1790
ANALYTICS

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The Influence of IEEE on Key Patents

Report prepared for:

Institute of Electrical and Electronic Engineers
445 Hoes Lane
Piscataway, NJ 08854, USA

Prepared By:

Anthony Breitzman, PhD

1790 Analytics, LLC
130 N. Haddon Ave.
Haddonfield, NJ 08033

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Executive Summary

Prior studies performed by 1790 Analytics have demonstrated a strong relationship between IEEE research and new patent development and have shown that citations to IEEE can often lead to higher impact patents. While prior reports focused on broad statistics of major technology categories, in this report we are interested in specific patents that are worth many millions of dollars. We highlight patents with significant financial and/or technological value. These patents contain key innovations that have spurred technological development in their industry or have led to significant financial benefits for their owners. The main findings of our report are:

- Patents have a highly skewed value and impact distribution. Very few patents have a major technological impact or have significant financial value. Many more patents have limited technological or financial value.

- The aim of this report is to isolate these important and valuable patents and identify which of them build upon IEEE science. We first identify patents that are cited frequently by later patents, since such patents are regarded as having a strong impact on technological developments. From among these high impact patents, we then identify those that cite at least four different IEEE articles as prior art. We then search for press releases and other announcements related to the patents to find evidence of high financial and/or technological value.

- Each of the 20 stories we highlight is selected because the patents involved appear to be of particular technological or financial value. Some of the patents we highlight have stimulated whole new areas of research. Other patents have had central roles in technology licenses and company purchases valued at tens - and, in some cases, hundreds - of millions of dollars.

Examples of patents highlighted in the report include:

- **DeepMap** was founded in 2016 and made developing mapping technology built specifically for artificial intelligence its mission. The key use-case is in driverless cars because they thought mapping a solution for a machine driver instead of a human operator is the best way forward. Several of the key patents were invented by founder Mark Wheeler and many reference one or more IEEE published papers. In June 2021, Nvidia, a leading AI and GPU firm acquired DeepMap. Though the terms of the deal were not disclosed, it's believed Nvidia paid a substantial sum since DeepMap has raised more than $90 million in funding. Nvidia believes the purchase would enhance Nvidia DRIVE, its end-to-end autonomous vehicle (AV) platform. It made deals to install its hardware and software in forthcoming personal transports made by several leading automobile manufacturers including Mercedes-Benz. Nvidia makes GPU chips but believes the autonomous vehicle space represents a $30 billion market.

- A patent for "Preauthorized wearable biometric device, system and method for use thereof." This patent, assigned to **Nymi**, is for a biometric wristband that broadcasts the user's heartbeat. The promise of the technology is that unique features of user heartbeats can be used for everything from logging into computers to starting your car to purchasing items at a store or restaurant without ever needing a password or key or credit card. On April 12, 2022 Nymi was acquired by Innomninds Software (a private software firm with 1000+ employees) for an undisclosed amount.

Prior to purchase Nymi raised $15 million in venture funding and had an estimated valuation of $47M to $70M in 2017.

The patent above references 6 IEEE articles as prior art. The two key papers appear to be (Biel et al., "ECG Anaysis: A new Approach in Human Identification," *IEEE Transactions on Instrumentation and Measurement*, Jun. 2001 and Hoekerna et al., "Geometrical Aspects of the Interindividual Variability of Multilead ECG Recordings," *IEEE Transactions on Biometrical Engineering*, May 2001.)

This suggests that the enabling science showing that heartbeats could be used for biometrics was published in an IEEE journal 13 years before the Nymi patent was filed.

- **LuxVue** was a startup that had raised $43 million venture funding before being acquired by **Apple** in 2014. In the last 10 years Apple has subsequently invested another $2.2 billion into LuxVue's microLED technology before abruptly announcing last month that is was cancelling its microLED wearable display project. Despite the setback, experts believe that MicroLEDs will ultimately replace OLED displays, but further development is needed to bring MicroLED costs down.

- **WiTricity** is a wireless charging startup with several patents that all reference over 30 IEEE articles each on average. They extensively license their wireless charging technology to Anjie Wireless, CidT Co Ltd, Foxconn Interconnect Technology, Green Power, jjPlus Corp, Neosen, and Voltraware. They are also working with several car companies for wirelessly charging electric and hybrid vehicles, including BMW, GM, Honda, Hyundai, Nissan, and Toyota. In 2022 Siemens invested $25 million in WiTricity and took a minority stake in the firm.

- **Zoox** is an autonomous vehicle company which was purchased by **Amazon** in 2020 for $1.2 billion. In 2023 Zoox started to operate driverless robotaxis in California and Las Vegas. The key patents of Zoox are invented or co-invented by the Zoox founders Timothy Kentley Klay and Jesse Sol Levinson. The Zoox patents shown in the body of the report are all highly cited and all very dependent on IEEE science. Most of the patents have more than 10 references to IEEE science and the 17 patents highlighted in the report collectively reference IEEE papers a combined 372 times.

- **Butterfly Network** was founded by Dr. Jonathan Rothberg, a serial entrepreneur in the medical technology industry who is known for his contributions to gene sequencing. He started Butterfly Network in 2011 after his daughter developed a rare disease called tuberos sclerosis that required constant imaging and he was struck at how inaccessible and expensive traditional ultrasounds were. Butterfly's technology, which it calls an "ultrasound-on-chip" is designed to perform diagnostic imaging and measurement of blood vessels and examine the cardiac, abdominal, urological, fetal, gynecological, and musculoskeletal systems [Butterfly1].

Instead of piezoelectric crystals, Butterfly iQ's device uses semiconductor chips allowing for a lower sales price and more versatility than traditional alternatives. It consists of an ultrasound scanner using its semiconductor chip and connects to a smartphone to view the image. As of September 2024 the device retails for $2,600 compared to between $15,000 and $100,000 for traditional ultrasound systems. The global market for Ultrasound equipment is estimated to be about $6 billion.

In developing countries, ultrasound can be used as a diagnostically superior and safer method than X-ray to diagnose critical global health issues like pediatric pneumonia. Butterfly has teamed with the Gates Foundation to distribute their portable device to developing countries or other areas without access to existing ultrasound technology.

The 23 key patents (virtually all of them list Dr. Rothberg as the first inventor) are not only highly cited but they heavily reference IEEE science as prior art. On average each patent references IEEE about 20 times (468 total for 23 patents).

- **FireEye** was founded in 2004 by Ashar Aziz, a former Sun Microsystems engineer. Initially, FireEye focused on developing virtual machines to download and test internet traffic before shifting to a cybersecurity firm. In June 2021, FireEye sold its name and products business to **Symphony Technology Group** (STG) for $1.2bn. STG also bought McAffee Enterprise and combined the two firm to launch **Trellix** a private cybersecurity firm.

  The FireEye patents heavily reference science in IEEE journals and conferences. Many of the key patents for FireEye have more than 10 references to IEEE published papers.

- **Kandou Technologies** is a Swiss startup co-founded in 2011 by former postdoc Harm Cronie and his Professor Amin Shokrollahi while at Ecole Polytechnique Federale de Lausanne (EPFL). Kandou was spun-off after raising $10 million in venture funding. Kandou designs high speed, energy and pin efficient serial links connecting integrated circuit components such as processor and memory, or processor and processor. Serial links account for a major part of the energy consumption of electronic devices and represent an energy and speed bottleneck. Any improvement in their design directly leads to faster and more energy efficient electronic devices. Kandou's technology uses a new mode of transmission on serial links to transmit more bits on existing connections, using less energy. The technology is based on a number of patents which represent several man-years of research in discrete mathematics, circuit design, and high-speed algorithm design.

  In their latest round of Funding (August 2023), Kandou secured $72.3 million, reflecting the robust confidence our investors have in our technology and strategic direction. This brings the total investment in Kandou to an impressive $280 million.

  The key patents are very highly cited and reference about 10 IEEE articles each on average. The paper (Wang et al., "Applying CDMA Technique to Network-on-Chip," IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 15, No. 10 (Oct. 1, 2007), pp. 1091-1100.) is referenced in 5 of the key Kandou patents. Other frequently referenced papers appear in semiconductor or communications journals and conferences such as *IEEE Transactions Audio and Electroacoustics, IEEE Transactions of Information Theory, IEEE International Conference on Communications, IEEE Journal of Solid-State Circuits* and others.

- A total of 20 stories like these are contained in the report. In each case, we have written summaries of potentially very valuable patents, which have already had a significant technological impact. In every case the patent or set of patents are highly cited and build extensively on IEEE science.

Contents

Introduction

This report is a new look at so-called "blockbuster" or "breakthrough" patents – patents that contain interesting technology and are also shown to be valuable. We first investigated these kinds of patents in 2006 [Thomas1] and then again in 2009 [Breitzman1]. We did a completely new look at these types of patents in 2020 [Breitzman4]. In this version we've refreshed the stories from the 2020 report as well as added new stories for FireEye, DeepMap, and Perceive.

Placing a value on patents is, in general, a difficult endeavor. Economist Yi Deng [Deng] found that patents in electronics had a median value of only $14,000. That is, half of all patents in electronics are worth much less than the cost to file them.

Researchers such as Harhoff [Harhoff1] have shown that the values of patents are highly skewed, with more than 25% worth $50,000 or less, 75% worth less than $1 million and only about 0.3% worth $50 million. Although Deng's research is based on European patents, and Harhoff's on German patents, there is no reason to believe that a similarly skewed distribution does not exist for US patents.

In fact, there is reason to believe that Harhoff's values are optimistic and that it's likely that a much smaller percentage of US patents are worth $1 million or more. A figure that is frequently used in the US business press is that 97% of all patents never make any money [AllBusiness].

In this report we are interested in patents that are worth many millions of dollars. We highlight patents with significant financial and/or technological value. These patents contain key innovations that have spurred technological development in their industry or have led to significant financial benefits for their owners. The patents highlighted in this report also build extensively on IEEE publications. As such, IEEE science plays a major role in the scientific and technological foundation of these key innovations.

Methodology

In this report, our aim is to identify valuable patents that build upon IEEE research. To first identify valuable patents, we use citation analysis. Numerous validation studies – see [Breitzman2] for a review of such studies – have shown that patents cited by many later patents tend to contain important or valuable ideas that advance the state of the art. In simple terms, research suggests that highly cited patents tend to be more valuable than patents with few or no citations.

Citation distributions show the same skewed patterns as the patent valuations discussed above. For example, the mean number of citations received by a five-year-old patent is approximately five. However, this average consists of many patents with few or no citations, combined with a smaller number of patents with high numbers of citations. Specifically, for patents that are five years old, about 20% have received no citations, and 51% have two or fewer citations. Less than 10% have more than 10 citations and only 0.3% have more than 50 citations.

This skewed citation distribution has been shown to be related to the skewed value distribution. [Trajtenberg] and [Hall] both showed a correlation between patent value and citation frequency. Also [Harhoff2] showed that, among the 700+ patents in the Harhoff study referenced above, the patents with the most value tended to be the ones that were cited frequently by later patents.

Citations vary by age and technology category. Older patents have had a longer time to accumulate citations than recent patents and patents in fast moving active technologies like communications will receive more citations than older slower moving technologies such as ship-building. Therefore, the standard approach to examining citation impact is with a citation index [Colledge]. The way we construct our citation index is to calculate the mean number of citations for each year and technology category.

As an example consider patent 9,612,123 'Adaptive mapping to navigate autonomous vehicles responsive to physical environment changes.' This 2017 patent from Zoox, Inc. has already accumulated 293 citations through July 31, 2024. The patent office categorizes patents by a classification system called the CPC. This patent is in CPC class G01S. All of the patents issued in 2017 in class G01S have an average of 4.697 citations. Thus a typical patent from 2017 in this technology has 1 or fewer citations so far. The Zoox patent has 293 citations and therefore a citation index of 293/4.697 = 62.38. Typically a citation index of greater than 1.5 indicating 50% more citations than expected is a good indicator of high citation impact.

Our approach builds upon the relationships between citations and value suggested by this earlier research. Since we wish to find valuable patents that build upon IEEE science, we first identify patents that are cited frequently by later patents. We then identify which of these highly cited patents are themselves highly dependent on IEEE publications.

To find patents dependent upon IEEE, we examine the Non-Patent References (NPRs) provided by high-impact patents. NPRs contain prior art in the form of scientific papers, books, conference papers, and other published materials.

There is a good reason to put this second condition on the patents. Figure 1 taken from [Breitzman3] shows that patents that reference IEEE science tend to be cited higher than patents that do not.

Figure 1: 2004-2023 Citation Index of US Patents Referencing IEEE Papers and Conferences Versus US Patents not Referencing IEEE for 20 Technology Categories
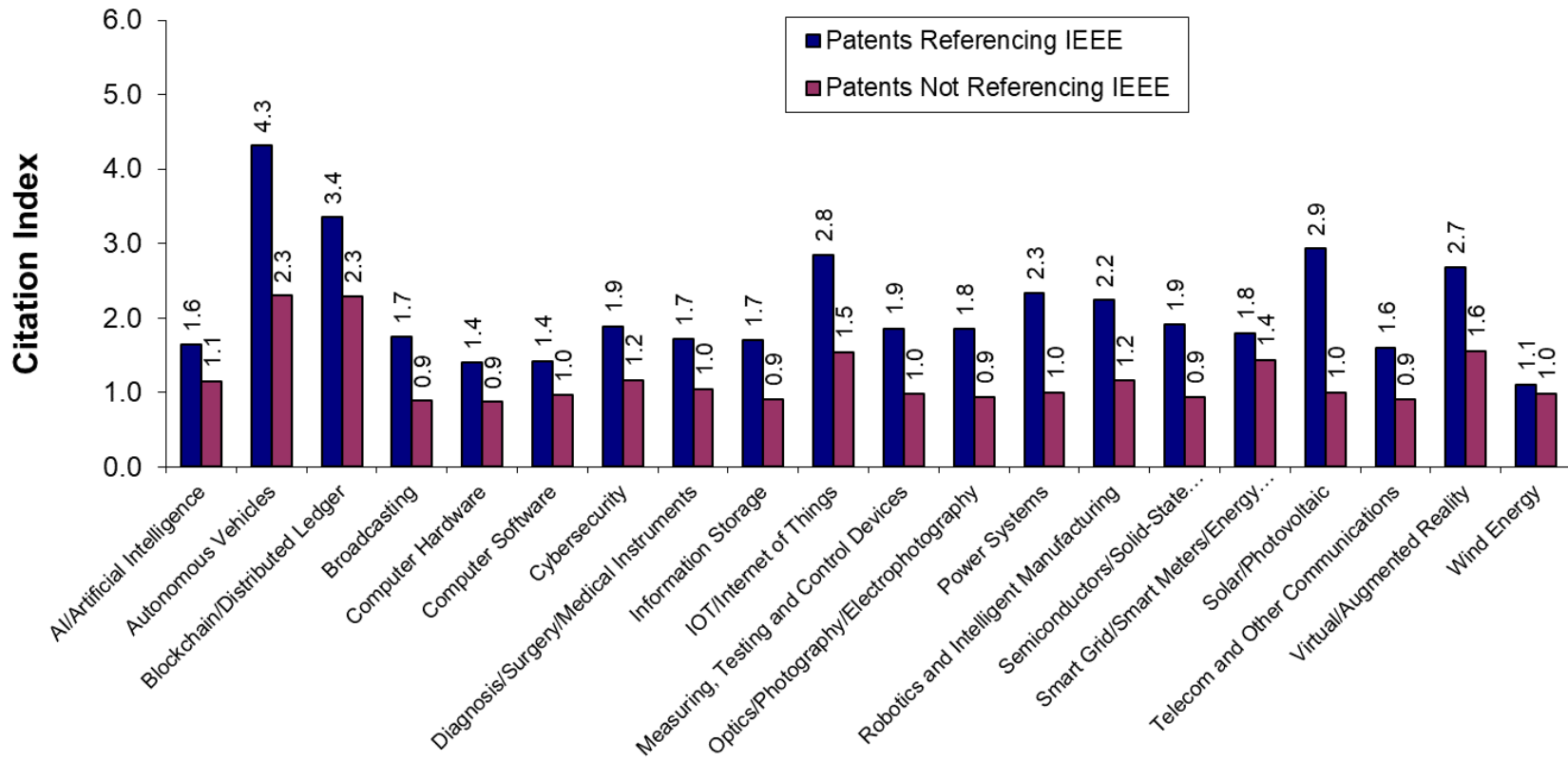
Specifically, our approach is to identify patents that:

1. have a citation index of at least 1.5 (i.e. received at least 50% more citations than would be expected for a patent with the same patent classification and issue year) and
2. reference at least 4 different IEEE publications

Once that set of patents is identified as a superset of potentially high-value, high-impact patents, we research specific patents and companies looking for stories suggesting the patents or technology are valuable. In some cases the story may be about a single patent, but in many cases the technology is protected by a group of patents.

Below are 20 stories related to patented technology that is worth millions of dollars, and builds extensively on IEEE science. The remainder of the report is organized into the following sections: Artificial Intelligence, Autonomous Vehicles, Biometrics, Computer Hardware, Computer Software, Defense Technologies, Medical Technologies, Robotics, Wireless Charging.

Results

Artificial Intelligence (AI)

DeepMap/Nvidia

DeepMap was founded in 2016 and made developing mapping technology built specifically for artificial intelligence its mission. The key idea was that mapping a solution for a machine driver instead of a human operator is the best way forward in autonomous vehicle development. Its founders, Dr. James Wu and Dr. Mark Wheeler saw the transformative potential of geographic information systems when working for Google, Baidu, and Apple [Deepmap1].

The key patents invented by Mark Wheeler can be found below in Table 1. Several are highly cited and about half reference one or more IEEE papers with patent number 10,999,511 "LIDAR and camera synchronization" referencing 5 different IEEE papers.

Table 1: Key Technology Patents from DeepMap founder

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
10816346	1	20171229	2020	31	23.11	Occupancy map updates based on sensor data collected by autonomous vehicles	Wheeler; Mark Damon, Wu; Xiaqing
10845820		20171222	2020	26	10.01	Route generation using high definition maps for autonomous vehicles	Wheeler; Mark Damon
10531004	2	20181019	2020	10	6.93	Lidar to camera calibration for generating high definition maps	Wheeler; Mark Damon, Yang; Lin
10670416		20171229	2020	9	6.71	Traffic sign feature creation for high definition maps used for navigating autonomous vehicles	Wheeler; Mark Damon, Yang; Lin, Miller; Derek Thomas
10897575		20200102	2021	4	4.36	Lidar to camera calibration for generating high definition maps	Wheeler; Mark Damon, Yang; Lin
10401500		20171228	2019	11	3.44	Encoding LiDAR scanned data for generating high definition maps for autonomous vehicles	Yang; Lin, Wheeler; Mark Damon,
10999511	5	20190924	2021	3	3.27	LIDAR and camera synchronization	Yang; Lin, Wheeler; Mark Damon

10859395		20171229	2020	3	2.24	Lane line creation for high definition maps for autonomous vehicles	Wheeler; Mark Damon, Yang; Lin, Piao; Dongzhen
10841496	2	20181015	2020	3	2.08	Lidar to camera calibration based on edge detection	Wheeler; Mark Damon, Yang; Lin
10469753	4	20181017	2019	4	2.04	Lidar and camera synchronization	Yang; Lin, Wheeler; Mark Damon
10498966		20181016	2019	4	2.04	Rolling shutter correction for images captured by a camera mounted on a moving vehicle	Wheeler; Mark Damon, Yang; Lin
10429194		20171229	2019	4	1.99	High definition map updates with vehicle data load balancing	Wheeler; Mark Damon
10436885	3	20181015	2019	6	1.88	Calibrating sensors mounted on an autonomous vehicle	Wheeler; Mark Damon, Yang; Lin

See Appendix A for the specific IEEE articles referenced by the patents in the table above (as well as all of the tables in the report). All of the IEEE papers that are referenced by multiple patents in the report can be found in Appendix B.

In June 2021, Nvidia, a leading AI and GPU firm acquired DeepMap. Though the terms of the deal were not disclosed, it's safe to assume Nvidia is paying a fairly substantial sum for the startup. DeepMap has raised more than $90 million in funding from investors that included Andreessen Horowitz [Deepmap2].

Nvidia believes the purchase would enhance Nvidia DRIVE, its end-to-end autonomous vehicle (AV) platform. It made deals to install its hardware and software in forthcoming personal transports made by several leading automobile manufacturers including Mercedes-Benz. Though the company's primary business is making gaming and AI hardware, self-driving car technology represents a $30 billion opportunity [Deepmap1].

Perceive/Amazon

Steven Teig is a serial entrepreneur who founded multiple startups including Simplex and Tabula. While acting as CTO for Xperi, he founded Perceive which was incubated within Xperi. Perceive focuses on hardware for running machine learning on mobile devices. Teig holds over 390 patents overall and is listed as an inventor on all the key AI patents of Perceive listed in Table 2 below. Teig currently acts as Co-CEO of Perceive [Perceive1].

With a focus on edge inference hardware and software technologies, Perceive enables low-power devices such as conferencing systems and wearable devices, some of which use Perceive's own AI-powered processor, called Ergo. Ergo brings performance and power efficiency to edge devices with the ability to handle many tasks—from object classification and detection to audio signal processing and language [Perceive2].

Amazon plans to acquire the AI chipmaker and model specialist Perceive Corp. for $80 million in cash to boost the company's large language models and edge computing capabilities in its Amazon Web Services product [Perceive2].

"We're excited to have signed a deal to acquire Perceive and bring over its talented team to join our efforts to bring large language models and multimodal experiences to devices capable of running on the edge," said Amazon in a statement announcing the acquisition [Perceive2].

The acquisition is expected to occur in the third quarter of 2024.

We see in Table 2 that all the key patents have at least one reference to an IEEE publication and several patents have more than 15 references to IEEE journals or conferences.

Table 2: Key AI Patents from Perceive

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
10586151	1	20160731	2020	5	1.68	Mitigating overfitting in training machine trained networks	Teig; Steven L.
10592732	4	20180221	2020	17	10.13	Probabilistic loss function for training network with triplets	Sather; Eric A., Teig; Steven L., Mihal; Andrew C.
10671888	4	20180221	2020	3	1.79	Using batches of training items for training a network	Sather; Eric A., Teig; Steven L., Mihal; Andrew C.
10740434	13	20180903	2020	21	11.09	Reduced dot product computation circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
10742959	2	20180112	2020	3	2.08	Use of machine-trained network for misalignment-insensitive depth perception	Mihal; Andrew, Teig; Steven
10936951	5	20160809	2021	2	1.21	Machine learning through multiple layers of novel machine trained processing nodes	Teig; Steven L.
11017295	7	20171116	2021	2	1.21	Device storing ternary weight parameters for machine-trained network	Teig; Steven L., Sather; Eric A.
11049013	19	20190628	2021	5	3.02	Encoding of weight values stored on neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11113603	8	20171116	2021	3	1.81	Training network with discrete weight values	Teig; Steven L., Sather; Eric A.
11151695	1	20190926	2021	2	1.60	Video denoising using neural networks with spatial and temporal features	Mihal; Andrew C., Teig; Steven L., Sather; Eric A.
11163986	4	20200417	2021	2	2.07	Using batches of training items for training a network	Sather; Eric A., Teig; Steven L., Mihal; Andrew C.
11170289	15	20181206	2021	7	4.23	Computation of neural network node by neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11205115	15	20181206	2021	3	1.81	Neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11210586	19	20190628	2021	6	3.62	Weight value decoder of neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11222257	10	20190821	2022	3	5.42	Non-dot product computations on neural network inference circuit	Ko; Jung, Duong; Kenneth, Teig; Steven L.
11250326	15	20181206	2022	27	48.76	Splitting neural network filters for implementation by neural network inference circuit	Ko; Jung, Duong; Kenneth, Teig; Steven L.
11250840	1	20190405	2022	2	3.31	Machine-trained network detecting context-sensitive wake expressions for a digital assistant	Teig; Steven L.
11295200	14	20181206	2022	3	5.42	Time-multiplexed dot products for neural network inference circuit	Ko; Jung, Duong; Kenneth, Teig; Steven L.
11347297	12	20190530	2022	3	5.92	Neural network inference circuit employing dynamic memory sleep	Ko; Jung, Duong; Kenneth, Teig; Steven L.
11348006	1	20200308	2022	1	1.81	Mitigating overfitting in training machine trained networks	Teig; Steven L.
11403530	13	20181206	2022	1	1.81	Using quinary weights with neural network inference circuit designed for ternary weights	Ko; Jung, Duong; Kenneth, Teig; Steven L.
11429861	8	20171116	2022	1	1.81	Device storing multiple sets of parameters for machine-trained network	Teig; Steven L., Sather; Eric A.
11468145	17	20190315	2022	8	15.80	Storage of input values within core of neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.

11475310	2	20171128	2022	1	1.81	Training network to minimize worst-case error	Teig; Steven L., Mihal; Andrew C.
11481612	17	20190315	2022	1	1.81	Storage of input values across multiple cores of neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11494657	6	20191008	2022	1	1.81	Quantizing neural networks using approximate quantization function	Sather; Eric A., Teig; Steven L.
11531868	17	20190315	2022	1	1.81	Input value cache for temporarily storing input values	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11531879	4	20190626	2022	4	7.22	Iterative transfer of machine-trained network inputs from validation set to training set	Teig; Steven L., Sather; Eric A.
11568227	18	20191217	2023	2	11.51	Neural network inference circuit read controller with multiple operational modes	Ko; Jung, Duong; Kenneth, Teig; Steven L.
11586902	9	20180314	2023	3	17.26	Training network to minimize worst case surprise	Sather; Eric A., Teig; Steven L., Mihal; Andrew C.
11586910	16	20190809	2023	1	5.75	Write cache for neural network inference circuit	Duong; Kenneth, Ko; Jung, Teig; Steven L.
11604973	16	20191127	2023	2	11.51	Replication of neural network layers	Sather; Eric A., Teig; Steven L.
11610154	4	20200203	2023	4	23.02	Preventing overfitting of hyperparameters during training of network	Teig; Steven L., Sather; Eric A.
11615322	19	20190729	2023	2	11.51	Compiler for implementing memory shutdown for neural network implementation configuration	Thomas; Brian, Teig; Steven L.
11625585	19	20190729	2023	2	11.51	Compiler for optimizing filter sparsity for neural network implementation configuration	Thomas; Brian, Teig; Steven L.
11783167	13	20190821	2023	1	5.75	Data transfer for non-dot product computations on neural network inference circuit	Ko; Jung, Duong; Kenneth, Teig; Steven L.

Autonomous Vehicles

DeepMap/Nvidia (See Artificial Intelligence)

The DeepMap story could go into Autonomous Vehicles because the main use-case for DeepMap is in the Autonomous Vehicle space, however the mapping technology was built specifically for artificial intelligence and so the story is in that section.

Zoox/Amazon

Zoox is a company that has patents in many technology areas (Autonomous vehicles, Artificial Intelligence, Robotics, Software etc) but is most accurately described as an autonomous vehicle firm.

On June 26, 2020 Amazon and Zoox signed a definitive merger agreement, under which Amazon acquired Zoox as a wholly owned subsidiary for over $1.2 billion [zoox1].

In 2023 Zoox was given Approval by the California Department of Motor Vehicles to begin testing self-driving robotaxis on open public roads [zoox2]. In June 2023 Zoox expanded its robotaxi business to Las Vegas after being authorized by the Nevada Department of Motor Vehicles to operate its autonomous robotaxis on Nevada public roads [zoox3].

The key patents of Zoox can be found in Table 3 below. All of them are invented or co-invented by the Zoox founders Timothy Kentley Klay and Jesse Sol Levinson. Kentley Klay was CEO until August 2018, when he was suddenly fired by the board one month after Zoox closed a $500 million funding round at a

$3.2 billion post-money valuation [zoox4]. Klay remained chairman of the board and co-founder Levinson went from CTO to President.

The Zoox patents shown in Table 3 are all highly cited and all very dependent on IEEE science. Most of the patents have more than 10 references to IEEE science and collectively the 17 patents in Table 3 reference IEEE a combined 372 times.

Table 3: Key Technology Patents of Zoox

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
9494940	22	20151104	2016	49	3.32	Quadrant configuration of robotic vehicles	Kentley; Timothy David
9507346	11	20151104	2016	271	18.34	Teleoperation system and method for trajectory modification of autonomous vehicles	Levinson; Jesse Sol, Kentley; Timothy David, Sibley; Gabriel Thurston
9517767	20	20151104	2016	105	14.93	Internal safety systems for robotic vehicles	Kentley; Timothy David, Gamara; Rachad Youssef, Behere; Sagar
9606539	14	20151104	2017	114	11.12	Autonomous vehicle fleet service and system	Kentley; Timothy David, Levinson; Jesse Sol, Gamara; Rachad Youssef
9612123	13	20151104	2017	293	62.38	Adaptive mapping to navigate autonomous vehicles responsive to physical environment changes	Levinson; Jesse Sol, Sibley; Gabriel Thurston
9630619	26	20151104	2017	52	11.89	Robotic vehicle active safety systems and methods	Kentley; Timothy David, Levinson; Jesse Sol, Lind; Amanda Blair
9632502	39	20151105	2017	247	24.09	Machine-learning systems and techniques to optimize teleoperation and/or planner decisions	Levinson; Jesse Sol, Sibley; Gabriel Thurston, Rege; Ashutosh Gajanan
9701239	26	20151104	2017	49	11.72	System of configuring active lighting to indicate directionality of an autonomous vehicle	Kentley; Timothy David, Gamara; Rachad Youssef
9720415	13	20151104	2017	94	9.17	Sensor-based object-detection optimization for autonomous vehicles	Levinson; Jesse Sol, Kentley; Timothy David, Douillard; Bertrand Robert
9734455	56	20151104	2017	86	9.64	Automated extraction of semantic information to enhance incremental mapping modifications for robotic vehicles	Levinson; Jesse Sol, Sibley; Gabriel Thurston, Rege; Ashutosh Gajanan
9754490	14	20151105	2017	228	27.54	Software application to request and control an autonomous vehicle service	Kentley; Timothy David, Gamara; Rachad Youssef, Linscott; Gary
9804599	17	20151104	2017	31	3.02	Active lighting control for communicating a state of an autonomous vehicle to entities in a surrounding environment	Kentley-Klay; Timothy David, Gamara; Rachad Youssef
9878664	28	20151104	2018	16	4.75	Method for robotic vehicle communication with an external environment via acoustic beam forming	Kentley-Klay; Timothy David, Levinson; Jesse Sol, Lind; Amanda Blair
9910441	11	20151104	2018	36	6.30	Adaptive autonomous vehicle planner logic	Levinson; Jesse Sol, Sibley; Gabriel Thurston, Kentley-Klay; Timothy David
9916703	11	20151104	2018	368	60.60	Calibration for autonomous vehicle operation	Levinson; Jesse Sol, Douillard; Bertrand Robert, Sibley; Gabriel Thurston

| 9958864 | 15 | 20151104 | 2018 | 41 | 7.17 | Coordination of dispatching and maintaining fleet of autonomous vehicles | Kentley-Klay; Timothy David, Gamara; Rachad Youssef |
| 10048683 | 36 | 20161228 | 2018 | 22 | 3.85 | Machine learning systems and techniques to optimize teleoperation and/or planner decisions | Levinson; Jesse Sol, Sibley; Gabriel Thurston, Rege; Ashutosh Gajanan |

Biometrics

Nymi/Bionym

Nymi (originally Bionym) is a Canadian company with technology right out of a science fiction movie. Everyone's heartbeat is unique based on the size and shape of the heart and the orientation of the heart valves. Nymi has used this idea to develop wearable devices that authenticate a person's identity via their heartbeat, giving access to secure places/sites by a watch-like band [Nymi1]. In May 2017, Nymi raised $15M in a second round of funding [Nymi2].

On April 12, 2022 Nymi was acquired by Innomninds Software (a private software firm with 1000+ employees) for an undisclosed amount [Nymi6].

The original use-case was for authorized consumer payments. In a venture between TD Bank, Mastercard and Nymi, the prototype band is linked to the pilot participant's MasterCard account. The user is then able to purchase items at participating retail stores across Canada by holding the Nymi Band up to the tap-and-go terminal [Nymi3].

Other applications include replacing passwords for computers and smartphones. In January 2020, Nymi partnered with Werum IT Solutions to launch a biometric authentication solution to be used in a biopharmaceutical shop floor. It would enable individuals to securely and seamlessly authenticate to systems, devices and machines via a smart wristband [Nymi4].

The Nymi Band is a wearable device that can be worn under all types of protective clothing and is uniquely assigned to each user, based on their unique biometric identity. "We are convinced that having Nymi as part of our K.ME-IN biometric authentication solution is going to make our pharmaceutical and biotech customers even more productive," says Obay Alchorbaji, Product Manager, Werum IT Solutions. "With our new solution we address the very real challenge in the pharmaceutical and biopharmaceutical market of ensuring secure and fast authentication, while also meeting compliance and data integrity requirements. We help our customers cut authentication times by up to 75%, thus significantly increasing their production efficiency." [Nymi4]

The same article mentions that Nymi currently works with many of the top 100 pharmaceutical firms [Nymi4].

What makes the Nymi Band unique is that, once authenticated, it remains on, transmitting the wearer's identity until removed. It is considered the most secure biometric for authentication because the wearer needs to be alive and, unlike fingerprints or iris-scans, a person's unique heartbeat signal is difficult to reproduce [Nymi5].

Nymi's 9 US patents are shown in Table 4. The key patent is #8,994,498 with the title "Preauthorized wearable biometric device, system and method for use thereof." Three other patents in the table have

the same title and are continuations of the '498 patent. This patent has 369 citations, which is 48 times as many as expected for a patent of this age and technology.

Table 4: All US Patents Granted to Nymi

Patent #	#IEEE References	Application Date	Grant Date	# Cites	Citation Index	Title	First 3 Inventors
8994498	6	20140724	20150331	369	48.63	Preauthorized wearable biometric device, system and method for use thereof	Agrafioti; Foteini, Martin; Karl, Oung; Stephen
9032501	6	20140818	20150512	29	4.11	Cryptographic protocol for portable devices	Martin; Karl, Vahlis; Evgene
9189901	6	20150326	20151117	16	1.29	Preauthorized wearable biometric device, system and method for use thereof	Agrafioti; Foteini, Martin; Karl, Oung; Stephen
9197414	6	20150331	20151124	32	4.53	Cryptographic protocol for portable devices	Martin; Karl, Vahlis; Evgene
9349235	6	20151116	20160524	9	0.89	Preauthorized wearable biometric device, system and method for use thereof	Agrafioti; Foteini, Martin; Karl, Oung; Stephen
9407634	6	20151123	20160802	6	0.96	Cryptographic protocol for portable devices	Martin; Karl, Vahlis; Evgene
9472033	6	20160523	20161018	5	0.49	Preauthorized wearable biometric device, system and method for use thereof	Agrafioti; Foteini, Martin; Karl, Oung; Stephen
9646261	6	20120510	20170509	47	5.27	Enabling continuous or instantaneous identity recognition of a large group of people based on physiological biometric signals obtained from members of a small group of people	Agrafioti; Foteini, Bui; Francis Minhthang, Hatzinakos; Dimitrios
9832020	6	20160801	20171128	3	0.56	Cryptographic protocol for portable devices	Martin; Karl, Vahlis; Evgene

All nine of Nymi's patents reference the same six IEEE articles. Two of the articles seem to be key pieces of enabling prior art and predate the first Nymi patent application by 13 years:

- Biel et al., "ECG Anaysis: A new Approach in Human Identification," *IEEE Transactions on Instrumentation and Measurement*, vol. 50, No. 3, Jun. 2001, pp. 808-812.
- Hoekerna et al., "Geometrical Aspects of the Interindividual Variability of Multilead ECG Recordings," *IEEE Transactions on Biometrical Engineering*, vol. 48, No. 5, May 2001, pp. 551-559.

This suggests that the enabling science showing that heartbeats could be used for biometrics was published in an IEEE journal 13 years before the Nymi patent was filed. The other IEEE references are similar and can be found in Appendix A and Appendix B.

Communications

BAE Systems/UK Army (See Defense Related)

The BAE Systems Tactical Hotspot is a compact mobile digital communications system that could go in the communications category. However, since it is being used by the UK army, and is aimed at other defense departments, the story can be found in the defense-related technology section below.

Cap Wireless/Triquint/Qorvo (See Semiconductors)

Cap Wireless - which invented the Spatium™ broadband amplifiers product line - could be placed in the communications category. However, since it was purchased by Triquint Semiconductors, the story can be found in the semiconductor section below.

Nomadix/ Assa Abloy

Nomadix is a firm started by a professor and one of his students. It is called Nomadix because Professor Kleinrock was an expert in nomadic communication networks (or the use of portable computing devices on mobile communications networks). Dr. Kleinrock is a member of the Internet Hall of Fame, an IEEE fellow, an ACM fellow, a recipient of the IEEE Internet Millennium Award, the IEEE Leonard G. Abraham Prize Paper Award, the IEEE Harry M. Goode Award and many others [Nomadix1].

In September 1969, the host computer in Kleinrock's laboratory at UCLA became the first node of ARPANET, an early packet switching network and precursor to today's World Wide Web. At the start of the 1990s, Kleinrock was an early researcher in the field of nomadic computing years before portable computing devices and wireless internet networks were being widely commercialized. In the late 1990s, Kleinrock founded Nomadix along with Joel Short, then a graduate student at UCLA, to develop technologies that would satisfy a growing expectation on behalf of consumers that their computing devices, which were increasingly shrinking in size, would be able to connect to the internet anywhere [Nomadix2].

Nomadix was acquired by Assa Abloy in March 2024 but Nomadix but continues to operate as a standalone company [Nomadix3].

Nomadix's internet access gateway technologies allow a business to control public connectivity to their private wireless internet networks. These gateways are in use in places like hotels, cafes, laundromats or other businesses where WiFi is offered to customers. The company holds 51 US patents and has shipped more than 50,000 gateway units [Nomadix2].

Nomadix describes itself as the world leader in innovative guest-facing cloud-managed network edge devices and the leading provider of intelligent network devices that make nomadic computing and public internet access easy while facilitating more than 5 million connections daily worldwide [Nomadix3]. As of 2024 Nomadix provides internet services to top hotel chains such as Choice Hotels, Hilton, Marriott, and Hyatt amongst others. [Nomadix4]

In addition to selling internet devices to hotels, laundromats, and other public spaces, Nomadix has made the news for many public lawsuits. In 2016 Nomadix won a lawsuit against BlueprintRF which used to sell competing devices to hotels including Marriott, Hyatt, and Choice Hotels amongst others that are now served by Nomadix. The patents involved in the lawsuit are shown in Table 5 [Nomadix2].

The terms of the patent infringement award were not disclosed, but in March 2009, a judge awarded Nomadix a $3.2M judgment and granted a permanent injunction against another competitor named Second Rule. Others who have been sued by Nomadix and who have agreed to pay licensing fees include Aruba Networks (owned by Hewlett Packard Enterprises) and Wayport (owned by AT&T).

The seven patents in Table 5 are all co-invented by the co-founder Joel Short and all are highly cited. Five of the seven also reference at least 68 IEEE articles as prior art. As such, IEEE science forms an important part of the foundation for this internet technology.

Table 5: Patents named in Nomadix v. BlueprintRF

Patent #	#IEEE References	Application Date	Grant Date	# Cites	Citation Index	Title	First 3 Inventors
8364806	70	20120803	20130129	251	17.98	Systems and methods for providing content and services on a network system	Short; Joel E., Pagan; Florence C. I., Goldstein; Josh J.
8266269	82	20111219	20120911	76	5.26	Systems and methods for providing content and services on a network system	Short; Joel E., Pagan; Florence C. I., Goldstein; Josh J.
8266266	92	20100111	20120911	69	4.77	Systems and methods for providing dynamic network authorization, authentication and accounting	Short; Joel E, Pagan; Florence C. I., Goldstein; Josh J
8156246	92	20110926	20120410	66	4.42	Systems and methods for providing content and services on a network system	Short; Joel E., Pagan; Florence C. I., Goldstein; Josh J.
6636894	0	19991208	20031021	418	4.40	Systems and methods for redirecting users having transparent computer access to a network using a gateway device having redirection capability	Short; Joel E., Perelyubskiy; Denis I.
6868399	0	20001020	20050315	160	2.33	Systems and methods for integrating a network gateway device with management systems	Short; Joel E., Delley; Frederic, Logan; Mark F.
8788690	68	20131202	20140722	17	2.14	Systems and methods for providing content and services on a network system	Short; Joel E., Pagan; Florence C. I., Goldstein; Joshua J.

Computer Hardware and Peripherals

Project SOLI-Google

Project Soli is a new gesture-recognition technology based on radar, unlike established approaches based on visual or infrared light such as stereo cameras, structured light, or time-of-flight sensors. This novel approach uses small high-speed sensors and data-analysis techniques to detect fine motions with sub-millimeter accuracy [Soli2]. Thus, for instance, Project Soli technology enables a user to issue commands to a computer by rubbing a thumb and forefinger together in pre-defined patterns. Applications might include sensors embedded in clothing, switches that don't require physical contact, and accessibility technology [Soli2].

The project is headed by Ivan Poupyrev a former scientist for Disney Imagineering who was named one of Fast Company's "100 Most Creative People in Business 2013" [Soli3]. Poupyrev is now the head of Google's Advanced Technology and Projects group (ATAP) and the head of project Soli and Jacard amongst others. He is also lead inventor on several of Google's gesture recognition patents shown in Table 6.

In Jan. 2019 the *Patently Apple* website mentioned that Google won a major patent for an In-Air Gesturing System in November 2019 [Soli4]. Although the website did not specifically mention patent #10,139,916, this patent appears to be the one in question. They go on to say:

> What makes this granted patent interesting is that The Federal Communications Commission (FCC) said in an order late on Monday that it would grant Google a waiver to operate the Soli sensors at higher power levels than currently allowed.
> … Google says the virtual tools can approximate the precision of natural human

hand motion and the sensor can be embedded in wearables, phones, computers and vehicles. The FCC also noted that the sensors can also be operated aboard aircraft. … The system could apply to home automation and control systems, entertainment systems, audio systems, other home appliances, security systems, netbooks, and e-readers. Note that computing device can be wearable, non-wearable but mobile, or relatively immobile (e.g., desktops and appliances) [Soli4]

A 2022 *Wired* Article contains the following quote about the technology:

> What if your computer decided not to blare out a notification jingle because it noticed you weren't sitting at your desk? What if your TV saw you leave the couch to answer the front door and paused Netflix automatically, then resumed playback when you sat back down? What if our computers took more social cues from our movements and learned to be more considerate companions? [Soli7]

This technology has been embedded in the current Google Nest products to help users track their sleep patterns without the use of cameras [Soli5].

The future for gesture technology seems certain: Grand View Research estimates that the global gesture recognition market will be worth nearly $31 billion by 2025, up from $6.2 billion in 2017 [Soli6].

Table 6: Patents related to Google's Project SOLI

Patent #	#IEEE References	Application Date	Grant Date	# Cites	Citation Index	Title	First 3 Inventors
10139916	9	20160429	20181127	63	17.52	Wide-field radar-based gesture recognition	Poupyrev; Ivan
10088908	9	20150923	20181002	81	22.53	Gesture detection and interactions	Poupyrev; Ivan, Schwesig; Carsten, Schulze; Jack
9971415	8	20170110	20180515	53	14.74	Radar-based gesture-recognition through a wearable device	Poupyrev; Ivan, Aiello; Gaetano Roberto
9921660	10	20141001	20180320	79	21.97	Radar-based gesture recognition	Poupyrev; Ivan
9811164	7	20141014	20171107	91	18.76	Radar-based gesture sensing and data transmission	Poupyrev; Ivan
9778749	12	20140924	20171003	77	15.87	Occluded gesture recognition	Poupyrev; Ivan
9646481	5	20141222	20170509	17	2.31	Alarm setting and interfacing with gesture contact interfacing controls	Messenger; Jayson, Yuen; Shelten
9575560	5	20140623	20170221	117	24.12	Radar-based gesture-recognition through a wearable device	Poupyrev; Ivan, Aiello; Gaetano Roberto
8812259	4	20131009	20140819	21	3.20	Alarm setting and interfacing with gesture contact interfacing controls	Messenger; Jayson, Yuen; Shelten

The patents are all very highly cited and reference IEEE science extensively. The nine patents in Table 6 reference IEEE 69 times (an average of 7.6 IEEE references per patent). Poupyrev is also an author on a whitepaper describing the technology [Soli1] which references 23 different IEEE published articles.

One of the papers referenced in all 7 of the patents above is (Wang,"Micro-Doppler Signatures for Intelligent Human Gait Recognition Using a UWB Impulse Radar", *2011 IEEE International Symposium on Antennas and Propagation (APSURSI)*, Jul. 3, 2011, pp. 2103-2106.) Another is (Espina,"Wireless Body Sensor Network for Continuous Cuff-less Blood Pressure Monitoring", *IEEE/EMBS International Summer School on Medical Devices and Biosensors*, Sep. 2006.) The is also this paper that is referenced in 6 of the 7 patents above (Pu,"Whole-Home Gesture Recognition Using Wireless Signals", MobiCom '13 *IEEE/ACM Proceedings of the 19th annual international conference on Mobile computing & networking*, Aug. 27, 2013.)

Again, the full list of all IEEE articles referenced in the patents above (and in all the tables) can be found in Appendix A.

LuxVue/Apple

An interesting set of patents are those filed by LuxVue, which were then assigned to Apple after its acquisition of LuxVue in 2014. Terms of the deal were not disclosed but the estimated cost was $450 million [LuxVue2].

According to venture capitalist John Doer, LuxVue had "a technical breakthrough in displays." LuxVue's patents are related to micro-LED displays. According to Doer, one of the other killer advantages of micro-LED displays are they are 9X brighter yet use much less power than required today. Doer mentions that 90% of the power associated with a smartphone is used to power the display [LuxVue1].

Table 7 shows 21 patents that were reassigned from LuxVue Technology to Apple as part of the acquisition. This set of patents are at the heart of the acquisition and are interesting for several reasons. They are all very highly cited, with many having a citation index above 20 and some above 50. Note that a Citation Index has an expected value of 1.0, so patent #8,791,474 with 269 citations is actually cited 26 times as often as peer patents of the same age and technology class. Each of the patents in Table 7 reference at least 4 IEEE articles, and collectively these 21 patents contain 104 references to IEEE science.

Many of the patents in Table 7 are invented or co-invented by Andreas Bibl, Kapil Sakanriya or Kelly McGrody. Bibl was the CEO of LuxVue prior to the acquisition and continues to have patents granted with Apple. Sakanriya was the VP of technology with LuxVue prior to the acquisition and now holds the title Director, Engineering and Product development with Apple. McGrody was Director of LED Device Technology at LuxVue and then a Senior Engineering Manager at Apple through 2018 and is now self-employed.

Hence, with the LuxVue acquisition by Apple, we see evidence of a valuable display technology developed by researchers building extensively on IEEE science.

Table 7: Patents reassigned from LuxVue to Apple

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8426227	6	20120213	2013	141	19.24	Method of forming a micro light emitting diode array	Bibl; Andreas, Higginson; John A., Law; Hung-Fai Stephen
8552436	5	20121207	2013	64	10.45	Light emitting diode structure	Bibl; Andreas, Higginson; John A., Law; Hung-Fai Stephen
8791474	5	20130315	2014	269	26.85	Light emitting diode display with redundancy scheme	Bibl; Andreas, Sakariya; Kapil V., Griggs; Charles R.
8928021	5	20130618	2015	41	7.76	LED light pipe	Bibl; Andreas, McGroddy; Kelly

8987765	5	20130617	2015	234	44.26	Reflective bank structure and method for integrating a light emitting device	Bibl; Andreas, Griggs; Charles R.
9087764	6	20130726	2015	70	13.24	Adhesive wafer bonding with controlled thickness variation	Chan; Clayton Ka Tsun, Bibl; Andreas
9111464	7	20130618	2015	144	39.17	LED display with wavelength conversion layer	Bibl; Andreas, McGroddy; Kelly
9153171	4	20121217	2015	209	53.51	Smart pixel lighting and display microcontroller	Sakariya; Kapil V., Bibl; Andreas, McGroddy; Kelly
9178123	5	20121210	2015	165	31.21	Light emitting device reflective bank structure	Sakariya; Kapil V., Bibl; Andreas, Hu; Hsin-Hua
9240397	5	20150123	2016	114	20.90	Method for integrating a light emitting device	Bibl; Andreas, Griggs; Charles R.
9252375	5	20130315	2016	106	19.43	Method of fabricating a light emitting diode display with integrated defect detection test	Bibl; Andreas, Sakariya; Kapil V., Griggs; Charles R.
9318475	5	20140515	2016	57	10.45	Flexible display and method of formation with sacrificial release layer	Bibl; Andreas, Golda; Dariusz
9343448	4	20150921	2016	26	4.77	Active matrix emissive micro LED display	Sakariya; Kapil V., Bibl; Andreas, Hu; Hsin-Hua
9367094	5	20131217	2016	107	18.06	Display module and system applications	Bibl; Andreas, Sakariya; Kapil V., Pavate; Vikram
9484504	8	20130514	2016	122	22.36	Micro LED with wavelength conversion layer	Bibl; Andreas, McGroddy; Kelly
9570427	5	20151221	2017	40	9.73	Method for integrating a light emitting device	Bibl; Andreas, Griggs; Charles R.
9583466	6	20131227	2017	40	9.73	Etch removal of current distribution layer for LED current confinement	McGroddy; Kelly, Hu; Hsin-Hua, Bibl; Andreas
9583533	5	20140313	2017	123	29.92	LED device with embedded nanowire LEDs	Hu; Hsin-Hua, Bibl; Andreas
9626908	4	20150819	2017	91	38.92	Smart pixel lighting and display microcontroller	Sakariya; Kapil V., Bibl; Andreas, McGroddy; Kelly
9865832	4	20150713	2018	110	35.33	Light emitting diode display with redundancy scheme	Bibl; Andreas, Sakariya; Kapil V., Griggs; Charles R.

The IEEE papers referenced in these patents are related to Optics, MEMS (Micro-Electro-Mechanical Systems), and Semiconductors. A full list of the papers can be found in Appendix A and the IEEE papers referenced 3 or more times can be found in Appendix B starting at page B-7.

According to a 2023 report from the Yole Group in addition to paying $450 million for the technology. In the ensuing decade, it has poured an additional $2.2 billion into further development of Micro-LEDs [LuxVue2].

> Apple could benefit in two ways from this bet. First, microLED should give it a highly differentiating display with unmatched brightness, contrast, color, viewing angle, and lower power consumption. To get that, Apple is willing to pay a significant premium. Second, just like it did when it parted from Intel for its microprocessors to design its own and use TSMC for manufacturing, Apple will gain some independence from the well-established display industry and behemoths like Samsung, LG or BOE, which currently supply its OLED smartphone displays. With microLEDs, Apple could better control its supply chain, ultimately sourcing its microLED chips and various key elements from multiple foundries and suppliers. By adopting a disruptive display-driving technology (AKA "Microdrivers"), Apple could even completely part ways with traditional display makers [LuxVue2].

In spite of the $2.2 billion investment, Apple recently announced that it is cancelling its microLED wearable display project. Still, it is widely believed that microLEDs have high promise and are likely to be the display technology to replace OLEDs. However, given the current development costs, experts believe it will take 5-10 years for microLEDs to mature in most display segments [LuxVue3].

Later reports suggested that the project was cancelled not because the technology is not good, but because the current cost is too high. Currently a 2-inch microLED watch screen could cost Apple around $150, while the existing OLED display costs $38 [LuxVue4].

Sonos/Google

On January 7, 2020 wireless audio specialist Sonos filed a patent infringement suit against Google claiming it has knowingly used its patented technology without paying for it since 2016. The grievance relates to Google's portfolio of smart, wireless, networked speakers, now marketed under the collective brand of Google Home. Sonos says it gave Google access to its patents in 2013 in order to allow Google Play Music to work on the Sonos platform. At the time Google had no competing hardware. A few years later Google launched Chromecast and the Google Home assistant with features including multi-room support which appears to be one of the key infringements [Sonos1].

A snippet of the lawsuit labeled Google's Unjust Enrichment follows:

> Google's infringement of Sonos's patented inventions has paved the way for Google to generate billions of dollars in revenue. A December 2018 market report by Royal Bank of Canada, for example, concluded that Google has sold over 40 million Google Home devices in the U.S. and that Google generated $3.4 billion in Google Home revenue in 2018 alone. Royal Bank of Canada also found that, as of August 2017, Google had sold more than 55 million Chromecast devices and that Google generated $998 million in Chromecast revenue in 2018. Further, Royal Bank of Canada estimated that in 2018 Google generated $3.4 billion in Pixel device revenue [Sonos2].

Table 8 shows the 5 specific patents named in the lawsuit, although Sonos claims Google has infringed others. The two most recent patents have not had time to accumulate any citations but the top two patents in Table 8 appear to be related to the multi-room feature and they are very highly cited. These two patents have 22 references to IEEE articles and the five patents have a total of 44 references to IEEE science.

Table 8: Patents specified in Sonos v. Google

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8588949	6	20120914	2013	339	16.77	Method and apparatus for adjusting volume levels in a multi-zone system	Lambourne; Robert A., Millington; Nicholas A. J.
9195258	16	20140220	2015	135	17.79	System and method for synchronizing operations among a plurality of independently clocked digital data processing devices	Millington; Nicholas A. J.
9219959	0	20140609	2015	43	5.37	Multi-channel pairing in a media system	Kallai; Christopher, Ericson; Michael Darrell Andrew, Lambourne; Robert A.

| 10209953 | 11 | 20180831 | 2019 | 9 | 3.44 | Playback device | Millington; Nicholas A. J. |
| 10439896 | 11 | 20190311 | 2019 | 6 | 2.12 | Playback device connection | Millington; Nicholas A. J., Hainsworth; Paul V. |

According to Reuters:

> Sonos won a $32.5 million patent-infringement verdict against Google last year [2023] in California federal court, which a federal judge overturned months later. Google has countered with its own U.S. patent lawsuits against Sonos. Sonos asked the U.S. International Trade Commission in 2020 to block Google from importing products that it said infringed its patents. The ITC determined in 2022 that Google violated five Sonos patents and banned the tech giant from importing infringing devices, but it also said Google could import products that it had redesigned to leave out the patented technology [Sonos3].

Synaptics Inc/Pacinian

The case study of Pacinian should be taught in every business school. The two founders raised $6 million in angel funding between 2007 and 2012 and sold their firm to Synaptics in 2012 for $30 million before ever launching a product [Pacinian1].

Co-founders Jim Schlosser and Cody Peterson observed that computers were becoming smaller and sleeker but that keyboards were still heavy, clunky, and easily damaged. They developed a ThinTouch™ keyboard that uses tiny magnets and a small ramp to generate the desired typing feel. Pressing the keys makes the magnets separate and allows a tiny depression of the key. Users feel they are pressing down keys, but the keys barely move – less than 1 millimeter. The smaller key depression meant keyboards could be skinnier – barely more than the width of two credit cards [Pacinian1].

Between 2007 and 2009 the two men filed 19 patents related to their keyboard. All have been subsequently reassigned to Synaptics. The 14 patents with ten or more citations are shown in Table 9. The key patent "Touchpad with capacitive force sensing" has 128 citations in just eight years (peer patents of the same age and technology class have less than three citations on average). All of the patents in Table 9 are highly cited relative to their peers and each references 3.7 IEEE articles on average.

In addition to keyboards, as of 2024 Synaptics now uses the capacitive touch technology in smart-phones, biometric devices and touchpads in the IOT (Internet-of-things) and automotive industry [Pacinian2].

Table 9: Key patents reassigned from Pacinian to Synaptics

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
7741979	3	20071127	2010	51	6.68	Haptic keyboard systems and methods	Schlosser; James William, Peterson; Cody George, Huska; Andrew
8199033	4	20090127	2012	44	4.72	Haptic keyboard systems and methods	Peterson; Cody George, Huska; Andrew Parris, Schlosser; James William
8203531	4	20090312	2012	14	1.58	Vector-specific haptic feedback	Peterson; Cody George, Huska; Andrew Parris, Schlosser; James William
8248277	4	20090127	2012	77	8.26	Haptic keyboard systems and methods	Peterson; Cody George, Huska; Andrew Parris, Schlosser; James William
8248278	6	20100601	2012	80	8.58	Haptic keyboard assemblies, systems and methods	Schlosser; James William, Peterson; Cody George, Huska; Andrew

8294600	4	20090213	2012	73	7.83	Keyboard adaptive haptic response	Peterson; Cody George, Huska; Andrew Parris, Schlosser; James William
8309870	4	20111212	2012	35	2.72	Leveled touchsurface with planar translational responsiveness to vertical travel	Peterson; Cody G., Krumpelman; Douglas M., Levin; Michael D.
8310444	4	20090127	2012	23	1.19	Projected field haptic actuation	Peterson; Cody George, Huska; Andrew P., Schlosser; James William
8542134	0	20120831	2013	61	9.66	Keyboard adaptive haptic response	Peterson; Cody George, Huska; Andrew Parris, Schlosser; James William
8599047	3	20120427	2013	38	6.02	Haptic keyboard assemblies and methods	Schlosser; James William, Peterson; Cody George, Huska; Andrew
8735755	0	20120306	2014	56	12.44	Capacitive keyswitch technologies	Peterson; Cody George, Krumpelman; Douglas M., Huska; Andrew P.
8760413	7	20091015	2014	53	4.60	Tactile surface	Peterson; Cody George, Krumpelman; Douglas M., Huska; Andrew P.
8912458	5	20120806	2014	11	1.28	Touchsurface with level and planar translational travel responsiveness	Peterson; Cody G., Krumpelman; Douglas M., Levin; Michael D.
9349552	4	20120906	2016	128	48.08	Touchpad with capacitive force sensing	Huska; Andrew P., Krumpelman; Douglas M., Peterson; Cody G.

The key IEEE papers are from the field of robotics.

- "Touch and Haptics", *2004 IEEE/RSJ International Conference on Intelligent Robots and Systems*
- Bar-Cohen, Yoseph "Electric Flex", *IEEE Spectrum Online*, (Jun. 2004),6 pages.
- Biggs, James "Some Useful Information for Tactile Display Design", *IEEE Transactions on Man-Machine Systems*, vol. 11, No. 1,(1970), pp. 19-24.

The first is actually an incomplete reference. Touch and Haptics was a workshop within the *IEEE/RSJ Conference on Robots and Systems*, but the incomplete reference is repeated in 7 of the patents above. It could potentially be for the paper (Kheddar, A., "Problems in designing inclusive haptic devices." In: *Touch and Haptics Workshop, IEEE/RSJ International Conference on Intelligent Robots and Systems,* Sendai, Japan 2004.) or it could be for other papers in the workshop. The second paper above has the cryptic title "Electric Flex" but it is related to electrically activated plastic muscles in a robotic arm. It's not clear how this is related to haptic keyboards but this paper is referenced by 7 of the patents above as well. The third paper (referenced in 5 of the patents above) is related to a tactile display. Other referenced IEEE papers can be found in Appendix A and Appendix B.

Computer Software

Palantir

Palantir is a Data Mining and Cybersecurity firm co-founded in 2003 by billionaire Peter Thiel (PayPal co-founder). Although it is not primarily a cybersecurity firm it gained its foothold with the CIA and other agencies in cybersecurity. In 2017, it was famously fired by its largest private cybersecurity client Home Depot for being too expensive [Palantir1].

Palantir has two software products 'Gotham' and 'Foundry' whose main purpose is data fusion or integration (taking structured data like databases and spreadsheets as well as unstructured data like email and integrating and transforming it into a single data asset).

March 2020 it won an $80 million Navy contract, beating out the more well-known defense contractor Raytheon as well as 30 other firms. "The Navy will use Palantir's software to fuse together existing data sets that are walled off from one another, forming a broader operating system the Pentagon is calling Naval Operational Business Logistics Enterprise, or NOBLE. The terms of the deal were finalized last week," Palantir spokeswoman Lisa Gordon said [Palantir2].

One month earlier, Palantir and BAE systems won a joint bid to update the army's intelligence software suite which could be worth $823 million over eight years. This bid was also won against Raytheon [Palantir3]. This contract is interesting because Raytheon won the initial contract several years ago and Palantir sued the US Army saying that the government was paying Raytheon to reinvent software that was already available off-the-shelf from Palantir. A judge agreed and the bidding for updating the original system was opened to Palantir [Palantir4].

In 2022 Palantir won a $5 million contract with the CDC. "A successful federal response to COVID requires real time situational awareness to manage rapidly changing epidemiology," said Dr. Bill Kassler, Palantir's chief medical officer - USG. "Palantir's technology provides public health officials, from the federal to the local levels, with the tools they need to make informed, up-to-date decisions about sending medications and other resources where they are needed most." [Palantir5]

Last month (August 8, 2024) Palantir's stock jumped on news it is partnering with Microsoft to bring AI to US government agencies. Key takeaways from that partnership:

- Palantir Technologies and Microsoft announced a partnership to provide the U.S. government with artificial intelligence (AI) and cloud capabilities.
- The companies said the U.S. defense and intelligence community will have access to Microsoft's cloud and AI offerings, including OpenAI's models, as well as Palantir's AI Platform.
- Shares of Palantir surged 10% in intraday trading Thursday following the news, while Microsoft shares were also higher.
  [Palantir6]

The key Palantir patents related to Artificial Intelligence, Computer Software, and Cybersecurity can be found in Table 10. The patents are highly cited for their age and reference IEEE heavily. The 20 patents in Table 10 have 106 references to IEEE articles (about 5.3 IEEE references per patent on average).

Table 10: Key patents of Palantir

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8855999	3	20140205	2014	139	16.11	Method and system for generating a parser and parsing complex data	Elliot; Mark
8930897	4	20131002	2015	240	31.63	Data integration tool	Nassar; Anthony Albert
9009827	3	20140516	2015	333	47.15	Security sharing system	Albertson; Jacob, Hildebrandt; Melody, Singh; Harkirat
9021260	6	20140829	2015	248	32.68	Malware data item analysis	Falk; Matthew, Yousaf; Timothy, Staehle; Joseph
9043696	5	20140227	2015	181	23.85	Systems and methods for visual definition of data associations	Meiklejohn; David, Fedderly; Matthew, Henke; Joseph
9100430	7	20141229	2015	40	5.66	Systems for network risk assessment including processing of user access rights associated with a network of devices	Seiver; Miles, Rosenblum; Charles

9116975	3	20141001	2015	207	27.28	Systems and user interfaces for dynamic and interactive simultaneous querying of multiple data stores	Shankar; Ankit, Ash; Andrew, Stowe; Geoff
9367872	6	20141222	2016	105	11.53	Systems and user interfaces for dynamic and interactive investigation of bad actor behavior based on automatic clustering of related data in various data structures	Visbal; Alexander, Thompson; James, Sum; Marvin
9558352	9	20150428	2017	24	4.95	Malicious software detection in a computing system	Dennison; Drew, Stowe; Geoff, Anderson; Adam
9589299	6	20160511	2017	11	1.60	Systems and user interfaces for dynamic and interactive investigation of bad actor behavior based on automatic clustering of related data in various data structures	Visbal; Alexander, Thompson; James, Sum; Marvin
9646396	3	20150114	2017	12	2.77	Generating object time series and data objects	Sharma; Tilak, Chuang; Steve, Chiu; Rico
9648036	8	20160713	2017	302	56.45	Systems for network risk assessment including processing of user access rights associated with a network of devices	Seiver; Miles, Cohen; Stephen
9857958	3	20150424	2018	10	2.78	Systems and user interfaces for dynamic and interactive access of, investigation of, and analysis of data objects stored in one or more databases	Ma; Jason, Davidson; Aaron
9880987	9	20150519	2018	6	1.67	System and method for parameterizing documents for automatic workflow generation	Burr; Brandon, Pundle; Akshay, Simler; Kevin
9891808	5	20160316	2018	10	2.78	Interactive user interfaces for location-based data analysis	Wilson; Matthew Julius, Alexander; Tom, Cervelli; Daniel
9898335	9	20160502	2018	6	1.67	System and method for batch evaluation programs	Marinelli, III; Eugene E., Namara; Yogy
9898509	3	20161027	2018	14	3.89	Malicious activity detection system capable of efficiently processing data accessed from databases and generating alerts for display in interactive user interfaces	Saperstein; Craig, Schwartz; Eric, Cho; Hongjai
9953445	5	20140703	2018	10	2.80	Interactive data object map	Cervelli; Dan, GoGwilt; Cai, Prochnow; Bobby
9965937	3	20140829	2018	9	1.76	External malware data item clustering and analysis	Cohen; David, Ma; Jason, Fu; Bing Jie
9998485	6	20140915	2018	11	2.63	Network intrusion data item clustering and analysis	Cohen; David, Ma; Jason, Fu; Bing Jie

The key IEEE papers referenced by the patents above can be found in Appendix A and B. Most are related to data integration or malware detection. One paper (Li et al., "Interactive Multimodal Visual Search on Mobile Device," *IEEE Transactions on Multimedia*, vol. 15, No. 3, Apr. 1, 2013, pp. 594-607.) is a data integration paper that is referenced in 11 of the patents above as we see in page B-11.

Cybersecurity

FireEye/Trellix

FireEye was founded in 2004 by Ashar Aziz, a former Sun Microsystems engineer [FireEye1]. Initially, FireEye focused on developing virtual machines to download and test internet traffic before shifting to a cybersecurity firm. Table 11 contains all the FireEye patents for which Aziz is an inventor. We see that

while some are related to virtual machines, most are related to cybersecurity and malware detection, and all of them reference IEEE science heavily.

In December 2012, founder Aziz stepped down as CEO and former McAfee CEO David DeWalt was appointed to the position, however as we see in Table 11, Aziz's patent output continued for the company through 2023. We also note that all of the patents reference IEEE published science extensively.

Table 12 contains FireEye patents not invented by Aziz but are related to cybersecurity and reference IEEE heavily.

In June 2021, FireEye sold its name and products business to Symphony Technology Group (STG) for $1.2bn. STG also bought McAffee Enterprise and combined the two firm to launch Trellix a private cybersecurity firm [FireEye1].

We see in Tables 11 and 12 that the FireEye patents heavily reference science in IEEE journals and conferences. Many of the key patents for FireEye have more than 10 references to IEEE published papers.

Table 11: Key FireEye Patents invented by Founder Ashar Aziz

#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
14	20200214	2023	1	6.135824	System and method for detecting malicious traffic using a virtual machine configured with a select software environment	Aziz; Ashar
10	20170329	2021	27	19.81643	Verification and enhancement using detection systems located at the network periphery and endpoint devices	Aziz; Ashar, Ismael; Osman Abdoul
15	20180716	2020	13	6.419076	Malicious network content detection	Aziz; Ashar, Uyeno; Henry, Manni; Jay
15	20180416	2020	14	7.394283	Threat-aware architecture	Ismael; Osman Abdoul, Aziz; Ashar
11	20180305	2020	20	9.875502	System and method for virtual analysis of network data	Aziz; Ashar, Radhakrishnan; Ramesh, Ismael; Osman
14	20170417	2020	18	8.887952	System and method for bot detection	Aziz; Ashar, Lai; Wei-Lung, Manni; Jayaraman
14	20160801	2020	16	7.900402	System for detecting a presence of malware from behavioral analysis	Aziz; Ashar
14	20161019	2019	20	7.059047	System, apparatus and method for automatically verifying exploits within suspect objects and highlighting the display information associated with the verified exploits	Aziz; Ashar, Amin; Muhammad, Ismael; Osman Abdoul
11	20160829	2019	142	50.11923	Distributed systems and methods for automatically detecting unknown bots and botnets	Mushtaq; Atif, Rosenberry; Todd, Aziz; Ashar
11	20141031	2019	32	11.29447	System and method for threat detection and identification	Aziz; Ashar, Lai; Wei-Lung, Manni; Jayaraman
11	20171016	2019	16	6.118812	Framework for efficient security coverage of mobile software applications	Ismael; Osman Abdoul, Song; Dawn, Aziz; Ashar
15	20160331	2019	68	24.00076	Centralized aggregation technique for detecting lateral movement of stealthy cyber-attacks	Aziz; Ashar
14	20170828	2019	21	8.030941	System and method for generating a malware identifier	Pidathala; Vinay K., Bu; Zheng, Aziz; Ashar

14	20170306	2019	22	7.764951	Subscription based malware detection under management system control	Aziz; Ashar
10	20170626	2019	24	8.470856	Malware detection verification and enhancement by coordinating endpoint and malware detection systems	Aziz; Ashar, Ismael; Osman Abdoul
11	20151123	2018	145	40.3257	System and method for malware containment	Aziz; Ashar, Lai; Wei-Lung, Manni; Jayaraman
11	20140630	2018	146	34.85149	System and method for virtual analysis of network data	Aziz; Ashar, Radhakrishnan; Ramesh, Ismael; Osman
12	20150622	2018	142	33.89666	Electronic message analysis for malware detection	Aziz; Ashar, Uyeno; Henry, Manni; Jay
12	20160902	2018	139	33.18053	Systems and methods for analyzing PDF documents	Staniford; Stuart Gresley, Aziz; Ashar
11	20141124	2018	139	33.18053	Systems and methods for malware attack prevention by intercepting flows of information	Aziz; Ashar, Lai; Wei-Lung, Manni; Jayaraman
11	20171204	2018	141	33.65795	Systems and methods for malware defense	Aziz; Ashar
11	20160527	2017	152	28.41433	System and method for detecting anomalous behaviors using a virtual machine environment	Aziz; Ashar
11	20131011	2017	204	38.13502	System and method for bot detection	Aziz; Ashar, Lai; Wei-Lung, Manni; Jayaraman
11	20140327	2017	167	34.42767	System and method for run-time object classification	Pidathala; Vinay K., Bu; Zheng, Aziz; Ashar
11	20140327	2017	146	27.29271	System and method for IPS and VM-based detection of suspicious objects	Aziz; Ashar, Amin; Muhammad, Ismael; Osman Abdoul
11	20151102	2017	147	30.3046	Framework for efficient security coverage of mobile software applications	Ismael; Osman Abdoul, Song; Dawn, Aziz; Ashar
11	20161205	2017	144	26.91884	Subscriber based protection system	Aziz; Ashar
11	20130930	2017	148	27.66658	System and method of detecting malicious content	Aziz; Ashar
11	20140225	2017	157	29.34901	System and method for signature generation	Aziz; Ashar
11	20160404	2016	155	24.83334	Systems and methods for computer worm defense	Aziz; Ashar
12	20150330	2016	154	24.67312	Systems and methods for analyzing malicious PDF network content	Staniford; Stuart Gresley, Aziz; Ashar
11	20130314	2016	289	48.78408	Distributed systems and methods for automatically detecting unknown bots and botnets	Mushtaq; Atif, Rosenberry; Todd, Aziz; Ashar
11	20150211	2016	206	33.00431	System, apparatus and method for automatically verifying exploits within suspect objects and highlighting the display information associated with the verified exploits	Aziz; Ashar, Amin; Muhammad, Ismael; Osman Abdoul
11	20130819	2016	206	33.00431	Systems and methods for unauthorized activity defense	Aziz; Ashar
11	20140630	2016	207	33.16452	System and method for analyzing packets	Aziz; Ashar, Radhakrishnan; Ramesh, Ismael; Osman
11	20120510	2015	250	35.39575	Systems and methods for detecting malicious PDF network content	Staniford; Stuart Gresley, Aziz; Ashar
11	20140924	2015	210	29.73243	Framework for iterative analysis of mobile software applications	Ismael; Osman Abdoul, Song; Dawn, Aziz; Ashar

Table 12: Key FireEye Patents not invented by Ashar Aziz

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
9223972	11	20140331	2015	301	39.66614	Dynamically remote tuning of a malware content detection system	Vincent; Michael, Thioux; Emmanuel, Vashisht; Sai
9311479	11	20130314	2016	240	40.51273	Correlation and consolidation of analytic data for holistic view of a malware attack	Manni; Jayaraman, Eun; Philip, Berrow; Michael M.
9363280	11	20140822	2016	178	28.51828	System and method of detecting delivery of malware using cross-customer data	Rivlin; Alexandr, Mehra; Divyesh, Uyeno; Henry
9483644	11	20150331	2016	169	28.52772	Methods for detecting file altering malware in VM based analysis	Paithane; Sushant, Vashisht; Sai, Yang; Raymond
9495180	11	20130510	2016	156	26.33328	Optimized resource allocation for virtual machines within a malware content detection system	Ismael; Osman Abdoul
9594904	11	20150423	2017	171	35.25228	Detecting malware based on reflection	Jain; Varun, Singh; Abhishek
9609007	11	20160606	2017	183	34.20936	System and method of detecting delivery of malware based on indicators of compromise from different sources	Rivlin; Alexandr, Mehra; Divyesh, Uyeno; Henry
9661009	11	20160718	2017	171	31.96612	Network-based malware detection	Karandikar; Shrikrishna, Amin; Muhammad, Deshpande; Shivani
9690936	11	20140701	2017	160	32.98459	Multistage system and method for analyzing obfuscated content for malware	Malik; Amit, Deshpande; Shivani, Singh; Abhishek
9736179	11	20130930	2017	157	29.34901	System, apparatus and method for using malware analysis results to drive adaptive instrumentation of virtual machines to improve exploit detection	Ismael; Osman Abdoul
9773112	11	20140929	2017	181	37.31382	Exploit detection of malware and malware families	Rathor; Hirendra, Dalal; Kaushal
9838417	11	20141230	2017	153	28.60126	Intelligent context aware user interaction for malware detection	Khalid; Yasir, Paithane; Sushant, Vashisht; Sai
9910988	11	20151023	2018	143	39.76949	Malware analysis in accordance with an analysis plan	Vincent; Michael, Mesdaq; Ali, Thioux; Emmanuel
10027689	11	20140929	2018	196	46.78693	Interactive infection visualization for improved exploit detection and signature generation for malware and malware families	Rathor; Hirendra, Dalal; Kaushal, Gupta; Anil
10083302	11	20161229	2018	139	38.65705	System and method for detecting time-bomb malware	Paithane; Sushant, Vincent; Michael, Vashisht; Sai
10122746	11	20170501	2018	141	33.65795	Correlation and consolidation of analytic data for holistic view of malware attack	Manni; Jayaraman, Eun; Philip, Berrow; Michael M.
10133866	11	20151230	2018	156	43.3849	System and method for triggering analysis of an object for malware in response to modification of that object	Kumar; Vineet, Otvagin; Alexander, Borodulin; Nikita
10515214	14	20151023	2019	28	10.70792	System and method for classifying malware within content created during analysis of a specimen	Vincent; Michael, Mesdaq; Ali, Thioux; Emmanuel
10523609	14	20161227	2019	39	13.76514	Multi-vector malware detection and analysis	Subramanian; Sakthi

10552610	10	20170619	2020	24	12.67591	Adaptive virtual machine snapshot update framework for malware behavioral analysis	Vashisht; Sai Omkar, Ha; Phung-Te, Paithane; Sushant
10554507	10	20170929	2020	30	14.81325	Multi-level control for enhanced resource and object evaluation management of malware detection system	Siddiqui; Mumtaz, Radhakrishnan; Manju, Otvagin; Alexander
10581874	14	20151231	2020	25	12.34438	Malware detection system with contextual analysis	Khalid; Yasir, Vashisht; Sai Omkar, Otvagin; Alexander
10581879	10	20170619	2020	23	11.35683	Enhanced malware detection for generated objects	Paithane; Sushant, Vashisht; Sai Omkar
10601848	14	20170629	2020	22	10.86305	Cyber-security system and method for weak indicator detection and correlation to generate strong indicators	Jeyaraman; Sundararaman, Ramaswamy; Ramaswamy
10616266	10	20160930	2020	21	10.36928	Distributed malware detection system and submission workflow thereof	Otvagin; Alexander
10657251	15	20170626	2020	19	10.0351	Multistage system and method for analyzing obfuscated content for malware	Malik; Amit, Deshpande; Shivani, Singh; Abhishek
10671726	15	20140922	2020	30	15.84489	System and method for malware analysis using thread-level event monitoring	Paithane; Sushant, Vincent; Michael, Vashisht; Sai
10785255	10	20160930	2020	23	11.35683	Cluster configuration within a scalable malware detection system	Otvagin; Alexander, Subramanian; Sakthi, Krilovs; Krists
10791138	10	20180329	2020	21	10.36928	Subscription-based malware detection	Siddiqui; Mumtaz, Radhakrishnan; Manju
10817606	10	20160629	2020	22	11.61959	Detecting delayed activation malware using a run-time monitoring agent and time-dilation logic	Vincent; Michael

Defense Related

BAE Systems/US Department of Defense

Less than 4% of US patents are co-assigned (that is co-owned by two or more entities). Generally, companies are secretive about their technology and only occasionally will inventors from multiple organizations cooperate on an invention. When we see co-assigned patents, they are generally between companies in a joint venture, or a company and a university professor or lab. Given this background, we were intrigued when we found three patents (numbers 8,437,700, 8,442,445, and 8,515,473) that are co-assigned to BAE Systems and the US Army. The first two share the same title "Protocol reference model, security and inter-operability in a cognitive communications system" and were granted days apart (See Table 13).

After some research we found that BAE Systems has contracts for cognitive communication systems with the Department of Defense (DOD), US Navy, US Army, and DARPA (Defense Advanced Research Projects Agency).

A cognitive communication system is a kind of smart radio that automatically detects the best wireless channels in its vicinity to avoid user interference and congestion. Such a radio automatically detects available channels in wireless spectrum, then changes its transmission or reception parameters accordingly to allow more concurrent wireless communications in a given spectrum band at one location [BAE3].

According to MarketWatch.com, the Global Cognitive Radio market in 2019 was $3.7 billion and is expected to reach $7 billion by 2026. The market leaders are BAE Systems followed by Raytheon and Thales [BAE4].

As of 2024, Cognitive Radios have evolved into Cognitive Electronic Warfare Systems. According to 360iResearch, the Cognitive Electronic Warfare System market is projected to Reach $47.58 billion by 2030. BAE Systems is at the Forefront of Cognitive Electronic Warfare System Market with a Strong 11.85% Market Share [BAE5]

We were able to locate additional relevant patents by the same inventors related to cognitive communications (See Table 13). With BAE being a market leader in the space they probably have several more patents, but these seem to be the closest in terms of title language. The three patents mentioned above are very highly cited with citation indexes between 14 and 20 (meaning they are cited at least 14 times as often as peer patents of the same age and technology class). The eight patents in Table 13 reference 58 IEEE articles and standards with the two of the top patents citing 18 IEEE articles.

Many of the references are to Draft Standard IEEE 802.22 well as articles about the standard. A sample of the IEEE references from the patents below follows:

- Lim et al., IEEE 802.22-07/0257r10 MAC-SM-SSF Interface, Jul. 7, 2007, pp. 1-22.
- Cavalcanti et al., IEEE 802.22-07/xxxxr0 Updated Figures for draft 0.3, May 2007, pp. 1-4.
- Kim et al., IEEE 802.22-07/0523r0 WRAN Protocol Reference Model (PRM), Nov. 7, 2007, pp. 1-9.
- Ko et al., IEEE 802.22-07/0523r1 WRAN Protocol Reference Model (PRM), Nov. 7, 2007, pp. 1-8.
- Stevenson et al., IEEE 802.22-05/0007r47 Functional Requirements for the 802.22 WRAN Standard, Jan. 2006, pp. 1-49.
- IEEE P802.22/D04.3 Draft Standard for Wireless Regional Area Networks Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands, Nov. 2007, pp. 1-350.
- IEEE P802.22/WD05.0 Draft Standard for Wireless Regional Area Networks Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Policies and procedures for operation in the TV Bands, May 11, 2006, pp. 1-372.
- Cordeiro et al., "IEEE 802.22: An Introduction to the First Wireless Standard based on Cognitive Radios", Journal of Communications, vol. 1, No. 1, Apr. 2006, 10 pages.
- Mody et al., "IEEE P802.22 Wireless RANs Protocol Reference Model Enhancements in 802.22", May 15, 2005, 4 pages.
- Mody et al., "IEEE 802.22 Wireless RANs Meeting Minutes of the Security Ad-Hoc Group in 802.22", Jun. 9, 2008, 3 pages., Vo. 47, No. 3, Mar. 2012.

Table 13: BAE patents related to cognitive communication

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8154666	5	20081223	20120410	8	1.10	Spectrum sensing function for cognitive radio applications	Mody; Apurva N

8437700	18	20080811	20130507	112	14.02	Protocol reference model, security and inter-operability in a cognitive communications system	Mody; Apurva N., Sherman; Matthew J., McNeil; Kevin
8442445	18	20080811	20130514	111	13.89	Protocol reference model, security and inter-operability in a cognitive communications system	Mody; Apurva N., Sherman; Matthew J., Reddy; Ranga
8515473	4	20080306	20130820	123	20.80	Cognitive radio methodology, physical layer policies and machine learning	Mody; Apurva N., Blatt; Stephen R., Mills; Diane G.
8898468	3	20101203	20141125	8	1.35	Method for ensuring security and privacy in a wireless cognitive network	Reddy; Ranga, Kiernan; Thomas, Mody; Apurva N.
9420454	5	20141030	20160816	2	0.54	Method for ensuring security and privacy in a wireless cognitive network	Reddy; Ranga, Kiernan; Thomas, Mody; Apurva N.
9445263	5	20141030	20160913	1	0.27	Method for ensuring security and privacy in a wireless cognitive network	Reddy; Ranga, Kiernan; Thomas, Mody; Apurva N.

BAE Systems/UK Army

In 2017 BAE Systems, Airbus, and General Dynamics (GD) partnered to develop the Strike Tactical Hotspot concept demonstrator, a new network technology for the British Army. Tactical Hotspot is a compact mobile digital communications set that can be deployed securely in an armored vehicle to enable front-line troops to communicate securely with their command headquarters. When fitted to an adapted, Panther armored combat vehicle with self-erecting radio masts, the hotspot can provide secure connectivity over several miles. Under a contract worth $1.62 million, BAE will supply two experimental Strike Tactical Hotspots to the British Army [BAE1].

In this report, $1.62 million may not sound like very much money, but that is only to build the two hotspots for demonstration purposes. BAE is hoping to sell many more not only to the UK army but to many NATO countries. While this technology will serve immediate needs, BAE is looking ahead to 2030 and beyond to understand how soldiers will operate and communicate. "In the future we'll see a huge increase in numbers of unmanned vehicles, and that will place a training and communication burden upon the military," says Amy Ennion, a systems engineer within BAE Systems [BAE2].

There are likely multiple patents related to the technology but the most similar BAE patent is also among its most highly cited. Patent number 9,119,179 "Skypoint for mobile hotspots" has 124 citations in less than five years (see Table 14). Peer patents of the same age and technology have fewer than three citations on average so this patent has a citation index of 49.72. That is, this patent is cited almost 50 times more than expected. The patent leans heavily on IEEE science. Ten of its 13 Non-Patent references are to papers in IEEE journals and conferences.

Although this is technology to be deployed in 2030 it actually relies on science from the early 2000's. The paper that seems to be most similar is "Anticipatory Routing for Highly Mobile Endpoints," by Fabrice Tchakountio and Ram Ramanathan from the *IEEE Workshop on Mobile Computing Systems and Applications (WMCSA 2004)*.

Table 14: BAE Patent number 9,119,179

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
9119179	10	20130606	2015	143	26.93	Skypoint for mobile hotspots	Firoiu; Victor, LaPrise; Scott B.

Since there is only one patent related to this story, the IEEE papers will not appear in Appendix B. However, we see from Appendix A page A-6 that the IEEE references come from military conferences such as *MILCOM the IEEE Military Communications Conference* and periodicals such as *IEEE Journal on Selected Areas in Communications, IEEE Transactions on Communications, IEEE Communications Magazine.*

Medical Related

Butterfly Network

Butterfly Network was founded by Dr. Jonathan Rothberg, a serial entrepreneur in the medical technology industry who is known for his contributions to gene sequencing. He started Butterfly Network in 2011 after his daughter developed a rare disease called tuberos sclerosis that required constant imaging and he was struck at how inaccessible and expensive traditional ultrasounds were. Butterfly's technology, which it calls an "ultrasound-on-chip" is designed to perform diagnostic imaging and measurement of blood vessels and examine the cardiac, abdominal, urological, fetal, gynecological, and musculoskeletal systems [Butterfly1].

Instead of piezoelectric crystals, Butterfly iQ's device uses semiconductor chips allowing for a lower sales price and more versatility than traditional alternatives. It consists of an ultrasound scanner using its semiconductor chip and connects to a smartphone to view the image. The goal was to create a device that retails for around $2,000, with an additional monthly subscription fee for the associated software that ranges from $35 to $100. Traditional ultrasound machines cost between $15,000 and $100,000. The global market for Ultrasound equipment is estimated to be about $6 billion [Butterfly1].

"Just as putting a camera on a semiconductor chip made photography accessible to anyone with a smartphone and putting a computer on a chip enabled the revolution in personal computing before that, Butterfly's ultrasound-on-a-chip technology enables a low-cost window into the human body, making high-quality diagnostic imaging accessible to anyone," Rothberg said in a statement [Butterfly1].

In developing countries, ultrasound can be used as a diagnostically superior and safer method than X-ray to diagnose critical global health issues like pediatric pneumonia. Butterfly has teamed with the Gates Foundation to distribute their portable device to developing countries or other areas without access to existing ultrasound technology. [Butterfly1]

In 2018 Butterfly raised a $250 million Series D financing round that increased its total funding to more than $350 million and placed a valuation on the firm at $1.25 billion [Butterfly1].

In 2020 Butterfly made the news as a tool for fighting the Covid-19 virus in areas with limited imaging capability. The portable ultrasound can be used to potentially diagnose the virus by looking for anomalies in the lower region of a patient's lung [Butterfly2].

In March 2022, Butterfly received a $5 Million grant from the Bill and Melinda Gates foundation to support product development for an AI-Enabled portable obstetric ultrasound device for low and middle income countries. [Butterfly3]

As of August 2024, Butterfly's portable ultrasound devices are available for as little as $2,699 [Butterfly4]. (This compares very favorably with a traditional ultrasound device that costs upwards of $15,000 and sometimes as much as $100,000.)

Butterfly currently has 68 US patents but many of them were filed and granted subsequent to their big funding rounds. The 23 patents shown in Table 15 are most likely related to the key innovation. These patents were issued before the end of 2018 and have many citations from later patents. Virtually all of them list Dr. Rothberg as the first inventor. The patents in Table 15 are not only highly cited but they heavily reference IEEE science as prior art. On average each patent references IEEE about 20 times (468 total for 23 patents).

Table 15: Key patents of Butterfly Networks

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8852103	30	20121017	2014	95	1.90	Transmissive imaging and related apparatus and methods	Rothberg; Jonathan M., Sanchez; Nevada J., Charvat; Gregory L.
9061318	12	20141205	2015	42	5.32	Complementary metal oxide semiconductor (CMOS) ultrasonic transducers and methods for forming the same	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9067779	20	20150302	2015	100	19.27	Microfabricated ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Alie; Susan A., Fife; Keith G.
9229097	18	20150417	2016	70	10.05	Architecture of single substrate ultrasonic imaging devices, related apparatuses, and methods	Rothberg; Jonathan M., Ralston; Tyler S., Sanchez; Nevada J.
9242275	17	20140313	2016	65	9.34	Complementary metal oxide semiconductor (CMOS) ultrasonic transducers and methods for forming the same	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9268015	29	20140227	2016	21	3.01	Image-guided high intensity focused ultrasound and related apparatus and methods	Rothberg; Jonathan M., Sanchez; Nevada J., Charvat; Gregory L.
9290375	17	20150513	2016	37	10.34	Complementary metal oxide semiconductor (CMOS) ultrasonic transducers and methods for forming the same	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9327142	27	20141205	2016	34	2.67	Monolithic ultrasonic imaging devices, systems and methods	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9351706	28	20141205	2016	36	0.82	Interconnectable ultrasound transducer probes and related methods and apparatus	Rothberg; Jonathan M., Fife; Keith G., Sanchez; Nevada J.
9394162	27	20150519	2016	41	14.95	Microfabricated ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Alie; Susan A., Fife; Keith G.

9492144	8	20151202	2016	29	0.66	Multi-level pulser and related apparatus and methods	Chen; Kailiang, Ralston; Tyler S.
9499392	17	20140204	2016	45	12.58	CMOS ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9499395	17	20160212	2016	28	7.83	Complementary metal oxide semiconductor (CMOS) ultrasonic transducers and methods for forming the same	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9505030	17	20150417	2016	46	6.61	Ultrasonic transducers in complementary metal oxide semiconductor (CMOS) wafers and related apparatus and methods	Rothberg; Jonathan M., Fife; Keith G., Sanchez; Nevada J.
9533873	17	20140204	2017	45	18.09	CMOS ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9705518	9	20151202	2017	28	8.32	Asynchronous successive approximation analog-to-digital converter and related methods and apparatus	Chen; Kailiang, Ralston; Tyler S.
9718098	17	20160519	2017	18	2.94	CMOS ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9738514	27	20161012	2017	18	11.18	Complementary metal oxide semiconductor (CMOS) ultrasonic transducers and methods for forming the same	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9895718	17	20161111	2018	19	3.96	CMOS ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.
9899371	17	20160908	2018	19	6.10	Ultrasonic transducers in complementary metal oxide semiconductor (CMOS) wafers and related apparatus and methods	Rothberg; Jonathan M., Fife; Keith G., Sanchez; Nevada J.
9910017	27	20160609	2018	23	13.66	Microfabricated ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Alie; Susan A., Fife; Keith G.
9910018	26	20160609	2018	22	13.06	Microfabricated ultrasonic transducers and related apparatus and methods	Rothberg; Jonathan M., Alie; Susan A., Fife; Keith G.
9944514	27	20170619	2018	19	14.36	Complementary metal oxide semiconductor (CMOS) ultrasonic transducers and methods for forming the same	Rothberg; Jonathan M., Fife; Keith G., Ralston; Tyler S.

Several of the IEEE patents are referenced in multiple patents. For example the paper (Nikoozadeh et al., "Forward-Looking Intracardiac Ultrasound Imaging Using a 1-D CMUT Array Integrated With Custom Front-End Electronics," *IEEE Trans Ultrason Ferroelectr Freq Contr*. Dec. 2008;55(12):2651-60.) is cited in 21 of the 23 patents above.

There are several other IEEE papers referenced in multiple patents above that can be found in Appendix B. Most of the papers are from the *IEEE Ultrasonics Symposium* or the *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control.*

Conformis

Conformis claims to sell the only "truly patient-specific total knee replacement" (individually sized and shaped, or customized, to fit each patient's unique anatomy). "Conformis knee replacements are designed to match every aspect of your natural knee. The goal of any knee replacement is to be pain-free, restore natural motion, and for patients to return to their everyday activities" according to their website [Conformis1].

Although Conformis has hundreds of patents, the 45 patents in Table 16 are the patents related to the Conformis patient-specific knee products (iUni, iDUO, and iTotal Knee Replacement Systems) [Conformis2].

As shown in Table 16, the 45 patents typically mention "patient-selectable" or "patient-adapted" to describe the customized fitting knee replacements. These patents are very highly cited with many cited 6 to 10 times as often as peer patents in the same age and technology classes. The 45 patents also contain 219 references to IEEE journals and conferences (average of 4.86 IEEE references) which is rather high given that medical devices are not really thought of as a core area for IEEE.

A list of the IEEE papers referenced in the 45 patents can be found in Appendix A and Appendix B. Many of the papers are referenced in multiple patents. Multiple papers are published in IEEE Transactions on Medical Imaging as well as the IEEE Nuclear Science Symposium and Medical Imaging Conference and International Conference of the IEEE Engineering in Medicine and Biology Society.

In 2013 Conformis received $167 million in funding to develop the custom knee replacements [Conformis3]. In October 2019 they signed a $30 million licensing deal with Stryker. $14 million is to license Conformis' patient-specific instrumentation for use with Stryker's Triathlon total knee replacement system and $16 million to develop a new patient-specific knee replacement system to be sold under the Stryker name [Conformis4].

"Conformis is excited to partner with Stryker – a leader in orthopedic surgical innovation – to further expand CT-based solutions to the market. Such solutions are the future of healthcare, enabling surgeons to provide personalized care based on a patient's unique anatomy," said Conformis CEO Mark Augusti [Conformis4].

In 2022 a study was published in the Journal of Bone & Joint Surgery Reviews. The study found that 72.3 percent of the patients studied preferred their fully personalized Conformis knee replacement, compared to 6.4 percent of patients who preferred their traditional off-the-shelf (OTS) implant. The remaining 21.3 percent reported no perceived difference between the two knee implants [Conformis5].

Table 16: Patents related to Conformis patient-specific knee products

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
7468075	10	20021127	2008	593	6.03	Methods and compositions for articular repair	Lang; Philipp, Steines; Daniel, Timsari; Bijan
7618451	2	20031125	2009	597	6.73	Patient selectable joint arthroplasty devices and surgical tools facilitating increased accuracy, speed and simplicity in performing total and partial joint arthroplasty	Berez; Aaron, Fitz; Wolfgang, Lang; Philipp

7634119	0	20031204	2009	261	12.56	Fusion of multiple imaging planes for isotropic imaging in MRI and quantitative image analysis using isotropic or near-isotropic imaging	Tsougarakis; Konstantinos, Steines; Daniel, Timsari; Bijan
7981158	2	20080609	2011	464	8.37	Patient selectable joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Bojarski; Raymond A.
8066708	2	20070206	2011	371	4.72	Patient selectable joint arthroplasty devices and surgical tools	Lang; Philipp, Fitz; Wolfgang, Bojarski; Raymond A.
8083745	2	20080314	2011	370	4.75	Surgical tools for arthroplasty	Lang; Philipp, Fitz; Wolfgang, Bojarski; Ray
8105330	2	20080609	2012	361	5.70	Patient selectable joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Bojarski; Raymond A.
8122582	2	20090128	2012	266	20.36	Surgical tools facilitating increased accuracy, speed and simplicity in performing joint arthroplasty	Burdulis, Jr.; Albert G., Fitz; Wolfgang, Vargas-Voracek; Rene
8234097	5	20100224	2012	230	21.26	Automated systems for manufacturing patient-specific orthopedic implants and instrumentation	Steines; Daniel, Zhuravlev; Alexey
8337501	4	20100510	2012	255	8.26	Patient selectable joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Bojarski; Raymond A.
8337507	10	20081222	2012	201	3.63	Methods and compositions for articular repair	Lang; Philipp, Steines; Daniel, Tsourgarakis; Konstantinos
8366771	4	20100510	2013	179	4.24	Surgical tools facilitating increased accuracy, speed and simplicity in performing joint arthroplasty	Burdulis, Jr.; Albert G., Fitz; Wolfgang, Vargas-Voracek; Rene
8377129	2	20091027	2013	174	4.12	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8439926	2	20090305	2013	233	3.65	Patient selectable joint arthroplasty devices and surgical tools	Bojarski; Raymond, Fitz; Wolfgang, Lang; Philipp
8480754	10	20100225	2013	184	5.26	Patient-adapted and improved articular implants, designs and related guide tools	Bojarski; Ray, Chao; Nam, Fitz; Wolfgang
8529630	2	20120924	2013	155	4.43	Patient selectable joint arthroplasty devices and surgical tools	Bojarski; Raymond A., Fitz; Wolfgang, Chao; Nam T.
8545569	10	20040105	2013	151	4.31	Patient selectable knee arthroplasty devices	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8551099	4	20100510	2013	166	5.79	Surgical tools for arthroplasty	Lang; Philipp, Fitz; Wolfgang, Bojarski; Raymond A.
8551102	2	20120924	2013	145	2.27	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8551103	2	20120924	2013	147	2.30	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8556906	4	20120924	2013	141	2.50	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8556907	2	20120924	2013	141	2.50	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8556983	10	20110309	2013	196	5.60	Patient-adapted and improved orthopedic implants, designs and related tools	Bojarski; Raymond A., Chao; Nam, Slamin; John
8561278	2	20120924	2013	142	20.78	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8562618	2	20120924	2013	134	2.10	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8568479	2	20120924	2013	137	3.24	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
8568480	2	20120924	2013	131	3.10	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel

8585708	4	20100511	2013	107	1.68	Patient selectable joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Bojarski; Raymond A.
8623026	2	20110810	2014	166	3.52	Patient selectable joint arthroplasty devices and surgical tools incorporating anatomical relief	Wong; Terrance, Bojarski; Raymond A., Steines; Daniel
8634617	6	20111206	2014	146	12.76	Methods for determining meniscal size and shape and for devising treatment	Tsougarakis; Konstantinos, Steines; Daniel, Vissa; Bhaskar Rao
8638998	2	20120109	2014	138	12.06	Fusion of multiple imaging planes for isotropic imaging in MRI and quantitative image analysis using isotropic or near-isotropic imaging	Steines; Daniel, Timsari; Bijan, Tsougarakis; Konstantinos
8657827	2	20111122	2014	160	2.92	Surgical tools for arthroplasty	Fitz; Wolfgang, Lang; Philipp, Bojarski; Raymond A.
8709089	12	20100503	2014	102	3.32	Minimally invasive joint implant with 3-dimensional geometry matching the articular surfaces	Lang; Philipp, Steines; Daniel, Bouadi; Hacene
8768028	12	20100511	2014	74	6.98	Methods and compositions for articular repair	Lang; Philipp, Steines; Daniel
8771365	10	20100623	2014	90	3.92	Patient-adapted and improved orthopedic implants, designs, and related tools	Bojarski; Raymond A., Lang; Philipp, Chao; Nam
8882847	5	20041124	2014	95	4.18	Patient selectable knee joint arthroplasty devices	Burdulis, Jr.; Albert G., Fitz; Wolfgang, Lang; Philipp
8906107	10	20111111	2014	60	2.61	Patient-adapted and improved orthopedic implants, designs and related tools	Bojarski; Raymond A., Chao; Nam, Slamin; John
8945230	5	20100512	2015	40	2.35	Patient selectable knee joint arthroplasty devices	Lang; Philipp, Steines; Daniel, Fitz; Wolfgang
8951260	2	20080613	2015	45	0.89	Surgical cutting guide	Lang; Philipp, Fitz; Wolfgang, Steines; Daniel
8974539	10	20111111	2015	54	3.17	Patient-adapted and improved articular implants, designs and related guide tools	Bojarski; Raymond A., Chao; Nam, Slamin; John
9055953	14	20100511	2015	59	1.16	Methods and compositions for articular repair	Lang; Philipp, Steines; Daniel
9107680	6	20121218	2015	59	1.16	Patient selectable joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Bojarski; Raymond A.
9326780	3	20140106	2016	79	1.81	Patient selectable joint arthroplasty devices and surgical tools incorporating anatomical relief	Wong; Terrance, Bojarski; Raymond A., Steines; Daniel
9358018	3	20120227	2016	42	0.96	Joint arthroplasty devices and surgical tools	Fitz; Wolfgang, Lang; Philipp, Steines; Daniel
9387079	8	20131010	2016	24	1.97	Patient-adapted and improved articular implants, designs and related guide tools	Bojarski; Raymond A., Slamin; John, Lang; Philipp

InTouch Health/Teladoc Health

InTouch Health makes medical tele-robotic systems. In June 2020 Teledoc completed its $600 million acquisition of InTouch Health [InTouch3].

InTouch, with $80 million in sales in 2019, is the much smaller firm. However, it supports more than 3,600 care locations around the world - including many of the top 20 U.S. health systems - as they deploy telehealth programs across their enterprises [InTouch1].

Teladoc was Ranked #1 among direct-to-consumer telehealth providers in the J.D. Power 2019 U.S. Telehealth Satisfaction Study. Services from Teladoc Health include telehealth, expert medical services, AI

and analytics, and licensable platform services. The organization delivers care in 130 countries and in more than 30 languages, partnering with employers, hospitals and health systems, and insurers to transform care delivery [InTouch1].

The tele-medicine industry has gotten a large boost from the Covid-19 pandemic as this excerpt from the Motley Fool points out:

> Specifically, hospitals have been busy dealing with COVID-19 patients, and to reserve resources for those suffering from the potentially deadly disease -- and to avoid unnecessary exposure to the virus on the part of the public -- many turned to telehealth services for some routine medical needs. Teladoc famously reported that its number of visits skyrocketed in March, and demand will likely remain high for a little while. These developments have boosted the profile of telehealth providers, leading many to conclude that people will seek to continue to have access to these services even after the pandemic subsides. Donna O'Shea, chief medical officer of population health management for UnitedHealthcare (one of the largest health insurance companies in the U.S.), certainly believes that. In a recent virtual conference called Telehealth's Tipping Point, O'Shea asserted that UnitedHealthcare's members will want to "continue to have access to their providers through telehealth." This bodes well for the future of telehealth, and in particular for Teladoc, which remains the biggest player in this industry [InTouch2]

As of December 31, 2023 Teledoc had $2.6 billion in revenue and nearly 5,000 employees [InTouch4].

InTouch had 96 US patents through 2019. The key patents related to tele-robotics, tele-presence, and video conferencing are shown in Table 17. Many of the patents are invented by Yulun Wang who founded the firm and retired as CEO in 2016 but assumed the positions of Chairman and Chief Innovation Officer. These patents are very highly cited. Overall the set of 33 key patents is highly cites, but patents 8,170,241 and 8,996,165 each have more than a thousand citations, making them some of the highest cited patents in the whole patent system. The 33 patents in Table 17 reference IEEE science heavily. Each of the patents has about 26 references to IEEE articles on average with one (8,209,051 Medical tele-robotic system) having 75 references to IEEE.

Table 17: Key patents of InTouch

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
6320947	0	19990914	2001	114	2.44	Telephony platform and method for providing enhanced communication services	Joyce; Simon James, Gupta; Prafulla C., Vaidya; Manohar S.
7142945	6	20040806	2006	122	1.79	Medical tele-robotic system	Wang; Yulun, Laby; Keith Phillip, Jordan; Charles S.
7142947	3	20040806	2006	109	3.26	Medical tele-robotic method	Wang; Yulun, Laby; Keith Phillip, Jordan; Charles S.
7158859	3	20030514	2007	156	3.06	5 degrees of freedom mobile robot	Wang; Yulun, Laby; Keith Phillip, Jordan; Charles S.
7158860	3	20030912	2007	122	2.39	Healthcare tele-robotic system which allows parallel remote station observation	Wang; Yulun, Jordan; Charles S., Pinter; Marco

7158861	7	20030918	2007	108	2.12	Tele-robotic system used to provide remote consultation services	Wang; Yulun, Jordan; Charles S.
7161322	2	20031118	2007	122	2.80	Robot with a manipulator arm	Wang; Yulun, Laby; Keith Phillip, Mukherjee; Ranjan
7164969	6	20040102	2007	138	2.71	Apparatus and method for patient rounding with a remote controlled robot	Wang; Yulun, Kavoussi; Louis
7164970	6	20040806	2007	110	2.16	Medical tele-robotic system	Wang; Yulun, Laby; Keith Phillip, Jordan; Charles S.
7171286	2	20030912	2007	146	4.72	Healthcare tele-robotic system with a robot that also functions as a remote station	Wang; Yulun, Jordan; Charles S., Laby; Keith Phillip
7222000	7	20050118	2007	104	3.35	Mobile videoconferencing platform with automatic shut-off features	Wang; Yulun, Jordan; Charles S., Pinter; Marco
7262573	6	20040217	2007	118	2.70	Medical tele-robotic system with a head worn device	Wang; Yulun, Jordan; Charles S., Laby; Keith Phillip
7289883	15	20070105	2007	119	2.34	Apparatus and method for patient rounding with a remote controlled robot	Wang; Yulun, Kavoussi; Louis
7593030	22	20041015	2009	104	5.73	Tele-robotic videoconferencing in a corporate environment	Wang; Yulun, Jordan; Charles S., Southard; Jonathan
7761185	16	20061003	2010	98	3.53	Remote presence display through remotely controlled robot	Wang; Yulun, Jordan; Charles S., Pinter; Marco
7769492	28	20060222	2010	115	4.21	Graphical interface for a remote presence system	Wang; Yulun, Jordan; Charles S., Pinter; Marco
7813836	28	20031209	2010	94	3.26	Protocol for a remotely controlled videoconferencing robot	Wang; Yulun, Jordan; Charles S., Pinter; Marco
8116910	28	20070823	2012	89	3.92	Telepresence robot with a printer	Walters; Derek, Pinter; Marco, Southard; Jonathan
8170241	13	20080417	2012	1318	45.12	Mobile tele-presence system with a microphone system	Roe; David Bjorn, Sanchez; Daniel Steven, Pinter; Marco
8179418	26	20080414	2012	103	6.66	Robotic based health care system	Wright; Timothy C., Lai; Fuji, Pinter; Marco
8209051	75	20060927	2012	95	3.56	Medical tele-robotic system	Wang; Yulun, Laby; Keith Phillip, Jordan; Charles S.
8340819	56	20090916	2012	89	5.22	Mobile videoconferencing robot system with network adaptive driving	Mangaser; Amante, Southard; Jonathan, Pinter; Marco
8401275	56	20090327	2013	96	8.22	Mobile robot with a head-based movement mapping scheme	Wang; Yulun, Jordan; Charles S., Laby; Keith P.
8463435	48	20090106	2013	92	4.91	Server connectivity control for tele-presence robot	Herzog; John Cody, Whitney; Blair, Wang; Yulun
8670017	56	20100304	2014	83	9.26	Remote presence system including a cart that supports a robot face and an overhead camera	Stuart; David, Sanchez; Daniel Steven, Lai; Fuji
8836751	33	20111108	2014	82	1.64	Tele-presence system with a user interface that displays different communication links	Ballantyne; James, Temby; Kelton, Rosenthal; James
8849679	96	20081125	2014	84	15.54	Remote controlled robot system that provides medical images	Wang; Yulun, Jordan; Charles S., Pinter; Marco
8849680	66	20090129	2014	88	4.90	Documentation through a remote presence robot	Wright; Timothy C., Lai; Fuji, Pinter; Marco
8861750	16	20120328	2014	73	4.06	Mobile tele-presence system with a microphone system	Roe; David Bjorn, Sanchez; Daniel Steven, Pinter; Marco
8897920	22	20090417	2014	82	4.56	Tele-presence robot system with software modularity, projector and laser pointer	Wang; Yulun, Pinter; Marco, Hanrahan; Kevin

8902278	34	20120725	2014	101	11.27	Systems and methods for visualizing and managing telepresence devices in healthcare networks	Pinter; Marco, Brallier; Greg, Ross; Scott
8996165	35	20081021	2015	1236	162.88	Telepresence robot with a camera boom	Wang; Yulun, Jordan; Charles S., Hanrahan; Kevin
9098611	37	20130314	2015	30	3.95	Enhanced video interaction for a user interface of a telepresence network	Pinter; Marco, Jordan; Charles S., Sanchez; Daniel

The articles:

- Paulos, et al., "Designing Personal Tele-Embodiment", Presented at the IEEE International Conference on Robotics and Animation, Leuven, Belgium, May 20, 1998.
- Pin et al., "A New Family of Omnidirectional and Holonomic Wheeled Platforms for Mobile Robots", IEEE, vol. 10, No. 4, Aug. 1994.

are both referenced in all 16 of the patents above. Other IEEE papers that are referenced in multiple patents above can be found on page B-4 of Appendix B.

Robotics

InTouch Health/Teladoc Health (See Medical Related)

InTouch's technology could be placed in the robotics category, but the story can be found in the Medical Related category above.

Olis/BluHaptic/University of Washington

Olis is another firm started by a professor. This firm was started by Dr. Howard Chizeck, professor of electrical and computer engineering and adjunct professor of bioengineering at the University of Washington [Olis1].

Olis is a very interesting startup. Here is an excerpt from an interview with Dr. Chizeck:

> While at the University of Washington, I was working on trying to provide a sense of touch for surgeons performing robotic surgery. With National Science Foundation (NSF) support, we developed technology using the Microsoft Kinect to generate point clouds and render haptic forces. An opportunity was presented by the Strategic Environmental Research and Development Program (SERDP) – a consortium program of the Department of Defense, Environmental Protection Agency, and Department of Energy – to remove unexploded munitions from lake bottoms. We figured that since we were already remotely manipulating a teleoperated robot for surgery, how could that be so different from underwater munitions? So I started a company, BluHaptics (later changed to Olis Robotics) and we wrote a seed grant proposal that got funded. We were then committed to try and make that work. Then, in the development of that technology for underwater munitions, it became apparent that there were a lot of other underwater applications that could use telerobotics.

Table 18: Olis Haptic and Telerobotic patents

Patent #	#IEEE References	Application Date	Grant Date	# Cites	Citation Index	Title	First 3 Inventors
9148443	18	20130703	2015	29	4.11	Enhanced security and safety in telerobotic systems	Chizeck; Howard Jay, Bonaci; Tamara, Lendvay; Thomas
9471142	57	20120615	2016	5	0.84	Methods and systems for haptic rendering and creating virtual fixtures from point clouds	Chizeck; Howard Jay, Rydén; Fredrik, Kosari; Sina Nia
9477307	61	20140124	2016	11	1.86	Methods and systems for six degree-of-freedom haptic interaction with streaming point data	Chizeck; Howard Jay, Ryden; Fredrik
9686306	9	20131030	2017	209	39.07	Using supplemental encrypted signals to mitigate man-in-the-middle attacks on teleoperated systems	Chizeck; Howard Jay, Bonaci; Tamara
9736167	18	20150917	2017	0	0.00	Enhanced security and safety in telerobotic systems	Chizeck; Howard Jay, Bonaci; Tamara, Lendvay; Thomas
9753542	58	20161011	2017	21	4.33	Methods and systems for six-degree-of-freedom haptic interaction with streaming point data	Chizeck; Howard Jay, Ryden; Fredrik, Stewart; Andrew
10226869	57	20150302	2019	7	1.38	Haptic virtual fixture tools	Chizeck; Howard Jay, Stewart; Andrew, Ryden; Fredrik
10394327	40	20150911	2019	10	3.82	Integration of auxiliary sensors with point cloud-based haptic rendering and virtual fixtures	Chizeck; Howard Jay, Huang; Kevin, Ryden; Fredrik

After spinning out of the University of Washington in 2013, Olis has had a number of accomplishments.

- In 2014 it won a grant from the National Science Foundation (NSF) and Small Business Administration (SBA) totaling $897,000 through 2016 [Olis3].
- In 2017 it raised $1.36 million in angel investment [Olis2].
- In 2017 it won a grant from NASA and SBA totaling $873,000 through 2018 [Olis3].
- In 2019 Olis won a $50,000 grant to study options for satellite-servicing robots. This may turn into a $1.5 million grant in the future [Olis4]
- In 2019 Olis announced a partnership with Forum Energy Technologies (terms not disclosed) to develop Olis Remotely Operated Vehicles (ROVs) controllers for the offshore energy market [Olis4].
- In 2019 Olis entered into an agreement with iCsys, part of the Envirex Group, for sales, distribution and support of Olis Robotics machine-learning ROV controllers (terms not disclosed) [Olis4].
- In 2019 Olis partnered with one of the biggest names in space, Maxar Technologies, to work on a new robotic mission that is part of NASA's planned mission back to the moon in 2024 [Olis4].
- In August 2023 Olis raised an additional $4 million from several angel investors and venture capital firms to explore new markets for tools that make it possible to monitor and control industrial robots remotely and securely [Olis5].

Table 18 shows the eight patents Olis has related to Haptics and Telerobotics. Most of the patents are highly cited, and patent 9,686,306 "Using supplemental encrypted signals to mitigate man-in-the-middle attacks on teleoperated systems" has 209 citations, meaning it is cited 39 times more than a peer patent of the same year and technology class. All the patents are co-authored by Dr. Chizeck and all rely on IEEE

science for prior art. The eight patents have a total of 318 references to IEEE conference and journal articles (an average of 39 each).

The key papers (see Appendix A and Appendix B) are mostly robotics related and appear in journals and conferences such as *IEEE/ASME Transactions on Mechatronics*, *IEEE/RSJ Int'l Conf. on Intelligent Robots and Systems*, *IEEE International Conference on Robotics and Automation*, and *IEEE Virtual Reality Annual International Symposium.*

Semiconductors

Butterfly Network (See Medical Related)

Butterfly's technology, which it calls an "ultrasound-on-chip" could be categorized with the semiconductor cases, but we placed it in the Medical Related category above.

Kandou

Kandou Technologies is a Swiss startup co-founded in 2011 by former postdoc Harm Cronie and his Professor Amin Shokrollahi while at Ecole Polytechnique Federale de Lausanne (EPFL). Kandou was spun-off after raising $10 million in venture funding.

Kandou designs high speed, energy and pin efficient serial links connecting integrated circuit components such as processor and memory, or processor and processor. Serial links account for a major part of the energy consumption of electronic devices and represent an energy and speed bottleneck. Any improvement in their design directly leads to faster and more energy efficient electronic devices. Kandou's technology uses a new mode of transmission on serial links to transmit more bits on existing connections, using less energy. The technology is based on a number of patents which represent several man-years of research in discrete mathematics, circuit design, and high-speed algorithm design [Kandou1].

In their latest round of Funding (August 2023), Kandou secured $72.3 million, reflecting the robust confidence our investors have in our technology and strategic direction. This brings the total investment in Kandou to an impressive $280 million [Kandou2].

In January 2024 Kandou was recognized on the The Tech Tour Growth50 Europe 2024 list. The Tech Tour Growth50 is a highly competitive program that identifies and supports Europe's fastest-growing technology companies [Kandou3].

Table 19 shows the early key patents filed in 2013 and earlier while both co-founders were still with the firm (Cronie Harm has since left). The table contains patents assigned to EPFL as well as those assigned to Kandou. These are the patents for the original technology from which Kandou raised its early funding. It now has more than 100 patents but many of those are to build a firewall around the original technology. The patents in Table 19 are very highly cited and most have many references to IEEE prior art (121 total, an average of ten each).

Table 19: Key patents of Kandou

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8539318	3	20101230	2013	128	25.66	Power and pin efficient chip-to-chip communications with common-mode rejection and SSO resilience	Cronie; Harm, Shokrollahi; Amin

8593305	6	20120705	2013	138	21.07	Efficient processing and detection of balanced codes	Tajalli; Armin, Cronie; Harm, Shokrollahi; Amin
8649445	5	20110217	2014	138	23.69	Methods and systems for noise resilient, pin-efficient and low power communications with sparse signaling codes	Cronie; Harm, Shokrollahi; Amin, Tajalli; Armin
8718184	6	20120503	2014	135	28.67	Finite state encoders and decoders for vector signaling codes	Cronie; Harm, Shokrollahi; Amin
8989317	6	20121107	2015	134	16.98	Crossbar switch decoder for vector signaling codes	Holden; Brian, Shokrollahi; Amin
9015566	10	20130916	2015	100	14.16	Power and pin efficient chip-to-chip communications with common-mode rejection and SSO resilience	Cronie; Harm, Shokrollahi; Amin
9083576	7	20130315	2015	99	15.86	Methods and systems for error detection and correction using vector signal prediction	Hormati; Ali
9288082	15	20130515	2016	102	16.34	Circuits for efficient detection of vector signaling codes for chip-to-chip communication using sums of differences	Ulrich; Roger, Hunt; Peter
9288089	15	20100520	2016	114	18.26	Orthogonal differential vector signaling	Cronie; Harm, Shokrollahi; Amin
9300503	15	20130315	2016	89	14.26	Methods and systems for skew tolerance in and advanced detectors for vector signaling codes for chip-to-chip communication	Holden; Brian, Shokrollahi; Amin, Singh; Anant
9401828	16	20110705	2016	80	14.95	Methods and systems for low-power and pin-efficient communications with superposition signaling codes	Cronie; Harm, Shokrollahi; Amin
9667379	17	20110606	2017	68	9.63	Error control coding for orthogonal differential vector signaling	Cronie; Harm, Shokrollahi; Amin

The paper (Wang et al., "Applying CDMA Technique to Network-on-Chip," IEEE Transactions on Very Large Scale Integration (VLSI) Systems, vol. 15, No. 10 (Oct. 1, 2007), pp. 1091-1100.) is referenced in 5 of the patents above. Other frequently referenced papers appear in semiconductor or communications journals and conferences such as *IEEE Transactions Audio and Electroacoustics, IEEE Transactions of Information Theory, IEEE International Conference on Communications, IEEE Journal of Solid-State Circuits* and others.

Cap Wireless/Triquint/Qorvo

In 2013, Triquint Semiconductor purchased Cap Wireless for $14.8 million. Cap owned the Spatium™ broadband amplifiers product line and the five patents in Table 20 related to the amplifiers [Cap1].

Table 20: Cap Wireless patents related to Spatium amplifiers

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
7215220	30	20040823	2007	271	17.50	Broadband power combining device using antipodal finline structure	Jia; Pengcheng
7911271	0	20081210	2011	15	1.92	Hybrid broadband power amplifier with capacitor matching network	Jia; Pengcheng
9276304	29	20121126	2016	239	32.62	Power combiner using tri-plane antennas	Behan; Scott, Courtney; Patrick
9287605	29	20121218	2016	241	32.90	Passive coaxial power splitter/combiner	Daughenbaugh, Jr.; Paul, Behan; Scott, Courtney; Patrick
9293801	29	20121126	2016	224	30.58	Power combiner	Courtney; Patrick, Behan; Scott

According to Triquint's press release announcing the acquisition: "Spatium technology dramatically improves broadband RF power efficiency through the use of patented coaxial spatial combining techniques. Spatium provides other performance advantages including solid-state reliability, smaller form factors, higher power densities and reduced weight compared to either TWTA-based systems or conventional planar power combining products. Spatium can provide faster time-to-market and can seamlessly incorporate GaN MMIC performance breakthroughs while reducing product lifecycle costs" [Cap2].

The press release goes on to say that the global market for these devices is $600 million [Cap2]. In 2015 Triquint Semiconductor merged with RFMD and the combined entity renamed itself Qorvo [Cap3].

Qorvo in 2024 has revenues in excess of $3.77 billion and continues to sell the Spatium amplifiers. According to its website: "Qorvo's patented Spatium® RF power combining technology provides a wide band, highly reliable, efficient alternative for traveling wave tube amplifier (TWTA) replacements, for commercial and defense communications, radar, electronic warfare (EW) and many other applications. When state of the art solid state power amplification is required, the Spatium family of standard products is your best solution." [Cap4].

All of the five patents acquired with Cap Wireless are highly cited, but 4 of the 5 are extremely highly cited (most patents get fewer than 15 citations over their lifetime, but these have more than 200 citations). Three of the very highly cited patents also reference 29 IEEE articles and the fourth references 30 IEEE articles. The common inventor on three of the patents Scott Behan, recently retired as the Senior Product Marketing Manager at Qorvo [Cap5].

Most of the IEEE papers referenced in the patents above are related to Microwaves. The paper (York, Robert A. et al., "Quasi-Optical Power Combining Using Mutually Synchronized Oscillator Arrays," *IEEE Transactions on Microwave Theory and Techniques*, vol. 39, No. 6, Jun. 1991, pp. 1000-1009.) is typical. This paper is referenced in 3 of the 5 patents above. Other papers (see Appendix A and Appendix B) are from *IEEE Microwave and Wireless Components Letters*, *Microwave Symposium Digest*, and *IEEE Microwave and Guided Wave Letters*, and other Microwave related journals and conferences.

Perceive/Amazon (See Artificial Intelligence)

Perceive's technology can be considered semiconductor related, but since it's chips are primarily aimed at the Artificial Intelligence market, we placed it in that category.

Wireless Charging

WiTricity

WiTricity has 50+ patents captured in the Power Systems category of our annual report discussing patent references to major publishers. All of these patents are highly cited, and on average each references 33 IEEE articles. To save space, we show only the top 20 cited patents from WiTricity (Table 21) but most of them have very similar titles and all have to do with wirelessly charging devices. The patents are extensively licensed. Some of the companies licensing WiTricity technology include: Anjie Wireless, CidT Co Ltd, Foxconn Interconnect Technology, Green Power, jjPlus Corp, Neosen, Toyota, and Voltraware [Witricity1].

In 2022 Siemens invested $25 million in WiTricity and took a minority stake in the firm. The press release contained the following:

Siemens and WiTricity will work together to drive innovation in the emerging market for wireless EV charging. This market is expected to reach USD 2 billion by 2028 in Europe and North America alone, according to Siemens' calculations. The two companies seek to bridge the gaps in the global standardization of wireless charging for electric passenger and light duty commercial vehicles, to enable interoperability between vehicles and infrastructure, as well as support market penetration. In addition, both parties will collaborate to advance the technical development of wireless charging systems. [Witricity2]

Table 21: Key patents of WiTricity

Patent #	#IEEE References	Application Date	Grant Year	# Cites	Citation Index	Title	First 3 Inventors
8035255	24	20091106	2011	416	10.67	Wireless energy transfer using planar capacitively loaded conducting loop resonators	Kurs; Andre B., Karalis; Aristeidis, Hall; Katherine L.
8106539	23	20100311	2012	292	7.83	Wireless energy transfer for refrigerator application	Schatz; David A., Lou; Herbert T., Kesler; Morris P.
8304935	26	20091228	2012	237	6.35	Wireless energy transfer using field shaping to reduce loss	Karalis; Aristeidis, Kurs; Andre B., Campanella; Andrew J.
8324759	26	20091228	2012	228	6.11	Wireless energy transfer using magnetic materials to shape field and reduce loss	Karalis; Aristeidis, Kurs; Andre B., Campanella; Andrew J.
8629578	25	20130221	2014	285	13.26	Wireless energy transfer systems	Kurs; Andre B., Karalis; Aristeidis, Kesler; Morris P.
8643326	50	20110106	2014	226	6.41	Tunable wireless energy transfer systems	Campanella; Andrew J., Lou; Herbert T., Kesler; Morris P.
8667452	26	20121105	2014	72	13.34	Wireless energy transfer modeling tool	Verghese; Simon, Efe; Volkan, Kesler; Morris P.
8692412	26	20100330	2014	65	11.07	Temperature compensation in a wireless transfer system	Fiorello; Ron, Kulikowski; Konrad J.
8729737	27	20120208	2014	323	55.00	Wireless energy transfer using repeater resonators	Schatz; David A., Hall; Katherine L., Kesler; Morris P.
8847548	114	20130807	2014	37	6.30	Wireless energy transfer for implantable devices	Kesler; Morris P., Hall; Katherine L., Kurs; Andre B.
8901778	74	20111021	2014	53	11.02	Wireless energy transfer with variable size resonators for implanted medical devices	Kesler; Morris P., Hall; Katherine L., Kulikowski; Konrad
8912687	36	20111103	2014	65	9.83	Secure wireless energy transfer for vehicle applications	Kesler; Morris P., Kurs; Andre B., Karalis; Aristeidis
8928276	72	20120323	2015	59	5.96	Integrated repeaters for cell phone applications	Kesler; Morris P., Kurs; Andre B., Karalis; Aristeidis
8937408	36	20110420	2015	433	43.71	Wireless energy transfer for medical applications	Ganem; Steven J., Kesler; Morris P., Hall; Katherine L.
8946938	36	20111018	2015	52	5.25	Safety systems for wireless energy transfer in vehicle applications	Kesler; Morris P., Kulikowski; Konrad, Lou; Herbert Toby
8963488	38	20111006	2015	90	9.08	Position insensitive wireless charging	Campanella; Andrew J., Hall; Katherine L., Karalis; Aristeidis
9318898	35	20150625	2016	305	45.91	Wireless power harvesting and transmission with heterogeneous signals	John; Michael Sasha
9369182	33	20130621	2016	66	12.84	Wireless energy transfer using variable size resonators and system monitoring	Kurs; Andre B., Karalis; Aristeidis, Kesler; Morris P.
9515494	70	20150409	2016	50	7.53	Wireless power system including impedance matching network	Kurs; Andre B., Karalis; Aristeidis, Campanella; Andrew J.

Conclusions

This report has examined the influence of IEEE science upon key patented technologies across a range of cutting-edge technologies. It highlights twenty stories of companies that have designed products around patents with significant technological and/or financial impact, and that build extensively on IEEE science.

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