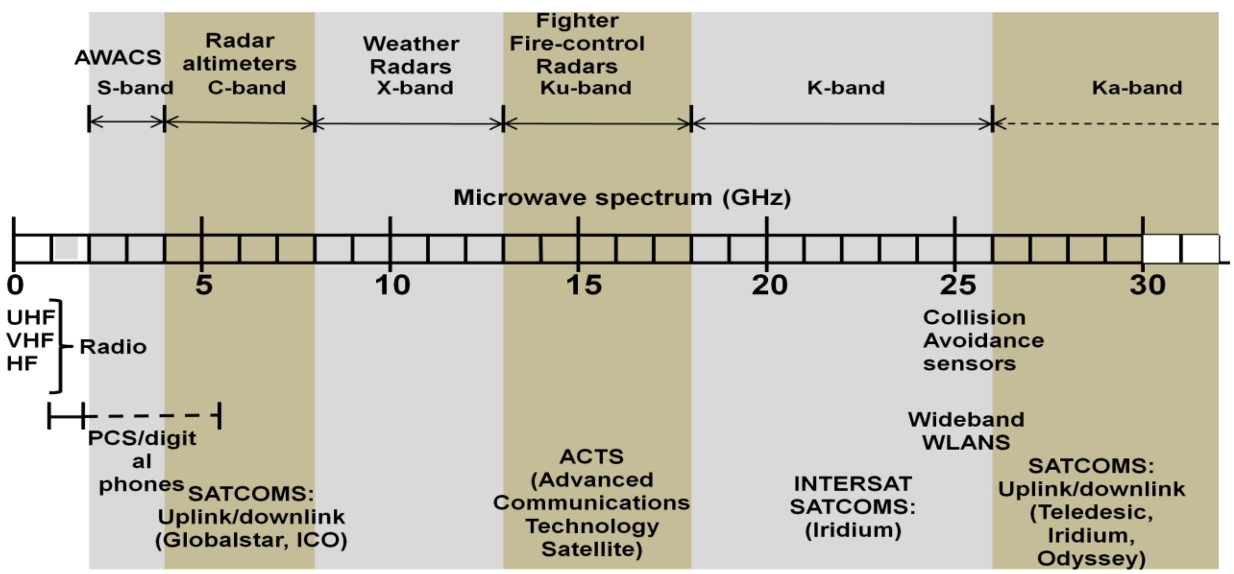
COMMERCIAL TECHNOLOGY TRENDS FOR RADARS

Background

1. The development and deployment of radar is one of the great historical achievements of the military industrial base. Although the first practical use of radar can be attributed to American physicists conducting scientific experiments in 1925, most of the major technical and engineering innovations that made the widespread use of radar possible were developed by the military R&D establishments of the United States, the United Kingdom, and Germany before and during World War II. After the war, radar began to be used in many civilian applications, including weather avoidance, navigation, and maritime surveillance. Later, radar was used for high-resolution area mapping and for many civilian space applications. Nonetheless, the major technology developments in radar continued to be driven by the demanding performance and environmental requirements of military systems. This was particularly true in the 1950s and 1960s with the introduction of extremely sophisticated multirole fighter fire control radars for air-to-air and air-to-ground operations.

2. Until recently, the vast majority of radio-frequency consumer products operated well below the 1 GHz frequency range on the electromagnetic spectrum. Fire-control radar, however, typically operated much higher up the electromagnetic spectrum in the X-band (8–12.5 GHz) and lower Ku-band (12.5–18 GHz) frequency ranges, thus requiring substantially different—and more demanding— hardware and technical and manufacturing techniques for parts and components. Throughout most of the Cold War era, therefore, military radar and other military electronics requirements drove most of the technology developments in the microwave frequency range (about 1 GHz to 30 GHz) and millimetre-wave (MMW) frequency range (30–100 GHz).



The Dual-Use Microwave Spectrum

3. Phased-array radars, based on electronically scanning antennas populated with transmit/receive (T/R) modules that employ GaAs (Gallium Arsenide, an important semiconductor used to make MW frequency integrated circuits) MMIC chips, are on the cutting edge of military radar technology. They provide numerous advantages over conventional radars, particularly for fighter aircraft, including lower radar cross-section, simultaneous multiple-target engagement capabilities, extended target-detection range, higher survivability, greater reliability, and reduced weight and size. By 1990, however, a technology revolution appeared to be under way in the commercial sector regarding microwave and MMW (millimetre wave) technologies. Many defence-critical RF microwave/ MMW technologies directly relevant to military radars, CNI, EW, intelligence gathering, and other sensors appear increasingly likely to be driven by civilian market demands.

Basics of Radar System

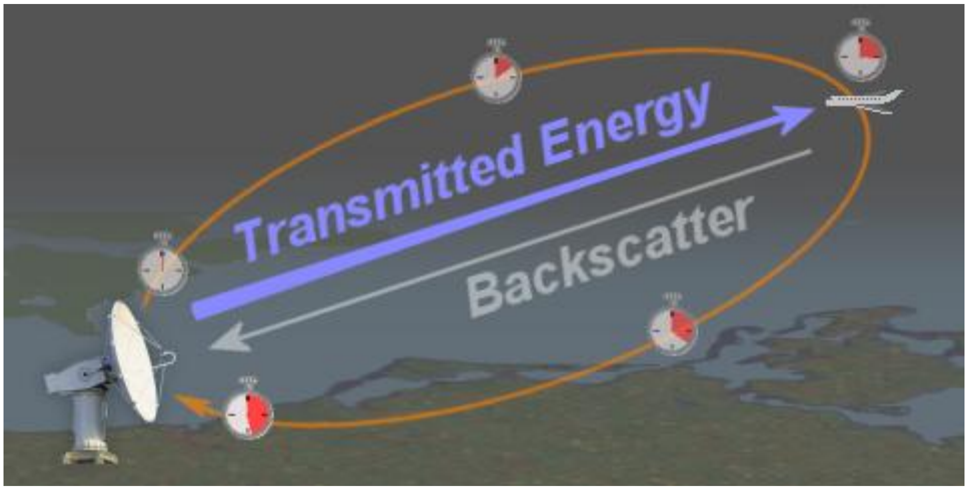
4. Radar measurement of range, or distance, is made possible because of the following properties of radiated electromagnetic energy:-

(a) Reflection of electromagnetic waves. The electromagnetic waves are reflected if they meet an electrically leading surface. If these reflected waves are received again at the place of their origin, then that means an obstacle is in the propagation direction.

(b) Electromagnetic energy travels through air at a constant speed, at approximately the speed of light.

(c) This energy normally travels through space in a straight line**,** and will vary only slightly because of atmospheric and weather conditions. By using of special radar antennas this energy can be focused into a desired direction.

These principles can basically be implemented in a radar system, and allow the determination of the distance, the direction and the height of the reflecting object.



Path followed by EM Wave for Radars

The radar antenna illuminates the target with a microwave signal, which is then reflected and picked up by a receiving device. The electrical signal picked up by the receiving antenna is called echo or return. The radar signal is generated by a powerful transmitter and received by a highly sensitive receiver. All targets produce a diffuse reflection i.e. it is reflected in a wide number of directions. The reflected signal is also called scattering. **Backscatter** is the term given to reflections in the opposite direction to the incident rays. Radar signals can be displayed on the traditional plan position indicator (PPI) or other more advanced radar display systems. A PPI has a rotating vector with the radar at the origin, which indicates the pointing direction of the antenna and hence the bearing of targets.

Components

- **Transmitter:** The radar transmitter produces the short duration high-power RF pulses of energy that are into space by the antenna.
- **Duplexer**: The duplexer alternately switches the antenna between the transmitter and receiver so that only one antenna need be used. This switching is necessary because the high-power pulses of the transmitter would destroy the receiver if energy were allowed to enter the receiver.
- **Receiver:** The receivers amplify and demodulate the received RF-signals. The receiver provides video signals on the output.
- **Radar Antenna:** The Antenna transfers the transmitter energy to signals in space with the required distribution and efficiency. This process is applied in an identical way on reception.
- **Indicator:** The indicator should present to the observer a continuous, easily understandable, graphic picture of the relative position of radar targets.

Radar Signal Processor

5. The signal processor is that part of the system which separates targets from clutter on the basis of Doppler content and amplitude characteristics. In modern radar sets the conversion of radar signals to digital form is typically accomplished after IF amplification and phase sensitive detection. At this stage they are referred to as video signals, and have a typical bandwidth in the range 250 KHz to 5 MHz. The signal processor includes the following components:

- The I&Q Phase Detector.
- The Moving Target Indication.
- The Constant False Alarm Rate detection.

The plot extraction and plot processing elements are the final stage in the primary radar sensor chain. The essential process is that of generating and processing plots as distinct from processing waveforms. The main components are:

- The plot extractor or hit processor (translates hits from the signal processor to plots).

- The plot processor (combines primary radar plots and minimises false plots).
- The plot combiner (combines primary and secondary plots, uses complementary features to minimise false alarms).

Imaging Radar / Non-Imaging Radar:

6. Imaging Radar forms a picture of the observed object or area. Imaging radars have been used to map the Earth, other planets, asteroids, other celestial objects and to categorize targets for military systems. Typically implementations of a Non-Imaging Radar system are speed gauges and radar altimeters. These are also called scatterometers since they measure the scattering properties of the object or region being observed. Non-Imaging Secondary Radar applications are immobilizer systems in some recent private cars.

- **Primary Radar:** A Primary Radar transmits high-frequency signals which are reflected at targets. The raised echoes are received and evaluated. This means, unlike secondary radar sets a primary radar unit receive its own emitted signals as an echo again.
- **Secondary Radar:** The airplane must have a transponder (transmitting responder) on board and this transponder responds to interrogation by transmitting a coded reply signal. This response can contain much more information, than a primary radar unit is able to acquire (e.g. an altitude, an identification code or also any technical problems on board such as a radio contact loss ...).
- **Pulsed Radars:** Pulse radar sets transmit a high-frequency impulse signal of high power. After this impulse signal, a longer break follows in which the echoes can be received, before a new transmitted signal is sent out. Direction, distance and sometimes if necessary the height or altitude of the target can be determined from the measured antenna position and propagation time of the pulse-signal.
- **Unmodulated CW- Radar:** The transmitted signal of these equipments is constant in amplitude and frequency. This equipment is specialized in speed measuring.

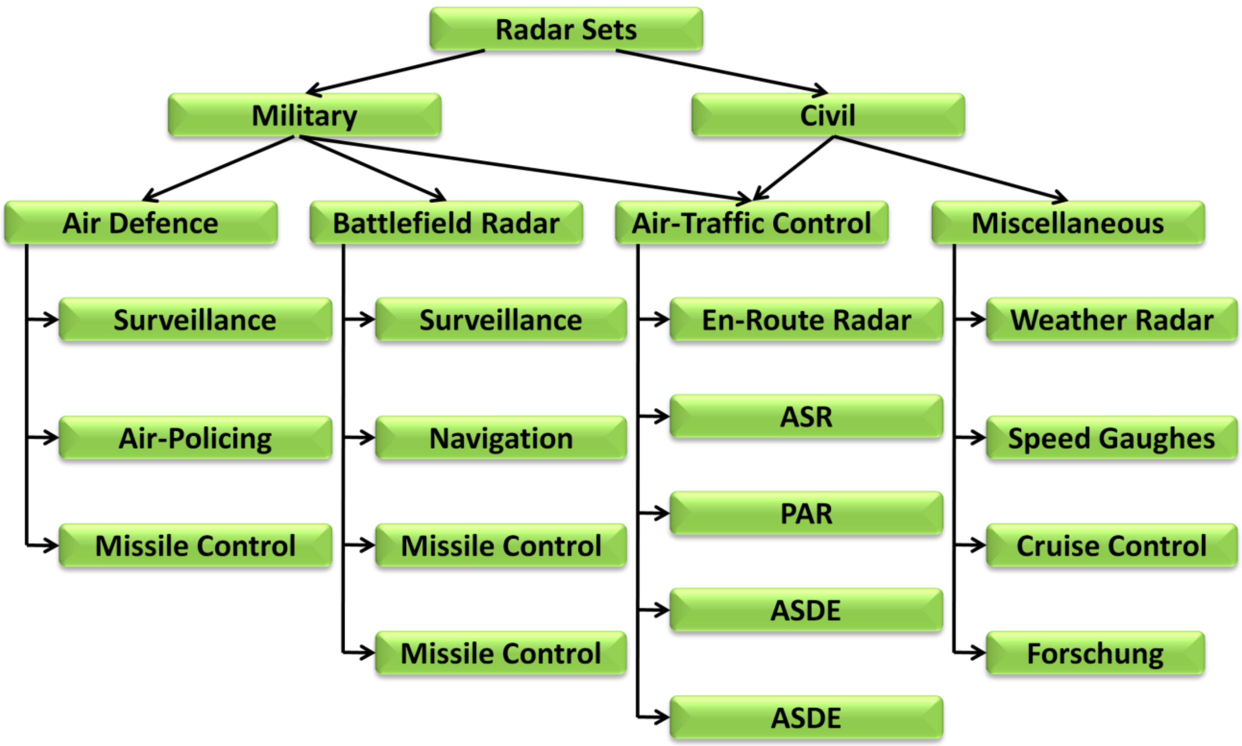
Bistatic Radar Sets

7. Generally, the transmitter and receiver share a common antenna, which is called a monostatic radar system. Bistatic radar consists of separately located (by a considerable distance) transmitting and receiving sites. Therefore, monostatic Doppler radar can be upgraded easily with a bistatic receiver system or (by use of the same frequency) two monostatic radars are working like bistatic radar. Bistatic radar makes use of the forward scattering of the transmitted energy. By receiving the side lobes of the transmitting radars direct beam, the receiving sites radar can be synchronized. If the main lobe is detected, azimuth information can be calculated also. A number of specialized bistatic systems are in use, for example, where multiple receiving sites are

used to correlate target position. A tactical idea in Kosovo war was possibly transmitting stations radiated the airplane outside the (technical) weapons range of activity and a second station could command the air defense weapon system only by passive reception. VHF-radars like P-12 or P-18 are particularly suitable for such bistatic arrangement.

PSR vs. SSR

8. Primary Surveillance Radar (PSR) works with passive echoes. The transmitted high-frequency impulses are reflected by the target and then received by the same radar unit. Well, direct cause of the reflected echo is the transmitting impulse sent out by the radar unit. Secondary Surveillance Radar (SSR) works with active answer signals. The secondary radar unit transmits and also receives high-frequency impulses, the so called interrogation. This isn't simply reflected, but received by the target by means of a transponder which receives and processes. After this the target answers with another frequency, the response telegram which is produced and transmitted. Both systems have advantages and disadvantages due to the different principles. If one wins safe information about direction, height and distance of the targets with the primary radar, then the secondary surveillance radar still provides additional information, like signal identification and also the altitude of the targets.



Classification of Radars

9. A factor > 1000 as a guide value can be assumed. From this a substantially simpler, smaller and cheaper transmitter follows. The receiver can be more insensitive,

since the power of the active answers is higher than the power of the passive echoes. This circumstance adversely affects, however, the influence of the side lobes. This must be compensated by using suitable measures of the side lobe suppression. Since the transmitting frequency and receiving frequency are different, no clutter disturbances arise. No MTI-system therefore is needed to the compensation of ground clutter. On the other hand a frequency change is impossible by jamming. Special disturbances at secondary radar equipments make additional wiring measures necessary. Radar systems may be divided into types based on the designed use.

Multi Function Radars

10. Active array Multifunction Radars (MFRs) enable modern weapon systems to cope with saturation attacks of very small radar cross-section missiles in a concentrated jamming environment. Such MFRs have to provide a large number of fire-control channels, simultaneous tracking of both hostile and defending missiles, and mid-course guidance commands. The active phased-array antenna comprises flat sensor panels consisting of arrays of GaAs modules transmitting variable pulse patterns and building up a detailed picture of the surveillance area. A typical fixed array configuration system could consist of about 2,000 elements per panel, with four fixed panels. Each array panel can cover 90° in both elevation and azimuth to provide complete hemispherical coverage. The operational functions of a Multi Target Tracking Radar (MTTR) include:

- Long-range search;
- Search information with high data rate for low-flying aircraft;
- Search information with high resolution of close in air targets;
- Automatic position and height information;
- Simultaneous tracking of a lot of aircraft targets;
- Target designation facilities for other systems.

Phased Array Antenna

11. A phased array antenna is composed of lots of radiating elements each with a phase shifter. Beams are formed by shifting the phase of the signal emitted from each radiating element, to provide constructive/destructive interference so as to steer the beams in the desired direction. The signal is amplified by constructive interference in the main direction. The beam sharpness is improved by the destructive interference. The main beam always points in the direction of the increasing phase shift. If the signal to be radiated is delivered through an electronic phase shifter giving a continuous phase shift, the beam direction will be electronically adjustable. However, this cannot be extended unlimitedly. The highest value, which can be achieved for the Field of View (FOV) of a phased array antenna, is 120° (60° left and 60° right).

Advantages	Disadvantages
High gain width low side lobes.	The coverage is limited to a 120 degree sector in azimuth and

	elevation.
Ability to permit the beam to jump from one target to the next in a few microseconds.	Deformations of the beam while the deflection.
Ability to provide an agile beam under computer control.	Low frequency agility.
Arbitrarily modes of surveillance and tracking.	Very complex structure (processor, phase shifters).
Free eligible Dwell Time.	Still high costs.
Multifunction operation by emitting several beams simultaneously.	
Fault of single components reduces the capability and beam sharpness, but the system remains operational.	

MOBILE COMMUNICATIONS SATELLITES

12. Although the commercial future of many of these systems appears to be in doubt, the new generation of MEO and LEO mobile communications satellite systems are pushing commercial microwave technology up the microwave spectrum closer to technology areas of interest for fire-control radars. If successful, these satellite systems could open up a major new commercial market for active phased array radar technologies. Unlike automotive collision avoidance systems that use only a few T/R modules per vehicle, next-generation communication satellites will mount large phased-array antennas populated with almost as many T/R modules as on antennas on phased-array fire-control radars. Most existing communication satellites systems are based on a small number of large geostationary satellites in high-altitude orbits that broadcast a single beam that covers large portions of the world's surface. These satellites are well suited for television transmission and fixed telephone communications. In the mid 1980s, however, engineers began envisioning satellite communication systems that could provide global mobile cellular phone and data transmission capabilities. This concept required much larger numbers of smaller, low-altitude satellites with directional antennas that could transmit many "spot beams" to specific small areas on the earth's surface. This proposed capability required antennas populated with many T/R modules based on GaAs MMIC technology. In addition, market pressures for more data-carrying capabilities, combined with growing demand for more broadcasting frequencies, had already been pushing communication satellite transmitters further up the electromagnetic spectrum, from C-band frequencies (4–8 GHz) beyond the X-band into the Ku-band (12.5–18 GHz). Launched in September 1993, the National Aeronautics and Space Administration's Advanced Communications

Technology Satellite (ACTS) provided one of the first successful demonstrations of broadband Ku-band satellite communications.

AUTOMOTIVE SENSORS

13. The emergence of automotive ACC and collision warning systems, as well as the projected new generation of LEO and MEO mobile communications satellite systems, are of particular relevance to the future of commercial defence-related RF/microwave technologies. Both these products are promoting the development for the first time of high-technology commercial radar T/R modules that are planned for large-scale, low-cost commercial production. Almost every major automobile manufacturer is investigating a variety of new automotive sensors for ACC, the most interesting of which for our purposes are T/R radar modules that are mounted on front and rear bumpers. Most of the so-called "Big LEOs" are projected to have many communication satellites equipped with up-link/down-link and intra satellite communication antennas that will be heavily populated with GaAs MMIC-based T/R modules. Automotive electronics companies and defence microwave component vendors are developing collision warning systems.

CHANGING REQUIREMENTS

14. With the advances in ECM techniques, stealth technology, and target operational performances, eg, manoeuvrability and speed, the following new requirements need to be considered for seeker design: transmitted waveform is random or random-like in contrast to conventional pulse, continuous, frequency modulated continuous wave waveform. The inherent advantage with this noise radar seeker is its low cost. The noise radar seeker transmits a very wide band random noise signal. It makes a copy of what it transmits and correlates it with the return signal. To function, the seeker processor and converters must clock at > 1 GHz speed. This design is made possible by the recent advances in high-speed digital signal processing technology. The salient features of this technology are: Low peak power for reduced vulnerability of extremely high bandwidth, which in turn gives detection as well as less demanding power supply high-range resolution. Range resolution up to system 15 cm is possible with noise radar seekers.

MMW-Pseudo Random Code Seekers

15. Multisensor data fusion being implemented through data link for faster signal processing for large data handling and also for imaging Low radar cross section detection and tracking capability to meet stealth technology advancements. The millimetre wave (MMW) radar seekers have become attractive option in many seeker applications, including PGMs (Precision Guided Missiles) and imaging sensors. These have undergone extensive evaluation over the last decade, offering a route to achieve miniaturised seeker. The latest developments aim at completely solid state, highly reliable, and low-cost systems. Two configurations, viz., pulsed and frequency-modulated continuous wave (FMCW), have emerged as the favoured solutions for the first generation of smart weapon applications, being used commercially off the shelf (COTS). However for both of these implementations, components for the development of low-cost complexity of the millimetre wave technology seeker pulsed radar system

requires higher power, and therefore, expensive transceiver circuit to meet. The above requirements have pushed the radar's signal-to-noise ratio requirement, while FM seeker technology to adopt entirely newer concepts. CW system offers the advantage of simple and has led to the development of the following low-cost transceiver circuitry, but has stringent new concepts: transmitter-receive requirements.

CONCLUSION

16. The broader bandwidth requirements of PCS/digital cellular phones, WLANs, DBS, mobile communications satellite systems, and other new consumer broadband technology products have led to an explosion of commercial parts and components development in exotic microwave areas that previously were almost entirely dominated by the military. A dramatic case in point is the widespread commercial development of whole new families of GaAs MMIC and application specific integrated circuits (ASICs) for the new commercial applications. GaAs MMIC RF power amplifiers and other RF analog devices developed for PCS and other mobile communications may be particularly relevant to future military RF applications, as are some of the manufacturing processes for the T/R modules developed for automotive sensors and mobile communications satellites.

17. As a result, for the first time, commercial applications are becoming increasingly important in the development of new technologies, especially in lower-cost manufacturing processes for RF/microwave devices. Many of the parts and components being developed for consumer products may not be directly applicable to or usable in military fire control radars, nor do they necessarily possess the performance capabilities, ruggedness, and reliability required for the harsh environment in which fighters must operate. Nonetheless, the commercial marketplace is clearly becoming increasingly dominant in broad sectors of RF/microwave technologies and manufacturing processes in a way that could benefit defense applications. Design methodologies, process technologies, and many other areas that have direct relevance to military radar system design and development are likely to be increasingly driven by the commercial market. Commercially developed parts and components will be available for incorporation in military systems, but will such items developed for consumer products possess the high-performance capabilities required for incorporation into weapon systems?