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UNITED STATES PATENT AND TRADEMARK OFFICE

BEFORE THE PATENT TRIAL AND APPEAL BOARD

INTEL CORPORATION
Petitioner

v.

QUALCOMM INCORPORATED
Patent Owner

Case IPR2019-00128

DECLARATION OF PATRICK FAY, PH.D.
U.S. PATENT NO. 9,154,356
CHALLENGING CLAIMS 1, 7, 8, 11, 17, and 18

TABLE OF CONTENTS

I. INTRODUCTION

1. My name is Patrick Fay.

2. I am a Professor with tenure in the Department of Electrical Engineering at the University of Notre Dame. I earned a Bachelor of Science in Electrical Engineering from the University of Notre Dame in 1991, a Master of Science in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1993, and a Doctorate (Ph.D.) degree in Electrical Engineering from the University of Illinois at Urbana-Champaign in 1996.

3. I have approximately 22 years of experience in the field of electrical engineering, with particular experience in the field of RF transceivers, RF front ends, and related components. I have been the Director of the Notre Dame Nanofabrication Facility since 2003 and established the High-Speed Circuits and Devices Laboratory at Notre Dame in 1998.

4. For example, I have worked and published extensively on high-frequency devices suitable for use in low noise amplifiers, mixers, and oscillators, all of which are fundamental components of RF receivers and RF front ends. I have also published on compact models needed to design circuits with these devices, as well as benchmarking studies comparing these technologies to current approaches.

5. I have taught graduate and undergraduate level courses at the University of Illinois and at Notre Dame in electrical engineering, semiconductor devices, circuit design, and microwave circuit design. I regularly teach courses in analog circuit design. I developed and teach a course on RF and Microwave Circuits for Wireless Communications that combines classwork as well as laboratory measurements and design, with a focus on RF receivers. For these efforts, I was awarded the College of Engineering's Outstanding Teacher Award in 2015.

6. I have authored or co-authored more than 150 peer-reviewed technical publications, more than 160 conference presentations, and have 9 U.S. patents, with others pending, in the areas of inter-chip communication, semiconductor devices for low-power applications, and semiconductor devices for high-frequency applications. My resume includes a sample list of these publications.

7. I was named fellow of the Institute of Electrical and Electronics Engineer (IEEE) in 2016, which is the highest grade of membership conferred by the IEEE Board of Directors on an individual member.

8. In my time as a faculty member at Notre Dame, I have received grants to support research in device technologies suitable for high-performance RF applications. This work has been supported by the Office of Naval Research (ONR), the Defense Advanced Research Projects Agency (DARPA), the National

Science Foundation (NSF), and industrial collaborators. This has enabled me to establish an externally-funded research program in high-speed electronic and optoelectronic devices and circuits.

9. A copy of my CV is attached as Appendix A.

10. I have reviewed the specification, file history (including the cited references) and claims of U.S. Patent No. 9,154,356 to Aleksandar Miodrag Tasic and Anosh Davierwalla (the "'356 patent").

11. I have reviewed and understand the following references:

- U.S. Patent Application Publication 2012/0056681 ("Lee" (EX1335-Lee))
- 3GPP TR 36.912 V9.1.0; 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) (Release 9) ("Feasibility Study" (EX1304-Study))

12. I have been retained by Intel Corporation ("Petitioner") to provide my conclusions concerning the validity of the '356 patent in connection with its petition for *inter partes* review of the '356 patent.

13. I am being compensated at my normal consulting rate of $450 per hour for my work. My compensation is not in any way dependent on the outcome of any *inter partes* review, and in no way affects the substance of my statements

in this declaration, nor have I any financial or personal interest in the outcome of this proceeding.

14. To the best of my knowledge, I have no financial interest in Petitioner, or in the ’356 patent. To the extent any mutual funds or other investments I own have a financial interest in the Petitioner or the ’356 patent, I do not knowingly have any financial interest that would affect or bias my judgment.

II. UNDERSTANDING OF THE LAW

15. I am not an attorney. For the purposes of this declaration, Petitioner’s counsel has informed me about certain aspects of the law that are relevant to my analysis and conclusions. My understanding of the law is as follows:

16. A patent is presumed valid, and a challenger to the validity of a patent must show invalidity of the patent by clear and convincing evidence. Clear and convincing evidence is evidence that makes a fact highly probable.

17. A patent claim is invalid if it is “anticipated” by prior art. For a claim to be invalid because it is anticipated, all of its requirements must have existed in a single device or method that predates the claimed invention or must have been described in a single publication or patent, either expressly, inherently, or implicitly, that predates the claimed invention.

18. The description in a written prior art reference does not have to be in the same words as the claim, but all the requirements of the claim must be there,

either stated, necessarily implied (i.e., inherent), or implied, so that someone of ordinary skill in the art, looking at that one reference, would be able to make and use the claimed invention based on the reference.

19. A patent claim is also anticipated if there is clear and convincing proof that, more than one year before the filing date of the patent, the claimed invention was: patented anywhere in the world; or described in a printed publication anywhere in the world.

20. A patent claim is invalid if the claimed invention would have been obvious to a person of ordinary skill in the art at the time the application was filed. This means that even if all the requirements of a claim cannot be found in a single prior art reference that would anticipate the claim or constitute a statutory bar to that claim, the claim is invalid if it would have been obvious to a person of ordinary skill at the time of the alleged invention. That is, the claim is obvious if the person of ordinary skill could adapt the reference to meet the claim by applying known concepts to achieve expected results.

21. The determination of whether a claim is obvious should be based upon several factors, including:

- the level of ordinary skill in the art that someone would have had at the time of the claimed invention;
- the scope and content of the prior art; and

- what differences, if any, existed between the claimed invention and the prior art.

22. In considering the question of obviousness, it is also appropriate to consider any objective indicia (or secondary considerations) of obviousness or non-obviousness that may be shown. These include:

- whether a product that practices the claimed invention has achieved commercial success, to the extent any such success is due to the merits of the claimed invention;
- whether a long-felt need existed in the prior art for the solution provided by the claimed invention;
- whether there were unsuccessful attempts by others to find the solution provided by the claimed invention;
- whether there was copying of the claimed invention by others;
- whether there were unexpected and/or superior results from the claimed invention;
- whether there was acceptance by others of the claimed invention as shown by praise from others in the field or from the licensing of the claimed invention; and

- whether there was independent invention of the claimed invention by others before or at about the same time the named inventor conceived of it.

23. I further have been informed and understand that a “nexus” must exist between the claimed invention and the alleged commercial success. In other words, proof of commercial success of a product that practices the claimed invention is not enough; there must be evidence that the commercial success resulted, at least in meaningful part, from the claimed invention.

24. I have been informed and understand a patent claim composed of several elements is not obvious merely because each of its elements was independently known in the prior art. In evaluating whether such a claim would have been obvious, it is relevant to consider if there would have been a reason that would have motivated a person of ordinary skill in the art to combine the known elements or concepts from the prior art in the same way as in the claimed invention. For example, market forces or other design incentives may be what produced a change, rather than true inventiveness. It is also appropriate to consider:

- whether the change was merely the predictable result of using prior art elements according to their known functions, or whether it was the result of true inventiveness;

- whether there is some teaching or suggestion in the prior art to make the modification or combination of elements claimed in the patent;
- whether the innovation applies a known technique that had been used to improve a similar device or method in a similar way; or
- whether the claimed invention would have been obvious to try, meaning that the claimed innovation was one of a relatively small number of possible approaches to the problem with a reasonable expectation of success by those of ordinary skill in the art.

25. In considering obviousness, it is important to be careful not use the benefit of hindsight.

26. A single prior art reference can alone render a patent claim obvious, if any differences between that reference and the claims would have been obvious to a person of ordinary skill in the art at the time of the alleged invention—that is, the patent claim is obvious if a person of ordinary skill could readily adapt the prior art reference to meet the claim by applying known concepts to achieve expected results.

27. I have been informed that claim construction is a matter of law and that the final claim construction will ultimately be determined by the Board. For the purposes of my analysis in this proceeding and with respect to the prior art, I have been informed that patents are currently reviewed in an *inter partes* review

(IPR) proceeding under the “broadest reasonable interpretation” standard (hereinafter “BRI standard”).

28. I have been informed that the BRI standard refers to the broadest reasonable interpretation that a person of ordinary skill in the art would give to a claim term in light of the specification.

29. I have been informed that under the Phillips standard, claim terms are generally given their plain and ordinary meaning as understood by a person of ordinary skill in the art at the time of the invention, with the claim term read not only in the context of the particular claim in which the disputed term appears, but also in the context of the entire patent, including the specification.

30. I have been informed that the Patent Owner can serve as his or her own lexicographer. As such, if a claim term is provided with a specific definition in the specification, that claim term should be interpreted in light of the particular definition provided by the Patent Owner.

III. BACKGROUND TECHNOLOGY

31. I understand that the ’356 patent issued from U.S. App. No. 13/590,423, which was filed on August 21, 2012, and that it claims priority to provisional application U.S. Provisional Application No. 61/652,064, which was

filed on May 25, 2012.[1] The apparatus described in the ’356 patent involves several well-known components and design principles for low noise amplifiers within a radio frequency (RF) receiver configured to support carrier aggregation (CA). In this section, I explain the basic operation and characteristics of such front-end receivers and low noise amplifiers, as well as the principles behind carrier aggregation. This information was well known in the art before the Patent Owner’s alleged conception date for the ’356 patent.

A. Basic Receiver Front End

32. A wireless communication system is a system for transmitting and receiving signals using radios. A receiver within a wireless device, such as a cellular phone, receives radio frequency signals from various base stations, such as cell towers. Each radio frequency signal may fall within a particular radio ***frequency band***, which defines a range of frequencies in the electromagnetic spectrum. In the United States, the FCC allocates radio frequency bands for specific uses, such as FM radio broadcasts or maritime navigation. Each

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[1] For purposes of this declaration, I consider May 25, 2012 to be the earliest priority date of the ’356 patent. I have been informed and understand that Patent Owner has alleged a conception date of March 25, 2012, in a related matter. The concepts I describe in this declaration were known before that date.

frequency band contains different ***carriers***, which are subcomponents of the frequency band used to carry information. Carriers are analogous to channels in terrestrial broadcast systems (e.g., FM radio) in that each carrier may contain different information. Additionally, in typical wireless communication applications (e.g. cellular telephony) carriers can be dynamically assigned to specific users or applications. For instance, a carrier may be used to transmit a voice call to one user, and subsequently to provide data for another user.

33. A wireless device contains an antenna that picks up radio frequency signals from the air. Antennas are not selective and capture both desired and undesired signals, including signals that are not of interest to the user or wireless device and signals on frequency bands assigned for other purposes. In order to extract the desired information from the received signals, the receiver removes the undesired signals to process only the frequencies on which the relevant information is carried. To do so, the receiver filters the signal captured by the antenna, amplifies the signal frequencies that remain after filtering, and down converts[2] the signal using "mixers" to enable further processing. Figure 1, shown below, is an illustration of the "direct-conversion" receiver used in the '356 patent (*see* EX1301-'356-Patent at Fig. 4B) that includes an antenna for receiving the

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[2] Down conversion centers the frequencies in a signal at a lower frequency range.

signals (in light blue), a low noise amplifier for amplifying the signals (in red), mixers for down conversion (in navy), and various filters for removing undesired signals (in yellow and green).

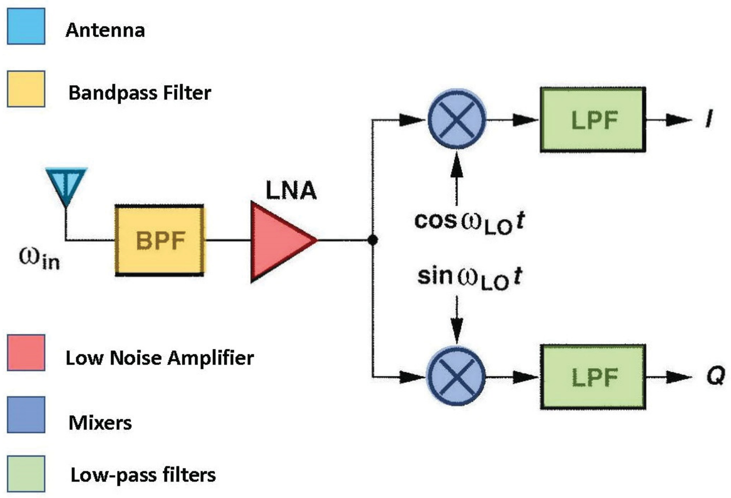

Figure 1. A direct-conversion receiver containing an antenna, a band-pass filter, a low noise amplifier, and two mixers coupled to low-pass filters.

34. The antenna in the receiver shown in Figure 1 captures a variety of signals from the air. The band-pass filter (BPF) attenuates (effectively removes) all frequencies that fall outside the desired frequency band.[3] The low noise

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[3] Attenuation is the opposite of amplifying. Although an amplifier increases the power, or amplitude, of a signal, resulting in a "gain," a filter decreases the amplitude of undesired frequencies.

amplifier increases the power of the remaining carriers.[4] Finally, the mixers down convert the signal to enable the low-pass filters (LPFs) to extract the relevant information on particular carriers. The '356 patent implements the same basic receiver structure, which was commonly used in wireless communication systems before the Patent Owner's alleged conception date for the '356 patent. *See,* e.g., EX1301-'356-Patent at Fig. 4B. I have drawn Figures 2-5 below to illustrate these various processing steps.

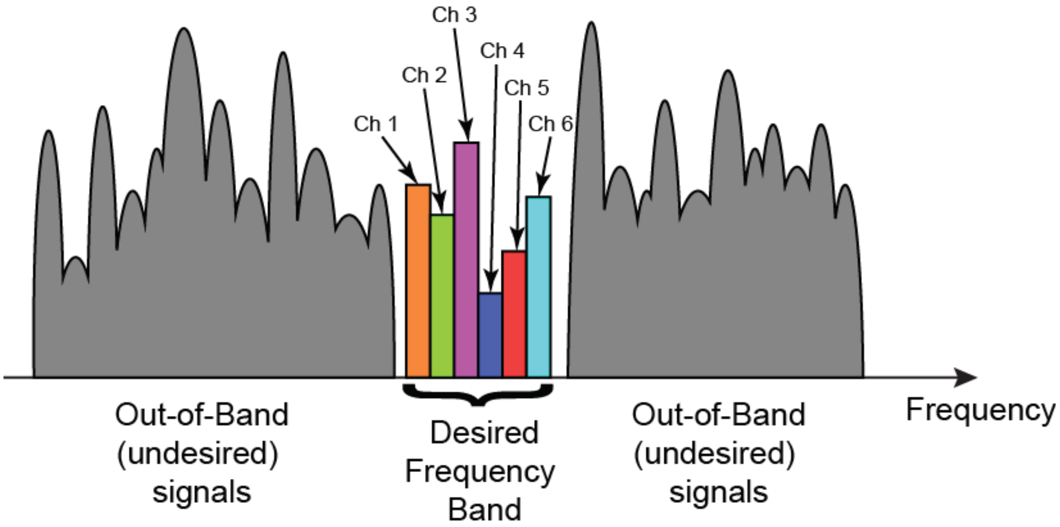

Figure 2. The antenna receives signals over a wide range of frequencies, only some of which carry the desired information.

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[4] The amplification – or increase in the power of the signal – is called its "gain."

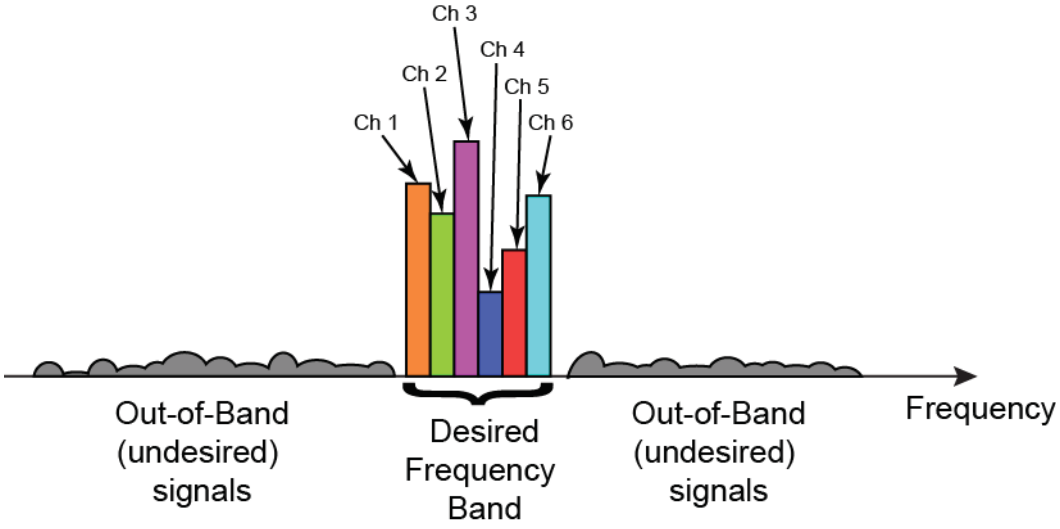

Figure 3. A band-pass filter reduces the power of frequencies outside the desired frequency band, effectively removing them.

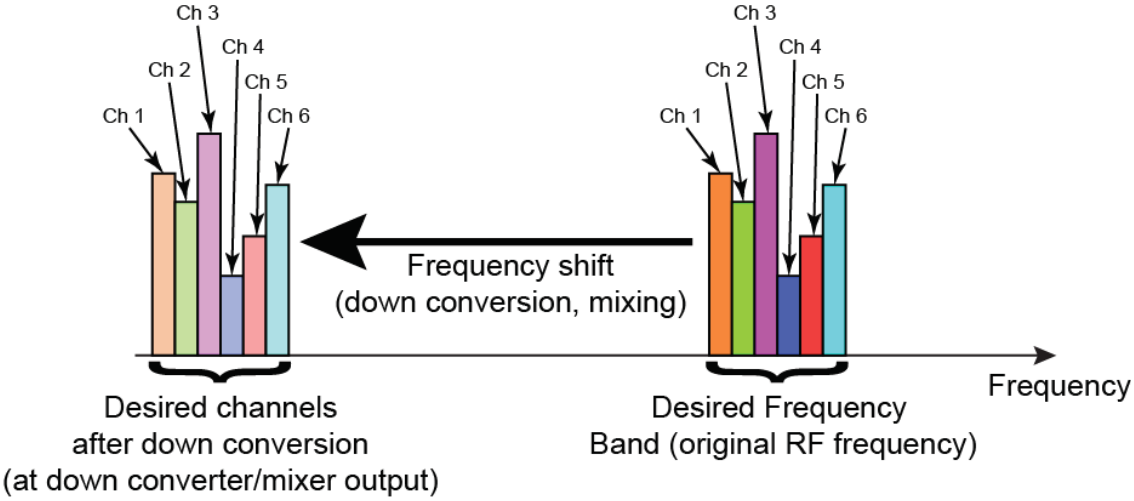

Figure 4. A mixer shifts the frequencies to a lower range, in order to enable further processing.

Figure 5. Additional filters, such as a low-pass filter, further refine the signal to select the specific carrier of interest (Ch 2 in this illustration).

B. Low Noise Amplifiers

35. A low noise amplifier ("LNA") is a well-known and widely used component of the receiver front-end. The purpose of the LNA is to increase the power of a received signal while introducing minimal "noise."[5] In addition to providing amplification, LNA designers must also consider a number of other issues, including gain control and impedance matching, which I describe below.

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[5] Noise refers to random variation in a signal that does not carry information. The signal-to-noise ratio quantifies the proportion of meaningful information compared to non-meaningful variation.

1. Cascode Configuration

36. A cascode configuration of an amplifier improves isolation, gain, and bandwidth by using two components called transistors[6] arranged in a vertical, or stacked, configuration, instead of a single transistor. Cascode amplifiers include a common source "transconductance" transistor that receives an input voltage signal (Vin) and converts it to current with an applied gain, and a common gate "cascode" transistor that couples the current to the output signal. In Figure 6 below, Q1 is the ***transconductance*** transistor, while Q2 is the ***cascode*** transistor.

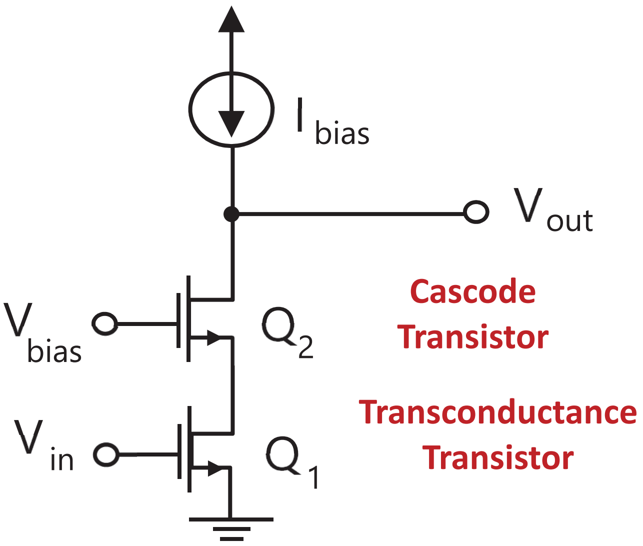

Figure 6. Cascode Amplifier: Q1 is the transconductance transistor and Q2 is the cascode transistor.

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[6] A transistor is a basic component of amplifier design. A transistor can act either as a switch or as an amplifier.

37. An amplified output signal (Vout) requires current to flow through the amplifier. For current to flow, voltage signals must be applied to the gates of ***both*** the transconductance transistor and the cascode transistor. For example, if the bias voltage (Vbias) provided to the gate of the cascode transistor is too low, no output will be provided from the amplifier even if the transconductance transistor continues to receive the RF input voltage signal (Vin). Thus, supplying too low of a voltage to the gates of either transistor in a cascode amplifier effectively disables the amplifier.

38. The cascode configuration is a decades-old idea that remains a popular choice for amplifier design due to its improved performance characteristics. Indeed, the ’356 patent uses the cascode configuration in the typical fashion of RF communication systems to achieve the known benefits, as was known at the time of the Patent Owner’s alleged conception date for the ’356 patent.

C. Carrier Aggregation

39. Information can be transmitted using a single carrier between the transmitter and the receiver by encoding information on a single base frequency occupying a particular frequency range. A technique called carrier aggregation (“CA”), however, allows for the transmission of data on multiple carriers to or from a radio. Related or unrelated data may be encoded on different carriers and

received simultaneously for concurrent processing. Simultaneous processing can increase the data rate between the transmitter and receiver by allowing information to be extracted from multiple carriers at the same time.

40. Increasing download speeds is one of many uses of carrier aggregation. By transmitting related or unrelated information over multiple carriers, carrier aggregation can increase the bandwidth available for transmission. Carrier aggregation also allows mobile network operators to more efficiently deploy available spectrum and make use of "fragmented spectrum."[7] Aggregating fragmented spectrum increases network throughput even as the total amount of bandwidth remains constant. As another example, carrier aggregation can be used to enhance "wireless backhaul," which refers to back-end

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[7] A mobile network operator may own a certain frequency spectrum allocation, i.e. ranges of frequencies under the operator's control. Some of those frequency ranges may be broken up, or separated, by spectrum that the operator does not own, such as frequency bands owned by others or allocated for other purposes. This creates "fragmented spectrum" and makes some frequency ranges too narrow to transmit high-speed data on their own. Carrier aggregation allows the operator to piece these fragments together to create larger effective bandwidth for use in transmission of data.

communications between central and peripheral nodes in a communication network. For example, a corporate internet network can transmit data to an Internet Service Provider (ISP) using multiple carriers, which enhances overall network performance.

41. Carrier aggregation can be divided into three categories. Carrier aggregation between or among carriers that are next to each other in the frequency spectrum is called ***intra-band contiguous carrier aggregation***. Carrier aggregation between or among carriers that are in the same frequency band but not directly adjacent to each other in frequency spectrum is called ***intra-band non-contiguous carrier aggregation***. Finally, carrier aggregation between carriers in different frequency bands is called ***inter-band carrier aggregation***. I have illustrated these varieties of carrier aggregation in Figure 7, below. The green channels indicate the carriers being aggregated.

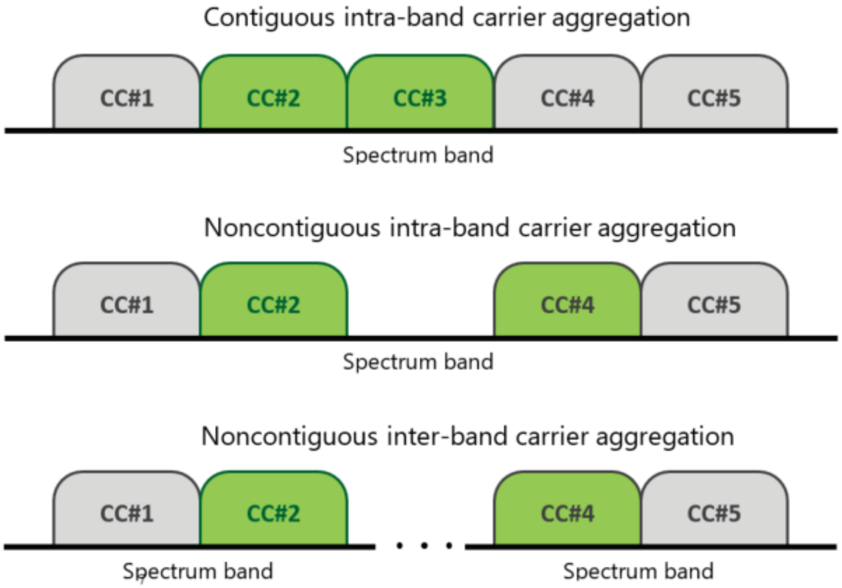

Figure 7. (a) Contiguous intra-band CA, (b) noncontiguous intra-band CA, and (c) inter-band CA.

42. Because of the bandwidth requirements for processing far-apart carriers, a receiver configured for carrier aggregation typically uses multiple RF front-ends on different receive paths. Each receive path supports a particular range of carriers. As an example, one receive path may support carriers in a first frequency band, while another receive path may support carriers in a different frequency band. Figure 8, below, shows one example of a receiver configured to support carrier aggregation by sending different carriers to different receive paths. The ’356 patent also uses multiple receive chains to support carrier aggregation because it has multiple “amplifier stages” for different sets of carriers, with each

set of carriers processed by a different amplifier stage and corresponding mixer to support carrier aggregation. *See* EX1301-’356-Patent at 8:10-12, 8:32-35.

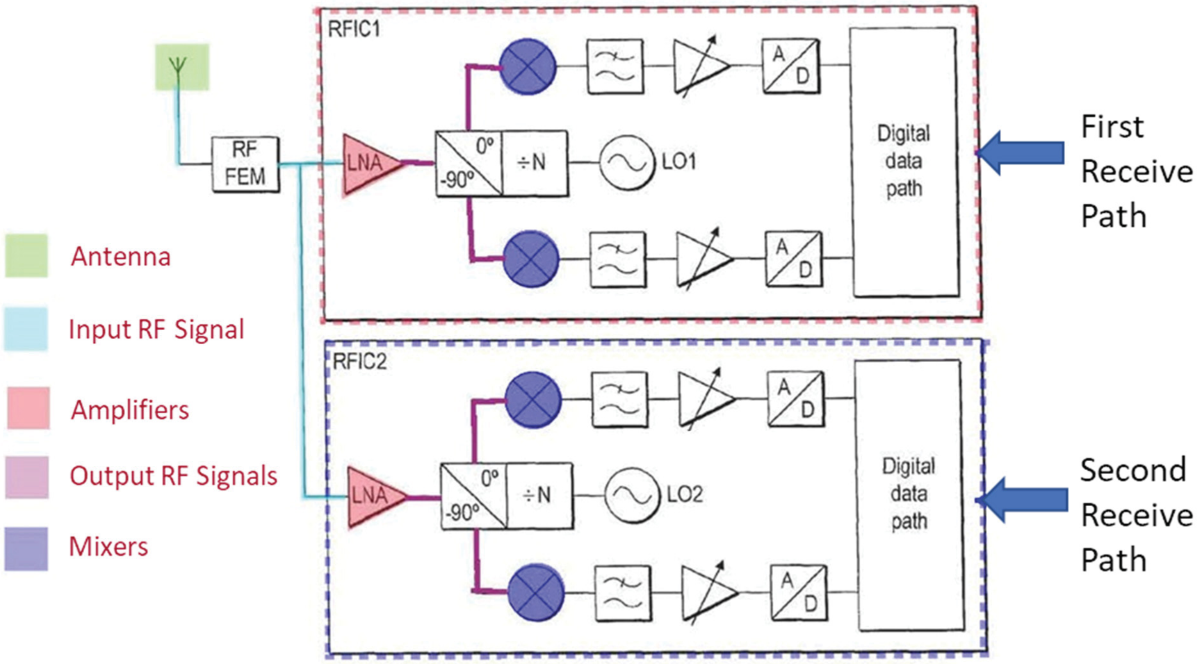

Figure 8. A carrier-aggregation enabled receiver with two receive paths. Source: U.S. Patent No. 8,442,473 (“Kaukovuori” (EX1325-Kaukovuori))

D. Optional Receiver Circuits

43. In order to address various challenges in LNA design, a variety of design techniques and circuits are used, a few of which I describe below.

1. Impedance Matching Circuits

44. LNA design must also address the issue of impedance matching. Impedance is the effective resistance of a circuit to current flow when voltage is

applied. If the impedance of the ***source***—the electrical component that provides the signal power—is not commensurate with the impedance of the ***load***—the electrical component that consumes power—some of the signal may be reflected and power transfer is not maximized. To avoid this problem, LNA designers typically use impedance matching circuits that ensure proper conditions for maximizing power transfer, minimizing signal reflection, and establishing a low noise figure.

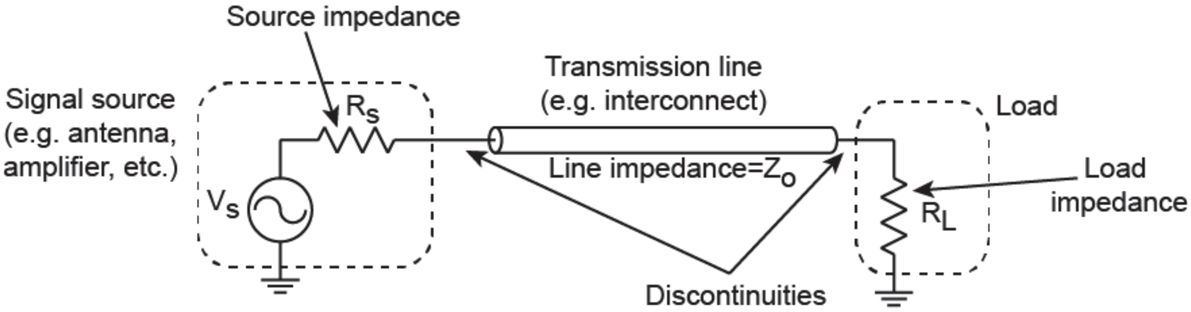

Figure 9. Impedance mismatch due to discontinuities, which may result in signal reflection and suboptimal power transfer.

45. An impedance matching circuit is one solution to the problem of impedance matching. An impedance matching network operating at the input stage is called an input matching circuit or network, while an impedance matching network operating at the output is an output matching network. Many topologies can be used for an impedance matching network, such as the L-network, shown in Figure 10, below.

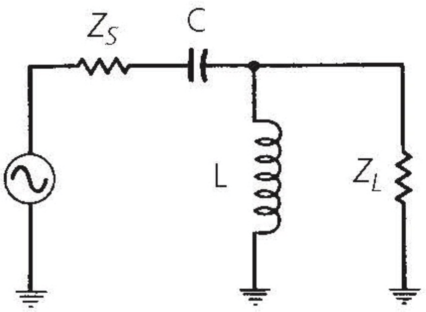

Figure 10. An impedance matching circuit arranged in an L topology.

46. Traditional impedance matching circuits provide ideal impedance matching at only one frequency. Thus, to achieve optimal impedance matching at a variety of different frequencies, LNA designers have turned to tunable matching networks that use components with variable electrical characteristics. Tunable impedance matching networks have become well-known in recent decades and were used before the ’356 patent, and those of ordinary skill in the art knew of the advantages and tradeoffs of using tunable impedance matching networks. For example, tunable matching networks provide higher performance and better noise figure at the acceptable expense of modestly increased complexity and reduced bandwidth relative to the other techniques (e.g., use of source degenerative inductors, feedback-based approaches, or broadband attenuators). The ’356 patent applies the idea of tunable matching circuits in a standard way to provide impedance matching and improved noise figure in different modes, as was known

in the field of RF communication systems before the Patent Owner’s alleged conception date for the ’356 patent. *See* EX1301-’356-Patent at 13:47-51.

2. Feedback Circuit

47. A feedback circuit can improve the stability of a signal processing circuit or system by providing feedback. The feedback circuit may be installed between the input and output of an amplifier and reduces the level of the amplifier’s input based on the level of the amplifier’s output. The amount of input reduction can be a fraction of the output value. This reduces the gain of the signal, while also reducing the effect of random variations on the amplified signal. A feedback circuit can also improve the input and output impedance matching, which can increase bandwidth. For this reason, feedback circuits are often selected when other performance characteristics take priority over maximizing the gain of the amplifier. Feedback circuits are also a century-old idea that are commonly used in circuit design. The ’356 patent applies the feedback circuit concept in the typical fashion by using them in addition to or as a substitute for matching network circuits to achieve the same benefits of impedance matching, as was known before the Patent Owner’s alleged conception date for the ’356 patent. *See* EX1301-’356-Patent at 10:35-41.

3. Inductors

48. An inductor is a basic electrical component that can be used to provide impedance matching and improve the linearity of an amplifier either in place of or in addition to an input matching network. In particular, when used in the "source degeneration" configuration within an LNA, the input impedance, noise figure, and linearity of an LNA can be improved. An inductor stores electrical energy when current flows through it, which results in an effective impedance that influences the signal. Unlike resistive circuit elements, inductors add little noise because they are (approximately) lossless circuit elements. Inductors, particularly if placed in series with the source of a common-source transistor, may be used in addition to, or in place of, other feedback circuits and/or impedance matching circuits to achieve similar benefits. In fact, the '356 patent uses inductors as an alternative to, or in addition to, feedback circuits; this was a known approach in the field of communication systems before the Patent Owner's alleged conception date for the '356 patent. *See* EX1301-'356-Patent at 10:35-40, 10:56-59.

IV. OVERVIEW OF THE '356 PATENT

49. The '356 patent describes its invention as an LNA that "support[s] carrier aggregation" and that "may have better performance and may be used for various types of electronic devices such as wireless communications devices."

EX1301-’356-Patent at 2:22-25. The ’356 patent achieves the alleged improved performance through the use of multiple amplifier stages. Each amplifier stage receives and amplifies a carrier-aggregated input RF signal and provides a separate output to a different load circuit. EX1301-’356-Patent at Abstract. The LNAs of the ’356 patent also support a non-carrier aggregation mode by disabling additional amplifier stages. *Id*. at 8:45-54. I have examined the claims, specification, and prosecution history, which confirm my understanding.

A. Independent Claim 1

50. Claim 1 relates to a low noise amplifier with a first amplifier stage and a second amplifier stage to amplify an input radio frequency (RF) signal employing carrier aggregation. EX1301-’356-Patent at 20:43-61. The first amplifier stage is configured to be independently enabled or disabled, and the second amplifier stage is configured to be independently enabled or disabled. *Id.* at 20:44-45, 20:54-55. In a carrier-aggregation mode, both amplifier stages are enabled, and each amplifier stage receives and amplifies a common input RF signal and provides a separate output RF signal to a different load circuit. *Id.* at 20:44-48. Each output RF signal includes a different carrier of the multiple carriers. *Id.* at 20:51-53, 20:58-61. I have annotated Figure 4B of the ’356 patent, shown below, to illustrate this operation.

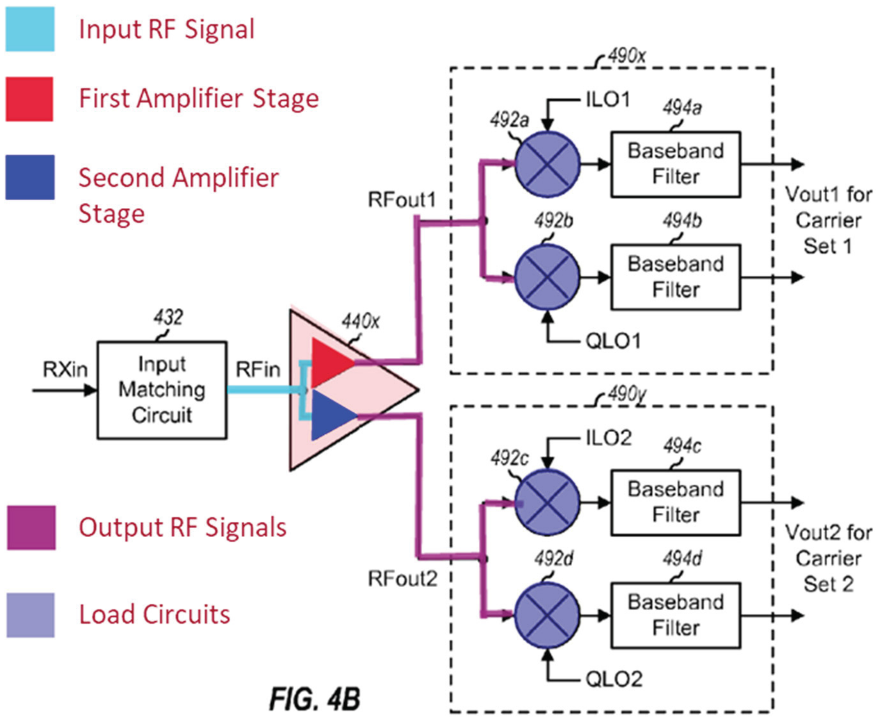

FIG. 4B

('356 Patent, FIG. 4B)

51. Figure 6A, reproduced below, shows a more detailed view of the LNA supporting carrier aggregation. It includes two amplifier stages, first amplifier stage 650a and second amplifier stage 650b, comprising a transconductance transistor (called a "gain" transistor) and a cascode transistor.[8] EX1301-'356-Patent at 7:47-60. The gates of the respective gain transistors (654a and 654b) receive the input RF signal, RFin; their drains are coupled to the source of the

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[8] In the '356 patent, the specification refers to transconductance transistors as "gain" transistors. Transconductance transistors provide "transconductance gain."

cascode transistors (656a and 656b), and their sources are coupled to ground through the source degeneration inductors 652a and 652b. *Id.* at 7:49-52, 7:63-66, 8:4-9, 8:24-28. The drains of the cascode transistors, 656a and 656b, are coupled to different load circuits, 690a and 690b. *Id*. at 7:66-8:01. Switches 658a and 658b connect the gates of the cascode transistors to either bias voltage, Vcasc, or to circuit ground, to enable or disable the amplifiers, respectively. *Id*. at 8:01-04. The amplifier arrangement shown in Figure 6A is the well-known "cascode" design that has been used decades before the '356 patent.

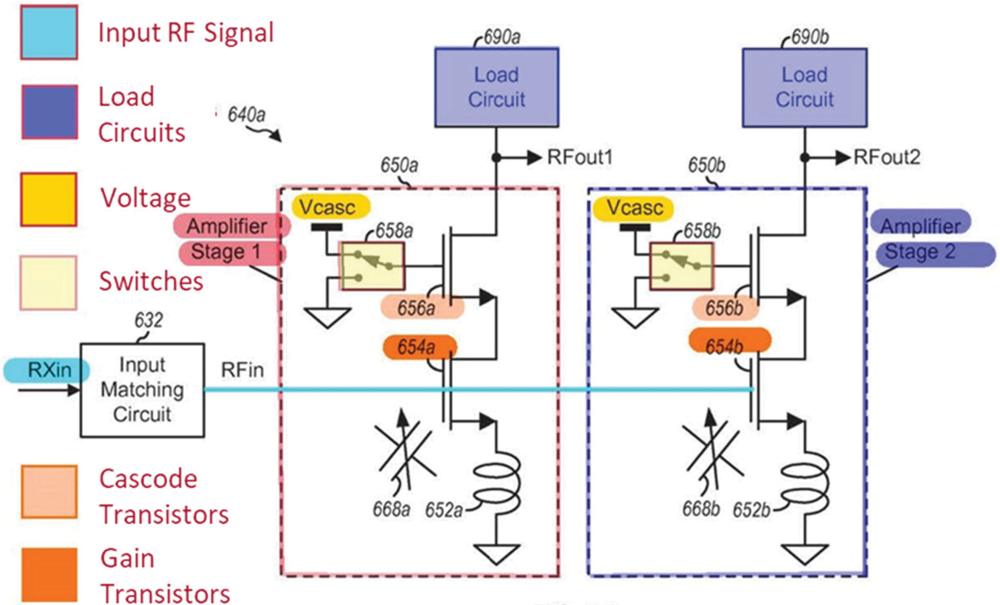


FIG. 6A

('356 Patent, FIG. 6A)

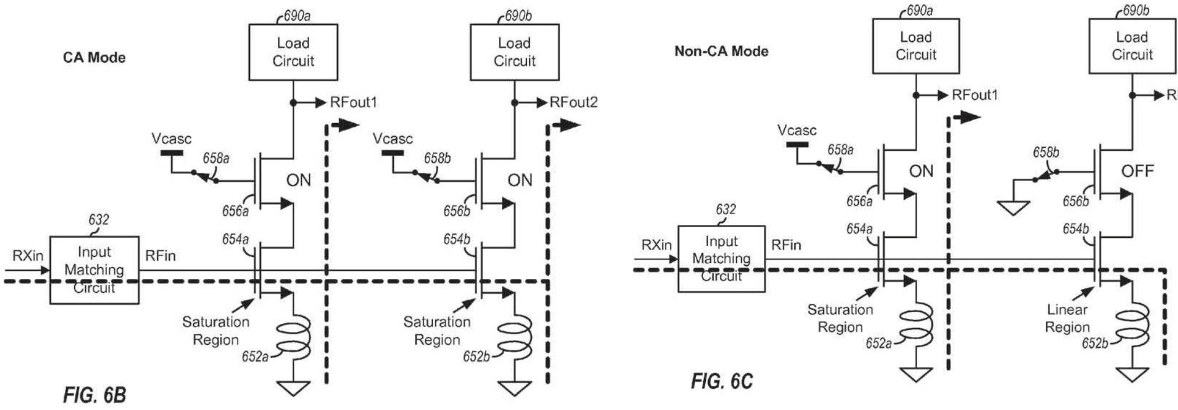
52. When an amplifier stage is enabled, the switch 658a or 658b connects the gate of the respective cascode transistor to the bias voltage Vcasc to enable

current to flow. *See* EX1301-'356-Patent at 8:4-9, 8:12-13, 8:36-59. The input matching circuit 632 receives the receiver input signal, RXin, and provides an input RF signal, RFin, to the amplifier stage. *Id*. at 7:47-52.

53. The gain transistor, 654a or 654b, converts the input RF voltage signal received at its gate terminal to a corresponding current signal at its drain terminal, while providing some amplification (*see* Section III.B.1 discussion of transconductance), and the cascode transistor, 656a or 656b, receives the signal from the gain transistor and provides the amplified output to either the first or the second load circuit, 690a or 690b. *See id.* at 8:1-4, 8:12-13, 8:37-42. When the amplifier stage is disabled, the switch 658a or 658b connects the gate of the cascode transistor to ground, which prevents current from flowing. *See id.* at 8:4-9, 8:47-57. The input matching circuit 632 continues to provide the input RF signal to both amplifier stages. However, because the gate of the cascode transistor 656a and/or 656b is connected to circuit ground, current does not flow, and no output signal is provided. *See id.* at 8:4-9, 8:12-13, 8:36-59. Switch 658a permits the first amplifier stage to be enabled or disabled independently. Meanwhile, switch 658b permits the second amplifier stage to be enabled or disabled independently.

54. The independent enabling or disabling of amplifier stages allows the LNA of the '356 patent to support both carrier aggregation and non-carrier

aggregation in different modes. In the carrier aggregation mode, both amplifier stages are enabled, and both amplify and provide output to their respective load circuits. *See* EX1301-'356-Patent at 8:37-44. In the non-carrier aggregation mode, only one amplifier stage is enabled and providing output. *Id*. at 8:46-47. In the figures below, the dashed arrows illustrate signal paths in the carrier aggregation and non-carrier aggregation modes of operation.



('356 Patent, FIGs. 6B-6C)

B. Independent Claim 17

55. Claim 17 of the '356 patent describes a method using an amplifier similar to the one recited in claim 1. Claim 17 differs from claim 1 in that the second amplifier stage can receive the same or a different input RF signal, which may not employ carrier aggregation, and the output RF signals do not have to be provided to a load circuit. EX1301-'356-Patent at 22:21-23.

V. LEVEL OF ORDINARY SKILL IN THE ART

56. A person of ordinary skill in the art at the time of the alleged invention would have had at least an M.S. degree in electrical engineering (or equivalent experience) and would have had at least two years of experience with the structure and operation of RF transceivers and related structures (or the equivalent).

57. I exceeded these requirements for one of ordinary skill in the art at the Patent Owner's alleged conception date for the '356 patent.

VI. CLAIM CONSTRUCTION

58. My invalidity analysis does not depend on whether the claims are analyzed under the broadest reasonable interpretation standard or the possible alternative constructions discussed below. The claims are anticipated and/or obvious under all these constructions.

A. "carrier aggregation"

59. The term "carrier aggregation" appears in challenged claims 1 and 17 in the phrase "input RF signal employing carrier aggregation." EX1301-'356-Patent at 20:49. 22:17-18. "Carrier aggregation" in the '356 patent means "simultaneous operation on multiple carriers." This construction comes directly from the specification, which defines the term. *See* EX1301-'356-Patent at 1:32-33 ("A wireless device may support ***carrier aggregation, which is simultaneous***

operation on multiple carriers." (emphasis added)); *id.* at 2:53-54 ("Wireless device 110 may support ***carrier aggregation, which is operation on multiple carriers***." (emphasis added)); *id.* at 2:54-55 ("Carrier aggregation may also be referred to as multi-carrier operation."); *see also id*. at 1:33-35 ("A carrier may refer to a ***range of frequencies*** used for communication and may be associated with certain characteristics." (emphasis added)).

60. This construction is consistent with the understanding of persons having ordinary skill in the art. As described above, carrier aggregation is commonly understood to mean sending data to or from a radio on multiple carriers at the same time. Carrier aggregation is known to have multiple uses and is not limited to any particular use. In light of this multi-purpose operation, it is my conclusion that "simultaneous operation on multiple carriers" captures the meaning of "carrier aggregation" to a person having ordinary skill in the art.

61. In a related matter *Certain Mobile Electronic Devices and Radio Frequency and Processing Components Thereof*, Investigation No. 337-ITC-1093, the Patent Owner agreed "carrier aggregation" includes "simultaneous operation on multiple carriers" but also argued that "carrier aggregation" required increased

bandwidth for a user and/or increased "aggregated" data rate.[9] This construction is narrower than the construction which, in my view, is the broadest reasonable interpretation, because it specifies only one use of the multi-carrier operation out of the other possible uses I describe above in Section III.C. In any event, the difference is not material to my invalidity analysis here; the prior art I have relied on in my discussion below discloses multi-carrier operation that a person of ordinary skill would have recognized as resulting in increased bandwidth for a user of a wireless receiver and/or increased data rate. I conclude, therefore, that the challenged claims are anticipated and/or obvious under either construction.

VII. SUMMARY OF THE PRIOR ART REFERENCES

A. U.S. Patent Application Publication 2012/0056681 ("Lee")

62. As Patent Owner admitted in the ITC1093 Investigation, Lee discloses the key limitations—a first amplifier stage configured to be independently enabled or disabled and a second amplifier stage configured to be independently enabled or disabled—that the Examiner believed were missing from the prior art and that were the basis for the decision to allow the '356 patent. EX1337-ITC at 2190:8-25. Patent Owner also admitted that Lee discloses every limitation of the

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[9] The Administrative Law Judge construed "carrier aggregation" as "simultaneous operation on multiple carriers" in the related matter Inv. No. 337-ITC-1093.

challenged independent claims other than the "carrier aggregation" limitation. EX1337-ITC at 2174:9-24, 2190:8-25. As explained, below, Lee also teaches carrier aggregation. While Lee is listed as a cited reference on the '356 patent, along with 350 other references, it was not applied by the Examiner during prosecution. Lee teaches LNAs (referred to as "signal amplification circuits") that can "support several different kinds of radio connections," such as Bluetooth and WiFi. EX1335-Lee ¶¶2-3. Lee teaches using one LNA shared between different radio connections to "reduce the hardware cost and the chip size of the multi-radio device." *Id.* ¶2. Lee thus teaches an LNA that "can receive / transmit signals according to one input." *Id.* Figure 2 of Lee shows a signal amplification circuit capable of supporting multiple simultaneous radio connections. The signal amplification circuit 200 "includes a plurality of amplifier blocks 202_1-202_N" which are outlined below in red and blue in an annotated Figure 2. *Id.* ¶26.

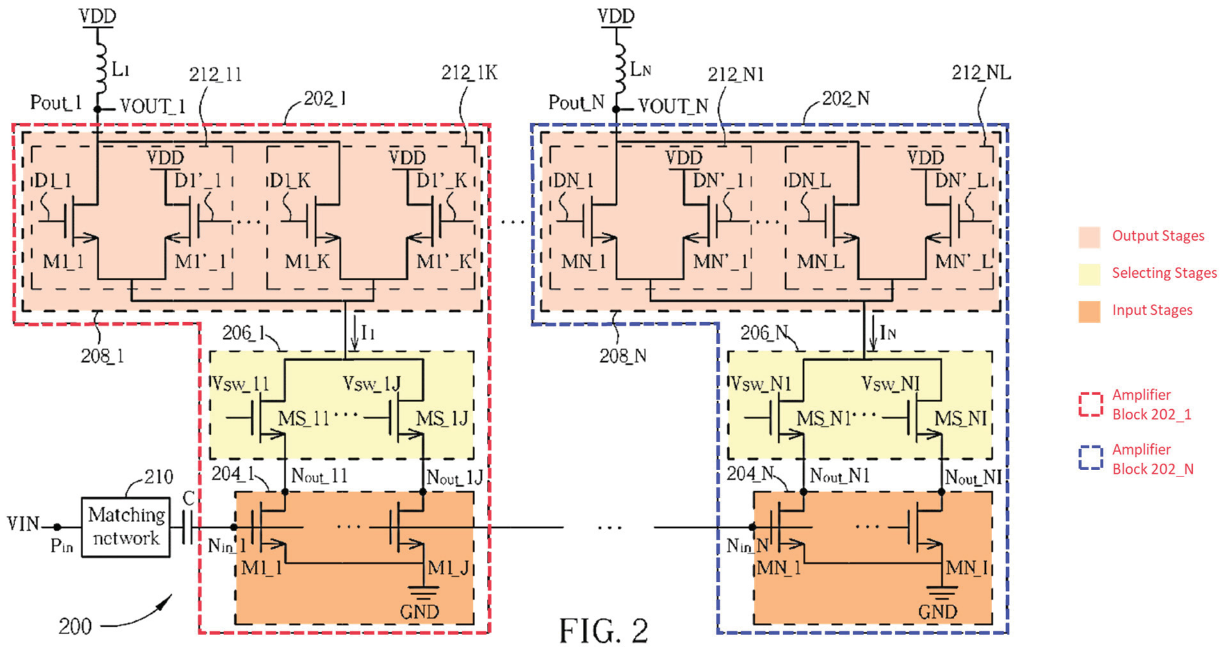

FIG. 2

63. Each amplifier block includes (1) an "input stage" 204 (highlighted in dark orange), (2) a "selecting stage" 206 (highlighted in yellow), and (3) multiple "output stages" 208 (highlighted in light orange).[10] *Id.* The input stage receives "an input signal VIN" on its input node, Nin. *Id.* The selecting stage "selectively couple[s] the input stage . . . to the output stage." *Id.* ¶27. The output stages "are coupled to a plurality of output ports Pout_1-Pout_N" and "generate a plurality of

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[10] Lee refers to each stage with reference to the amplifier block in which it is found. For instance, Lee refers to input stage "204_1" to designate the input stage of amplifier block 1, and input stage "204_N" to designate the input stage of amplifier block N. *See* EX1335-Lee ¶26.

processed signals VOUT_1-VOUT_N, respectively" for corresponding output ports. *Id*. ¶¶28, 35.

64. Each amplifier block supports a different type of radio connection by providing output to a different radio signal processing system. *Id*. ¶29. For example, in Figure 2, "the output port Pout_1 is coupled to a first radio signal processing system (e.g., a WiFi receiver/transmitter) and the output port Pout_N is coupled to a second radio signal processing system (e.g., a Bluetooth receiver/transmitter)," so that amplifier block 202_1 supports a WiFi connection, while amplifier block 202_N supports a Bluetooth connection. *Id.*

65. The amplification circuit can operate in different modes depending on the number of signals on the input VIN. In a "shared" mode, the input VIN contains only one radio signal, so only one of the amplifier blocks 202_1-202_N is enabled, while the others are disabled. For example, "when only the WiFi function of the multi-radio device is required to be active . . . , the output stage 208_1 is enabled" for "generating the corresponding processed signal VOUT_1," while "the output stages in the remaining amplifier blocks are disabled." EX1335-Lee ¶33. Similarly, "when only the Bluetooth function of the multi-radio device is required to be active . . . , the output stage 208_N is turned on, whereas all of the output stages in the remaining amplifier blocks are disabled." *Id.* However, in a "combo mode," the input VIN contains both a WiFi and Bluetooth

signal, such that "both of the WiFi function and Bluetooth function of the multi-radio device are required to be active," and "the output stages 208_1 and 208_N are both enabled at the same time." *Id.*

66. The signal amplification circuit 200 of Lee effectuates the different modes by independently enabling or disabling the output stages. EX1335-Lee ¶33. For example, if output stage 208_1 is required for generating the corresponding processed signal VOUT_1, "the output stage 208_1 is enabled by making each of the transistor element pairs 212_11-212_1K have one turned on transistor element and one turned-off transistor element." *Id.* On the other hand, if output stage 208_1 is not required to be enabled for generating the signal VOUT_1, "the output stage 208_1 is disabled by turning off both of the first transistor element and the second transistor element included in each of the transistor element pairs 212_11-212_1K." *Id.* The transistor elements can be turned off using control signals D1 (e.g., for amplifier block 202_1) to DN (e.g., for amplifier block 202_N). *Id.* An annotated version of Lee Figure 2, below, illustrates the "shared" mode in which the first amplifier block 202_1 is enabled, while the second amplifier block 202_N is disabled, using the output stages 208_1 and 208_N, respectively.

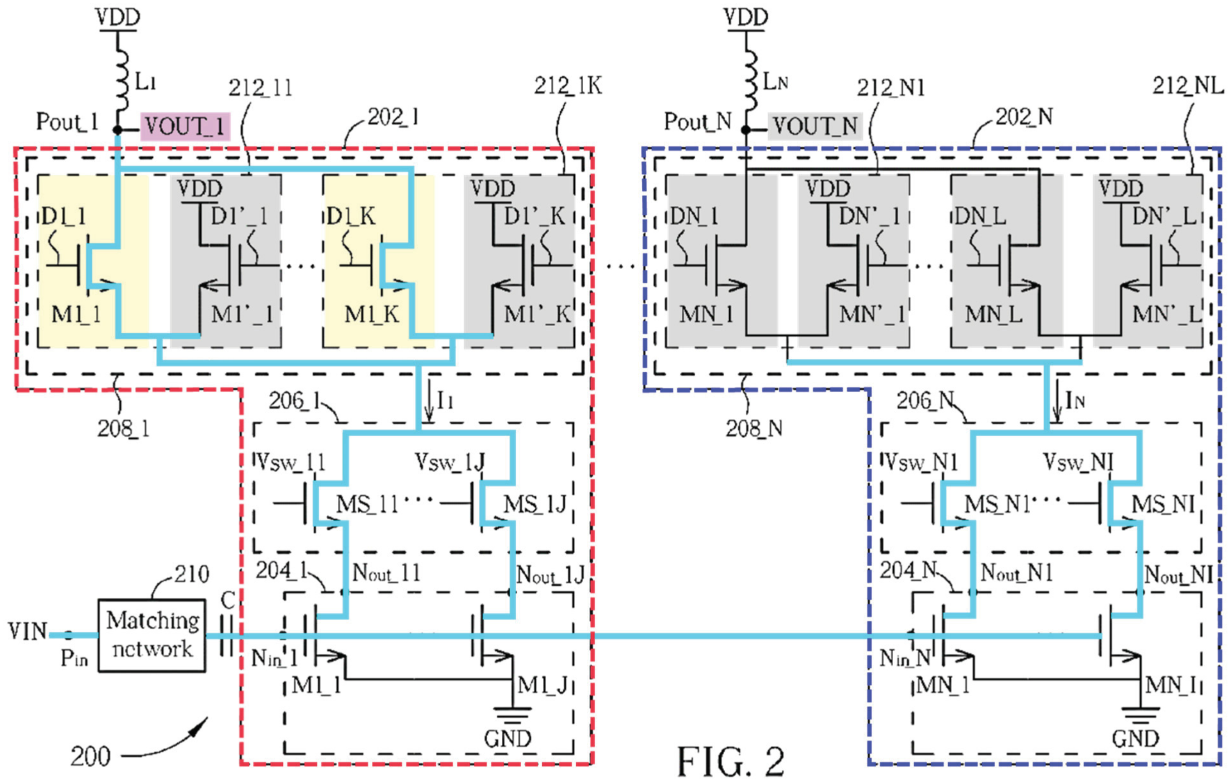

FIG. 2

67. As noted above, Petitioner challenged the validity of claims 1 and 17 in the ITC 1093 Investigation, referred to in Section II.B, *supra.* In that proceeding, Patent Owner agreed that Lee teaches every limitation of claims 1 and 17 except for limitations 1.d and 17.d reciting "carrier aggregation." EX1337-ITC at 2174:9-24, 2190:8-25. As explained in Section IX.A.1.d, *infra*, Lee teaches this limitation, and even if it did not teach "carrier aggregation," as described in Section IX.C, *infra*, Lee in view of Feasibility Study renders this limitation obvious.

68. I have been informed and understand that while Lee was cited on the face of the '356 patent, it was not the subject of any office action by the examiner.

B. 3GPP TR 36.912 Feasibility study for Further Advancements for E-UTRA (LTE-Advanced) (Release 9) ("Feasibility Study")

69. The 3rd Generation Partnership Project ("3GPP") is a standard-development and -setting body in the field of telecommunications. The Feasibility Study is a technical report by 3GPP focused on extensions to LTE Release 8,[11] most notably, with carrier aggregation. It describes carrier aggregation as aggregation of "two or more component carriers . . . in order to support wider transmission bandwidths of up to 100 MHz." EX1304-Study at 8. The Feasibility Study describes both contiguous and non-contiguous carrier aggregation and is consistent with how the term is used by persons having ordinary skill in the art.[12] *See id.* at 9.

70. The Feasibility Study also describes possible user equipment configurations for use with carrier aggregation. *Id*. at 9. It recognizes that, consistent with what I explained in Section III.C, multiple RF front-ends may be necessary to support far apart carriers in non-contiguous carrier aggregation. *See id*. at 26 ("[U]sing a single wideband-capable RF front end is undesirable in the case of Intra band noncontiguous CC due to the unknown nature of the signal on the 'unusable' portion of the band. In the case non-adjacent Inter band [sic]

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[11] LTE is a 4G Mobile Communications Standard.

[12] I described the different types of carrier aggregation in Section III.C.

separate RF front end are necessary.”). Thus, the Feasibility Study recognizes that carrier aggregation is best supported by receivers that have multiple receive paths.

71. I have been informed and understand that the Feasibility Study was not considered by the Examiner during prosecution of the ’356 Application. I have been informed and understand that the examiner considered the 3GPP TS 36.101 specification (“3GPP TS 36.101”), which also dealt with carrier aggregation in LTE. *See* EX1301-’356-Patent at 2:65. I conclude that the Feasibility Study provides considerably more practical detail than 3GPP TS 36.101, by describing, for instance, illustrative receiver architectures for use with carrier aggregation.

VIII. SUMMARY OF CONCLUSIONS

72. It is my conclusion that every limitation described in claims 1, 7, 8, 11, 17, and 18 of the ’356 patent is disclosed by the prior art, and each claim is anticipated and/or rendered obvious by the prior art.

IX. INVALIDITY OF THE CHALLENGED CLAIMS

A. Ground I: Claims 1, 7, 8, 11, 17, and 18 Are Anticipated by Lee

1. <u>Claim 1</u>

a) *“An apparatus comprising”*

73. Lee discloses an apparatus, namely amplification circuits. EX1335-Lee ¶1; EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

b) *"a first amplifier stage configured to be independently enabled or disabled"*

74. Lee discloses a first amplifier stage (e.g., amplifier block 202_1) configured to be independently enabled or disabled (e.g., by independently enabling or disabling output stage 208_1). An "amplifier stage" in the '356 patent may comprise (1) a gain transistor,[13] and (2) a cascode transistor arranged in a cascode configuration. EX1301-'356-Patent at 17:58-18:1; Fig. 6A. Figure 2 of Lee shows amplifier block 202_1, which includes an input stage 204_1, a selecting stage 206_1, and an output stage 208_1. EX1335-Lee ¶26. Amplifier block 202_1 is the first amplifier stage, as shown in annotated Figure 2 below.

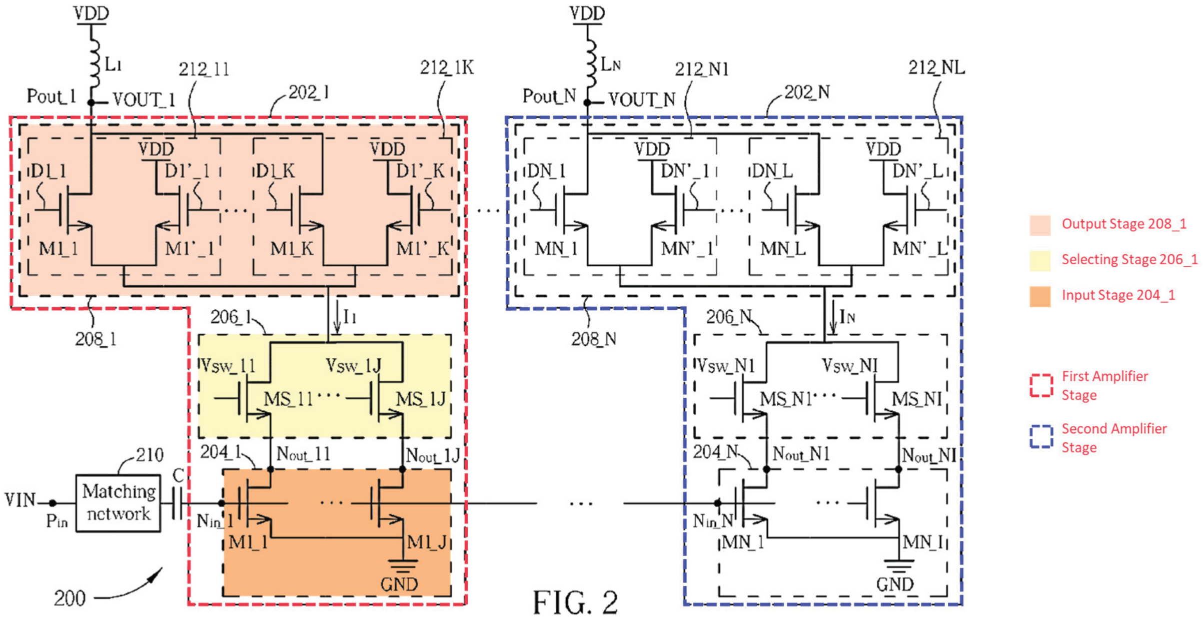

FIG. 2

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[13] "Gain" is the generic measurement of amplification. Any transistor that amplifies is a "gain" transistor.

75. The first amplifier stage 202_1 is configured to be independently enabled or disabled using its output stage 208_1.[14] When the first amplifier stage 202_1 is required to be active, such as to process a WiFi signal, "the output stage 208_1 is enabled by making each of the transistor element pairs 212_11-212_1K have one turned-on transistor element and one turned-off transistor element." EX1335-Lee ¶33. At the same time, if the amplifier stage "is not required to be enabled for generating the corresponding processed signal VOUT_1, the output stage 208_1 is disabled by turning off both of the first transistor element and the second transistor element included in each of the transistor element pairs 212_11-212_1K." *Id.* The transistor element pairs in output stage 208_1 can be turned on and off using control signals D1_1-D1_K and D1'_1-D1'_K.[15] *Id.* An annotated version of Figure 2 shows the first amplifier stage independently enabled using the

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[14] Lee teaches two different configurations for independently enabling or disabling the amplifier stages, using either the "selecting" stages 206 or the "output" stages 208 in each amplifier block. EX1335-Lee ¶¶29, 33. For simplicity, this declaration focuses on the configuration using the output stages 208.

[15] Control signals D1_1 to D1_K control the first transistor element of transistor pairs 1 through K, while control signals D1'_1 to D1'_K control the second transistor element in 1 through K transistor pairs. *See* EX1335-Lee at Fig. 2.

output stage 208_1, while the second amplifier stage is disabled using the corresponding output stage 208_N, below. *See also* EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

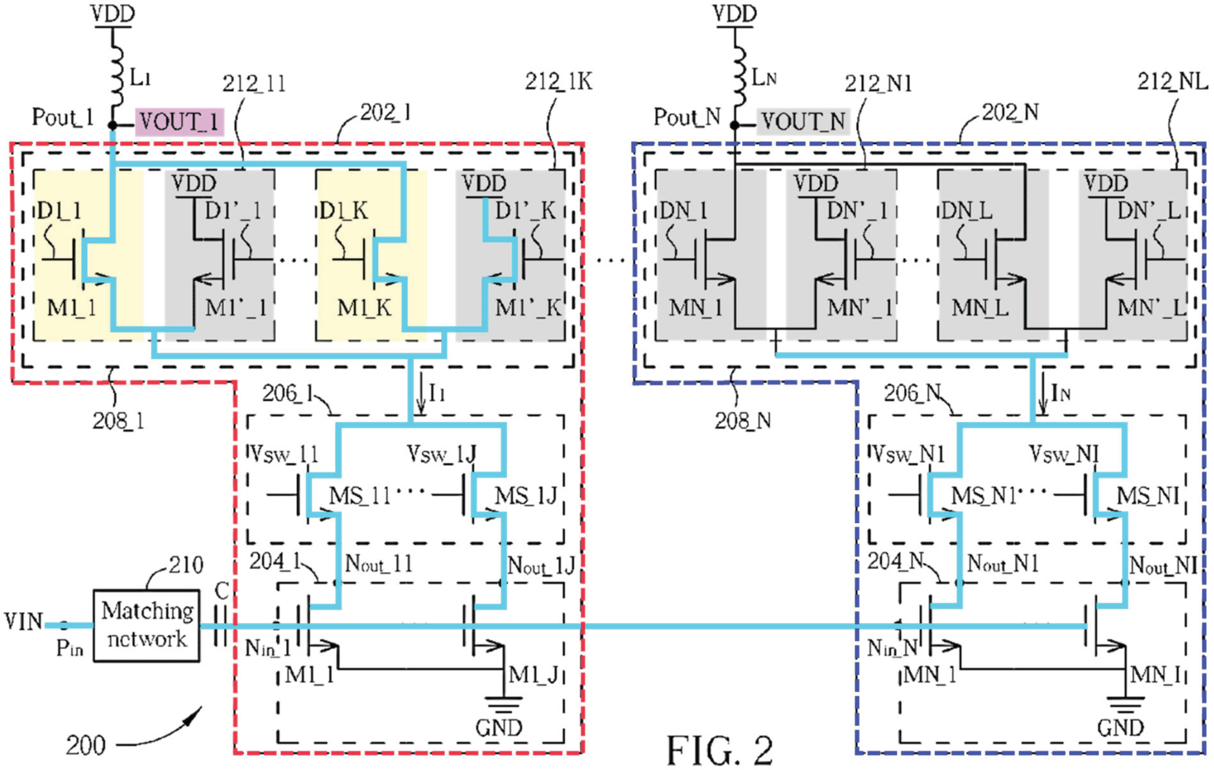

FIG. 2

c) *"the first amplifier stage further configured to receive and amplify an input radio frequency (RF) signal and provide a first output RF signal to a first load circuit when the first amplifier stage is enabled"*

76. Lee discloses this limitation. Lee teaches the first amplifier stage (e.g., amplifier block 202_1) configured to receive and amplify an input radio frequency (RF) signal (e.g., VIN) and provide a first output RF signal (e.g., VOUT_1) to a first load circuit (e.g., a WiFi receiver/transmitter, or inductive load

L_1) when the first amplifier stage is enabled (e.g., "when enabled"). As explained above, amplifier block 202_1 (comprising the input stage 204_1, the selecting stage 206_1, and the output stage 208_1) is the first amplifier stage. Lee explains that an "input signal VIN is transmitted to the input nodes Nin_1-Nin_N of the input stages 204_1-204_N," including the input stage 204_1 of the first amplifier stage. EX1335-Lee ¶26. The "selecting stage 206_1 selectively couples the input stage 204_1 to the output stage 208_1," *id*. ¶27, and the output stage 208_1 "generat[es] the corresponding processed signal (e.g., VOUT_1 . . .) to the corresponding output port (e.g., Pout_1 . . .) according to a gain." *Id*. ¶28. "[T]he output port Pout_1 is coupled to a first radio signal processing system (e.g., a WiFi receiver / transmitter)," which is a load circuit.[16] *Id*. ¶ 29. Lee therefore teaches that the first output RF signal is provided to a first load circuit.

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[16] The '356 patent states that a load circuit "may include one or more inductors, capacitors, transistors, mixers, etc." EX1301-'356-Patent at 5:3-5. A receiver includes one or more of these components and is therefore a load circuit. Moreover, Lee teaches that the output stage 208_1 is coupled to an inductive "load (e.g., the inductor L_1)," which is also a load circuit. *Id*.; EX1335-Lee ¶28.

77. As shown in Figure 2, below, the first amplifier stage in Lee is configured to receive and amplify an input RF signal (VIN) and provide a first output RF signal (VOUT_1) to a first load circuit (e.g., a WiFi receiver/transmitter) via output port Pout_1. VIN is a radio frequency (RF) signal because it "may include a plurality of radio-frequency signals." EX1335-Lee ¶17. VOUT_1 is an RF signal because it is one of "a plurality of received signals corresponding to the radio-frequency signals . . . generated as outputs" prior to downconversion. *Id*. EX1335-Lee ¶17; EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

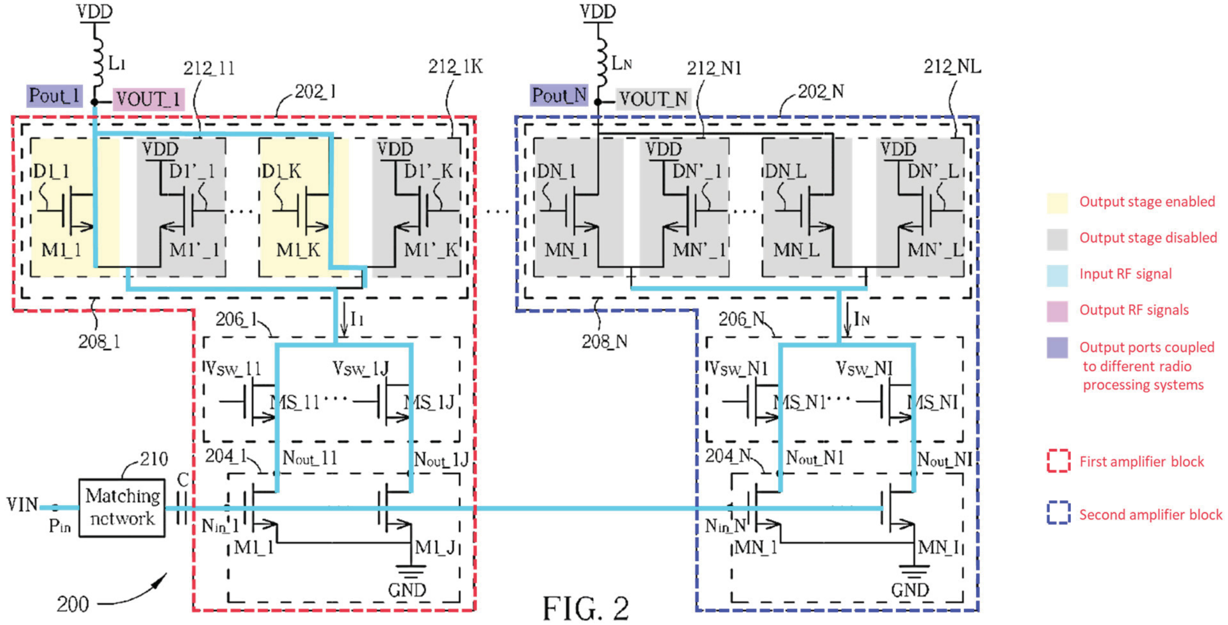

FIG. 2

78. Finally, Lee further teaches that the first amplifier stage performs this function only "when . . . enabled." Lee states that "[e]ach of the output stages generates a corresponding processed signal to a corresponding output port

according to a gain . . . when enabled." EX1335-Lee ¶4; *see also id.* at ¶28. Thus, "if the output stage 208_1 is required to be enabled for generating the corresponding processed signal VOUT_1, the output stage is enabled," but "if the output stage 208_1 is not required to be enabled for generating the corresponding processed signal VOUT_1, the output stage 208_1 is disabled." *Id.* ¶33; EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

d) *"the input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device"*

79. Lee teaches this limitation: Lee teaches the input RF signal (e.g., VIN) employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies (e.g., "plurality of radio frequency signals (e.g., a Bluetooth signal and a WiFi signal) received by a single antenna") to a wireless device (e.g., a "mobile device"). First, Lee teaches an input RF signal comprising transmissions sent on multiple carriers at different frequencies to a wireless device. It discloses that "the input signal VIN may include a plurality of radio frequency signals (e.g., a Bluetooth signal and a WiFi signal) received by a single antenna." EX1335-Lee ¶17. Bluetooth and WiFi signals are transmitted on

different carriers.[17] *Cf.* EX1337-ITC at 2196:18-2197:4. Moreover, Lee teaches that the amplifier can be used in a "mobile device," and therefore describes a wireless device. EX1335-Lee ¶2. Thus, Lee teaches an input RF signal (VIN) comprising transmissions sent on multiple carriers at different frequencies to a wireless device.

80. Lee further teaches that the input RF signal employs carrier aggregation. Carrier aggregation is "simultaneous operation on multiple carriers." *See* Section VI.A; EX1301-'356-Patent at 1:32-35; 2:53-55. Lee discloses that in the "combo" mode, "when both of the WiFi function and Bluetooth function of the multi-radio device are required to be active," "the output stages 208_1 and 208_N are ***both enabled at the same time***" in order to process both a WiFi signal and a Bluetooth signal at the same time. *Id*. ¶33 (emphasis added). Lee therefore teaches simultaneous operation on multiple carriers—it teaches receiving and processing data on multiple carriers at the same time in a single input RF signal, VIN. *See also* EX1337-ITC at 2205:12-18 (Patent Owner's expert in the ITC

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[17] Using frequency hopping and/or selection of operating channels, Bluetooth and WiFi signals will be transmitted over different carriers to avoid interference. Furthermore, the frequency "grid" of carriers defined in the Bluetooth standard is different from the frequency plan defined in the WiFi standards.

1093 Investigation testified that "Lee is capable of receiving both a Wi-Fi signal and a Bluetooth signal at the same time.")

81. Furthermore, even if carrier aggregation were construed as simultaneous operation on multiple carriers that increases bandwidth for a wireless device, Lee also teaches this result. Specifically, carriers occupy bandwidth, and transmitting or receiving data on multiple carriers increases bandwidth to the sum of the carriers' frequency ranges. For example, receiving data over two 20 MHz carriers increases bandwidth to 40 MHz, as shown in Figure 10 below:

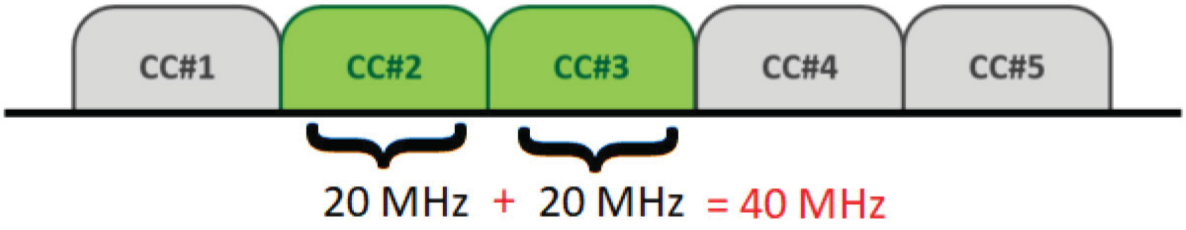

Figure 10. Transmitting data over two 20 MHz carriers increases available bandwidth to 40 MHz (the sum of the carriers' bandwidths).

Lee therefore teaches carrier aggregation.

82. In the related ITC 1093 Investigation, Patent Owner argued that Lee does not teach a single "input RF signal" because the input signal VIN includes "a plurality of radio frequency signals." EX1335-Lee ¶17; EX1337-ITC at 2205:19-22. But the disclosure of Lee is no different than the disclosure of the '356 patent. As shown below by a comparison of Figure 2 of Lee and Figure 6A of the '356

patent, both Lee and the ’356 patent disclose a single input RF signal that is provided from an input matching circuit to the amplifier stages.

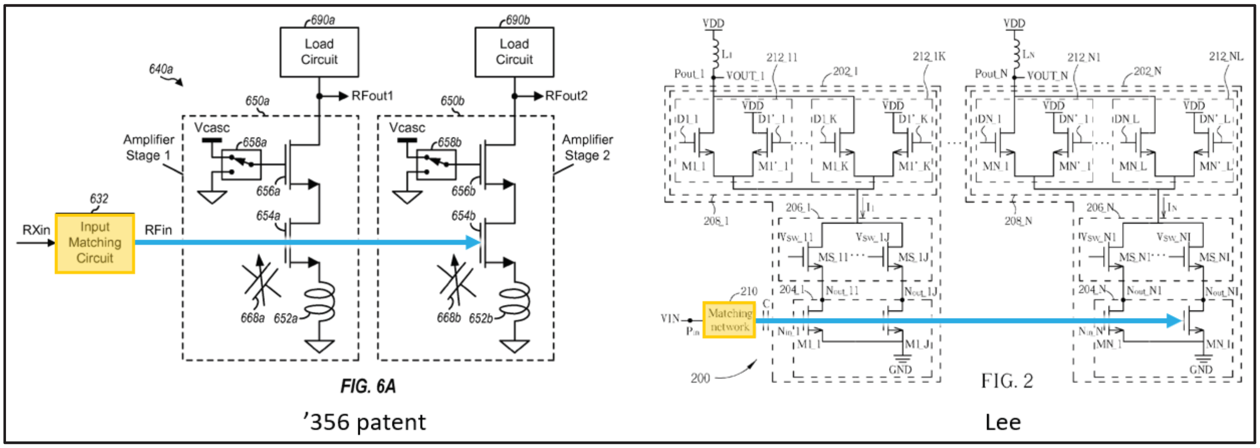

FIG. 6A

’356 patent

FIG. 2

Lee

See EX1301-’356-Patent at 7:49-52 (“Matching circuit 632 receives a receiver input signal, RXin, . . . , and provides an input RF signal RFin.”), Abstract (“first amplifier stage receives and amplifies an input radio frequency (RF) signal and provides a first output RF signal to a first load circuit”), *id.* at 17:52-54 (“input RF signal may comprise transmissions sent carriers at different frequencies to a wireless device”), *id.* at Fig. 6A (showing “RXin” and “RFin”);[18] EX1335-Lee

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[18] The ’356 patent states that “antenna 410 receives transmissions on multiple carriers in the same band and provides a received RF signal,” which is “provided as a receiver input signal, RXin, to an input matching circuit.” EX1301-’356-Patent at 4:56-60. The matching circuit then “provides an input RF signal, RFin, to CA LNA 440.” *Id.* at 4:63-65.

¶17 (“input signal VIN is transmitted to the input nodes” of the amplifier blocks via the input matching circuit).

83. Patent Owner also argued in the same investigation that Lee does not teach “carrier aggregation” because it does not describe “increased aggregated data rate.” EX1337-ITC at 2170:3-19. But even assuming carrier aggregation were construed to require an “increased aggregated data rate,” Lee teaches carrier aggregation. Receiving data on two or more carriers carrying non-redundant data simultaneously increases the data rate to the sum of the two carriers’ data rates. For example, if the first carrier transmits data at 50 megabits per second and the second carrier transmits data at 25 megabits per second, transmitting data over both of those carriers at the same time increases the aggregated data rate to 75 megabits per second. This is consistent with the prosecution history and its discussion of “increased aggregated data rate.” Patent Owner distinguished the prior art reference Hirose (EX1324-Hirose) on the grounds that it described sending redundant data over three different carriers and therefore did not lead to an “increased aggregated data rate.” Lee, however, is different from Hirose: Lee uses multiple carriers to send different data, not redundant data, and Lee therefore does teach an “increased aggregated data rate.”

e) *"the first output RF signal including at least a first carrier of the multiple carriers"*

84. Lee teaches this limitation: Lee teaches the first output RF signal (e.g., VOUT_1) including at least a first carrier of the multiple carriers (e.g., a WiFi carrier). Lee teaches that "the input signal VIN may include a plurality of radio frequency signals," and that "a plurality of received signals corresponding to the radio-frequency signals [in VIN] are ***generated as outputs*** of the signal amplification circuit." EX1335-Lee ¶17 (emphasis added). As described above, Bluetooth and WiFi are sent over different carriers. The first output RF signal VOUT_1 is one of the "generated outputs" of the amplification circuit. *See id.* ¶28 ("a plurality of processed signals VOUT_1-VOUT_N"). VOUT_1 includes a WiFi carrier, for example. *See id.* ¶¶29, 33. Thus, the first output RF signal VOUT_1 includes at least a first carrier of the multiple carriers because it corresponds to at least one of the radio-frequency signals within VIN. EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

f) *"a second amplifier stage configured to be independently enabled or disabled"*

85. Lee teaches this limitation: Lee teaches a second amplifier stage (e.g., amplifier block 202_N) configured to be independently enabled or disabled (e.g., by independently enabling or disabling output stage 208_N). Figure 2 shows

amplifier block 202_N, which includes an input stage 204_N, a selecting stage 206_N, and output stage 208_N. EX1335-Lee ¶26. Amplifier block 202_N is the second amplifier stage, as shown in annotated Figure 2 below.

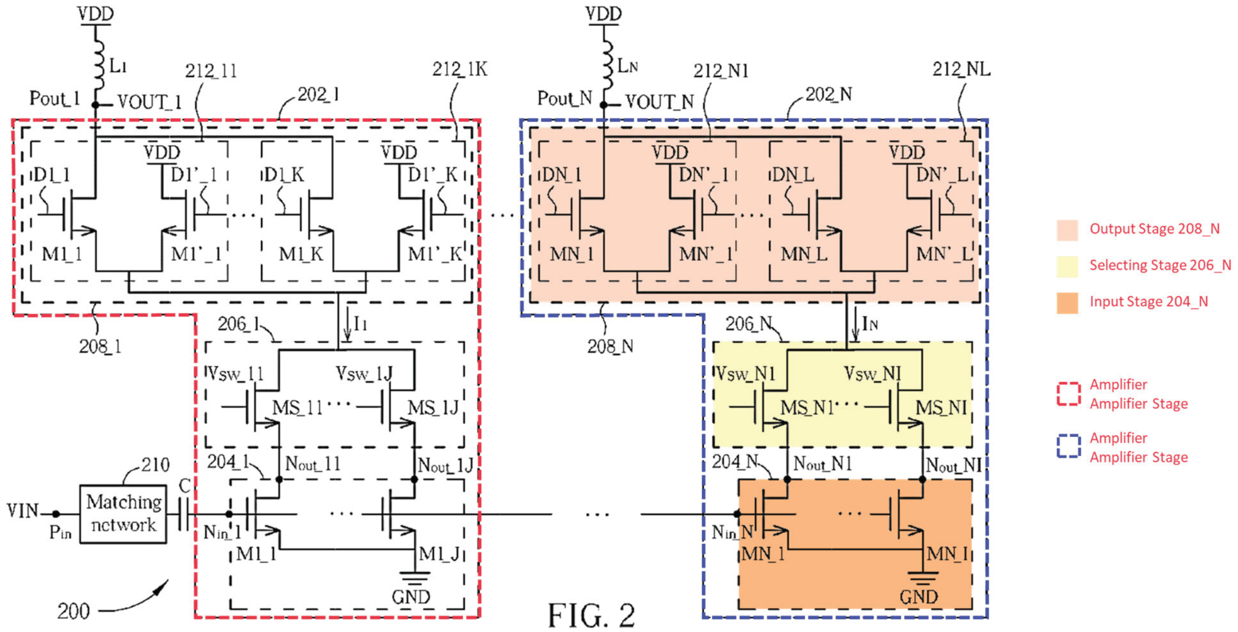

FIG. 2

86. Lee teaches that the second amplifier stage is configured to be independently enabled or disabled via its output stage 208_N. When the second amplifier stage is required to provide output, such as "when only the Bluetooth function of the multi-radio device is required to be active, . . . the output stage 208_N is turned on" by enabling one transistor element in each pair 212_N1-212_NL using control signals DN_1-DN_L and DN'_1-DN'_L, similarly to the first amplifier stage. EX1335-Lee ¶33. However, if the second amplifier stage is not required to be active, then output stage 208_N is disabled. *Id.* An annotated version of Figure 2, below, shows the second amplifier stage 202_N enabled using

the output stage 208_N, while the first amplifier stage 202_1 is disabled. EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

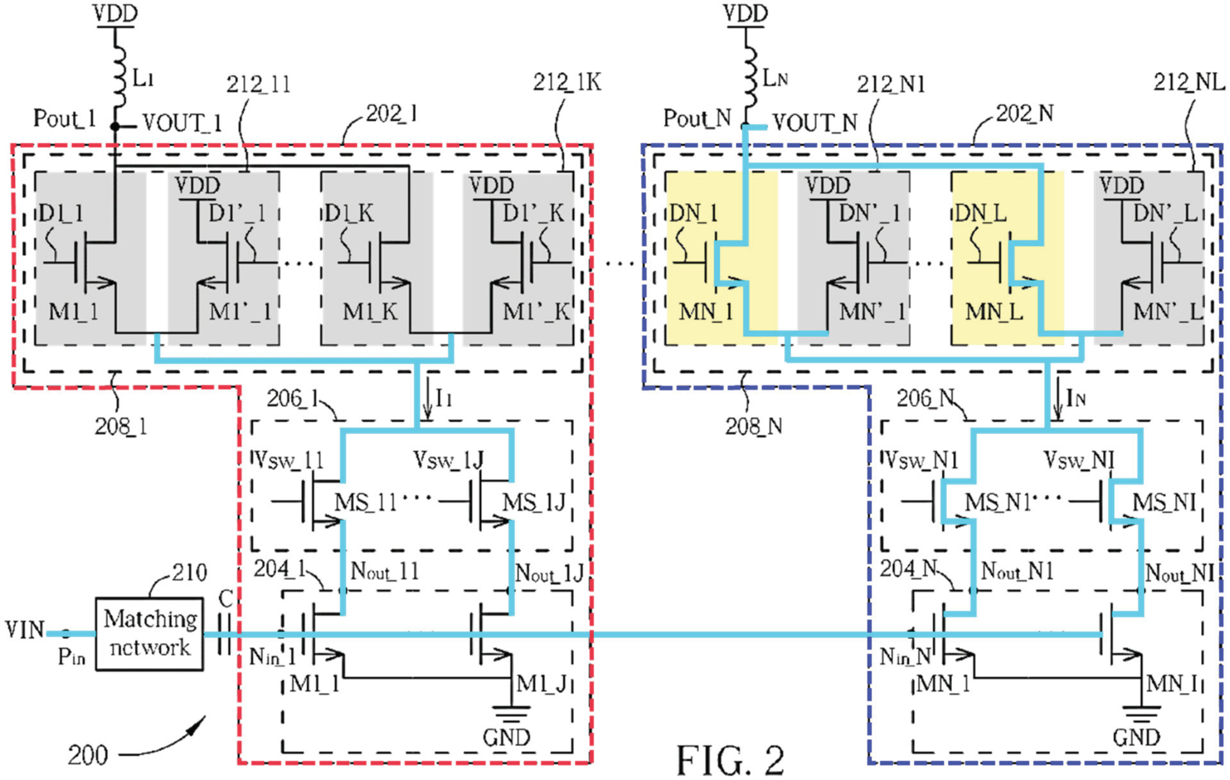

FIG. 2

g) *"the second amplifier stage further configured to receive and amplify the input RF signal and provide a second output RF signal to a second load circuit when the second amplifier stage is enabled"*

87. Lee discloses this limitation: Lee teaches the second amplifier stage (e.g., 202_N) further configured to receive and amplify the input RF signal (e.g., VIN) and provide a second output RF signal (e.g., VOUT_N) to a second load circuit (e.g., a Bluetooth receiver/transmitter, or inductive load L_N) when the second amplifier stage is enabled (e.g., "when enabled"). As described above,

amplifier block 202_N, comprising the input stage 204_N, the selecting stage 206_N, and the output stage 208_N, is the second amplifier stage. Lee discloses that "input signal VIN is transmitted to the input nodes Nin_1-Nin_N of the input stages 204_1-204_N via matching network 210," including the input stage 204_N of the second amplifier stage. EX1335-Lee ¶26. The second amplifier block is arranged in substantially the same way as the first amplifier block, with the selecting stage 206_N coupling the input stage 204_N to the output stage 208_N, and the output stage 208_N generating a corresponding output signal VOUT_N to the corresponding output port Pout_N. *See id.* ¶28. The second amplifier block receives and amplifies the input RF signal VIN. *Id.* ¶¶4, 28 (describing generation of "a corresponding processed signal to a corresponding output port according to a gain"). Moreover, Lee explains that "the output port Pout_N is coupled to a second radio signal processing system (e.g., a Bluetooth receiver/transmitter)," which is another load circuit.[19] *Id.* ¶29. Lee therefore teaches a second amplifier

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[19] The '356 patent states that a load circuit "may include one or more inductors, capacitors, transistors, mixers, etc.," and a receiver includes one or more of these components. EX1301-'356-Patent at 5:3-5. Moreover, Lee teaches that the output stage 208_N is coupled to an inductive "load (e.g., the inductor L_N)," which is a load circuit. EX1335-Lee ¶28.

stage configured to receive and amplify an input RF signal (VIN) via its input stage 204_N and provide a second output RF signal (VOUT_N) to a second load circuit (e.g., a Bluetooth receiver/transmitter) via output port Pout_N, as shown in Figure 2, below. EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

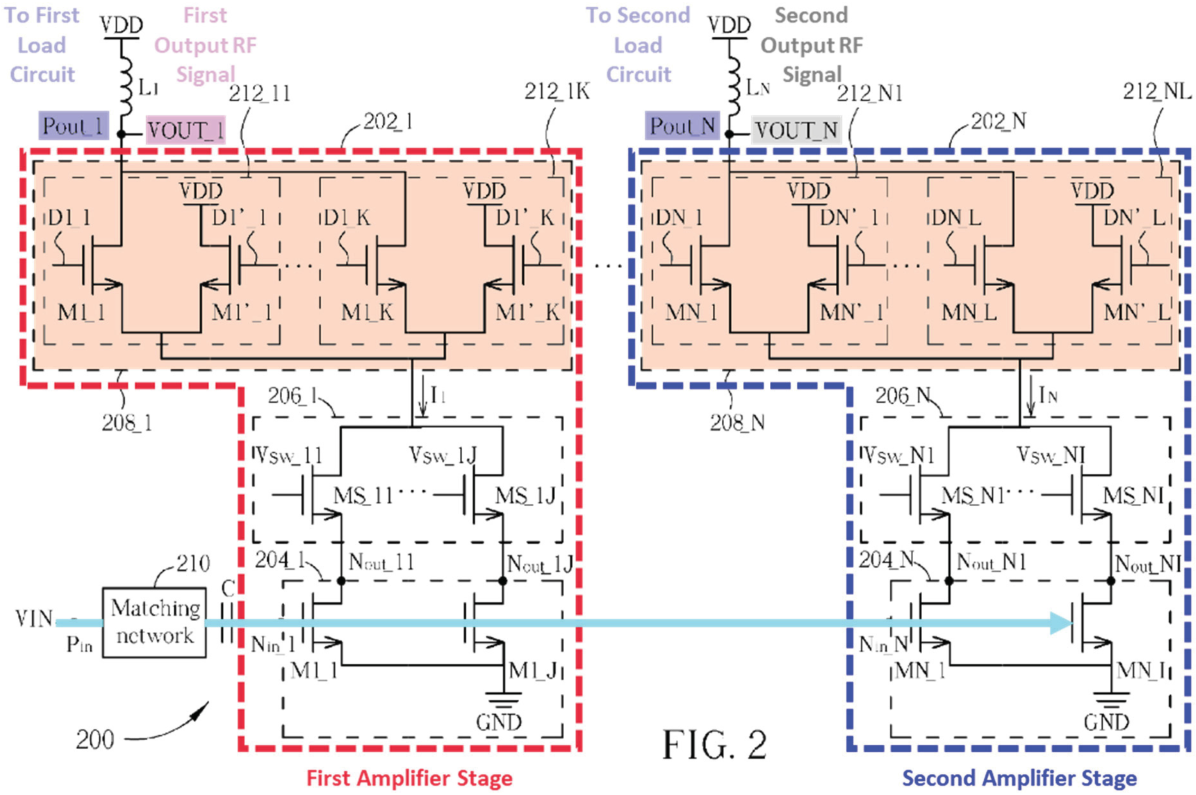

FIG. 2

88. Finally, as described above, Lee teaches that the second amplifier stage is configured to perform this function "when . . . enabled." *See* EX1356-Lee ¶28 ("the output stage is . . . implemented for generating a corresponding processed signal (e.g., . . . VOUT_N) to the corresponding output port (e.g., . . . Pout_N) according to a gain . . . of the input stage when enabled."); *id.* ¶4 ("Each

of the output stages generates a corresponding processed signal to a corresponding output port according to a gain . . . when enabled."); *id.* ¶33 ("when only the Bluetooth function of the multi-radio device is required to be active . . . the output stage 208_N is turned on"). EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

h) *"the second output RF signal including at least a second carrier of the multiple carriers different than the first carrier."*

89. Lee teaches this limitation: Lee teaches the second output RF signal (e.g., VOUT_N) including at least a second carrier of the multiple carriers (e.g., a Bluetooth carrier) different than the first carrier (e.g.*,* a WiFi carrier). Lee explains that "the input signal VIN may include a plurality of radio-frequency signals (e.g., a Bluetooth signal and a WiFi signal) received by a single antenna," and that "a plurality of received signals corresponding to the radio-frequency signals [in the input signal VIN] are ***generated as outputs*** of the signal amplification circuit." EX1335-Lee ¶17 (emphasis added). As described above, Bluetooth and WiFi are sent over different carriers. *Cf.* EX1337-ITC at 22196:18-2197:4. The second output RF signal VOUT_N is one of the "generated outputs" of the amplification circuit. *See* EX1335-Lee ¶28 ("a plurality of processed signals VOUT_1-VOUT_N"). VOUT_N includes a Bluetooth carrier, for example. *See id.* ¶¶29, 33. Thus, the second output RF signal VOUT_N includes

at least a second carrier of the multiple carriers because it corresponds to at least one of the radio-frequency signals in VIN. EX1337-ITC at 2190:8-21 (Patent Owner in the ITC 1093 Investigation did not dispute that Lee discloses this limitation).

90. Lee therefore teaches the apparatus of claim 1.

2. **Claim 7**

a) *"The apparatus of claim 1, further comprising:"*

91. As described in Section IX.A.1, Lee's Figure 2 and its accompanying disclosure teach the apparatus of claim 1. As described below, Lee's Figure 4 and its accompanying disclosure also teach the apparatus of claim 1.[20]

92. Lee Figure 4 discloses claim elements 1[a] and 1[b]: *"An apparatus comprising a first amplifier stage configured to be independently enabled or disabled."* As illustrated in the annotated Lee Figure 4, below, Lee discloses an apparatus (e.g., amplification circuit 400) comprising a first amplifier stage (e.g., transistor M'_1 and output stage 304_1, shown in red below). EX1335-Lee ¶¶34, 35, 38, Fig. 4. This first amplifier stage is configured to be independently enabled or disabled. EX1335-Lee ¶37 ("When only the WiFi function of the

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[20] The amplifier circuit 400 "is similar to that of the exemplary signal amplification circuit 300." EX1335-Lee ¶38.

multi-radio device is required to be active, the output stage 304_1 is enabled, whereas the remaining output stages in the signal amplification circuit . . . are disabled. . . Similarly, when only the Bluetooth function of the multi-radio device is required to be active, the output stage 304_N is turned on, whereas the remaining output stages in the signal amplification circuit . . . are disabled.”). Amplification circuit 400 may also operate in combo mode, in which both stages are enabled. *See* EX1335-Lee ¶¶41-42, 33.

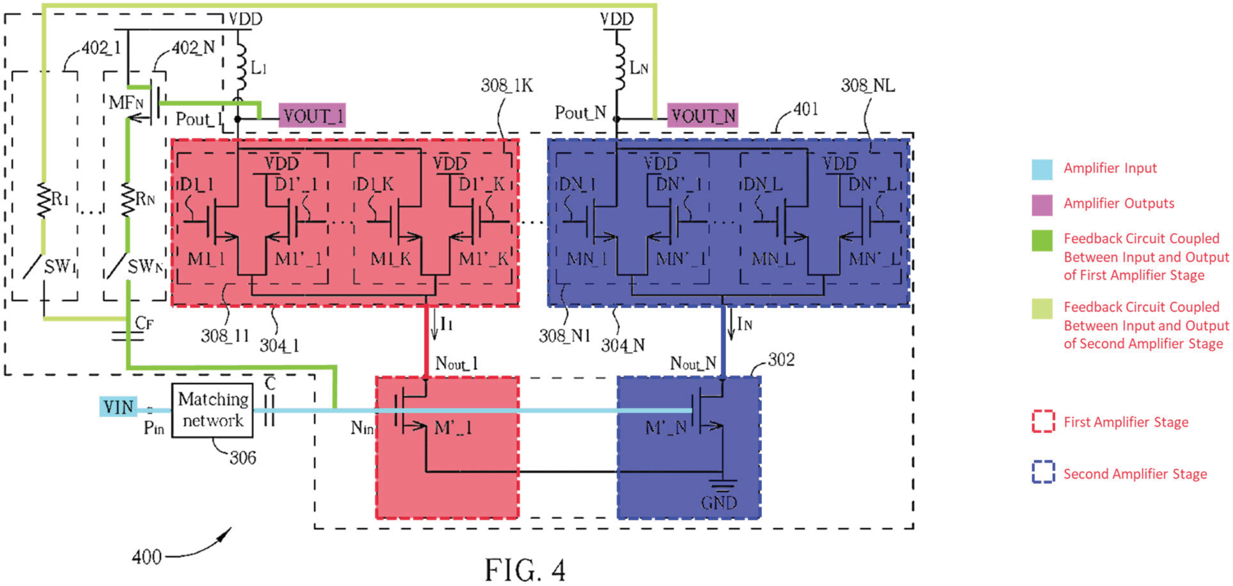


FIG. 4

93. Lee Figure 4 discloses claim element 1[c]: *“the first amplifier stage further configured to receive and amplify an input radio frequency (RF) signal and provide a first output RF signal to a first load circuit when the first amplifier stage is enabled.”* The first amplifier stage in Lee Figure 4 (e.g., the transistor M’_1 and output stage 304_1) is configured to receive and amplify an input radio frequency (RF) signal (e.g., receive the VIN and generate “a corresponding output

according to a gain") and provide a first output RF signal (e.g., VOUT_1) to a first load circuit (e.g., a "WiFi receiver/transmitter" or "inductive load" L_1) when the first amplifier stage is enabled (e.g., if "the output stages 304_1 and 304_N are enabled alternately under the mode, the signal amplification circuit . . . refers the input signal VIN to generate the processed signal VOUT_1 for WiFi connection and the other processed signal VOUT_N for Bluetooth connection alternately."). EX1335-Lee ¶¶34-37.

94. Lee Figure 4 discloses claim element 1[d]: *"the input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device."* The input RF signal VIN of Lee Figure 4 employs carrier aggregation as recited in claim 1[d] for the reasons identified above in Section IX.A.1.d.

95. Lee Figure 4 discloses claim element 1[e]: *"the first output RF signal including at least a first carrier of the multiple carriers."* Lee teaches this limitation for similar reasons as explained above in Section IX.A.1.e. *See also* EX1335-Lee ¶¶37-38 ("Pout_1 is coupled to a first radio signal processing system (e.g., a WiFi receiver / transmitter)").

96. Lee Figure 4 discloses claim element 1[f]: *"a second amplifier stage configured to be independently enabled or disabled."* Lee discloses a second amplifier stage (e.g., transistor M'_N and output stage 304_N, shown in blue,

above). EX1335-Lee ¶¶38, 34-35, FIG. 4. This second amplifier stage is configured to be independently enabled or disabled. EX1335-Lee ¶37 ("When only the WiFi function of the multi-radio device is required to be active, the output stage 304_1 is enabled, whereas the remaining output stages in the signal amplification circuit . . . are disabled. . . Similarly, when only the Bluetooth function of the multi-radio device is required to be active, the output stage 304_N is turned on, whereas the remaining output stages in the signal amplification circuit . . . are disabled."). Amplification circuit 400 may also operate in combo mode, in which both stages are enabled. *See* EX1335-Lee ¶¶42, 33, 41.

97. Lee Figure 4 discloses claim element 1[g]: *"the second amplifier stage further configured to receive and amplify the input RF signal and provide a second output RF signal to a second load circuit when the second amplifier stage is enabled."* The second amplifier stage in Lee Figure 4 (e.g., the transistor M'_N and output stage 304_N) is configured to receive and amplify an input radio frequency (RF) signal (e.g., receive the VIN and generate "a corresponding output according to a gain") and provide a second output RF signal (e.g., VOUT_N) to a second load circuit (e.g., a "Bluetooth receiver/transmitter" or "inductive load" L_N) when the second amplifier stage is enabled (e.g., if "the output stages 304_1 and 304_N are enabled alternately under the mode, the signal amplification circuit . . . refers the input signal VIN to generate the processed signal VOUT_1 for WiFi

connection and the other processed signal VOUT_N for Bluetooth connection alternately.”). EX1335-Lee ¶¶34-37.

98. Lee Figure 4 discloses claim element 1[h]: *“the second output RF signal including at least a second carrier of the multiple carriers different than the first carrier.”* Lee teaches this limitation for similar reasons as explained above in Section IX.A.1.h. *See also* EX1335-Lee ¶¶37-38 (“Pout_N is coupled to a second radio signal processing system (e.g., a Bluetooth receiver / transmitter)”).

99. Lee Figure 4, and its accompanying disclosure, therefore also teaches the apparatus of claim 1.

b) *“a feedback circuit coupled between an output and an input of at least one of the first and second amplifier stages.”*

100. Lee discloses this limitation of claim 7: Lee discloses a feedback circuit (e.g., feedback elements 402_1-402_N and/or AC coupling capacitor C_F) coupled between an output (e.g., VOUT_1 and/or VOUT_N) and an input (e.g., input node N_{in}) of at least one of the first and second amplifier stages. Figure 4 shows a signal amplification circuit that “includes a plurality of feedback elements coupled to the output ports VOUT_1-VOUT_N, respectively.” EX1335-Lee ¶38. “[E]ach of the feedback elements is coupled between a specific output port and the input node Nin of the input stage 302,” and is “used for feeding a specific processed signal generated at the specific output port to the input node . . . when . .

. enabled." *Id*. Each feedback element may be adjusted to the particular application (e.g., WiFi vs. Bluetooth) and may be switched on when that amplifier stage is enabled in a shared mode. *Id.* Lee therefore teaches a feedback circuit coupled between an output and an input of at least one of the first and second amplifier stages, as shown in annotated Figure 4 of Lee, above.

101. Lee therefore discloses the apparatus of claim 7.

3. **Claim 8**

a) *"The apparatus of claim 7"*

102. As described in Section IX.A.2, Lee discloses the apparatus of claim 7.

b) *"the feedback circuit comprising a resistor, or a capacitor, or both a resistor and a capacitor."*

103. Lee discloses this limitation. Lee explains that the feedback circuit in Figure 4 may be "implemented by an active feedback element or a resistive feedback element." EX1335-Lee ¶38. In an active feedback configuration, the feedback element "includ[es] a transistor element MFN, a ***resistor*** RN, and a switch SWN." *Id*. In a passive feedback configuration, the feedback element "include[s] a ***resistor*** R1 and a switch SW1." *Id*. (emphasis added) Lee therefore teaches the feedback circuit comprising a resistor in both configurations. In addition to the feedback elements, Lee teaches that "an AC coupling capacitor CF is placed between the input stage 302 and the feedback elements 401_1-402_N."

Id. The feedback circuit in Lee thus comprises a resistor, or a capacitor, or both a resistor and a capacitor, as shown in annotated Lee Figure 4, below.

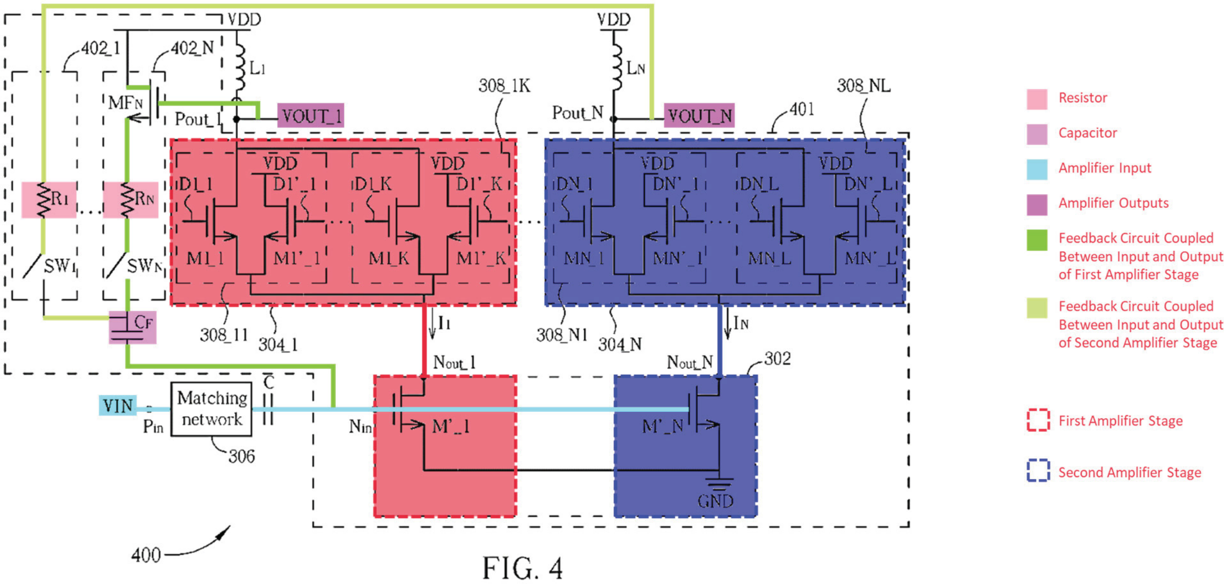


FIG. 4

104. Accordingly, Lee discloses the apparatus of claim 8.

4. **Claim 11**

a) *"The apparatus of claim 1, further comprising:"*

105. As described in Section IX.A.1, Lee discloses the apparatus of claim 1.

b) *"an input matching circuit coupled to the first and second amplifier stages and configured to receive a receiver input signal and provide the input RF signal."*

106. Lee discloses this limitation: Lee teaches an input matching circuit (e.g., matching network 210) coupled to the first (e.g., 202_1) and second (e.g., 202_N) amplifier stages and configured to receive a receiver input signal (e.g.,

VIN) and provide the input RF signal (e.g., the signal leaving matching network 210, to which Lee also refers as "VIN"). Lee explains that "the input signal VIN may include a plurality of radio frequency signals (e.g., a Bluetooth signal and a WiFi signal) ***received by a single antenna***." EX1335-Lee ¶17 (emphasis added). Lee further explains that "[t]he input signal VIN is transmitted to the input nodes Nin_1-Nin_N of the input stages 204_1-204_N ***via the matching network 210*** and an AC coupling capacitor C." EX1335-Lee ¶26 (emphasis added). Input stage 204_1 is part of the first amplifier stage 202_1 and input stage 204_N is part of the second amplifier stage 202_N. EX1135-Lee ¶¶26, 27. The matching network 210 provides "desired impedance matching" and is "designed to meet the impedance matching requirements." *Id*. Lee therefore teaches an input matching circuit coupled to the first and second amplifier stages (through their input stages 204_1 and 204_N) and configured to provide the input RF signal (e.g., the signal leaving matching network 210, to which Lee also refers as "VIN"), as shown in annotated Lee Figure 2, below.

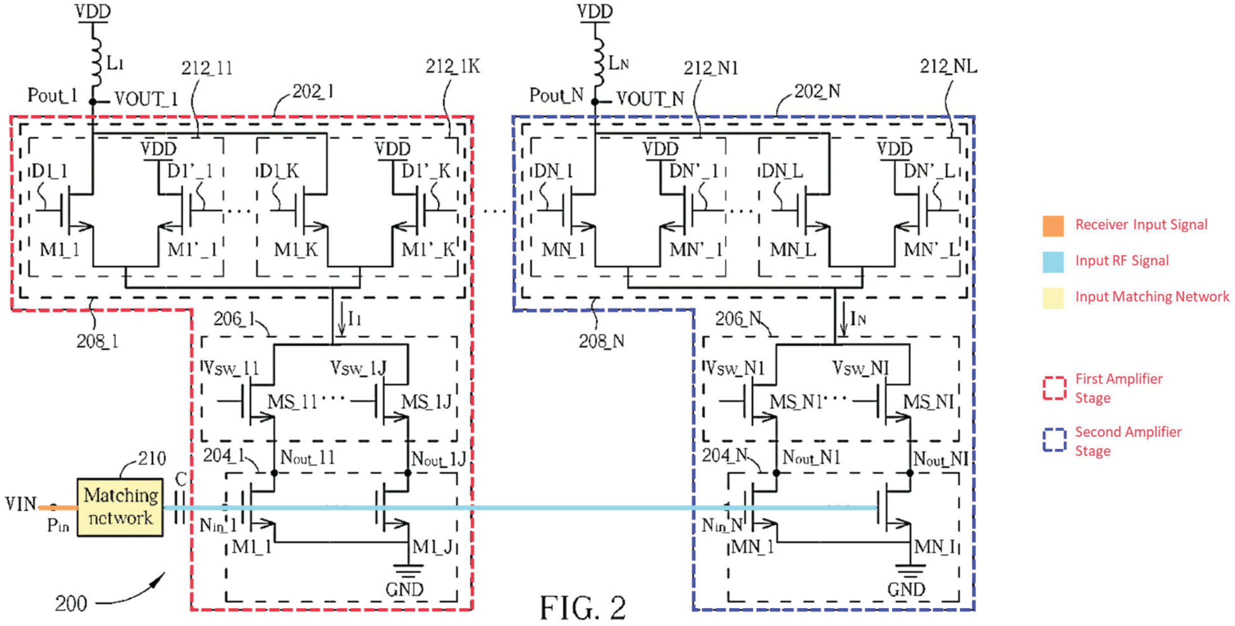


FIG. 2

107. Lee also discloses that the input matching network is configured to receive the receiver input signal. The receiver input signal in the '356 patent is the signal provided to the input matching network after the antenna. *See* EX1302-'356-Patent at 4:56-65 ("[A]ntenna 410 receives transmissions on multiple carriers in the same band and provides a received RF signal. The received RF signal is routed through switches/duplexers 424 and provided as a receiver input signal, RXin, to an input matching circuit 432. Matching circuit . . . provides an input RF signal, RFin, to CA LNA 440."). In Lee, "the input signal VIN may include a plurality of radio-frequency signals . . . received by a single antenna" and provided to the matching network. EX1335-Lee ¶¶17, 26. Lee therefore teaches that the matching network is configured to receive the receiver input signal.

108. Accordingly, Lee discloses the apparatus of claim 11.

5. **Claim 17**

a) *"A method comprising"*

109. Lee discloses the method of claim 17 for the reasons stated in Section IX.A.1 (for claim 1). As explained in further detail, below, Lee discloses a method for amplifying input RF signals in a receiver that supports carrier aggregation.

b) *"amplifying a first input radio frequency (RF) signal with a first amplifier stage to obtain a first output RF signal when the first amplifier stage is enabled,"*

110. Lee discloses this limitation of claim 17 for the same reasons described in Sections IX.A.1.b and IX.A.1.c (limitations 1.b and 1.c of claim 1).

c) *"the first amplifier stage configured to be independently enabled or disabled,"*

111. Lee discloses this limitation of claim 17 for the same reasons described in Section IX.A.1.b (limitation 1.b).

d) *"the first input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device,"*

112. Lee discloses this limitation of claim 17 for the same reasons described in Section IX.A.1.d (limitation 1.d).

e) *"the first output RF signal including at least a first carrier of the multiple carriers; and"*

113. Lee discloses this limitation of claim 17 for the same reasons described in Section IX.A.1.e (limitation 1.e).

> f) *"amplifying the first input RF signal or a second input RF signal with a second amplifier stage to obtain a second output RF signal when the second amplifier stage is enabled,"*

114. This limitation requires amplifying an input RF signal with a second amplifier stage to obtain a second output RF signal when the second amplifier stage is enabled. The input RF signal that must be amplified is recited in the alternative – it can be either "the first input RF signal" or "a second input RF signal." *See* EX1301-'356-Patent at 22:21-22. As described in Sections IX.A.1.f. and IX.A.1.g (limitations 1.f and 1.g), Lee teaches amplifying ***the first input RF signal*** with a second amplifier stage to obtain a second output RF signal when the second amplifier stage is enabled. Lee therefore teaches this limitation.

> g) *"the second amplifier stage configured to be independently enabled or disabled,"*

115. Lee discloses this limitation of claim 17 for the same reasons described in Section IX.A.1.f (limitation 1.f).

> h) *"the second output RF signal including at least a second carrier of the multiple carriers different than the first carrier."*

116. Lee discloses this limitation of claim 17 for the same reasons described in Section IX.A.1.h (limitation 1.h).

117. Accordingly, Lee discloses the method of claim 17.

6. **Claim 18**

a) *"The method of claim 17, further comprising:"*

118. As described in Section IX.A.5, Lee discloses the method of claim 17.

b) *"enabling the first and second amplifier stages in a first mode to obtain the first and second output RF signals"*

119. Lee discloses this limitation. As explained in Section IX.A.1.d, Lee teaches a first "combo" mode where "both of the WiFi function and Bluetooth function of the multi-radio device are required to be active" and "the output stages 208_1 and 208_N are ***both enabled at the same time***." EX1335-Lee ¶33 (emphasis added). Each output stage is "enabled for generating the corresponding processed signal," and therefore both the first output RF signal VOUT_1 and the second output RF signal VOUT_N are generated in the combo mode. *Id.* ("[E]ach of the output stages 208_1-208_N is further arranged to determine if a processed signal is allowed to be generated at a corresponding output port.")

c) "*enabling the first amplifier stage and disabling the second amplifier stage in a second mode to obtain the first output RF signal but not the second output RF signal."*

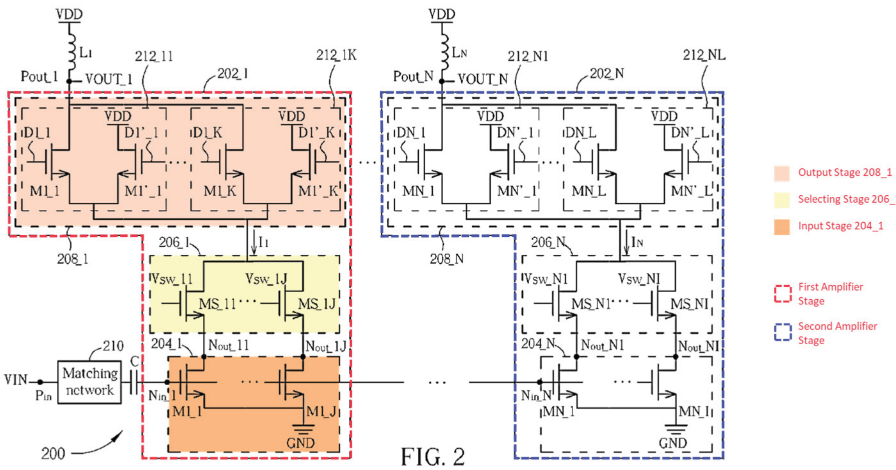
120. Lee discloses this limitation. As explained in Section VII.A, Lee teaches a second "shared" mode where "only the WiFi function of the multi-radio device is required to be active" and "the output stage 208_1 is enabled, whereas all of the output stages in the remaining amplifier blocks are disabled." EX1335-

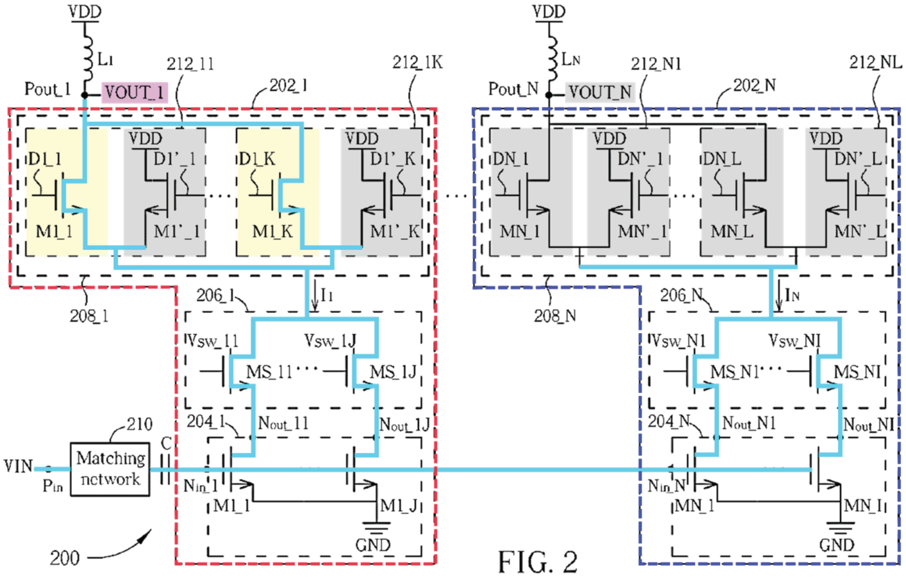
Lee ¶33. Further, because "each of the output stages 208_1-208_N is further arranged to determine if a processed signal is allowed to be generated at a corresponding output port," disabling the second output stage 208_N in the second mode means that the second output RF signal VOUT_N is not provided. *Id.* Lee therefore teaches enabling the first amplifier stage and disabling the second amplifier stage in a second mode, so as to obtain the first output RF signal but not the second output RF signal.

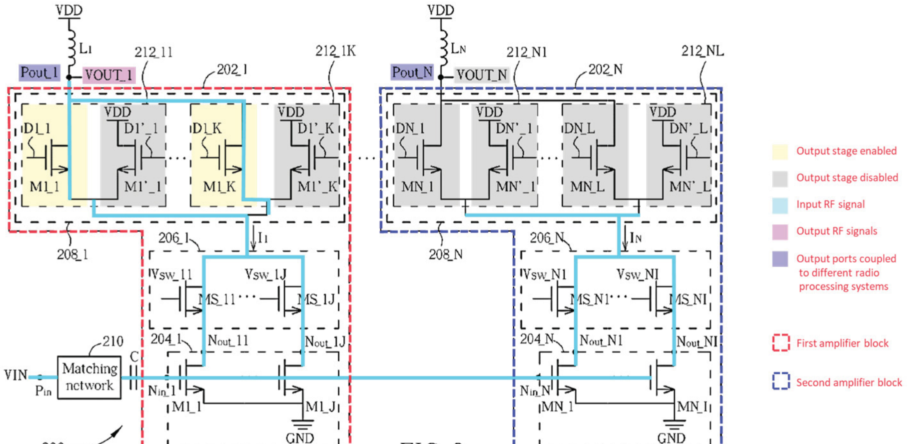
121. Accordingly, Lee teaches the method of claim 18.

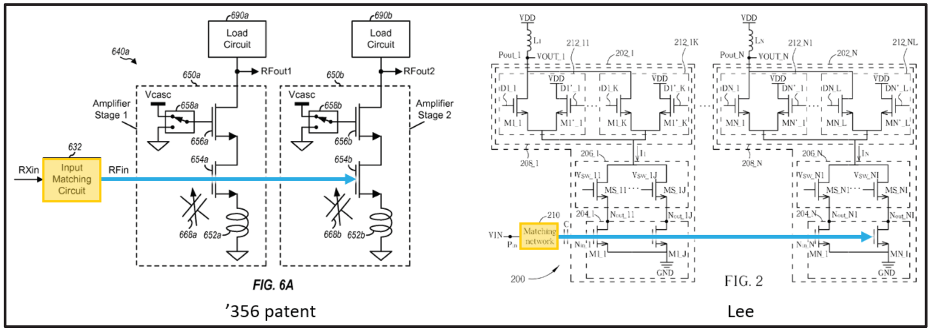
122. The chart below provides a summary of the disclosure of the reference in this ground discussed above and presented in the form of a claim chart.

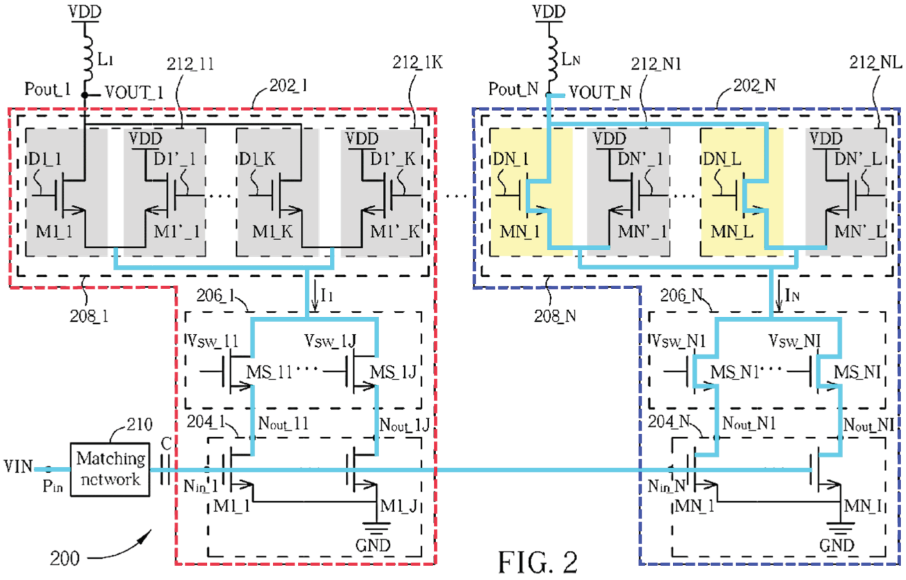
Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
'356 Patent Claim	**Lee**
Claim 1	
[1a] An apparatus comprising:	EX1335-Lee ¶1 ("amplification circuits"). EX1337-ITC at 2190:8-21 (Qualcomm's expert, Dr. Foty: "Q Now, your dispute with Dr. Fay on the issue of the '356 patent anticipation concerns a single limitation of claims 1 and 17; correct? A I believe that to be the case, yes. Q And you do not otherwise dispute Dr. Fay's conclusion that Lee satisfies the elements of claims 1 and 17; right? A Other than what I've cited, I do not contest that. Q And specifically, you dispute that Lee discloses the input signal employing carrier aggregation; right? A I believe the full phrase is "the input RF signal." Whatever the phrase I quoted in my testimony a few moments ago was the one I am referring to, yes.").

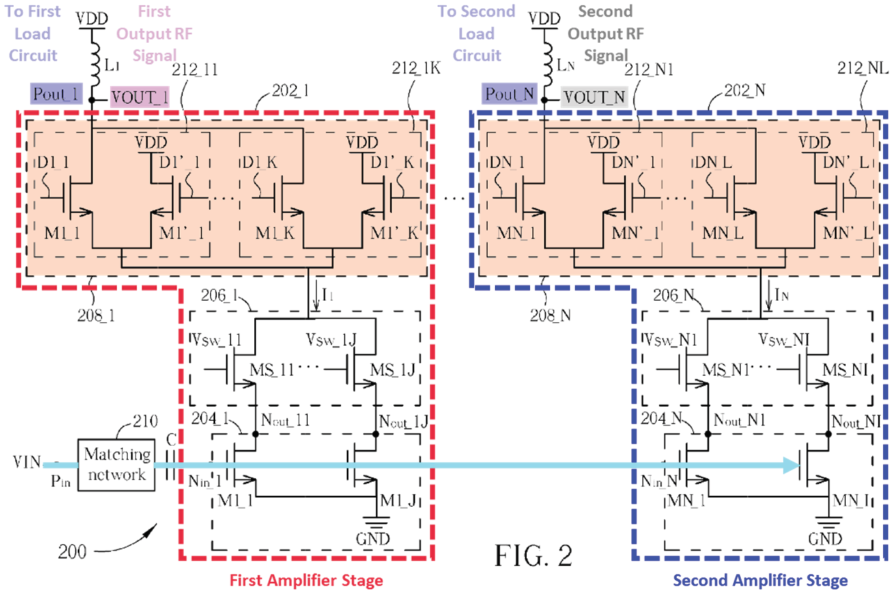
Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
[1b] a first amplifier stage configured to be independently enabled or disabled,	EX1335-Lee ¶26 (“each of the amplifier blocks 202_1-202_N respectively has its own input stage, selecting stage, and output stage”). EX1335-Lee ¶33 (“if the output stage 208_1 is required to be enabled for generating the corresponding processed signal VOUT_1, the output stage 208_1 is enabled by making each of the transistor element pairs 212_11-212_1K have one turned-on transistor element and one turned-off transistor element”). EX1335-Lee ¶33 (“if the output stage 208_1 is not required to be enabled for generating the corresponding processed signal VOUT_1, the output stage 208_1 is disabled by turning off both of the first transistor element and the second transistor element included in each of the transistor element pairs 212_11-212_1K.”).  FIG. 2

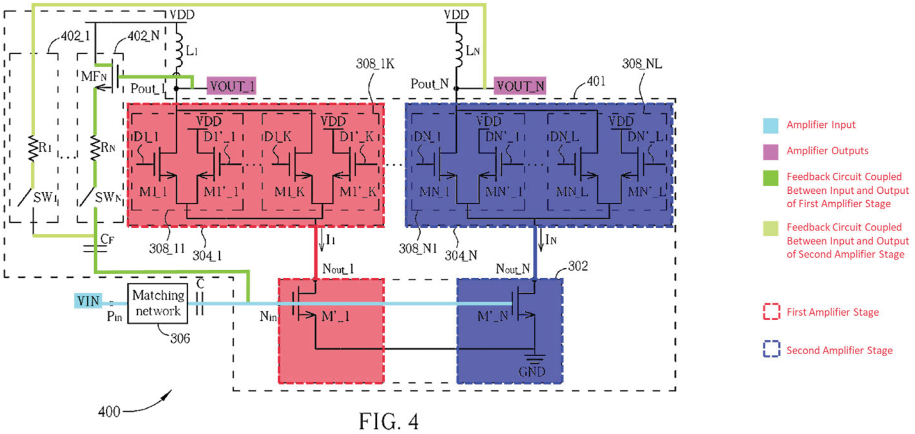
Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	 FIG. 2 EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[1c] the first amplifier stage further configured to receive and amplify an input radio frequency (RF) signal and provide a first output RF signal to a first load circuit when the first amplifier stage is enabled,	EX1335-Lee ¶26 (“input signal VIN is transmitted to the input nodes Nin_1-Nin_N of the input stages 204_1-204_N.”). EX1335-Lee ¶27 (“selecting stage 206_1 selectively couples the input stage 204_1 to the output stage 208_1.”) EX1335-Lee ¶28 (“output stage [208_1] . . . generat[es] the corresponding processed signal (e.g., VOUT_1 . . .) to the corresponding output port (e.g., Pout_1 . . .) according to a gain.”). EX1335-Lee ¶29 (“[T]he output port Pout_1 is coupled to a first radio signal processing system (e.g., a WiFi receiver/transmitter).”).

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	EX1335-Lee ¶4 (“each of the output stages generates a corresponding processed signal to a corresponding output port according to a gain . . . ***when enabled***.”).  FIG. 2 EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[1d] the input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device,	EX1335-Lee ¶17 (“the input signal VIN may include a plurality of radio frequency signals (e.g., a Bluetooth signal and a WiFi signal) received by a single antenna.”). EX1335-Lee ¶33 (“when both of the WiFi function and Bluetooth function of the multi-radio device are required to be active (i.e., the signal amplification circuit should operate under the combo mode), the output stages 208_1 and 208_N are ***both enabled at the same time***.”) (emphasis added). EX1337-ITC at 2205:12-18 (Qualcomm’s expert, Dr. Foty: “Q But you agree that Lee discloses signals its amplifier circuit are designed to receive simultaneously. You'd agree with that; right?

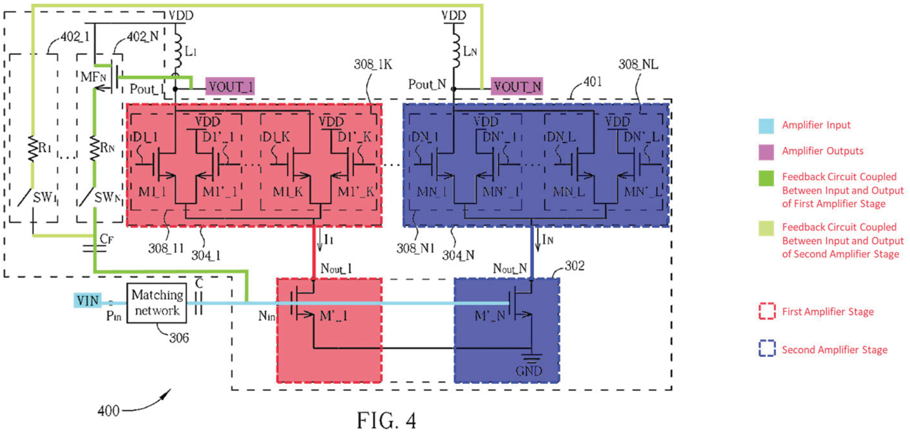
Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	A Lee does not require that both signals are received at the same time, but Lee is capable of receiving both a Wi-Fi signal and a Bluetooth signal at the same time.”). EX1301-’356-Patent at FIG 6A; EX1335-Lee at FIG. 2:  FIG. 6A ’356 patent FIG. 2 Lee
[1e] the first output RF signal including at least a first carrier of the multiple carriers; and	EX1335-Lee ¶17 (“the input signal VIN may include a plurality of radio frequency signals” and “a plurality of received signals corresponding to the radio-frequency signals [in VIN] are ***generated as outputs*** of the signal amplification circuit.”). EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[1f] a second amplifier stage configured to be independently enabled or disabled,	EX1335-Lee ¶26 (“each of the amplifier blocks 202_1-202_N respectively has its own input stage, selecting stage, and output stage”). EX1335-Lee ¶33 (“when only the Bluetooth function of the multi-radio device is required to be active (i.e., the signal amplification circuit 200 should operate under the shared mode), the output stage 208_N is turned on, whereas all of the output stages in the remaining amplifier blocks are disabled.”).

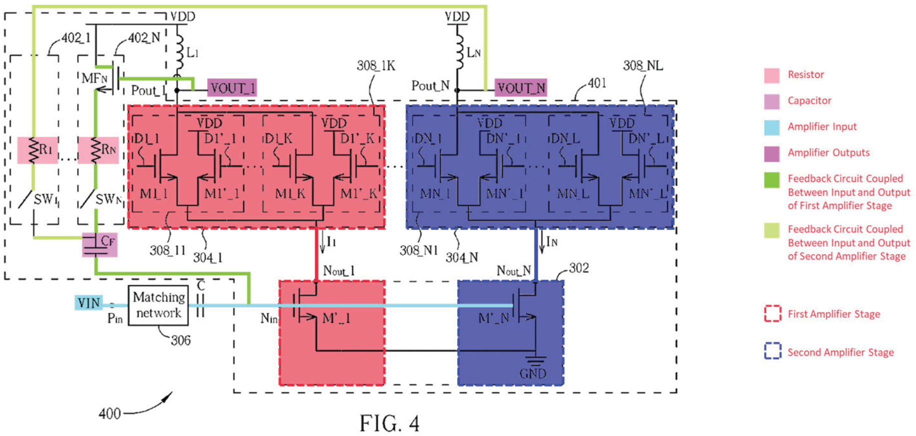
Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	 FIG. 2 EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[1g] the second amplifier stage further configured to receive and amplify the input RF signal and provide a second output RF signal to a second load circuit when the second amplifier stage is enabled,	EX1335-Lee ¶26 (“input signal VIN is transmitted to the input nodes Nin_1-Nin_N of the input stages 204_1-204_N via matching network 210”). EX1335-Lee ¶27 (“selecting stage 206_N selectively couples the input stage 204_N to the output stage 208_N”) EX1335-Lee ¶28 (“output stage [208_1] . . . generat[es] the corresponding processed signal (e.g., VOUT_1 . . .) to the corresponding output port (e.g., Pout_1 . . .) according to a gain.”). EX1335-Lee ¶4 (“each of the output stages generates a corresponding processed signal to a corresponding output port according to a gain . . . ***when enabled***.”) (emphasis added).

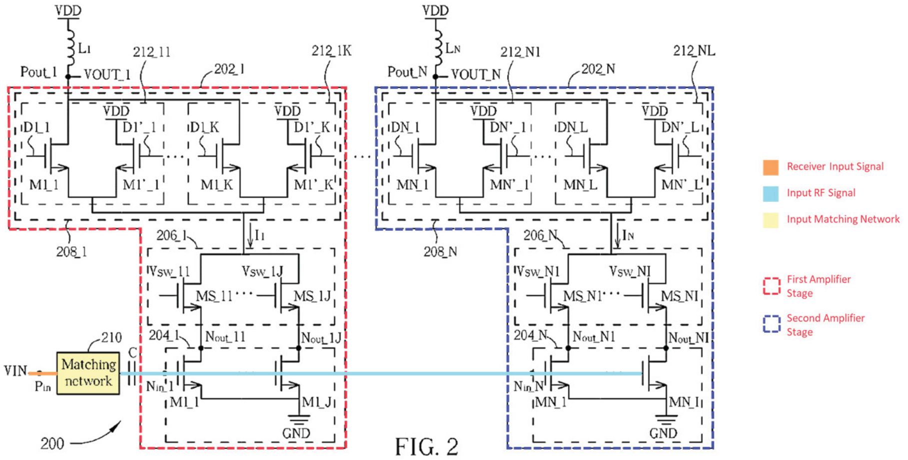
Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	 FIG. 2 EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[1h] the second output RF signal including at least a second carrier of the multiple carriers different than the first carrier.	EX1335-Lee ¶17 (“the input signal VIN may include a plurality of radio frequency signals” and “a plurality of received signals corresponding to the radio-frequency signals [in VIN] are ***generated as outputs*** of the signal amplification circuit.”) (emphasis added). EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
Claim 7	**Lee**
[7a] The apparatus of claim 1, further comprising:	*See* [1a] – [1h], *supra*; EX1335-Lee FIG. 2. *See also*, EX1335-Lee FIG. 4: 1[a] and 1[b]: *“An apparatus comprising a first amplifier stage configured to be independently enabled or disabled”***:**

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	EX1335-Lee ¶37 (“When only the WiFi function of the multi-radio device is required to be active, the output stage 304_1 is enabled, whereas the remaining output stages in the signal amplification circuit . . . are disabled. . . Similarly, when only the Bluetooth function of the multi-radio device is required to be active, the output stage 304_N is turned on, whereas the remaining output stages in the signal amplification circuit . . . are disabled.”). EX1335-Lee ¶¶33-35, 38, 41-42, FIG. 4.  FIG. 4 1[c]: *“the first amplifier stage further configured to receive and amplify an input radio frequency (RF) signal and provide a first output RF signal to a first load circuit when the first amplifier stage is enabled”***:** EX1335-Lee ¶37 (“If the output stages 304_1 and 304_N are enabled alternately under the mode, the signal amplification circuit 300 refers the input signal VIN to generate the processed signal VOUT_1 for WiFi connection and the other processed signal VOUT_N for Bluetooth connection alternately.”). EX1335-Lee ¶¶34-37.

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	1[d]: *“the input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device,”*: *See* [1d], *supra*. 1[e]: *“the first output RF signal including at least a first carrier of the multiple carriers; and”*: *See* [1e], *supra*. EX1335-Lee ¶37-38 (“Pout_1 is coupled to a first radio signal processing system (e.g., a WiFi receiver / transmitter)”). 1[f]: *“a second amplifier stage configured to be independently enabled or disabled”*: EX1335-Lee ¶37 (“When only the WiFi function of the multi-radio device is required to be active, the output stage 304_1 is enabled, whereas the remaining output stages in the signal amplification circuit . . . are disabled. . . Similarly, when only the Bluetooth function of the multi-radio device is required to be active, the output stage 304_N is turned on, whereas the remaining output stages in the signal amplification circuit . . . are disabled.”) EX1335-Lee ¶¶33-35, 38, 41-42. 1[g]: *“the second amplifier stage further configured to receive and amplify the input RF signal and provide a second output RF signal to a second load circuit when the second amplifier stage is enabled”*: EX1335-Lee ¶37 (“If the output stages 304_1 and 304_N are enabled alternately under the mode, the signal amplification circuit 300 refers the input signal VIN to generate the processed signal VOUT_1 for WiFi connection and the other processed signal VOUT_N for Bluetooth connection alternately.”).

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	EX1335-Lee ¶34-37. 1[h]: *“the second output RF signal including at least a second carrier of the multiple carriers different than the first carrier.”*: *See* [1h], *supra*. EX1335-Lee ¶37-38 (“Pout_N is coupled to a second radio signal processing system (e.g., a Bluetooth receiver / transmitter)”).
[7b] a feedback circuit coupled between an output and an input of at least one of the first and second amplifier stages.	EX1335-Lee ¶38 (“includes a plurality of feedback elements coupled to the output ports VOUT_1-VOUT_N, respectively.”). EX1335-Lee ¶38 (“[E]ach of the feedback elements is coupled between a specific output port and the input node Nin of the input stage 302,” and is “used for feeding a specific processed signal generated at the specific output port to the input node . . . when . . . enabled.”).  FIG. 4
Claim 8	**Lee**
[8a] The apparatus of claim 7,	*See* [7a] – [7b], *supra*.

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
[8b] the feedback circuit comprising a resistor, or a capacitor, or both a resistor and a capacitor.	EX1335-Lee ¶38 (“feedback element, includ[es] a transistor element MFN, a ***resistor*** RN, and a switch SW_N” and “include[s] a ***resistor*** R1 and a switch SW1”). EX1335-Lee ¶38 (“an AC coupling capacitor CF is placed between the input stage 302 and the feedback elements 401_1-402_N.”).  FIG. 4
Claim 11	**Lee**
[11a] The apparatus of claim 1, further comprising:	*See* [1a] – [1h], *supra*.
[11b] an input matching circuit coupled to the first and second amplifier stages and configured to receive a receiver input signal and provide the input RF signal.	EX1335-Lee ¶26 (“[t]he input signal VIN is transmitted to the input nodes Nin_1-Nin_N of the input stages 204_1-204_N ***via the matching network 210*** and an AC coupling capacitor C.”) (emphasis added). EX1135-Lee ¶¶26 (“The matching network 210 is . . . implemented for providing desired impedance matching”). EX1135-Lee ¶¶26 (“The matching network . . . 210 should be properly designed to meet the impedance matching requirements.”).

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
	EX1335-Lee ¶17 (“the input signal VIN may include a plurality of radio-frequency signals . . . received by a single antenna.”)  FIG. 2
Claim 17	**Lee**
[17a] A method comprising:	EX1335-Lee ¶4 (“exemplary signal amplification circuit ***is for processing*** an input signal”) (emphasis added). EX1335-Lee ¶45 (“numerous modifications and alterations of the device and ***method*** may be made while retaining the teachings of the invention”) (emphasis added). EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[17b] amplifying a first input radio frequency (RF) signal with a first amplifier stage to obtain a first output RF signal when the first amplifier stage is enabled	*See* [1b], [1c], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
[17c] the first amplifier stage configured to be independently enabled or disabled	*See* [1b], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[17d] the first input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device,	*See* [1d], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2205:12-18 (admitting that “Lee is capable of receiving both a Wi-Fi signal and a Bluetooth signal at the same time.”).
[17e] the first output RF signal including at least a first carrier of the multiple carriers; and	*See* [1e], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[17f] amplifying the first input RF signal or a second input RF signal with a second amplifier stage to obtain a second output RF signal when the second amplifier stage is enabled,	*See* [1f], [1g], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
[17g] the second amplifier stage configured to be independently enabled or disabled,	*See* [1f], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).

Ground I: Claims 1, 7, 8, 11, 17, and 18 Anticipated by Lee	
’356 Patent Claim	**Lee**
[17h] the second output RF signal including at least a second carrier of the multiple carriers different than the first carrier.	*See* [1h], *supra*. EX1337-ITC (testimony of Qualcomm’s expert, Dr. Foty) at 2190:8-21 (admitting he does not dispute that Lee discloses this claim limitation).
Claim 18	**Lee**
[18a] The method of claim 17, further comprising:	*See* [17a]-[17h], *supra*.
[18b] enabling the first and second amplifier stages in a first mode to obtain the first and second output RF signals; and	EX1335-Lee ¶33 (in the “combo” mode, “when both of the WiFi function and Bluetooth function of the multi-radio device are required to be active,” “the output stages 208_1 and 208_N are ***both enabled at the same time***” in order to process both a WiFi signal and a Bluetooth signal at the same time) (emphasis added). EX1335-Lee ¶33 (“each of the output stages 208_1-208_N is further arranged to determine if a processed signal is allowed to be generated at a corresponding output port”).
[18c] enabling the first amplifier stage and disabling the second amplifier stage in a second mode to obtain the first output RF signal but not the second output RF signal.	EX1335-Lee ¶33 (in a “shared” mode “only the WiFi function of the multi-radio device is required to be active” and “the output stage 208_1 is enabled, whereas all of the output stages in the remaining amplifier blocks are disabled.”) EX1335-Lee ¶33 (“each of the output stages 208_1-208_N is further arranged to determine if a processed signal is allowed to be generated at a corresponding output port”).

B. Ground II: Claims 7 and 8 Are Obvious Over Lee

1. *Claim 7*

a) *"The apparatus of claim 1, further comprising:"*

123. As described in Section IX.A.1, Lee teaches the apparatus of claim 1.

b) *"a feedback circuit coupled between an output and an input of at least one of the first and second amplifier stages."*

124. Lee discloses this limitation. Lee Figure 4 shows a signal amplification circuit that "includes a plurality of feedback elements coupled to the output ports VOUT_1-VOUT_N, respectively." EX1335-Lee ¶38. "[E]ach of the feedback elements is coupled between a specific output port and the input node Nin of the input stage 302," and is "used for feeding a specific processed signal generated at the specific output port to the input node . . . when . . . enabled." *Id.* Each feedback element may be adjusted to the particular application (e.g., WiFi vs. Bluetooth) and may be switched on when that amplifier stage is enabled in a shared mode. *Id.* Lee therefore teaches a feedback circuit coupled between an output and an input of at least one of the first and second amplifier stages, as shown in annotated Figure 4 of Lee below.

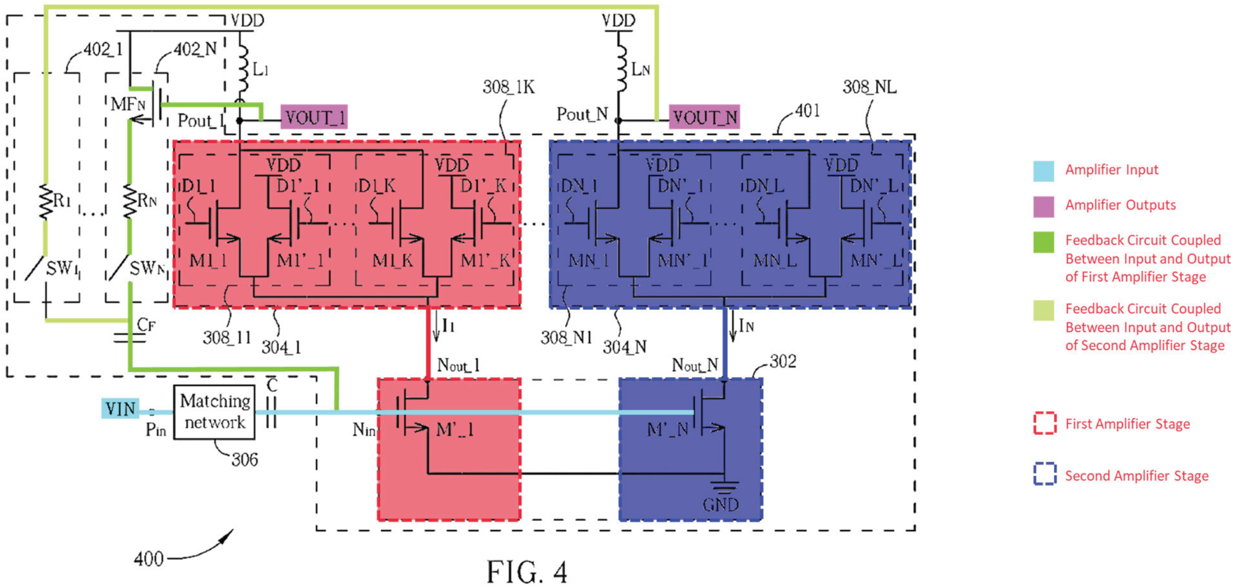


FIG. 4

125. It would have been obvious to one of ordinary skill in the art to combine the feedback circuit of Lee Figure 4 with the amplification circuit of Lee Figure 2. Lee explains that "[w]ith the feedback elements implemented in the signal amplification circuit 400, the input matching performance can be improved greatly" and that, for example, "a wider input frequency range can be covered by the signal amplification circuit 400." EX1335-Lee ¶39. This combination would have involved nothing more than combining prior art elements (the feedback elements 402_1 and/or 402_N of Figure 4 and the amplification circuit 200 of Figure 2) according to known methods (coupling feedback elements 402_1 and/or 402_N at one end to the input signal between the matching network and the input node Nin, and at the other end to the output signal VOUT_1 and/or VOUT_N, as shown and described with respect to Lee Figure 4), to yield predictable results (to

"improv[e] greatly" the "input matching performance" and "cover[]" a "wider input frequency range"). *See id*.

126. A person of ordinary skill in the art would have understood the feedback circuit in Figure 4 as a known technique for improving input matching performance. EX1335-Lee ¶39 ("input matching performance can be improved greatly" and "wider input frequency range can be covered"). Lee already describes input matching with respect to the amplification circuit 200 of Figure 2, stating that the "matching network . . . 210 should be properly designed to meet the impedance matching requirements." *Id.* ¶26. A person having ordinary skill in the art would have recognized the amplification circuit 200 of Figure 2 as a known circuit ready for improvement (i.e. that "should be properly designed to meet the impedance matching requirements") to yield the predictable result of the improved input matching performance and wider input frequency range described with respect to Lee Figure 4.

127. Finally, a person of ordinary skill in the art would have found this combination obvious to try. Lee suggests fluidity of components among its described embodiments: "[t]his document does not intend to distinguish between components that differ in name but not function." EX1335-Lee ¶16. Lee also notes that "[t]hose skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while

retaining the teachings of the invention." EX1335-Lee ¶45. Given how Lee describes the amplification circuits 200 and 400 from Figure 2 and Figure 4 using similar terms and with similar functionality, and describes a finite number of embodiments of "similar" amplification circuits 100, 200, 300, 400, 600, a person of ordinary skill in the art would have found the addition of the feedback circuit of Figure 4 to the amplification circuit of Figure 2 obvious to try. EX1335-Lee ¶¶16, 33, 39.

128. Accordingly, Lee renders obvious the apparatus of claim 7.

2. *Claim 8*

a) *"The apparatus of claim 7,"*

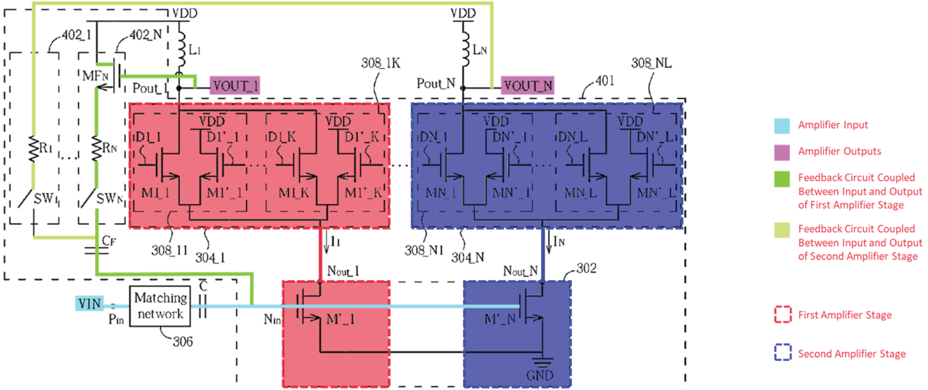
129. As described in Section IX.B.1, Lee renders obvious the apparatus of claim 7.

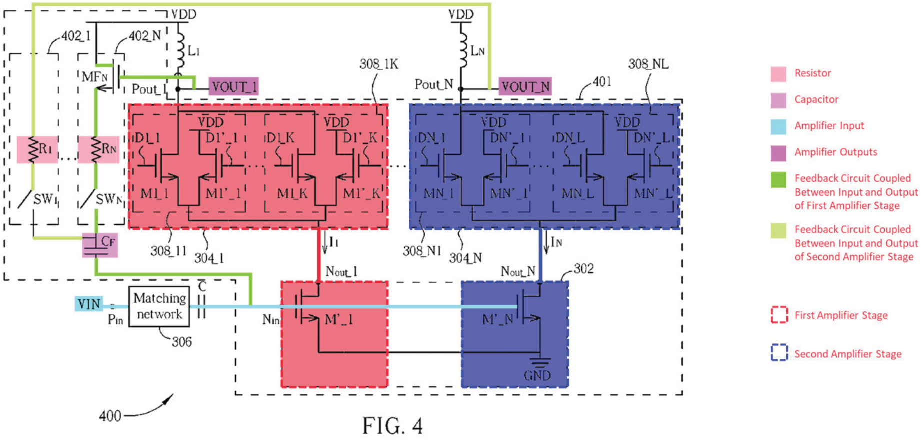
b) *"the feedback circuit comprising a resistor, or a capacitor, or both a resistor and a capacitor."*

130. Lee teaches this limitation of claim 8 for the same reasons described in Section IX.A.3.b (limitation 8.b). For the reasons stated above in Section IX.B.1, one of ordinary skill in the art would have combined the feedback circuit of Lee Figure 4 with the amplification circuit of Lee Figure 2.

131. Accordingly, Lee renders obvious the apparatus of claim 8.

132. The chart below provides a summary of the disclosure of the reference in this ground discussed above and presented in the form of a claim chart.

Ground II: Claims 7 and 8 are Obvious Over Lee	
’356 Patent Claim	**Lee**
Claim 7	**Lee**
[7a] The apparatus of claim 1, further comprising:	*See* [1a] – [1h], *supra*; EX1335-Lee FIG. 2.
[7b] a feedback circuit coupled between an output and an input of at least one of the first and second amplifier stages.	EX1335-Lee ¶38 (“includes a plurality of feedback elements coupled to the output ports VOUT_1-VOUT_N, respectively.”). EX1335-Lee ¶38 (“[E]ach of the feedback elements is coupled between a specific output port and the input node Nin of the input stage 302,” and is “used for feeding a specific processed signal generated at the specific output port to the input node . . . when . . . enabled.”).  FIG. 4 **<u>Motivation to Combine</u>** *See* [7a]-[7b], *supra*. EX1335-Lee ¶39 (“[w]ith the feedback elements implemented in the signal amplification circuit 400, the input matching performance can be improved greatly” and, for example, “a wider input frequency range can be covered by the signal amplification circuit 400.”).

Ground II: Claims 7 and 8 are Obvious Over Lee	
’356 Patent Claim	**Lee**
	EX1335-Lee ¶39 (“matching network . . . 210 should be properly designed to meet the impedance matching requirements.”). EX1335-Lee ¶16 (“[t]his document does not intend to distinguish between components that differ in name but not function.”). EX1335-Lee ¶45 (“Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention.”).
Claim 8	**Lee**
[8a] The apparatus of claim 7,	*See* [7a] – [7b], *supra*.
[8b] the feedback circuit comprising a resistor, or a capacitor, or both a resistor and a capacitor.	EX1335-Lee ¶38 (“feedback element, includ[es] a transistor element MFN, a ***resistor*** RN, and a switch SW$_N$” and “include[s] a ***resistor*** R1 and a switch SW1”) (emphasis added). EX1335-Lee ¶38 (“an AC coupling capacitor CF is placed between the input stage 302 and the feedback elements 401_1-402_N.”).  FIG. 4 **Motivation to Combine**

Ground II: Claims 7 and 8 are Obvious Over Lee	
’356 Patent Claim	**Lee**
	See [7a]-[7b], *supra*. EX1335-Lee ¶39 (“[w]ith the feedback elements implemented in the signal amplification circuit 400, the input matching performance can be improved greatly” and, for example, “a wider input frequency range can be covered by the signal amplification circuit 400.”). EX1335-Lee ¶39 (“matching network . . . 210 should be properly designed to meet the impedance matching requirements.”). EX1335-Lee ¶16 (“[t]his document does not intend to distinguish between components that differ in name but not function.”). EX1335-Lee ¶45 (“Those skilled in the art will readily observe that numerous modifications and alterations of the device and method may be made while retaining the teachings of the invention.”).

C. Ground III: Claims 1, 7, 8, 11, 17, and 18 Are Obvious Over Lee in View of the Feasibility Study

133. The Feasibility Study also discloses an input RF signal employing carrier aggregation, as recited in limitations 1.d and 17.d (*see* Sections IX.A.1.d and IX.A.5.d). The ’356 patent discloses the use of carrier aggregation in LTE. *See* EX1301-’356-Patent at 2:53-67. The Feasibility Study teaches that “LTE-Advanced extends LTE release 8 with support for *Carrier Aggregation*, where two or more *component carriers* (CC) are aggregated in order to support wider

transmission bandwidths up to 100MHz and for spectrum aggregation." EX1304-Study at 22. It further teaches that a "terminal may simultaneously receive one or multiple component carriers depending on its capabilities." *Id*.

134. A person having ordinary skill in the art would have found it obvious to turn to the amplification circuit of Lee in order to process the carrier-aggregated input RF signal of the Feasibility Study and would have been motivated to combine those references. The Feasibility Study recognizes that wireless mobile devices can be configured to operate with input RF signals employing carrier aggregation. *See* EX1304-Study at 9 ("It is possible to configure a UE [user equipment][21] to aggregate a different number of component carriers originating from the same eNB [base station] and of possibly different bandwidths in the UL [uplink] and the DL [downlink]."). The Feasibility Study further suggests that an ideal receiver for noncontiguous intra-band and inter-band carrier aggregation would have multiple RF front-ends. *See id*. at 26 (describing "Option B" with "multiple" Rx architecture for non-contiguous carrier aggregation). The Feasibility Study characterizes an "RF front end" as having its own gain control (amplifier), mixer, and analog-to-digital conversion. *See id.* ("RF front end (i.e.,

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[21] "User equipment" is and was understood by those skilled in the art to include wireless mobile devices such as cellular telephones.

mixer, AGC [Automatic Gain Control], ADC [Analog-to-Digital conversion)"). Lee teaches multiple amplifier blocks providing output to different receivers. *See* EX1335-Lee ¶29. Lee thus teaches the exact type of receiver that the Feasibility Study recognizes would work with signals employing carrier aggregation. The motivation to combine Lee with the teachings of the Feasibility Study arises from the references themselves and requires nothing more than substitution of the "plurality of radio frequency signals" of Lee for the "Carrier Aggregation" signals described in the Feasibility Study.

135. A person having ordinary skill in the art would have been motivated to use the carrier-aggregated input RF signal of the Feasibility Study with the amplification blocks of Lee. The Feasibility Study teaches that carrier aggregation may provide benefits, such as wider transmission bandwidths and spectrum aggregation. *See* EX1304-Study at 8. The Feasibility Study further teaches that carrier aggregation is supported by LTE-Advanced. *Id*. A person of ordinary skill in the art would have been motivated to use the input RF signal employing carrier aggregation of the Feasibility Study with the amplification blocks of Lee in order to achieve these benefits and unlock the features of LTE-Advanced.

136. A person of ordinary skill in the art would have had a reasonable expectation of success in using the carrier aggregated input RF signals as

described in the Feasibility Study with the amplification blocks of Lee. The Feasibility Study teaches that a receiver front-end with multiple processing paths can successfully support carrier aggregation. EX1304-Study at 26. The circuitry of Lee is capable of receiving and processing the types of signals described in Feasibility Study, and any further modifications that would have been made to Lee to accept the input RF signal of the Feasibility Study would have involved nothing more than well-known receiver tuning and filtering techniques.

137. Lee teaches all of the remaining limitations of claims 1, 7, 8, 11, 17, and 18 for the same reasons described in Sections IX.A.1 – IX.A.6, and Lee renders claims 7 and 8 unpatentable under 35 U.S.C. §103(a) for the same reasons described in Sections IX.B.1 – IX.B.2. Accordingly, Lee in view of the Feasibility Study renders claims 1, 7, 8, 11, 17, and 18 obvious.

138. The chart below provides a summary of the disclosure of the references in this ground discussed above and presented in the form of a claim chart.

Ground III: Claims 1, 7, 8, 11, 17, 18 are Obvious Over Lee and Feasibility Study	
’356 Patent Claim	**Lee, Feasibility Study**
[1a]-[1c], [1e]-[1h], [7a]-[7b], [8a]-[8b], [11a]-[11b], [17a]-[17c], [17e]-[17h], [18a]-[18c]	*See* [1a]-[1c], [1e]-[1h], [7a]-[7b], [8a]-[8b], [11a]-[11b], [17a]-[17c], [17e]-[17h], [18a]-[18c], *supra*.
[1d] the input RF signal employing carrier aggregation	*See* [1d], [17d], *supra*.

Ground III: Claims 1, 7, 8, 11, 17, 18 are Obvious Over Lee and Feasibility Study	
’356 Patent Claim	**Lee, Feasibility Study**
comprising transmissions sent on multiple carriers at different frequencies to a wireless device, [17d] the first input RF signal employing carrier aggregation comprising transmissions sent on multiple carriers at different frequencies to a wireless device,	EX1304-Study at 8 (“LTE-Advanced extends LTE Rel.-8 with support for Carrier Aggregation, where two or more component carriers (CCs) are aggregated in order to support wider transmission bandwidths up to 100MHz and for spectrum aggregation.”) *Id*. at 9 (“Carrier aggregation is supported for both contiguous and non-contiguous component carriers with each component carrier limited to a maximum of 110 Resource Blocks in the frequency domain using the LTE Rel-8 numerology It is possible to configure a UE to aggregate a different number of component carriers originating from the same eNB and of possibly different bandwidths in the UL and the DL. In typical TDD deployments, the number of component carriers and the bandwidth of each component carrier in UL and DL will be the same.”) *Id*. at 22 (“LTE-Advanced extends LTE release 8 with support for Carrier Aggregation, where two or more component carriers (CC) are aggregated in order to support wider transmission bandwidths up to 100MHz and for spectrum aggregation. A terminal may simultaneously receive one or multiple component carriers depending on its capabilities”) **<u>Motivation to Combine</u>** *See* [1a]-[1h], [17a]-[17h], [18a]-[18c], *supra*. EX1335-Lee ¶17 (“the input signal VIN may include a plurality of radio frequency signals (e.g., a Bluetooth signal and a WiFi signal) received by a single antenna.”). EX1304-Study at 8 (“LTE-Advanced extends LTE Rel.-8 with support for Carrier Aggregation, where two or more component carriers (CCs) are aggregated in order to support wider transmission bandwidths up to 100MHz and for spectrum aggregation.”)

<table>
<tr><th colspan="2">Ground III: Claims 1, 7, 8, 11, 17, 18 are Obvious Over Lee and Feasibility Study</th></tr>
<tr><th>’356 Patent Claim</th><th>Lee, Feasibility Study</th></tr>
<tr><td></td><td>

Id. at T. 11.3.3.1-1:

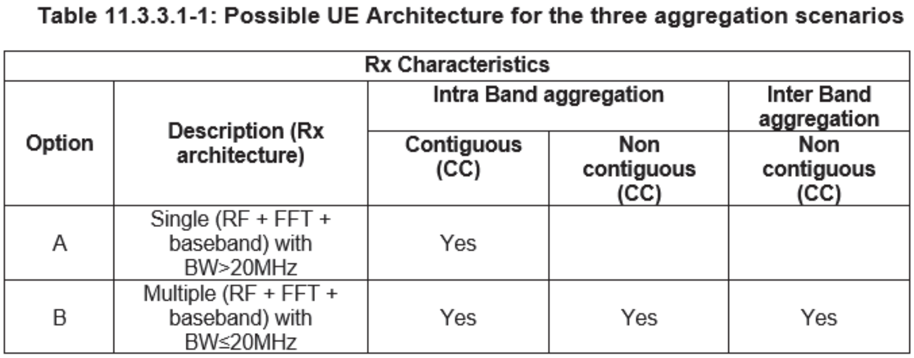

Table 11.3.3.1-1: Possible UE Architecture for the three aggregation scenarios

<table>
<tr><th colspan="5">Rx Characteristics</th></tr>
<tr><th rowspan="2">Option</th><th rowspan="2">Description (Rx architecture)</th><th colspan="2">Intra Band aggregation</th><th>Inter Band aggregation</th></tr>
<tr><th>Contiguous (CC)</th><th>Non contiguous (CC)</th><th>Non contiguous (CC)</th></tr>
<tr><td>A</td><td>Single (RF + FFT + baseband) with BW>20MHz</td><td>Yes</td><td></td><td></td></tr>
<tr><td>B</td><td>Multiple (RF + FFT + baseband) with BW≤20MHz</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
</table>

Id. at 26 (“Option A
- UE may adopt a single wideband-capable (i.e., >20MHz) RF front end (i.e., mixer, AGC, ADC) and a single FFT, or alternatively multiple "legacy" RF front ends (<=20MHz) and FFT engines. The choice between single or multiple transceivers comes down to the comparison of power consumption, cost, size, and flexibility to support other aggregation types.

Option B
- In this case, using a single wideband-capable RF front end is undesirable in the case of Intra band non contiguous CC due to the unknown nature of the signal on the ‘unusable’ portion of the band. In the case non adjacent Inter band separate RF front end are necessary.”)

</td></tr>
</table>

X. AVAILABILITY FOR CROSS-EXAMINATION

139. In signing this declaration, I recognize that the declaration will be filed as evidence in a contested case before the Patent Trial and Appeal Board of the United States Patent and Trademark Office. I also recognize that I may be

subject to cross examination in the case and that cross examination will take place within the United States. If cross examination is required of me, I will appear for cross examination within the United States during the time allotted for cross examination.

XI. RIGHT TO SUPPLEMENT

140. I reserve the right to supplement my conclusions in the future to respond to any arguments that the Patent Owner raises and to take into account new information as it becomes available to me.

XII. JURAT

141. I declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Dated: November 9, 2018

Patrick Fay, Ph.D.

APPENDIX A

Patrick Fay

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University of Notre Dame
261 Fitzpatrick Hall
Notre Dame, IN 46556
(574) 631-5693
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Education:

Ph.D., Electrical Engineering — July 1996
University of Illinois at Urbana-Champaign — GPA: 5.0/5.0
Thesis Advisor: I. Adesida
Thesis Title: A High Speed Monolithically Integrated Photoreceiver for Long Wavelength Communication Systems

M.S., Electrical Engineering — May 1993
University of Illinois at Urbana-Champaign — GPA: 5.0/5.0
Thesis Advisor: J. Lyding
Thesis Title: Scanning Tunneling Microscope Based Lithography on Silicon (100) for Microelectronic Device Fabrication

B.S., Electrical Engineering — May 1991
University of Notre Dame — GPA: 3.96/4.0

Research and Teaching Experience

Professor, August 2008 to present, *University of Notre Dame*
Associate Professor, August 2003 to 2008, *University of Notre Dame*
Assistant Professor, August 1997 to 2003, *University of Notre Dame*

- Director of Notre Dame Nanofabrication Facility (NDNF), January 2003 to present
- Established High Speed Circuits and Devices Laboratory featuring analog electronic device and circuit characterization at frequencies up to 1 THz (including vector network analysis to 750 GHz, spectrum analysis, modulation analysis, noise figure measurement, mixer characterization, nonlinear vector network analysis, detection spectral response), digital circuit testing to 40 Gb/s, optoelectronic device characterization to 50 GHz, variable-temperature device and circuit characterization, and device-level characterization including current-voltage and capacitance-voltage measurement, optical photoresponse characterization at wavelengths from 200 nm to 12 μm, deep-level transient spectroscopy, and low-frequency noise spectroscopy
- Established externally-funded research program in high-speed electronic and optoelectronic devices and circuits. Research emphasis on compound semiconductor microelectronics (including design and fabrication of HEMTs, HFETs, MISFETs, HBTs, RTDs, heterostructure photodetectors, and millimeter-wave detectors), circuit demonstrations of device technologies, development and use of micromachining techniques for the fabrication of microwave components, sensors, and packaging
- Developed and taught graduate-level course in optoelectronic devices and applications
- Developed advanced undergraduate/graduate level microwave circuit design and microwave measurements course and associated instructional Microwave Circuit Design and Measurements Laboratory (EE 40458, 60558)
- Revised and taught Electronics II course and laboratory (EE 30342) 2003-07, 2014-15
- Participated in the development of a new multidisciplinary first-year engineering course sequence (EG 111/112); taught EG 112 during 2001-2002
- Revised and taught Electronics I course and lab (EE 20242) 1998-2000, 2008-2010

Research and Teaching Experience (cont.)

Visiting Assistant Professor, August 1996 to August 1997
Visiting Postdoctoral Research Associate, August 1996 to August 1997
University of Illinois at Urbana-Champaign

- Responsible for teaching undergraduate solid-state physics and devices course (UIUC EE 340) and integrated circuit technology course (UIUC EE 344)
- Investigated advantages and achievable performance of several approaches to monolithic integration for optoelectronic integrated circuit (OEIC) fabrication. OEICs for long-wavelength photoreceiver applications using p-i-n and MSM photodetectors and high electron mobility transistors (HEMTs) designed, fabricated, and characterized.

Research Assistant, August 1991 to July 1996
University of Illinois at Urbana-Champaign

- Designed, fabricated, and tested high-speed (>18 GHz) monolithic optical MSM/HEMT receivers for 1.55 μm wavelength fiber optics communication. Microwave circuit design completed using Hewlett-Packard's MDS circuit simulation package; RF characterization of discrete devices and complete system using both frequency- and time-domain methods
- Developed several lithographic processes for high-resolution electron-beam lithography suitable for fabrication of optoelectronic integrated circuits and monolithic microwave integrated circuits with Cambridge EBMF 10.5
- Characterized surface damage due to reactive-ion etching processing in InAlAs/InGaAs/InP heterostructure FETs and its impact on FET performance
- Developed silicon nitride-based passivation process for InAlAs/InGaAs heterostructure FETs, and characterized the effect of the process on device performance
- Developed and characterized several wet etches useful in the fabrication of integrated circuits in the InAlAs/InGaAs/InP material system
- Refined STM-induced oxidation of silicon (100) surface, and used it to modify NMOS device behavior

Other Work Experience

Independent programmer from 1987-1996, producing custom computer software which includes an industrial inventory system, an educational software for geography, and a system to monitor cleanroom usage and arrange for garment laundering and accounting.

Scholarships and Fellowships

- Tau Beta Pi Graduate Research Fellow (1991-1992)
- National Science Foundation Graduate Research Fellow (1992-1995)
- University of Illinois Graduate College Fellow (1991-1992)

Honors and Awards

- Department of Electrical Engineering Outstanding Teacher Award, 2018
- Fellow of IEEE; citation: for contributions to compound semiconductor tunneling and high-speed device technologies, 2016
- Featured as “Faculty Spotlight” by Keysight Technologies, May 2016, http://www.keysight.com/main/editorial.jspx?cc=US&lc=eng&ckey=2745865&nid=-34792.0&id=2745865
- College of Engineering Outstanding Teacher Award, 2015
- IEEE Electron Device Society Distinguished Lecturer, 2015
- Co-recipient of Best Student Poster award, Broadband Wireless Access & Applications Center conference, May 2014
- Co-recipient of IEEE Transactions on Advanced Packaging Best Paper Award, 2007

Honors and Awards (cont.)

- Senior Member of IEEE, March 2002
- IEEE Outstanding Teacher Award, Dept. of Electrical Engineering, 1998-1999
- Finalist, Society for the Advancement of Materials and Process Engineering's award program, 1991
- U.S. Patent #5,880,482 awarded for "Low Dark Current Photodetector," March 9, 1999
- U. S. Patents #7,608,919 and 7,612,443 for "System for Inter-Chip Communication," October 27, 2009 and November 3, 2009, respectively.
- U.S. Patent #8,021,965 awarded for "Inter-Chip Communication," September 20, 2011.
- U.S. Patent #8,592,859 awarded for "Methods and Apparatus for Antimonide-Based Backward Diode Millimeter-Wave Detectors," November 26, 2013.
- U.S. Patent #8,623,700 for "Inter-Chip Communication," awarded January 7, 2014.
- U.S. Patent #8,796,733 awarded for "Low Voltage Tunnel Field-Effect Transistor (TFET) and Method of Making Same," August 5, 2014.
- U.S. Patent #9,633,976 for "Systems and Methods for Inter-Chip Communication," April 25, 2017.
- U. S. Patent #9,954,085 for "Group III-Nitride Compound Heterojunction Tunnel Field-Effect Transistors and Methods for Making the Same," April 24, 2018.

Professional Memberships

- Member of Eta Kappa Nu, Tau Beta Pi
- Fellow of IEEE
- Member of IEEE Electron Device Society, IEEE Microwave Theory and Techniques Society, IEEE Lasers and Electro-Optics Society, IEEE Components, Packaging, and Manufacturing Technology Society

Books and Monographs

1. P. Fay, "Introduction to Microwave and RF Engineering," The RF and Microwave Handbook, 2nd. ed., J. Michael Golio, ed., CRC Press, Boca Raton, 2008. Variations of this chapter also appear in RF and Microwave Passive and Active Technologies, RF and Microwave Applications and Systems, and RF and Microwave Circuits, Measurements, and Modeling, Mike Golio, ed., CRC Press, Boca Raton, 2008.
2. P. Fay, "High Speed Photodetectors and Photoreceivers," High Speed Photonic Devices, Nadir Dagli, ed., Taylor and Francis, New York, 2006.
3. G. H. Bernstein, L. O. Chua, A. I. Csurgay, P. Fay. Y. F. Huang, W. Porod, A. Rodriguez-Vasquez, B. Roska, T. Roska, F. Werblin, and A. Zarandy, "Biologically-Inspired Cellular Machine Architectures," Managing Nano-Bio-Info-Cogno Innovations: Converging Technologies in Society, W. S. Bainbridge and M. C. Roco, eds., Springer, Doordrecht, 2006.
4. P. Fay, "Introduction to Microwave and RF Systems Engineering," Microwave and RF Product Applications, J. Michael Golio, ed., CRC Press, Boca Raton, 2003.
5. J-. H. Jang, P. Fay, and I. Adesida, "Optoelectronic Receivers," Encyclopedia of Optical Engineering, R. G. Driggers, ed., Marcel Dekker, New York, NY, 2002.
6. P. Fay, "Photodetectors," Encyclopedia of Materials: Science and Technology, S. Mahajan, ed., Elsevier Science, Oxford UK, 2001.
7. P. Fay, "Introduction to Microwave and RF Engineering," The RF and Microwave Handbook, J. Michael Golio, ed., CRC Press, Boca Raton, 2000.

Books and Monographs (cont.)

8. P. Fay and I. Adesida, "Processing of Epitaxial Heterostructure Devices," Volume 1: Heterostructures for High-Performance Devices, pp. 55-102, Maurice Francome and Colin E. C. Wood, eds., *Handbook of Thin Film Devices: Frontiers of Research, Technology and Applications*, Academic Press, 2000.
9. P. Fay, "Photodetectors," Reference Module in Materials Science and Materials Engineering, S. Hashmi, ed., Elsevier, Oxford UK, pp. 1-16, 2016.

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1. J. Wang, R. McCarthy, C. Youtsey, R. Reddy, J. Xie, E. Beam, L. Guido, L. Cao, and P. Fay, "High Voltage Vertical GaN p-n Diodes by Epitaxial Lift-Off from Bulk GaN Substrates," *IEEE Electron Dev. Lett.*, vol. 39, no. 11, pp. 1716-1719, DOI: 10.1109/LED.2018.2868560, 2018.
2. G. Silva-Oelker, C. Jerez-Hanckes, and P. Fay, "Study of W/HfO_2 grating selective thermal emitters for thermophotovoltaic applications," *Optics Express*, vol. 26, no. 22, pp. A929-936, DOI: 10.1364/OE.26.00A929, 2018.
3. L. Cao, C. F. Lo, H. Marchand, W. Johnson, and P. Fay, "Low-Loss Coplanar Waveguides on GaN-on-Si Substrates," *IEEE Microwave and Wireless Components Lett.*, vol. 28, no. 10, pp. 861-863, DOI 10.1109/LMWC.2018.2867084, 2018.
4. J. Wang, L. Cao, J. Xie, E. Beam, R. McCarthy, C. Youtsey, and P. Fay, "High voltage, high current GaN-on-GaN p-n diodes with partially compensated edge termination," *Appl. Phys. Lett.*, vol. 113, pp. 023502-1 -5, DOI 10.1063/1.5035267, 2018.
5. L. Cao, J. Wang, G. Harden, H. Ye, R. Stillwell, A. J. Hoffman, and P. Fay, "Experimental characterization of impact ionization coefficients for electrons and holes in GaN grown on bulk GaN substrates," *Appl. Phys. Lett.*, vol. 112, no. 26, pp. 262103-1 -5, DOI 10.1063/1.5031785, 2018.
6. H. Amano, Y. Baines, E. Beam, M. Borga, T. Bouchet, P. Chalker, M. Charles, K. Chen, N. Chowdhury, R. Chu, C. De Santi, M. De Souza, S. Decoutere, L. Di Cioccio, B. Eckardt, T. Egawa, P Fay, J. Freedsman, L Guido,O. Häberlen, G. Haynes, T. Heckel, D. Hemakumara, P. Houston, J. Hu, M. Hua, Q. Huang, A. Huang, S. Jiang, H. Kawai, D. Kinzer, M. Kuball, A. Kumar, K. Lee, X. Li, D. Marcon, M. März, R. McCarthy, G. Meneghesso, M. Meneghini, E. Morvan, A. Nakajima, E. Narayanan, S. Oliver, T. Palacios, D. Piedra, M. Plissonnier, R. Reddy, M. Sun, I. Thayne, A. Torres, N. Trivellin, V. Unni, M. Uren, M. Van Hove, D. Wallis, J. Wang, J. Xie, S. Yagi, S. Yang, C. Youtsey, R. Yu, E. Zanoni, S. Zeltner, and Y. Zhang, "The 2018 GaN power electronics roadmap," *J. Physics D: Appl. Phys*, vol. 51, no. 16, 163001 pp. 1-48, DOI 10.1088/1361-6463/aaaf9d, 2018.
7. J. Ren, Z. Jiang, P. Fay, J. Hesler, C. Tong, and L. Liu, "High-Performance WR-4.3 Optically Controlled Variable Attenuator with 60-dB Range," *IEEE Microwave and Wireless Components Lett.*, vol. 28, no. 6, p. 512-514, DOI 10.1109/LMWC.2018.2823589, 2018.
8. H. Lu, P. Paletti, W. Li, P. Fay, T. Ytterdal, and A. Seabaugh, "Tunnel FET Analog Benchmarking and Circuit Design," *IEEE J. Exploratory Solid-State Computational Devices and Circuits*, vol. 4, pp. 19-25, DOI: 10.1109/JXCDC.2018.2817541, 2018.
9. J. Encomendero, R. Yan, A. Verma, S. M. Islam, V. Protasenko, S. Rouvimov, P. Fay, D. Jena, and H. Xing, "Room temperature microwave oscillations in GaN/AlN resonant tunneling diodes with peak current densities up to 220 kA/cm2," *Appl. Phys. Lett.,* vol. 112, no. 10, p. 103101-1 -5, DOI: 10.1063/1.5016414, 2018.

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10. S. Rahman, Z. Jiang, M. Shams, P. Fay, and L. Liu, “A G-Band Monolithically Integrated Quasi-Optical Zero-Bias Detector Based on Heterostructure Backward Diodes Using Submicrometer Airbridges,” *IEEE Trans. Microwave Theory and Techniques*, vol. 66, no. 4, p. 2010-2017, DOI: 10.1109/TMTT.2017.2779133, 2018.
11. W. Li, M. Brubaker, B. Spann, K. Bertness, and P. Fay, “GaN Nanowire MOSFET with Near-Ideal Subthreshold Slope,” *IEEE Electron Device Lett*., vol. 39, no. 2, pp. 184-187, DOI: 10.1109/LED.2017.2785785, 2018.
12. G. Silva-Oelker, R. Aylwin, C. Jerez-Hanckes, and P. Fay, “Quantifying the Impact of Random Surface Perturbations on Reflective Gratings,” *IEEE Trans. Antennas and Propagation*, vol. 66, p. 838-847, DOI: 10.1109/TAP.2017.2780902, 2018.
13. J. Encomendero, F. Faria, S. M. Islam, V. Protasenko, S. Rouvimov, B. Sensale-Rodriguez, P. Fay, D. Jena, and H. Xing, “New Tunneling Features in Polar III-Nitride Resonant Tunneling Diodes,” *Phys. Rev. X*, vol. 7, p. 041017-1-12, DOI: 10.1103/PhysRevX.7.041017, 2017.
14. C. Lund, B. Romanczyk, M. Catalano, Q. Wang, W. Li, D. DiGiovanni, J. Kim, P. Fay, S. Nakamura, S. DenBaars, U. Mishra, and S. Keller, “Metal-organic chemical vapor deposition of high quality, high indium composition N-polar InGaN layers for tunnel devices,” *J. Appl. Phys*., vol. 121, p. 185707-1-9, DOI: 10.1063/1.4983300, 2017.
15. J. Fernandez-Berni, M. Niemier, X. S. Hu, H. Lu, W. Li, P. Fay, R. Carmona-Galan, and A. Rodriguez-Vazquez, “TFET-based well capacity adjustment in active pixel sensor for enhanced high dynamic range,” *Electronics Lett*., vol. 53, pp. 622-624, DOI: 10.1049/el.2016.4548, 2017.
16. J. Wang, C. Youtsey, R. McCarthy, R. Reddy, N. Allen, L. Guido, J. Xie, E. Beam, and P. Fay, “Thin-film GaN Schottky diodes formed by epitaxial lift-off,” *Appl. Phys. Lett.,* vol. 110, pp. 173403-1 -5, DOI: 10.1063/1.4982250, 2017.
17. C. Youtsey, R. McCarthy, R. Reddy, K. Forghani, A. Xie, E. Beam, J. Wang, P. Fay, T. Ciarkoski, E. Carlson, and L. Guido, “Wafer-scale epitaxial lift-off of GaN using bandgap-selective photoenhanced wet etching,” *Phys. Stat. Solidi B*, vol. 254, no. 8, pp. 1600774-1-6, DOI 10.1002/pssb.201600774, 2017. Cover feature article in August 2017 issue.
18. M. I. Shams, Z. Jiang, S. Rahman, L. J. Cheng, J. Hesler, P. Fay, and L. Liu, “A 740-GHz Dynamic Two-Dimensional Beam-Steering and Forming Antenna Based on Photo-Induced Reconfigurable Fresnel Zone Plates,” *IEEE Trans. Terahertz Sci. Tech.,* vol. 7, no. 3, pp. 310-319, DOI: 10.1109/TTHZ.2017.2681431, 2017.
19. L. Liu, S. Rahman, Z. Jiang, W. Li, and P. Fay, “Advanced Terahertz Sensing and Imaging Systems Based on Integrated III-V Interband Tunneling Devices,” *Proc. IEEE*, vol. 105, no. 6, pp. 1020-1034, DOI 10.1109/JPROC.2016.2636245, 2017.
20. A. Crippa, R. Maurand, D. Kotekar-Patil, A. Corna, H. Bohuslavskyi, A. Orlov, P. Fay, R. Laieville, S. Barraud, M. Vinet, M. Sanquer, S. De Franceschi, and X. Jehl, “Level Spectrum and Charge Relaxation in a Silicon Double Quantum Dot Probed by Dual-Gate Reflectometry,” ACS *Nano Lett.,* vol. 17, pp. 1001-1006, DOI: 10.1021/acs.nanolett.6b04354, 2017.
21. Y. Zhang, G. Vigil, L. Cao, A. Khan, D. Bernirschke, T. Ahmed, P. Fay, and S. Howard, “Saturation compensated fluorescence lifetime imaging microscopy,” *Optics Lett*., vol. 42, no. 1, pp. 155-158, DOI: 10.1364/OL.42.000155, 2017.

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22. Z. Jiang, M. I. Shams, L. Cheng, P. Fay, J. Hesler, C. Tong, and L. Liu, “Investigation and Demonstration of WR-4.3 Optically-Controlled Waveguide Attenuator,” *IEEE Trans. THz Science Technol.*, vol. 7, no. 1, pp. 20-26, 2017.
23. P. Fay, T. Lu, J. Kulick, and G. H. Bernstein, “Ultra-Wide Bandwidth Inter-Chip Interconnects for Heterogeneous Millimeter-Wave and THz Circuits,” *J. Infrared, Millimeter, and Terahertz Waves*, vol. 37, no. 9, pp. 874-880, DOI 10.1007/s10762-016-0278-5, 2016.
24. H. Lu, W. Li, Y. Lu, P. Fay, T. Ytterdal, and A. Seabaugh, “Universal Charge-Conserving TFET SPICE Model Incorporating Gate Current and Noise,” *IEEE J. Exploratory Solid-State Computational Devices and Circuits*, vol. 2, pp. 20-27, DOI: 10.1109/JXCDC.2016.2582204, 2016.
25. W. Li, P. Fay, T. Yu, and J. Hoyt, “Microwave detection performance of $In_{0.53}Ga_{0.47}As/GaAs_{0.5}Sb_{0.5}$ quantum-well tunnel field-effect transistors,” *Electronics Lett.*, vol. 52, no. 10, pp. 842-844, DOI: 10.1049/el.2016.0328, 2016.
26. W. Li, L. Cao, C. Lund, S. Keller, and P. Fay, “Performance projection of III-nitride heterojunction nanowire tunneling field-effect transistors,” *Phys. Status Solidi A*, vol. 213, pp. 905-908, DOI 10.1002/pssa.201532564, 2016.
27. S. Rahman, Z. Jiang, P. Fay, and L. Liu, “Integration and fabrication of high-performance Sb-based heterostructure backward diodes with submicron-scale airbridges for terahertz detection,” *J. Vacuum Science and Technol.*, B, vol. 34, no. 4, p. 041330, DOI 10.1116/1.4953551, 2016.
28. M. Qi, K. Nomoto, M. Zhu, Z. Hu, Y. Zhao, V. Protasenko, B. Song, X. Yan, G. Li, J. Verma, S. Bader, P. Fay. H. Xing, and D. Jena, “High breakdown single-crystal GaN p-n diodes by molecular beam epitaxy,” *Appl. Phys. Lett.*, vol. 107, pp. 232101-1 -4, DOI 10.1063/1.4936891, 2015.
29. C. Lorenz, S. Hemour, W. Li, Y. Xie, J. Gauthier, P. Fay, and K. Wu, “Breaking the Efficiency Barrier for Ambient Microwave Power Harvesting with Heterojunction Backward Tunnel Diodes,” *IEEE Trans. Microwave Theory and Techniques*, vol. 61, no. 12, pp. 4544-4555, DOI 10.1109/TMTT.2015.2495356, 2015.
30. L. Ohlsson, P. Fay, and L. E. Wernersson, “Picosecond dynamics in a millimeter-wave RTD-MOSFET wavelet generator,” *Electronics Lett.*, vol. 51, no. 21, pp. 1671-1673, DOI 10.1049/el.2015/1329, 2015.
31. X. Yan, W. Li, S. M. Islam, K. Pourang, H. Xing, P. Fay, and D. Jena, “Polarization-induced Zener tunnel diodes in GaN/InGaN/GaN heterojunctions,” *Appl. Phys. Lett.*, vol. 107, pp. 163504-1-5, DOI 10.1063/1.4934269, 2015.
32. W. Chen, B. Chen, A. Holmes, and P. Fay, “Investigation of traps in strained-well InGaAs/GaAsSb quantum well photodiodes,” *Electronics Lett.,* vol. 51, no. 18, pp. 1260-1262, DOI 10.1049/el.2015.2191, 2015.
33. Z. Jiang, Y. Lu, Y. Tan, Y. He, M. Povolostkyi, T. Kubis, A. Seabaugh, P. Fay, and G. Klimeck, “Quantum Transport in AlGaSb/InAs TFETs with Gate Field In-Line with Tunneling Direction,” *IEEE Trans. Electron Devices*, vol. 62, no. 8, pp. 2445-2449, DOI 10.1109/TED.2015.2443564, 2015.

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34. W. Li, S. Sharmin, H. Ilatikhameneh, R. Rahman, Y. Lu, J. Wang, X. Yan, A. Seabaugh, G. Klimeck, D. Jena, and P. Fay, "Polarization-Engineered III-Nitride Heterojunction Tunnel Field-Effect Transistors," *IEEE J. Exploratory Solid-State Computational Devices and Circuits*, vol. 1, pp. 28-34, DOI 10.1109/JXCDC.2015.2426433, 2015.
35. P. Fay, O. Aktas, D. Bour, and I. C. Kizilyalli, "Experimental observation of RF avalanche gain in GaN-based PN junction diodes," *Electronics Lett.*, vol. 51, no. 13, pp. 1009-1010, DOI 10.1049/el.2015.1551, 2015.
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37. M. A. Khan, Q. Zheng, D. Kopp, W. Buckhanan, J. Kulick, P. Fay, A. Kriman, and G. H. Bernstein, "Thermal Cycling Study of Quilt Packaging," *J. Electronic Packaging*, vol. 137, no. 2, pp. 021008-1 -7, DOI 10.1115/1.4029245, 2015.
38. Y. Zhao, W. Chen, W. Li, M. Zhu, Y. Yu, B. Song, J. Encomendero, B. Sensale-Rodriguez, H. Xing, and P. Fay, "Direct electrical observation of plasma wave-related effects in GaN-based two-dimensional electron gases," *Appl. Phys. Lett.*, vol. 105, p. 173508-1-5, 2014.
39. Y. Yue, X. Yan, W. Li, H. Xing, D. Jena, and P. Fay, "Faceted Sidewall Etching of n-GaN on Sapphire by Photo-electro-chemical Wet Processing," *J. Vacuum Science and Technol.* B, vol. 32, p. 061201-1 -5, 2014.
40. Z. Jiang, S. Rahman, J. Hesler, P. Fay, and L. Liu, "Design and Characterisation of a 200 GHz Tunable Lens-Coupled Annular-Slot Antenna with 50 GHz Tuning Range," *IET Microwaves, Antennas, and Propagation*, vol. 8, no. 11, pp. 842-848, 2014.
41. M. I. B. Shams, Z. Jiang, S. Rahman, J. Qayyum, L. J. Cheng, H. G. Xing, P. Fay, and L. Liu, "Approaching real-time terahertz imaging with photo-induced coded apertures and compressed sensing," *Electronics Lett.*, vol. 50, no. 11, pp. 801-803, 2014.
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49. Z. Jiang, S. M. Rahman, P. Fay, J. L. Hesler, and L. Liu, "Tunable 200 GHz lens-coupled annular-slot antennas using Schottky varactor diodes for all-electronic reconfigurable terahertz circuits," *Electronics Lett.*, vol. 49, no. 23, pp. 1428-1430, 2013.
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55. B. Tiwari, P. Fay, G. H. Bernstein, A. Orlov, and W. Porod, "Effect of Read-Out Interconnects on Polarization Characteristics of Nanoantennas for the Long-Wave Infrared Regime," *IEEE Trans. Nanotechnology*, vol. 12, no. 2, pp. 270-275, 2013.
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150. M. Arafa, P. Fay, K. Ismail, J. O. Chu, B. S. Meyerson, and I. Adesida, "High Speed P-Type SiGe Modulation-Doped Field-Effect Transistors," *IEEE Electron Device Lett.*, vol. 17, no. 3, pp. 124-126, 1996.

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Refereed Publications (cont.)

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155. N. Pan, J. Elliot, H. Hendriks, L. Aucoin, P. Fay, and I. Adesida, "InAlAs/InGaAs High Electron Mobility Transistors on Low Temperature InAlAs Buffer Layers by Metalorganic Chemical Vapor Deposition," *Appl. Phys. Lett.*, vol. 66, no. 2, pp. 212-214, 1995.
156. R. Grundbacher, P. Fay, and I. Adesida, "Fabrication and Characterization of InAlAs/InGaAs Striped-Channel Modulation-Doped Field Effect Transistors," *J. Vac. Sci. Technol. B*, vol. 12, no. 6, pp. 3750-3754, 1994.
157. P. Fay, R. T. Brockenbrough, G. Abeln, P. Scott, S. Agarwala, I. Adesida, and J. Lyding, "Scanning Tunneling Microscope Stimulated Oxidation of Silicon (100) surfaces," *J. Appl. Phys*, vol. 75, no. 11, pp. 7545-7549, 1994.

Invited Lectures and Addresses

1. P. Fay, J. Wang, L. Cao, W. Li, R. McCarthy, R. Reddy, C. Youtsey, C. F. Lo, H. Marchand, W. Johnson, M. Brubaker, and K. Bertness, “Prospects for High Performance RF Interconnects and Functional Integration Using GaN on Silicon,” *IEEE Silicon Nanoelectronics Workshop*, Honolulu, HI, June 2018.
2. A. Kummel, W. Li, A. Kerr, E. Chagarov, S. Gu, T. Kaufman-Osborn, S. Madisetti, J. Wu, P. Asbeck, S. Oktyabrsky, and P. Fay, “Passivation of High K/GaN Interfaces for GaN Tunnel FETs,” *Electrochemical Society (ECS) Meeting*, Seattle, WA, May 2018.
3. P. Fay, “Nanoelectronics: It’s More Fun Than It Sounds,” DoD Starbase Indiana STEM outreach program, January 2018.
4. P. Fay, W. Li, L. Cao, K. Pourang, S. M. Islam, C. Lund, S. Saima, H. Ilatikhameneh, T. Amin, J. Huang, R. Rahman, H. Xing, D. Jena, S. Keller, G. Klimeck, M. Brubaker, B. Spann, and K. Bertness, “III-N Nanowire Devices for Low Power Applications,” International Workshop on the Physics of Semiconductor Devices, New Delhi, India, December 2017.
5. P. Fay, “Electronics: Past, Present, and Wild Guesses About the Future,” Introduction to Engineering Program, Notre Dame, IN, June 2017.
6. P. Fay and D. Jena, “Low-Power Electronic Switches with Gallium Nitride Transistors,” SRC Starnet-ACCEL eWorkshop Series, April 2017.
7. P. Fay, “Novel Heterostructure Devices for Ultra-Scaled Logic,” American Physical Society Meeting, New Orleans, March 2017.
8. P. Fay, W. Li, D. Digiovanni, L. Cao, K. Pourang, H. Ilatikhameneh, F. Chen, T. Ameen, R. Rahman, G. Klimeck, C. Lund, S. Keller, S. M. Islam, A. Chaney, Y. Cho, and D. Jena, “III-N Heterostructure Devices for Low-Power Logic,” China Semiconductor Technology International Conference, Shanghai, March 2017.
9. P. Fay, W. Li, D. DiGiovanni, A. Chaney, S. M. Islam, D. Jena, M. Brubaker, K. Bertness, “III-N Nanowire FETs for Low-Power Applications,” Workshop on Compound Semiconductor Materials and Devices, Safety Harbor, FL, February 2017.
10. L. Liu, Z. Jiang, M. Shams, S. Rahman, and P. Fay, “Dynamically Tunable and Reconfigurable Antennas for Advanced THz Sensing and Imaging,” Int’l Union of Radio Science National Radio Science Meeting (URSI-NRSM), Boulder, CO, Jan. 2017.

Invited Lectures and Addresses (cont.)

11. P. Fay, W. Li, L. Cao, K. Pourang, S. M. Islam, C. Lund, H. Ilatikahameneh, T. Amin, J. Huang, R. Rahman, D. Jena, S. Keller, G. Klimeck, M. Brubeker, K. Bertness, "Tunneling in III-N Heterostructures for Low-Power Electronics," American Vacuum Society Int'l Symp., Nashville, TN, Nov. 2016.
12. P. Fay, "Nanoscale Devices and Integration for Low-Power Computation, Energy Harvesting, and Imaging," Mathematical and Computational Engineering Seminar, Pontifical Universidad de Chile, Santiago, Chile, October 2016.
13. P. Fay. J. Wang, C. Youtsey, R. McCarthy, R. Reddy, T. Ciarkowski, E. Carlson, L. Guido, A. Xie, and E. Beam, "GaN-Based Epitaxial Lift-off for Device Applications," International Workshop on Nitrides, Orlando, FL, Oct. 2016.
14. P. Fay, W. Li, D. Digiovanni, L. Cao, K. Pourang, H. Ilatikhameneh, F. Chen, T. Ameen, R. Rahman, G. Klimeck, C. Lund, S. Keller, S. M. Islam, A. Chaney, Y. Cho, and D. Jena, "III-N Heterojunctions for Tunnel Field-Effect Transistors," Steep Transistors Workshop, Ecole Polytechnique Federal de Lausanne, Lausanne, Switzerland, Sept. 2016.
15. P. Fay, W. Li, Y. Cao, and Y. Zhao, "Beyond Power: III-N Devices for Low-Power Systems, Millimeter-Wave Applications, and More," IEEE SBmicro Conf., Belo Horizonte, Brazil, August 2016.
16. P. Fay, "Advances in III-V Heterostructure Devices and Integration for Millimeter-Wave and THz Sensing and Imaging," IEEE Electron Device Society Distinguished Lecture, Federal Univ. of Minas Gerais – UFMG, Belo Horizonte, Brazil, August, 2016.
17. P. Fay, W. Li, L. Cao, K. Pourang, S. M. Islam, C. Lund, S. Saima, H. Ilatikhameneh, T. Amin, J. Huang, R. Rahman, D. Jena, S. Keller, and G. Klimeck, "Novel III-N Heterostructure Devices for Low-Power Logic and More," IEEE Int'l. Conf. on Nanotechnology, Sendai, Japan, August 2016.
18. P. Fay, W. Li, S. Rahman, Z. Jiang, and L. Liu, "Tunneling-Based Heterostructure Devices for Millimeter-Wave and THz Sensing," National Aerospace and Electronics Conf., Dayton, OH, July 2016.
19. P. Fay, "GaN Devices and Technology," short course at Semicon West, San Francisco, CA, July 2016.
20. P. Fay, "Nanoscale Devices and Integration for Low-Power Computation, Energy Harvesting, and Imaging," Great Lakes Science Boot Camp for Librarians, Notre Dame, IN, July 2016.
21. P. Fay, W. Li, S. Rahman, Z. Jiang, and L. Liu, "Advances in III-V Heterostructure Devices and Integration for Millimetre-Wave and THz Sensing and Imaging," Workshop on Compound Semiconductor Devices and Integrated Circuits Held in Europe (WOCSDICE), Aveiro, Portugal, June 2016.
22. P. Fay, "III-N Heterostructure Devices for Low-Power Logic and More," 14th Annual Nanotechnology Workshop, Center for Nanoscale Science and Technology, Urbana, IL, May 2016.
23. P. Fay, "GaN-Based Electronics for RF, Power, and More," SunEdison Semiconductor, St. Peters, MO, April 2016.
24. L. Liu, M. I. B. Shams, Z. Jiang, S. Rahman, J. L. Hessler, L. J. Cheng, and P. Fay, "Tunable and reconfigurable THz devices for advanced imaging and adaptive wireless communication," SPIE Optics and Photonics Conf., San Diego, CA, August 2016.

Invited Lectures and Addresses (cont.)

25. P. Fay, W. Li, K. Pourang, and D. Jena, "GaN-based Nanowire Tunnel FETs for Low Power Electronics," Workshop on Compound Semiconductor Materials and Devices, Tucson, AZ February 2016.
26. A. Seabaugh, S. Fathipour, W. Li, H. Lu, J. H. Park, A. C. Kummel, D. Jena, S. Fullerton-Shirey, and P. Fay, "Steep subthreshold swing tunnel FETs: GaN/InN/GaN and transition metal dichalcogenide channels," *Proc. Int'l Electron Devices* Meeting, pp. 35.6.1-35.6.4, Washington DC, 2015.
27. P. Fay, W. Li, L. Cao, X. Yan, K. Pourang, M. Islam, S. Saima, J. Huang, T. Armin, H. Ilatikhameneh, R. Rahman, G. Klimeck, C. Lund, S. Keller and D. Jena, "III-N Heterojunction Tunnel Field-Effect Transistors," Steep Transistors Workshop, Notre Dame, IN, October 2015.
28. P. Fay, "Advances in III-V Heterostructure Devices and Integration for Millimeter-Wave and THz Sensing and Imaging," Univ. of Michigan, Ann Arbor, MI, April 2015.
29. P. Fay, W. Li, T. Yu, and J. Hoyt, "Interband Tunneling FETs for High-Sensitivity Millimeter-Wave and THz Detection," Workshop on Compound Semiconductor Materials and Devices, Charleston, SC, February 2015.
30. P. Fay, "Advances in III-V Heterostructure Devices and Integration for Millimeter-Wave and THz Sensing and Imaging," Ecole Polytechnique de Montreal Centre for Research in Radiofrequency Electronics Seminar, Montreal, Canada, September 2014.
31. P. Fay, Y. Xie, Y. Zhao, Z. Jiang, S. Rahman, H. Xing, B. Sensale-Rodriguez, and L. Liu, "Emerging Electronic Devices for THz Sensing and Imaging," SPIE Optics and Photonics Conf., vol. 9199, San Diego, CA, August 2014.
32. P. Fay, W. Li, J. Wang, X. Yan, and D. Jena, "Prospects for III-N Interband Tunnel FETs for Low-Power Applications," Workshop on Compound Semiconductor Materials and Devices, San Antonio, TX, February 2014.
33. P. Fay, "GaN Devices and Technology," Skyworks Solutions, Inc., Irvine, CA, January 2014.
34. P. Fay, Y. Lu, G. Zhou, T. Vasen, Y. Xie, M. I. Shams, Z. Zhang, H. Xing, and A. Seabaugh, "Interband Tunneling in InAs/AlGaSb Heterostructures: Devices for Low-Power Logic and THz Applications," International Semiconductor Device Research Symposium, Bethesda, MD, December 2013.
35. H. G. Xing, G. Zhou, M. O. Li, Y. Lu, R. Li, M. Wistey, P. Fay, D. Jena, and A. Seabaugh, "Tunnel FETs with tunneling normal to the gate," Berkeley Symp. on Energy Efficient Electronic Systems, Berkeley, CA, October 2013.
36. P. Fay, "GaN Devices and Technology," IEEE Bipolar/BiCMOS Circuits and Technology Meeting, Bordeaux, France, September 2013.
37. P. Fay, G. Zhou, Y. Lu, R. Li, T. Vasen, A. Seabaugh, and H. Xing, "III-V Tunnel FETs for Energy Efficient Logic," Workshop on Compound Semiconductor Devices and Integrated Circuits – Europe, Warnemunde, Germany, May 2013.
38. P. Fay, "Advances in III-V Heterostructure Devices for Millimeter-Wave and THz Applications," Raytheon Multifunction RF System Technology Network Symposium, Tuscon, AZ, April 2013.
39. P. Fay, "High Performance III-V Electronic and Optoelectronic Devices for RF & Millimeter-Wave Applications," Agilent Technologies, Santa Clara, CA, March 2013.

Invited Lectures and Addresses (cont.)

40. P. Fay, Z. Zhang, Y. Xie, M. I. Shams, L. Liu, and S. Rahman, “Heterostructure Backward Diodes for Sensing and Imaging,” Workshop on Compound Semiconductor Materials and Devices, New Orleans, LA, 2013.
41. P. Fay, “III-V Compound Semiconductor Devices for Millimeter-Wave and THz Applications,” Dept. of Electrical and Information Technology, Lund University, Lund, Sweden, June 2012.
42. P. Fay, Y. Lu, H. Xing, and A. Seabaugh, “Design Considerations in III-V Tunnel FETs,” Workshop on Compound Semiconductor Materials and Devices, Napa, CA, 2012.
43. P. Fay, Z. Zhang, Y. Xie, and M. I. Shams, “Heterostructure Backward Diode Detectors for Millimeter-wave through THz Detection and Imaging,” *URSI National Radio Science Meeting*, Boulder, CO, 2012.
44. A. Seabaugh, S. Chae, P. Fay, W. Hwang, T. Kosel, Q. Liu, Y. Lu, T. Vasen, M. Wistey, G. Xing, G. Zhou, and Q. Zhang, “III-V Tunnel Field-Effect Transistors,” Electro-Chemical Society Meeting, Boston, MA, October 2011.
45. P. Fay, “High Performance Heterostructure Backward Diode Detectors,” *SPIE Defense and Security Conf.*, Orlando, FL, April 2011.
46. P. Fay and Z. Zhang, “Advances in High Sensitivity Millimeter-Wave-THz Detectors” Workshop on Compound Semiconductor Materials and Devices, Savannah, GA, February 2011.
47. L. Liu, T. Wang, A. Biswas, Z. Cai, F. Watanabe, A. S. Biris, M. Lieberman, G. H. Bernstein, H. Xing, and P. Fay, “Narrow Spectral Features of Cellulose Nanocomposities Chracterized by Frequency Domain Terahertz Spectroscopy,” Proc. Int’l. Conf. on Composites/Nano Engineering, Anchorage, AK, July 2010.
48. W. Porod, J. A. Bean, Z. Sun, B. Tiwari, G. Szakmany, G. H. Bernstein, and P. Fay, “Nanostructure Antennas for the LW-IR Regime,” Proc. Int’l Microwave Symp. 2010, paper TH3E, pp. 1412-1415, Anaheim, CA, May 2010.
49. P. Fay and X. Xing, “InGaAs Channel MOSFETs with InAlP-Oxide Gate Dielectric,” Workshop on Compound Semiconductor Materials and Devices, Newport Beach, CA, February 2010.
50. P. Fay, “High-Speed Devices and Integration for Wireless and Sensing Applications,” Laboratory for Physical Sciences, Univ. of Maryland, College Park, MD, October 2009.
51. A. Seabaugh, D. Jena, T. Fang, P. Fay, S. Kabeer, T. Kosel, Y. Lu, S. Koswatta, K. Tahy, T. Vasen, D. Wheeler, H. Xing, Q. Zhang, G. Zhou, J. –M. Kuo, P. Pinsukanjana, H. Zhu, and Y. –C. Kao, “Low-Subthreshold-Swing Tunnel Transistors,” Silicon Nanoelectronics Workshop, Kyoto, Japan, June 2009.
52. P. Fay, “Advances in Interconnects and Packaging for High-Performance and Sensing Applications,” Univ. of Illinois at Urbana-Champaign, Urbana, IL, April 2009.
53. G. H. Bernstein, J. Kulick, D. Kopp, J. Bonath, J. Brockman, W. Buckhanan, S. Dai, P. Fay, M. Khan, A. Kriman, Y. Lee, C. Liang, M. Niemier, M. Padberg, D. Rinzler, R. Savino, and G. Snider, “Quilt Packaging - a Quasi-Monolithic Way to Merge Heterogeneous Technologies and Scales,” 6th Annual Conference, Foundations of Nanoscience (FNANO), Snowbird, UT, April 2009.
54. P. Fay, “Advances in High-Speed Devices for Wireless and Sensing Applications,” Univ. of Virginia, Charlottesville, VA, March 2009.

Invited Lectures and Addresses (cont.)

55. P. Fay, N. Su, and Z. Zhang, “Antenna-Coupled Heterostructure Diodes for Millimeter-Wave and THz Imaging,” Workshop on Compound Semiconductor Materials and Devices, Ft. Myers, FL, February 2009.
56. D. Jena et al., “Comparative Study of Epitaxial Exfoliated Graphene FETs,” Workshop on Compound Semiconductor Materials and Devices, Ft. Myers, FL, February 2009.
57. P. Fay, G. H. Bernstein, and W. Porod, “Antenna-Coupled Tunnel-Diode Nanosensors for Millimeter-Wave Through Infrared Imaging,” Army Research Lab, Adelphi, MD, August 2008.
58. P. Fay, "Advances in High-Speed Devices and Packaging for Wireless and Sensing Applications," Tyndall National Institute, Cork, Ireland, July 2008.
59. P. Fay, “Advances in High-Speed Devices for Wireless and Sensing Applications,” Dept. of Electrical and Computer Engineering, University of Pittsburgh, Pittsburgh, PA, October 2007.
60. P. Fay, “Advances in High-Speed Devices for Wireless and Sensing Applications,” TriQuint Semiconductor, Richardson, TX, September 2007.
61. P. Fay, “Heterostructure Backward Diodes for Millimeter-Wave and THz Detection,” Sandia National Lab, Albuquerque, NM, August 2007.
62. G. H. Bernstein, Q. Liu, G. Snider, A. Tong, W. Buckhanan, J. Kulick, D. Kopp, and P. Fay, “Quilt Packaging: A New Paradigm in Interchip Communications,” Sandia National Lab, Albuquerque, NM, August 2007.
63. P. Fay, G. H. Bernstein, Q. Liu, G. Snider, A. Tong, W. Buckhanan, J. Kulick, and D. Kopp, “Quilt Packaging – A New Approach to Integration for High Performance Systems,” DARPA Exascale Computing Meeting, Atlanta, GA, July 2007.
64. P. Fay, X. Li, Y. Cao, J. Zhang, T. H. Kosel, and D. C. Hall, “III-V MOSFETs with Native Oxide Gate Dielectrics – Progress and Promise,” *2007 International Conference on Compound Semiconductor Manufacturing Technology*, paper 12.1, pp. 227-230, Austin, TX, May 2007.
65. G. H. Bernstein and P. Fay, “Quilt Packaging: A New Paradigm in Interchip Communications,” Rockwell-Collins, Cedar Rapids, IA, March 2007.
66. P. Fay “Heterostructure Backward Diodes for Millimeter Wave and THz Radar Applications,” Through-Barrier Imaging Technologies Workshop, Argonne National Lab, Argonne, IL, January 2007.
67. G. H. Bernstein and P. Fay, “Quilt Packaging: A New Paradigm in Interchip Communications,” MA/COM Corp, Lowell, MA, January 2007.
68. P. Fay, invited expert panelist “”Compound Semiconductor MOSFETs: Fact or Fiction?”, *IEEE Compound Semiconductor Integrated Circuits Symposium*, 2006.
69. G. H. Bernstein, Q. Liu, Z. Sun, A. Tong, G. Snider, and P. Fay, “Quilt Packaging: A New Paradigm in Interchip Communications,” Raytheon Corporation, Santa Barbara, CA, February, 2006.
70. P. Fay and D. C. Hall, “Compound Semiconductor Native Oxides: Materials and Devices,” presented at RFMD Inc., Greensboro, NC, 12/14/05.

Invited Lectures and Addresses (cont.)

71. A. Seabaugh, Q. Liu, S. Sutar, Q. Zhang, W. Zhao, Y. Yan, D. Wheeler, B. Wu, S. Kabeer, Z. Racz, and P. Fay, "Low Power, High Speed, and Mixed-Signal Tunneling Device Technology," Int. COE Workshop on Nano Processes and Devices and their Applications, pp. 37-38, Nagoya Univ., Japan, 2005.
72. P. Fay, "Advances in Devices for Wireless and Optoelectronic Systems," presented at the University of Michigan, Ann Arbor, MI, 7/19/05.
73. G. H. Bernstein and P. Fay, "Quilt Packaging: A New Paradigm in Heterogeneous Integration," Cray, Inc., Chippewa Falls, WI, December, 2004.
74. P. Fay, "Photodetectors and Receivers for Telecommunications," presented at Spectrolab, Inc., Sylmar, CA, August 2001.
75. P. Fay "Photodetectors and Photoreceivers for High Speed Telecommunications," presented at Filtronic Solid State, Inc., Santa Clara, CA, June 2001.
76. P. Fay "Photodetectors and Photoreceivers for High Speed Telecommunications," presented at TriQuint Semiconductor, Inc., Dallas, TX, November 2000.
77. P. Fay and B. Walvoord, "A New Integrated Laboratory Course for Microwave Circuit Design and Measurements," Proc. Intl. Conf. on Engineering and Computer Education, Rio de Janeiro, August 1999.
78. P. Fay, C. Caneau, and I. Adesida, "High-Speed MSM-HEMT and PIN-HEMT Monolithic Photoreceivers," Proc. Intl. Microwave and Optoelectronics Conf., Rio de Janeiro, August 1999.

Conference Presentations and Publications

1. Y. Shi, S. Rahman, J. Ren, Y. Deng, P. Fay, and L. Liu, "An Integrated Polarization-Resolved Quasi-Optical THz Detector Based on Heterostructure Backward Diodes," *Lester Eastman Conf. on High Performance Devices*, paper III.9, Columbus, Ohio, August 2018.
2. A. Ebadi-Shahrivar, P. Fay, B. Hochwald, and D. Love, "Multi-Antenna SAR Estimation with Linear Time," USNC-URSI Radio Science Meeting, Boston, July 2018.
3. J. Wang, L. Cao, J. Xie, E. Beam, C. Youtsey, R. McCarthy, L. Guido, and P. Fay, "Vertical GaN-on-GaN p-n Diodes with 10-A Forward Current and 1.6 kV Breakdown Voltage," *IEEE Device Research Conf.*, paper III-B.2, Santa Barbara, CA, June 2018.
4. H. Ye and P. Fay, "Investigation of Effect of Growth Temperature on Deep Levels in GaAs Photovoltaics," *Electronic Materials Conf.,* paper JJ03, Santa Barbara, CA, June 2018.
5. P. Fay, J. Wang, L. Cao, W. Li, R. McCarthy, R. Reddy, C. Youtsey, C. F. Lo, H. Marchand, W. Johnson, M. Brubaker, and K. Bertness, "Prospects for High Performance RF Interconnects and Functional Integration Using GaN on Silicon," *IEEE Silicon Nanoelectronics Workshop*, paper 9.2, Honolulu, HI, June 2018.
6. J. Wang, L. Cao, R. McCarthy, C. Youtsey, L. Guido, J. Xie, E. Beam, and P. Fay, "High-Performance Vertical GaN P-N Diodes Fabricated with Epitaxial Lift-Off from GaN Substrates," *Int'l Symp. On Compound Semiconductors*, paper We1D1.5, Cambridge, MA, June 2018.
7. L. Cao, J. Wang, G. Harden, A. Hoffman, and P. Fay, "Measurement of Electron and Hole Impact Ionization Coefficients in GaN P-N Junctions on Native GaN Substrates," *Int'l Symp. On Compound Semiconductors*, paper We1D1.6, Cambridge, MA, June 2018.

Conference Presentations and Publications (cont.)

8. J. Encomendero, R. Yan, A. Verma, S. M. Islam, V. Protasenko, S. Rouvimov, P. Fay, D. Jena and H. Xing, "Room Temperature Microwave Oscillators Enabled by Resonant Tunneling Transport in III-Nitride Heterostructures," *Int'l Symp. On Compound Semiconductors*, paper We2C2.2, Cambridge, MA, June 2018.
9. L. Cao, C. F. Lo, H. Marchand, W. Johnson, and P. Fay, "Low-Loss Coplanar Waveguides on GaN-on-Si Substrates for MMICs," Proc. GaN Marathon 2.0, Padova, Italy, April 2018.
10. P. Fay, W. Li, L. Cao, K. Pourang, S. M. Islam, C. Lund, S. Saima, H. Ilatikhameneh, T. Amin, J. Huang, R. Rahman, H. Xing, D. Jena, S. Keller, G. Klimeck, M. Brubaker, B. Spann, and K. Bertness, "III-N Nanowire Devices for Low Power Applications," International Workshop on the Physics of Semiconductor Devices, New Delhi, India, December 2017.
11. J. Wang, L. Cao, J. Xie, E. Beam, R. McCarthy, C. Youtsey, and P. Fay, "High Voltage Vertical p-n Diodes with Ion-Implanted Edge Termination and Sputtered SiNx Passivation on GaN Substrates," *IEEE International Electron Devices Meeting (IEDM)*, San Francisco, CA, December 2017.
12. J. Zhang, C. Alessandri, P. Fay, A. Seabaugh, T. Ytterdal, E. Memisevic, and L. Wernersson, "Projected Performance of Experimental InAs/GaAsSb/GaSb TFET as Millimeter-Wave Detector," *Berkley Symp. On Energy Efficient Electronic Systems*, Berkeley, CA, October 2017.
13. L. Cao, C. Lo, H. Marchand, W. Johnson, and P. Fay, "Coplanar Waveguide Performance Comparison of GaN-on-Si and GaN-on-SiC Substrates," *IEEE Compound Semiconductor Integrated Circuits Conf.*, Miami, October 2017.
14. W. Li, M. Brubaker, B. Spann, K. Bertness, and P. Fay, "GaN-Channel Nanowire MOSFETs for Low Power Applications," *Topical Workshop on Heterostructure Materials*, Kagoshima, JP, August 2017.
15. J. Encomendero, S. M. Islam, S. Rouvimov, P. Fay, D. Jena, and H. Xing, "Record High Peak Current Density of Over 180 kA/cm^2 in GaN/AlN Resonant Tunneling Diodes," *Int'l Conf. on Nitride Semiconductors (ICNS)*, Strasbourg, FR, July 2017.
16. A. Ebadi-Shahrivar, J. Ren, P. Fay. B. Hochwald, J. M. Jin, and D. Love, "Mixed Quadratic Model for Peak Spatial-Average SAR of Coherent Multiple Antenna Devices," *IEEE AP-S Symp. On Antennas and Propagataion and USNC-URSI Radio Science Meeting*, San Diego, CA, July 2017.
17. G. Silva-Oelker, R. Aylwin, C. Jerez-Hanckes, and P. Fay, "Uncertainty Quantification for Electromagnetic Scattering by 1D Perfect Electric Conducting Gratings," *Int'l Conf. on Mathematical and Numerical Aspects of Wave Propagation (WAVES 2017)*, Minneapolis, May 2017.
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Conference Presentations and Publications (cont.)

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149. D. H. Chow, J. N. Schulman, P. Fay, J. Lu, Y. Xu, G. H. Bernstein, A. Gonzalez, P. Mazumder, E. T. Croke, H. L. Dunlap, K. S. Holabird, M. A. Morgan, and S. Weinreb, “Interband Tunneling Diodes for High Performance Electronics and Millimeter Wave Detection,” Third Workshop on the Fabrication, Characterization, and Applications of 6.1 Å III-V Semiconductors, Snowbird, UT, 2001.

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151. J. H. Jang, G. Cueva, I. Adesida, P. Fay, W. E. Hoke, and P. J. Lemonias, “Photoresponses of Metamorphic Double-Heterojunction Photodiodes Under High Power Optical Illumination,” Proc. IEEE Lasers and Electro-Optics Society Meeting, vol. 1, pp. 384-385, 2001.

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159. G. Cueva, A. Mahajan, P. Fay, M. Arafa, and I. Adesida, "Ring Oscillator Using InAlAs/InGaAs/InP Enhancement/Depletion-Mode High Electron Mobility Transistor Direct-Coupled FET Logic Inverters," Proc. 9th Intl. Conference on Indium Phosphide and Related Materials, Hyannis, MA, pp. 157-160, 1997.

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161. W. Wohlmuth, M. Arafa, A. Mahajan, P. Fay, and I. Adesida, "Engineering Schottky Barrier Heights in InGaAs Metal-Semiconductor-Metal Photodetectors," SPIE Optoelectronics Symposium, San Jose, CA, 1997.
162. A. Mahajan, M. Arafa, P. Fay, C. Caneau, and I. Adesida, "160 GHz Enhancement-Mode InAlAs/InGaAs/InP High Electron Mobility Transistor," 54th Annual Device Research Conf. Digest, Santa Barbara, CA, pp. 132-133, 1996.
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164. A. Mahajan, P. Fay, M. Arafa, G. Cueva, and I. Adesida, "Monolithic Integration of InAlAs/InGaAs/InP Enhancement- and Depletion-Mode High Electron Mobility Transistors," Tech. Digest, International Electron Devices Meeting, San Francisco, pp. 51-54, 1996.
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166. I. Adesida, P. Fay, W. Wohlmuth, and C. Caneau, "High Performance InAlAs/InGaAs/InP HEMT/MSM-Based OEIC Photoreceivers," Tech. Digest, International Electron Devices Meeting, Washington, D.C., pp. 579-582, 1995.
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168. P. Fay, W. Wohlmuth, C. Caneau, and I. Adesida, "A 15 GHz Bandwidth Lattice-Matched InAlAs/InGaAs/InP HEMT-Based OEIC Photoreceiver," 53rd Annual Device Research Conf. Digest, Charlottesville, VA, pp. 70-71, 1995.
169. M. Arafa, P. Fay, K. Ismail, J. O. Chu, B. S. Meyerson, and I. Adesida, "High Performance Submicron-Gate SiGe P-Type Modulation-Doped Field Effect Transistors," 53rd Annual Device Research Conf., Charlottesville, VA, pp. 20-21, 1995.
170. P. Fay, R. B. Brockenbrough, J. R. Tucker, J. W. Lyding, H. Hagendorn, T. Fayfield, and T. K. Higman, "STM-Patterned Modulated Gate Silicon MOSFET," presented at American Vacuum Society Meeting, Chicago, IL, 1992.

Invited Technical Articles and Reports

1. A. Orlov, P. Fay, G. Snider, X. Jehl, S. Barraud, and M. Sanquer, “Dual-port reflectometry technique: charge identification in nanoscaled single electron transistors,” *IEEE Nano Magazine*, vol. 9, no. 2, pp. 24-32, 2015.
2. B. Hochwald, D. Love, Su Yan, P. Fay, and J. M. Jin, “Incorporating specific absorption rate constraints into wireless signal design,” *IEEE Communications Magazine*, vol. 52, no. 9, pp. 126-133, 2014.

Invited Technical Articles and Reports (cont.)

3. J. P. Allain, S. Bakhtiari, E. Baranoski, A. Bernstein, G. Boreman, J. Benizer, M. Carr, W. Chin, M. Clements, A. des Rosiers, T. Du Bosg, R. Dowla, P. Fay, N. Gopalsami, D. Kerner, R. Klann, R. Leach, Jr., T. Linnenbrink, B. Ludewigt, D. McMakin, D. Muh, D. Reyna, C. Seifert, S. Sheen, and K. Ziock, contributors; P. Bythrow, editor, "Through-Barrier Imaging Technologies Report," National Consortium for MASINT Research, Defense Intelligence Agency, 2007.
4. P. Fay, S. Chandrasekhar, and I. Adesida, "High-Speed Optoelectronic Receivers for Fiber-Optic Communications," *IEEE Circuits and Devices*, vol. 14, no. 5, pp. 16-25, 1998.

Professional Service

- Reviewer for *IEEE Electron Device Letters, IEEE Transactions on Electron Devices, Electronics Letters, IEEE Photonics Technology Letters*, *IEEE Journal of Quantum Electronics*, *IEEE Trans. on Microwave Theory and Techniques, IEEE Microwave and Wireless Components Letters, IEEE Journal of Solid-State Circuits, IEEE Transactions on Nanotechnology, IEEE Transactions on Advanced Packaging, IEEE Sensors Journal, Optics Express, Solid-State Electronics, Optical and Quantum Electronics*, *Journal of Vacuum Science and Technology,* and the *Journal of Crystal Growth*.
- Session Chair: Microwave Devices II at Int'l Microwave and Optoelectronics Conf., Rio de Janeiro, August 1999; Laboratory Innovations II at Int'l Conf. on Engineering and Computer Education, Rio de Janeiro, August 1999.
- NSF panel reviewer: SBIR/STTR program September 27, 1999; ITR program April 26, 2001
- Editorial Advisory Board member for The RF and Microwave Handbook, J. Michael Golio, ed., CRC Press, Boca Raton, 2000.
- Local Arrangements Chair, 2004 Device Research Conference, Notre Dame, IN, June 2004.
- Technical Program Committee, 2006 Device Research Conference, Penn State University, June 2006.
- Technical Program Committee, 2007-present, Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH).
- Technical Program Committee, and Local Arrangements Chair, 2007 Device Research Conference, Notre Dame, IN, June 2007.
- Technical Program Committee, 2007, 2008 International Electron Devices Meeting (IEDM).
- Session Chair: Quantum, Power, and Compound Semiconductor Devices – III-V FETs for Microwave, Millimeter-Wave, and Digital Applications at 2007 International Electron Devices Meeting (IEDM).
- Editorial Advisory Board member for The RF and Microwave Handbook, 2nd ed., J. Michael Golio, ed., CRC Press, Boca Raton, 2007.
- Technical Program Committee Vice-Chair, 2009 Device Research Conference, Penn State Univ., June 2009.
- Technical Program Sub-committee Chair (Quantum, Power and Compound Semiconductors technical area), 2009 International Electron Devices Meeting (IEDM), Washington, DC, December 2009.

Professional Service (cont.)

- Invited session organizer, 2009 Electronic Materials Conference, Penn State Univ., June 2009.
- Associate editor, *IEEE Transactions on Advanced Packaging*, 2009-2011.
- Technical Program Committee Chair, 2010 Device Research Conference, Univ. of Notre Dame, June 2010.
- Conference Chair, 2011 Device Research Conference, Univ. of California, Santa Barbara, June 2011.
- Board of Directors, Device Research Conference, 2010-2018.
- Executive Committee and Publicity Vice-Chair, 2010 International Electron Devices Meeting (IEDM), San Francisco, CA, December 2010.
- Executive Committee and Publicity Chair, 2011 International Electron Devices Meeting (IEDM), Washington, DC, December 2011.
- Associate editor, *IEEE Transactions on Components, Packaging, and Manufacturing Technology*, 2011-present.
- Executive Committee and Short-Course Vice-Chair, 2012 International Electron Devices Meeting (IEDM), San Francisco, CA, December 2012.
- Executive Committee and Short-Course Chair, 2013 International Electron Devices Meeting (IEDM), Washington, DC, December 2013.
- Executive Committee and Technical Program Vice-Chair, 2014 International Electron Devices Meeting (IEDM), San Francisco, CA, December 2014.
- Executive Committee and Technical Program Chair, 2015 International Electron Devices Meeting (IEDM), Washington, D.C., December 2015.
- Executive Committee and Conference Chair, 2016 International Electron Devices Meeting (IEDM), San Francisco, CA, December 2016.
- Executive Committee, 2010-present, Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH).
- University Liaison, 2012 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Boston, MA, May 2012.
- University Liaison, 2013 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), New Orleans, LA, May 2013.
- Audio/Visual Services Chair, 2014 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Denver, CO, May 2014.
- Workshop Chair, 2015 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Palm Springs, CA, May 2015.
- Registration Chair, 2016 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Miami, FL, April 2016.
- Exhibits Chair, 2017 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Palm Springs, CA, May 2017.
- Technical Program Chair, 2018 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Austin, TX, May 2018.

Professional Service (cont.)

- Conference Chair, 2019 Compound Semiconductor Manufacturing Technology Conference (CS-MANTECH), Minneapolis, MN, April/May 2019.
- Technical Program Committee Member, 2014 IEEE Lester Eastman Conference on High Performance Devices, Cornell Univ., August 2014.
- Technical Program Chair, 2018 IEEE Lester Eastman Conference on High Performance Devices, Columbus, OH, August 2018.
- Member, IEEE Electron Devices Society Compound Semiconductor Devices and Circuits Technical Committee, January 2014-Dec. 2019.
- Member, IEEE Electron Device Society Technical Conferences and Meetings Committee, August 2014-December 2016.
- IEEE Electron Device Society Board of Governors member (at large), January 2015-December 2017.
- IEEE Electron Device Society Compound Semiconductor Devices & Circuits Committee Chair, January 2018- December 2019.
- IEEE Electron Device Society Masters and PhD Fellowship Committee member, January 2018 – December 2019.
- IEEE Electron Device Society Meetings and Technical Conferences Committee member, January 2018 – December 2019.
- Editorial Board member and Associate Editor, *Electronics Letters* (IET), 2015-present.
- Editorial Board member and Associate Editor, *IEEE Transactions on Electron Devices*, 2015-present.
- Guest editor, special section on the Compound Semiconductor Manufacturing Technology Conference in *IEEE Trans. Semiconductor Manufacturing*, vol. 29, no. 4, 2016.
- Invited participant in NSF ECCS division workshop to assess and re-evaluate policies on broader impacts for research proposals, May 2016.
- Editorial Board member and Associate Editor, *IEEE Transactions on Microwave Theory and Techniques*, 2016 – present.
- Guest editor, special section on the Compound Semiconductor Manufacturing Technology Conference in *IEEE Trans. Semiconductor Manufacturing*, vol. 30, no. 4, 2017.
- International Advisory Board, IEEE Electron Devices and Technology Meeting, 2016-2018.
- Program Co-Chair, Topical Workshop on Heterostructure Materials (TWHM), Kirishima, Japan, August 2017.
- Program Chair, Workshop on Compound Semiconductor Materials and Devices (WOCSEMMAD), February 2018.
- Guest editor, special section on the Compound Semiconductor Manufacturing Technology Conference in *IEEE Trans. Semiconductor Manufacturing*, vol. 31, no. 4, 2018.

Department, College, and University Service

- Oversight and technical direction of cleanroom facility in Stinson-Remick Hall
- Director, Notre Dame Nanofabrication Facility
- College of Engineering EG 111/112 Steering Committee

Department, College, and University Service (cont.)

- Department of Electrical Engineering Undergraduate Committee, Graduate Committee, Library Committee, Undergraduate Laboratory Committee, and Committee on Appointments and Promotions
- 2014, Member of Committee on the Future of the Core Curriculum, Univ. of Notre Dame
- 2014-2015, Member of University Laboratory Safety Advisory Committee, Univ. of Notre Dame
- 2015-present, Chair, University Laboratory Safety Advisory Committee, Univ. of Notre Dame
- 2015-2018, College Council, College of Engineering, Univ. of Notre Dame

M.S. Students Advised

Yujun Shi (graduated M.S., May 2000)
Goran Rauker (graduated M.S., May 2000)
Bo Yang (graduated M.S., May 2001)
Xiang Li (graduated M.S., January 2002)
Kranti Tantwai (graduated M.S., January 2002)
Rajkumar Sankaralingam (graduated M.S., May 2002)
Zhuowen Sun (graduated M.S., May 2002)
Robie Meyers (graduated M.S., January 2003)
Yogesh Wakchaure (graduated M.S., August 2004)
Shishir Rai (graduated M.S., October 2004)
Man Ni (graduated M.S. November 2004)
Ning Su (graduated M.S., May 2005)
Yong Tang (graduated M.S., May 2005)
Li Yan (graduated M.S., August 2007)
Xiu Xing (graduated M.S., January 2008)
David Kopp (graduated M.S., January 2008)
Ze Zhang (graduated M.S., May 2008)
Yeqing Lu (graduated M.S., May 2011)

M.S. Theses Directed

Kranti Tantwai (Thesis defense passed 11/02)
Robie Meyers (Thesis defense passed 11/03)
Shishir Rai (Thesis defense passed 10/04)
Yogesh Wakchaure (Thesis defense passed 8/04)
Man Ni (Thesis defense passed 11/04)
Ning Su (Thesis defense passed 4/2005)
Yong Tang (Thesis defense passed 4/2005)
Xiu Xing (Thesis defense passed 10/2007)
Ze Zhang (Thesis defense passed 3/2008)
Yeqing Lu (Thesis defense passed 3/2011)
Wenjie Chen (Thesis defense passed 4/2011)
Yuning Zhao (Thesis defense passed 11/2012)
Wenjun Li (Thesis defense passed 11/2014)

Ph.D. Theses Directed

Bo Yang (thesis defended 4/2005)
Xiang Li (thesis defended 7/2005)
Rajkumar Sankaralingam (thesis defended 10/2005)
Zhuowen Sun (thesis defended 4/06)

Ph.D. Theses Directed (cont.)

Heng Yang (co-advised with G. H. Bernstein; thesis defended 10/2007)
Jing Zhang (co-advised with T. Kosel; thesis defended 12/2007)
Ning Su (thesis defended 2/2008)
Yong Tang (co-advised with A. Orlov; thesis defended 11/2009)
Ze Zhang (thesis defended 7/2011)
Xiu Xing (thesis defended 4/2013)
Wenjie Chen (thesis defended 7/2013)
David Kopp (thesis defended 4/2014)
Yeqing Lu (thesis defended 3/2015)
Yuning Zhao (thesis defended 7/2015)
Wenjun Li (thesis defended 11/2016)
Jingshan Wang (thesis defended 6/2018)

Postdoctoral Researchers Advised

Byung Han (8/01 - 3/02)
Philippe Zatta (9/01 -5/02)
Bo Yang (11/06 - 8/07)
Yong Tang (3/10 – 8/10)

Grants and Contracts Awarded

“Ultra-high-speed E/D HEMT ADCs,” PI (P. Fay), ONR via subaward from Univ. of Illinois at Urbana-Champaign: $156,486; 3/1/98 - 5/30/01.

“Wireless Communications as a Catalyst for Curriculum Integration: A New Microwave Measurement and Design Laboratory,” PI (P. Fay, O. Collins, and B. Walvoord), NSF: 136,814; 6/1/98 - 5/31/00.

“SBIR: High Power InGaP PHEMT,” PI (P. Fay), AFOSR via subaward from MicroLink Devices: $16,500; 5/1/98 - 11/30/01.

“Sb-Based III-V Quantum Devices and Circuits for Ultra-High Frequency Digital Signal Processing Applications,” Co-PI (G. H. Bernstein and P. Fay), ONR: $1,182,896; 5/1/98 - 12/31/00.

“CAREER: Micromachining of Gallium Nitride and Related Materials for Microwave and Optoelectronic Applications,” PI (P. Fay), NSF: $237,650; 6/1/99 - 11/30/04.

“Acquisition of Instrumentation for an Experimental Radio Facility in Support of Wireless Digital Communications Research,” Co-PI (D. J. Costello, O. Collins, P. Fay, T. Fuja, and Y.- F. Huang), NSF: $547,566; 9/1/99 – 8/31/03.

“Fabrication and Measurements of High Speed, High Temperature Quantum-dot Cellular Automata,” Co-PI (G. L. Snider, P. Fay, G. H. Bernstein, A. Orlov, and A. C. Seabaugh), ONR: $343,000; *3/31/00 - 3/30/01*.

“Acquisition of Electronic Instrumentation for NanoScience Research and Education,” Co-PI (A. Seabaugh, G. H. Bernstein, P. Fay, D. C. Hall, and G. L. Snider), NSF: $132,000; 9/1/00 - 8/31/01.

“Fabrication of III-V HEMTs and HBTs,” PI (P. Fay), MicroLink Devices: $65,039; 8/1/00 - 8/31/01.

Grants and Contracts Awarded (cont.)

"Development of a Microfluidics-Based Blood Monitoring System," Co-PI (G. H. Bernstein, J. B. Brockman, O. M. Collins, P. Fay, M. Gad-el-Hak, M. Lieberman, A. C. Seabaugh, and G. L. Snider), 21st Century Research and Technology Fund: $1,720,536; 8/4/00 - 8/4/02.

"A Novel High-Speed Electrometer for Nanoscale Electronic Device Research," PI (P. Fay, A. Orlov, G. Snider), NSF: $294,000; 6/1/01 - 11/30/05.

"NIRT: Self-Aligned and Self-Limited Quantum Dot Nanoswitches," PI (P. Fay, G. L. Snider, A. Orlov), NSF via subaward from Ohio State Univ.: $581,859; 7/1/01 - 6/30/06.

"High Speed InP OEIC," PI (P. Fay), BMDO via subaward from MicroLink Devices: $20,000; 1/1/02 - 9/30/02.

"Antimonide-Based Compound Semiconductors," PI (P. Fay, A. C. Seabaugh), DARPA via subaward from HRL Laboratories: $441,735; 7/1/01 - 4/30/05.

"Electronic Properties and Device Applications of III-V Compound Semiconductor Native Oxides," Co-PI (D. C. Hall, P. Fay, G. L. Snider, T. H. Kosel, and B. A. Bunker), AFOSR: $779,508; 5/1/01 - 4/30/05.

"Hybrid Integration of Optoelectronics for High-Speed Photoreceivers," PI (P. Fay), TriQuint Semiconductor: $213,449; 6/15/01 - 3/31/04.

"RF Device Measurement and Modeling," PI (P. Fay), Delphi Automotive: $39,044; 9/14/01 - 12/31/02.

"Testing Methodologies for Monolithic Photoreceivers," PI (P. Fay), Xindium Technologies, Inc.: $119,650; 9/17/01 - 7/9/02.

"NIRT: Architectures and Devices for Quantum-dot Cellular Automata," Co-PI (P. M. Kogge, P. Fay, C. S. Lent, A. O. Orlov, and G. L. Snider), NSF: $999,999; 7/15/02 - 6/30/07.

"Mixed Signal Nanoelectronics," Co-PI (A. Seabaugh, P. Fay, G. H. Bernstein, and O. Collins), ONR: $1,734,615; 8/15/02 - 2/14/07.

"Sb-based RITD/HEMT Devices & Circuits," PI (P. Fay), ONR via subaward from Univ. of Michigan: $125,003; 9/1/03 - 8/31/04.

"A Very High Efficiency Thermophotovoltaic Converter for the General Purpose Heat Source," PI (P. Fay), NASA via subaward from Essential Research, Inc.: $79,938; 7/1/03 - 6/30/04.

"Biologically-Inspired CNN Image Processors with Dynamically-Integrated Hyperspectral Nanoscale Sensors," Co-PI (W. Porod, P. Fay, Y.- F. Huang, and G. H. Bernstein), ONR: $6,898,793; 7/15/03 - 8/31/08.

"Native-Oxide Defined AlGaAs Heterostructure Bipolar Transistors," Co-PI (D. C. Hall and P. Fay), NSF via subaward from Vega Wave Systems, Inc: $31,984; 7/1/03 - 12/31/03.

"Multi-spectral Nanoantenna Infrared Sensors," Co-PI (W. Porod, G. H. Bernstein, and P. Fay), MDA via subaward from Eutecus, Inc., $60,000; 10/1/04 - 9/30/05.

"Focal Plane Array Processors with Adaptive Visual Range and Nanoantenna Sensors," Co-PI (W. Porod, G. H. Bernstein, and P. Fay), ONR via subaward from Eutecus, Inc.: $21,000; 10/1/04 - 9/30/05.

"X-Ray Diffractometer," Co-PI (D. Jena, J. L. Merz, A. C. Seabaugh, J. K. Furdyna, W. Porod, P. Fay, D. C. Hall, and H. Xing), ONR: $207,275; 4/1/05 - 3/31/06.

Grants and Contracts Awarded (cont.)

"Micro Thermophotovoltaic Converter with High Efficiency Photonic Crystal Emitter," PI (P. Fay), DARPA via subaward from Essential Research Inc.: $60,000; 1/1/05 - 12/31/05.

"High-Bandwidth High-Resolution Plasma Sensor for Hypersonic Flow Measurements," Co-PI (T. Corke and P. Fay), AFOSR via subaward from Innovative Scientific Solutions, Inc.: $420,000; 3/22/05 - 3/30/06.

"GaAsSb-based HBTs for W-band Amplifiers," PI (P. Fay), NASA via subaward from MicroLink Devices, Inc.: $20,007, 2/1/05-7/31/05.

"NIRT: Extremely-Mismatched Materials for Advanced Nanodevices," PI (P. Fay, A. S. Brown (Duke), T. Kuech (Wisconsin) and A. C. Seabaugh), NSF: $1,312,000; 8/1/05 - 7/31/09.

"Quilt Packaging: A New Paradigm for the Integration of Heterogeneous Communications Systems-in-Package [UND_FY05_009]," Co-PI (G. H. Bernstein, P. Fay, and G. Snider), NSF: $275,822; 7/1/05 - 6/30/07.

"Low-Cost, High-Power Transmit/Receive Modules for X-band Radars," PI (P. Fay), MDA via subaward from Vega Wave Systems: $29,513; 9/1/05 - 8/31/06.

"Multispectral Nanoantenna Infrared Sensors," Co-PI (W. Porod, P. Fay, and G. H. Bernstein), MDA via subaward from Eutecus, Inc.: $700,000; 9/30/05 - 3/30/07.

"Focal Plane Array Processors with Adaptive Visual Range and Millimeter Wave Sensors," Co-PI (W. Porod, P. Fay, and G. H. Bernstein), ONR via subaward from Eutecus, Inc.: $90,000; 9/30/05 - 3/30/07.

"Heterojunction Bipolar Transistor Power Amplifiers for Long-Range X-band Communications," PI (P. Fay), NASA via subaward from Vegawave Systems: $23,000; 1/24/06 - 7/24/06.

"X-Band InGaP HBT Amplifiers," PI (P. Fay), AFOSR via subaward from MicroLink Devices: $30,000; 5/15/6 - 4/30/07.

"Advanced Sensors for Millimeter-wave Detection and Imaging," PI (P. Fay), NSF: $568,085; 9/1/06 - 8/31/10.

"Low-Cost, High-Power Transmit/Receive Modules for X-band Radars," PI (P. Fay), MDA via subaward from Vega Wave Systems: $224,999; 8/29/06 - 8/29/08.

"GaAs MOSFET Development," Co-PI (D. C. Hall and P. Fay), RFMD, Inc.: $296,894; 4/1/06 - 12/31/08.

"ABL (airborne laser) detection sensor improvements," Co-PI (W. Porod, J. Brockman, G. Snider, and P. Fay), MDA via subaward from Aerodyne Research, Inc.: $45,000; 8/18/06 - 2/17/07.

"Novel Superconnects for Ultrahigh-Performance Hybrid Communications Systems," Co-PI (G. H. Bernstein and P. Fay), NSF: $304,248; 1/1/07-12/31/09.

"InGaP DHBTs for High-Efficiency L-band T/R Modules," PI (P. Fay), NASA, via subaward from MicroLink Devices: $29,265; 1/1/07 - 6/30/07.

Grants and Contracts Awarded (cont.)

"Ultra-Wide-Bandwidth Contiguous Superconnects for Advanced Computing Systems," Co-PI (G. H. Bernstein, G. L. Snider, J. B. Brockman, and P. Fay), NSA: $970,826; 9/28/07 - 9/27/09.

"Millimeter-wave and THz Medical Imaging," PI (P. Fay), Traycer Diagnostic Systems: $85,500; 6/1/08 - 5/31/09.

"Midwest Institute for Nanoelectronics Discovery," Co-PI (A. Seabaugh, T. H. Kosel, C. S. Lent, W. Porod, P. Fay, D. Jena, H. Xing, X. Hu, M. Niemier, G. H. Bernstein), SRC: $3,791,312; 4/1/08 - 3/30/11.

"Epitaxial Lift-Off of High Current Photodetectors," PI (P. Fay), DARPA, via subaward from MicroLink Devices: $30,000; 9/1/08 - 6/30/09.

"Engineering of Oxide/Nitride Structures," Co-PI (D. Jena, D. C. Hall, A. C. Seabaugh, T. H. Kosel, P. Fay, H. Xing, and J. Merz), ONR: $1,529,349; 12/10/08 - 12/31/10.

"Collaborative Research: Characterization of Traps in GaInAs/GaAsSb Multiple Quantum Well Structures," PI (P. Fay), NSF: $259,498; 5/1/09 – 4/31/12.

"Backside Contact Multijunction Solar Cells for High-Concentration Applications," PI (P. Fay), DOE via subaward from MicroLink Devices: $30,000; 9/1/09 – 4/30/10.

"Ultrafast RF & Mixed-Signal Electronics with Ultrascaled Binary AlN/GaN HEMTs," Co-PI (G. Xing, P. Fay, G. Snider, D. Jena), DARPA, via subaward from TriQuint Semiconductor: $4,000,000; 11/30/09 – 11/29/12.

"2010 Device Research Conference Travel Support," PI (P. Fay), ONR, $5,000; 7/1/10 – 8/31/10.

"A Room Temperature Portable Terahertz Camera Using Zero Bias Sb-Based Heterostructure Backward Diodes for Imaging Applications," Co-PI (L. Lie, H. Xing, and P. Fay), NSF: $359,281; 7/1/10 – 6/30/13.

"Manufacturing Design for THz Focal Plane Arrays," PI (P. Fay), Traycer Diagnostic Systems: $30,000; 7/1/2010 – 6/30/2011.

"Backside Contact Multijunction Solar Cells for High-Concentration Applications, Phase II," PI (P. Fay), DOE, via subaward from MicroLink Devices: $150,000; 8/15/2010 – 8/14/2012.

"Backside Contact Multijunction Solar Cells for High-Concentration Applications, Phase III," PI (P. Fay), DOE, via subaward from MicroLink Devices: $30,000; 10/1/2010 – 9/30/2012.

"Characterization of Traps in pHEMT FETs by Deep Level Transient Spectroscopy," PI (P. Fay), Avago Technologies: $10,000; 1/11/2011 – 7/15/2011.

"Midwest Institute for Nanoelectronics Discovery (MIND), Phase 1.5" Co-PI (A. Seabaugh, G. H. Bernstein, P. Fay, S. Hu, D. Jena, T. Kosel, M. Niemier, W. Porod, M. Wistey, and G. Xing), SRC: $2,200,986; 1/1/2011 – 12/31/2012.

"Collaborative Research: Multiband, Ultrasensitive Terahertz Imaging Receivers Based on Quasi-Optical Balanced Hot-Electron Mixers," Co-PI (L. Liu, P. Fay, S. T. Ruggiero), NSF: $220,000; 6/1/2011 – 5/31/2014.

"Front End Optoelectronics for Future Radio Communications," PI (P. Fay), DARPA, via sub-award from MicroLink Devices: $150,000; 3/15/2011 – 3/14/2013.

Grants and Contracts Awarded (cont.)

"Collaborative Development of GaAs MOSFETs," PI (P. Fay), RFMD Inc., $100,000; 6/1/2011 – 5/31/2012.

"III-N Devices and Architectures for Terahertz Electronics," PI (P. Fay, D. Jena, H. Xing), ONR: $6,300,000; 6/1/2011 – 5/31/2016.

"Multiple Transmitter Chains to Minimize Exposure to Electromagnetic Radiation in Portable Devices," Co-PI (B. Hochwald and P. Fay), NSF: $200,000; 8/1/2011 – 7/31/2012.

"Advanced Sensors for Millimeter-Wave Detection and Imaging," PI (P. Fay), Naval Postgraduate School: $151,000; 9/1/2011 – 8/31/2012.

"GaN Power Device and Process Integration for Microscale Power Conversion," Co-PI (D. Jena, H. Xing, P. Fay), DARPA, via subaward from Teledyne Scientific: $700,000; 10/24/2011 – 10/28/2013.

"Nanoelectronic Material Characterization using Single Electron Transistors," Co-PI (A. Orlov, P. Fay), NSF, $465,000; 6/1/2012 – 5/31/2015.

"Center for Low Energy System Technology (LEAST)," Co-PI (A. Seabaugh, H. Xing, D. Jena, M. Niemier, P. Fay, X. S. Hu, and S. Fullerton), DARPA/SRC, $5,155,673; 1/15/2013 – 10/31/2013.

"Heterostructure Backward Diode Array Fabrication," PI (P. Fay), Traycer Diagnostic Systems, Inc.: $44,884; 9/1/2013 – 2/28/2014.

"PolarJFET: A Novel Vertical GaN Power Transistor Concept," Co-PI (H. Xing, D. Jena, P. Fay), ARPA-E, $2,496,428; 2/1/2014 – 1/31/2018.

"High-Power Vertical-Junction Field-Effect Transistors Fabricated on Low-Dislocation-Density GaN by Epitaxial Lift-Off," PI (P. Fay), ARPA-E, via subaward from MicroLink Devices, $630,000; 2/1/2014 – 1/31/2018.

"Ultra-Lightweight, High-Efficiency Epitaxial Lift-Off Solar Cells and Arrays," PI (P. Fay), Navy, via subaward from MicroLink Devices, $45,000; 9/9/14 – 4/9/15.

"Modeling, Analysis, and Code Design for Portable Wireless Device Transmitters Subject to an Electromagnetic Exposure Constraint," Co-PI (B. Hochwald, P. Fay), NSF, $851,192; 9/1/14 – 8/31/17.

"Study of Bulk GaN-Based Vertical IMPATT Diodes for GHz to THz Applications," PI (P. Fay), ONR, $249,469; 5/1/2015 – 4/30/2016.

"Low-Complexity High-Bandwidth Multiport Matching Networks for Coupled Loads," Co-PI (B. Hochwald, P. Fay), NSF, $448,994; 8/1/15 – 7/31/18.

"Dry etching of through-wafer via holes in Ge substrates," PI (P. Fay), MicroLink Devices, Inc., $15,000; 5/18/15 – 11/17/15.

"Ultra-Lightweight, High-Efficiency Epitaxial Lift-off Solar Cells and Arrays, phase II," PI (P. Fay), Navair via subaward from MicroLink Devices, $21,000; 9/1/15 – 12/31/15.

"Advanced Tunneling-Based Detectors and Imaging Systems for Millimeter-Wave and THz Sensing and Imaging," PI (P. Fay, L. Liu), NSF, $380,000; 8/1/2015 – 7/31/2018.

"Novel High-Efficiency Lightweight and Flexible Solar Cells for UAVs," PI (P. Fay), Navair, via subaward from MicroLink Devices, $24,000; 2/1/2016 – 1/31/2017.

Grants and Contracts Awarded (cont.)

"Lightweight Composite ELO IMM TJ Solar Cells with High Specific Power and Conversion Efficiency," PI (P. Fay), Navair, via subaward from MicroLink Devices, $210,550; 3/1/2016 – 2/28/2018.

"Devices and Architectures for THz Electronics," PI (P. Fay), ONR, $1,499,996; 6/1/2016 – 12/31/2017.

"Wideband Time-domain Millimeter-wave Device and Channel Characterization Testbed," Co-PI (J. Chisum, P. Fay, B. Hochwald, and T. Pratt), AFRL/ONR, $326,573; 9/1/2015 – 8/31/2016.

"GaN-Based IMPATTs for Microwave and Millimeter-Wave Generation," PI (P. Fay), ONR, $733,776; 9/1/2016 – 8/31/2019.

"Optically-controlled Waveguide Architectures for Advanced Tunable and Reconfigurable THz Circuits," Co-PI (L. Liu and P. Fay), NSF, $360,000; 8/1/2017 – 7/31/2020.

"Advanced Ultra-Linear mmW Transistors Enabling DREaM," PI (P. Fay), DARPA, via subaward from HRL Laboratories, $596,824; 11/21/2017 – 6/30/2021.

"Applications and Systems-driven Center for Energy-Efficiency Integrated Nano Technologies (ASCENT)," Co-PI (S. Datta, P. Fay, M. Niemier), SRC/DARPA, $26M (PI share $1.25M); 1/2/2018 – 12/31/2022.

Applications and Systems-driven Center for Energy-Efficiency Integrated Nano Technologies (ASCENT), State of Indiana Matching" Co-PI (S. Datta, P. Fay, M. Niemier), IEDC, $1,575,000 (PI share $650,000); 1/2/2018 – 7/31/2018.