The role of active millimetre wave radar in defence surveillance

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Contents

- Why consider millimetre wave radar ?
  – what roles do they play ?
- Review of millimetre wave technology – filling the “THz gap”
- Capability – performance, benefits and defence applications
- Future
  – higher resolution and improved detection at lower cost ?

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Why consider millimetre wave radar ?

Electromagnetic spectrum

Wavelength	10 km	1km	100m	10m	1m	10 cm	1 cm	1mm	100 um	10 um	1 um	
Band	VLF	LF	MF	HF	VHF	UHF	SHF	EHF	IR			Visible

RF

Microwaves

Millimetre waves

Sub-millimetre waves

Frequency	30 kHz	300 KHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz	3 THz	30 THz	300 THz

Microwave and **millimetre wave** use	
UK usage	US usage
	W-band 56-100 GHz
V-band 50-75 GHz	**V-band 46-56 GHz**
O-band 40-70 GHz	**Q-band 36-46 GHz**
Q-band 27-40 GHz	**Ka-band 33-36 GHz**
K-band 18-27 GHz	K-band

Official International Telecommunications Union (ITU) Geneva	
Band designation	Metric designation
Band No. 11 EHF 30-300 GHz	**Millimetric**
Band No. 10 SHF 3-30 GHz	Centimetric

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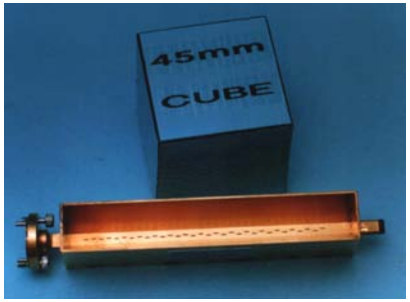
Why consider millimetre wave radar ?

- Compact, small physical size and equipment weight

  - Size, Weight And Power (SWAP) requirements are more likely to be met for high mobility and covert users



slotted waveguide antenna

courtesy
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- Narrow antenna beamwidth with physically small aperture

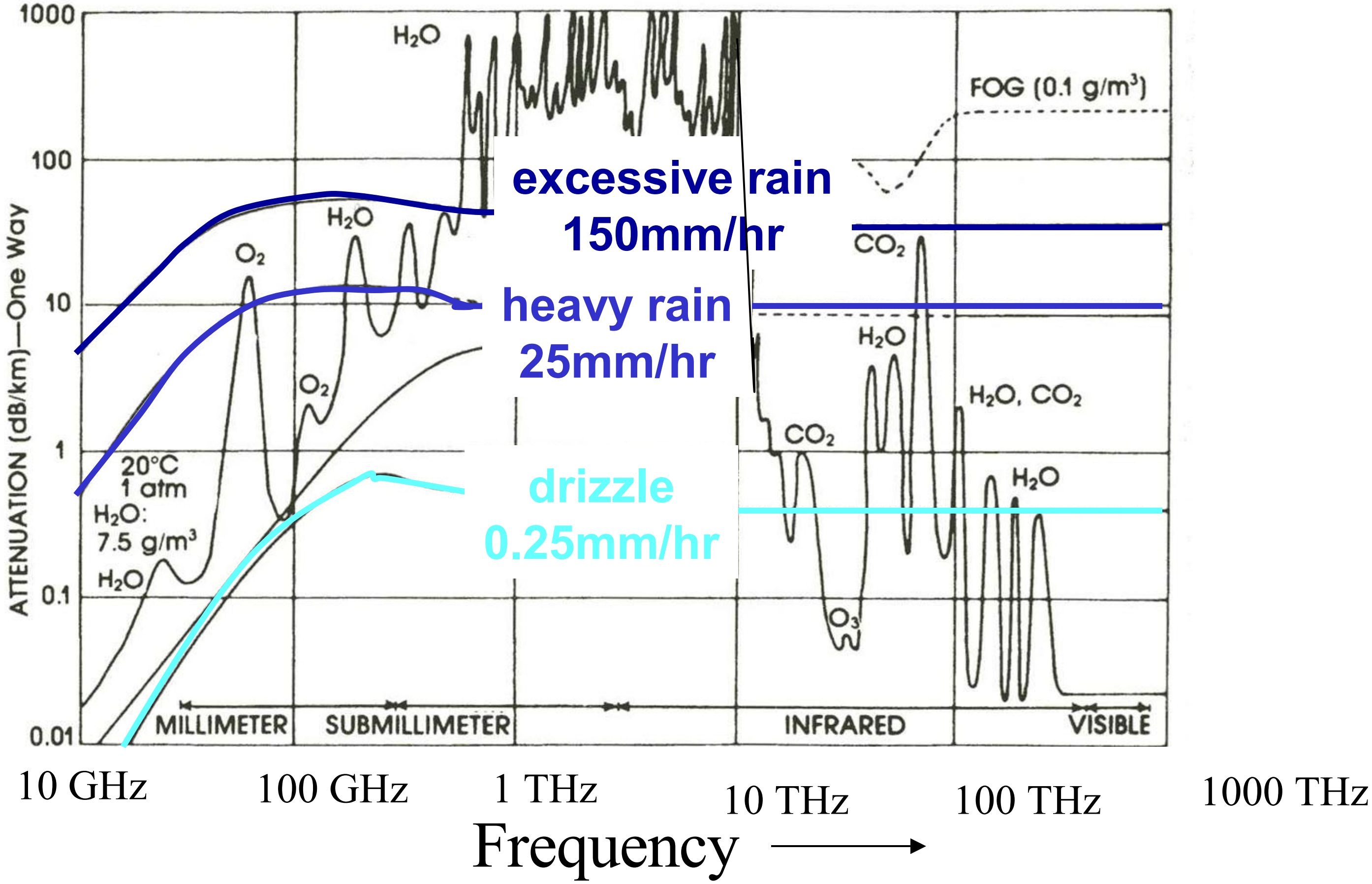
- Relatively low antenna sidelobes

- Low spectral occupancy

  - RF electromagnetic spectrum is sparsely occupied (at the moment !) at millimetric/sub-millimetric wavelengths

- Availability of relatively large RF bandwidth (UWB)

- Attenuation by atmospheric gases, rain and fog
- Masking or 'self-screening' effect of atmospheric attenuation
- Reduced RF power density at remote sites
  - low probability of exploitation (LPE) / minimal EMI/EMC problems
- Covert operation
  low propagation "overshoot"/ low probability of intercept (LPI)



What roles do they play ?

- **Defence radar**
  - **Surveillance and acquisition**
  - **Fire control and tracking**
  - **Instrumentation and measurements**
  - **Guidance and seekers**

- Numerous alternative roles (defence and non-defence related) including :

Medical and dental imaging, gene sequencing, ultra-fast chemistry for studying intermolecular interactions, charge movement and circuit diagnostics, security screening, hazardous chemical detection, Space Shuttle tile inspection, nanometre scale microscopy, Foreign Object Detection (FOD), automobile collision warning, UAV sense and avoid, environmental mapping etc ..

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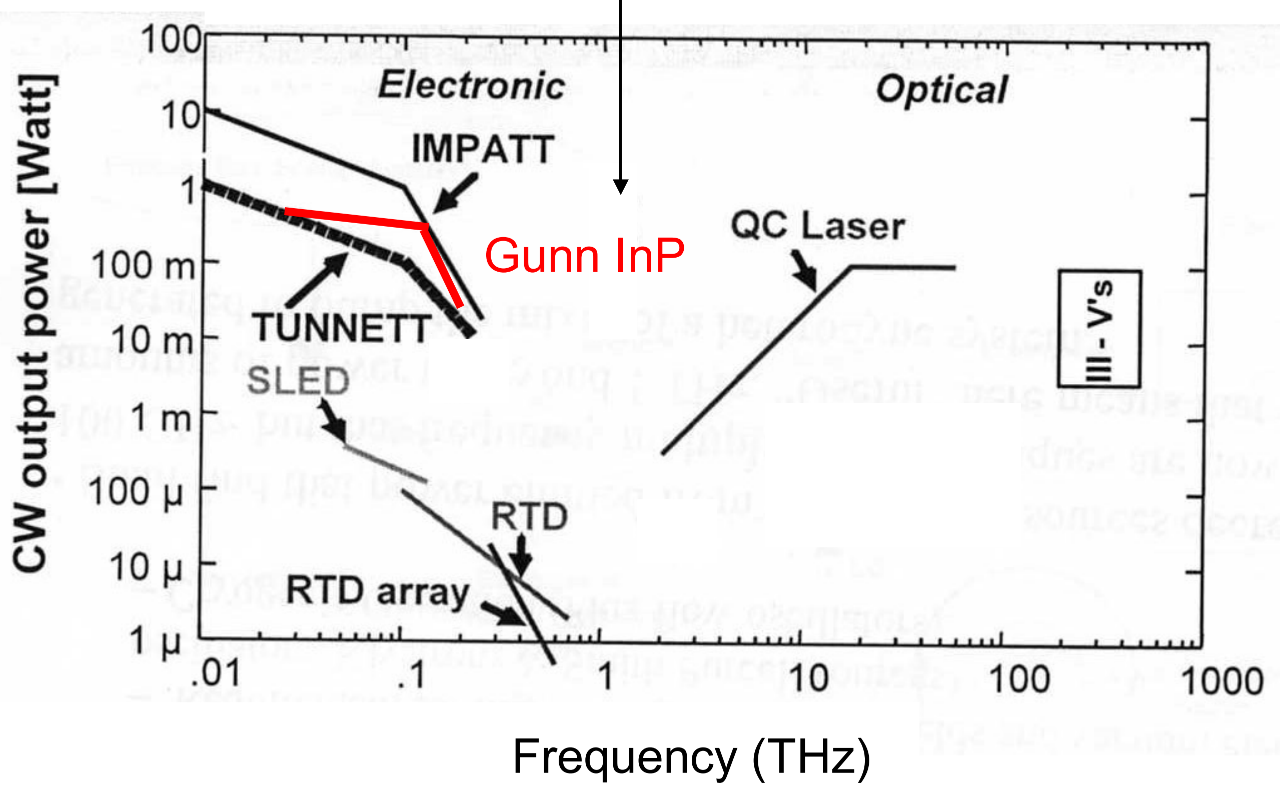
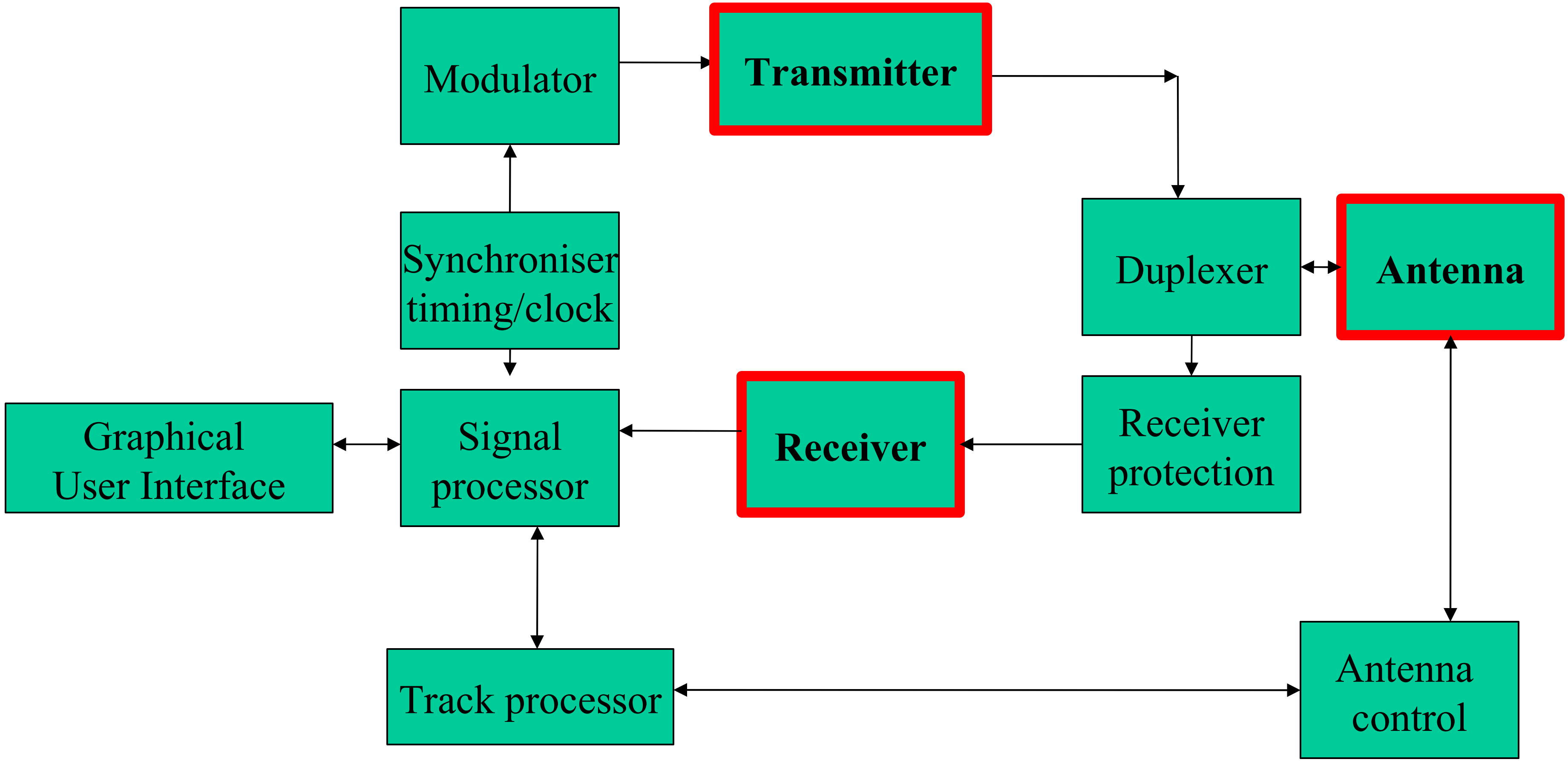
Review of millimetre wave technology

- filling the "THz gap"



Generic millimetre wave radar



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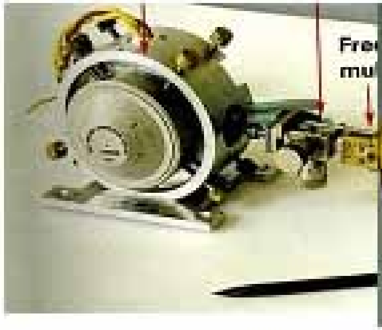
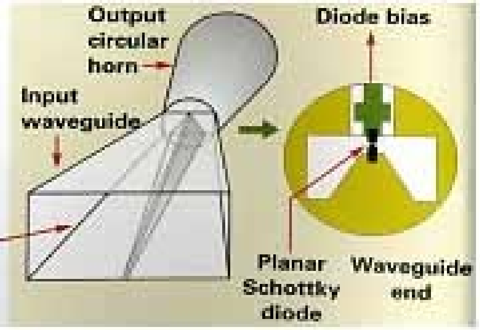
Transmitter

- RF power sources needed in transmitter and receiver local oscillator
- RF power (CW or pulsed), low noise (spurii, phase noise close to carrier), lifetime
- Size, Weight and Power (SWAP) requirements (including cryo-cooling, if needed)
- RF power from fundamental sources generally diminishes above 100 GHz
- Frequency multiplication using non-linear devices to generate harmonics provides much greater RF power above 100 GHz
  typ. GaAs Schottky-barrier varactor or HBV diodes driven at 60 – 100 GHz

  Diode arrays and MM MMICs as drivers typ.12 mw @ 400 GHz / 2 mw @ 800 GHz



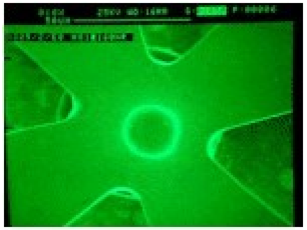


Millimetre wave RF power sources

- Solid state source technologies
  - cavity stabilised Si/GaAs/InP Gunn diode
  - low cost
  - most powerful fundamental oscillators within single semiconductor device
- Impact Avalanche Transit Time (IMPATT)
- Tunnel (Injection) Transit Time (TUNNETT)
- Superlattice Electron(ic) Device (SLED)
- Resonant Tunnel Diode (RTD)
  - highest operating frequency InAs/AlSb @ 712 GHz
- Quantum Cascade Laser (QCL) 2mw@ 2.8 THz

typical RF powers (peak)

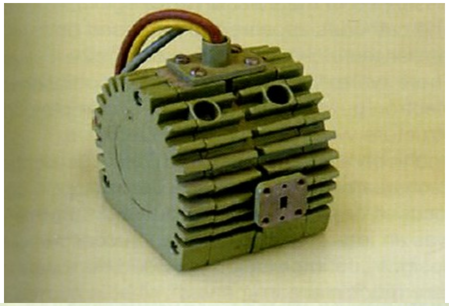
310 mw	@ 80 GHz
60 mw	@ 94 GHz
34 mw	@ 193 GHz
3.7 mw	@ 297 GHz
3.5 mw	@ 300 GHz
> 1mw	@ 325 GHz
> 0.6 mw	@ 328 GHz



courtesy
e2V Technologies Ltd

Millimetre wave RF power sources

- Travelling Wave Tube (TWT) / Magnetron typ. 6kW @ 95 GHz
- Free-electron laser (FEL) / Smith-Purcell
- Extended Interaction Klystron (EIK) typ. 2 kw @ 95 GHz
- Extended Interaction Oscillator (EIO) typ. >100 w @ 80 GHz
- Gyrotron / Gyro-klystron typ. 500 kW (peak) @ 95 GHz
  typ. 3.5 Mw @ 30 GHz
- Backward Wave Oscillator (BWO)
  180 GHz to 1.5 THz
  needs high voltage, magnetic fields and vacuum
- Orotron (Ledatron) typ.>20w > 370 GHz
- Super-radiance phenomenon ultra-high power pulses
  typ. 300 Mw peak 200w mean at 38 GHz
- Superconducting flux–flow oscillator
  - needs cryogenic cooling
- Molecular vapour laser - limited tunability
- Synchrotron / Clinotron
- Carcinotron typ. > 500 GHz



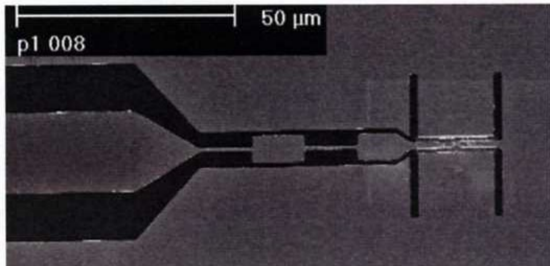
Examples of BWO devices

Receiver

- Heterodyne techniques, as opposed to direct or video detection
  - generally superior sensitivity
  - relatively high spectral resolution
  - greater availability of devices

- "State of the art" … sensitive room temperature receivers are based upon heterodyne mixers using GaAs Schottky barrier diodes
  - up to 2.5 THz (>0.5 mw of LO RF power for low noise performance and ≈ 5 mw for balanced receiver to cancel LO noise)
  - demanding requirement for fundamental or harmonic semiconductors

- Sensitivity improvements with low temperature devices such as Superconductor-Insulator-Superconductor (SIS) tunnel junction mixer and Hot Electron Bolometers (HEB)



2.5 THz Nb HEB

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Receiver

- IF amplifier integration
  - integrated hybrid and MM MMIC technology has improved noise figure by minimising waveguide transitions and couplings

- Hermetic sealing
  - cheaply by E-plane probe transition

- Mixer diode overload protection
  - back to back diode/PIN diode arrangement with overload protection > 1 watt (mean)

- Extensive use of waveguide components
  - extensive heritage to beyond 1 THz
  - manufacture by precision machining photolithography, electro-forming and micro-machining

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Antenna

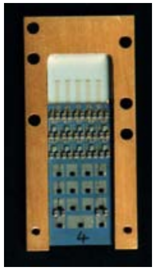
- Most millimetric antenna designs are scaled variants of microwave approaches

W-band Foster scanner
courtesy
Q-par Angus Ltd

- Extensive use of reflector based antenna - dual-reflector (Cassegrain) arrangement avoids waveguide losses associated with front-feeding

- Lens and horn antennas avoid aperture blockage and sidelobe effects

Q-band dielectric
immersion lens

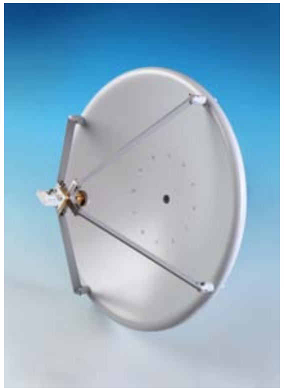


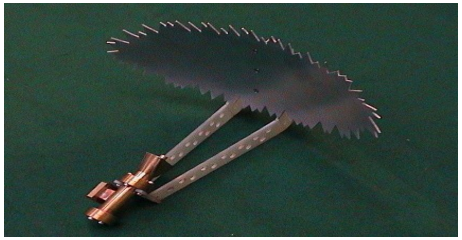
- Size and weight of lens based antennas are much less than microwave counterpart

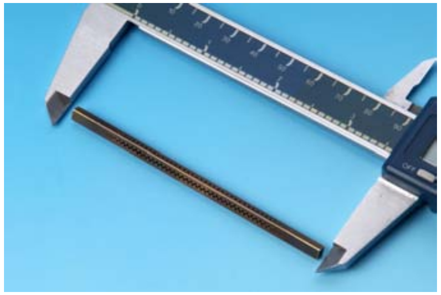
- Surface accuracy and stability more stringent than at microwaves

Antenna

- Reflector antennas
  - prime focus
  - dual reflector (Cassegrain)
  - offset fed
  - shaped / reconformable reflector
- Lens antennas
  - dielectric immersion lens
  - zoned dielectric
  - Luneburg
- Horn antennas
  - flared
  - multimode
  - corrugated
  - lens corrected
- Dielectric rod
- Slotted waveguide antennas
- Leaky waveguide antennas
- Microstrip antennas


prime focus reflector


offset fed reflector


slotted waveguide array

courtesy
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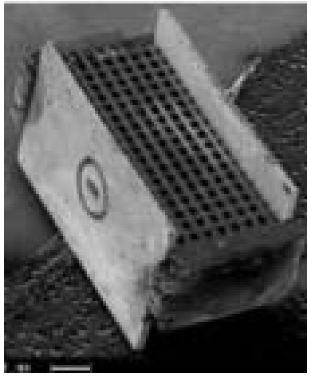
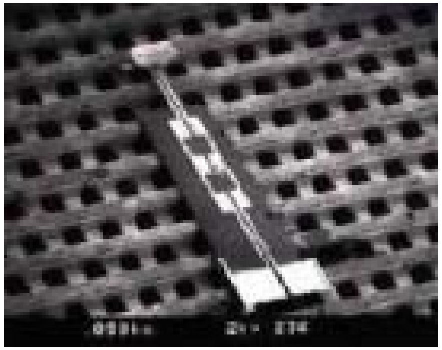
Antenna


EBG waveguide

- Exploitation of novel materials

- Electronic Band Gap (EBG) materials are structured dielectrics which are photonic analogues of semiconductors
- artificially engineered periodic materials to deter the propagation of electromagnetic radiation over a specified band
- surface waves and back radiation are strongly suppressed within the bandgap
- fabrication up to 500 GHz


EBG antenna
dipole antenna
on wood-pile structures

- Key features
  - periodicity
  - lattice geometry
  - dielectric constant
  - fractional volume

- Metamaterials / negative refractive index materials

- Millimetre wave active phased array based antenna

Capability – performance, benefits and applications

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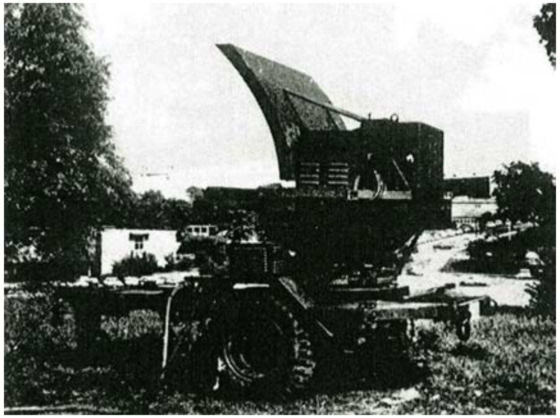
Capability – performance, benefits and applications

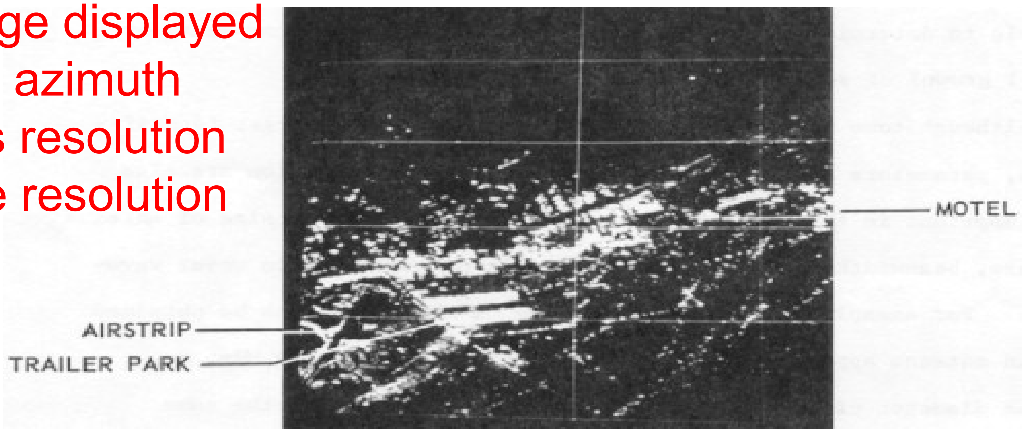
- Small size and weight coupled with rapid scanning and high resolution in angle and range provide excellent resolution of the surveillance volume

- In 1959, the degree of terrain mapping detail from a 70 GHz surveillance radar (AN/MPS-29) permitted vehicle navigation using data solely derived without use of optical sensors – the forerunner of collision avoidance radar



Ref: Long, Rivers and Butterworth (1960)

4 to 9 km range displayed
30 degree azimuth
0.2 degrees resolution
7.5 m range resolution



Sierra Vista, Arizona, USA

- Major counter-measure threats

ECM (active)

Unintentional
Mutual interference
EMI
Intentional (jamming)
Noise
Deception

ECM (passive)

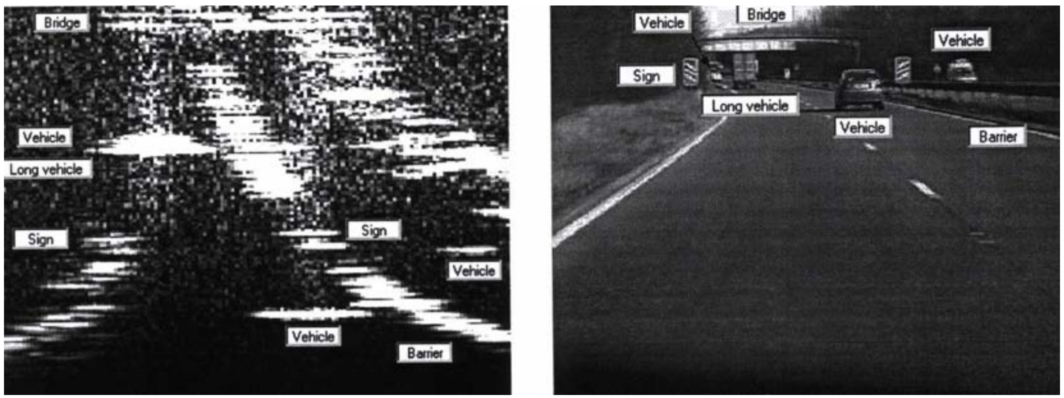
Chaff
RAM / signature
Modification
Foliage / natural cover
Camouflage screens
False targets (confusion)
Decoys (target-like)
Clutter
Rain, snow, hail
Ground
Sea
Atmospheric / contaminants
Fog
Smoke
Dust

ESM

Direction Finding (DF)
ELINT receivers
Defence suppression
Anti-radiation missiles (ARM)

Capability – performance, benefits and applications

- Narrow antenna beamwidth / low sidelobes with compact and small aperture
- High angular tracking accuracy
- Reduced ECM vulnerability
- Reduction of multipath and clutter at low elevation angles
- Improved multiple target discrimination
- Improved non-cooperative target identification (NCTI)
- Penetration of some optically opaque materials
- Mapping quality resolution



77 GHz radar and video based measurements from a traffic scene (circa 1998)

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Examples of current millimetre wave defence radar systems

- EDT-FILA (Brazil) fire-control system 8-40 GHz
- Small Fred (Russian Federation and associated states (CIS) ground surveillance 20-40 GHz
- SNAR-10 (CIS) surveillance 20-40 GHz
- TOR (CIS) surface-to-air missile system 20-40 GHz
- Cross Swords (CIS) missile fire control 20-40 GHz
- Gukol-4 (CIS) weather/navigation 20-40 GHz
- Systema (CIS) airborne millimetric surveillance, search and rescue, landing aid 100 GHz
- Romeo II (France) obstacle avoidance 40-100 GHz
- EL/M-2221 (Israel) multi-function search, track and guidance/gunnery 27-40 GHz
- ASADS (Netherlands) anti-aircraft gun fire-control 35 GHz
- FLYCATCHER Mk2 (Netherlands) dual band I/K band air defence
- SPEAR (Netherlands) low level air defence fire-control 35 GHz
- LIROD (Netherlands) fire control and surveillance system 20-40 GHz
- STING (Netherlands) fire control 20-40 GHz
- STIR (Netherlands) tracking and illumination 20-40 GHz
- Eagle (Sweden) air defence fire-control 20-40 GHz

Flycatcher Mk2

courtesy of Thales

Examples of current millimetre wave defence radar systems

- Longbow (US) millimetric 94 GHz fire control
- Battlefield Combat Identification Systems BCIS (US) all-weather question-and-answer battlefield identification system 38 GHz band
- AN/SPN-46(V) (US) ship borne precision approach and landing system 20-40 GHz
- AN/APQ-175 (US) airborne multi-mode 20-40 GHz
- Surveilling Miniature Attack Cruise Missile SMACM (US) tri-mode seeker 94 GHz
- Airborne Data Acquisition System ADAS (UK) F, I and J bands, 35 GHz and 94 GHz
- Maritime Clifftop Radar MCR (UK) F, I and J bands, 35 GHz and 94 GHz
- Mobile Instrumented Data Acquisition System MIDAS (UK) F, I and J bands, 35 GHz and 94 GHz
- Type 282 (UK) tracking and ranging for test sites 20-40 GHz
- MARCAL (UK) muzzel velocity 20-40 GHz
- Type 911 (UK) surface to air missile tracking 40-100 GHz
- W800 (UK) ground based surveillance FM-CW radar 77 GHz
- TARSIER (UK) ground based surveillance 94 GHz

W800 radar
courtesy NAVTECH Ltd

- Longbow™ system comprised of 94 GHz fire control radar (FCR) and "fire-and-forget" HELLFIRE missile system

- Fielded on US Army Apache AH-64 and British Army WAH-64 Attack Helicopter
- Moving target detection to >8 km range, stationary targets to >6 km range
- Target identification (non-cooperative) to class (such as tracked, wheeled etc)

Longbow™ system
courtesy of Lockheed Martin/Northrop Grumman

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Future

- Packaging improvements / integrated components (MMICs)
  - smaller size, lower weight, lower prime power (SWAP)
  - Surface Mount Device (SMD) and flip chip replacing wire bond

- System performance improvements
  - higher RF power performance
  - wider RF bandwidth
    - exploitation of ultra wideband (UWB) RF capability
  - lower receiver noise
  - more reliable / wider use of solid state RF sources

- Exploitation of new materials, techniques and technologies
  - GaN, InP/metamorphic HEMTs
  - EBG, metamaterials/ negative refractive index (NRI) materials
  - Micro-Systems Technologies (MST)/ RF MEMs / MM MEMs

- Validation of computer tools (CAD) and electromagnetic (EM) modelling for design, measurement and analysis

Future

- Cost reductions - Enhanced military capability at lower equipment cost .. Is it possible ?

  - cost reductions are likely with growing uptake of huge civil markets such as automobile collision warning systems (70-80 GHz) short range radio links / WLANs and optical communications

  - availability of large scale COTS manufactured components and sub-systems

  - radar technology at millimetric/sub-millimetric wavelengths has been relatively expensive but is now more affordable than ever

- Greater functionality - coherent , fully polarised, multiple beams, beam agility

- Dual/multi- frequency detection, tracking, classification sensors (multi-mode)
  - microwave / millimetre wave / E-O (IR)
  - IFF, Non-Cooperative Target Identification (NCTI)
  - Electronic Protection Measures (EPM) ECCM / ESM
  - interferometry / polarimetry / polarisation agile modes
  - autonomy (knowledge-based, adaptive / Radar Resource Management)
  - interoperability ? NEC, high speed missiles ?

Future

- Lightweight surveillance radar
  - Uninhabited Air Vehicle (UAV) / Uninhabited Combat Air Vehicle (UCAV)
  - UAV (military and civil) collision warning / sense and avoid systems
  - Airborne Intercept (AI) / manned combat aircraft
  - Long Range Cruise Missile (LRCM)/Air Launched UAV (ALUAV)/
  - Intelligence, Surveillance and Reconnaissance (ISR) provided by loitering munitions / High Altitude Platforms (HAP)
  - man-pack infantry portable systems
    all-weather surveillance of man-made targets
    such as personnel and mortars at low altitude
  - submarine periscope systems
  - war gas (Sarin, Soman etc) and bio-agent (Anthrax etc)

W-band surveillance radar
courtesy
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- "See-thru-wall" systems
  - dismounted combat within urban environments
  - concealed weapon (ceramic / plastic) detection
  - substance detection
  - detection of Improvised Explosive Devices (IED)
  - personnel / passenger bag screening

Thank you

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Questions ?