COMMUNICATIONS
FORUM

DEFENSE COMMUNICATIONS: THE FUTURE DIRECTION

December 1, 1988

Seminar Notes

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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Seminar Notes

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COMMUNICATIONS FORUM

This session of the Communications Forum focused on the vital role of defense communications in our country's national security and emphasized the demanding environmental conditions under which such systems must operate. Both surface (terrestrial) and satellite systems were addressed with particular attention to motivation(s) for systems changes which are under way and the potential impact of emerging technologies to support these changes.

The first speaker, Walter E. Morrow, Jr., Director of Lincoln Laboratory and a Professor of Electrical Engineering and Computer Science at MIT, provided the audience with background on defense communications before the two other speakers from the Lab discussed the specifics of surface and satellite communications. Mr. Morrow explained that there are several classes of military communications, including: (1.) strategic force control which involves distances of long range (1000-10,000 km) and modest capacities, (2.) tactical force control which entails modest range (1 to 1000 km) and many channels of modest capacity, (3.) intelligence systems which relate to situations with few channels of high capacity, and (4.) administrative/logistic where there are many channels of modest capacity. He emphasized that there are specific technical characteristics which are desirable for strategic force communications, particularly high availablity (greater than 99% per circuit), long range (global), resistance to interference, resistance of propagation media to physical disruption, and difficult to detect transmissions from force elements. The strategic force communications might involve terrestrial, air and/or underwater operations.

Mr. Morrow provided an historical overview of the evolution of long-range communications techniques. For example, surface wave, (LF-MF) 100-500 kHz was used in the early 1950s, but is constrained by the fact that there are very few frequencies available at the low-end of the spectrum and this technique also requires very large towers which are not feasible for a plane or ship. Another long-range communications technique, Ionospheric Refraction, (HF) 2-30 MHz (100-200 km), used before World War II, suffered from low reliability (50-90%), vulnerability to jamming, and would theoretically be disabled by the effects of a nuclear attack. After WWII, Tropospheric Scatter, (UHF) 300-3000 MHz, actually a modification of Ionospheric Refraction, emerged as an alternative long-range communications technique. Although Troposheric Scatter offers higher frequencies, the range is limited (200-400 km) and thus requires repeater stations (terminals) which is not optimal for defense communications situations.

Mr. Morrow went on to discuss the important role that satellites can play in the future direction of defense communications. Although Morrow admits that satellites are expensive, "they last a long time and are used extensively today for communications around the earth." He believes that DOD will continue to use satellites for their communications for a long time to come. Morrow feels that, looking toward the future, heavy commercial communications traffic will go completely by undersea light fiber cable.

Mr. Morrow believes that today the United States is in more control of its weapons in contrast to its "fragile" control of nuclear weapons in the 1950s and 1960s. He remains positive about the investment the U.S. has made and continues to make in the area of command and control of its military communications.

The next speaker from MIT's Lincoln Laboratory was Robert Rafuse who addressed the area of terrestrially based communications technologies with an emphasis on the use of surface-wave systems (ELF-VLF-LF) to provide long-range communications for strategic force control. Dr. Rafuse used the submarine as a basic example to illustrate problems continuing to face the command and control of two-way communications systems of nuclear-capable forces.

According to Dr. Rafuse military communications systems must conform to certain requirements for physical security, covertness, resistance to jamming, low vulnerability to weapon effects, high reliability/availability, operate at reasonable cost and at "vanishingly" small rate of false commands, and offer service to mobile platforms (i.e., aircraft, submarines, land-mobile missile carriers). According to Rafuse, these requirements stem from the philosphy that "strategic communications which are unreliable and highly vulnerable are destabilizing." Rafuse admits that there is no invulnerable system so a cost-benefit analysis has to be done to assess the risk tradeoffs of any communications system. His philosophy for effective strategic communications also espouses the use of multiple communications methods to obtain much improved reliability at modest cost. Rafuse also explained how timeliness of communications can influence the choice of communications methods, e.g., tactical forces can often wait 5 to 15 minutes, while forward strategic forces usually cannot tolerate such communications delays.

Dr. Rafuse went on to summarize the various terrestrial methods by which strategic military communications such as "Emergency Action Messages" (EAMs) might be sent to platforms (e.g., bombers, submarines, etc.). Also, guided-wave systems such as telephone lines, cable, fiber-optics, microwave links, common-carrier and dedicated systems could be used especially for communications to land-based troops. According to Dr. Rafuse another alternative is the use of broadcast by electromagnetic, "free-space" propagation. In reality Rafuse noted that these communications techniques are often used in combination with the above and other techniques. In general he emphasized that any military communications system must be effective in highly stressed scenarios.

Dr. Rafuse went on to discuss the communications needs for "report back" communications required for obtaining status, retargeting, authentication, etc. information of military platforms. According to Rafuse, in general, "report back" systems suffer from the same physics limitations and technologies as EAMs with a few exceptions. For example, mobile weapon-delivery platforms generally do not simultaneously carry large transmitters or large antennas since this might have a serious impact on a mission.

Rafuse displayed a chart (see Exhibit 1) of the radio-frequency spectrum from 100 GHz to 10 Hz, and the corresponding wavelengths of 1 mm to 100 Mm. He discussed the highlights of propagation physics and the depth of 1-percent penetration in water, as well as noting examples of occupants by particular systems, e.g., the Seafarer system uses frequencies just under 100 Hz, corresponds to wavelengths of 10 Mm, experiences a seawater penetration depth in excess of 100 m, and suffers from no major physics problems.

Dr. Rafuse discussed communications problems particular to submarines given that they usually travel in depths of over 1000 feet, must be acoustically and electromechanically quiet, use thermoclines for shielding, approach the surface only to launch, and prefer not to use towed or shallow-depth antennas. He noted some partial solutions to some of the submarine communications problems: To address forward communications needs, Rafuse recommended the Seafarer system as the best option. He noted that the Navy VLF system requires shallow depth and/or towed antennas. According to Rafuse, use of blue-green laser systems may be possible in the future. In addition, Rafuse explained that the currently available communications systems for report back and status do not provide submarines with an optimal level of security since most methods require operation at or near periscope depth.

Dr. Rafuse believes that developments in technology will have an impact on both military and commercial communications offerings. He foresees benefits coming from the "evolution/revolution" in solid-state digital (VLSI) circuitry, e.g., enable small mobile military platforms to do sophisticated signal processing. Rafuse also sees advances in analog devices and circuit technology which should translate into size and cost benefits for military systems. He notes that despite these technological advances, military communication developments will continue to be constrained by the laws of physics.

In closing, Dr. Rafuse admits that the submarine is a special case and will continue to have communications problems. Although, he notes, blue-green laser technology may be a partial solution. He believes that "some, but not all, of the future systems will be satcom-based". In general, Rafuse suggests a strategy of parallelism and avoidance of weak links. He is optimistic that solid-state technology such as VLSI will continue to evolve and have a positive impact on military communications systems. Rafuse also holds the door open for "arcane" technologies and new physical principles in hopes of addressing the needs of military communications.

The third speaker, David R. McElroy, Jr., Leader of the Satellite System Engineering Group at MIT's Lincoln Laboratory, focused his talk on the use of satellite systems for present and future defense communications applications. He noted that the Department of Defense is currently pursuing a number of new directions in the area of satellite communications.

McElroy's presentation concentrated on the characteristics of MILSATCOM (Military Satellite Communications) Service. These systems typically consist of a few large (greater than 2000 lb.) satellites which are deployed in high altitude circular orbits (e.g., geosynchronous altitude orbits). These satellites also use broadbeam antennas in order to serve multiple terminals: large fixed sites with antennas of at least 20 feet and power of more than 10 kw to small installations on ships, aircraft, and ground vehicles involving 1-to-2 foot antennas and only a few watts of transmitter power.

McElroy noted that satellites are comprehensive in their coverage since only a few satellites are needed for full earth coverage. Not only can satellites provide coverage across a wide geographic area, they are often more cost effective because they are distance insensitive. According to Dr. McElroy, the cost of providing satellite communications links among a number of locations within a coverage region is not a direct function of the distance among the locations.

Dr. McElroy reviewed the frequency bands that SATCOM systems currently use ranging from UHF (250 MHz) to K-band (12 GHz)--(refer to Exhibit 2). SATCOM is currently used for military, mobile, and commercial applications by the United States and other countries. MILSATCOM currently uses the UHF and X-Band. For the future, McElroy stated that SHF bands (30/20 GHz) are being considered for commercial uses by several countries including the U.S., Japan and European nations. In addition, the United States, NATO nations, and possibly the USSR are planning to use an EHF/SHF combination for a new generation of "robust" MILSATCOM spacecraft.

McElroy discussed a number of factors which affect the performance of a MILSATCOM system. These include "jamming," the effects of rain (at the higher frequencies), the threat of detection (for some users), and the effects of a potentially nuclear disturbed path. He noted that these factors will be addressed in future MILSATCOM research.

Dr. McElroy believes the future direction of MILSATCOM includes a number of goals. According to McElroy three of the more important goals involve increasing capacity, improving interference protection and detectability, and achieving autonomous configuration control. Also important to MILSATCOM's future is the development of smaller, lighter-weight implementations, intersatellite links, and links to submerged platforms. McElroy noted that some anticipated approaches to achieving these goals might involve the use of antenna directivity, higher frequencies, spectrum spreading, and/or signal processing techniques. For example, spectrum spreading helps improve the interference/detectability protection of communications systems.

According to McElroy, as MILSATCOM systems move to EHF frequencies, the large bandwidth allocations allow systems to have increased capacity, as well as wideband spectrum spreading. On the down side, these higher frequencies experience increased propagation losses due to weather effects. McElroy noted that future EHF systems will incorporate sufficient link margin into the system to alleviate these weather effects in order to capitalize on the increased capacity and robustness of the system.

Dr. McElroy also explained the technical advantages of using a signal processing satellite as opposed to a conventional satellite. In a conventional MILSATCOM system which uses transponder channels, the received combination of user signals plus interference and noise is repeated on the downlink. In contrast, a signal processing satellite demodulates and remodulates the user signals on-board the satelite. The downlink power can then be utilized to transmit only the user signals without the interference and noise. According to McElroy this improves the interference protection for the system and increases the capacity of the links.

McElroy also provided an overview of the advantages and disadvantages of conventional versus satelite-based switchboards. The conventional MILSATCOM systems are controlled through a ground-based control station and involve static assignment, entail slow reconfiguration, and involve a control station setting-up the links. In contrast, a satellite-based system allows users to contact the controller directly via SATCOM channels thus allowing rapid configuration of links in response to users demands.

McElroy was enthused with the potential advantages that lighter-weight implementations promise for defense communications. The smaller satellites will bring down the incremental cost for additional space assets. Smaller satellites will also mean that smaller (perhaps mobile) launch vehicles can be used to place the satellites in orbit. According to McElroy this will help increase system survivability through the rapid establishment or replenishment of space segments. In conclusion, McElroy also noted that the use of inter-satellite links (60 GHz or optical links) and the use of blue-green lasers to penetrate sea water could improve future MILSATCOM applications.

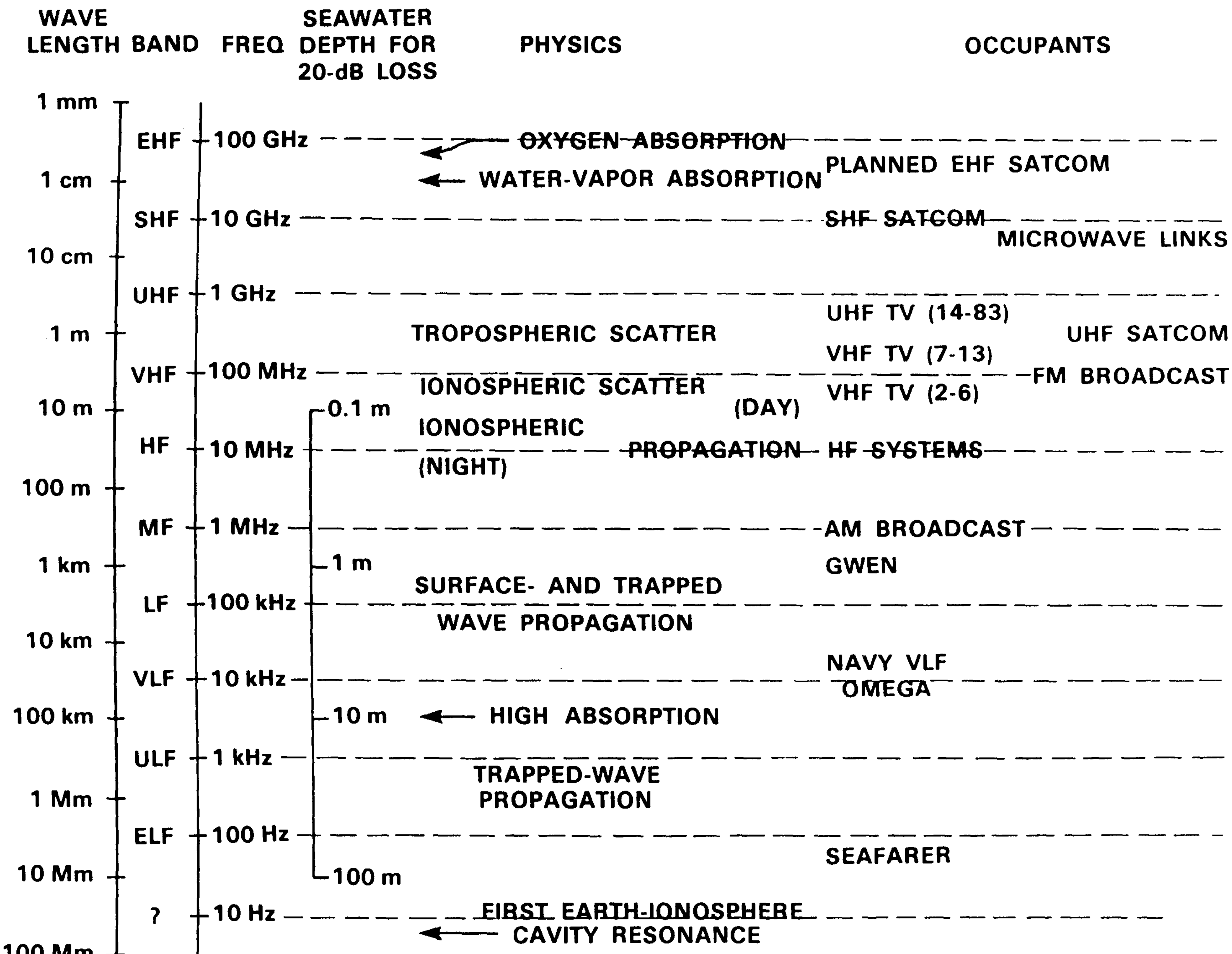
WAVE LENGTH
BAND
FREQ
SEAWATER DEPTH FOR 20-dB LOSS
PHYSICS
OCCUPANTS
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
10 km
100 km
1 Mm
10 Mm
100 Mm
EHF
SHF
UHF
VHF
HF
MF
LF
VLF
ULF
ELF
?
100 GHz
10 GHz
1 GHz
100 MHz
10 MHz
1 MHz
100 kHz
10 kHz
1 kHz
100 Hz
10 Hz
0.1 m
1 m
10 m
100 m
OXYGEN ABSORPTION
WATER-VAPOR ABSORPTION
TROPOSPHERIC SCATTER
IONOSPHERIC SCATTER
(DAY)
IONOSPHERIC
PROPAGATION
(NIGHT)
SURFACE- AND TRAPPED
WAVE PROPAGATION
HIGH ABSORPTION
TRAPPED-WAVE
PROPAGATION
FIRST EARTH-IONOSPHERE
CAVITY RESONANCE
PLANNED EHF SATCOM
SHF SATCOM
MICROWAVE LINKS
UHF TV (14-83)
UHF SATCOM
VHF TV (7-13)
FM BROADCAST
VHF TV (2-6)
HF SYSTEMS
AM BROADCAST
GWEN
NAVY VLF
OMEGA
SEAFARER
112670-1

TABLE I

FREQUENCIES USED FOR SATELLITE COMMUNICATIONS

FREQUENCIES		APPLICATIONS	USERS
CURRENT			
➡ UHF	(0.25-0.4 GHz)	MILITARY/LAND MOBILE	USA, USSR
L-BAND	(1.6 GHz)	SEA/AIR MOBILE	INTERNATIONAL
S-BAND	(2 GHz)	TT&C	USA
C-BAND	(6/4 GHz)	COMMERCIAL	INTERNATIONAL
➡ X-BAND	(8/7 GHz)	MILITARY	USA, NATO, USSR
K-BAND	(14/12,11 GHz)	COMMERCIAL	INTERNATIONAL
PLANNED			
SHF	(30/20 GHz)	COMMERCIAL	USA, JAPAN, EUROPE
➡ EHF	(44/20 GHz)	MILITARY	USA, NATO, USSR?

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TABLE II