIC logo to reflect the expanded RFIC technology. A logo that was simple, eye catching, easy to remember, and easy to use in stationeries. After a few iterations, the final logo had the following:

- The EM wave is a connector for all frequency bands
- Used our traditional blue background, and with the white lines to have a strong contrast so that it was easy to be recognized afar.
- The straight rectangle lines around the waves show the precision of engineering required in this technology.”

[Louis C.T. Liu]


Louis Liu

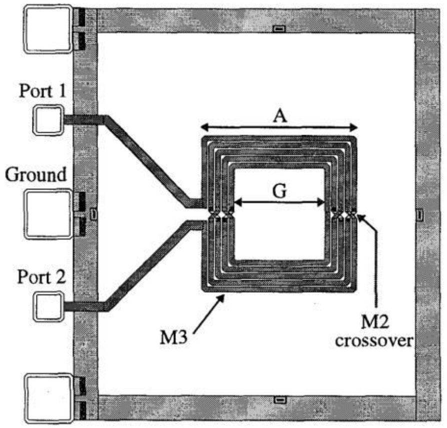
When Did RFIC "Take Off"?

Silicon transformation to RF? When did that get traction?
Was this related to when spiral inductors had Q-factor>1 and were reproducible?

"Starting in the late 90's and early 2000's. In my view, there was a transition away from GaAs to Si, largely driven by lower cost and higher levels of integration." [Joe Staudinger]

"In 1990 both Motorola and Bell-Labs-Agere had inductors on silicon working in RFICs. With regular 1 to 2um metal you could get Q of 5. When the University papers came in they sent a barrage of inductor papers. The people in industry never thought you can publish a paper about a spiral inductor. At the time the GaAs people argued that the inductors on Silicon were bad because of the substrate and not the metal. The shift to thick metal came when Steven Dow (friend of David Lovelace) from Motorola proposed using 25um Bump metal to make inductors, and was the first to achieve a Q of 20. The rest is history and the CMOS foundries started offering top thick metal." [Natalino Camilleri]

"When the spiral inductor on silicon can achieve a reasonable Q to make the circuits work, it took off. When I was a graduate student at UCLA working for Prof. Itoh (early 1990s), I helped a student from Prof. Abidi's group to design and simulate their spiral inductor on silicon. When I started working on silicon RFIC, the key focus was also the on-chip inductor, trying to push for high Q to replace off-chip inductors. I published a paper at the 1998 RFIC Symposium, reporting Q reaching 37.5 at 1 GHz on high resistivity silicon substrate (a proprietary substrate made in Bell Labs). Many RFIC designers who came from analog IC background said the ability to have on-chip inductors changed the way they designed circuits and enabled them to get into 'RF'. [Jenshan Lin]



From: M. Danesh, RFIC 1998.

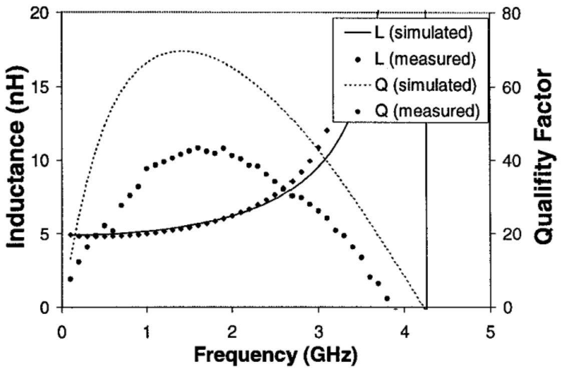
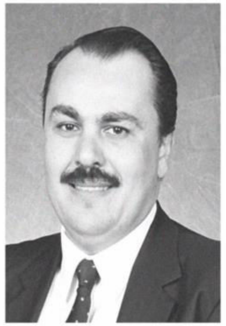


Fig. 3 Frequency response of the high-Q spiral inductor.

From: J. Lin, RFIC 1998.

Historical Accounts from Senior Chairs

What are some of the key highlight benchmarks that RFIC has contributed throughout the 25 years?


Natalino Camilleri

"Innovation is incremental, and it is difficult to get big shifts. The one major shift that I remember was the move from BiCMOS to just CMOS. The IBM-ADI (Jim Moniz- Christian Kermarrec) guys were pushing BICMOS. BiCMOS was also big at Motorola, Rockwell-Conexant-Skyworks, Agere, Siemens, etc. We had several lunch Panel sessions arguing about BiCMOS vs. CMOS, Christian Kermarrec from ADI was a proponent of BiCMOS for 10 years. Then I invited him to a Plenary session in 2002 and he made a switch and told everyone "BiCMOS is over, CMOS wins" You can do the same thing in CMOS cheaper and more integrated." [Natilino Camilleri]


Joe Staudinger

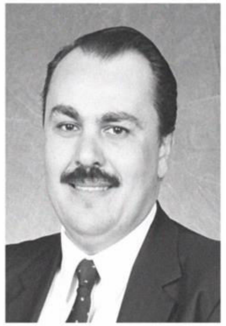
"I would say that around 1997 was a transition from largely military / DoD to more emphasis on commercial. The MMWMC was largely focused on GaAs technology with strong connection to DoD and military apps. At that time, cellular was still very young, but gaining papers. The trend continues to this day where nearly all the papers are commercial and/or academic, and [have migrated] from III-V to Si based content. Cellular (both handset and infrastructure) were strong drivers in the directional change to RFIC."   [Joe Staudinger]


Jenshan Lin

"I think we can use LNA noise figure, VCO phase noise, PA output power, PAE, etc. as benchmarks to show how the RFIC key performance parameters had been improved over the years. Certainly, those numbers depend on frequencies. Another simple benchmark is the highest operating frequency of RFIC that eventually got into THz range, which I used in my lecture to tell students that RF covers THz and RFIC covers THz IC." [Jenshan Lin]

Paths to Success

“RFIC was successful because of all the growth in the cellular business, all the early pioneers came from the cellular business, all the TPC members were from companies in the business. Back then, companies actually paid their employees to publish. RFIC Symp. was the hotbed of RFIC innovation exchange. As the industry became more competitive, people from industry started getting sensitive with the information and some papers were like data sheets. The committee did not like this and then more people from academia were invited because they were able to speak more freely.”
[Natalino Camilleri]


Natalino Camilleri

“Another aspect to RFIC’s success was moving the TPC meeting to being co-located with ISSCC. This engaged more members of the SSCC into RFIC. The RFIC Symposium is unique in that it is the only conference to bridge both the solid-state circuits and microwave theory societies (SSCS and MTTS).”
[Larry Kushner]


Larry Kushner

“The rapid development and application of the IC technology in the past 25 years has greatly impacted our lives in a way that we never could have imagined.   The RFIC Symposium has provided an important forum in facilitating this change. It is so gratifying to see many of our colleagues have been thriving in both the technology development and business successes in RFIC-related fields.”
[Louis Liu]


Louis Liu

RFIC Committees in the Early Years

1997 – The first RFIC Steering Committee

Back row: I. Bahl, J. Schellenberg, E. Cohen, M. Calcatera, E. Strid, H.-C. Huang, D. Williams
Front row: R. Kagiwada, F. Ali, V. Nair, L. Liu, C. Kermarrec, M. Kumar, T. Tokumitsu

1998 – Technical Program Committee

Back row: M. Ravel, A. Adar, R. Kagiwada, L. Liu, M. Kumar, J. Mandal, F. Ali, C. Kermarrec. S. Kiaei , T. Tewksbury, V. Nair
Front row: N. Camilleri, I. Bahl, E. Cohen, T. Tokumitsu, L. Larson, J.Moniz, D. Lovelace, H.-C. Huang

2002 – Steering Committee

Back row: E. Reese, L. Boglione, D. Lovelace, K. Ashby, S. Lloyd
Middle row: N. Camilleria, R. Kagiwada, F. Ali, S. Kiaei, J. Staudinger
Front row:, V. Nair, L. Liu, M. Kumar, T. Quach, J. Lin

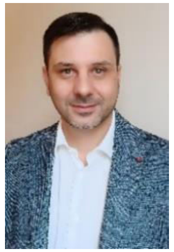
2001 – Technical Program Committee

Back row: K. Ashby, S. Lloyd, S. Heinan, Y. Deval, D. Lovelace, K. Kobayashi, N. Camilleria, B. Thompson
Front row: S. Kiaei, R. Kagiwada, L. Liu, J. Staudinger, A. Jerng, J. Mondal, A. Gupta, F. Ali, V. Nair
Not shown: D. Allstot, T. Cho, J. Choma, S. Embabi, I. Galton, R. Harjani, B. Kohn, M. Kumar, D. Ngo

Today's RFIC Symposium in 2022

Message from 2022 General Chair and TPC Chairs

Osama Shana'a
2022 General Chair



Donald Lie and Danilo Manstretta
2022 TPC Chair and Vice-Chair

The IEEE RFIC Symposium (RFIC) is the premier annual forum focused exclusively on presenting the latest research results in radio frequency (RF), mmWave, and wireless integrated circuits. RFIC is part of the International Microwave Symposium Week, the world's largest RF & microwave technical convention.

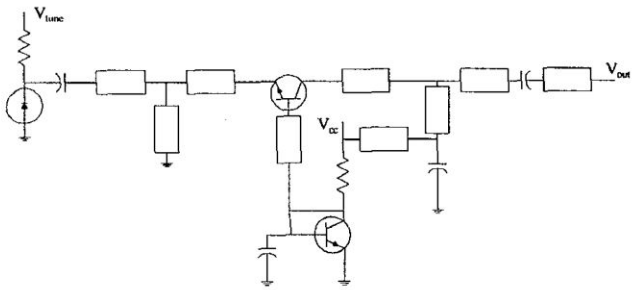
We are excited to see a very healthy RFIC paper submission this year, which has rebounded back to the pre-pandemic era level and with a 47% increase from 2021. The technical papers will be presented through parallel sessions. Our sessions include topics spanning from highly integrated wireless systems-on-chip and low-power radios to detailed publications on new power amplifiers, voltage-controlled oscillators, and front-end circuitry. As the 5G market heats up, increasingly more mmWave content is being published at RFIC, as well as sub-THz papers targeting future 6G.

TODAY, the RFIC Symposium has an expanded scope that includes RF Systems and Applications related to novel applications of RFICs at the systems level. This reflects the fact that more research challenges are being addressed at higher levels through new architectures, new usage models, new calibration techniques, and new integration approaches.

This is represented by our rich technical paper sessions, 13 workshops and one technical lecture that cover a wide range of advanced topics in RFIC technology, including: digitally intensive PAs and transmitters; mmWave and THz systems for imaging, spectroscopy and radar; wideband and high efficiency mm-Wave CMOS PA Design for 5G; human-body communications; recent developments in sub-6 GHz PAs and front-end modules; mmWave design challenges and solutions for 6G; wireless proximity communication; toward Tbps optical and wireline transceivers; system design for advanced radios; advanced interference mitigation; large-scale antenna arrays; micro and nano technologies challenges for 6G; and emerging cryogenic techniques for quantum information processing.

On behalf of the RFIC Steering and Executive Committees, we welcome you to join us at the 2022 RFIC Symposium in Denver Colorado. Please visit the RFIC 2022 website (http://rfic-ieee.org/) for more details and updates.

RFIC Symposium VCOs: Then and Now



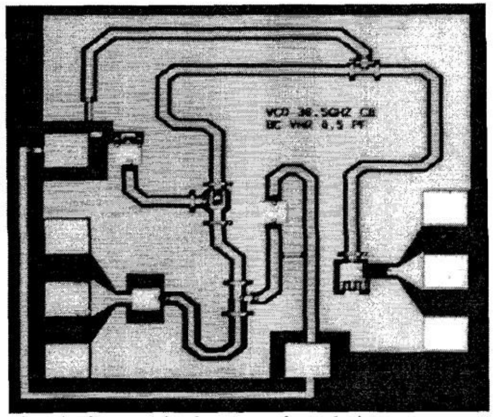
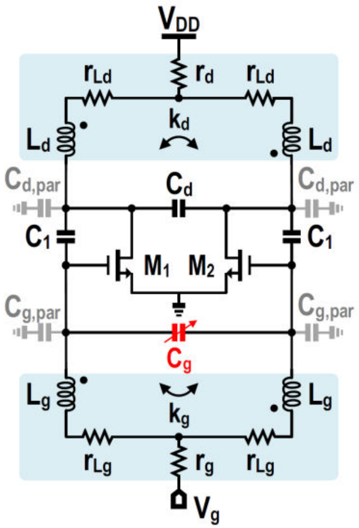
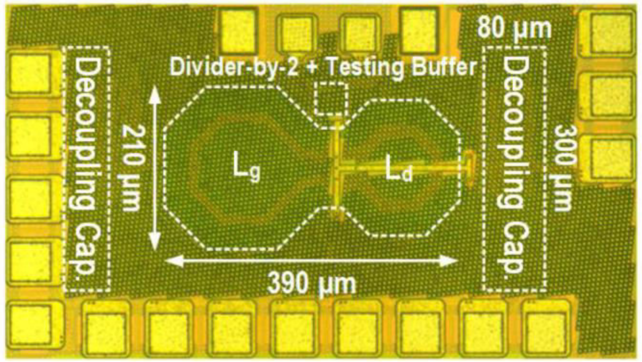


Fig. 5: Photograph of common base design





- 1997 – Low phase noise Ka-band VCOs using InGaP/GaAs HBTs and coplanar waveguide

  [Heins et al., RFIC 1997]

- 2020 – A 24.5-to-28.3GHz Multi-LC-Tank Fully-Differential VCO

  [Guo et al., RFIC 2020]

RFIC Symposium PAs: Then and Now

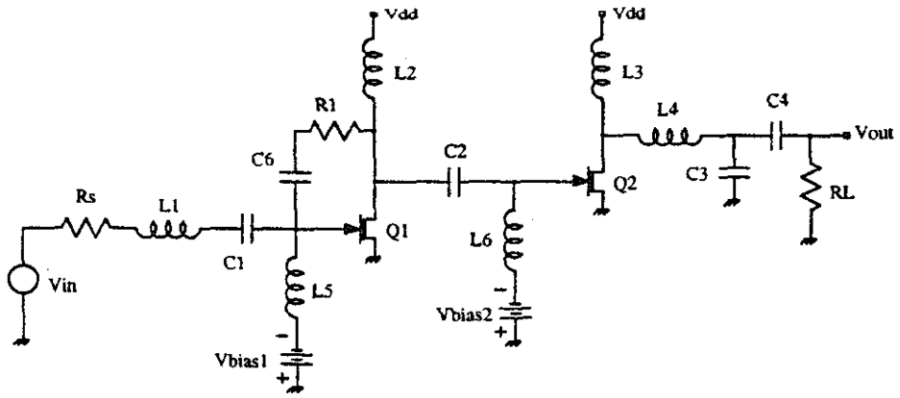


Figure 2. Simplified Power Amplifier

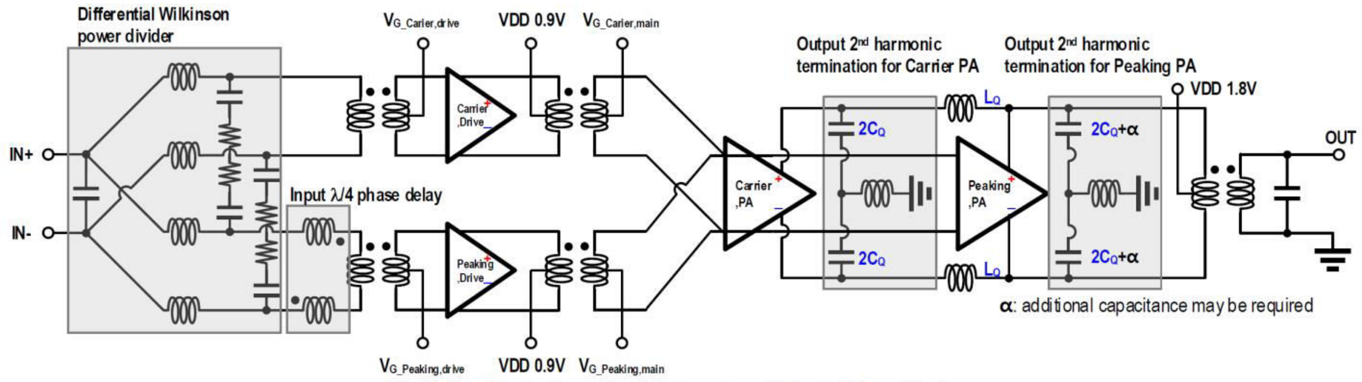


Fig. 3. Top-level schematic of the two-stage Doherty PA architecture.

- 1998 – A 3.4 V, 1 watt cellular DAMPS GaAs MESFET power amplifier with 50% efficiency

  [Taylor, RFIC 1998]

- 2021 – A 24.5–29.5GHz Broadband Parallel-to-Series Combined Compact Doherty Power Amplifier in 28-nm Bulk CMOS for 5G Applications

  [Kim et al., RFIC 2021]

RFIC Symposium LNAs: Then and Now

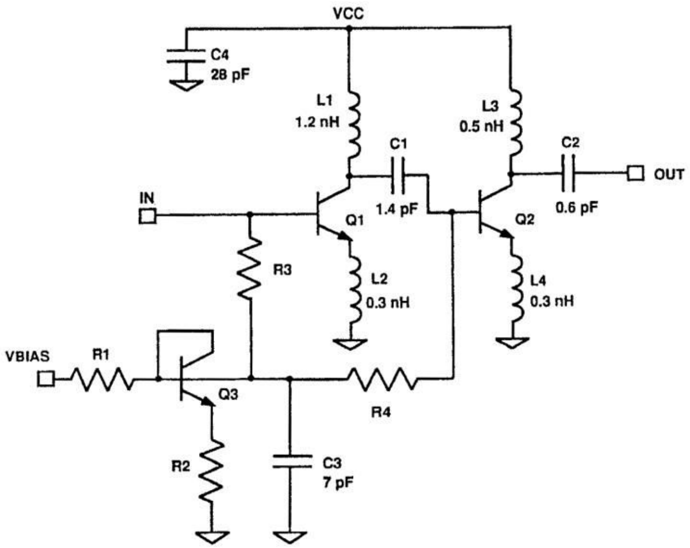
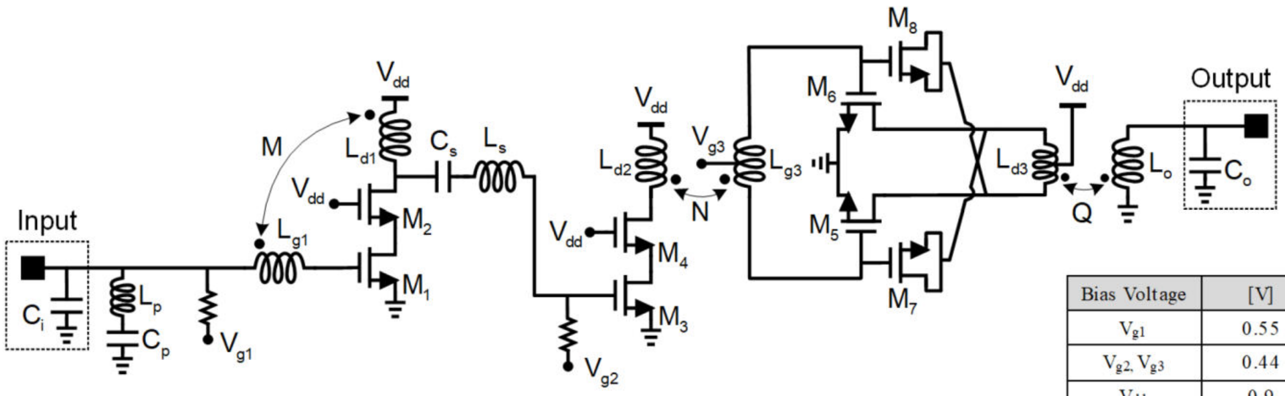


Fig. 1. Simplified schematic of the LNA.



Bias Voltage	[V]
V_{g1}	0.55
V_{g2}, V_{g3}	0.44
V_{dd}	0.9

- 1997 – A 5.8-GHz 1-V low-noise amplifier in SiGe bipolar technology

  [Soyuer et al., RFIC 1997]

- 2021 – A 22.2-43 GHz Gate-Drain Mutually Induced Feedback Low Noise Amplifier in 28-nm CMOS

  [Ershadi et al., RFIC 2021]

RFIC Symposium Transceivers: Then and Now

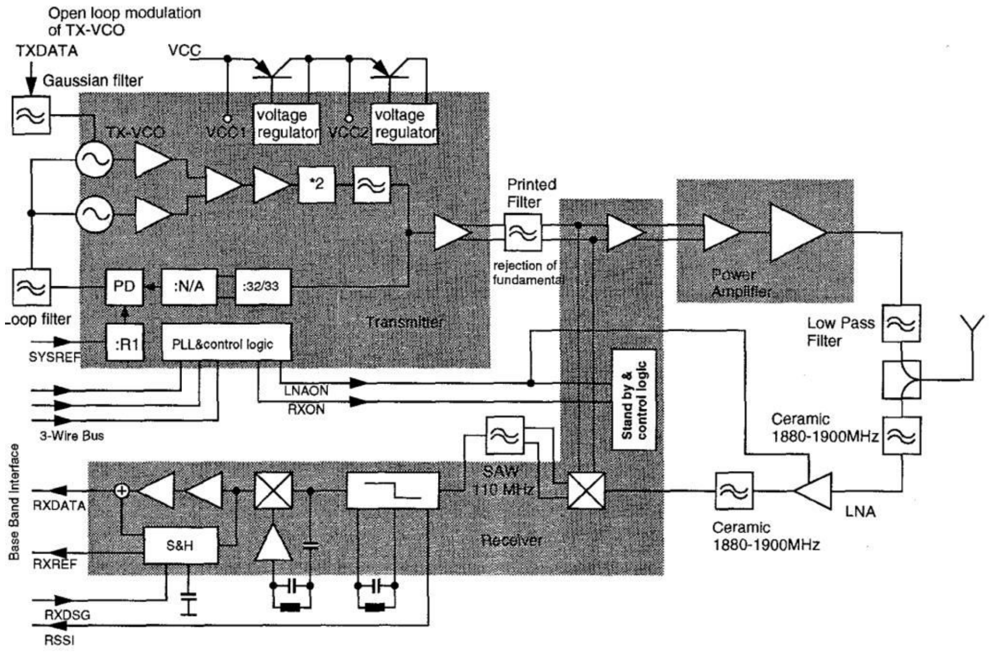


Figure 1: DECT radio block diagram of the 2nd generation chip set.

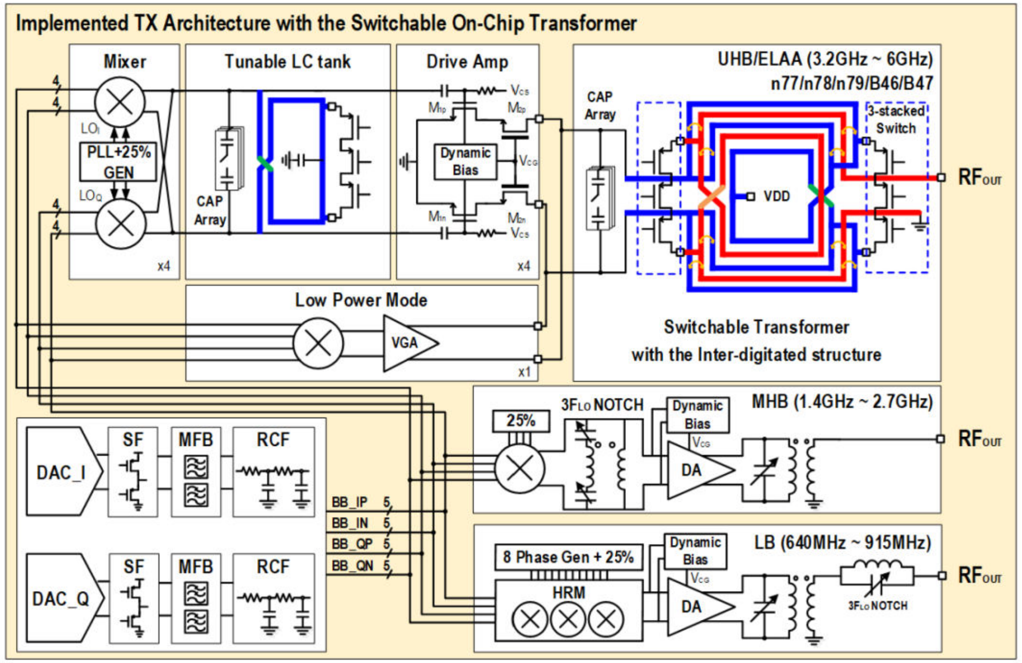


Fig. 2. Schematic of multi-band transmitter chain with switchable transformer and tunable LC-tank.

- 1997 – An integrated bipolar transmitter for DECT

  [Heinen et al., RFIC 1997]

- 2021 – A Sub-6GHz 5G New Radio Multi-Band Transmitter with a Switchable Transformer in 14nm FinFET CMOS

  [Jung et al., RFIC 2021]

RFIC Symposium mmWave: Then and Now

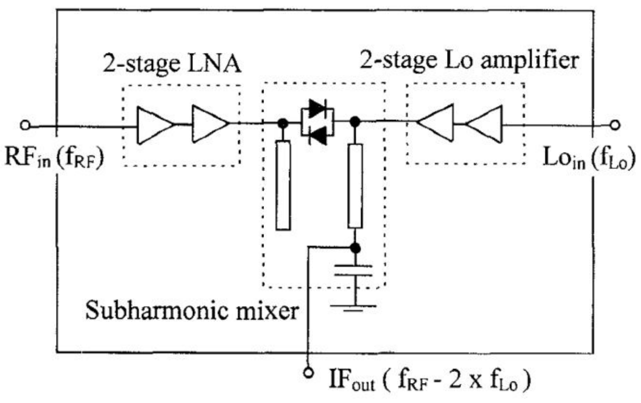


Fig.3 Block diagram of Receiver MMIC

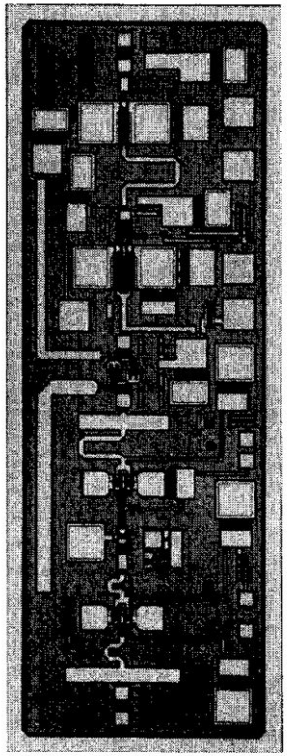


Fig.6 Receiver MMIC (2.3mm x 0.84mm)

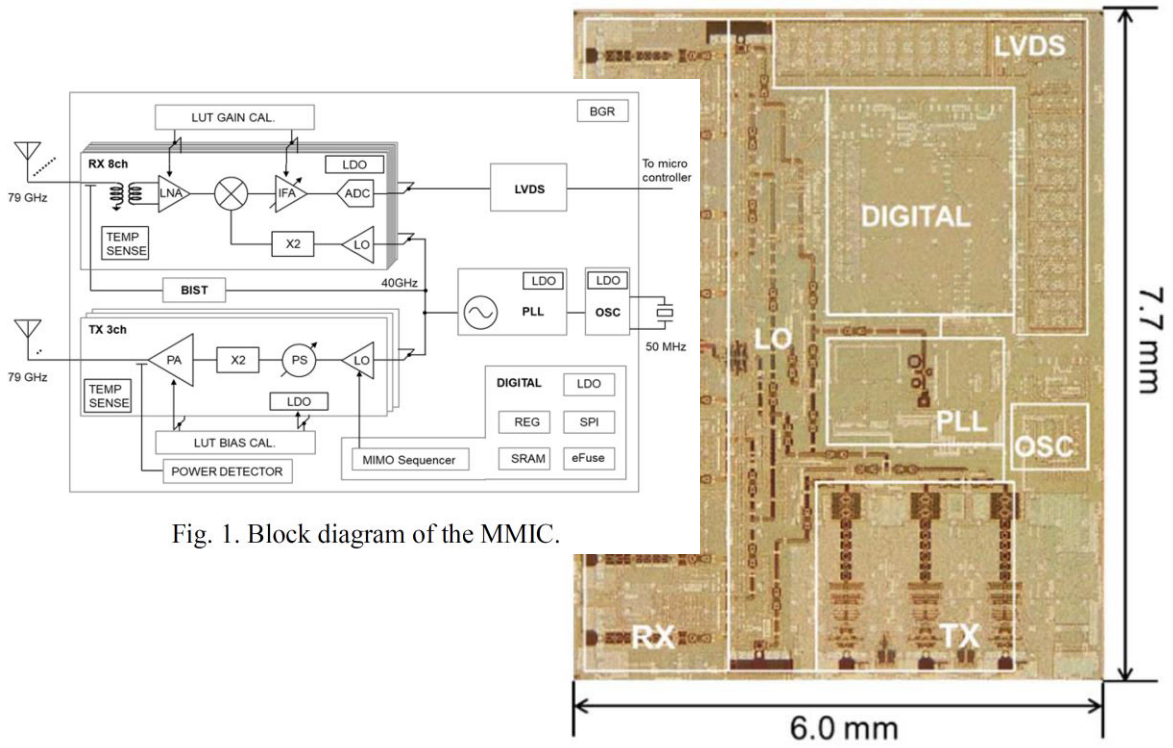


Fig. 1. Block diagram of the MMIC.

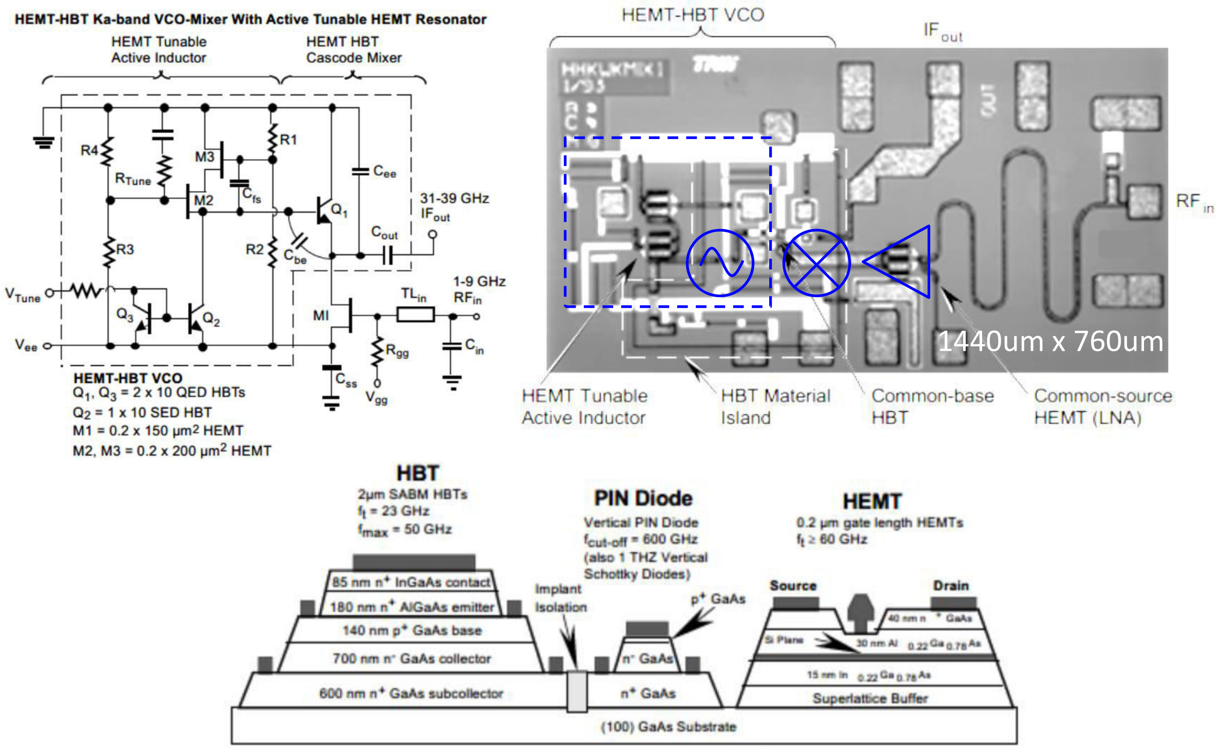
- 1997 – A V-band GaAs MMIC chip set on a highly reliable WSi/Au refractory gate process

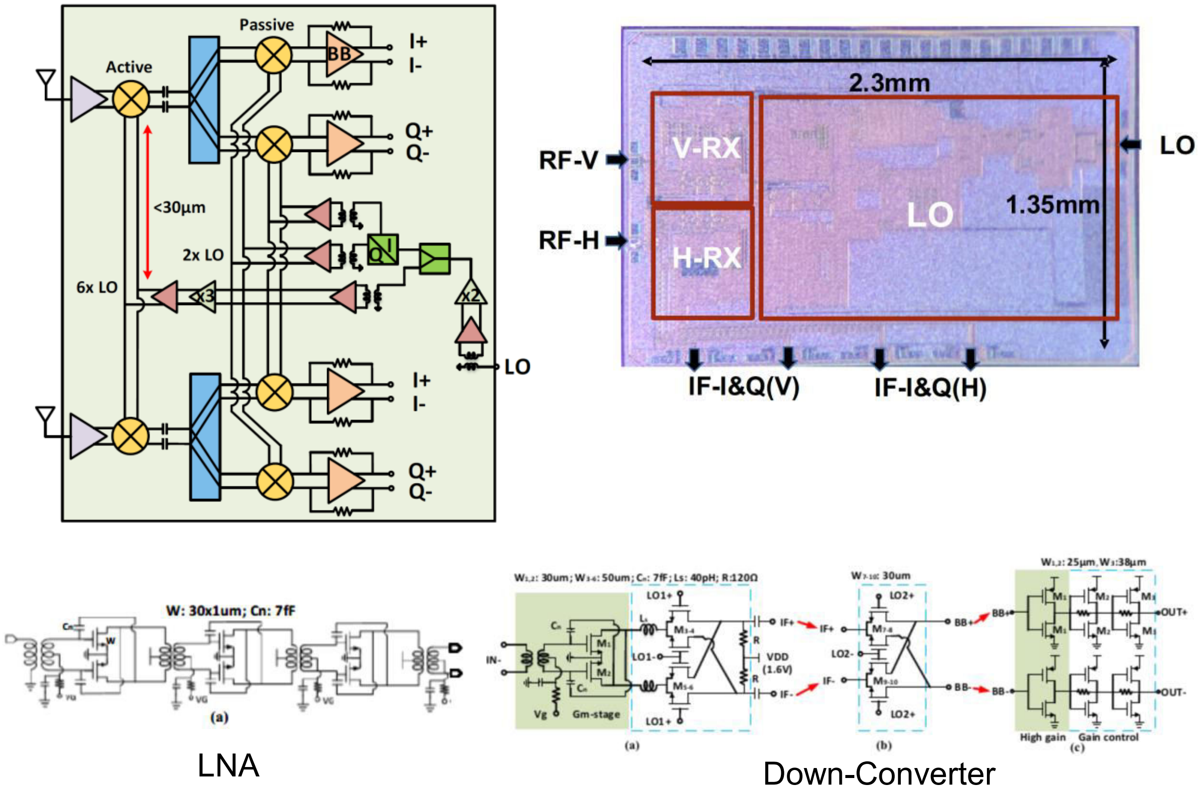
  [Mizoe et al., 1997 RFIC]

- 2021 – A 77 GHz 8Rx3Tx transceiver for 250 m long range automotive radar in 40 nm CMOS technology

  [Usugi et al., 2020 RFIC]

RFIC Symposium mmWave: Then and Now





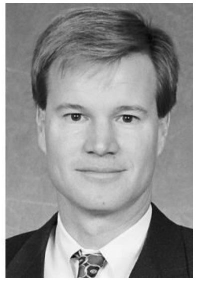
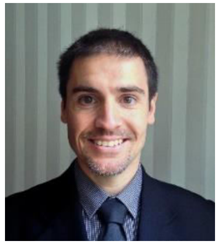
- 1997 –A Monolithically Integrated GaAs HBT and HEMT Multi-Function mmWave RFIC

[K.W. Kobayashi et al., 1997 RFIC]

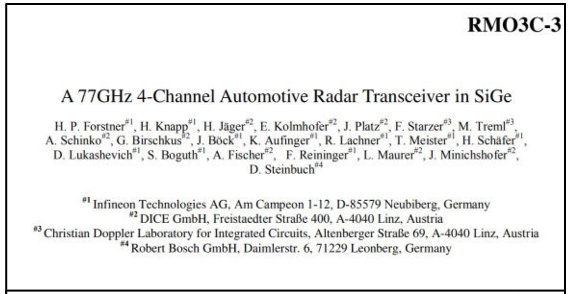
- 2021 – A 22nm FDSOI 2-Channel G-band Multi-Function Receiver RFIC

[C. Wang and G. Rebeiz, 2021 RFIC]

RFIC Symposium General Chairs

 Louis Liu 1997, Denver	 Vijay Nair 1998, Baltimore	 C. Kermarrec 1999, Anaheim	 Fazal Ali 2000, Boston	 David Lovelace 2001, Phoenix	 Sayfe Kiaei 2002, Seattle	 Natalino Camilleri 2003, Philadelphia	 Stephen Lloyd 2004, Ft. Worth	 Joe Staudinger 2005, Long Beach
 Stefan Heinen 2006, San Fran.	 Luciano Boglione 2007, Honolulu	 Jenshan Lin 2008, Atlanta	 Tina Quach 2009, Boston	 Yann Deval 2010, Anaheim	 David Ngo 2011, Baltimore	 Albert Jerng 2012, Montreal	 Chris Rudell 2013, Seattle	 Larry Kushner 2014, Tampa
 Bertan Bakkaloglu 2015, Phoenix	 Albert Wang 2016, San Fran.	 Kevin Kobayashi 2017, Honolulu	 Walid Ali-Ahmad 2018, Philadelphia	 Stefano Pellerano 2019, Boston	 Waleed Khalil 2020, Los Angeles	 Brian Floyd 2021, Atlanta	 Osama Shana'a 2022, Denver	 Donald Lie 2023, San Diego

Papers Submissions from 1997 to 2022

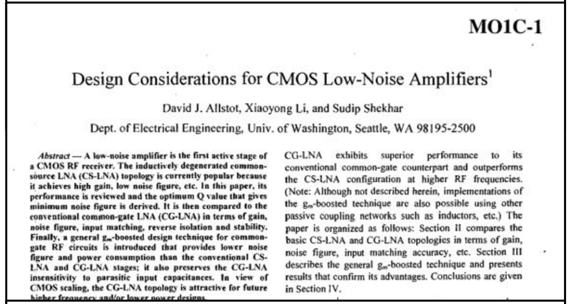


RMO3C-3

A 77GHz 4-Channel Automotive Radar Transceiver in SiGe

H. P. Forstner[#1], H. Knapp[#1], H. Jäger[#2], E. Kolmhofer[#2], J. Platz[#2], F. Starzer[#3], M. Treml[#3], A. Schinko[#2], G. Birschkus[#2], J. Böck[#1], K. Aufinger[#1], R. Lachner[#1], T. Meister[#1], H. Schäfer[#1], D. Lukashevich[#1], S. Boguth[#1], A. Fischer[#2], F. Reininger[#1], L. Maurer[#2], J. Minichshofer[#2], D. Steinbuch[#4]

[#1] Infineon Technologies AG, Am Campeon 1-12, D-85579 Neubiberg, Germany
[#2] DICE GmbH, Freistaedter Straße 400, A-4040 Linz, Austria
[#3] Christian Doppler Laboratory for Integrated Circuits, Altenberger Straße 69, A-4040 Linz, Austria
[#4] Robert Bosch GmbH, Daimlerstr. 6, 71229 Leonberg, Germany



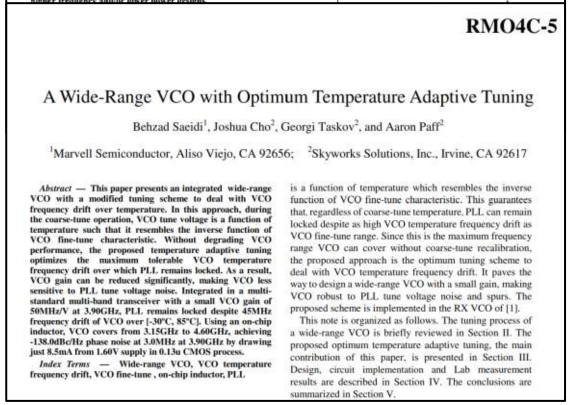
MO1C-1

Design Considerations for CMOS Low-Noise Amplifiers[1]

David J. Allstot, Xiaoyong Li, and Sudip Shekhar
Dept. of Electrical Engineering, Univ. of Washington, Seattle, WA 98195-2500

Abstract — A low-noise amplifier is the first active stage of a CMOS RF receiver. The inductively degenerated common-source LNA (CS-LNA) topology is currently popular because it achieves high gain, low noise figure, etc. In this paper, its performance is reviewed and the optimum Q value that gives minimum noise figure is derived. It is then compared to the conventional common-gate LNA (CG-LNA) in terms of gain, noise figure, input matching, reverse isolation and stability. Finally, a general g_m-boosted design technique for common-gate RF circuits is introduced that provides lower noise figure and power consumption than the conventional CS-LNA and CG-LNA stages; it also preserves the CG-LNA insensitivity to parasitic input capacitances. In view of CMOS scaling, the CG-LNA topology is attractive for future higher frequency and/or lower power designs.

CG-LNA exhibits superior performance to its conventional common-gate counterpart and outperforms the CS-LNA configuration at higher RF frequencies. (Note: Although not described herein, implementations of the g_m-boosted technique are also possible using other passive coupling networks such as inductors, etc.) The paper is organized as follows: Section II compares the basic CS-LNA and CG-LNA topologies in terms of gain, noise figure, input matching accuracy, etc. Section III describes the general g_m-boosted technique and presents results that confirm its advantages. Conclusions are given in Section IV.



RMO4C-5

A Wide-Range VCO with Optimum Temperature Adaptive Tuning

Behzad Saeidi[1], Joshua Cho[2], Georgi Taskov[2], and Aaron Paff[2]
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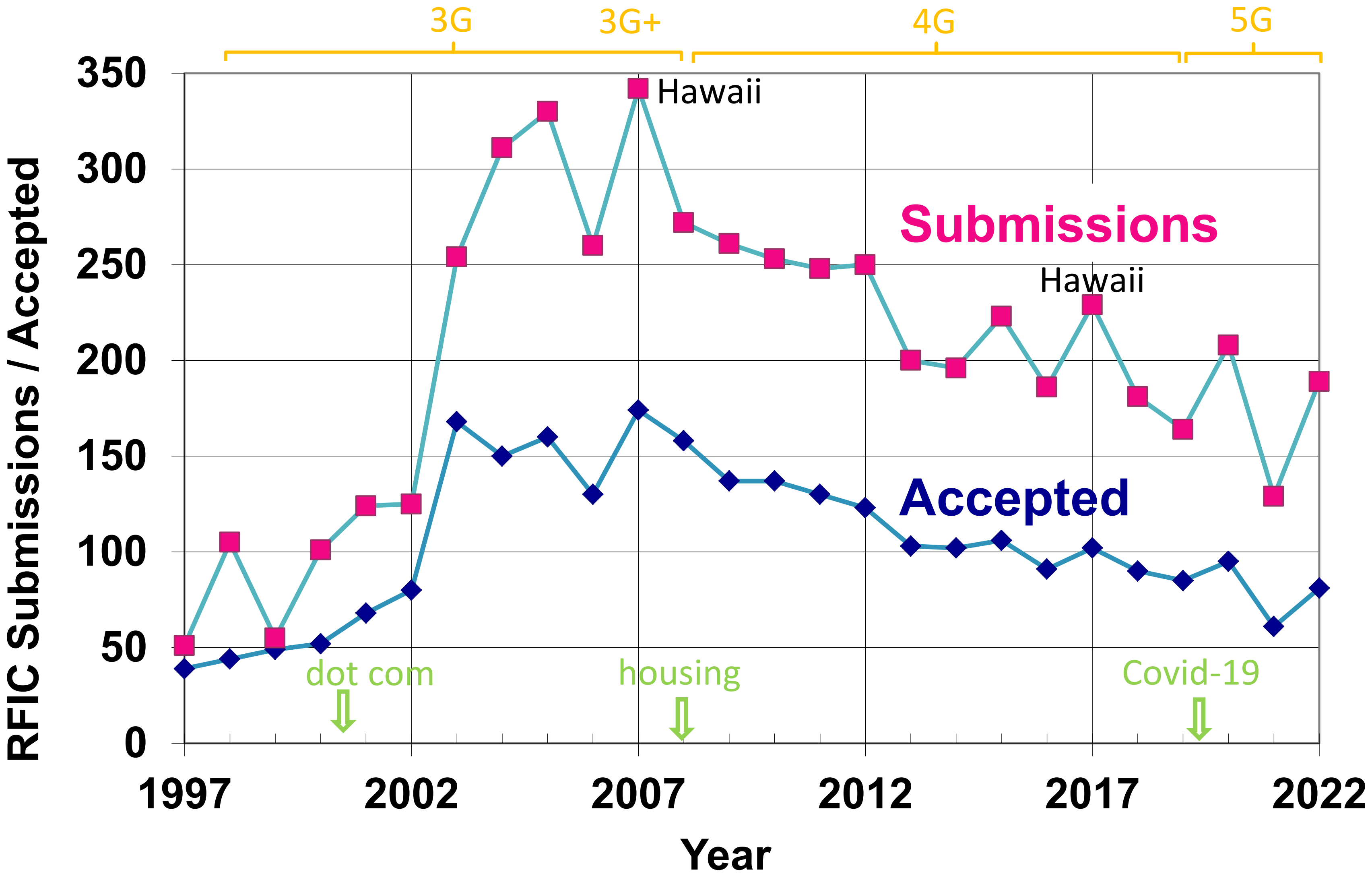
Abstract — This paper presents an integrated wide-range VCO with a modified tuning scheme to deal with VCO frequency drift over temperature. In this approach, during the coarse-tune operation, VCO tune voltage is a function of temperature such that it resembles the inverse function of VCO fine-tune characteristic. Without degrading VCO performance, the proposed temperature adaptive tuning optimizes the maximum tolerable VCO temperature frequency drift over which PLL remains locked. As a result, VCO gain can be reduced significantly, making VCO less sensitive to PLL tune voltage noise. Integrated in a multi-standard multi-band transceiver with a small VCO gain of 50MHz/V at 3.90GHz, PLL remains locked despite 45MHz frequency drift of VCO over [-30°C, 85°C]. Using an on-chip inductor, VCO covers from 3.15GHz to 4.60GHz, achieving -138.0dBc/Hz phase noise at 3.0MHz at 3.90GHz by drawing just 8.5mA from 1.60V supply in 0.13u CMOS process.

Index Terms — Wide-range VCO, VCO temperature frequency drift, VCO fine-tune, on-chip inductor, PLL

is a function of temperature which resembles the inverse function of VCO fine-tune characteristic. This guarantees that, regardless of coarse-tune temperature, PLL can remain locked despite as high VCO temperature frequency drift as VCO fine-tune range. Since this is the maximum frequency range VCO can cover without coarse-tune recalibration, the proposed approach is the optimum tuning scheme to deal with VCO temperature frequency drift. It paves the way to design a wide-range VCO with a small gain, making VCO robust to PLL tune voltage noise and spurs. The proposed scheme is implemented in the RX VCO of [1].

This note is organized as follows. The tuning process of a wide-range VCO is briefly reviewed in Section II. The proposed optimum temperature adaptive tuning, the main contribution of this paper, is presented in Section III. Design, circuit implementation and Lab measurement results are described in Section IV. The conclusions are summarized in Section V.



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- She passed away on 15 July 2014.
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