Advances in Sensor Technology which Enables Autonomous Vehicles

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- **- CTO Able Device, http://abledevice.com/**
- **- CEO RFSigint**
- **- Visiting & Adjunct Professor, TCNJ**

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Outline

* VEHICLE SENSORS TECHNOLOGY TAXONOMY
* BIRTH of VEHICLE SENSORS & Motivation
  * EEC I – EEC 3 EGR, Pressure, Temperature, Oxygen, etc.
  * ACCELEROMETER, ODOMETER, SENSOR PID CODES CAN BUS
* SENSORS which ENABLE SELF-DRIVING VEHICLES
  * LIDAR – LIGHT DETECTION AND RANGING
  * IMAGERS – MULTIMPLE 2D, 3D
  * RADAR – 24 GHz MICROWAVE
* ADVANCES IN MACHINE LEARNING / CLASSIFICATION of DATA
  * Convolutional Neural Networks
* FUTURE of VEHICLE SENSORS through NEW PATENT ANALYSIS

SAE and NHTSA Classification

SAE Name	SAE	NHTSA	NHTSA Name
Human driver monitors the driving environment			
No automation	0	0	No automation
Driver assistance	1	1	Function-specific automation
Partial automation	2	2	Combined function automation
Automated driving system monitors the driving environment			
Conditional automation	3	3	Limited self-driving automation
High automation	4	4	Full self-driving automation
Full automation	5		

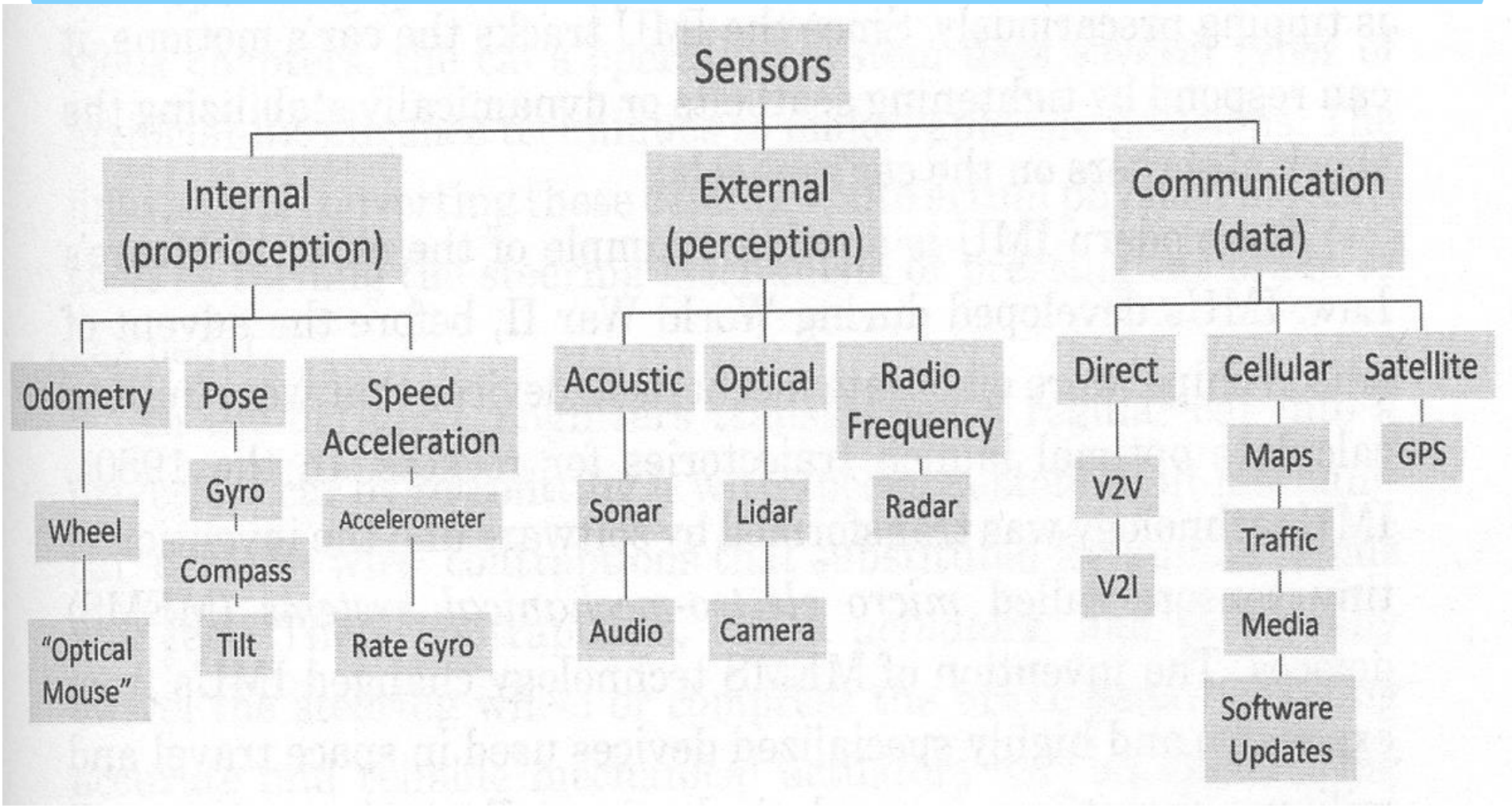
SAE J3016: http://www.sae.org/misc/pdfs/automated_driving.pdf

NHTSA: www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf

Connected vs. Automated

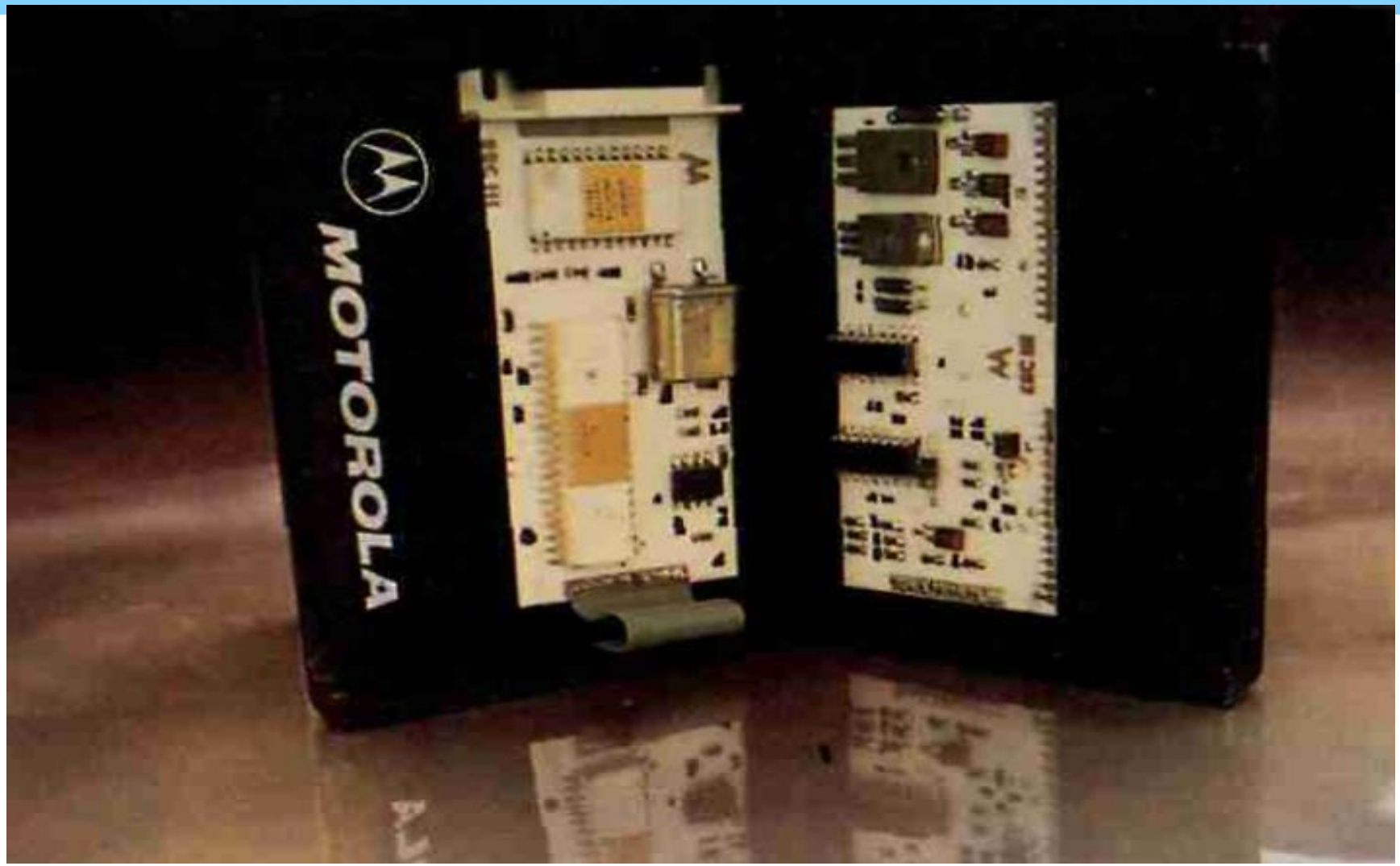
- **Automated**
  - At least some control of vehicle functions
  - Does not depend on CV technology
  - Examples: current applications (forward collision avoidance, traffic jam assist), Google car
- **Connected**
  - V2V, V2I, V2P communications
  - Advisories and warnings to the driver
  - Example: Safety Pilot
- **Automated and Connected**
  - Example: Cooperative Adaptive Cruise Control

Self-Driving Vehicle Sensor Taxonomy



Ref: Driverless: Intelligent Cars and the Road Ahead, Hod Lipson and Melba Kurman, MIT Press, 2016, pg. 189

1977 FIRST MICROCOMPUTER IN AN AUTOMOBILE – MOTOROLA EEC I-III



REF: https://www.motorolasolutions.com/content/dam/msi/docs/en-xw/static_files/1977_Motorola_Annual_Report.pdf

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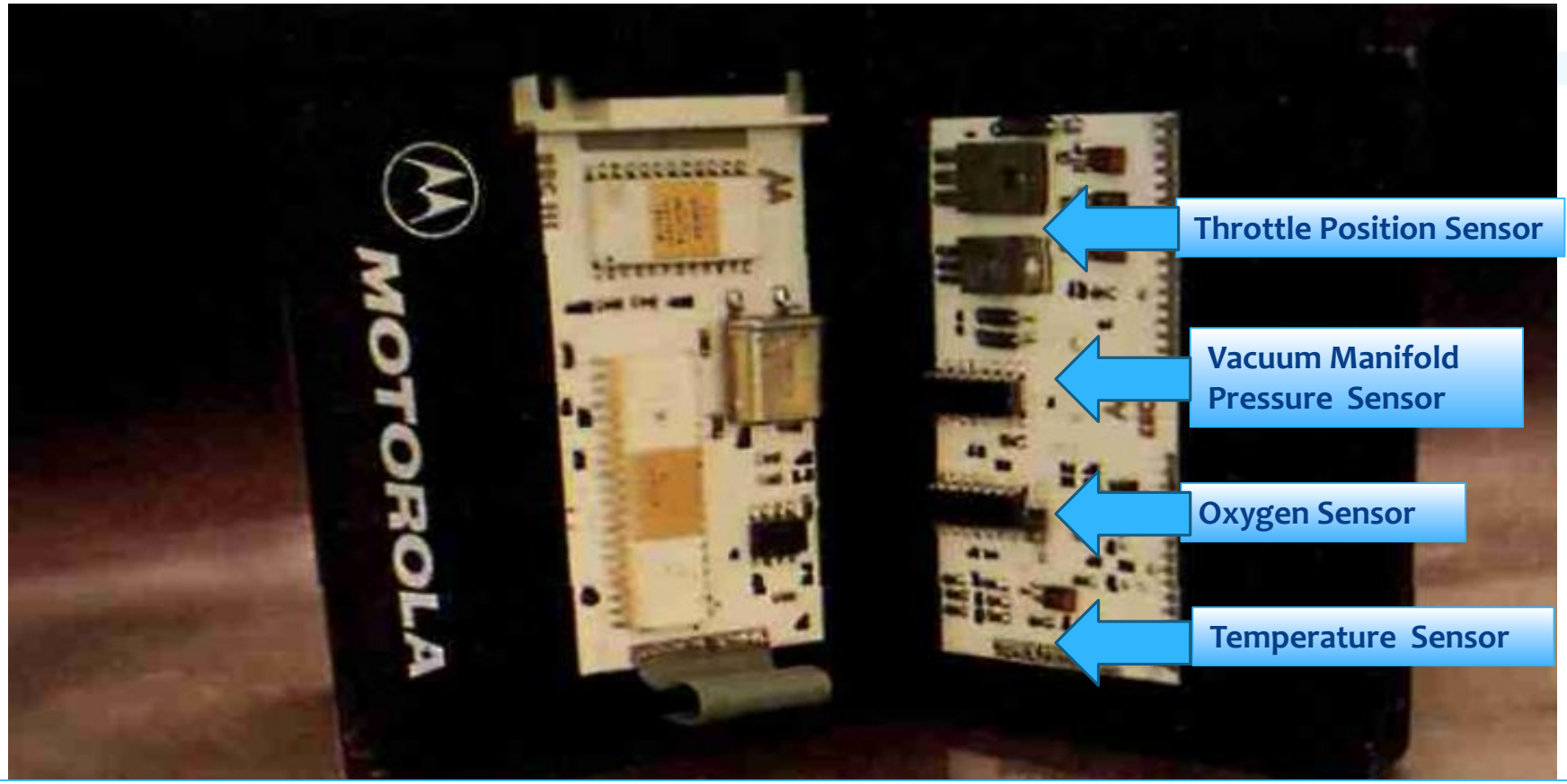
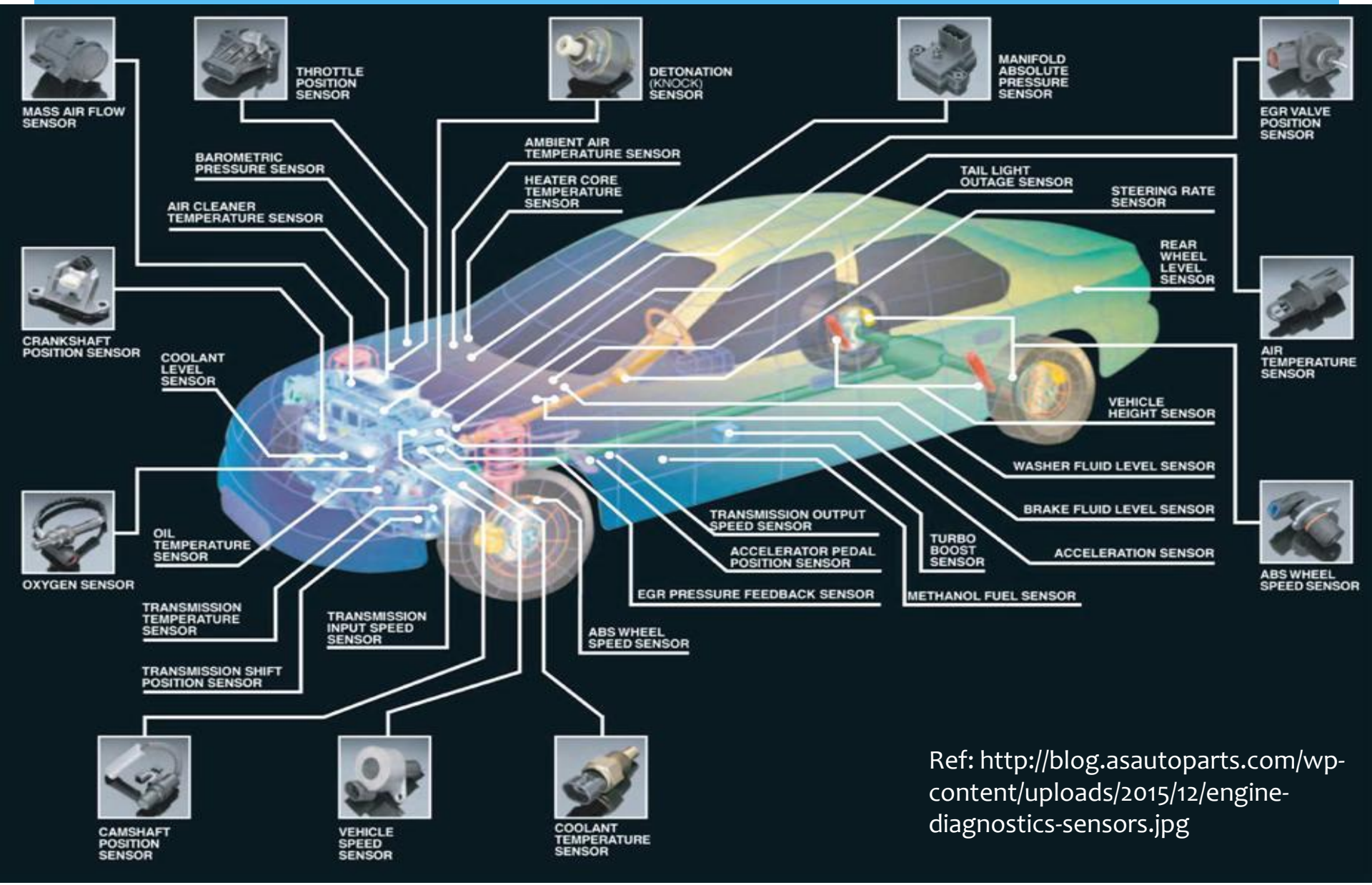


"The company reinforced its strong position in the automotive engine electronics business when the Automotive Products Division, in cooperation with the Semiconductor Group, won a competitive design award from Ford for an electronic engine control (EEC). Under terms of the award. Motorola will supply to Ford at least 25 per cent of their EEC requirements for the 1980 model year."

REF: https://www.motorolasolutions.com/content/dam/msi/docs/en-xw/static_files/1977_Motorola_Annual_Report.pdf

2017 Internal Vehicle Sensors



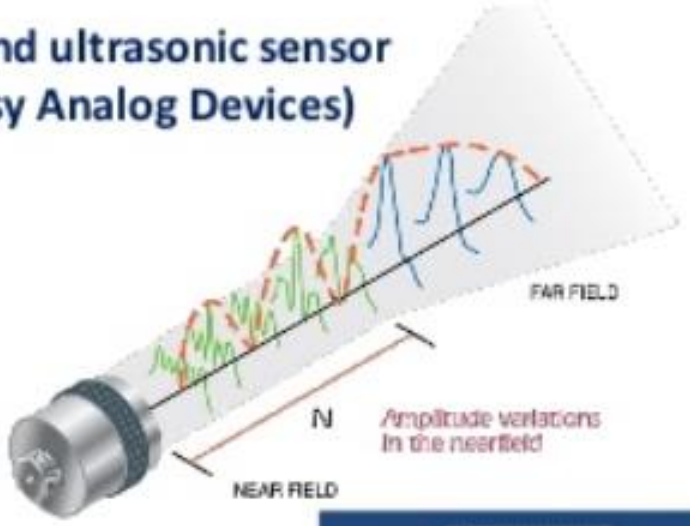
Ref: http://blog.asautoparts.com/wp-content/uploads/2015/12/engine-diagnostics-sensors.jpg

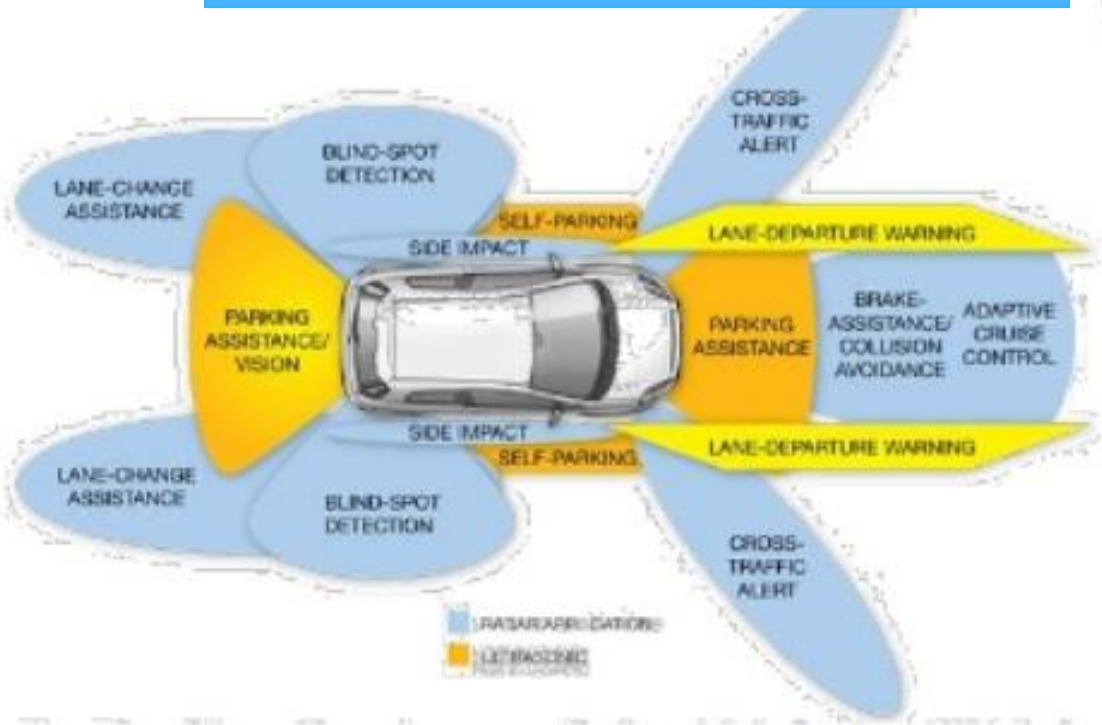
Ultrasonic and RF Radar Sensors

Ultrasonic sensors are used to assist the driver in autonomous vehicle.

Ultrasonic and RF Radar sensors are limited in range but work through conditions of poor visibility and complements Vision and LIDAR sensors

Radar and ultrasonic sensor (Courtesy Analog Devices)

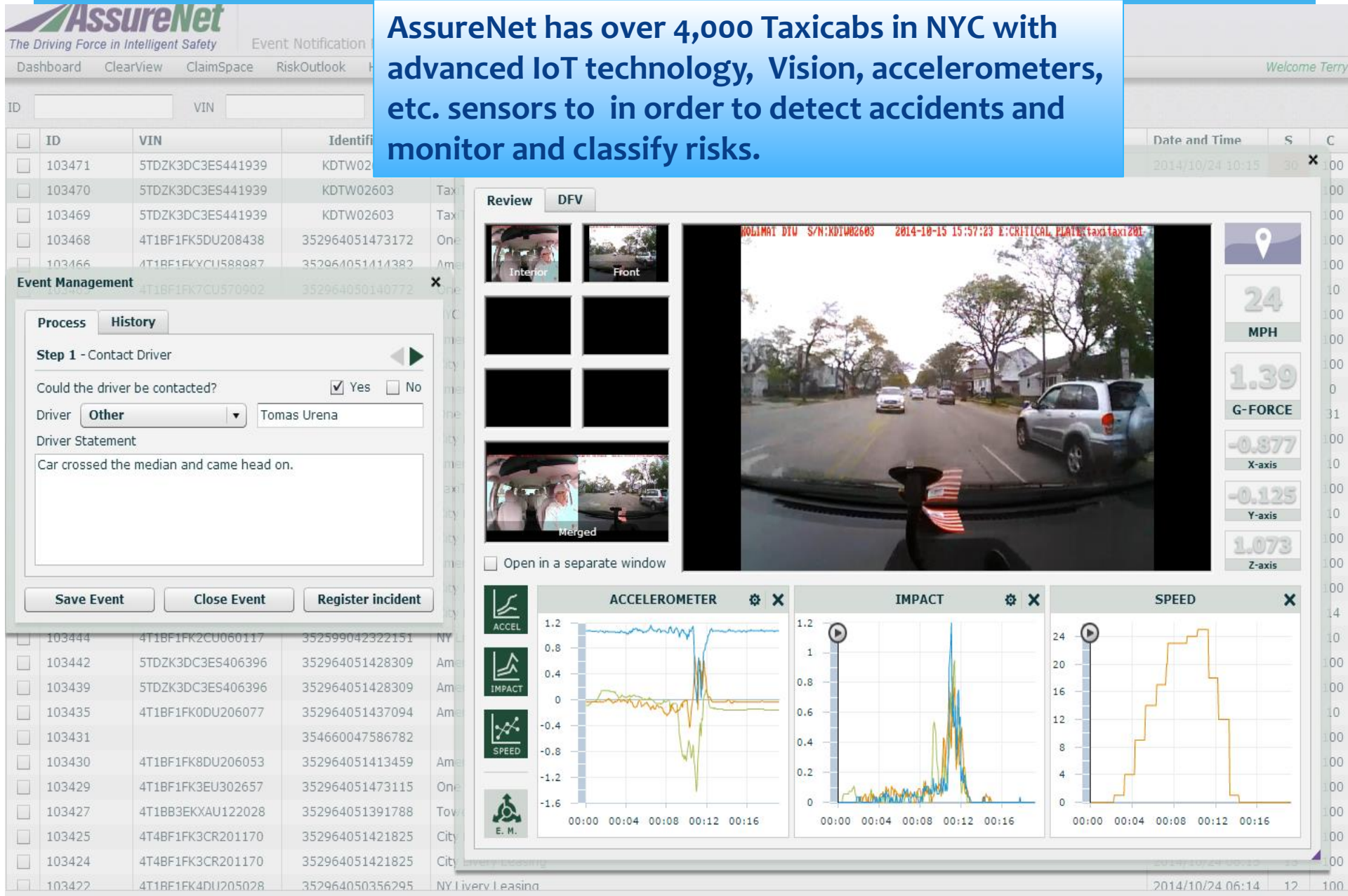




Variable gain amplifier used in ultrasonic sensor (USD12 each) (Courtesy Analog Devices)

AssureNet's CLEARVIEW Platform

AssureNet has over 4,000 Taxicabs in NYC with advanced IoT technology, Vision, accelerometers, etc. sensors to in order to detect accidents and monitor and classify risks.



AssureNet's CLEARVIEW Platform

Trigger EVENTS e.g. may be an accelerometer G-force transition threshold or a manual EVENT where the driver manually initiates a threat switch. Other EVENTS are enabled and customized per risk.

AssureNet

miniEgress™

AssureNet's Universal IoT Mobile Sensor Platform

ClearView

Powerful Industrial IoT Platform
Based on Qualcomm® Snapdragon™ 410 processor (APQ8016)

ClearView 'Big Data' Platform
Unstructured Data & Streaming Analytics

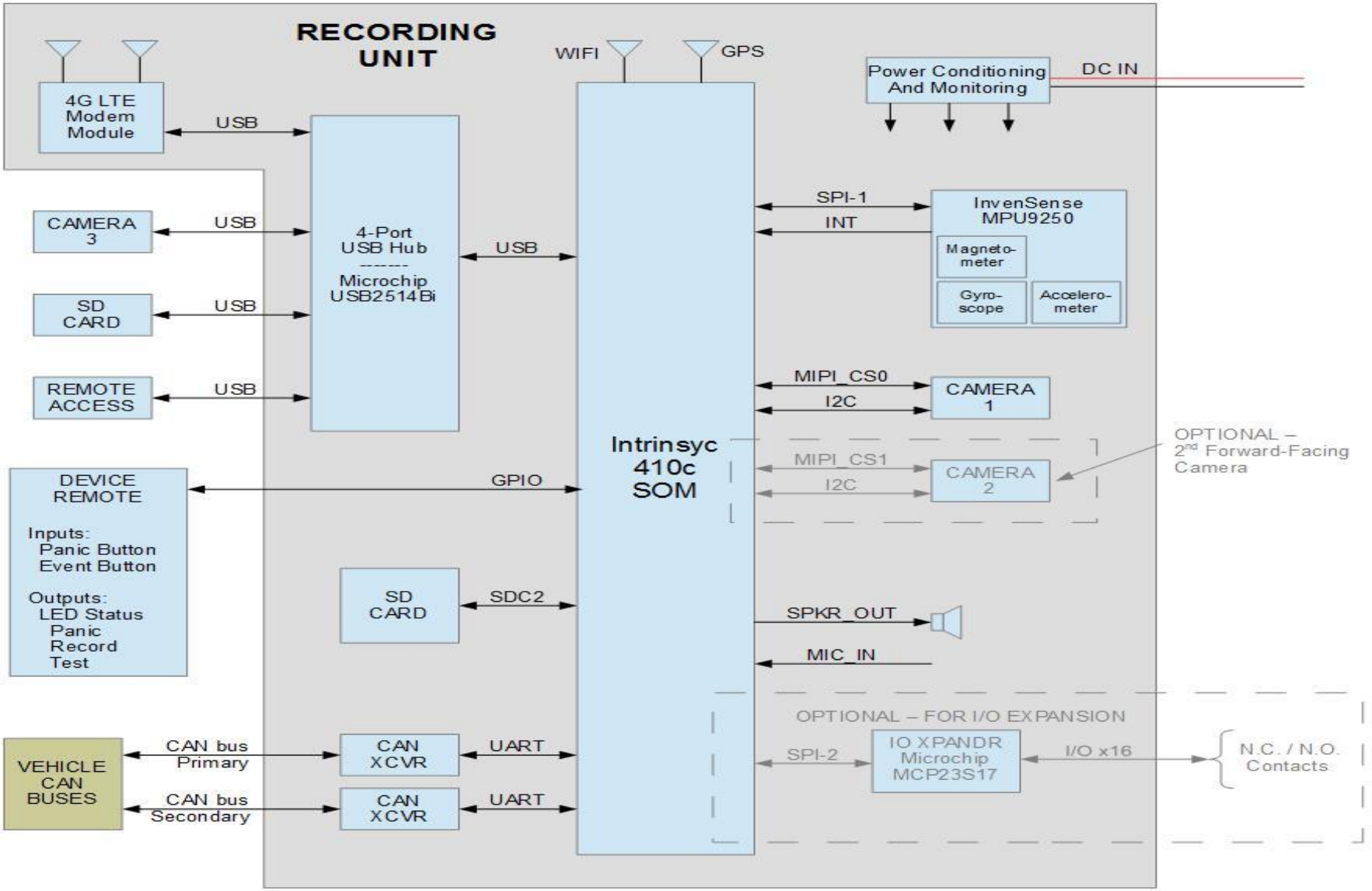
Android or Linux OS Applications
VEDR+ ADAS + Open/FastCV

WiFi 802.11b/g/n & Bluetooth 4.1
3G/4G, mesh & Orbcomm satellite options

Ruggedized
IP-69 enclosure for Industrial IoT Application

[1] Qualcomm Snapdragon processors are a product of Qualcomm Technologies, Inc

AssureNet's miniE Architecture



WAYMO (GOOGLE) SELF-DRIVING CAR

3- LIDAR SYSTEMS
9- CAMERAS
2- RADAR SENSORS

UBER SELF-DRIVING CAR

"Short-Term, as cars gain Level 2 or 3 automation (note SAE J3016 levels of automation) and legislation still requires human drivers to take the wheel as a backup – drivers will build confidence over time and ready for full automation."

http://electronicdesign.com/embedded/11-myths-about-autonomous-vehicles

TESLA SELF-DRIVING CAR

Tesla Model S cars and the newer Model X have had an Autopilot feature

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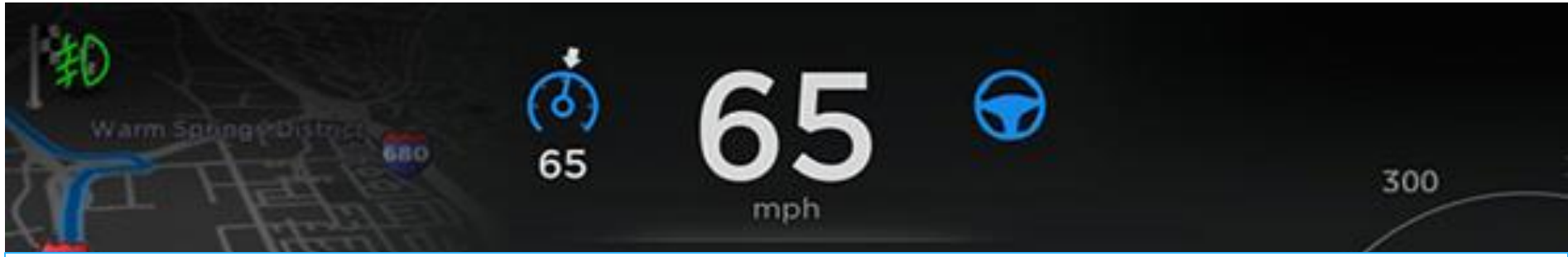


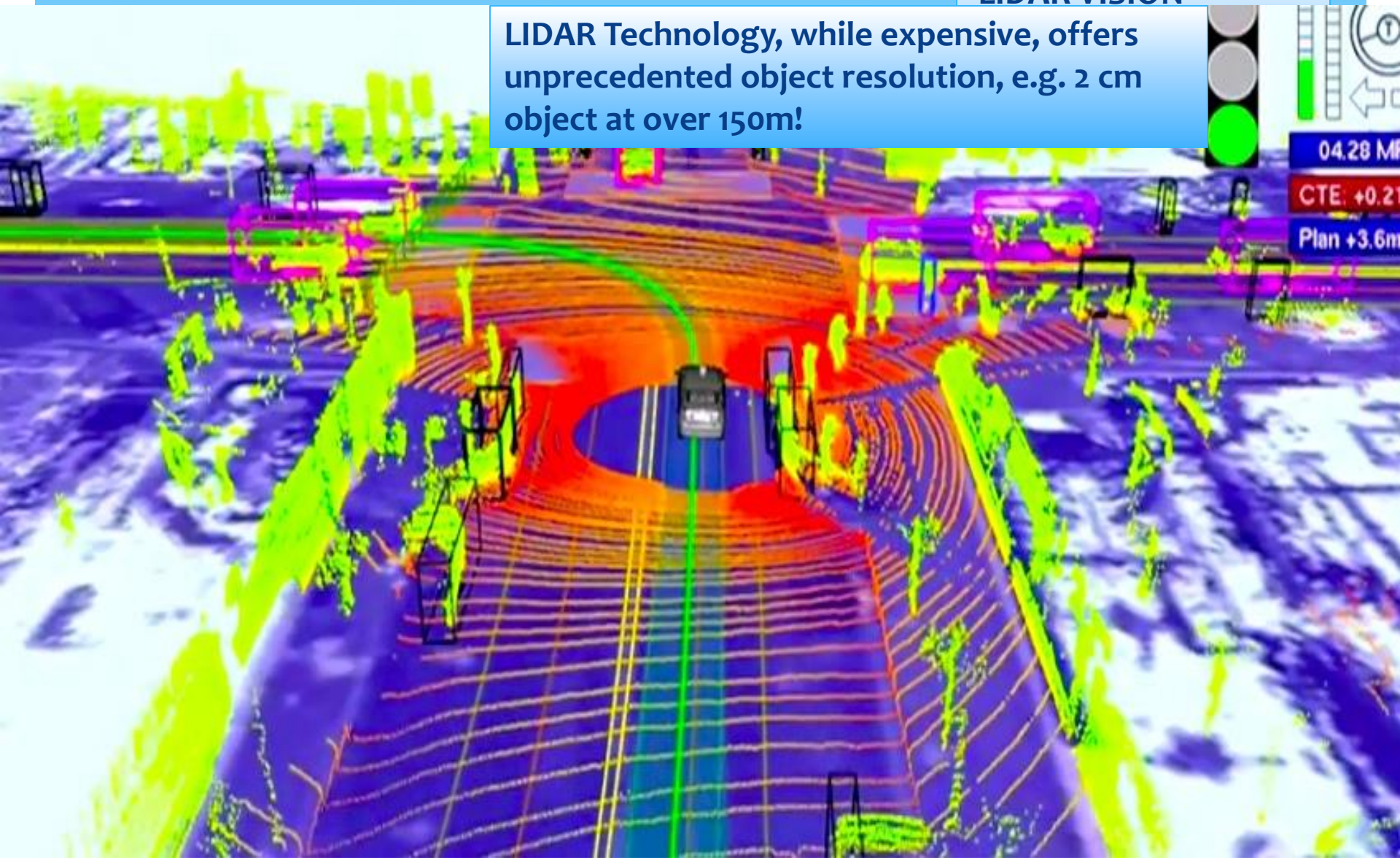
In May of 2016, a driver using Tesla's Autopilot **collided fatally with a tractor trailer.** Analysis indicates the autopilot software did not detect the white tractor trailer against a background of a bright sky – **additional fused radar & LIDAR sensors would have prevented this optical camera dynamic range limitation** as integrated in the WAYMO vehicle

http://electronicdesign.com/embedded/11-myths-about-autonomous-vehicles

WAYMO (GOOGLE) SELF-DRIVING CAR

LIDAR VISION

LIDAR Technology, while expensive, offers unprecedented object resolution, e.g. 2 cm object at over 150m!



GEN I LIDAR SPECS

Velodyne LiDAR™

HOME PRODUCTS INDUSTRY FAQ DOWNLOADS RESELLERS MEDIA ABOUT CAREERS CONTACT US

$8,000 each in 2015 !

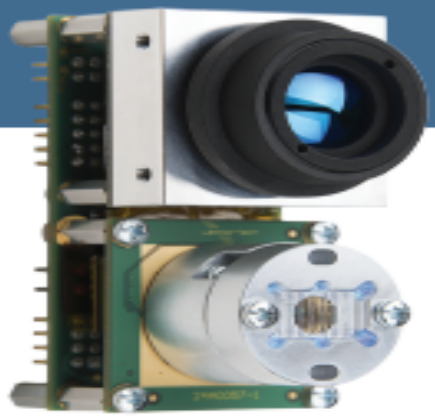
- 64 Channels
- 120m range
- 2.2 Million Points per Second
- 360° Horizontal FOV
- 26.9° Vertical FOV
- 0.08° angular resolution (azimuth)
- <2cm accuracy
- ~0.4° Vertical Resolution
- User selectable frame rate

GEN 2 LIDAR SPECS

Ref: https://www.youtube.com/watch?v=P3G_inKfj9A

COMPACT FIXED-BEAM LIDAR SENSOR MODULE

Multi-object, wide-beam optical detection and ranging over 8 segments



GEN II, <$250 in 2017

LeddarVu is a new solid-state LiDAR platform that combines the benefits of a compact architecture with superior performance, robustness and cost-efficiency.

LeddarVu Benefits

- Compact form factor (190 cm³)
- Fixed beam, no moving parts
- Proven reliability, even in harsh conditions
- Immune to ambient light
- Modular platform for flexible integration and customization
- Best cost/performance ratio

Vu8 Module Features

- Detection range up to 215 meters (~700 ft.)
- Compact and lightweight (~107 g)
- Multiple independent segments with simultaneous acquisition and lateral discrimination capabilities
- 20°, 48° and 100° beam width options, for optimized field of view
- Rapid refresh rate up to 100 Hz

LeddarVu - The new platform for next-gen Leddar sensors

LeddarVu brings a whole new dimension to sensing applications with an optimized modular design that offers a better range, a smaller form-factor and greater flexibility of integration than any other sensor module. Leveraging LeddarTech's unique expertise in LiDAR detection and ranging, every optical sensor built on the LeddarVu platform inherits the unique added value of Leddar, which is better sensitivity, immunity to ambient light and robust performance in inclement weather, and powerful signal processing.

Conceived to follow the evolution of the next generations of LeddarCore ICs, the LeddarVu platform fosters the development of highly differentiated and affordable solutions powered by optimized Leddar configurations.

Vu8 – 8 segments LiDAR sensor module

Vu8, the first Leddar sensor module built on the LeddarVu platform, leverages powerful class-1 laser illumination and 8 independent active detection elements into a single sensor, resulting in rapid, continuous and accurate detection and ranging of objects — including lateral discrimination — in the entire wide beam, without any moving parts. Detecting targets up to 215 m and weighting only 107 grams, the Vu8 uses a fixed laser light source, which significantly increases the sensor's robustness and cost-efficiency compared to any scanning LiDAR solution.

Vu8's source assembly combines the IR Laser emitter with a dominant wavelength of 905 nm and diffractive optics, providing a wide illumination beam which is available in three horizontal and two vertical field of view options. The receiver assembly includes 8 independent detection elements with simultaneous multi-object measurement capabilities and hosts the powerful Leddar signal processing algorithms. Vu8's carrier board hosts the electrical and communication interface of the module. Two interface configurations are available: SPI or USB-CAN-Serial (UART/RS-485).

Software Development Kit (SDK)

The Leddar Enabler SDK provides a user-friendly application programming interface (API) with .Net and C libraries and code examples. Sample code for both Windows and Linux, as well as MATLAB integration examples, are also provided.

GEN 2 LIDAR SPECS

<$250 in 2017

Characteristics

Number of segments 8

Beams 20°, 48°, 100°

Vertical FoV options 0.3°, 3°

Wavelength 905 nm

Power supply 12 VDC

Interface options SPI, USB, CAN, Serial (UART/RS-485)

Ocular safety Fulfills the requirements of IEC 60825-1:2014 (Third Edition); Class I laser product (certification pending)

System performance

Accuracy 5 cm

Data refresh rate up to 100 Hz[1]

Operating temperature range -40°C to +85°C

Distance precision 6 mm

Distance resolution 10 mm

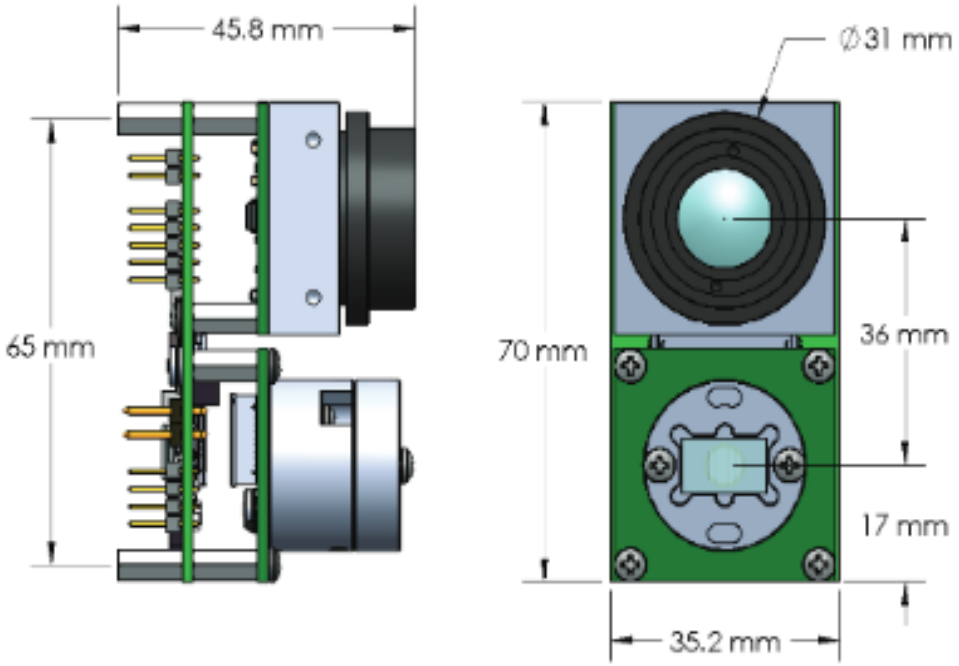
Power consumption 2 W

1 Depends on configuration

Ordering Information

VU8 - XXX - YYY - ZZ

Dimensions

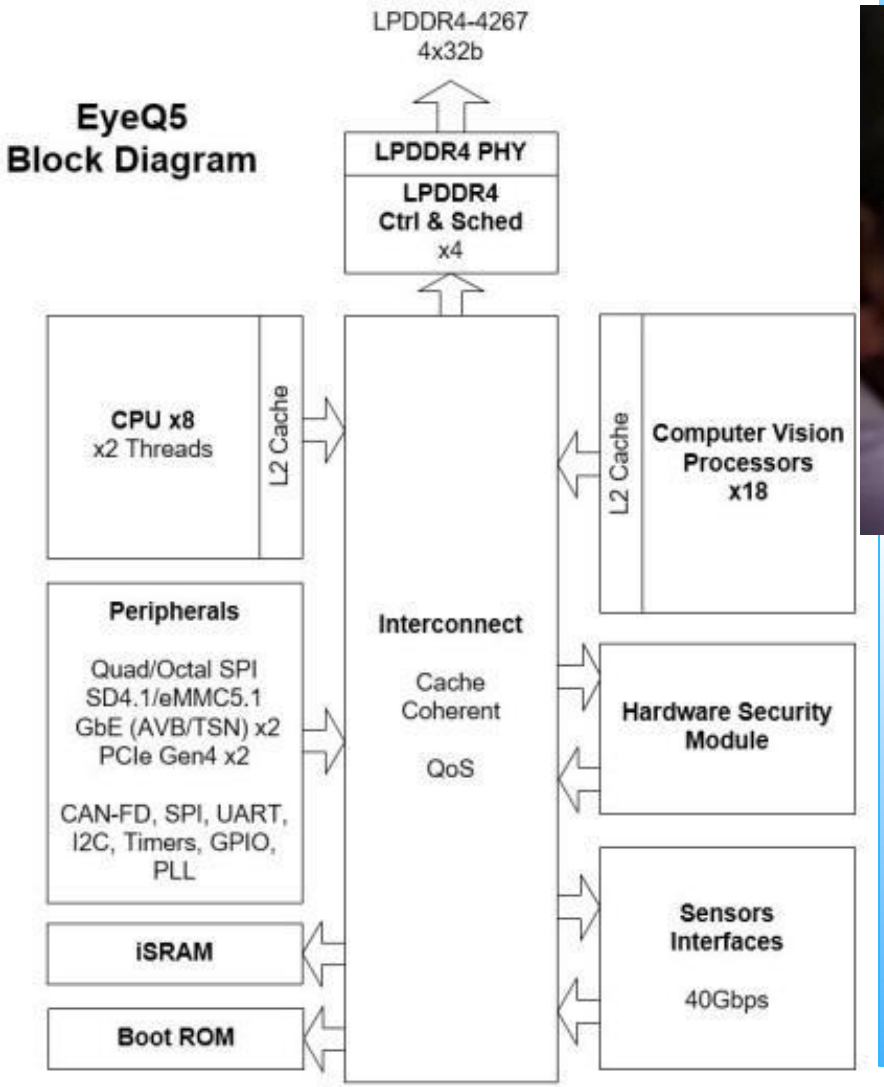


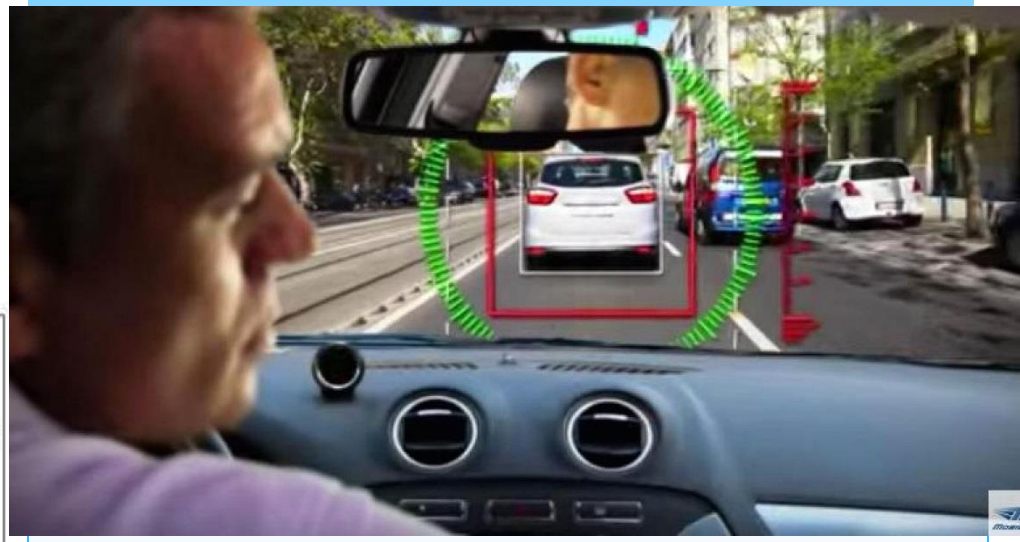
Dimensions for 48° configuration

Modular architecture

Sensors built on the LeddarVu platform offer

VISION and RADAR AUTOMOBILE CHIP SETS for MOBILEYE





The EyeQ5 will contain eight multithreaded CPU cores coupled with eighteen cores of Mobileye's next-generation, well-proven vision processors, explained Marco Monti, ST's executive vice president, Automotive and Discrete Group. In contrast, EyeQ4, a previous generation vision SoC, had 4 CPU cores and six Vector Microcode Processors

http://www.eetimes.com/document.asp?doc_id=1329704

VISION & MOBILEYE

Mobileye has been THE leader in the vehicle image and image recognition space and has recently been acquired by Intel (March 13, 2017) for $15.3B despite Tesla's claim that Mobileye's vision system is flawed.

"He (Intel's CEO) believes the future of autonomous driving hinges on 3D sensor fusion and machine learning. Chowry sees Mobileye's camera-focused technology as expendable and when it comes to advancing autonomous driving."

Ref: https://www.benzinga.com/analyst-ratings/analyst-color/17/03/9170134/intel-may-have-just-burned-15-billion-on-mobileye

System and method for vehicle detection and tracking US 7764808 B2 Priority Date March 20, 2003

A system and method for detecting and tracking an object is disclosed. A camera captures a video sequence comprised of a plurality of image frames. A processor receives the video sequence and analyzes each image frame to determine if an object is detected. The processor applies one or more classifiers to an object in each image frame and computes a confidence score based on the application of the one or more classifiers to the object. A database stores the one or more classifiers and vehicle training samples. A display displays the video sequence

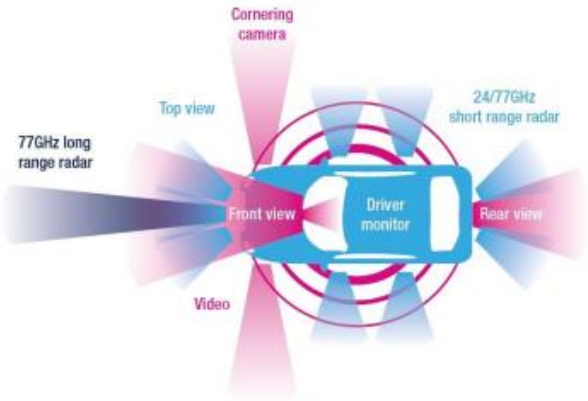
VISION and RADAR AUTOMOBILE CHIP SETS for MOBILEYE

Vision Processors & RADAR sensors

ST Leadership

- #1 with 30% market share in ADAS safety
- #1 Machine Vision in 2016
- #1 in RF RADAR Transceivers Market in 2016

The ADAS functionality



ST Sales in ADAS (M$)

- **2005**
  - Mobileye 1st Gen
- **2010**
  - Mobileye 2nd Gen
  - 1st 24Ghz Gen
- **2015**
  - Mobileye 3rd Gen
  - 2nd 24Ghz Gen
  - 1st 77Ghz Gen
- **2017**
  - Mobileye 4th Gen
  - 2nd 77Ghz Gen
  - Auto Parking MPU
  - Surround view Video Processor
- **2020**
  - Mobileye 5th Gen
  - High data rate Radar MCU
  - 360° Vision video processor

Highest Growth in RADAR Transceivers (> 30Munits expected to be shipped)

Powering de facto market standard for vision based ADAS (EyeQ)

Progressively expanding vision-based ADAS solutions

life.augmented

CONVOLUTIONAL NEURAL NETWORKS

The equivalent of the X-Prize applied to Vision recognition is to win the ImageNet Large-Scale Visual Recognition Challenge

"This contest has run every year since 2010 to evaluate image recognition algorithms.

Contestants in this competition have two simple tasks. Presented with an image of some kind, the first task is to decide whether it contains a particular type of object or not.

There are 1,000 different categories of objects ranging from abacus to zucchini, and contestants have to scour a database of over 1 million images to find every instance of each object.

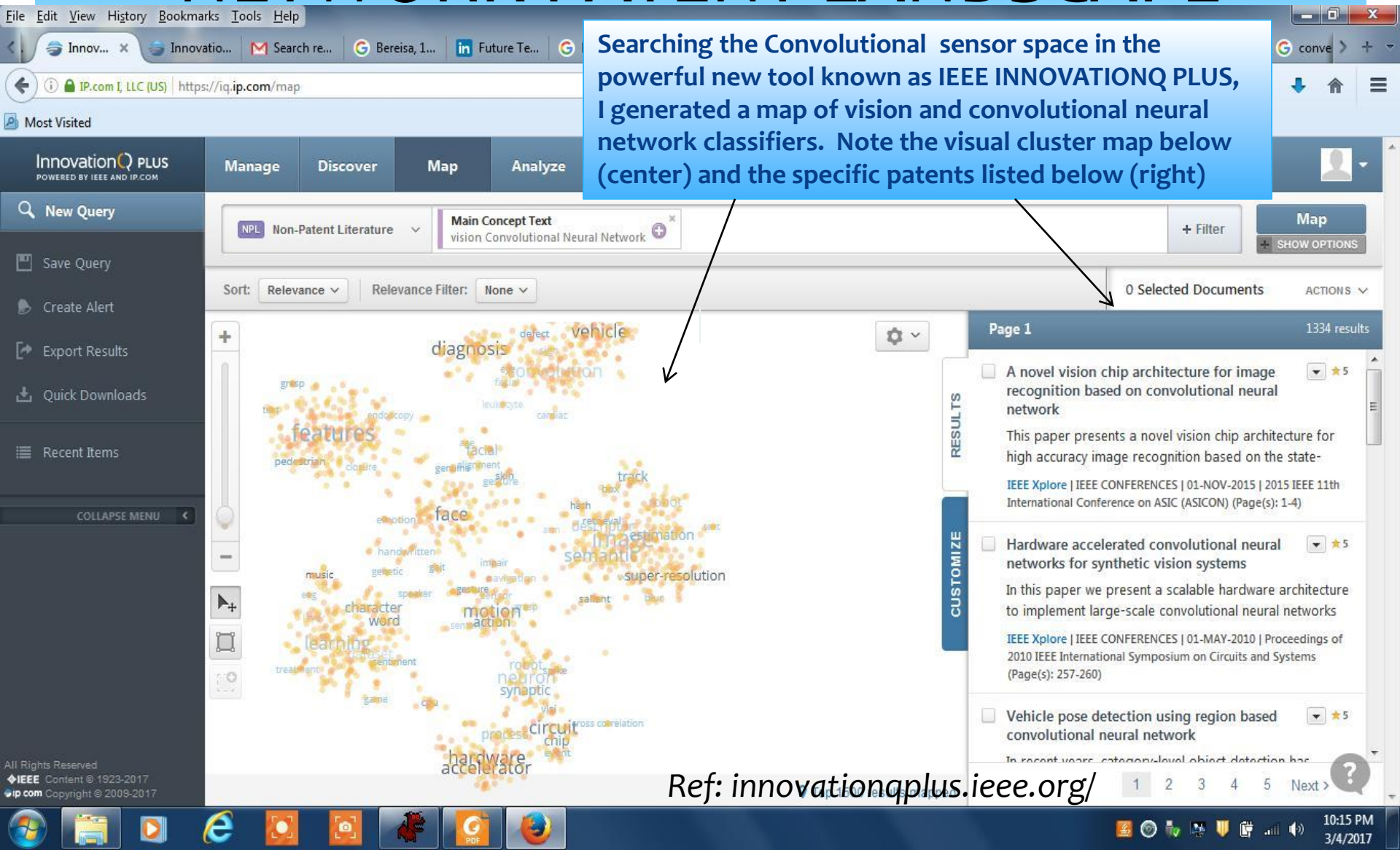
Ref: https://www.technologyreview.com/s/530561/the-revolutionary-technique-that-quietly-changed-machine-vision-forever/

A team from the University of Toronto in Canada, in 2012, entered an algorithm called **SuperVision**, which swept the floor with the opposition.

"This was the first time that a **deep convolutional neural network had won the competition, and it was a clear victory.** In 2010, the winning entry had an error rate of 28.2 percent, in 2011 the error rate had dropped to 25.8 percent. But SuperVision won with an error rate of only 16.4 percent in 2012 (the second best entry had an error rate of 26.2 percent).

That clear victory ensured that this approach has been widely copied since then."

CONVOLUTIONAL NEURAL NETWORK PATENT LANDSCAPE

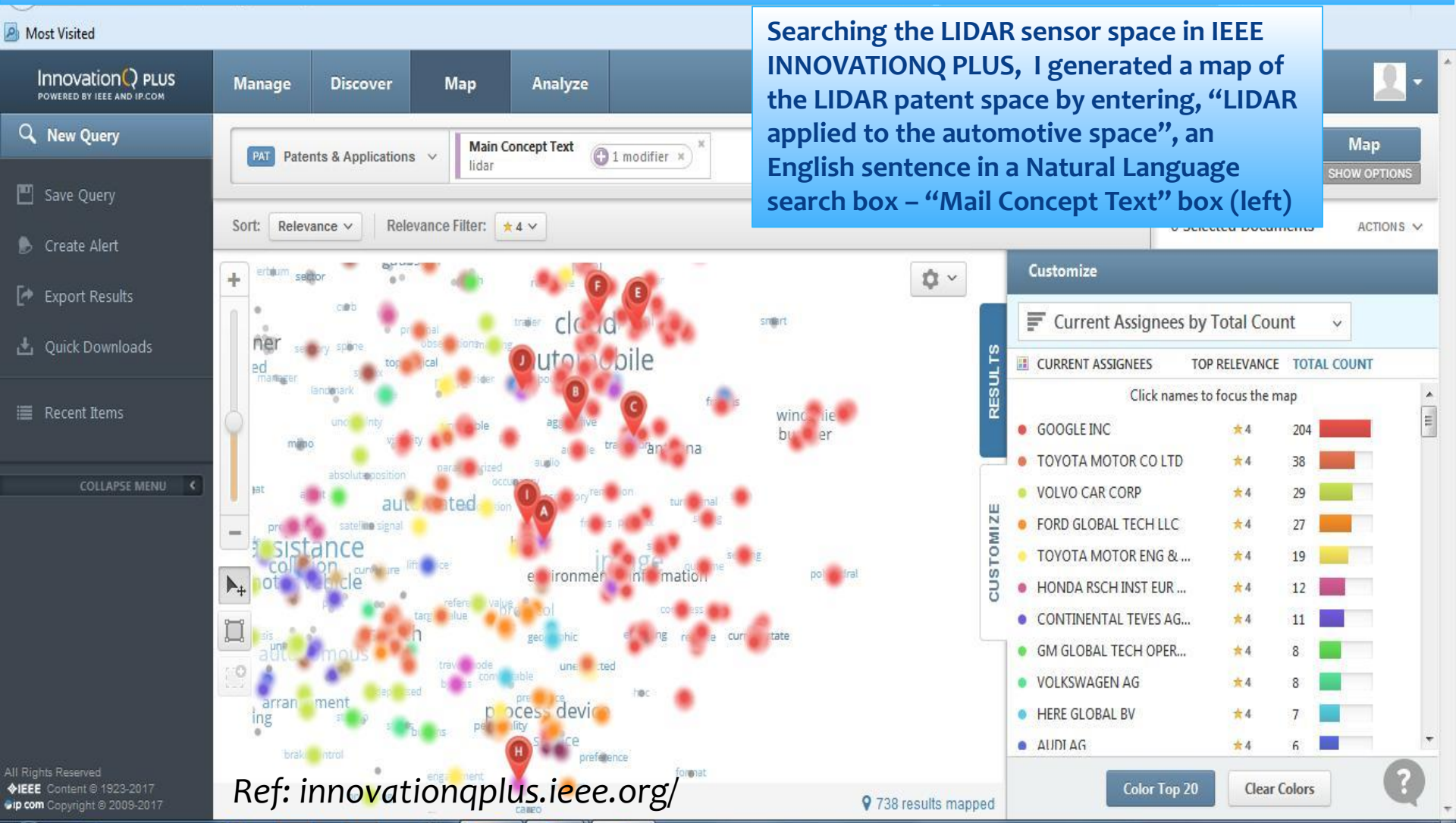


Ref: innovationqplus.ieee.org/

LIDAR SENSOR PATENT LANDSCAPE

LIDAR - Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges. Two variations, a spinning / MEMs or Solid State LIDAR.

Searching the LIDAR sensor space in IEEE INNOVATIONQ PLUS, I generated a map of the LIDAR patent space by entering, "LIDAR applied to the automotive space", an English sentence in a Natural Language search box – "Mail Concept Text" box (left)



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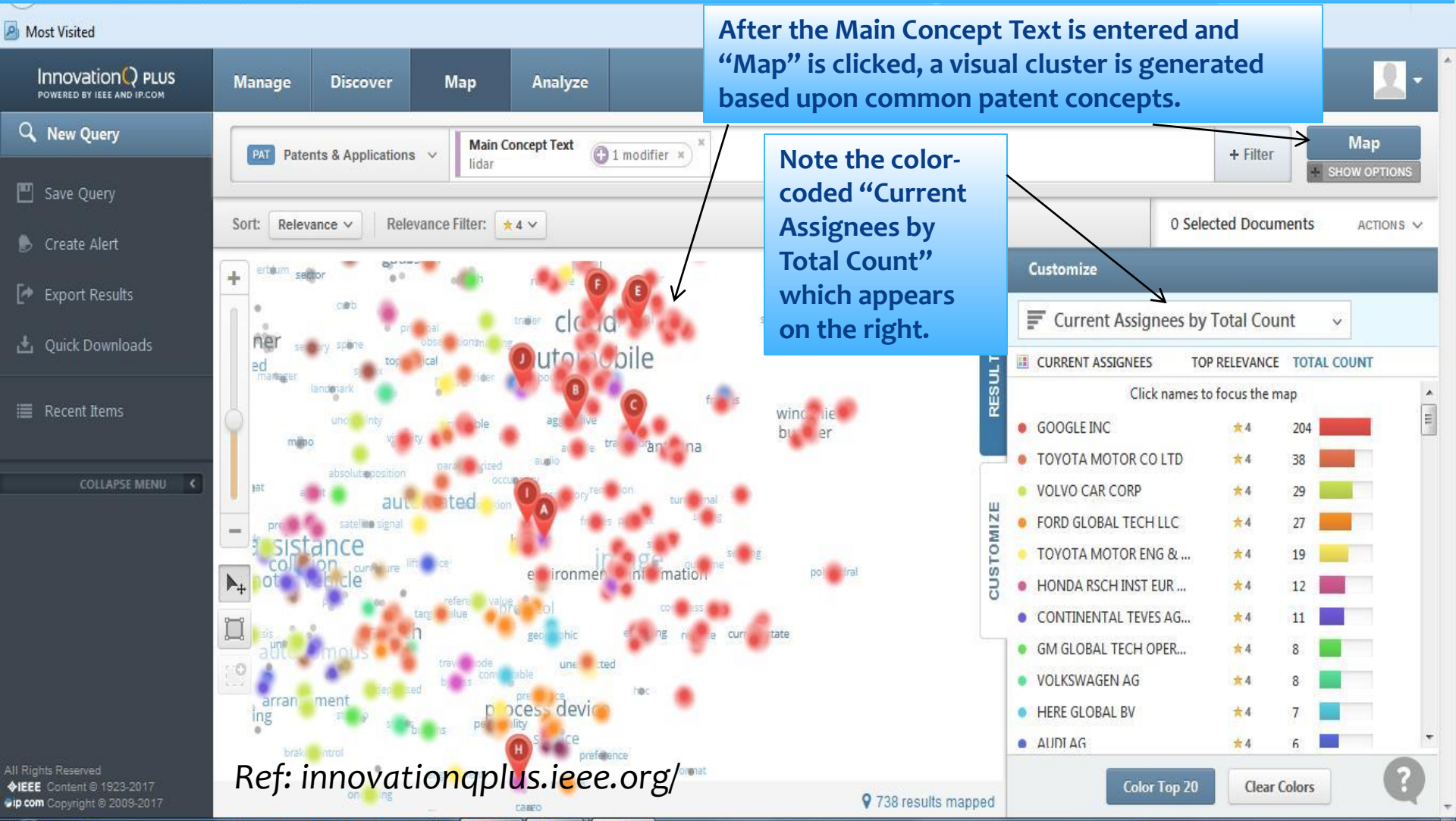

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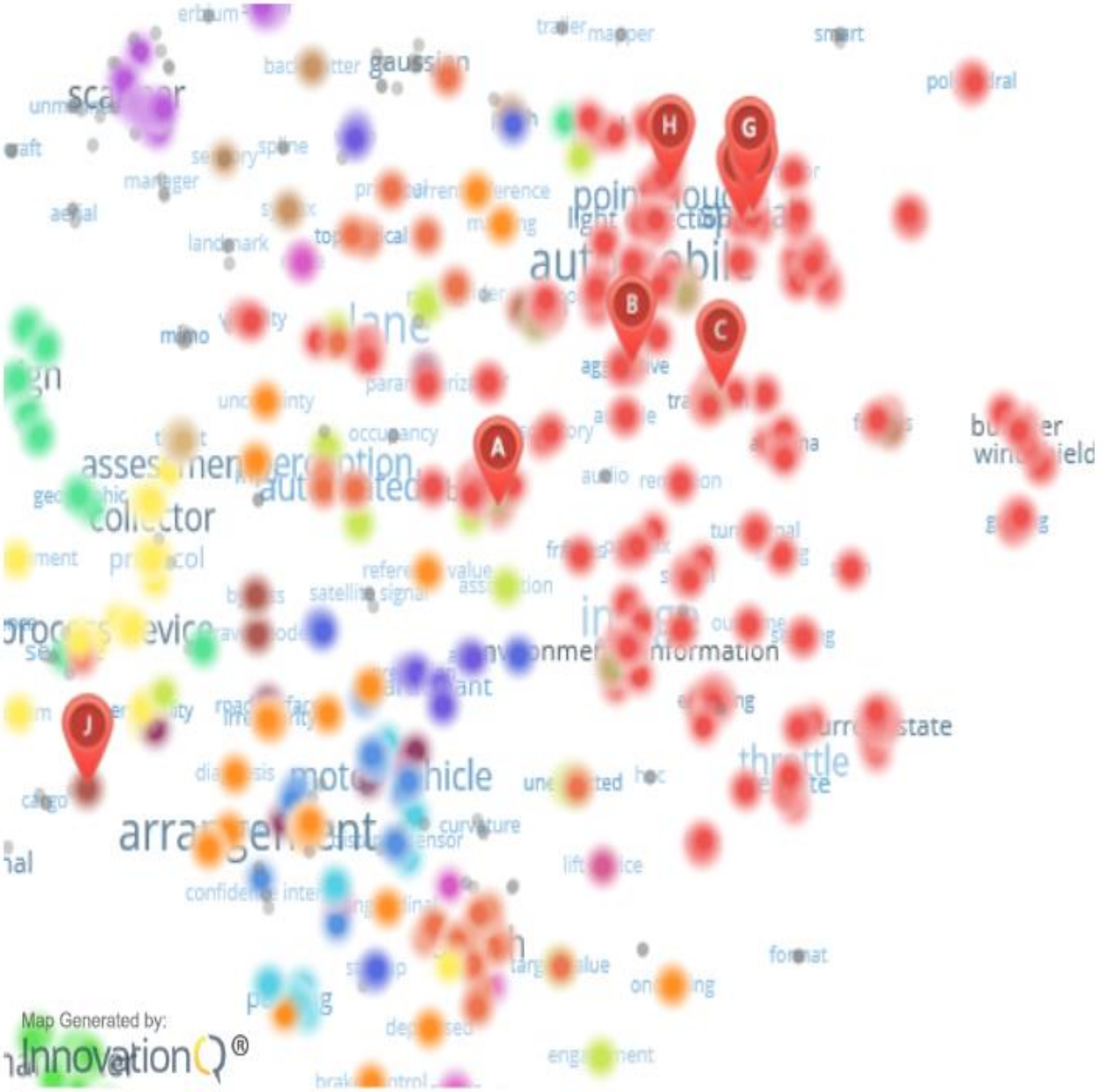

Selected Current Assignees

- GOOGLE INC (220)
- TOYOTA MOTOR CO LTD (38)
- VOLVO CAR CORP (38)
- FORD GLOBAL TECH LLC (23)
- TOYOTA MOTOR ENG & MFG NORTH AMERICA INC (20)
- ROBERT BOSCH GMBH (14)
- CONTINENTAL TEVES AG & CO OHG (13)
- GM GLOBAL TECH OPERATIONS INC (12)
- HONDA RSCH INST EUR GMBH (12)
- HERE GLOBAL BV (10)
- DEERE & CO (9)
- SAMSUNG ELTNC CO LTD (9)
- AUDI AG (7)
- DAIMLER AG (6)
- 삼성전자주식회사 (6)
- グーグル インコーポレイテッド (6)
- CARNEGIE MELLON UNIV (5)
- VOLKSWAGEN AG (5)
- 구글 인코포레이티드 (5)
- MASSACHUSETTS INST TECH (4)

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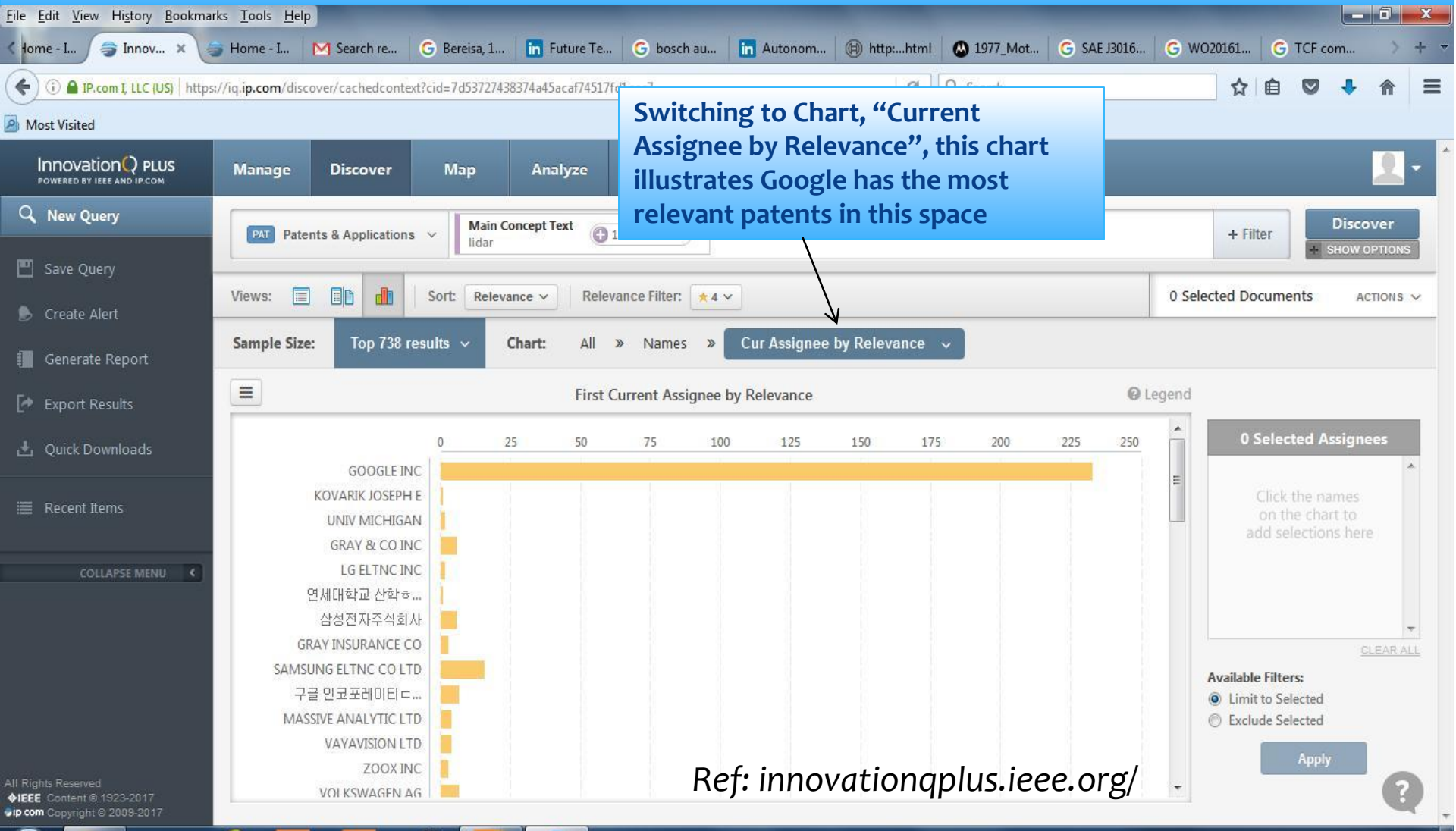

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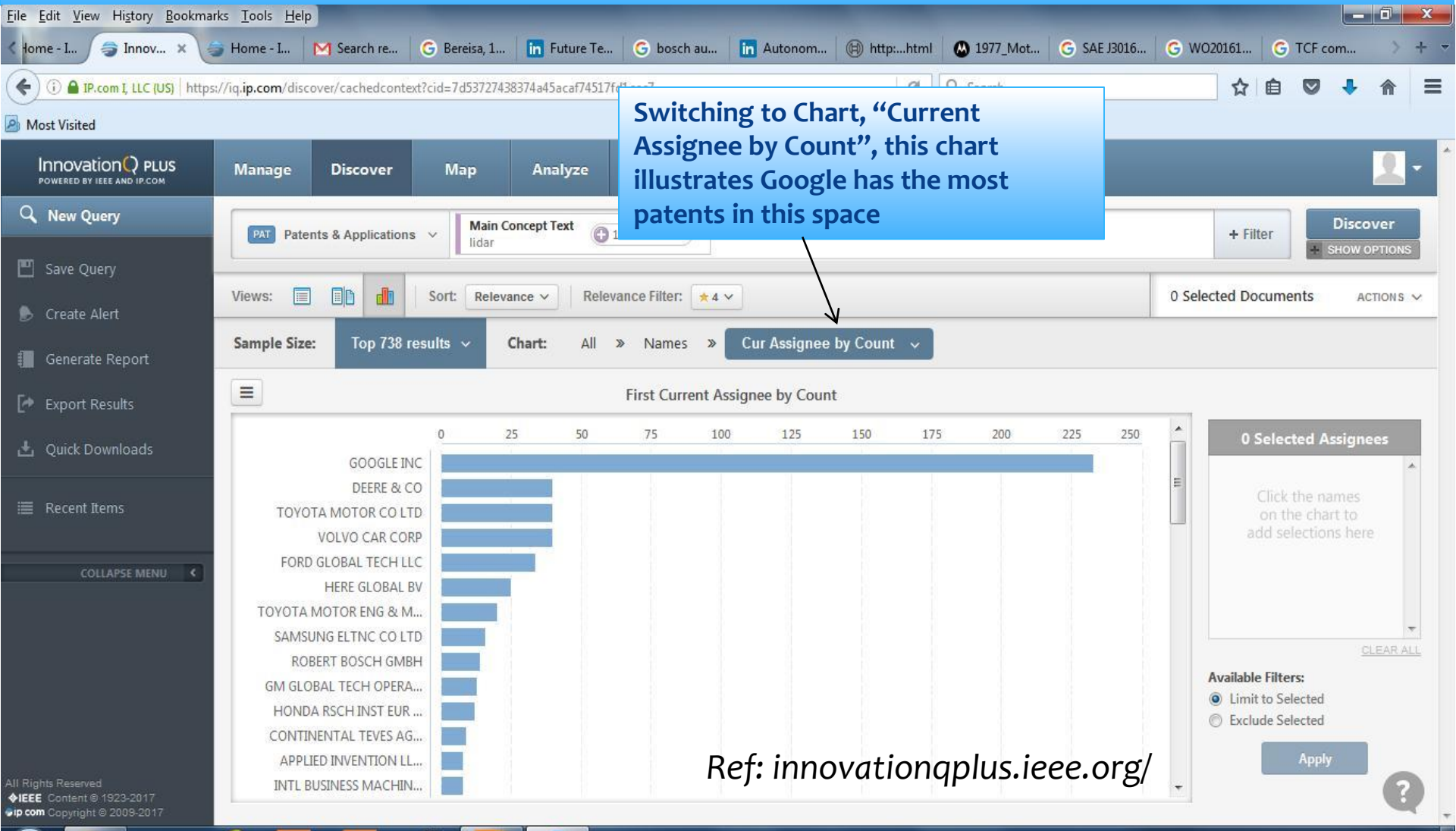

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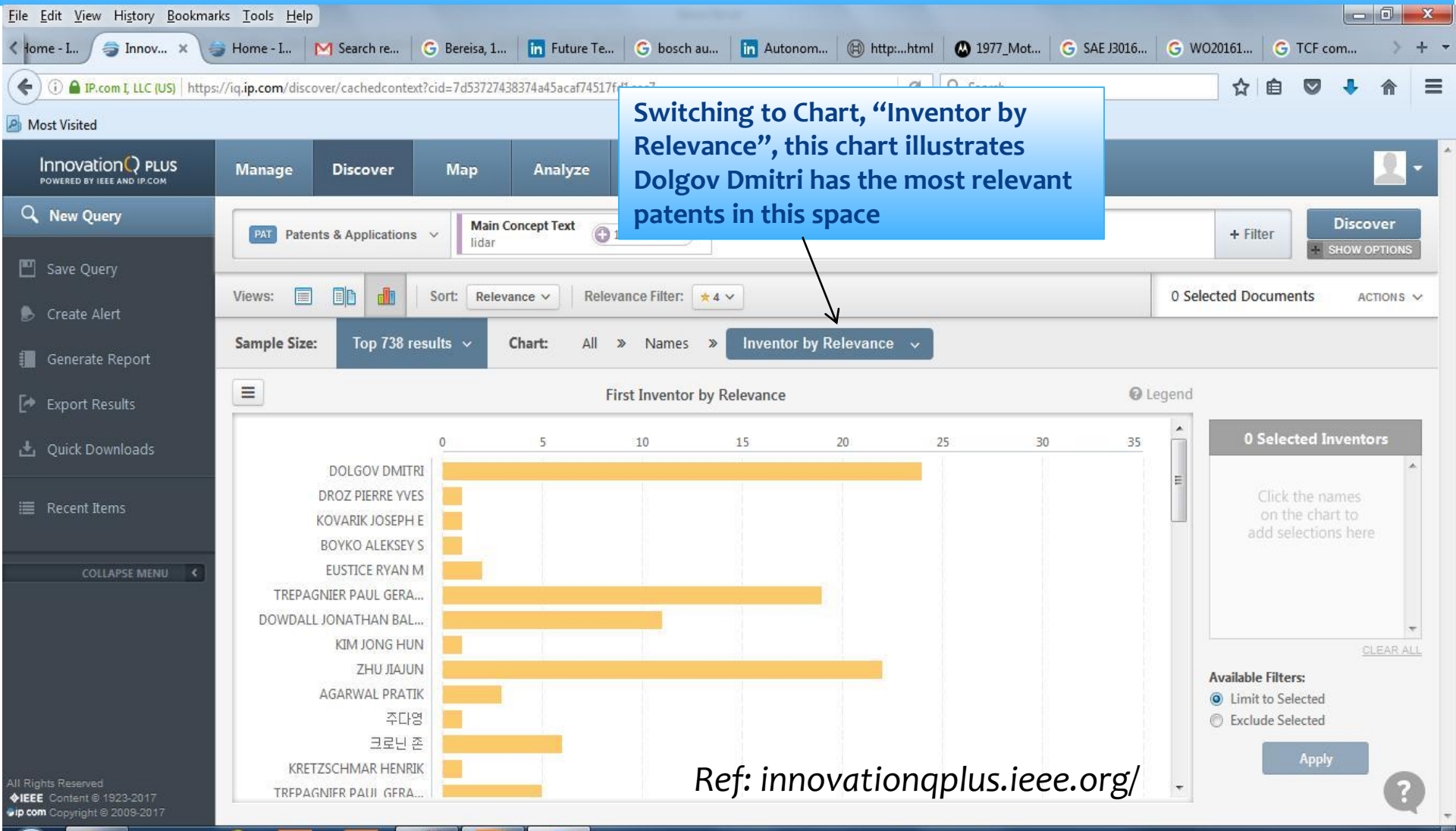

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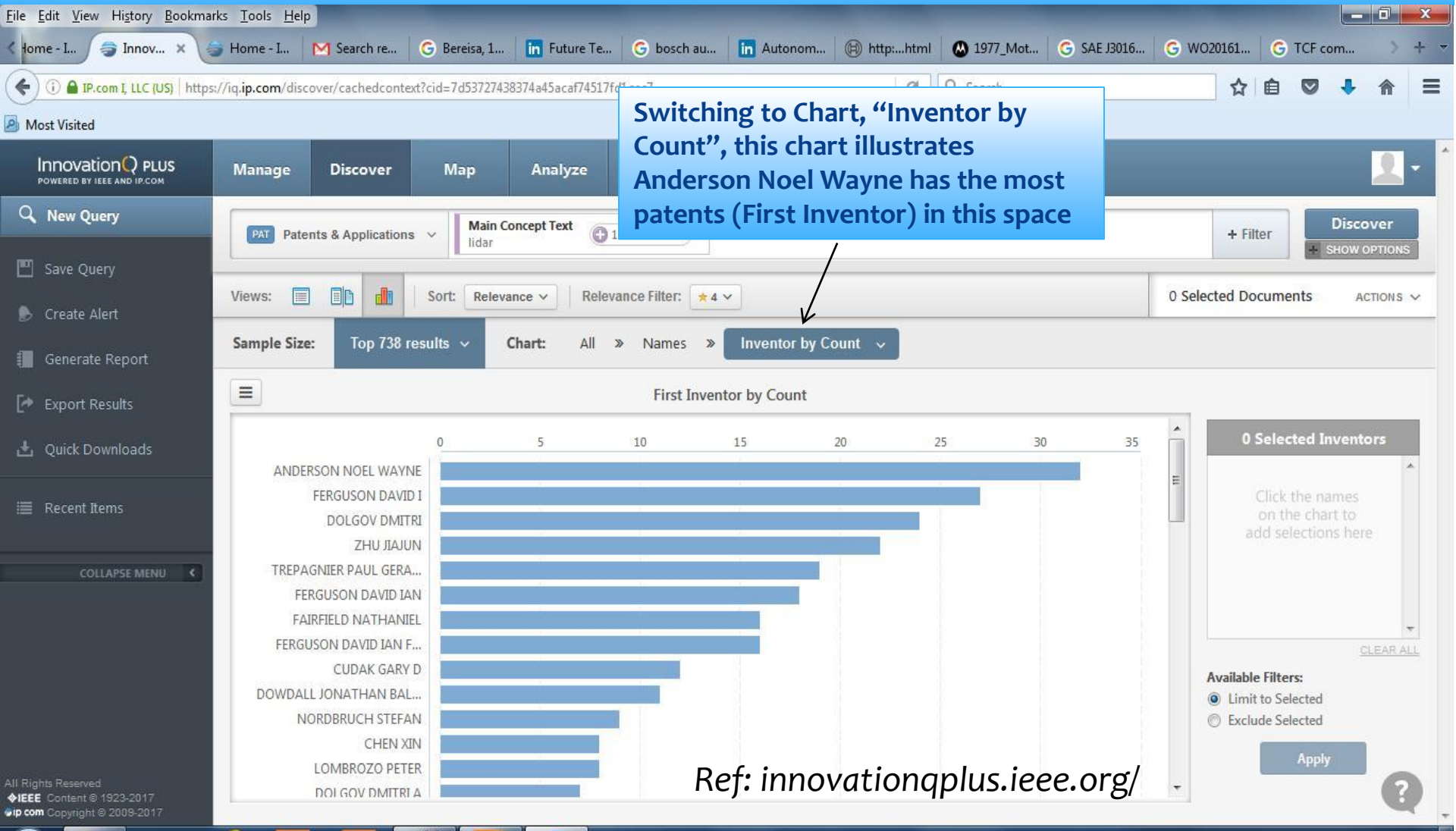

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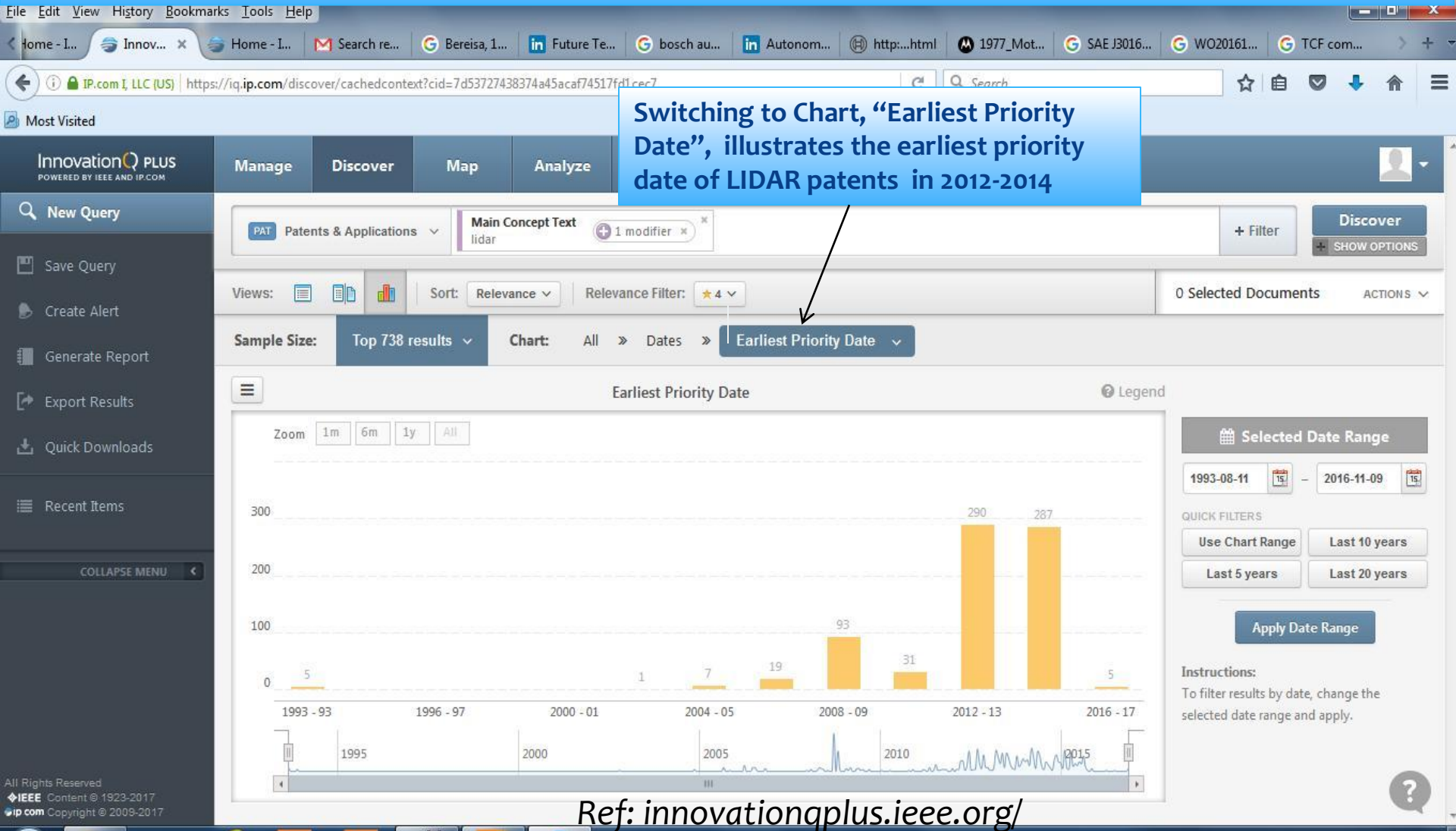

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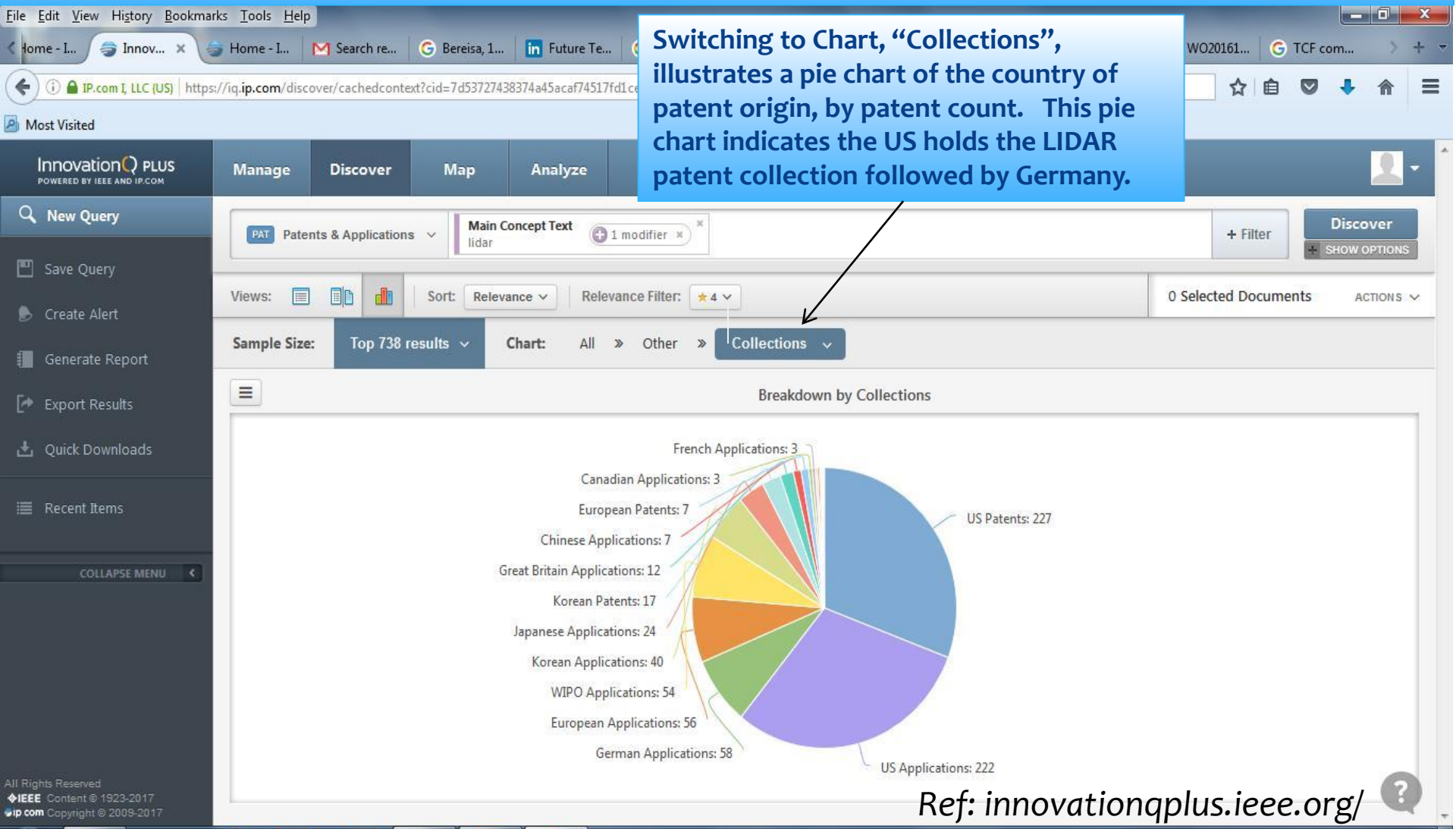
Switching to Chart, "Collections", illustrates a pie chart of the country of patent origin, by patent count. This pie chart indicates the US holds the LIDAR patent collection followed by Germany.



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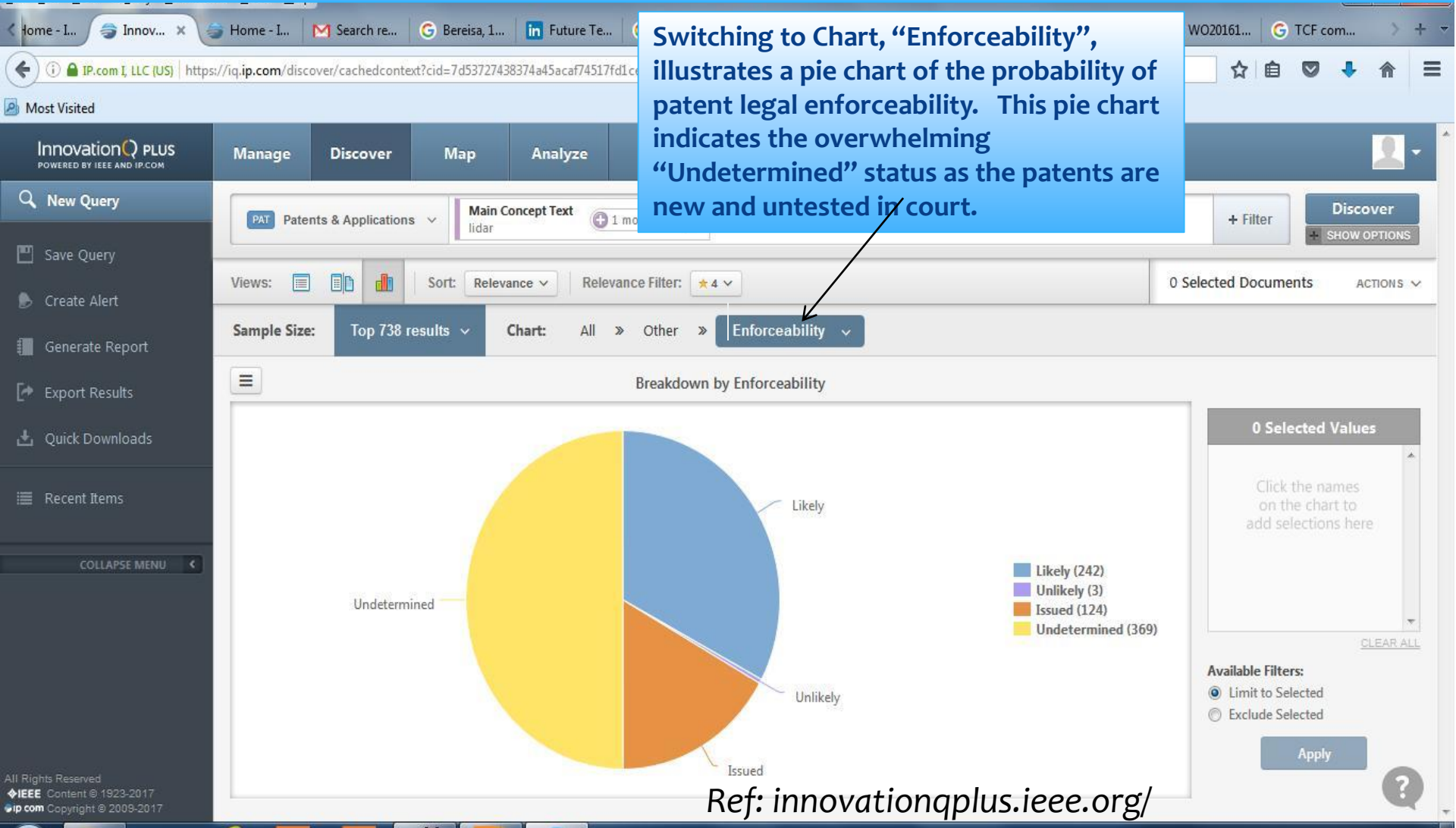
LIDAR SENSOR PATENT LANDSCAPE

LIDAR - Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges. Two variations, a spinning / MEMs or Solid State LIDAR.

Switching to Chart, "Enforceability", illustrates a pie chart of the probability of patent legal enforceability. This pie chart indicates the overwhelming "Undetermined" status as the patents are new and untested in court.



Ref: innovationqplus.ieee.org/