R&D Vision

ATLA
Acquisition,Technology & Logistics Agency

Toward the Realization of a Multi-Domain Defense Force and Beyond

Explanatory Documentation

Initiatives in the Electromagnetic Domain

March 31, 2020

Acquisition, Technology & Logistics Agency

What is the "R&D Vision?"

The R&D vision is a document which presents the principles on Research & Development (R&D), technological challenges, and roadmaps of the technologies required to realize our future defense capability for the purpose of strategically conducting advanced R&D from the viewpoint of the mid-to-long term.

The Ministry of Defense (MOD) has formulated *R&D vision concerning Future Fighter Aircraft* in 2010, and *R&D vision of Future Unmanned Vehicles* in 2016 based on *Strategy on Defense Production and Technological Bases and Defense Technology Strategy*. According to the direction shown in *National Defense Program Guidelines for FY 2019 and beyond* (approved by the National Security Council and Cabinet on December 18, 2018), the MOD has formulated the new R&D vision. They are leading to encouragement to acquisition and enhancement of the capabilities required for cross-domain operations such as "Electromagnetic spectrum (EMS) technologies", "Technologies for Persistent ISR including Space", and "Cyber defense technologies" as well as leading to that in traditional domains such as "Underwater warfare technologies" and "Stand-off defense technologies" in order to contribute to realization of Multi-domain Defense Force and to realize technological innovation required for further enhancement of future defense capability.

According to the R&D vision, the MOD will hereafter strategically foster technologies that become necessary in the future and conduct R&D effectively and efficiently.

Remarks: A decision-making whether to initialize a development for a deployment or not is comprehensively done by the perspective of defense program on various then-conditions including progresses of researches conducted depicted on the R&D vision, a latest national security environment, an availability of procuring a foreign weapon system, etc.

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Electromagnetic Spectrum (EMS) Technologies - Towards EMS Superiority

The significance and issues

The EMS domain is an important domain related to wide-ranging defense activities such as ISR, information sharing, precise guidance, etc. Among foreign countries improving their EW capabilities, therefore, is it necessary to endeavor to achieve effective and efficient use of EMS

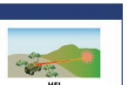
Function	The status quo	Issues
EW Capability – EA	• Evasion from a missile, etc. is a major application • Large-size jamming platform is the mainstream • Jamming capability needs to progress against improvement of target electronic device's EP capability	• Realization of missile defense by high-power energy • Divergence of jamming platform • Jamming capability exceeding advanced EP of target electronic device
EW Capability – EP	• Possibility of long-range detection by various enemy EM sensors • Possibility of disruption to radar and communication by advanced jamming capability • Possibility of damage by EMP ammunition, etc	• Evasion from long range detection by various enemy EMS sensors • Avoidance or alleviation from effects of advanced jamming • Protection from effects of EMP
EW Capability – ES	• Progress of LPI/LPD technology • Large-size SIGINT platform is the mainstream	• Enhancement of the capability to detect LPI/LPD radio wave • Divergence of SIGINT platform
EMS Management	• Necessity of EMS situational awareness for efficient use of EMS • Non-flexible EMS allocation	• Centralized EMS situational awareness • Flexible EMS allocation

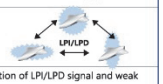
It is necessary to acquire the technology to realize cost-effective countermeasure by advanced EW weapon systems exceeding foreign countries' EW capability, while realizing efficient EMS usage through EMS management

Technologies for the MOD/SDF to acquire

It is necessary to acquire such technologies a high-power directional energy technology, LPI/LPD technology, advanced SIGINT technology, EMS domain awareness technology, etc. to solve issues

Function	Examples of the technologies to acquire
EW Capability – EA	• High-power directed energy technology (HEL and HPM) to be able to neutralize a variety of objects such as drones, various missiles, etc • Jamming (communication, radar, and EO/IR) technology which corresponds to various platforms and realizes optimal jamming against targets including network, according to various communication environment and target's EP capability
EW Capability – EP	• LPI/LPD technology corresponding to the EMS situation • Anti-jamming technology avoiding or alleviating influence of jamming • Protection technology against EMP effects
EW Capability – ES	• Broadband and high-resolution reception technology enabling reception and collection of LPI/LPD signal and weak electromagnetic wave under the presence of jamming • Small and lightweight ELINT technology mountable on unmanned platform
EMS Management	• EMS domain awareness technology enabling centralized grasp of EMS situation in the space and allocation status necessary for efficient EMS management • Optimal EMS allocation technology enabling effective and efficient use of EMS by flexible reallocation of EMS according to EMS situation in the space

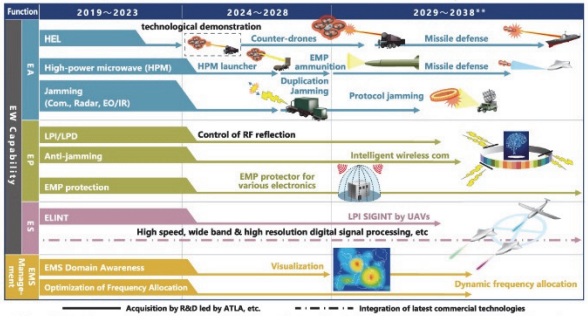




Technological Roadmap

*These are just for illustrative purpose of possible future weapon systems, not any determined development plan.

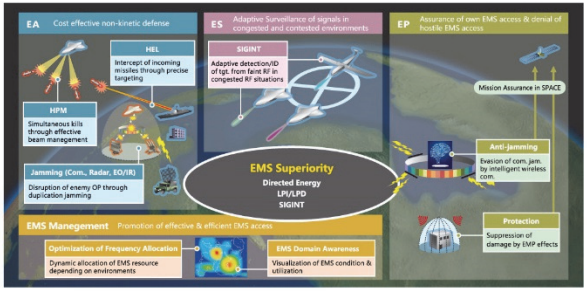
In the shorter-term viewpoint, the core technologies in the EMS domain such as a ground defense system (including HEL and HPM) against drones and other new threats, EMP ammunition, etc. should be established. Afterward, it is to realize diversity of mountable platforms and improvement of their power as well as other general EW capabilities and EMS management capability to support them



**The endpoints of arrows are tentative. In the view of the concept of streamlining R&D, we will endeavor to obtain the technologies earlier.

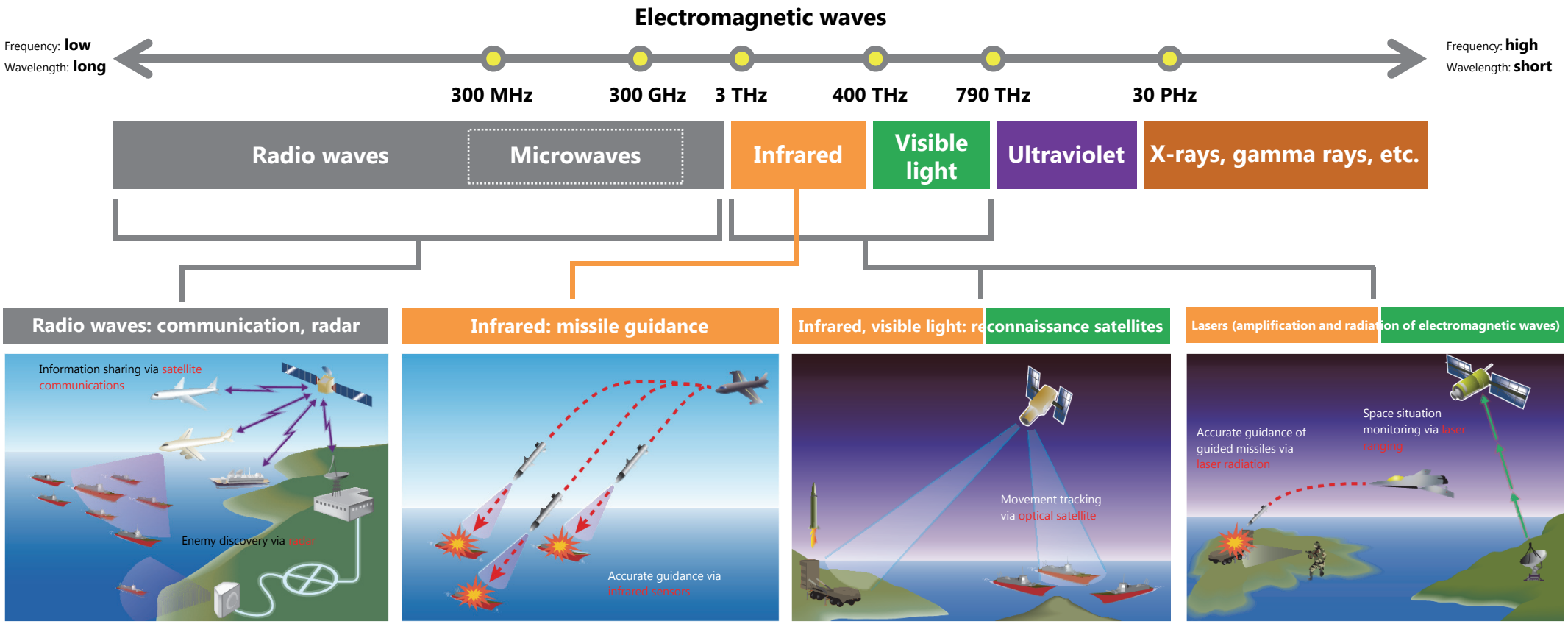
Future Notional Picture

Superiority in EMS domain should be achieved that affects the defense activity in any domains with core technologies: directed energy, stealth, SIGINT, optimization of frequency allocation and others



What are Electromagnetic Waves?

Electromagnetic waves are a general term for radio waves, infrared, visible light, x-rays, etc.



- In recent years, the use of electromagnetic waves has increased in the defense field.
- Specifically, electromagnetic waves are used for command communications, ISR, information gathering, and precision missile guidance, etc. and the importance and scope of application is likely to increase due to technological advances.
- In addition, methods of interfering with such electromagnetic wave usage have also advanced such that maintaining a superior position within the electromagnetic wave area now exerts a significant impact on the overall activities of the Ministry of Defense and the SDF including other areas.

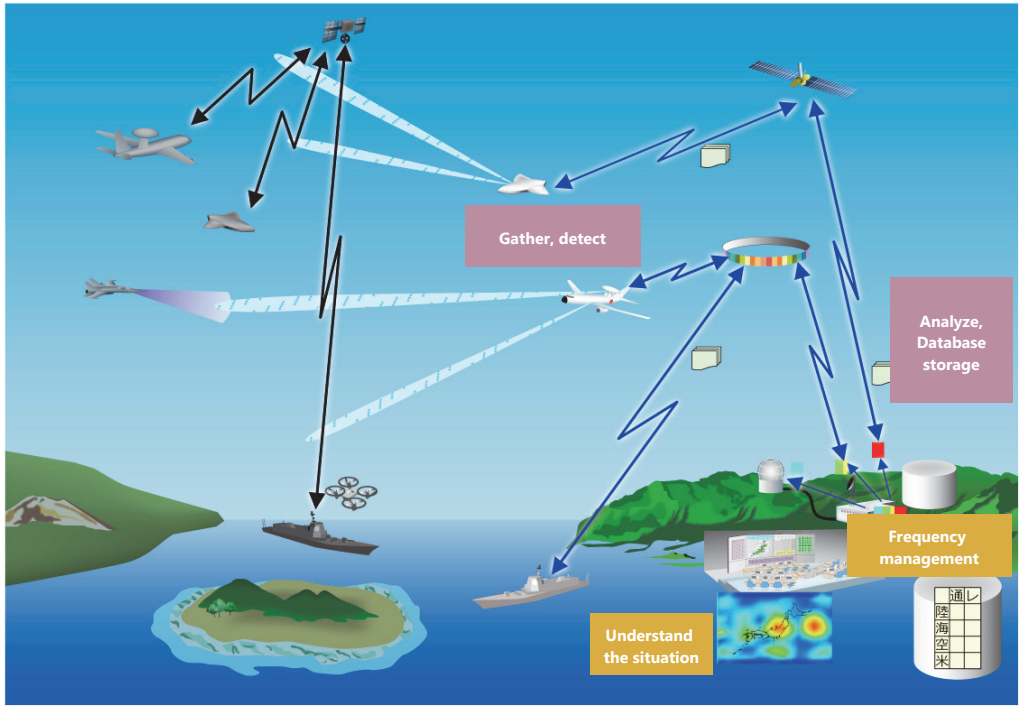
* "Radio waves" refers to electromagnetic waves at a frequency of 3 THz or less as defined under the Radio Act, and the approval of the Minister for Internal Affaires and Communication is required for the frequency used.
* GHz: Gigahertz (1 GHz = 1 billion hertz), THz: Terahertz (1 THz = 1,000 GHz), PHz: Petahertz (1 PHz = 1,000 THz)

Capabilities in the electromagnetic domain

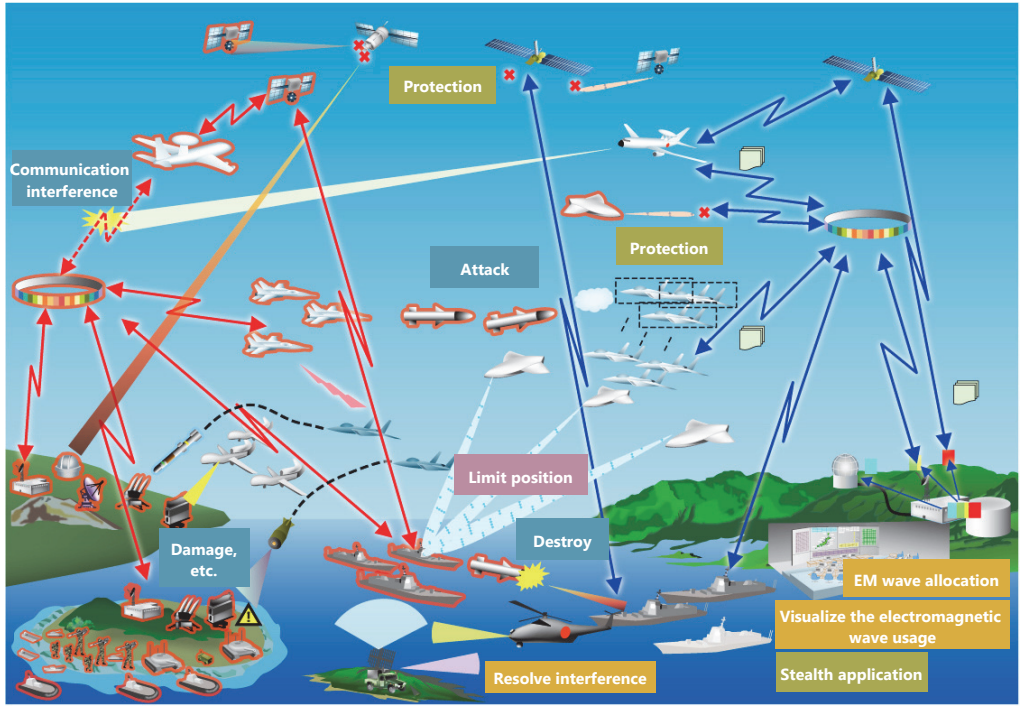
- Capabilities in the electromagnetic domain can be largely divided into "electronic warfare" capabilities for combat using electromagnetic waves and "EMS management" which appropriately manages and adjusts the use of electromagnetic waves.
- Of these two areas, "electronic warfare" generally consists of "attacks" to reduce and disable the opponent's combat capability, "protection" to limit the impact of electromagnetic wave jamming by the opponent, and "support" to gather the information required to implement attacks and provide protection.

Illustration of future activities in the electromagnetic domain

Peacetime Gather, analyze, and store electromagnetic wave information in a database



Emergency Respond through a combination of attacks, protection, support, and EMS management



Electronic warfare perception and initiatives in foreign countries

Due to the advances in information and communications technology (ICT[*1]), modern warfare is increasing its dependence on electromagnetic waves regardless of whether the domain of activity involves the land, sea, air, space, or cyberspace or the type of activity is command and control, movement, or attack.
Amidst this situation, in recent years foreign countries have been promoting initiatives to impede the use of electromagnetic waves, and some countries have demonstrated a high level of electronic warfare capability in actual fighting.
As a result of military modernization efforts, Russia electronically jammed the activities of unmanned aerial vehicles (UAV[*2]) during the Ukraine crisis and is said to have successfully jammed displays of military power by the Ukranian Army. In addition, Russia is said to have utilized an electronic warfare system called the "Krasukha-4" during the military intervention in Syria to effectively eliminate the no-fly zone established by the Western countries.
The strategic support unit established by China in 2015 has been identified as being responsible for missions relating to space, cyberspace, and electronic warfare. Moreover, Chinese electronic-warfare aircraft have become increasingly active in areas around Japan. In July 2017, a Y-8 electronic-warfare aircraft was confirmed for the first time, and subsequent activities by other electronic-warfare aircraft have been frequently confirmed around the East China Sea.
The U.S. announced its electromagnetic spectrum strategy in 2013 and electronic warfare policy in 2014 and has advanced initiatives to ensure flexibility with respect to electromagnetic wave usage and electromagnetic superiority. However, as the electronic warfare capabilities of foreign countries have improved in recent years, it has lead to an awareness that the U.S. superiority in electronic warfare is seriously threatened. The U.S. Department of Defense is positioning the electromagnetic wave domain as a domain/combat space which is equivalent to land/sea/air, space, and cyberspace and is emphasizing policies which will attach a new level of importance to this area.

Krasukha-4

*1 ICT: Information Communication Technologies

*2 UAV: Unmanned Aerial Vehicle

Perception and the current status of electronic warfare research and development at the Ministry of Defense

The "NATIONAL DEFENSE PROGRAM GUIDELINES for FY 2019 and Beyond" stipulate that capabilities will be acquired and strengthened in the new domains of space, cyberspace, and electromagnetic waves as priorities for strengthening defense capabilities.
While some research and development concerning electronic warfare has been implemented, systematic research and development in the electromagnetic domain has not yet been carried out. Due to the high degree of confidentiality concerning electronic warfare initiatives and the difficulty in obtaining technologies from foreign countries, Japan must conduct its own research and development.

(1) The efficient and effective use of electromagnetic waves is an important area for determining victory in modern warfare
(2) There is a possibility that some countries possess advanced electronic warfare capabilities, and impediments to electromagnetic wave usage are a realistic threat
(3) Due to the delay in systematic research and development initiatives and the difficulty in obtaining technologies, there is a possibility of a technological gap with foreign countries

Given the reasons stated above, the Ministry of Defense will promote various policies by clarifying the technological issues which it should resolve and developing an executable roadmap to steadily ensure Japan's technological dominance.

Status of Research and Development by the Ministry of Defense and Foreign Countries in the Electromagnetic Spectrum Domain

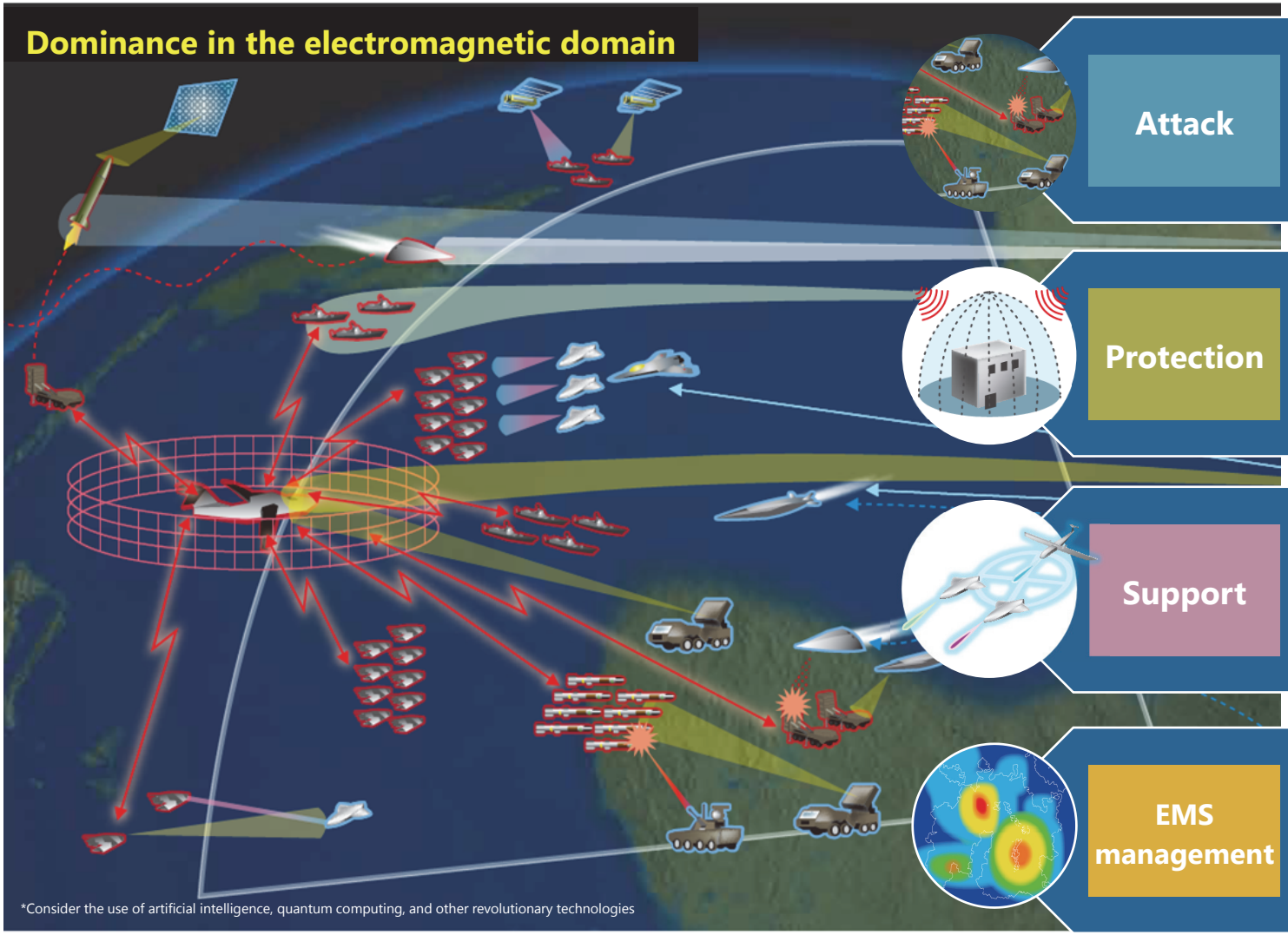
	Foreign countries	Ministry of Defense
Attack	● Off-board (mounted on the outside of aircraft) radar jamming technologies and efficient communication jamming technologies based on the target communications are advancing mainly in the U.S. and Europe ● The U.S. and Europe are making progress in the research and development of large-scale and small-scale high-power lasers ● Research and development of high-power microwaves which can be used against drones (miniature UAVs) is advancing mainly in the U.S.	● Researching and developing radar jamming equipment for training (ALQ-5), escort jammer (electronic defense apparatus equipped on fighter aircraft), etc. ● Researching the jamming of tactical data links, etc. ● Began creating a research prototype of a miniature high-power laser from FY 2018 Researched large-scale laser components
Protection	● U.S. and Russia possess advanced stealth technologies for fighter aircraft ● U.S. possesses technology which suppresses jamming signals in radars and communication equipment, etc.	● Conducting research which will contribute to improvements in radio wave stealth ● Researched radar which reduces the effects of radio wave interference
Support	● In the area of electronic information gathering, improvements in reception processing due to the shift to wideband receivers, increased sensitivity, and digital reception technologies as well as improvements in signal discrimination due to the use of artificial intelligence technologies are advancing mainly in the U.S. and Europe	● Developing next-generation radio wave measurement equipment on aircraft as an improvement in direction finding performance and signal analysis capability ● Researching the implementation of global coverage ES equipment in the area of advanced RF* self-defense *RF: Radio Frequency
EMS Management	● U.S. and other foreign countries are developing and operating tools to visualize and manage the use of electromagnetic waves	● Conducted research into interference rejection within systems and platforms

Current situation in Japan

- Steady track record in development and equipping in the areas of attack (electronic interference) and support.
- At the stage of researching component technologies for protection.
- At the stage of starting to examine EMS management

Concepts for Research and Development Initiatives in the Electromagnetic Domain

To ensure dominance in the electromagnetic domain in the future, we must understand and analyze the electromagnetic wave situation regardless of whether it is peacetime or an emergency and implement electronic countermeasures, etc. under the appropriate EMS management in an emergency. Therefore, it is important to expand the scope of information gathering, improve analysis and electronic countermeasure capabilities, networking, adaptation to UAVs and various other platforms, and improve electronic protection functions.



Attack

- Optimal jamming according to the target, environment, etc.
- Attacks which interfere with or destroy the threat target with directed energy technologies

Protection

- Secure a degree of freedom to avoid and mitigate jamming and interception, etc. through wideband ranges, high sensitivity, high-speed processing, high-speed communication, and data compression
- Self-protection, electromagnetic wave protection, and radio wave interference suppression

Support

- Information gathering, surveillance, and analysis compatible with a converging electromagnetic wave environment
- Multi-platform shift to expand the target surveillance area and move to full automation/manpower saving

EMS management

- Rapid and precise electromagnetic wave/electronic warfare control through networking
- Efficient and effective use of electromagnetic waves through visualization of the electromagnetic domain

Technologies Required for Equipment with Respect to the Electromagnetic Domain

Technological progress in electronic warfare

- Rapidly and effectively implementing electronic countermeasures by seizing the electromagnetic wave environment in real-time and establishing electronic warfare control will directly lead to combat superiority on the battlefields of the future
- Fundamental technologies for ensuring superiority in combat under appropriate EMS management are important
- Effective countermeasures for targeted radar and communications require technological development based on advances in electronic protection technologies. In particular, the monitoring of targeted tactical data link networks through satellites and other networks and the application of effective interference is important for ensuring combat superiority in the future as well
- Due to advances in laser processing techniques in the civilian sector, high-power and high beam quality laser light sources are being realized, which may make high-power laser systems that can destroy distant targets feasible
- It was reported in the U.S. that a technology demonstration successfully conducted a test flight of an unmanned aircraft (CHAMP) which emits high-power microwaves. It is estimated that high-power microwave weapons have reached the stage of practical technology application
- Evaluation technologies are important and essential for improving the performance of electronic warfare technologies
- With the advancing digitization of equipment used in electronic warfare, the simple and flexible generation or dynamic alteration of a wide variety of signals via software may become common going forward

Unmanned aircraft (CHAMP)

Source: United States Air Force web site

Direction of future development

- To ensure combat superiority, technologies for monitoring tactical data link networks including radar and satellites and jamming them as needed will continue to be important
- As the importance of networks increases, the electronic protection performance with respect to communication waves is also improving, and more advanced and intelligent communication jamming methods must be established for communication waves with anti-interception, jamming resistance, and low detection characteristics
- Research must be conducted into ELINT and stand-in jammers with miniature unmanned aircraft which lie at the opposite end of the spectrum from ELINT aircraft and stand-off jammers with large aircraft
- High-power directed energy weapons must be realized from the standpoint of low reaction time countermeasures for accelerated aircraft and missiles as well as low cost countermeasures for miniature unmanned aircraft, mortar shells, and other large-scale, low cost threats
- The effect (target vulnerabilities) of high-power microwaves on targets must be continuously analyzed and evaluated
- The low-observable characteristics of MOD assets must be improved with respect to various sensors
- Establishing a cycle of electronic attack, protection, and support without any delay requires the utilization of artificial intelligence, etc. to achieve a considerable degree of automation
- Effective ES systems must be examined for future EMS management
  In addition, data analysis of the targeted information/analysis technologies must also be improved
- Performance evaluation technologies for equipment which can handle stealth improvements in the equipment of foreign countries must also be improved
- Because there is little demand for electronic warfare technologies in the civilian sector, proactive initiatives by the Ministry of Defense are required

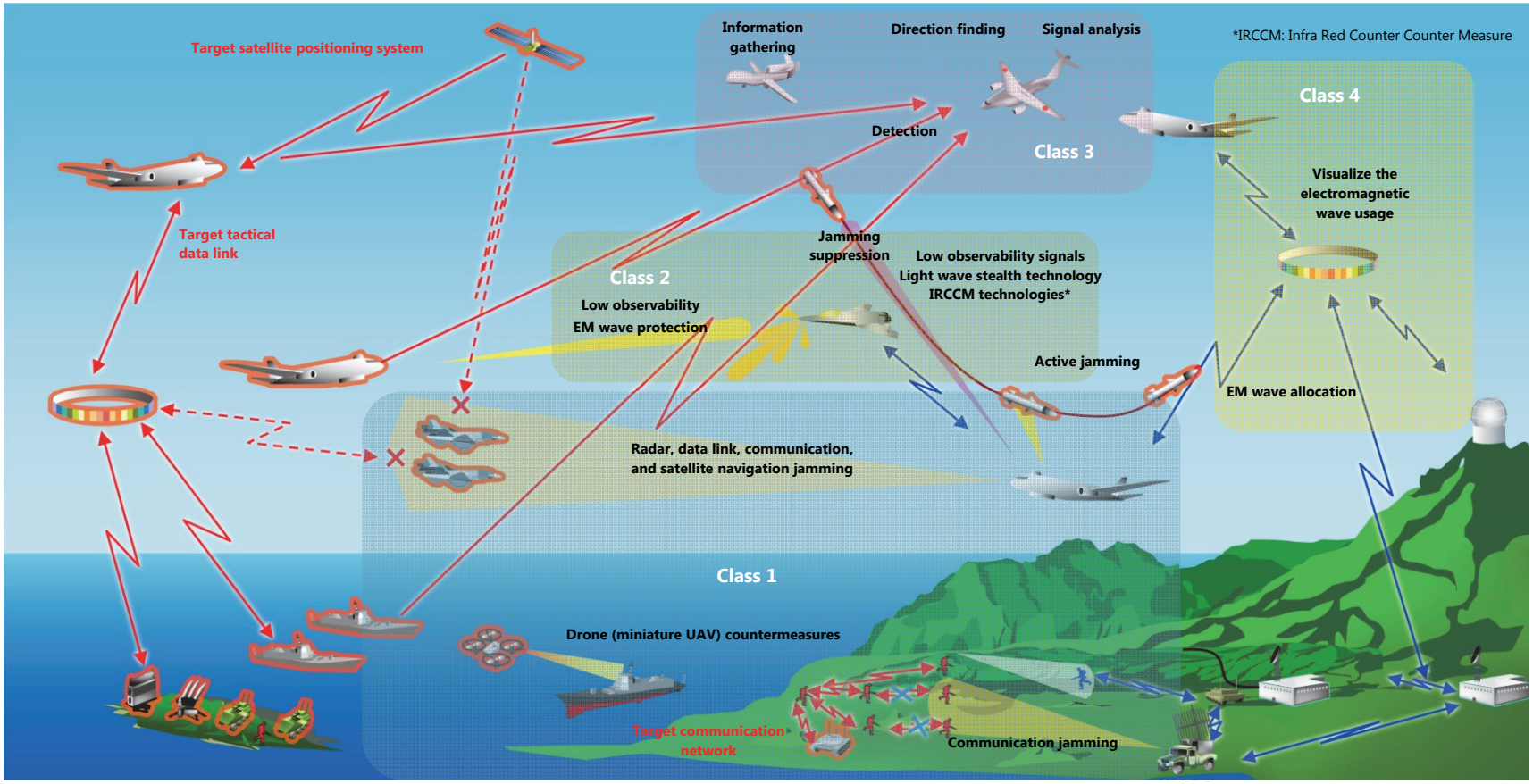
Advanced electronic warfare technologies which are key to the future

- Technologies which transmit the optimal high-power jamming signal after high-sensitivity detection, reception and analysis of tactical data link communications with superior anti-interception and anti-interference characteristics
- Technologies which trigger data errors, etc. by reproducing and transmitting the target communication signal
- Low-detection ELINT technologies, data integration technologies, and miniaturization and weight reduction technologies to realize ELINT systems that can be equipped on unmanned aircraft to enable effective ELINT with limited radio wave emissions
- High-power laser technologies which emit a high-power and high-quality beam to destroy a target
- Miniature and high power microwave amplification module technologies
- Radio wave control technologies which control one's own radiated waves according to the radar wave reflections from the opponent to neutralize the radio waves and apply stealth
- Artificial intelligence related technologies which achieve processing autonomy and acceleration to realize an electronic warfare cycle with no delay
- Technologies for evaluating integrated electronic warfare capabilities in fighter aircraft, etc. with respect to radar, communication equipment, and light wave sensors with all of the equipment linked and operating together
- High fidelity evaluation technologies which can also be applied to handling diverse threats
- RCS*2 evaluation technologies for bistatic radar*1 and indoor full-scale target measurement technologies
- Accurate RCS estimates through electromagnetic field analysis which applies the measurement results

*1 Bistatic radar: uses transmitters and receivers in different locations
*2 RCS: Radar Cross Section

Systematically promote the research and development pertaining to the electronic warfare technologies which require the most advanced and long-term technology development
to strategically acquire the advanced technologies to ensure Japan's technological dominance as well as dominance in future activities related to electromagnetic waves

Classifications of Electromagnetic Domain Technologies



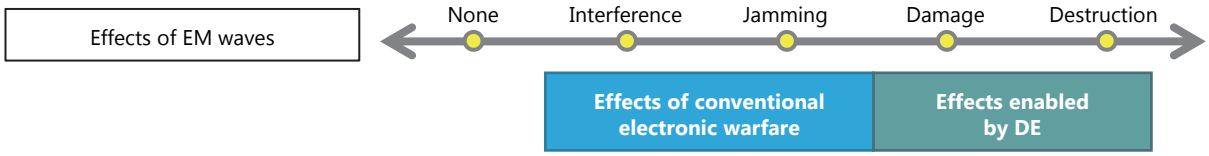
Classification	Description
Class 1 (Attack)	Includes jamming, deception, malfunction, and destruction, etc. of sensors, communication equipment, and other equipment which uses electromagnetic waves. (1) long-range jamming from stand-off jammers, (2) medium-range escort jammers on fighter aircraft, etc., (3) short-range jamming from stand-in jammers, and (4) countermeasures for various missiles using high-power laser microwaves
Class 2 (Protection)	Target self-protection, electromagnetic wave protection, frequency hopping, and other anti-jamming technologies as well as radio wave disruption, secure communication, and other low observability technologies.
Class 3 (Support)	Target technologies related to ES using radio waves. Includes radio wave information gathering (direction finding, launch origin identification, etc.) and signal analysis, etc.
Class 4 (EMS management)	Target technologies related to EMS management. Includes technologies for interference detection as well as visualization, awareness, and allocation of electromagnetic wave usage.

*In advancing each initiative, **electronic warfare evaluation technologies** which can accurately simulate the electromagnetic environment of the space and precisely ascertain the performance of the latest electronic equipment are also required.

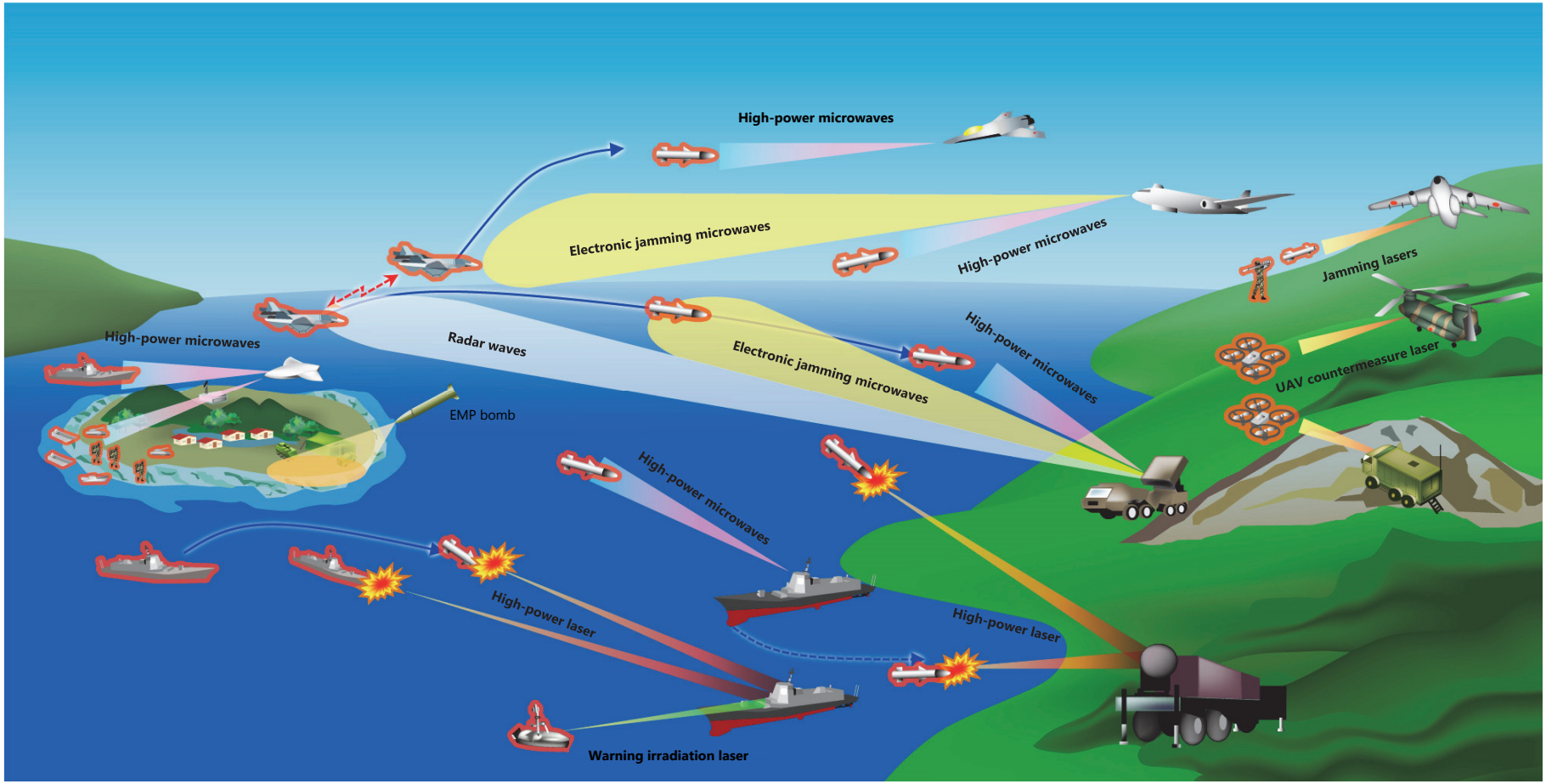
Important High-Power Directed Energy Technologies as Countermeasures

Directed Energy (DE*) technologies concentrate electromagnetic wave energy, etc. to change it into a high-power energy beam and specifically correspond to high-power lasers and microwaves, etc.

*DE: Directed Energy



Interference: slight impact only during emission
Jamming: effects continue after emission may recover naturally
Damage: recovery requires manual intervention
Destruction: recovery requires hardware and software replacement



Technological Issues Which Should be Addressed (1/8)

Attack (1) (Electronic jamming (communication, radar, light waves) technologies)

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies		Technology overview	Technological issues	Expected results
Jamming signal generation technologies	Protocol jamming technologies	Technologies which jam communications with a jamming wave that uses the protocol of the target wireless communication	Able to estimate the protocol of the target communication to generate and transmit a jamming wave using that protocol	High-level jamming with low observability according to the conditions of the target communication
	Unique word replication jamming technologies	Communication jamming technologies which use the structure of the target wireless communication	Able to use the structure of the target communication wave to generate and transmit a jamming wave	
	Received signal reproduction technologies	Technologies which generate a deceptive jamming wave for the target communication	Able to replicate with a precision that can modulate the target communication wave. Able to record and reproduce the received signal	
	High-fidelity signal generation technologies	Technologies which generate jamming signals that are close to the received signal	Realizing high-bit DRFM*	Jamming of electronic devices with a high degree of electronic protection
	Time synchronization deception technologies	Technologies which create false time synchronization for communication	Analyzing the time synchronization method and jamming it so that it cannot synchronize	Efficient jamming of data links, satellite navigation, etc.
Jamming transmission technologies	High power and wide band transmission technologies	Technologies which transmit at high power and across a wide band	Realizing high-power, wide band transmission modules	Increase in the number of electronic devices that can be jammed
Jamming control technologies	Link jamming technologies	Technologies that efficiently jam tactical data links and satellite navigation	The ability to select a highly efficient jamming method across a wide band according to the communication wave and control and transmit the jamming signal as well as jam satellite navigation	Efficient jamming of data links, satellite navigation, etc.
	High-speed response jamming	Technologies which provide the optimal time management for receiving and transmitting jamming signals	Realizing high-speed data transfers between transmitting and receiving	
	Transmission timing control technologies	Forces the target to receive a jamming wave at any time	The ability to estimate the target communication timing	High-level jamming with low observability according to the conditions of the target communication
Active jamming technologies (light wave)	Jamming technologies	Technologies which identify the type of infrared seeker and emit modulation or saturation jamming. Technologies which control the emitted infrared spectrum by using the structural radiation and suppress the emissions in the range used by the sensors	Continuously emitting laser light at a missile seeker, distinguishing a reticle-type/image seeker, and emitting modulation or saturation jamming	Avoidance of infrared seeker missiles through active jamming
	Connection technologies	Technologies which connect the MWS and jamming equipment and receive the target transfer	Connecting the MWS and jamming equipment and receiving the target information to switch to target tracking	
	Environmental resistance technologies	Technologies equipped for operation on large-scale aircraft	Environmental resistance when equipped on large-scale aircraft	

*DRFM: Digital Radio Frequency Memory MWS: Missile Warning System

Technological Issues Which Should be Addressed (2/8)

Countermeasures (2) (Directed energy technologies)

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies			Technology overview	Technological issues	Expected results
High-power laser	Laser light source technologies		Component technologies required to realize methods of improving the output of a single laser light source	Because miniature and easy-to-handle electrically powered lasers have physical output limits, technologies which maximally increase the output are required	High target destruction capability which can also be utilized in countermeasures for various missiles
	Beam coupling technologies		Component technologies required to realize methods of synthesizing the output generated from multiple laser light sources while inhibiting reductions in energy and beam quality	Requires technologies, etc. which uniformly remove the thermal factors that produce a reduction in beam quality when multiple lasers are combined	
	Target precision tracking and ranging technologies		Component technologies required for precision tracking which considers atmospheric conditions and achieving accurate light condensing on the target	Implementing precision tracking and ranging in a stable manner for high-speed targets	Accurate irradiation of various missiles, etc.
High-power microwaves	Miniature high power output technologies for power amplification modules		Component technologies required to realize high-power microwave systems which can enable high-power transmissions in a limited installation space	More efficient methods must be selected for the high-power micro amplification modules based on the trends in semi-conductor technologies	High target destruction and malfunction capabilities which can also be utilized in countermeasures for various missiles
	Array technologies for power amplification modules		Component technologies required to realize active phased arrays using power amplification modules that can emit high-power microwaves	Requires technologies which can arrange power amplification modules that can emit high-power microwaves in an active phased array and provide energy/beam management	
	Jamming effect measurement/evaluation technologies		Technologies for measuring/evaluating the impact of high-power microwave irradiation on missiles, etc.	Requires technologies which accurately assess the field intensity inside the missile as well as capture and clarify the phenomena occurring in the circuits, etc.	
	Power module technologies		Component technologies required to achieve a high peak envelope power to destroy electronic devices	Requires the development of new materials to obtain higher performance	
	Installation environment compatibility technologies		Component technologies which are compatible with the installation and electromagnetic environments of various platforms	Requires vibration resistance, moisture resistance, and other environmental resistance technologies as well as technologies to counter the effects within the aircraft and other aircraft during transmission	Improved possibilities for installation in various platforms
	Beam efficiency technologies		Beam steering convergence technologies, simultaneous multi-targeting technologies, and MIMO* technologies	Requires technologies which adjust the phase and strength of each module and control the wave surface	
	EMP bomb technologies	EMP bomb technologies	Technologies which disable equipment with electronic devices through a soft kill	Radiation power directional technologies, miniature power source technologies	EMP bombs which are effective against electronic devices with EMP resistance
		Anti-EMP protection technologies	Technologies which disable electronic devices by defeating the EMP protection performance	EMP performance analysis technologies	

*MIMO: Multiple Input Multiple Output

Technological Issues Which Should be Addressed (3/8)

Protection (1)

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies		Technology overview	Technological issues	Expected results
Low observability technologies	Radio wave reflection control technologies	Technologies which are part of the antenna to control the reflection frequencies by modulating the phase of the incoming waves	Because they are part of the antenna to control radio wave reflections, technologies which minimize the impact on the radio wave emissions must be established	Stealth which does not restrict the operational performance
	RCS management technologies	Technologies which retain their own RCS profile as data to manage the overall radio wave reflections	Because the RCS profile changes according to the angle and frequency, technologies which assess those changes in a sophisticated manner and appropriately control the radio waves must be established	
	Meta-material technologies*1	Technologies which inhibit the observability through optimization of the radio wave reflection characteristics	Balancing of the stealth and material characteristics in each applied location	
	Radar wave cloaking technologies	Stealth technologies which counteract anti-stealth radar by redirecting the radio waves	Application to wide bands and complex shapes	Avoid observation by anti-stealth radar
	Fire-resistant CFRP*2	Technologies for improving the fire resistance of the CFRP structure through the application, etc. of fire-resistant resin	Applying thermoplastic resin and other heat-resistant polymer composite materials	Lightweight stealth structures
	Low-RCS structural technologies (boltless joining)	Technologies for implementing lightweight, high survivability (impact-resistant, low-RCS (shape)) structures at a lower cost than all-CFRP structures by reducing the construction costs and the amount of CFRP used	Impact strength evaluation technologies Environmental performance evaluation	Low-cost stealth
Anti-jamming technologies	Direction-of-arrival suppression technologies	Technologies which lower the reception sensitivity in the jamming wave direction-of-arrival	Multi-wave countermeasures, narrow beam development	Uninterrupted detection or communications
	2D suppression technologies	Technologies which lower the reception sensitivity for the jamming wave direction-of-arrival and frequency	Acceleration, narrow beam development	
	Hopping technologies	Technologies which move to a frequency which differs from the jamming frequency to continue communications or detection	Short pulse development, acceleration	
	Robustness technologies	Technologies which limit the reduction in signal quality under jamming	Jamming-resistant modulation systems	
	Autonomous information transmission technologies	Technologies which autonomously establish and maintain communications even under jamming	Control systems for selecting efficient frequencies, communication systems based on the communication status	
	Communication environment estimation technologies	Technologies which estimate the radio wave environment (interference waves, jamming waves), radio placement information, frequency allocation information, and other aspects of the communication environment around the radio	High-precision communication environment estimation	
Low observability signal technologies	Concealment	Technologies which circumvent analysis even when intercepted through encryption	Encryption technologies and modulation/demodulation systems	Concealment of one's position, etc.
	Hopping technologies	Technologies which keep changing the frequency to avoid detection	Short pulse development, acceleration	
	Frequency spreading technologies	Communication technologies which spread the transmission power in the frequency direction	Wide band support and high efficiency, phase synchronization associated with wide band support	
	Low power technologies	Low observability technologies which lower the peak envelope power in the time or frequency direction to reduce the ES and other received power	Methods for reducing the peak envelope power that are compatible with communication efficiency	

*1 CFRP: Carbon Fiber Reinforced Plastic
*2 Meta-materials: Structures which possess electrical properties that do not exist in nature as a result of periodically arranging metals and other conductors into a structure at intervals which are less than the wavelengths of electromagnetic waves.

Technological Issues Which Should be Addressed (4/8)

Protection (2)

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies		Technology overview	Technological issues	Expected results
Light wave stealth technology	Infrared unwanted emission suppression technologies	Technologies which control the emitted infrared spectrum by using the structural radiation and suppress the emissions in the range used by the sensors	Support for near/mid/far infrared, heat resistance, large area	Concealment of various platforms
	Infrared absorption technologies	Stealth technologies which absorb and scatter the infrared emissions from the heat source	Improving the absorbed amount, ensuring the feasibility of construction	
	Future component technologies for reducing observability	Technologies which control the index of refraction of visible light rays to reduce observability under visible light	Technologies for controlling the amount of reflected visible light and the index of refraction	
	Infrared emission reduction coating technologies	Technologies which reduce infrared emissions by coating vehicle bodies	Infrared emission reduction technologies, environmental resistance technologies	
	Observability reduction system technologies	Technologies which control the temperature of vehicle surfaces by making the quantity of infrared emissions the same as the surrounding environment	Infrared emission quantity control technologies	
	Shape (change exhaust position) technologies	Technologies which reduce the quantity of infrared emissions through shapes and discharges	Making it low cost	
	Material and coating technologies	Technologies which reduce the quantity of infrared emissions through coatings and materials	Making it low cost	
IRCCM technologies	Light wave dome technologies	Improves anti-jamming characteristics for SRM* systems	Dome material technologies, optical property technologies, raindrop resistance	Improvement in the SRM accuracy rate
EM wave (EMP) protection technologies		Component technologies required to protect electronic devices from strong electromagnetic waves	Requires protective measure technologies according to the properties of the EM waves which are a threat	Avoid the destruction/malfunction of electronic devices due to high-power microwaves
Anti-laser technologies		Anti-laser component technologies which increase the resistance to laser attacks	Requires materials which effectively diffuse the heat from the ultrahigh temperature areas hit by the laser, materials which can reflect the laser light, or surface processing technologies	Reduction in damage from high-power lasers

*SRM: Short Range Missile

Technological Issues Which Should be Addressed (5/8)

Support

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies		Technology overview	Technological issues	Expected results
ELINT technologies	High precision direction finding technologies	Technologies which estimate multiple DOAs with high precision	Developing algorithms which can separate multiple waves and estimate the direction with high precision	High precision position limiting
	Communication wave analysis technologies	Technologies which estimate the communication wave specifications	Ability to estimate the specifications from faint communication waves in a poor reception environment.	Estimation and analysis of communication specifications from faint radio waves
	Low observability ELINT technologies	Agile radar*1, spectrum spreading*2, and other low observability ELINT technologies	Ability to engage in low observability ELINT in terms of space, frequency, and time	Low observability ELINT
Reception technologies	Wide band receiver technologies	Wide band technologies for receivers	Widen the instantaneous bandwidth of receivers to improve instantaneous detection	Low observability radio wave reception
	High resolution receiver technologies	High resolution technologies for receivers	Making receivers high-bit and expanding the dynamic range*3	
	Link surveillance technologies	Technologies which receive tactical data link communications with anti-jamming characteristics with a high sensitivity and across a wide band	Ability to receive communication waves which are frequency hopping at high speed across a wide band, detect the direction of the communication waves, and perform specification analysis	Jamming of tactical data link communications with anti-jamming characteristics
	Adaptive radio wave reception technologies	Technologies which switch to the optimal reception processing algorithm according to the reception environment	Ability to estimate the reception environment from the received signal and switch the processing algorithm	Radio wave reception in poor radio wave environments congested with EM waves
	Wide band/high resolution reception technologies	Wide band signal reception in poor reception environments	Ability to extract a wide band signal at high resolution from faint communication waves in a poor reception environment	
Networking technologies	Data integration technologies	Simple, on-board analysis technologies (extraction of the frequency, modulation system, pulse width, etc.) for the purpose of reducing transmission capacity	Technologies for on-board extraction of the received radio wave specifications (frequency, modulation system, direction, etc.) and transmission to the ground	Radio wave information gathering on unmanned aircraft and other miniature platforms
	Miniaturization and weight reduction technologies	Technologies for miniaturizing and reducing the weight of the antenna and receiver according to the unmanned aircraft payload	Ability to reduce the size and weight while maintaining the performance of the existing antenna and receiving equipment	
	Information sharing technologies	Technologies for instantaneous sharing of EM wave information between various platforms	Technologies for instantaneous sharing of EM wave information between platforms equipped with various EM wave equipment	
Light wave detection technologies	Detection technologies	Technologies for detecting ultraviolet or infrared to initially detect incoming missiles	Weak signal detection	Missile avoidance

*1 Agile radar: Pulse radar with a function that changes the transmitter's carrier frequency to a quantity greater than the pulse bandwidth in between the pulses or pulse groups with a pseudo-random sequence
*2 Spectrum spread: Technique which spreads the frequency between ten-fold and a thousand-fold compared to the frequency bandwidth of the information to improve the EP characteristics
*3 Dynamic range: Ratio of the maximum and minimum signals which an electronic device can process

Technological Issues Which Should be Addressed (6/8)

EMS management

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies		Technology overview	Technological issues	Expected results
EMS domain awareness technologies	EM wave visualization technologies	Technologies which gather information about the EM wave conditions in the combat space and provide visualization through integration with maps, etc.	Technologies which consider changes in the EM wave environment due to the frequencies and surrounding topography, etc. to generate and visualize a radio wave map across a wide area or in real-time	Simplified awareness of EM wave conditions
	Information integration, management technologies	Technologies for awareness of EM wave information in the combat space as well as managing and integrating EM wave information from other units and systems and newly detected EM wave information	Technologies for converting data format differences between units and systems and technologies for integrating and determining the correlation of EM wave information	Efficient management of various types of EM wave information
	Interference detection technologies	Technologies for identifying the presence of electromagnetic environment interference, etc. in the space and clarifying the target and conditions of the interference/electronic jamming	Detecting interference and identifying the causes in real time	Identification of EM wave interference
	Radio wave propagation calculation technologies	Technologies which take into account the topography to estimate the radio wave propagation of EM waves with dynamically changing radio wave specifications	Technologies which calculate and predict radio wave propagation and interference across a wide area	Support for the formulation of EM wave usage plans
	Electromagnetic environment analysis technologies	Technologies which realize high-speed automatic processing to ascertain the source of radio wave jamming and the radio wave specifications from the gathered radio wave information, topography, and other diverse peripheral information	Technologies which use information gathered under ordinary conditions to rapidly estimate the electromagnetic environment from the received waves in electronic warfare support, etc.	Acceleration of command and control through an awareness of the source of electromagnetic jamming, radio wave specifications, etc.
EM wave optimal allocation technologies	EM wave allocation optimization technologies	Technologies for managing the allocation conditions of the available EM waves by space, target, etc. and discovering the optimal allocation methods	Technologies for optimizing the EM wave combinations across a wide area when the EM wave environment is under dynamic conditions Technologies which optimize the EM wave combinations at high speed according to the EM wave conditions within the action area	Efficient usage of EM waves
	Planning support technologies	Technologies which support the drafting of electromagnetic combat operation plans according to predictions and evaluations of electromagnetic interference associated with COA* analysis and behavior	COA evaluation within the operation cycle time	Acceleration of operation plan drafting
	Countermeasure behavior formulation technologies	Technologies which support decision making requiring expertise and speed such as frequency switching, asset movement and the selection of other countermeasures, electronic countermeasure decisions and the selection of such radio wave specifications, and interference avoidance for sensors, radios, and electronic warfare equipment involved in these actions	Implementation of effective electronic countermeasures and support and the automation of decision making to limit their impact	Acceleration of decision making

*COA: Course of Action

Electronic warfare evaluation (1)

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies		Technology overview	Technological issues	Expected results
Evaluation and simulator technologies	Electronic warfare evaluation technologies	Technologies for evaluating the functions and performance of electronic warfare equipment	Support for future electronic warfare equipment which uses frequencies across a wide band is an issue going forward. Regarding the evaluation of light wave electronic warfare equipment used indoors, there has been no track record up to now, and it will take time to establish the technologies.	• Carry out equipment research and development which avoids information gathering by foreign countries by enabling the evaluation of equipment performance with respect to electronic countermeasures and support without externally leaking EM waves • Accurately evaluate the effect of the response to clarify the necessary performance improvements and countermeasures and implement an effective response • Accurately simulate radio wave reception in an environment which is close to the actual electromagnetic environment and accurately evaluate the radio wave collection capabilities to clarify the necessary performance improvements and countermeasures and implement effective support • Accurately evaluate the communication equipment, radar, and other radio wave radiation conditions and accurately ascertain the radio wave observability to clarify the necessary interception and jamming countermeasures and implement effective protection
	Radio wave environment simulation technologies	Technologies for reproducing the radio wave environment	Simulating an environment congested with many radar and communication waves is a future issue. Regarding the indoor simulation of a light wave electronic warfare environment, there has been no track record up to now, and it will take time to establish the technologies.	
	Bi/multistatic simulation technologies	Technologies for stimulating multiple transmission sources and reflected waves from any direction and angle of elevation at any time	In order to evaluate bi/multistatic radar*, technologies must be established to simulate signals which perform delay time control and Doppler frequency control.	
	Technologies for simulating vast, cluttered spaces	Technologies for simulating radio wave environments which are spatially vast and include clutter	In order to perform an evaluation in a radio wave environment which is close to real space, technologies must be established to simulate clutter with a two-dimensional area that spans the spatial and frequency axes.	
	Multisensor integrated simulation technologies	Technologies for generating simulated signals injected into radio wave and light wave sensors	In order to evaluate radio wave and light wave sensors, technologies must be established to simulate the combination and integration of various sensor information.	
	Congested radio wave environment simulation technologies	Technologies for simulating environments congested with communication, radio waves, and electronic warfare radio waves	Technologies are required for evaluating communication, radio waves, and electronic warfare equipment in environments congested with various communication, radio waves, and electronic warfare radio waves.	

*Multistatic radar: uses one or more transmitters and receivers in different locations. Bistatic radar is the case where there is only one transmitter and one receiver.

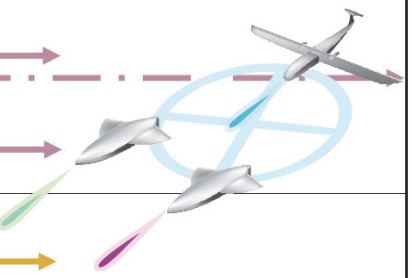
Electronic warfare evaluation (2)

Red: technologies which must be researched and developed primarily by the Ministry of Defense
Blue: technologies which can utilize the results of other equipment
Gray: technologies acquired through joint research with other institutions
Light blue: technologies awaiting progress in the civilian sector

Important component technologies			Technology overview	Technological issues	Expected results
RCS measurement and calculation technologies	Outdoor static measurement technologies	High precision static measurement technologies	Technologies for measuring the RCS of a stationary target with high precision	Unwanted wave suppression	• Accurately ascertain the RCS with respect to the various radars possessed by foreign countries to clarify the measures necessary to reduce RCS and improve the electronic capabilities of equipment
		Reflection source identification technologies	Technologies for imaging and identifying reflection sources through inverse synthetic aperture radar processing	Inverse synthetic aperture radar processing	
		Bistatic measurement technologies	Technologies for statically measuring the bistatic RCS	Bistatic near and far field conversion Bistatic unwanted wave suppression	
	Outdoor dynamic measurement technologies	High precision dynamic measurement technologies	Technologies for measuring the RCS with high precision under moving conditions	Data correction according to the position and attitude angle, etc. of the measurement target	
		Reflection source identification technologies	Technologies for imaging and identifying reflection sources through inverse synthetic aperture radar processing	Inverse synthetic aperture radar processing	
		Bistatic measurement technologies	Technologies for dynamically measuring the bistatic RCS	Control and correction between transmission/reception Data correction according to the position and attitude angle, etc. of the measurement target	
	Indoor static measurement technologies	High precision static measurement technologies	Technologies for measuring the RCS of a stationary target with high precision	Ultra-large compact range or ultra near/far field conversion processing	
		High resolution reflection source identification technologies	Technologies for high resolution imaging and reflection source identification through inverse synthetic aperture radar processing	Attitude angle control for large targets and other actual equipment	
	Electromagnetic field analysis technologies	High precision analysis technologies	Technologies for estimating RCS through simulation by entering the target shape, materials, etc.	Hybridization of the explicit solution technique and the approximate solution technique Processing acceleration Memory requirement reduction	
		Dynamic effect simulation technologies	Technologies which simulate target movement conditions, the surrounding environment, and other dynamic effects to estimate the observability	Solving the dynamic effects Applying the dynamic effects to the RCS simulation	

Research and Development Roadmap (1) (General)

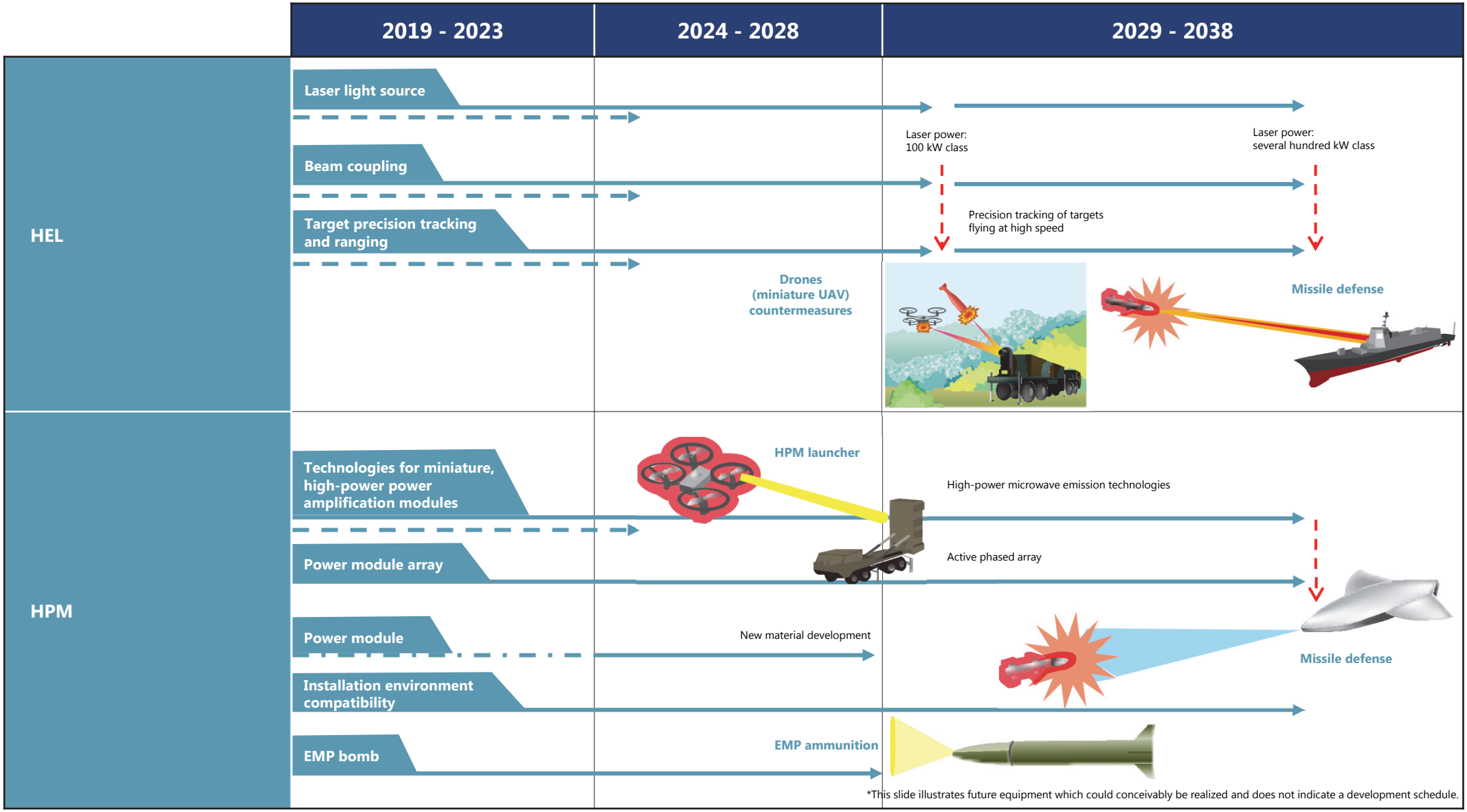
	2019 - 2023	2024 - 2028	2029 - 2038
EA (Electronic jamming (communication, radar, light waves) technologies)	Jamming signal generation	Duplication Jamming	Radio wave received signal generation function; Protocol jamming
	Jamming transmission		High-fidelity radio wave signal generation function; Incorporate the latest technologies
	Jamming control		
EP	LPI/LPD	Radio wave reflection control function	
	Anti-jamming, low observability signal		Intelligent wireless com
	Light wave stealth	Light wave unwanted radiation suppression function	Light wave absorption function
	EM wave (EMP) protection		EMP protector for various electronics
ES	ELINT	Communication wave analysis function	Communication wave analysis function in an adverse environment; LPI SIGINT by UAVs
	Reception	Adaptive radio wave reception function	Wide band/high resolution adaptive radio wave reception function
	Networking		
EMS Management	EMS Domain Awareness	Visualization	
	Optimization of Frequency Allocation		Dynamic frequency allocation



Primarily acquire through research and development
Acquire through joint research
Acquire through new civilian technologies

Note 1 Sufficiently examine the operational, technology, and cost aspects of establishing a specific research and development project.
Note 2 This slide illustrates future equipment which could conceivably be realized and does not indicate a development schedule.
Note 3 The endpoints of the arrows are only tentative. In light of the rapid research and development approach, we will strive for early technology acquisition.

Research and Development Roadmap (2) (Attack (High-power Directed Energy Technologies))



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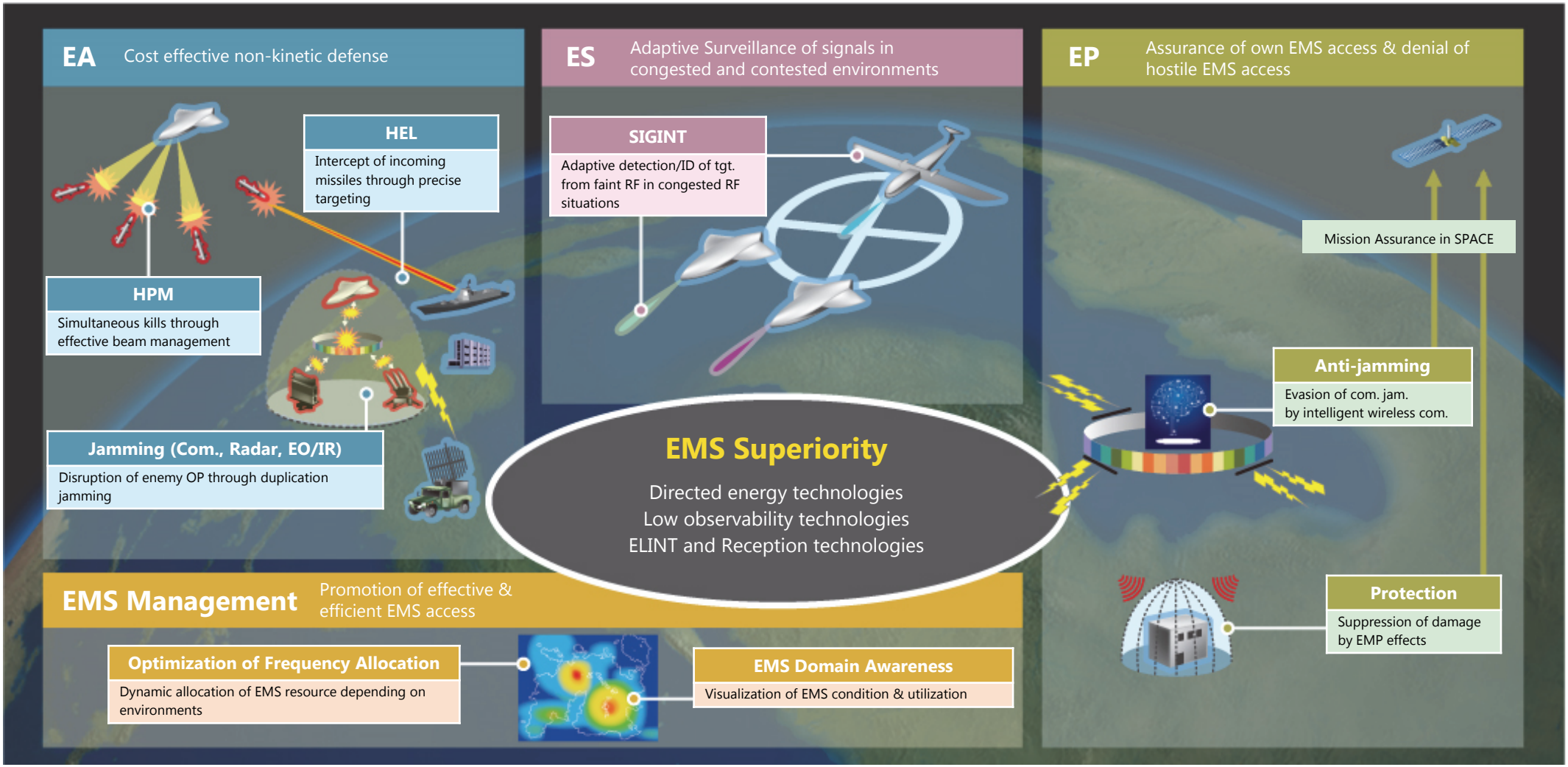
Note 2 This slide illustrates future equipment which could conceivably be realized and does not indicate a development schedule.
Note 3 The endpoints of the arrows are only tentative. In light of the rapid research and development approach, we will strive for early technology acquisition.

Future Notional Picture

Superiority in EMS domain should be achieved that affects the defense activity in any domains with core technologies: directed energy, stealth, SIGINT, optimization of frequency allocation and others



Primary method of advancing research and development

- Because the technologies pertaining to EM wave related activities and their operation are rapidly advancing, the concepts and road map indicated in this R&D vision shall be revised as necessary according to technological progress, etc. It is expected that the latest research and development in strategically important technology fields will lead to the cultivation and strengthening of Japan's technology foundation as well as the invention of superior equipment.
- Because the establishment of EM wave related activities requires a deepening of the integrated operation of the Land, Sea and Air SDF, such as EM wave information sharing and behavior control and optimization, in conjunction with technology acquisition, the research and development shall be implemented in concert with these types of operational considerations.
- Concerning the implementation of the research and development, MOD shall endeavor to rapidly and efficiently develop superior equipment by appropriately utilizing electronic warfare evaluation technologies and accurately and inexpensively assessing the effectiveness of the equipment in a more realistic environment.
- Artificial intelligence, quantum computers, sensing, communication, and other quantum technologies which are potentially game-changing technologies in the future are becoming borderless and dual-use. Because the speed of progress in the civilian sector is unusually fast, we will strive for continuous technology improvement and apply the latest technologies according to the progress of domestic and overseas technologies.

Close observation of trends in foreign countries concerning cyber and other related domains

- Regarding the relationship between the electromagnetic domain and cyberspace, while CEMA[*1] and EMW[*2], two approaches which unify both aspects, have emerged from the U.S. military, this topic is at the stage of global discussion. Activities in the electromagnetic domain and cyberspace will be clarified going forward as needed while closely observing the discussion in foreign countries.
  [*1] CEMA: Cyber Electromagnetic Activity
  [*2] EMW: Electromagnetic Maneuver Warfare
- The U.S. Army has created technical standards based on open architecture and modularization approaches for electronic devices that use EM waves such as radar and other sensors, communication devices, and electronic warfare devices for electronic jamming to advance device standardization and multi-functionality, simplify connections between equipment from different companies, and shorten the development cycle. Japan must also closely observe the trends in electronic device standardization in foreign countries and consider ways to resolve the conflict between the requirement to rapidly add equipment functions and improve capabilities with the requirement to restrain equipment acquisition costs.

Reference

Terminology Definitions

Name (abbreviation)	Definition
Directed Energy (DE)	Technologies which concentrate electromagnetic wave energy, etc. and change it into a high-power energy beam corresponding in particular to high-power lasers and microwaves, etc.
Electromagnetic Pulse (EMP)	Instantaneous, powerful EM waves which overload electronic devices and cause interference or destruction.
Digital Radio Frequency Memory (DRFM)	Electronic devices which digitize the received EM waves and retransmit EM waves processed through digital signal processing to enable advanced radar jamming.
Missile Warning System (MWS)	Equipment which detects the radar waves emitted by a missile or the infrared radiated from the plume, etc. to issue a warning about an approaching missile.
MIMO/Multiple Input Multiple Output	Technology which achieves a high antenna gain by synthesizing transmission (reception) signals from multiple, distributed antennas.
Active Phased Array	An antenna technology which can electronically scan the transmitting or receiving beam direction by aligning multiple antennas in an array and manipulating the phase of each antenna. The active type improves the reliability/maintainability and reduces the size and weight by attaching a transmission radio wave amplifier to each element antenna and distributing the transceiving functions.
Meta Material	Structures which possess electrical properties that do not exist in nature as a result of periodically arranging metals and other conductors into a structure at intervals which are less than the wavelengths of electromagnetic waves.
Carbon Fiber Reinforced Plastic (CFRP)	A composite material based on plastic which reinforces carbon fiber.
Dynamic Range	The ratio of the maximum and minimum signal values that can be measured by an electronic device.
Spectrum Spread (SS)	Technique which spreads the frequency between ten-fold and a thousand-fold compared to the frequency bandwidth of the information to improve the electronic protection characteristics.
Agile Radar	Pulse radar with a function that changes the transmitter's carrier frequency to a quantity greater than the pulse bandwidth in between the pulses or pulse groups with a pseudo-random sequence.
Multistatic Radar	*Radar which uses one or more transmitters and receivers in different locations. Bistatic radar is the case where there is only one transmitter and one receiver.
Synthetic Aperture Radar (SAR)	Radar which creates a virtually large antenna through movement to increase the high resolution and is equipped on aircraft and artificial satellites to be used in ground surface imaging, etc.

Reference

Previous Ministry of Defense Initiatives and Foreign and Domestic Technology Trends

- General Electronic Warfare Technologies
- High-power Directed Energy Technologies

Previous Initiatives at the Ministry of Defense (General Electronic Warfare Technologies)

Class 1 (Attack)

- Implemented and operating ALQ-5 as jamming for radar, although it is for training
- Developed electronic defense apparatus equipped on fighter aircraft for escort jammers
- Developed a new electronic warfare system as a ground-based communication jamming system

Electronic defense apparatus equipped on a fighter aircraft

- Researching the jamming of tactical data links and satellite navigation

Class 2 (Protection)

- Conducting research which will contribute to improvements in radio wave stealth
- Implemented a research prototype of a radar which adopts the STAP* system that is capable of reducing the effects of radio wave jamming during "early warning flight radar research"

*STAP: Space-Time Adaptive Processing

Class 3 (Support)

- Developing next-generation radio wave measurement equipment on aircraft as an improvement in direction finding performance and signal analysis capability
- Conducted research on the implementation of global coverage ES equipment in the area of advanced RF self-defense

next-generation radio wave measurement equipment on aircraft

Class 4 (EMS management)

- Started investigating component technologies related to EMS management

- ✓ Class 1 and 3 initiatives have been developed or partially equipped
- ✓ Component technologies are being researched for Class 2
- ✓ The details of the Class 4 initiatives must be considered going forward

Class 1 (Attack)

- Because there are high-power and wide band limits to on-board radar jamming, off-board jamming technologies have advanced in recent years. The U.S. is developing a pod-type of next-generation jamming equipment (NGJ) which is expected to be equipped on fighter aircraft.
- The development of technology for communication jamming is primarily advancing in the U.S. and Europe from the perspectives of generating efficient jamming waves according to the opponent's communications and power management.

NGJ

Source: Jane's

Class 2 (Protection)

- The balancing of stealth characteristics with flight performance is an issue. The U.S. and Russia possess advanced fighter aircraft technologies with the U.S. fielding the F-22 and Russia developing the PAK-FA/T-50.
- Jamming signal suppression applies to both radar and communication devices, and technologies such as adaptive null point forming are advancing.

F-22

Source: United States Air Force

Class 3 (Support)

- Within electronic information gathering, instantaneous wide band width and high sensitivity for receivers as well as high sensitivity direction finding are advancing to respond to target radars and communication devices with low detection. Improvements in reception processing due to DRFM and other digital reception technologies as well as improvements in signal discrimination due to the use of artificial intelligence technologies are advancing mainly in the U.S. and Europe.

Class 4 (EMS management)

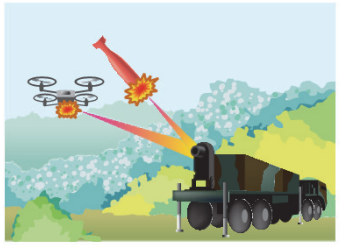
- The U.S. and other foreign countries are developing and operating tools to visualize and manage electromagnetic waves.
- Radio wave interference detection and allocation, etc. is primarily advancing in the civilian communication field. Military applications also utilize civilian technologies, and it is speculated that the EM wave allocation, etc. will be carried out going forward in conformance with EM wave use.

Previous Initiatives at the Ministry of Defense (High-Power Directed Energy)

High-power laser

- Regarding high-power laser systems which can be equipped on large-scale platforms such as ground installations or ships, etc., a "high-power laser system component research prototype" was implemented for the purpose of countering incoming missiles. The system feasibility was confirmed.
- Regarding high-power laser systems which can be equipped on vehicles and other miniature to medium-sized platforms, an "electrically powered high-power laser system research prototype" for the purpose of countering miniature unmanned aircraft and mortar shells, etc. has been underway since FY 2018.

High-power laser system component research prototype



Electrically driven high-power laser system research prototype

High-power microwaves

- Regarding large-scale, high-power microwaves, the "Microwave Evaluation Equipment Research Prototype" project has been underway since FY 2014, and peripheral technologies are being researched with a focus on high-power output and evaluation technologies for microwave power modules.
- Regarding miniature and medium-sized high-power microwaves, "research on basic technologies for EM pulse generation" has been underway since FY 2015 and is researching virtual cathode oscillating tubes, Marx-type high-voltage pulsed power supply equipment, etc.

✓ Research into component technologies for both high-power lasers and high-power microwaves is being carried out

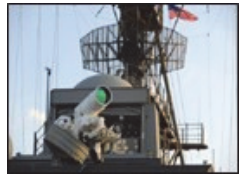
High-power lasers

- Regarding large-scale, high-power lasers, the U.S. demonstrated the ABL (Airborne Laser) system which uses an iodine laser, but it was later mothballed. Subsequently, the U.S. validated the practical application of a medium-sized platform using a fiber laser as the light source and started developing the SSL-TM (ship-based laser system) using a fiber laser.
- Regarding miniature, high-power lasers, both Europe and the U.S. are racing to establish miniature systems which use fiber lasers, but they have not yet reached the stage where they can be operated with several dozen kilowatts on one vehicle.
- The LaWS system, which combines six fiber lasers to reach 33 kW, was deployed in the Persian Gulf from 2014 until the end of 2017, and various operational compatibility tests were carried out.

SSL-TM

Source: United States Navy

LaWS



Source: United States Navy

High-power microwaves

- Ground-based, high-power microwave generators (Raytheon Phaser) for the purpose of disabling drones (miniature UAVs) and vehicle mounted high-power microwave generators used to irradiate human bodies and raise the skin surface temperature are being developed and demonstrated mainly in the U.S., and it is presumed that they have reached the practical application stage.
- Regarding high-power microwave generators which use large-scale electron tubes, GW-class generators have already been achieved, and it is presumed that the component technologies will mature based on future advancements in civilian technologies.
- High-power microwave generators equipped on guided missiles (CHAMP, etc.) are being researched and developed mainly in the U.S., and it is presumed that they are close to reaching the practical application stage.
- Advances in component technology miniaturization are also occurring in the civilian sector with a U.S. university developing a device with an output of 35 MW that can store all of the components including the power supply into a mounting volume with a diameter of 15 cm and a total length of 1.5 m.

Phaser

Source: Raytheon Company

CHAMP

Source: United States Air Force

Reference

Supplementary Documentation Regarding High-Power Directed Energy Technologies

Technological advances in high-power directed energy (high-power lasers)

- Due to advances in the laser processing field, high-power and high beam quality laser light sources are being achieved, and systems capable of destroying remote targets are now a reality
- In 2014, the U.S. Navy deployed and performed operational evaluations of laser systems in the Persian Gulf for the purpose of countering miniature unmanned aircraft and miniature vessels
- In addition to the U.S., England, Germany, and China, etc. are also researching and developing laser systems, which are being closely watched around the world as a game changer which possesses instantaneous response and low cost (high cost effectiveness) characteristics not found in conventional systems
- Japan maintains world leading laser medium manufacturing technologies such as ceramics, fiber, and semi-conductors. Moreover, it has established target tracking and ranging technologies in research prototype projects

Ship-mounted system deployed by the U.S. Navy in the Persian Gulf (LaWS)

Source: United States Navy web site

U.S. Army vehicle-mounted system (HELMTT)

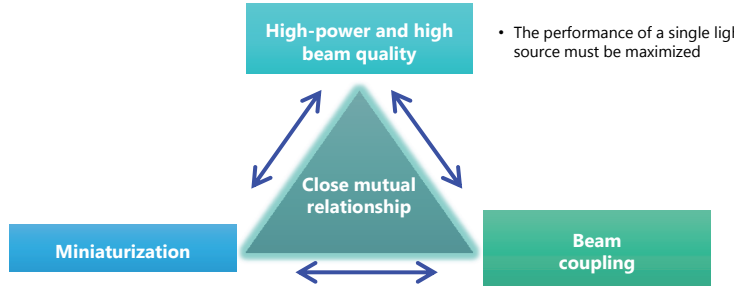
Source: United States Army web site

Direction of future development

- Stealth aircraft, cruise missiles that fly at low altitudes, and other air defense systems require a short reaction time
- Moreover, low-cost countermeasures must be established for miniature unmanned aircraft, mortar shells, and other inexpensive threats employed in large quantities
- Regarding the high-power laser technologies being researched and developed around the world, Japan must proactively undertake initiatives to realize its own technologies
- Technologies to protect against laser weapons must also be researched in parallel

Advanced technologies which are key to achieving high-power lasers

- Realizing laser systems that are suitable for equipment requires advanced, unique technologies which balance high-power, high-efficiency, and high beam quality with miniaturization
- In particular, it is estimated that technologies which inhibit reductions in beam quality while combining multiple beams are especially important
- while combining multiple beams are especially important How these technologies are handled for equipping must also be considered



Technological advances in high-power directed energy (high-power microwaves)

- Regarding high-power microwave weapons, it was reported that the U.S. has used an EMP bomb in actual combat and successfully flight tested an unmanned aircraft (CHAMP), so it is presumed that the technology has reached the practical application stage
- The development of high-power microwave generation technologies using active phased arrays is advancing in Japan due to the development of miniTWT* based on conventional TWT

*TWT: Traveling Wave Tube

High-power microwave edition of the Taurus KEPD 350 cruise missile

Source: iHS Jane's

Unmanned aircraft (CHAMP)

Source: United States Air Force web site

Direction of future development

- Due to advances in high-power microwave generation technologies in recent years, the feasibility of high-power directed energy countermeasure systems as a way to handle various types of missiles and other incoming threats by emitting powerful microwaves to disable the guidance functions of such threats has rapidly increased. High-power directed energy countermeasures have advantages such as a lack of numerical restrictions and low costs compared to conventional forms of protection using missiles or guns.
- The transmission of high-power microwaves for high-power directed energy countermeasures requires power amplification modules capable of transmitting a high peak envelope power. Moreover, active phased arrays using such modules are required to freely and instantaneously aim at incoming threats. Not only are miniaturization and high-power output essential for equipping power amplification modules on various platforms, but the operational environment including the electromagnetic environment, payload, and power supply capacity must be considered.
- Miniaturization is required to equip EMP on missiles and other shells, and the radiation characteristics of electronic devices protected from EMP must be understood.

Advanced technologies which are key to achieving high-power microwaves

- Miniature high power output technologies for power amplification modules required to achieve the active phased arrays capable of transmitting high power in a limited installation space
- Array technologies for power amplification modules required to achieve beam management
- Installation environment compatibility technologies which support the installation and electromagnetic environments of various platforms
- Establishment of technologies for accurately evaluating the irradiation effects of microwaves is also important
- EMP bomb technologies which temporarily or permanently disable the target sensor and information system functions instead of directly destroying them via conventional ammunition and precision guided weapons, etc.