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Transhorizon over-sea propagation tests with Line-of-Sight Lygarion® Data Link technology

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Abstract:

This paper describes the experimental tests results of the transhorizon NLoS propagation over the sea, with Line-of-Sight Lygarion® Data Link technology, between an experimental ship and a low altitude ground station located on the cost border.

A series of experiments were performed in order to measure and to better understand the achievable performances (in terms of link coverage) for high data rate transmission over the sea and thereby to meet the needs of "command/control" and sensor data transmission for an unmanned marine vehicle systems USV.

The maximum range in NLoS conditions over the sea is a critical issue for major applications, such as the control of an USV for which the unavailability of the data link could be hazardous and, in some cases, catastrophic.

The experimental results have good agreement with the simulated values, obtained taking into account some propagation losses.

Our results and analysis show that some of the NLoS over-sea propagations phenomenon such as the reflection from sea surface and the multipath may be significantly overcome by the use of steerable directional antennas, double QoS double stream (DQDS) protected waveforms as well as efficient link management link acquisition functions.

Key words: transhorizon NLoS propagation, USV, experimental tests, steerable directional antennas, DQDS.

1. Introduction

Radio-wave propagation in maritime environments has been the focus of much theoretical and experimental research over the years for a wide range of military and commercial applications [1-2] for a seashore country. For military, these include Mine Counter Measures (MCM), Intelligence, Surveillance and Reconnaissance (ISR), Anti-Submarine Warfare (ASW), and Fast Inshore Attack Craft (FIAC) for combat training. For commercial, these include Oil and Gas Exploration and Construction, Oceanographic Data Collection, Hydrographic and Environmental Surveys.

For this type of applications, there is the requirement to transmit large sensor data to the ground station operator. The transmitted data also includes command/control and telemetry and the status data. This information is necessary for the operator.

Classical maritime communication systems in coastal areas, mainly based on VHF and satellite communications systems, are not capable to satisfy these requirements because they suffer from one or more of the following weaknesses such low bandwidth or system capacity, short range and too expensive for many applications.

Recently, there are some growing interests in deployments of wireless systems in the maritime environments such as military maritime surveillance. Generally, these applications require the microwave radio systems to be operated in over-sea line-of-sight

(LoS) maritime environments (e.g., between a control station and a moving vessel).

In maritime environments, Unmanned Surface Vehicles (USV) are considerably used for a wide variety of military and commercial applications. They are remotely controlled and they perform their tasks autonomously with control from a host ship or on-shore-based station via high-data-rate communication links.

The main objective of the experimental tests is to measure and verify the maximum range obtained with NLoS conditions over the sea between an USV and a control station which is either on land or on a mother-ship.

This paper is organized as follows: Section II presents a brief description of the Lygarion® data link family used for unmanned aircraft systems (UAS), while Section III describes some key considerations for over-sea radio-wave propagations and some assumptions/requirements for such data link for maritime communication. The experimental tests details are given in section IV. Finally, Section V gives a conclusion and a summary of some results analysis.

2. Lygarion® Data Link Family Description

Lygarion® data link is a new generation, point-to-point, high data rate and programmable digital data link. This modular and compact solution is available in C and Ku bands for secure IP full duplex real-time wideband and C² data transmission, between two mobile platforms, up to 100 Mb/s data rate and 300 km range. It is primarily used for data transfer between a ground data terminal and an airborne or surface data terminal through:

- Uplink data transfer: used to Command and Control (C²) the UAV/USV and/or the payload:
  - UAV/USV command include: high level command (speed, heading and altitude), new flight plan …
  - Payload command include orientation and zoom
- Downlink data transfer:
  - Data provided by the Payload (video in case of observation payload)
  - UAV/USV state parameters (speed, position, attitude)
  - Payload state parameter

Lygarion® data link family is based on multi-platform-oriented product whose programmable and modular architecture allows to offer a large panel of datalink applications by configuration of:

- the antenna type,
- the tracking function,
- the programmable waveform type,
- the interfaces type.

Figure 1 illustrates the different product configurations allowed by the modular and therefore scalable design of the Lygarion® product family.

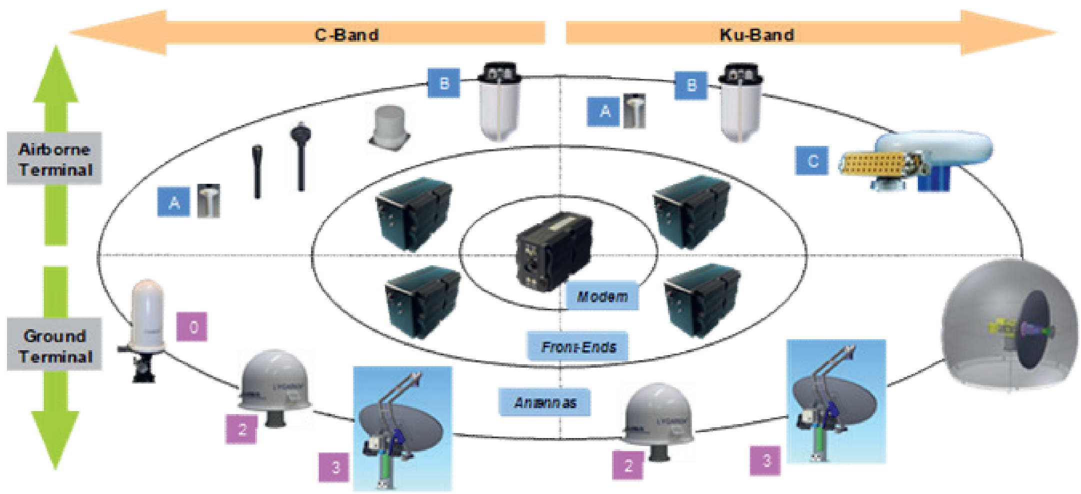

Figure 1: Lygarion® Product Family depending on the RF band application and the Data Terminal

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3. Key Considerations for Over-Sea Radio-wave Propagations

3.1. NLoS Propagation over the Sea

The radio wave propagation over sea is very different from over land, as the atmospheric conditions over the sea are the dominant influence of the propagation characteristics.

From the literature, it is well recognized that near sea-surface radio wave propagation could be affected by the:

- sea-surface reflection,
- refraction caused by evaporation duct,
- diffraction,
- and other multipath propagation phenomena.

These propagating mechanisms (depending on the frequency, antenna height and sea state conditions) will cause path losses and finally limit coverage area.

3.2. Propagation Loss

Figure 2 shows an example of Fresnel ellipsoid diagram (Fresnel zone with some diffraction) for a transhorizon radio wave propagation at frequency of 5 GHz and distance of 37 km. The diffraction loss is estimated to 25 dB

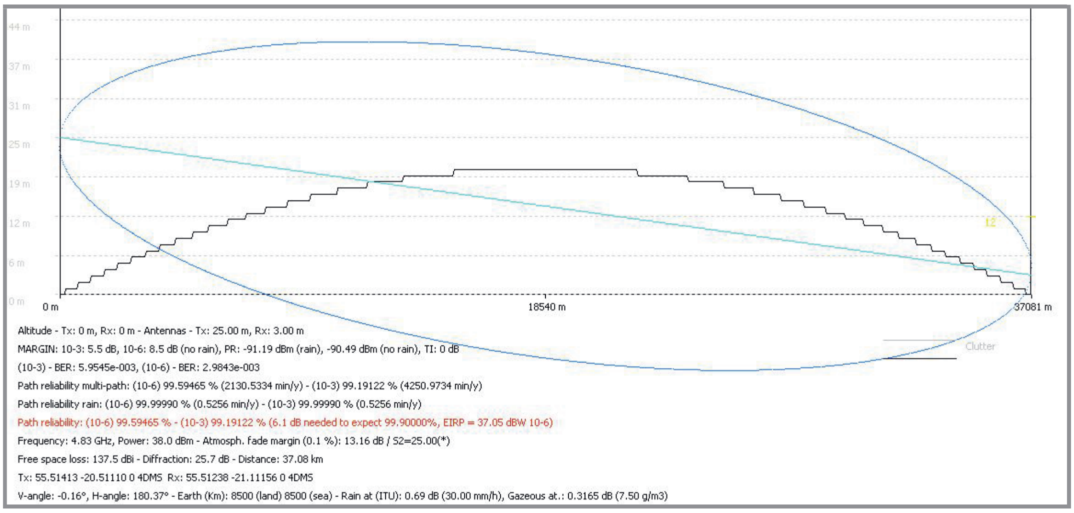

Figure 2: Fresnel ellipsoid for transhorison radio propagation @ 5 GHz

C-band has been selected due to its technical characteristics that make it particularly attractive for high data rate transmission:

- It has less attenuation compared to other bands
- The lower frequencies that C-band uses, perform better under adverse weather conditions than the Ku-band frequencies
- More gain with directional antennas on both platforms (ground and ship)
- Fresnel ellipsoid not too narrow allowing to benefit from a not too strong diffraction in trans-horizon propagation
- Lower C-band available and compatible in all ITU regions.

3.3 DQDS Waveform Spectrum Occupancy

The Lygarion® datalink operates in Frequency Division Duplex (FDD). Therefore, the front-end incorporate a split of the C-band in order to achieve decoupling between transmit and receive part of the bidirectional link.

The operating frequency: C-band [4.4 -5.0] GHz

- Uplink (GDT → SDT): [4.4 - 4.6] GHz
- Downlink (SDT → GDT): [4.8 - 5.0] GHz

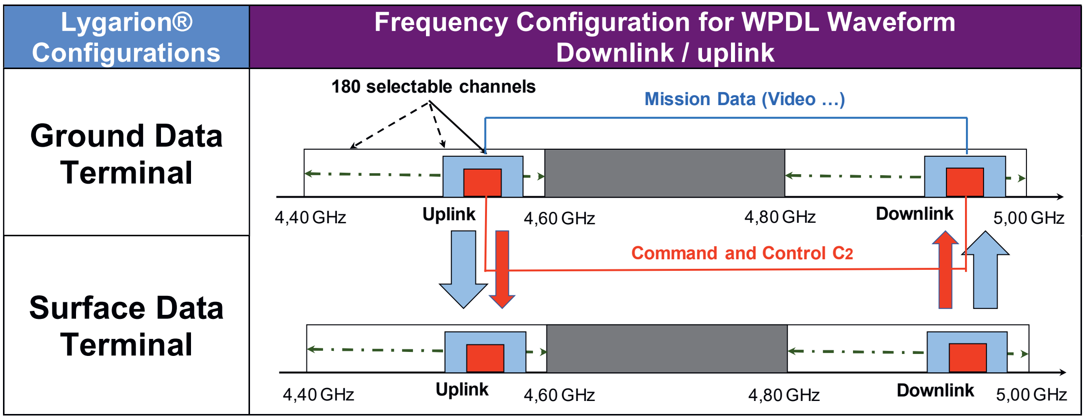

Figure 3: DQDS waveform spectrum occupancy

WPDL is a proprietary wide protected waveform based on BPSK modulation scheme and on the high jamming-resistance. The highly-protection and jam-resistance are achieved through:

- The use of several TRANSEC features including, Direct Sequence Spread Spectrum (DSSS), Frequency Hopping Spread (FHSS) and Forward Error Correction (FEC)
- Code Division Multiple Access (CDMA) C2 / high datarate stream segregation
- Extremely high C2 quality of service
- Two-stage channel coding.

As shown in Figure 3, the concept of this waveform permits :

- Real-time communication of double data stream C2 and wideband data (video)
- Double quality of service (QoS): each data stream ensures high QoS (with extremely high C2 quality of service) thanks to several Electronic Protection Measures.

That is why this protected waveform is denoted DQDS (Double QoS Double Stream) waveform.

In addition, the full duplex mechanism permits simultaneous and interference-free transmission of double stream from air/surface-to-ground and ground-to-air/surface enabling both sides to be in continuous communication.

3.4. Link Budget

The link budgets of the Lygarion® LOS Datalink System for waveforms WPDL and DVBS [3] are given below.

They take into account some provisions for the propagation attenuation loss:

- For WPDL waveform, the data rate for uplink is 19.2 kb/s and for downlink 5 Mb/s
- For DVB-S waveform, the data rate for uplink is 2 Mb/s and for downlink 10.71 Mb/s
- Operating frequency: C band
  - Up-link (GDT → SDT): 4.7 GHz
  - Down-link (SDT → GDT): 4.9 GHz
- Sea Data Terminal (SDT):
  - F-END of 6 W (38 dBm),
  - Directional antenna with gain of 13 dBi,
  - Omni-directional antenna with gain of 6 dBi,
  - SDT antenna height: 3 m
- Ground Data Terminal (GDT):
  - F-END of 6 W (38 dBm),
  - AZ/EL Directional antenna with gain of 23 dBi
  - GDT antenna height: 30 m

The following table provides a summary of the link budget of the Lygarion® LoS Datalink considering the ITU-R P.530 recommendation and the above assumptions. The link budget calculation incorporates atmospheric absorption and rain attenuations

.Data Rate		GDT Antenna	23 dBi	
		SDT Antenna	6 dBi	13 dBi
Downlink	5 Mb/s	Range	25.3 km (13.6 Nm)	30 km (16.2 Nm)
		Availability	98.6 %	96.5 %
		Link Margin	7.7 dB	6.1 dB
Uplink	19.2 kb/s	Range	25.3 km (13.6 Nm)	30 km (16.2 Nm)
		Availability	99.8 %	99.5 %
		Link Margin	16 dB	14.4 dB

Tab. 1: Lygarion® LOS Datalink link budget summary for WPD

Data Rate		GDT Antenna	23 dBi	
		SDT Antenna	6 dBi	13 dBi
Downlink	10.71 Mb/s	Range	25.3 km (13.6 Nm)	30 km (16.2 Nm)
		Availability	99.2 %	97.9 %
		Link Margin	10 dB	8.4 dB
Uplink	2 Mb/s	Range	25.3 km (13.6 Nm)	30 km (16.2 Nm)
		Availability	98.7 %	96.5 %
		Link Margin	7.6 dB	6 dB

Tab. 2: Lygarion® LOS Datalink link budget summary for DVB-S

3.5 Steerable Directional Antennas

Due to the movements (pitch, roll and yaw) of the ship in the sea, the use of a steerable directional antenna with tracking-pointing mechanism for both platforms (ship and costal station) has been considered. It should be noted that the steerable capability of ship and costal antennas, enables to compensate in real-time the sea wave moves thanks to INS/GPS compensation function implemented into the Lygarion® modem.

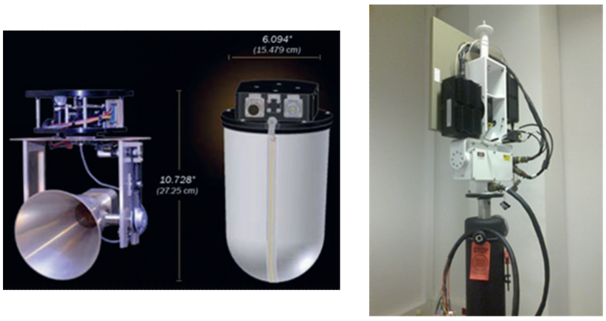

Figure 4: Steerable directional antennas for ship and costal station

In costal and marine environment, the use of a protection radome to shield the antenna from weather, improves the system availability since the antenna is not affected by winds, clouds and precipitation. It also improves the antenna performances since high winds or temperature variations can distort the shape and pointing direction of the antenna reflector.

Radome is also widely used to protect antennas which are continually in tracking while the ship undergoes pitch, roll and yaw movements.

Therefore, both directional antenna platforms (ship and costal station) have been equipped with a protection radome that also conceal the sensitive electronics of these antennas.

4. Experimental Tests Description

4.1. Tests Conditions

Experimental tests were carried out over-sea, between an experimental ship (Le CELADON) and a ground station located on the cost border in order to measure the maximum distance the USV can transmit high sensor data to the ground station depending of the sea state conditions

“Le CELADON” is an experimental ship suitable for sea trials, made available by “Sea Test Base” company.

Figure 5: The experimental ship (Le CELADON) from “Sea Test Base” company

The site is related mainly to the frequency authorization to transmit. It is also selected in order to ensure that the propagation is mainly over the sea surface and there is no blockage of the propagation signal. It is about the bay of Douarnenez which is located in the French county of Finistère in Brittany (in the Atlantic Ocean) north-western France. The tests were made continuously in November 2017. The location of the experiments is shown in Figure 6.

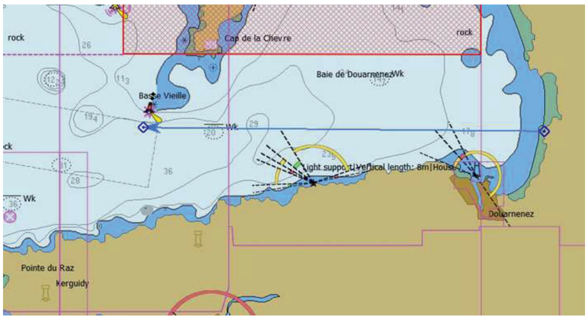

Figure 6: Location of the tests in the bay of Dournenez

- Frequency band: C-Band,

The authorisation to transmit in C band, necessary for the Lygarion® data link deployment, was assigned by ARCEP (the French regulator of the electronic communications and postal sectors).

Two frequencies were allocated:

- 4.7 GHz for uplink direction,
- 4.9 GHz for downlink direction.

These frequencies were retained despite the center frequency for uplink direction is in limit of the Lygarion® modem band pass filter (with an impact of -10 dB on the link budget calculation).

Two waveforms were tested:

- WPDL: a secure proprietary TRANSEC waveform
  - the data rate for uplink is 19.2 kb/s
  - the data rate for downlink 5 Mb/s (SDT → GDT)
- DVB-S: a standard (ETSI) waveform
  - the data rate for uplink is 2 Mb/s
  - the data rate for downlink 10.71 Mb/s (SDT → GDT)

4.2. Tests Equipments

4.2.1 Sea Data Terminal (SDT) on the Chip

As shown in Figure 7, the SDT is installed in the experimental ship at a height of 3 m above sea level and it consists of:

- Lygarion® modem
- A high-power amplifier F-END in C-band of 6 W (38 dBm),
- Directional antenna with gain of 13 dBi, Equipped with Inertial Navigation System (INS)/GPS allowing to compensate the platform movement,
- Omni-directional antenna with gain of 6 dBi,

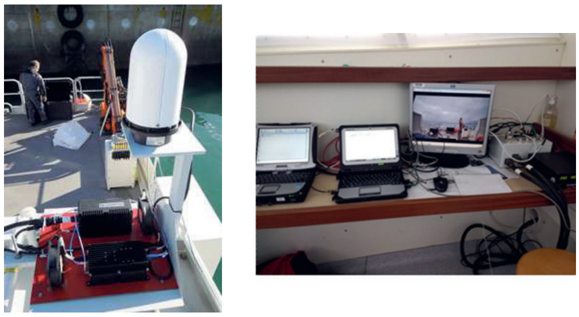

Figure 7: Lygarion® SDT on the experimental ship

Other equipment, necessary for setup and exploitation of the measurements, are housed within the boat cabin:

- Power supply unit 28 VDC-6A,
- An IP camera to generate a video stream,
- Two rugged laptops and display screen equipment,
- Associated cables.

4.2.2 Ground Data Terminal (GDT) on Shore

As shown in Figure 8, the GDT is located on the cost border (on shore) at an altitude of approximately 20 m and consists of:

- Lygarion® modem
- A high-power amplifier F-END in C-band of 6 W (38 dBm),
- Directional antenna with gain of 23 dBi
- Omni-directional antenna with gain of 2 dBi,
- 2-axis positioner allowing moving of Nx360° Azimuth and +/- 90° Elevation
- A height-adjustable tripod,

- A 19" rack containing a power supply unit 28 VDC-6A, interface board and some associated cables
- An electrical power generator.

Figure 8: Lygarion® GDT on shore

Other equipment (two rugged laptops and display screen equipment), necessary for the exploitation of the measurements, are housed within a small van.

The whole system was carefully calibrated on-site before the sea trials and checked again after the measurements. The system effect was minimized through the measurement of a back-to-back connection between the SDT and the GDT.

4.3. Measurement Routes

Measurements were carried out over-sea, between an experimental ship and a ground station located on the cost border (on shore: N 48°09'60.00", W 4°25'59.99"). The Measurements route and the location of the experimental ship are shown in the Figure 9.

During the trials, the experimental ship travelled with a maximum speed of 8 knots (speed between 4 to 8 knots. It was subjected to sea wave motion and variation.

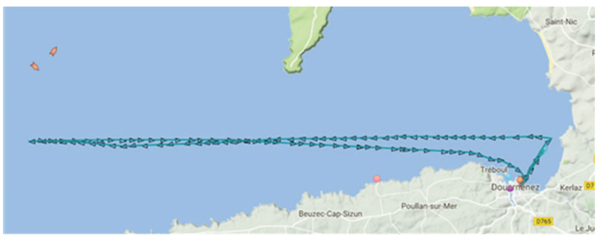

Figure 9: Measurements route and the location of the experimental ship (22 Nm)

4.4. Sea State Conditions

The sea state varies with time, as the wind conditions or swell conditions change.

Three sea conditions were encountered in this experimentation:

- calm or near calm sea state: low wind speed (< 2 knots), clear and sunny weather
- moderate swell sea state: light wind (4 knots) with slight swell, clear weather
- rough sea state: high wind (22 knots) with swell of 2.5 m, cloudy and foggy weather.

5. Conclusion and Discussion

A campaign of experiments was conducted to measure the performance of the transhorizon NLoS propagation over the sea at the C-band, with Line-of-Sight Lygarion® Data Link, between an experimental ship and a low altitude ground station located on the cost border. This chapter presents the experimental tests results and gives some analysis and discussion of the results.

5.1 Summary of Results

Results have shown that the achievable performances (maximum range reached for the USV to transmit large sensor data to the ground station operator) depending of the sea state conditions are as follows:

- For WPDL waveform:

Data Rate		GDT Antenna	2 dBi	23 dBi
		SDT Antenna	6 dBi	13 dBi
Downlink	5 Mb/s	Range	3.7 km (2 Nm)	36 km (19.5 Nm)
Uplink	19.2 kb/s	Range		39 km (21 Nm)

Tab. 3: Maximum range reached for WPDL waveform

- For DVB-S waveform:

Data Rate		GDT Antenna	2 dBi	23 dBi	
		SDT Antenna	6 dBi		13 dBi
Up/Down link	10.71 Mb/s	Range	8 km (4.3 Nm)	27.8 km (15 Nm)	40.7 km (22 Nm)
Up/Down link	44 Mb/s	Range			33 km (17.8 Nm)

Tab. 4: Maximum range reached for DVB-S waveform

The measured distances are found to agree with the simulated distances.

5.2 Analysis and Discussion of Results

Analysis of the measurements has revealed that when the ship is close to the shore the number of reflections is high and relatively strong and when the ship is further away in open sea, there is very few reflection. Moreover, the evaporation duct over the sea surface at 5 GHz frequency has negligible enhancement of signal strength for short-range.

Due to the frequency imposed by ARCEP (The French regulator of the electronic communications and postal sectors) in limit of the band pass filter for uplink direction (with an impact of -10 dB on the link budget calculation), certain measured performances are therefore below than those that would be possible to achieve in favourable conditions:

- Max distance for uplink @ 19.2 kb/s in WPDL reduced to 21 Nm
- Loss of the video in DVB-S at long distance whereas the downlink is still operating (camera in TCP-IP).

The performances achieved with omni-directional antennas in both GDT and SDT, whatever the waveform used, are comparatively low, probably degraded by multipath and the reflection phenomena.

However, the performances achieved with directional antenna in GDT and an omni-directional antenna in SDT, are very satisfying. It is thereby possible to envisage the use of an omni-directional antenna in the USV as long as the use of a directional antenna is preferred in GDT.

It should be noted that, the use of a directional antenna overcome signal degradation due to the sea surface reflection and other multipath phenomena caused by a combination of reflections from the sea surface and vessels in maritime communications.

These experimental tests also allowed pointing out the impact of the sea state conditions on the data link performances:

- A perfectly smooth sea provides a mirror effect very disruptive for radio wave propagation over sea;
- A significant swell (heavy swell conditions) (wave height more than 2 m) may cause some masking problems at long range (above 10 Nm);
- A calm (glassy) sea with slight swell represents the best propagation condition.

6. Acknowledgement

The experimental tests presented in this paper were carried out with Sea Test Base company. The authors would like to express their thanks to Sea Test Base company for supporting these experimentations.

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