Evolution of VLF and LF Systems

Abstract — The backbone of tactical submarine communication is the reception of the submarine fleet broadcast. This major command tool requires worldwide coverage and reception under submerged conditions. The physical boundaries require the use of very low (VLF) and low (LF) frequencies and available antenna design for these frequencies leads to very low available bandwidth. As this restriction allows for low data rates only, new concepts for the increase of data rates must be developed to increase bandwidth and data rates. This paper provides a general overview about current VLF-technology and latest considerations on improvements for updating the VLF-communication technology.

1 Introduction

The primary feature of submarines as a principal naval weapon system is its ability to operate covertly/undersea with a minimal signature. This core aspect of submarines operational value plays a major role in the design of submarines communication system.

Since the beginning of the 20th century, very low and low frequencies (VLF/LF) have been used to communicate with naval units and submarines.

Table 1. Frequency spectrum for long wave communication

Frequency	Abb.	Description
0 – 3 kHz	ELF	Extremely low frequency
3 – 30 kHz	VLF	Very low frequency
30 – 300 kHz	LF	Low frequency
300 – 3000 kHz	MF	Medium frequency
3 – 30 MHz	HF	High frequency

With the development of new technologies for the use of higher frequencies, VLF became more and more a niche solution just for submarine communication. For many years very little had been done regarding new fundamental innovations for VLF communication and its basic principles. This is a remarkable fact, considering to the extraordinary importance of VLF communication for the operational use of submarines. However, it is the author's belief that recent developments in VLF transmitting and receiving systems open the potential for improvement in how VLF/LF technology can be better utilized for submarine and other communication.

2 VLF/LF Wave Propagation

Compared with wave propagation conditions for higher frequencies VLF/LF communication has some specific characteristics. For the extreme long wavelength of VLF radio signals, the whole earth itself can be seen as a spherical cavity resonator. Mostly environmental effects like the height of the atmospheres D/E or F1/F2 layers, have an influence on the physical characteristics of the cavity resonator and as a result, also affect the propagation conditions for VLF radio waves. However, the height of these atmospheric layers primarily depends on the shift between day/night and summer/winter.

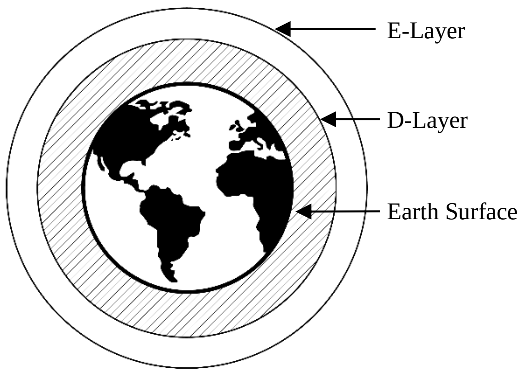

Fig. 1. The earth as a cavity resonator

Compared to higher frequencies, such as HF, the influence of these environmental conditions on wave propagation is rather negligible. As a result, VLF communication guarantees a much more robust worldwide wave propagation in comparison to higher frequencies (e.g. MF/HF).

In addition, the geographical differences in the energy level of the VLF wave become insignificant inside a spherical cavity resonator.

Concerning submarine communication, the most important aspect of VLF wave propagation is the fact that these radio waves are able to penetrate below the water surface. Other than some reflections, VLF radio waves are also able to propagate in salt water.

3 VLF/LF Transmission

3.1 General Principle

In general, most VLF transmitters operate with a radiated power between 500 and 1000 kW. The electrical wavelength for VLF ranges between 10 and 100 km.

Therefore, any VLF transmission antenna system can be seen as extremely electrically short. This requires the use of a special antenna tuning unit, which can cope with the extreme low radiation resistance and high transmitting power.

The use of extremely high power leads directly to the necessity of an antenna system designed with a high level of efficiency. Unfortunately, this fundamental requirement results in a very limited bandwidth for the antenna system. Therefore, the bandwidth limitation for VLF communication systems is directly related to the antenna- and antenna tuning unit design.

A typical bandwidth of VLF transmitter varies from 50 Hz to 500 Hz, which results in a typical modulation rate of 50 symbols per second for a 4-MSK signal (200 Bit per second).

3.2 Wideband VLF/LF transmission

The latest developments in VLF transmitting technology show that it is technically possible to increase VLF bandwidth beyond the 200 Bit per second limitation of legacy systems [2]. It is the combination of several new technologies which makes this possible.

3.2.1 Adaptive equalization

One requirement for enhancing the transmitted bandwidth is the implementation of an equalizer unit inside the transmitter. A linear pre-distortion of the input signal could be able to compensate for distortion effects from the antenna-frequency-curve.

3.2.2 Solid state amplifiers

The use of class D H-bridge solid state amplifiers guarantees high efficiency signal amplification. In addition, this technology is highly resistant against antenna mismatch.

3.2.3 New matching network topology

The latest research and deployments show that double tuned networks lead to an increase in VLF bandwidth [3]. This solution for a matching network causes an additional linear distortion of the transmit-signal. The use of adaptive equalization on this effect leads to a wider bandwidth (See No. 3.2.1).

Hershberger [2] shows that each of these three new technological approaches and the combination thereof leads to a wider bandwidth in VLF transmission. If desired for low bandwidth applications, instead of increasing the bandwidth these technologies can also be used to reduce the size of the transmit antenna.

4 VLF/LF wideband Reception on submarines

Due to the relatively small physical dimensions, VLF reception antennas on submarines can be seen as extremely electrical short (even more than on the transmitter site). Because very low energy has to be coupled out of the VLF far field, antennas with a relatively high bandwidth are normally used for VLF reception. Therefore, the reception of wideband VLF signals can be realised without any modifications of existing VLF reception antennas.

5 Conclusion

With reference to latest considerations on wideband VLF/LF systems [2], an increase in bandwidth and data rate for VLF/LF communication systems is possible today. This new technological approach leads to several operational advantages for submarines.

References:

[1] J. R. Johler, Propagation of the Low-Frequency Radio Signal, IRE 1961, P.405
[2] D. L. Hershberger, International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, IEEE 2017
[3] D. L. Hershberger, US Patent No.: US 9,571,132 B1

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