Electrical Engineering contributions to the Allied War effort in WWII

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IEEE Central Texas Section
Life Member Affinity Group
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Introduction

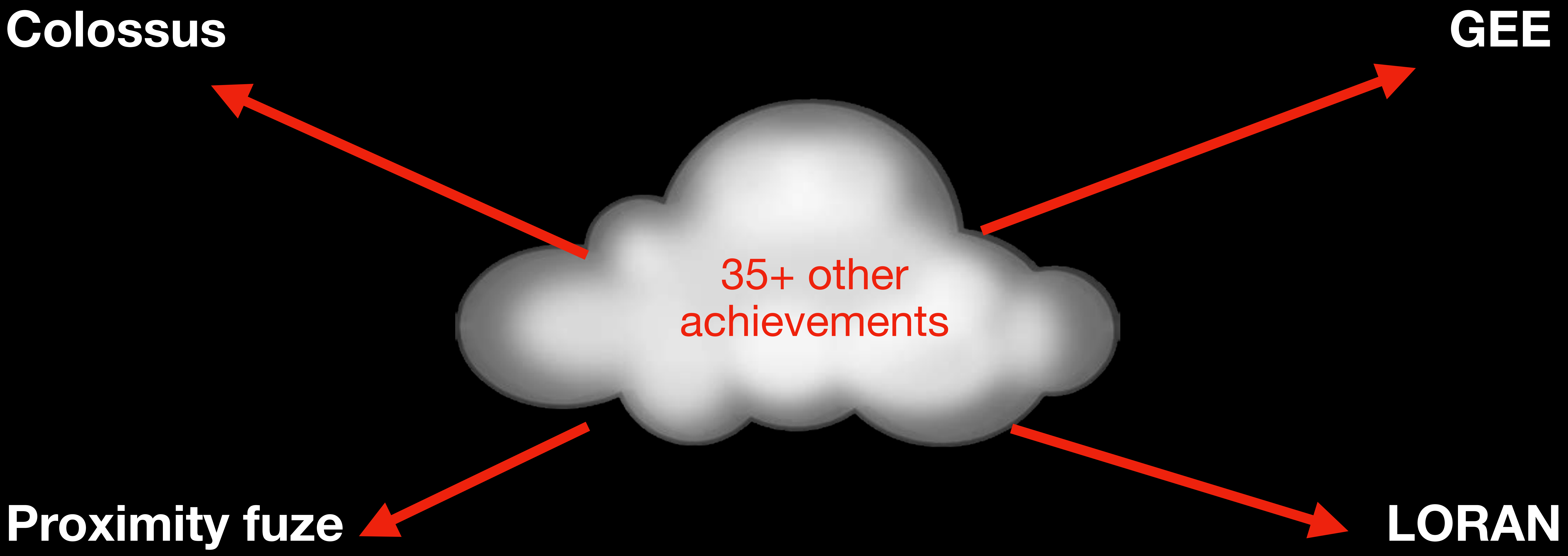
Why this topic?

- **Had a long standing interest in the WWII period**
- **Father and Uncle both served in WWII**
  - **Father with Allied headquarters in London, then in Paris**
  - **Uncle flew with 8th Air Force as radioman/gunner on a B-24**
- **I have volunteered as a docent at the Texas Military Forces Museum since July of 2019.**
  - **The 36th** Infantry Division has a rich history in WWII

Introduction (Cont'd)

- WWII history was something I wanted to dig deeper into
- Mythical 10000 hours of study making you an expert
  - Began quest to reach that goal
  - Books, Podcasts, documentaries
  - Just passed 2500 hours
- 30 September - 4 October IEEE History Week
- This topic seemed like a tie in to History Week at the nearest Life Member Affinity Group meeting

Engineers and scientists contributed to the Allied war effort in many ways



Partial List of Contributions

Computing
- Stibitz digital calculator
- US Navy Bombes
- Colossus
- Harvard Mark I
- ENIAC
- EDVAC
- Whirlwind

Navigation
- GEE
- LORAN

Anti-Submarine
- ASDIC
- Sonar
- FM Sonar
- Proximity fuse for depth charge
- Mark 24 Mine aka FIDO
- Passive sonar arrays
- Bathythermograph

Electronic Warfare
- Jamming

Aircraft
- AZON
- Drones
- Radio-controlled guidance of falling bombs
- Precision-guided munition

Radar
- Opana, Hawaii radar Site
- Chain Home radar stations
- Cavity Magnetron
- Proximity fuse
- Fire control radar
- British H2S
- Type 182 (Fishpond)

Communications
- The Gibson Girl survival radio
- VHF Radio
- Walkie Talkie
- SIGSALY
- Radio Relay

Training
- Television

Miscellaneous
- Magnetic mines
- Infra red night vision
- Buried Mine detection
- De Gaussing of Ships
- IFF responder
- Combat Information Center

Preparation

Preparation

Office of Scientific Research and Development (OSRD)

- Established by President Roosevelt in 1940, as National Defense Research Committee (NDRC) tasked with expanding the technological capacity of the country.
- The NDRC evolved into the OSRD And it entered into over 2,200 of R&D contracts with industrial and academic contractors, spending one to two orders of magnitude more than what the government was previously investing in science
- James Phinney Baxter III was the official historian of the Office of Scientific Research and Development during World War II. In his Pulitzer Prize–winning book, Scientists Against Time (1946), Baxter wrote that when the mission brought the cavity magnetron to America in 1940, “they carried the most valuable cargo ever brought to our shores."
- There were a total of 3,137 OSRD-funded, patented inventions

Preparation (Cont'd)

The Tizzard Mission, September 1940

- The British Technical and Scientific Mission Traveled to the US
- British Aeronautical Research Committee chairman Henry Tizard led the group
- He arranged to transfer UK military technology to the US in the event that Hitler's planned invasion of the UK should succeed
- They introduced US researchers to a number of UK developments in fields such as radar, jet propulsion, and also the early British research into the atomic bomb.

IEEE Milestone in Electrical Engineering and Computing

The IEEE Milestones in Electrical Engineering and Computing program honors significant technical achievements in all areas associated with IEEE. It is a program of the IEEE History Committee, administered through the IEEE History Center. Milestones recognize the technological innovation and excellence for the benefit of humanity found in unique products, services, seminal papers and patents.

Each milestone recognizes a significant technical achievement that occurred at least twenty-five years ago in an area of technology represented in IEEE and having at least regional impact. To date, more than a hundred and seventy Milestones have been approved and dedicated around the world.

Computing

Up to the 1940s, the word “computers” referred to people (mostly women) who performed complex calculations by hand.

Computing

Model 1 or Stibitz digital calculator

- In November 1937, George Robert Stibitz, then working at Bell Labs, completed a relay-based calculator he later dubbed the "Model K" (for "kitchen table", on which he had assembled it), which became the first binary adder
- The Model I, as the machine came to be called, was constructed between April and October 1939 at a cost of about $20,000

Computing (Cont'd)

Model 1 or Stibitz digital calculator

- It was a relay- based calculator with a seven-number memory capacity that could add, subtract, multiply, and divide complex numbers. It could add two eight-digit decimal numbers in a tenth of a second and took around a minute to multiply a pair of numbers
- The Mark I was very large consisting of two units: a panel containing about 400 to 450 relays, which performed the computations, and a teletype, outfitted with a special keyboard, which was used to enter mathematical problems and to record the answers.
- Even though it employed 440 relays it was found to be very reliable

Computing

US Navy Bombes

- The United States Naval Computing Machine Laboratory (NCML) was established in 1942 by the Navy and National Cash Register Company to design and manufacture a series of code-breaking machines ("bombes") targeting German Enigma machines, based on earlier work by the British at Bletchley Park
- plans were approved in January 1943 for an electromechanical machine, which became the US Navy bombe
- The first two experimental bombes went into operation in May 1943, running in Dayton so they could be observed by their engineers. Designs for production models were completed in April, 1943, with initial operation starting in early June.

Computing (Cont'd)

- Funding for a full, $2 million, navy development effort was requested on 3 September 1942 and approved the following day.
- The laboratory constructed 121 bombes which were then employed for code-breaking in the US Navy's signals intelligence and cryptanalysis group OP-20-G in Washington, D.C.
- Production was stopped in September 1944
- The U.S. Navy's Bombes, were seven feet high, two feet wide, and ten feet long. Each one weighed 5,000 lbs.

Computing (Cont'd)

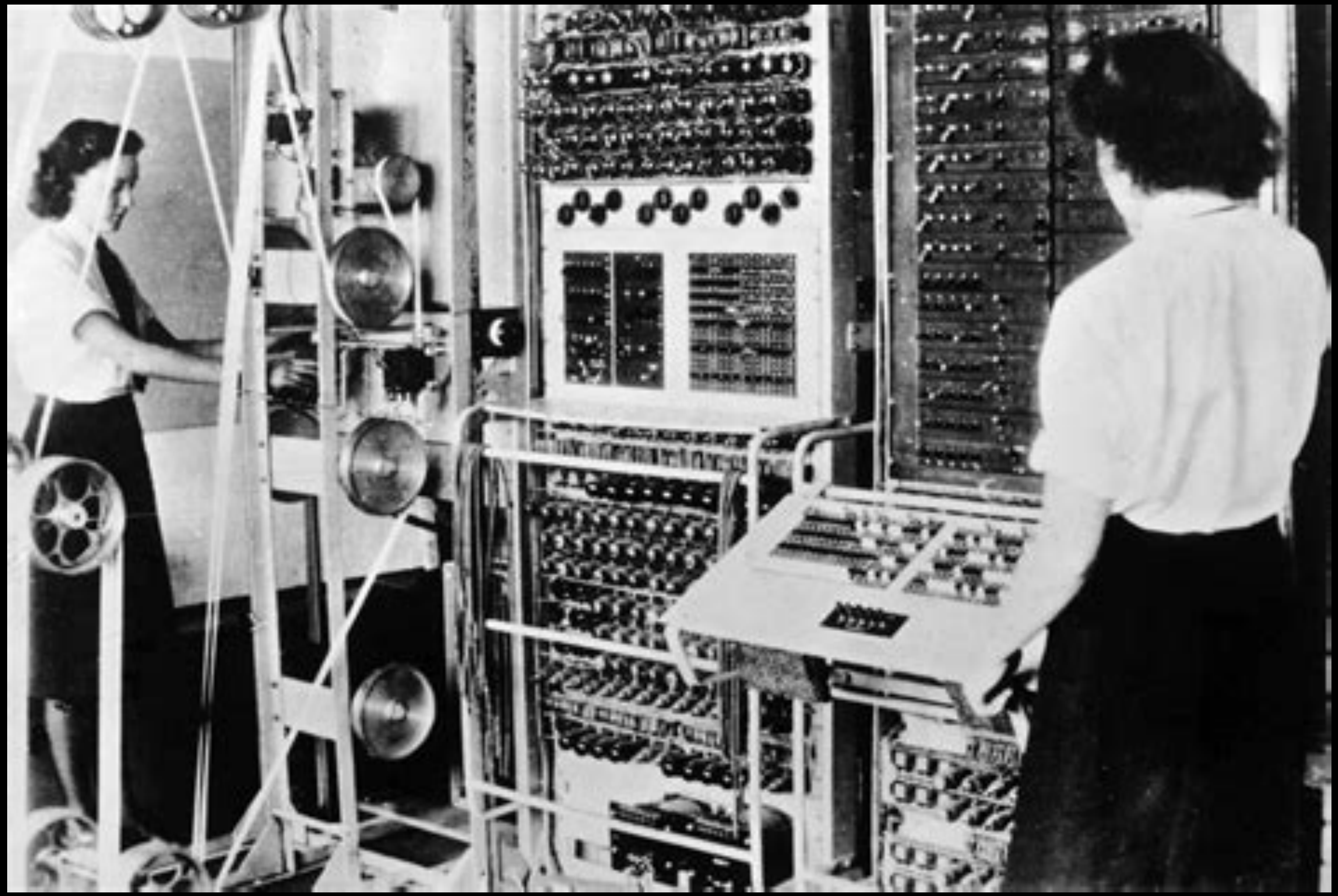
IEEE Milestone

US Naval Computing Machine Laboratory, 1942-1945, Dayton, Ohio, Dedicated 1 October 2001 - IEEE Dayton Section - In 1942, the United States Navy joined with the National Cash Register Company to design and manufacture a series of code-breaking machines. This project was located at the U.S. Naval Computing Machine Laboratory in Building 26, near this site. The machines built here, including the American "Bombes", incorporated advanced electronics and significantly influenced the course of World War II.

Computing

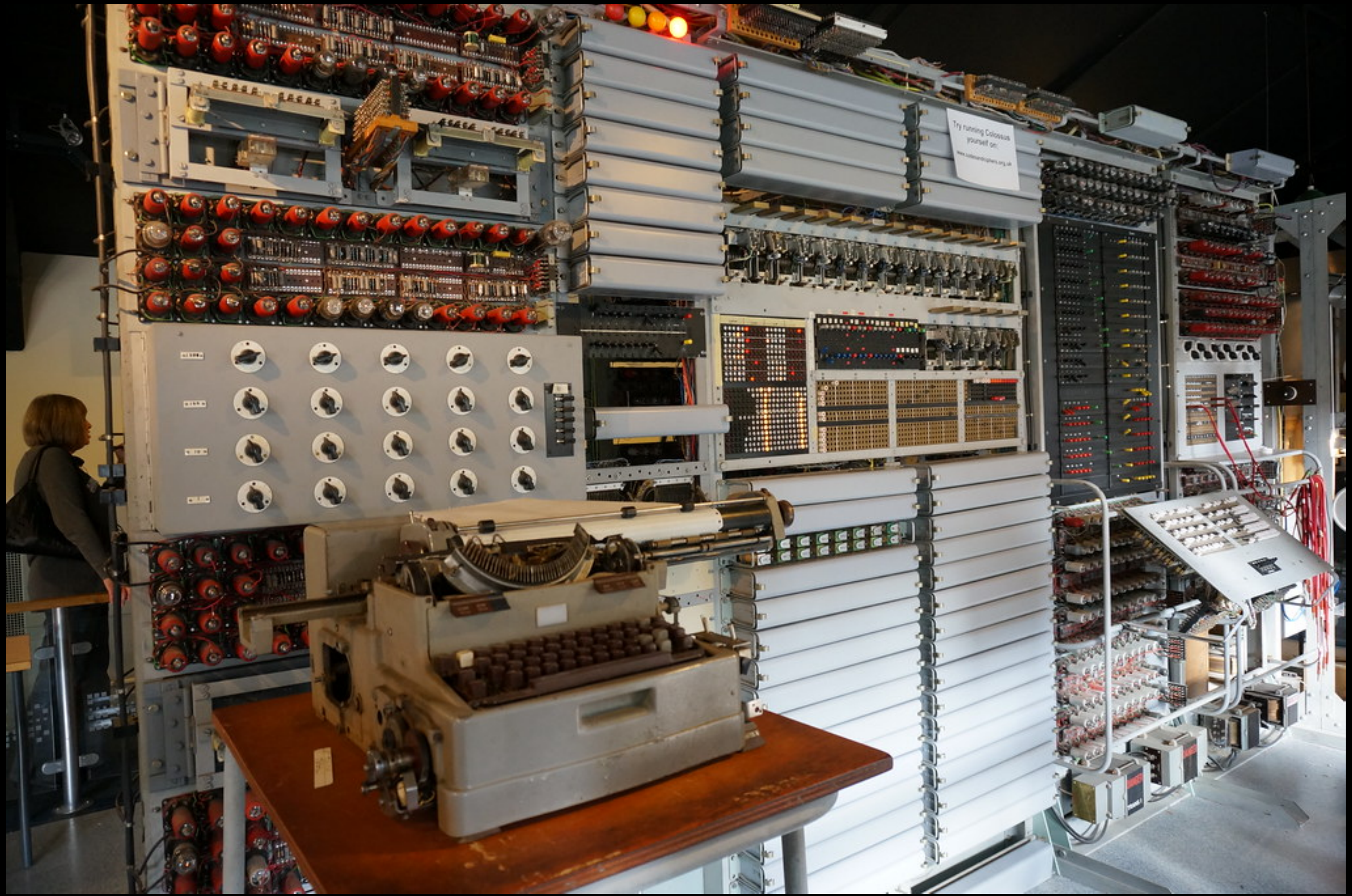
Colossus

- Colossus had an electronic memory, was programmable by means of switches and patch cords and could look for matching sequences that might help crack the code. Output was created by means of an IBM electric typewriter.
- The prototype, Colossus Mark 1, was entered service in December 1943 and was in use at Bletchley Park by early 1944.



Computing (Cent’d)

- An improved Colossus Mark 2 using shift registers to quintuple the processing speed
- Ten Colossi were in use by the end of the war and an eleventh was being commissioned.
- The prototype, Mark 1 Colossus, contained 1,600 thermionic valves (tubes)
- The Mark 2, the first of which contained 2,400 valves, became operational at 08:00 on 1 June 1944, just in time for the Allied Invasion of Normandy on D-Day

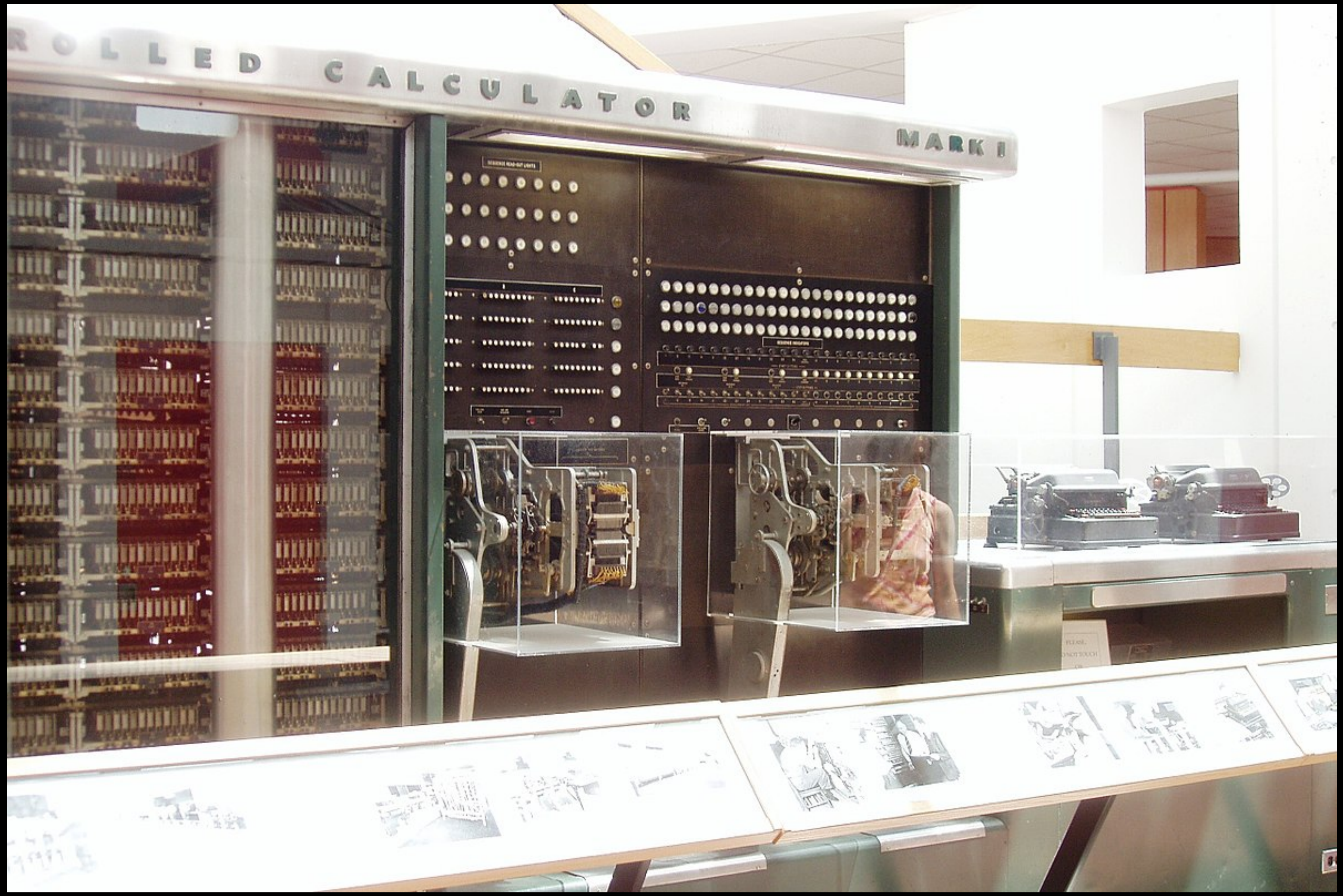


Colossus Mark 2, flickr.com

Computing

Harvard Mark I

- **Harvard and IBM worked together to fabricate the Automatic Sequence Controlled Calculator, later known simply as Mark I**
- **The Mark I was 70-ton electro-mechanical device installed on campus in 1944**
- **It is considered to be the first computer which could be programmed to execute complex calculations**



Harvard Mark I, en.wikipedia.org

Computing (Cont'd)

- Lieutenant Grace Hopper (later a U.S. Navy rear admiral) also programmed the Mark I machine at Harvard University during the war The Mark I consisted of a steel frame 51 feet long and 8 feet high that held the calculator.
- It consisted of an interlocking panel of small gears, counters, switches and control circuits, all only a few inches in depth.
- It used 500 miles of wire with three million connections, 3,500 multipole relays with 35,000 contacts, 2,225 counters, 1,464 tenpole switches and tiers of 72 adding machines, each with 23 significant numbers.

Computing (Cont'd)

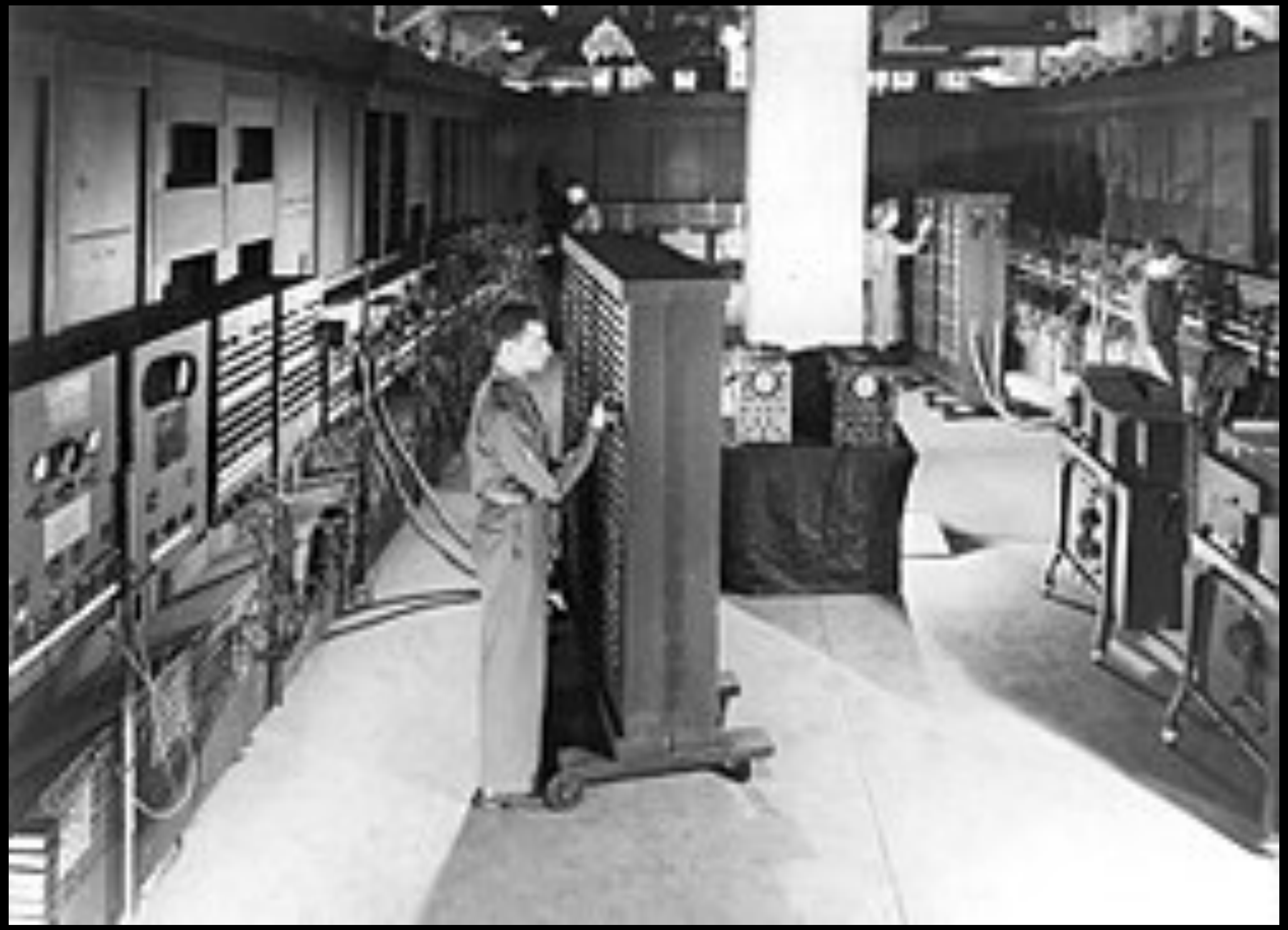
IEEE Milestone

Harvard Mark 1 Computer, 1944 - 1959, Cambridge, MA, Dedicated 10 November 2022 - IEEE Boston Section - The Mark I computer was a general-purpose electro-mechanical computer that could execute long computations automatically. It was conceived by Harvard University's Dr. Howard Aiken and built by International Business Machines Corporation in New York. The machine used mechanical punch-card tabulating equipment. Considered the first large-scale electro-mechanical computer, it was a leap forward in modern computing.

Computing

ENIAC (Honorable Mention)

- The Army was developing new artillery and each needed a range table
- At the time it took about twenty hours for a human to calculate one trajectory and each new gun needed about 500 trajectories in its range table. This meant that each new range table took about a month to calculate
- At the Moore School of Electrical Engineering under an Army contract the Electronic Numerical Integrator and Computer, or ENIAC was developed. It was primarily intended for calculating ballistic trajectories for artillery
- Work began on the machine in 1943 and only wrapped up in 1946
- ENIAC was the first programmable general-purpose electronic digital computer



ENIAC, en.wikipedia.org

Computing (Cont'd)

- It used plugboards for communicating instructions to the machine. This had the disadvantage that it took days to rewire the machine for each new problem
- ENIAC was built in the 50-by-30-foot basement of the Moore School.
- It consisted of 40 panels arranged in U-shape around three walls. Each panel was about 2 feet wide by 2 feet deep by 8 feet high.
- With more than 17,400 vacuum tubes, 70,000 resistors, 10,000 capacitors, 6,000 switches, and 1,500 relays, it was easily the most complex electronic system theretofore built.

Computing (Cont'd)

- When in operation it generated 174 kilowatts of heat
- It was constructed at a cost of more than $400,000
- It was the first computer to use electronic programming
- It had a high speed electronic "memory" based on vacuum tube circuits and could execute up to 5,000 additions per second

Computing (Cont'd)

IEEE Milestone

Electronic Numerical Integrator and Computer, 1946, Philadelphia, PA, U.S.A., Dedicated 1 September 1987 - IEEE Philadelphia Section - A major advance in the history of computing occurred at the University of Pennsylvania in 1946 when engineers put the Electronic Numerical Integrator and Computer (ENIAC) into operation. Designed and constructed at the Moore School of Electrical Engineering under a U. S. Army contract during World War II, the ENIAC established the practicality of large scale, electronic digital computers and strongly influenced the development of the modern, stored-program, general-purpose computer.

Computing

EDVAC (Honorable Mention)

- **Eckert ealized that if an electronic digital computer were designed to use binary logic wherein the only numbers are ones and zeros, he could store streams of binary numbers in such a “mercury delay line.” Circuits could also be built that could indefinitely refresh the number strings circulating in the lines to form a working high speed computer memory.**
- **By midsummer 1944 Eckert and Mauchly had prepared a preliminary design of a general purpose computer that could store instructions and data in a memory fast enough to work with an electronic central processing unit.**

EDVAC, en.wikipedia.org

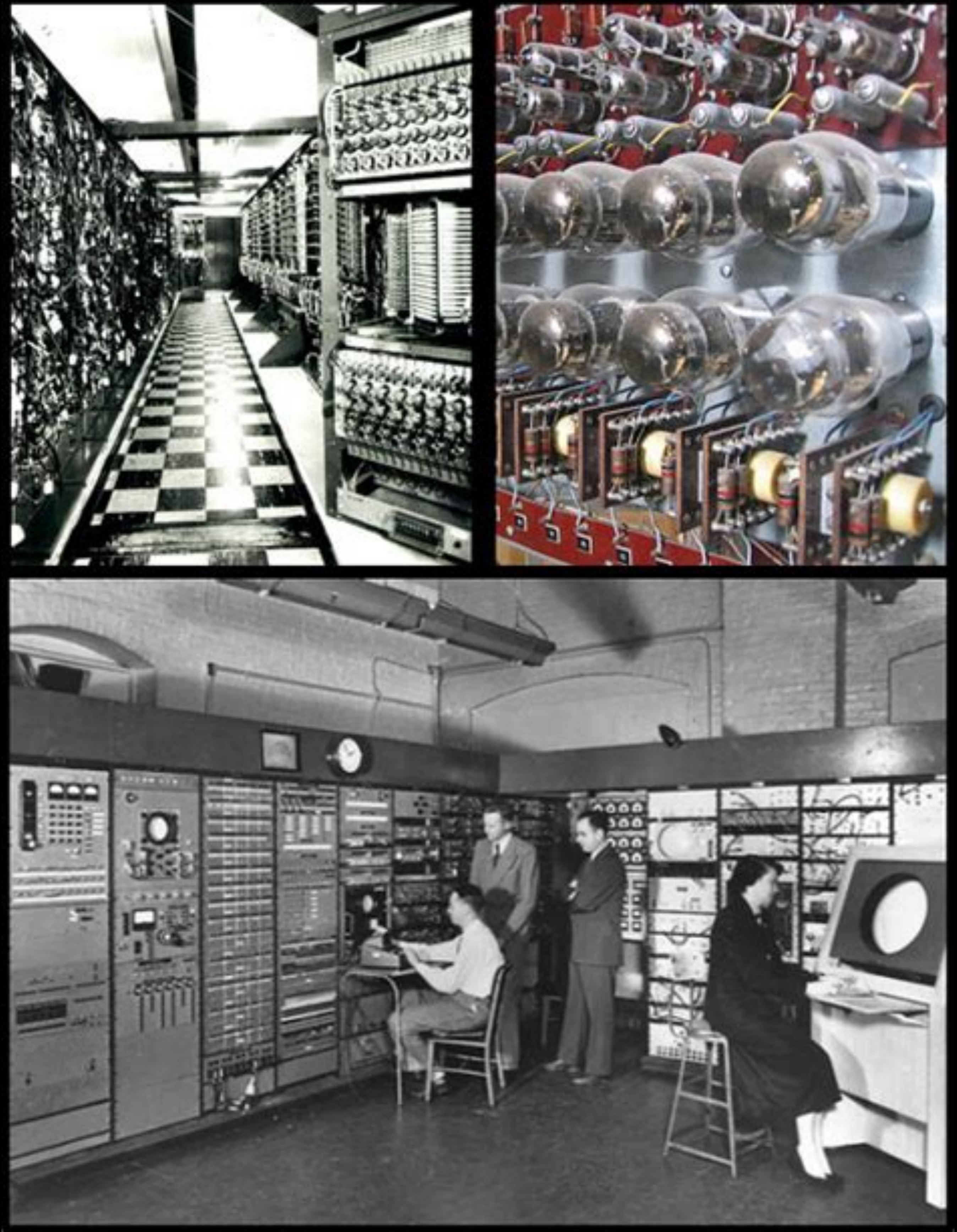
Computing

- The memory used 126 mercury delay lines which could store 1,024 forty four-bit binary numbers. Because of the high speed serial binary logic, EDVAC used only 3,500 vacuum tubes
- 1950 EDVAC had been installed at the Army's Aberdeen, MD, Ballistic Research Laboratory, and was in testing.

Computing

Whirlwind (Honorable Mention)

- In 1943 the head of Special Devices Division of the Navy’s Bureau of Aeronautics, wished to simulate the dynamics and pilot handling qualities of newly designed aircraft without actually building and flying the airplane.
- He had in mind a highly sophisticated version of the venerable Link blind flying trainerHe envisioned a large electronic analog computer, programmed with airplane stability derivatives obtained from wind tunnel testing of models of the aircraft to be simulated, which would compute the craft’s path through the air, its velocity, its lateral and vertical translations and its motions in roll, pitch and yaw. The computer would even move the cockpit by sending signals to mechanical servomechanisms



Whirlwind, flickr.com

Computing (Cont'd)

- In October 1945 he attended a conference on advanced computation techniques given on the MIT campus. Here he learned about the Moore School's ENIAC computer, and became convinced that a digital computer could be simpler and more reliable than the massive analog computer envisioned for the 2-K flight simulator.
- By March 1946 the flight simulator project was of diminishing interest to the Navy, but the Office of Research and Invention did approve development of the computer. It was to be completed at a cost of $1.2 million and delivered by June 1948.
- Whirlwind was in operation by March 1951
- It had electrostatic memory, and was running approximately 35 hours per week. It occupied 2,500 square feet and used 5000 vacuum tubes as well as 11,000 crystal rectifiers.

Computing (Cont'd)

IEEE Milestone

Whirlwind Computer, 1944-59, Cambridge, Massachusetts, Dedicated 27 June 2012 - IEEE Boston Section - The Whirlwind computer was developed at 211 Massachusetts Avenue by the Massachusetts Institute of Technology. It was the first real-time high-speed digital computer using random-access magnetic-core memory. Whirlwind featured outputs displayed on a CRT, and a light pen to write data on the screen. Whirlwind's success led to the United States Air Force's Semi Automatic Ground Environment - SAGE - system and to many business computers and minicomputers.

Navigation

Navigation

GEE

- **Gee, sometimes written GEE, was a radio-navigation system used by the Royal Air Force during World War II. The original design proposal was submitted in June 1940.**
- **It was the first Hyperbolic navigation systems that relied on the measurement of time delay between two radio signals to produce a fix. It entered service with RAF Bomber Command in 1942**
- **The accuracy was on the order of a few hundred metres at ranges up to about 350 miles**
- **For large, fixed targets, such as cities that were attacked at night, Gee offered enough accuracy to be used as an aiming reference**

Airborne GEE unit, en.wikipedia.org

Navigation (Cont'd)

- Experimental systems were set up in June 1940. By July the system clearly was usable to at least 300 miles at altitudes of 10,000 feet.
- Gee proved itself to be easy to use and more than accurate enough for its tasks. On 18 August 1941, Bomber Command ordered Gee into production
- 300 hand-made sets was placed for delivery on 1 January 1942
- Overall, 60,000 Gee sets were manufactured during World War II, used by the RAF, USAAF, and Royal Navy
- The first operational mission using Gee took place on the night of 8/9 March 1942, when a force of about 200 aircraft attacked Essen. It was installed on a Wellington. In total, 33% of the aircraft reached the target area, an enormous advance over earlier results.

Navigation (Cont'd)

- The first completely successful Gee-led attack was carried out on 13/14 March 1942 against Cologne. The leading crews successfully illuminated the target with flares and incendiaries and the bombing was generally accurate.
- A single pair of such transmitters would allow the aircraft to determine on which line they were, but not their location along it. For this purpose, a second set of lines from a separate station would be required. Ideally, these lines would be at right angles to the first, producing a two-dimensional grid that could be printed on navigational charts.
- an oscilloscope in the aircraft measured the time difference between two signals to determine location

Navigation

LORAN

- LORAN (LOng RANge Navigation) is a hyperbolic radio navigation system based on measuring the time-delay between sets of radio signals similar to the British GEE system
- The advantage of LORAN over celestial navigation is that it was more accurate during the day, worked at night , and in poor weather
- Orders for initial systems were sent out in December 1940 and became operational in early 1943
- It was used used for both naval vessels and aircraft
- While similar to the Gee system, LORAN operated at lower frequencies in order to provide an improved range up to 1,500 miles with an accuracy of tens of miles.
- LORAN used two frequency bands, at 1.85 and 1.95 MHz. These lower frequency systems were found to be much more stable electronically than the higher frequencies of GEE, nor was the accuracy of GEE needed

Navigation (Cont'd)

- It was first used for ship convoys crossing the Atlantic Ocean, and then by long-range patrol aircraft
- The enormous distances and lack of useful navigation points in the Pacific Ocean led to widespread use of LORAN for both ships and aircraft during the Pacific War. In particular, the accuracy offered by LORAN allowed aircraft to reduce the amount of extra fuel they would otherwise have to carry to ensure they could find their base after a long mission. This reduced fuel load allowed the bombload to be increased.
- By the end of World War II there were 72 LORAN stations, with over 75,000 receivers in use.

Navigation (Cont'd)

IEEE Milestone

Loran, 1940 - 1946, Cambridge, MA, U.S.A., Dedicated 27 June 2012 - IEEE Boston Section - The rapid development of Loran -- long range navigation -- under wartime conditions at MIT's Radiation Lab was not only a significant engineering feat but also transformed navigation, providing the world's first near-real-time positioning information. Beginning in June 1942, the United States Coast Guard helped develop, install and operate Loran until 2010.

Anti-Submarine Warfare

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Anti-Submarine Warfare

ASDIC

- The British began development in 1917 at the end of WWI
- In September 1940, British ASDIC technology was transferred for free to the United States. Research on ASDIC and underwater sound was expanded in the UK and in the US. Many new types of military sound detection were developed.
- Developments during the war resulted in British ASDIC sets that used several different shapes of beam, continuously covering blind spots.
- It used quartz piezoelectric crystals to produce the world's first practical underwater active sound detection apparatus
- It required an attacking vessel to pass over a submerged contact before dropping charges over the stern, resulting in a loss of ASDIC contact in the moments leading up to attack

Anti-Submarine Warfare (Cont'd)

- The strategy was modified into a creeping attack. Two anti-submarine ships were used. The "directing ship" tracked the target submarine on ASDIC from a position about 1500 to 2000 yards behind the submarine. The second ship, with her ASDIC turned off and running at 5 knots, started an attack from a position between the directing ship and the target.
- This attack was controlled by radio telephone from the directing ship, based on their ASDIC and the range (by rangefinder) and bearing of the attacking ship. As soon as the depth charges had been released, the attacking ship left the immediate area at full speed. The directing ship then entered the target area and also released a pattern of depth charges. The low speed of the approach meant the submarine could not predict when depth charges were going to be released.

Anti-Submarine Warfare

Sonar

- Work began on Sonar in 1930s
- By 1940, US sonars typically consisted of a magnetostrictive transducer and an array of nickel tubes connected to a 1-foot-diameter steel plate attached back-to-back to a Rochelle salt crystal in a spherical housing. This assembly penetrated the ship hull and was manually rotated to the desired angle.
- The 24 kHz Rochelle-salt transducers were replaced with ADP crystals.
- The ADP manufacturing facility grew from few dozen personnel in early 1940 to several thousands in 1942.

Anti-Submarine Warfare (Cont'd)

- By the end of the war standard US Navy scanning sonar operated at 18 kHz, using an array of ADP crystals
- Echo ranging systems detected U-boats with a series of pings that would echo back providing a distance and direction. To scan a 180 degree arc of water out to 5,000 yards using 5 degree increments, it took four minutes of pinging–sound waves in ocean water travel at a substantially constant rate of about 1,600 yards per second.

Anti-Submarine Warfare

FM Sonar

- Echo Ranging System (FM Sonar) – U.S. Patent 2,724,817 [11]
- This was a frequency modulated, pulsed active sonar, shortened to FM Sonar.
- This innovation allowed the Navy to track multiple targets with a single ping. The Navy registered it with the patent office in 1943.

Anti-Submarine Warfare

Proximity fuse for depth charge

- Apparatus for firing an underwater depth charge – U.S. Patent 3,511,182
- This addition detonated the depth charge only when it was close enough to damage the enemy submarine using a magnetostriction loudspeaker-microphone oscillator unit provided with a vibratory diaphragm and a three-quarter wavelength magnetostriction rod.
- It also prevented other depth charges from premature detonation caused by the shock of other charges exploding nearby.

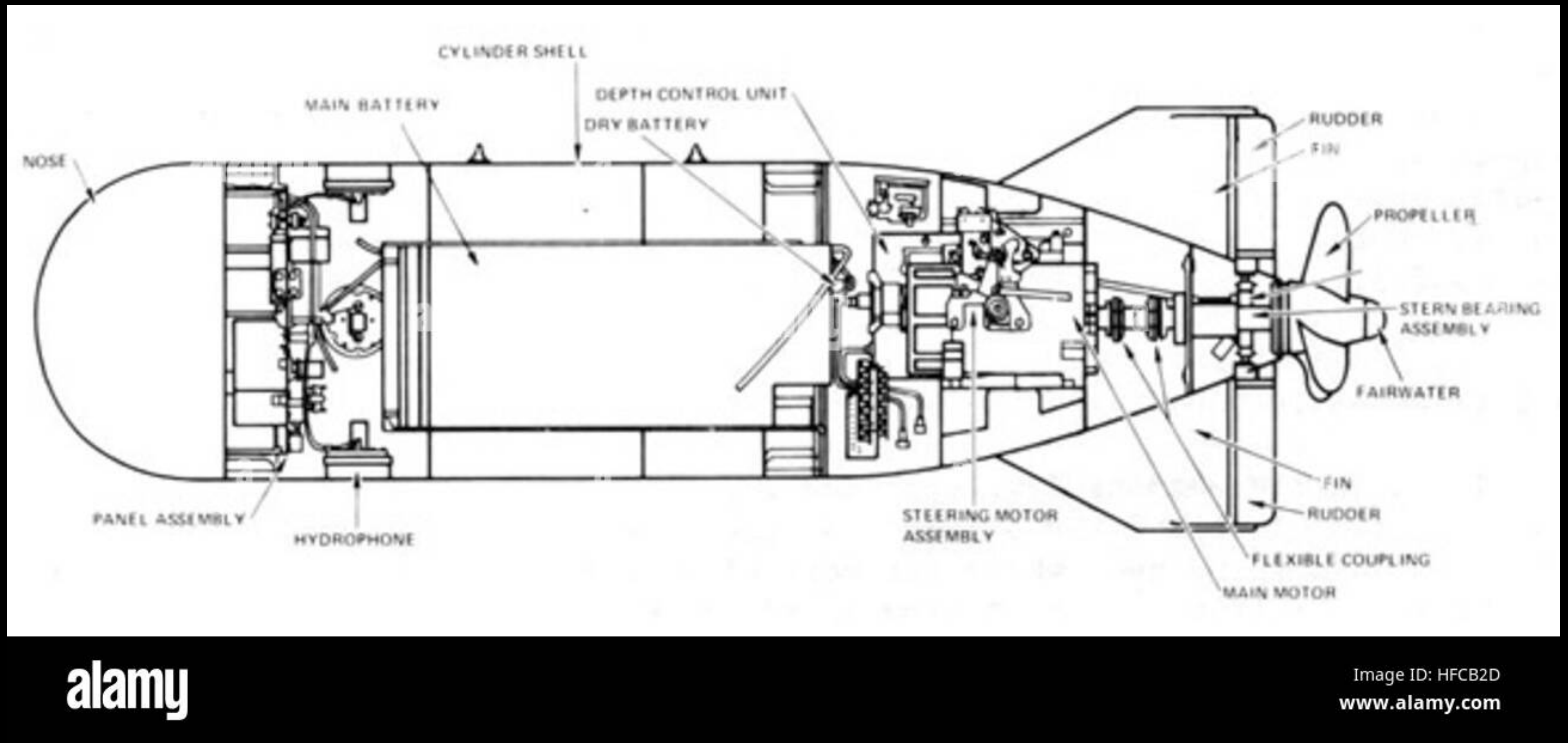
Anti-Submarine Warfare

Mark 24 Mine aka FIDO

- Fido was an acoustic torpedo
- USN studies for Fido began in late-1941.
- The torpedo entered service March 1943 and it was used until 1948.
- Approximately 4,000 were produced. 340 were deployed during the war. The 204 that were fired sunk 37 and damaging 18 German submarines
- Fido wad 19 inches in diameter, 84 inces long and weighed 680 pounds. The warhead contained 92 pounds of HBX explosives

Anti-Submarine Warfare

- The Mark 24 Mine or Fido was driven by a 7.5 hp off-the-shelf General Electric Washing Machine electric motor. A single propeller provided thrust.
- Power was applied by an on-board 48 volt lead acid battery
- Fido wad could reach a speed of 12 knots (22 km/h) for up to 10 minutes. This gave a range of about 4,000 yards
- The on-board homing system consisted of 4 piezoelectric hydrophones operating at 24 kHz and vacuum tube signal processing system with proportional steering.



Mark 24 Mine Diagram, alma.com

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Anti-Submarine Warfare

Passive Sonar Arrays

- Passive sonar arrays for submarines were developed from ADP crystals.
- Several crystal assemblies were arranged in a steel tube, vacuum-filled with castor oil, and sealed. The tubes then were mounted in parallel arrays.

Anti-Submarine Warfare

Bathythermograph

- Bathythermograph – U.S. Patent 2,515,034
- The Bathythermograph is useful when searching for submarines because temperature variations can cause inaccurate sonar tracking
- A bathythermograph is a small torpedo-shaped device that holds a temperature sensor and a transducer to detect changes in water temperature at versus depth down to approximately 900 feet.

Bathythermograph, Britannica.com

Anti-Submarine Warfare (Cont'd)

- The device is lowered from a ship into the water, and the temperature changes are recorded. Data was recorded on a glass slide and read once the bathythermograph was brought back to the ship.
- Because the bathythermograph would quickly react to changes in water temperature, it could be quickly lowered and retrieved from a moving vessel with accurate temperature results

Electronic Warfare

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Electronic Warfare

Jamming

- Transmitters were designed to jam radio channels, radar, navigation signals, and other military electronics
- American, British and Canadian scientists also developed sophisticated radio jammers to disrupt signal.
- Ultimately nine different jamming systems were deployed in the European theater against German glide bombs

Drones and guided bombs

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Drones and guided bombs

AZON

- The VB-1 AZON (from "AZimuth ONly" control) was a 1000 pound guided munition
- Once dropped it fell as a regular bomb on a gravity defined ballistic path
- The guidance system allowed the bomb to be steered left or right to hit the intended target
- It was used in both Europe and the CBI Theater

Nationalmuseum.af.mil

Drones and guided bombs

USN Bat

- The ASM-N-2 Bat was more advanced than the USAAF's VB-1 AZON
- It was the first guided missile used in combat. It had a long range and was very accurate
- It had its own on board, autonomous active radar seeker system to direct it to a target
- It was first used in the Pacific in August 1944
- It had difficulty distinguishing targets in a cluttered environment and could easily be misled by enemy countermeasures
- Primarily used in the Pacific Theater
- The Bat weighed 1000 pounds
- The Bat emitted shortwave radiation and was guided by the resulting radar echoes of the target

TBF Avenger carrying a Bat, flickr.com

Drones and guided bombs

Drones

- **Project Aphrodite was a program by the USAAF to use obsolete B-17s and PBY4s as radio controlled bombs. The missions flown were not generally successful**
- **By late 1943, commander of the USAAF General Henry H. Arnold, General directed Brigadier General Grandison Gardner's electronic engineers at Eglin Field, Florida, to outfit obsolete aircraf with automatic pilots so that they could be remotely controlled**
- **Project Aphrodite was ordered in June for the 8th Air Force to carry out at RAF Honington, in the UK**

en.wikipedia.org

IEEE Life members

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Drones and guided bombs

- B-17F and B-17G bombers were stripped of as much as possible to reduce their weigh by about 12,000 pounds. This allowed the aircraft to be loaded with more than twice the explosives of a normal B-17 bomb payload.
- The Azon bomb control system was adapted for use to control the aircraft. The standard AZON system could only control one axis of movement. Two systems were used to provide guidance in two directions.
- Two television cameras were added to the cockpit. One allowed the controlling aircraft to view thee main instrumentation panel. A second was placed in the nose to give a forward view. This was to allow the aircraft to be aimed at its target. The TV signals were transmitted from an antenna in the tail gun position of the B=17
- A whip aerial on the nose of the mothership received the signals

Drones and guided bombs

- The drone was flown by a volunteer crew of a pilot and a flight engineer to an altitude of 2,000 ft before control was transferred to the mothership operators. After successful turnover of control of the drone, the two-man crew would arm the payload and bail out.
- The aircraft control system was updated from the "double Azon" an improved system brought from the US named Castor
- The Castor missions were targeted against enemy installations that did not require long flights over enemy territory so reducing likelihood of the drone being brought down by flak.
- The approach of an end of the war in Europe caused the project to be canceled on 27 April

Drones and guided bombs

- Of 14 missions flown, none resulted in the successful destruction of a target.
- Many aircraft lost control and crashed or were shot down by flak, and many pilots were killed, though a handful of aircraft scored near misses.
- One notable pilot death was that of Lieutenant Joseph P. Kennedy, Jr., USNR, son of the former US Ambassador to the UK, who was expected to have a political career in the US and was the elder brother of future US President John F. Kennedy.

Radar

some historians have claimed that radar helped the Allies win the war more than any other piece of technology

Radar

Chain Home radar stations

- The Chain Home system was completed In 1940 and was deployed along the south and eat coasts of the UK
- With that system in place air defense were alerted nearly half an hour before attacking aircraft ere over Britain. The Chain Home system was a crucial part of the Dowding System, Britain's highly effective and sophisticated air defence network.
- Incoming aircraft could be picked up at a range of 80 miles
- The Chain Home system was designed to work at 25 MHz
- Chain Home stations were huge, static installations with steel transmitter masts over 100 metres high

flickr.com

Radar

- It was a pulsed radar system sending a burst of radio energy at a target, then measured the time it took for the energy to reflect back to its receiver. The radar calculated the range to the target by multiplying the time between sending the pulse and its return by the speed of light and then dividing by two.
- Chain Home relied on antennas that illuminated a huge area, like a floodlight. These antennas did not move or scan at all. Rather, Chain Home radar operators chose a target ("blip") on their screen and turned the knob of a special coil-like instrument to null out or minimize the blip.
- Then they could read the direction to this target from a scale around the knob. This device (called a radio goniometer) electronically steered the nulls from a pair of simple fixed receiving antennas.
- The Germans never made an effort to destroy the radar stations. Herman Göring, Luftwaffe's Commander, was convinced that the British radar towers were just a bluff

Radar

Cavity Magnetron

- The British developed the palm-size Magnetron CV1481 radar valve
- This was one of the technologies brought to the US by the Tizzard Mission
- The split-anode magnetron produced high-power microwaves,
- The cavity magnetron consisted of a cylindrical piece of metal that had a cathode running through a central hole. The surrounding anode had a series of symmetrical holes, or cavities, arranged in a circle around the central hole. The cross section looked like the chamber of a Colt revolver.
- When power was supplied to the cathode and a magnetic field surrounded the device, the oscillation of the electric charge around the cavities led to the radiation of electromagnetic waves. Each cavity created its own resonant frequency.

Iwm.org.uk

Radar

- A significant amount of development was undertaken at MIT in the US to improve and apply the device
- It was capable of generating 500 pulses per second and the pulse duration ranged from 0.7 to 2 μs. It could run at 3000MHz with a 450kW peak output
- During the war years, under government contract, the Massachusetts-based Raytheon Manufacturing Company became a major producer of the new cavity magnetron tubes and radar systems

Radar

IEEE Milestone

Development of the Cavity Magnetron, 1939-1941, Birmingham UK, Dedicated 4 June 2024 - IEEE United Kingdom and Ireland Section - in this building from 1939 to 1941, University of Birmingham researchers John Randall, Harry Boot, and James Sayers conceived and demonstrated fundamental ways to improve the output power, efficiency, and frequency stability of cavity magnetrons. Further developed and refined by others, these advances facilitated the Allies' deployment of microwave radar systems in World War II. Cavity magnetrons were later adapted for use in industrial heating and microwave ovens.

Radar

Opana, Hawaii radar site

- **At the time the US entered WWII the 105-MHz SCR-270 and the 205-MHz SCR-268 radar systems were available for use.**
- **There were 5 mobile SCR-270 radar stations deployed on Oahu. Each radar system was manned by a crew of 2 trainees. On the morning of December 7th all of the tower crews had finished their training and shut down at 7 am, but one ambitious crewman let his station run a little longer.**
- **An operator detected the massive Japanese attack that was heading for Pearl Harbo. He couldn't believe his eyes when he saw a big blur on the screen, in which he couldn't even count the number of planes,**

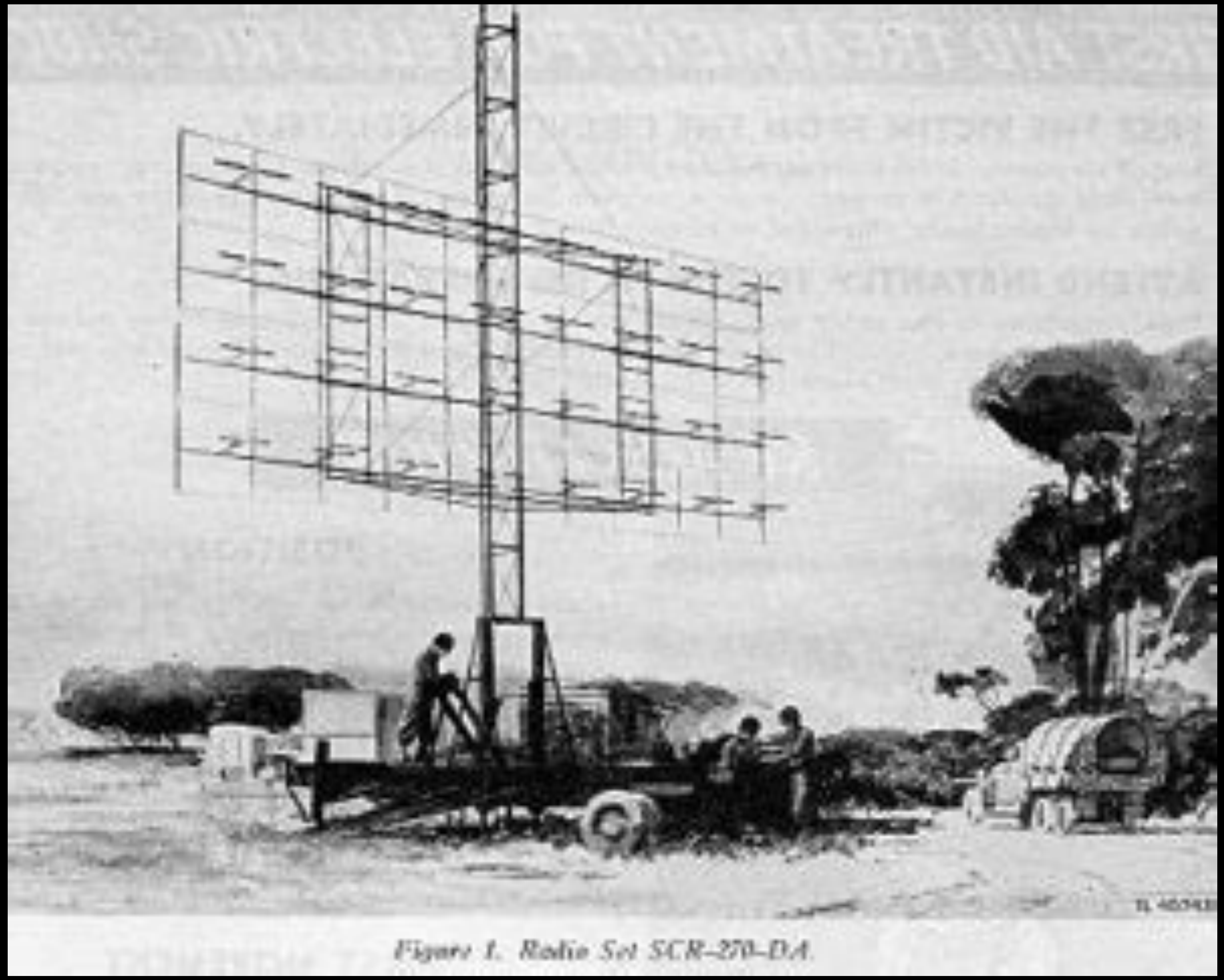


Figure 1. Radio Set SCR-270-DA

infoage.org

Radar

- Without other stations to triangulate he couldn't confirm it. He initially hesitated to call headquarters for verification, and then when he did, the lieutenant on duty didn't quite believe him, assuming the contact was a rookie's mistake or the product of faulty equipment. By the time he finally got around to verifying the information, the planes had gone past a big hill and vanished from the radar.

Radar

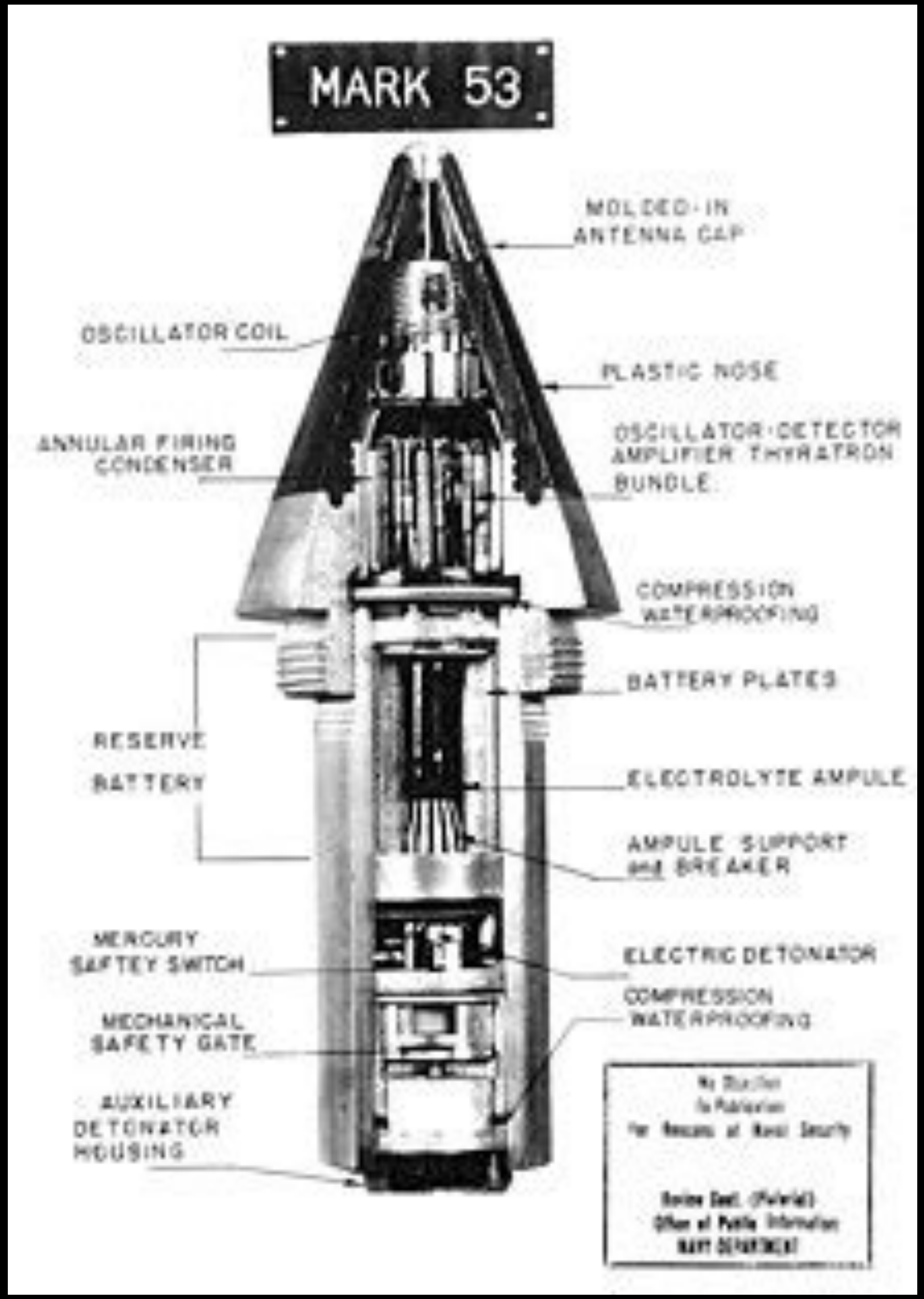
IEEE Milestone

Opana Radar Site, 1941, Kuhuku, Hawaii, U.S.A., Dedicated 1 February 2000 - IEEE Hawaii Section - On December 7, 1941, an SCR-270b radar located at this site tracked incoming Japanese aircraft for over 30 minutes until they were obscured by the island ground clutter. This was the first wartime use of radar by the United States military, and led to its successful application throughout the theater.

Radar

Proximity fuse

- A proximity fuze is a fuze that detonates an explosive device automatically when it approaches within a certain distance of its target. It uses the Doppler effect of reflected radio waves to sense the target
- Before the invention of the proximity fuze, detonation was upon direct contact, from a timer set at launch, or by an altimeter.
- Use against aircraft and ground assault
- Proximity fuzes fitted to such weapons as artillery and mortar shells solve this problem by having a range of set burst heights [7, 13 or 33 ft] above ground that are selected by gun crews.
- The proximity fuze was one of the most important technological innovations of World War II. It was so important that it was a secret guarded



Simple.wikipedia.org

Radar

Admiral Lewis Strauss said:

One of the most original and effective military developments in World War II was the proximity, or 'VT', fuze. It found use in both the Army and the Navy, and was employed in the defense of London. While no one invention won the war, the proximity fuze must be listed among the very small group of developments, such as radar, upon which victory very largely depended

Radar

- The fuse had very rigorous requirements
- anti-aircraft artillery shells experiences an acceleration up to 20,000 g. Beyond the extreme acceleration, artillery shells were spun by the rifling of the gun barrels at close to 30,000 rpm, creating immense centrifugal force
- The Western Electric Company and Raytheon Company modified miniature hearing-aid tubes to withstand these conditions
- The Allied design had four or five electron tubes. One tube was an oscillator connected to an antenna; it functioned as both a transmitter and an autodyne detector (receiver). Two of the four tubes in the VT fuze were used to detect, filter, and amplify this low frequency signal.
- When the reflected signal's amplitude was large enough, indicating a nearby object, it triggered the fourth tube – a gas-filled thyratron. Upon being triggered, the thyratron conducted a large current that set off the electrical detonator.

Radar

- By 1944, a large proportion of the American electronics industry concentrated on making the fuzes.
- While the cost started at $732 per fuse in 1942 , by 1945 the cost had dropped to $18. This permitted the purchase of over 22 million fuzes
- The fuse exploding a projectile directly over its target, rather than on impact, made the weapon five to 20 times more effective.
- The fuse was released to general use in 1944. Fuses for rockets and bombs went into full production and were used extensively. The first major combat use of the fuse was during the preinvasion bombardment of Iwo Jima in 1945.
- Some 8.3 million fuses were produced during the war

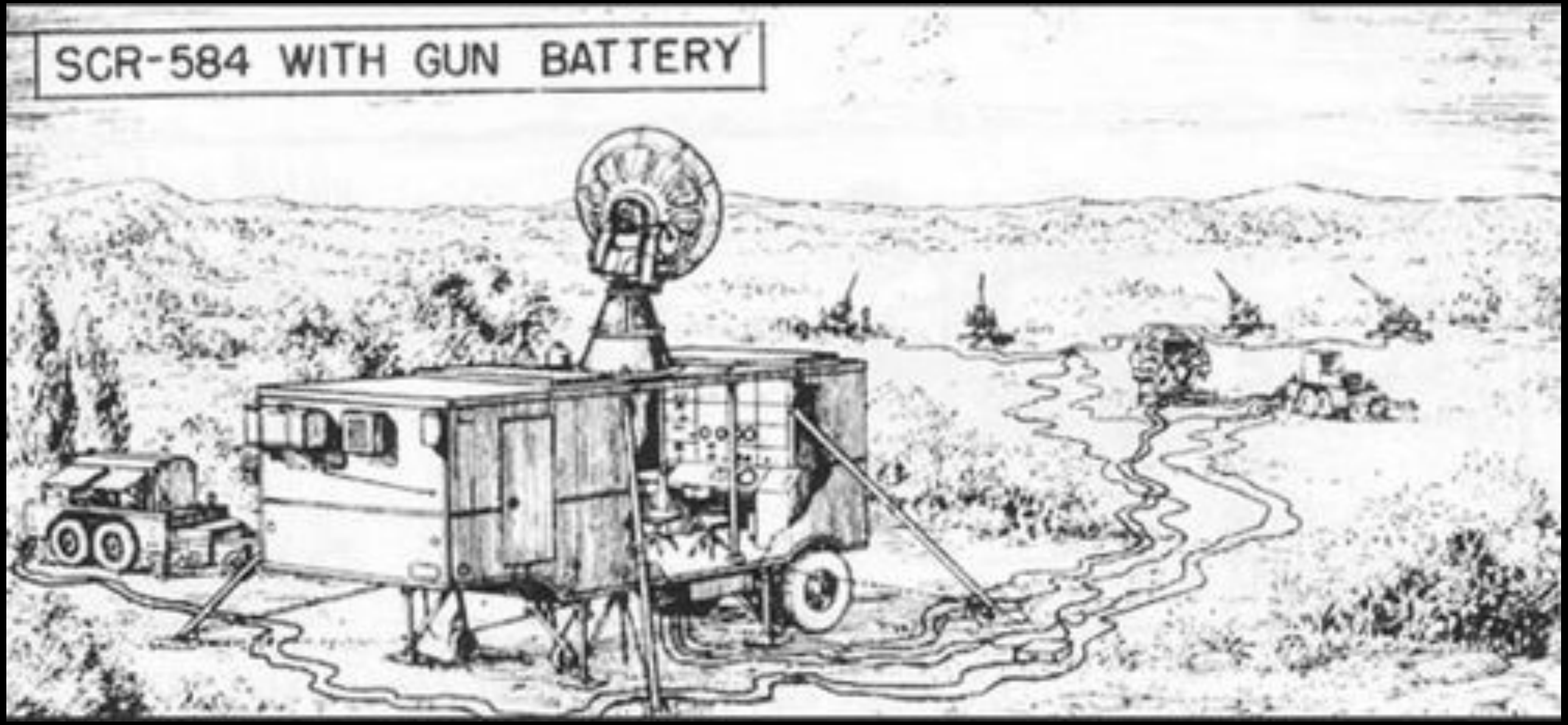
Radar

- Over the course of the German V-1 campaign, using the proximity fuse the proportion of flying bombs that were destroyed by the coastal anti-aircraft gun belt rose from 17% to 74%, reaching 82% during one day.
- 200,000 shells with VT fuzes were used in the Battle of the Bulge in December 1944.
- They made the Allied heavy artillery far more devastating, as all the shells now exploded just before hitting the ground
- U.S. General George S. Patton credited the introduction of proximity fuzes with saving Liège and stated that their use required a revision of the tactics of land warfare.

Radar

Fire control Radar

- SCR-584 was a widely used gunfire-control system.
- It employed conical scan tracking—in which a single offset radar beam is continuously rotated about the radar antenna's central axis—and, with its four-degree beamwidth, it had sufficient angular accuracy to place antiaircraft guns on target without the need for searchlights or optics.
- The SCR-584 operated in the frequency range from 2.7 to 2.9 GHz (known as the S band) and had a parabolic reflector antenna with a diameter of nearly 6.6 feet (2 metres).



Radionerds.com

Radar

- It was first used in combat early in 1944 on the Anzio beachhead in Italy. Its introduction was timely, since the Germans by that time had learned how to jam its predecessor, the SCR-268.
- The introduction of the SCR-584 microwave radar caught the Germans unprepared.
- By mid-1943 the SCR-584 was being delivered from production. This radar had a beamwidth of 4 deg (70 mr), and could track aircraft with an accuracy of about 1.5 rnr, adequate for direct input to AA gun directors.

Radar

British H2S

- In January 1942, a team was assembled to combine the magnetron with a new scanning antenna, and plan position indicator display.
- H2S was the first airborne, ground scanning radar system. It was developed for the Royal Air Force's Bomber Command during World War II to identify targets on the ground for night and all-weather bombing. This allowed attacks outside the range of the various radio navigation aids like Gee

en.wikipedia.org

Radar

- The H2S radar possible was used for the first time by British Stirling and Halifax bombers in 1943, to map the ground for night operations.
- Bomber Command started general use of H2S in the summer 1943. On the night of 24 July, the RAF began Operation Gomorrah, a large attack on Hamburg. By that time, H2S had been fitted to Lancasters, which became a backbone of Bomber Command. With the target marked by Pathfinders using H2S, RAF bombers hit the city with high explosive and incendiary bombs.
- The resolution of the early sets was too low to be useful over large cities like Berlin, in 1943 work started on a version operating in the X band at 3 cm (10 GHz), the H2S Mk. III. Almost simultaneously, its American equivalent was introduced as the H2X in October of that year. A wide variety of slightly different Mk. III's were produced before the Mk. IIIG was selected

Radar

- H2S Mk. III, and an experimental set was first used over Berlin on the night of 18/19 November 1943. In comparison to the first mission with the Mk. I sets, the results using Mk. III were described as "most outstanding”. Mk. III was rushed into production and saw its first real operational use on 2 December.
- From this point until the end of the war, the Mk. III became the backbone of the Bomber Command fleet, and a large variety of versions were introduced.
- in the summer of 1943 the decision was made to begin development of versions operating in the K band at 1.25 cm.

Radar

British Type 182 (Fishpond)

- The Type 182 was a modified H2S to see aircraft
- display showing everything in the air around the aircraft primarily as a defense against night fighters
- given the official title Type 182
- It was in productionby August 1943 [30]
- The first operational units went into service in October 1943, and by the spring of 1944, most of Bomber Command's aircraft carried it. Two hundred units of the prototype model were produced before a slightly modified version was introduced, the Type 182A. This version had the range fixed at 26,000 feet
- The Type 182 display was normally located at the radio operator's station, not the navigator's.
- Enemy fighters were easy to see as dots moving around within the pattern of returns.
- H2S, the antenna size was a function of the bomber's turret opening, and when combined with the 10 cm wavelength, this led to a resolution of 8 degrees in arc.
- On 6 February 1943, work began on an X band version of the electronics, operating at 3 cm. This would improve resolution to 3 degrees when used with the same antenna

Communications

Communications

The Gibson Girl survival radio

- **During World War II, Germany developed a hand-crank 500 kHz rescue radio, the "Notsender" (emergency transmitter) NS2. It used two vacuum tubes and was crystal-controlled. NS2 units were captured by the British. Britain gave a second unit captured in 1941 to the United States. They sought manufacturing of the units here because of limited capacity at home**
- **The US reverse engineered the German unit to product the SCR-578.**
- **Bendix Aviation Limited was approached and after theeUS Army and Navy became interested it was suggested that a joint Allied dinghy set to be developed.**

flickr.com

Communications

- When the US became directly involved in the war, the demand was escalated. An initial order for 11,600 sets was placed. The first sets were delivered in the last week of May 1942, initially by Bendix but later also assembled by a number of other contractors.
- United States Army Air Forces aircraft carried the SCR-578 on over-water operations. Nicknamed the Gibson Girl because of its hourglass shape, it was supplied with a fold-up metal frame box kite, and a balloon with a small hydrogen generator, for which the flying line was the aerial wire. Power was provided by a hand cranked generator.
- The transmitter component was the BC-778. The frequency was 500 kHz at 4.8 watts, giving it a range of 200 miles (300 km; 200 nmi). Keying could be automatic SOS (including the 4-second long dash for autoalarm), or manual. Crystals for frequency control were a scarce item for the U.S. during the war and the SCR-578 was not crystal-controlled.

Communications

- The SCR-578 consisted of a BC-778 transmitter unit and a number of accessories, (such as kite aerial, balloons with hydrogen generators) weighing 34 lb. Painted the usual bright yellow, it was completely packed in a single padded yellow canvas bag.
- The transmitter of the BC-778 was not crystal controlled. It consisted of an ECO RF oscillator-RF output valve (type 12A6), operating on 500 kHz, grid modulated by a 1000 Hz tone oscillator valve (type 12SC7). The aerial trimming capacitor rotated through 360 degrees, during half of which a switch closed, adding an extra capacitor. RF output was specified as 5 watts. The range of the SCR-578 was quoted as 200 miles to aircraft flying at 2000 ft.

Communications

- Power was derived from a double-voltage hand generator, delivering 24 volts LT and 330 volts HT. The nominal turning speed, approximately 80 revolutions per minute, was much less than the German generator. In addition to radio transmission, the set could be used as a hand-powered signal light, automatically keyed or continuously, intended to be used for visual signalling by night if an aircraft was heard. The M-308 signal lamp was plugged into a socket provided and strapped on top of the head with the straps under the chin.

Communications

VHF Radios

- The use of aircraft for search and rescue in World War II brought line-of-sight VHF radios into use.
- The much shorter wavelengths of VHF allowed a simple dipole or whip antenna to be effective. Early devices included the British Walter, a compact single vacuum tube oscillator design operating at 177 MHz (1.7 meter wavelength), and the German Jäger (NS-4), a two-tube master oscillator power amplifier design at 58.5 and, later, 42 MHz.
- These were small enough to include in life rafts used on single-seat fighter aircraft. AN/CRC-7 - World War II era set, 140.58 megahertz (2.1325 m)

Communications

Walkie-Talkie

- A walkie-talkie is a half-duplex communication device
- Multiple walkie-talkies use a single radio channel, and only one radio on the channel can transmit at a time, although any number can listen.
- Several different groups attributed to the development of the walkie Talkie
- Canadian inventor Donald Hings was the first to create a portable radio signaling system for his employer CM&S in 1937
- Hings received the Order of Canada for the device's significance to the war effort.
- Many versions of his packset, with the most recognizable being the Model C-58 Packset.
- designs were sent to a Toronto refrigerator factory to produce 18,000 models for allied troops in Europe and the tropics over the course of the war.

Communications

- Hings joined an engineering teams at Motorola
- The SCR-536 was conceived of in 1940 the “Handie-Talkie” two-way radio.
- It saw action in every theatre of war during the next five years, with nearly 40,000 of these units being made for the various services.
- The company went into full production of the SCR-536 in July of 1941, six months before Pearl Harbor. The team credited with the SCR-536 development is Don Mitchell, Ray Yoder, Jack Davis, Paul Smith, and several other Motorola engineers assisting them in developing a device.

SCR-536, engineers forum.com.ng

Communications

- **Motorola was to produce nearly 50,000 of the famed SCR-300 Walkie-Talkie units during the course of the war**
- **The first SCR-300 units were transported by air for use in the invasion of Italy by the Allied Forces. A sizeable quantity went to the Pacific. Perhaps their greatest contribution was in the European invasion, where their role in re-establishing order at the conclusion of the Battle of the Bulge gained Motorola tremendous recognition and a general feeling that perhaps the Walkie-Talkie was the single most useful piece of communications equipment employed in the invasion.**

SCR-300, military images.net

Communications

SIGSALY

- SIGSALY and was first deployed in 1943.
- It was a large and impressive system involving a large assortment of vacuum tubes, relays, synchronous motors, turntables, and other unique electromechanical equipment.
- It was power hungry and a typical installation weighted about 55 tons.
- The design was based on using a twelve-channel vocoder with ten channels each devoted to measuring the power of the voice signal in a portion of the voice frequency spectrum.
- The work was essentially completed in 1942 and patents were filed. Most patents would be kept secret until 1976!

flickr.com

Communications

- Beyond demonstrating the fundamentals of digital encrypted voice, SIGSALY incorporated many firsts identified by IEEE
  1. The first realization of enciphered telephony
  2. The first quantized speech transmission
  3. The first transmission of speech by Pulse Code Modulation (PCM)
  4. The first use of companded PCM
  5. The first examples of multilevel Frequency Shift Keying (FSK)
  6. The first useful realization of speech bandwidth compression
  7. The first use of FSK-FDM (Frequency Shift Keying-Frequency Division Multiplex) viable transmission method over a fading medium, and
  8. The first use of a multilevel "eye pattern" to adjust the sampling intervals.

Communications

- At the formal opening of SIGSALY service in the recently-completed Pentagon on 15 July 1943, Dr. O. E. Buckley, President of BTL (the developer of SIGSALY), said:

  We are assembled today in Washington and London to open a new service, - secret telephony. It is an event of importance in the conduct of the war that others here can appraise better than I. As a technical achievement, I should like to point out that it must be counted among the major advances in the art of telephony. Not only does it represent the achievement of a goal long sought - complete secrecy in radiotelephone transmission - but it represents the first practical application of new methods of telephone transmission that promise to have far-reaching effects.

Communications

- SIGSALY terminals were eventually established in Washington, D.C., London, Paris, North Africa, Hawaii, Guam, Manila, and Australia, among others.
- The system converts speech into low frequency signals that are not speech but contain a specification or description of it. Those signals were coded by a system that defies decoding by any but the intended recipient.
- The coded signals were transmitted over a radio circuit in such a way that an interceptor could not even distinguish the presence or absence of the signals.
- At the receiving end, the signals were decoded and restored. Speech is then regenerated nearly enough like the original that it may be clearly understood.

Communications

Radio Relay

- Radio Relay is a system to relay radioteletypewriter signals. With it a radioteletypewriter operator in Washington, London, or other capital could transmit directly by teleprinter to the commander in any theatre of war
- Radio relay telephone and teletypewriter circuits spanned the English Channel for the Normandy landing and later furnished important communication service for General George S. Patton, after his breakout from the Normandy beachhead.
- Sets employing frequency modulation and carrier techniques were developed and used, as were also radio relay sets that used radar pulse transmission and reception techniques and multiplex time-division methods for obtaining many voice channels from one radio carrier.

Training

Training

Television

- Television wa in its infancy, but was put to use by the military as a valuable training aid in military schools, where mass instruction, especially in manual skills

Miscellaneous

Miscellaneous

Magnetic mines

- Induction Ground Mine and Firing Mechanism – U.S. Patent 4,183,301 [11]
- The Navy developed underwater mines that would explode when a searching induction coil sensed the change in the magnetic field.
- The field change indicated a ship passing over or near the mine
- This invention improved on the magnetic mine design with a vertical induction coil and a drag chute that allowed the coil to stay vertical after being dropped by a surface ship. It was registered by the Navy with the U.S. Patent & Trade Office in 1944.

Miscellaneous

Infra red night vision

- In 1943, the U.S. began the development of an infrared sight to provide night-vision capability.
- The Army engineers devised a rather rudimentary instrument consisting of an electronic telescope and sealed-beam light, somewhat similar to an automobile headlight, fitted with an infrared filter. A lead-acid battery to power the device was carried in a canvas knapsack.
- A limited number of M3 carbines fitted with an improved infrared sniper scope system were eventually manufactured and were used during the battle for Okinawa.

M3 Sniperscope, history net.com

Miscellaneous

Buried Mine detection

- Building on the an exploring coil that was used for "treasure finders” a buried mine detector was created
- It used concentric coils which made that idea practical. Our first complete design was flown to North Africa in time for the Allied invasion. It was used to clear buried mines ahead of a column of advancing tanks.
- It was designated the SCR-625 and hundreds were used by the Allied forces.

105th.org

Miscellaneous

De Gaussing of Ships

- Steel ships create an invisible magnetic signature as they sail due to ferromagnetism. The earth projects a magnetic field. As a ship sails, it cuts across the planet's magnetic field, and the magnetic domains inside the steel of ship's hulls align and magnetize the hull.
- Magnetic mines detonate when they detect this signature, even when they're moored tens of meters underwater.
- Underwater explosions broke ship keels and breached submarine hulls. After only a single mine detonated, the possibility of more mines discouraged movement in the area, and tied down manpower and material for mine-spotting and disposal.

Miscellaneous

- British interwar research focused on induction units. The Royal Navy had researched magnetic induction from 1915 to detect submerged ships intruding into British harbors.
- As a submarine passes over a cable laid across the seabed, its magnetic field and motion induce current in the cable, which a galvanometer then displays to a human operator.
- A ship could be degaussed by fitteing it with a copper cable along its outer hull—projecting a “north pole up” field that neutralized the ship’s magnetic signature.
- Dec 10 the Admiralty ordered the fitting of degaussing coils to all military and merchant fleet vessels,
- “deperming.” Instead of fitting ships with a cable of their own, the Royal Navy would use a high-powered cable to “wipe” the accumulated magnetic field from a ship. This procedure left ships demagnetized for up to six months at a time.

Miscellaneous

IFF Responder

- Combined Research Group was charged with designing and developing an improved Allied "identification friend or foe" system. Used in conjunction with a radar to sort friendly from hostile blips. Separate frequencies for the interrogation of a radar target and for the target's reply signal greatly simplified the IFF hardware design.
- This became the separate-band radar identification system (IFF Mark III)
- The Mark III IFF system comprised an "interrogator-responsor" (IR) associated with a tracking radar, and a "transponder" on every aircraft or ship that might be a target. The IR was an adjunct to the tracking radar. It transmitted and received a pulse in synchronism with the radar pulse. The transponder received this transmitted pulse and responded with a coded pulse that was displayed on the radar screen beside the pulse reflected from the target. [19]
- The Mark III IFF was in a high frequency band (VHF 157- 187 MHz). This required new types of antennas and transmission-line circuits,

Miscellaneous

Combat Information Center

- The Combat Information Center is a room in a warship that functions as a tactical center and provides processed information for command and control of the near battlespace or area of operations.
- After the numerous losses during the various naval battles off Guadalcanal during the war of attrition in the Solomon Islands campaign and the Battle of Guadalcanal, the United States Navy employed operational analysis, determined many of their losses were due to procedure and disorganization, and implemented the Combat Information Centers, building on what was initially called "radar plot"
- The United States developed their Command Information Center concept in the winter of 1942–1943 and implemented it in a surge of refitting and retraining during 1943
- The earliest radar uses in the Pacific battles starting with the Coral Sea gave rise to the first tentative attempt to vector an Air CAP to approaching Japanese flights

Miscellaneous

- While in 1943 a destroyer CIC might just have been configured for anti-ship and anti-submarine warfare tasks, by the Battle of the Philippine Sea when set out as radar pickets had to undertake forward air controller (FAC) functions and somehow jam in air search radar and anti-air action control functions.
- By late 1943 when the first new construction carriers of the Essex-class fleet carriers and the Independence-class light carriers with many associated fleet vessels had reinforced the refitted USS Enterprise (CV-6) and the USS Saratoga (CV-3), the U.S. Navy was prepared to take the offensive and began evolving CIC procedures and operational doctrine for a fleet of carriers