TACAN and DF Systems Integration in the Colombian Oceanic Patrol Vessel: Challenges and Solutions

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Abstract

This article discusses the installation of TACAN and DF navigation systems on the Colombian Ocean Patrol Vessel to enhance operational and safety capabilities, especially for helicopter operations. It outlines the technical challenges of integrating these systems due to limited space and potential electromagnetic interference, detailing the analysis and planning process from 2017 to 2022. In 2023, naval commands confirmed the critical importance of the TACAN system. The main technical issue that has been identified pertains to optimizing both systems' antennas within the mast's confines to ensure optimal functionality and mitigate interferences. The article examines a range of technical solutions and integration strategies that have been devised to address these challenges.

Key words: Colombian Patrol Vessel (POC), Direction Finding (DF), Electromagnetic Compatibility (EMC), Electromagnetic Interference (EMI), Tactical Air Navigation System (TACAN).

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Introduction

The Colombian Patrol Vessel (POC) stands as a fundamental cornerstone in Colombia's comprehensive maritime security strategy, as outlined in the Operational Requirement Document [1]. Designed to operate both domestically and in collaboration with multinational forces, the POC is designed to carry out a wide range of missions, from maritime patrol and surveillance to interdiction and protection of human life at sea.

To effectively fulfill its deterrence role and meet the challenges of the changing maritime scenario, the POC must be equipped with state-of-the-art systems and sensors. Furthermore, its design must provide for the adaptability necessary to integrate emerging technologies and additional personnel as required by the mission, including capabilities such as a medium helicopter, an interceptor boat, naval intelligence systems and a remotely piloted naval air platform.

Implementing these capabilities involves a significant challenge: the optimal placement of multiple antennas and sensors in a limited space. The surface of ships, and particularly the mast, poses constraints that hinder the installation of communication, navigation and combat systems, especially those that require unobstructed range and line of sight.

The coexistence of systems such as TACAN (Tactical Air Navigation System) and DF (Direction Finding) exacerbates this challenge. Both systems, essential for POC operations, need to be located at the top of the mast for the best possible coverage. The TACAN, with its electromagnetic signal (on the order of kw power), can interfere with other electronic equipment. The DF, on the other hand, needs an elevated location to maximize its effectiveness in identifying and locating radio frequency sources.

The need to integrate these systems into the POC has been subject to analysis and discussion in the Colombian Navy during the last few years [2, 3, 4]. In 2023, the Naval Aviation Command[5] and the Naval Command[6] reasserted the importance of TACAN for embarked air operations, stressing the need to ensure crew safety and mission effectiveness.

In this context, the central question guiding this article arises: How to address the arrangement of the antennas of the TACAN and DF systems on the Colombian Ocean Patrol Vessel to meet identified operational and technical needs? Through a thorough analysis of the challenges and proposed solutions, this article seeks to provide a clear and detailed answer to this question, contributing to optimize the performance and effectiveness of the POC in fulfilling its mission.

Identification and Characterization of Equipment and Systems in the POC

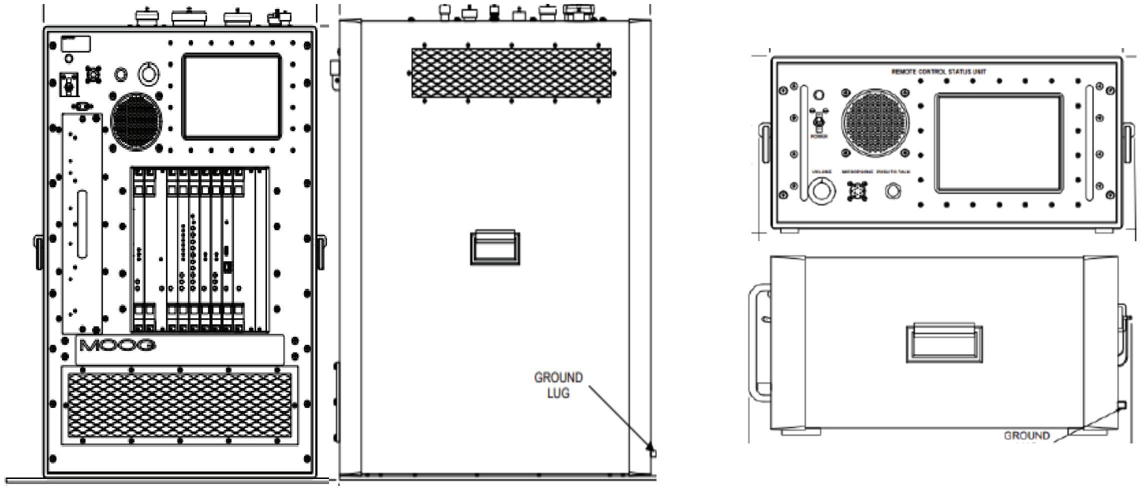
Before analyzing the specific location of the antennas on the Colombian Patrol Vessel (POC), it is essential to describe and verify the systems in question, as well as to make a comparison with other vessels where similar systems coexist.

TACAN System

The Tactical Air Navigation System (TACAN) was designed to assist air crews in locating the vessel where the system is installed. This is accomplished by sending radio navigation signals to the aircraft, which include azimuth and distance (in nautical miles) to the station, as well as the vessel identification code.

- Capacity: The TACAN system can provide distance information to a maximum of 250 aircraft simultaneously. However, azimuth and identification code information can be provided to an unlimited number of aircraft.
- Range: The maximum range of the TACAN

Fig. 1. (Left) MM7000 transponder radio beacon (right) Remote Control and Status Unit RCSU [7].



system under ideal conditions is typically in excess of 300 nautical miles (556 km). [7].

In addition, the TACAN system is made up of three fundamental pieces of equipment:

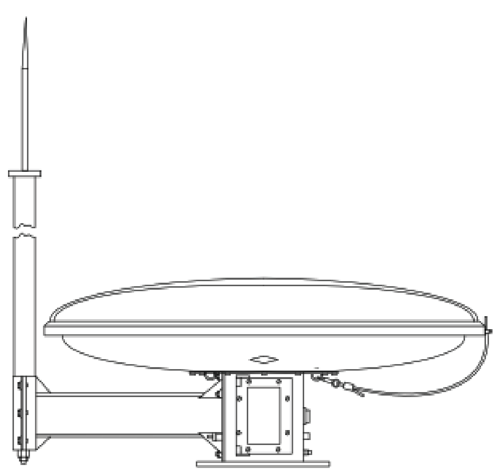
1. The MM-7000 transponder radio beacon is the heart of the TACAN system (see Fig. 1). Its main function is to act as a reference point for aircraft, replying to their interrogations and providing essential navigation information. It can receive and transmit on any of the 252 available channels, which can be selected via the front touch panel. The transmitter output power is over 1 kW peak (minimum) with a frequency range from 962 to 1213 MHz in transmit and from 1025 to 1150 MHz in receive.

As specified in [8], the TACAN System has three modes of operation: TACAN mode, operates and replies to interrogations with azimuth, distance and ID code signals; Demand mode, waits for 12 valid interrogations in 1 second, antenna not scanning and transmitter off. When received, the antenna and transmitter turn on and send azimuth, distance and ID code. If no interrogations are received within 60 seconds, the system returns to standby; and DME mode, the antenna is not scanning, but the transmitter is on. The system replies to interrogations with distance and ID code, but no azimuth signal is sent.

2) The Remote Control/Status Unit (not mandatory for the normal and full operation of the TACAN system). It controls the transponder beacon remotely (see Fig. 1).

3) The TACAN AS-3240A/URN antenna (see Fig. 2) receives the pulse train from the transponder beacon, electronically modulates it at both a frequency of 15 Hz and 135 Hz and transmits the modulated pulse train to the aircraft equipment. It also receives the interrogation signal from the aircraft systems and delivers the received pulse to the transponder beacon for processing.

Fig. 2. AS-3240A Antenna/URN TACAN system [7].



Basic Operation TACAN System

The system starts by receiving a specific interrogation pulse train from the aircraft's TACAN equipment to the vessel's on-board equipment. The vessel's equipment processes the interrogation received and replies with another pulse train containing distance, azimuth and the respective vessel ID code.

Upon receiving this information, the aircraft interprets the pulse train by extracting the vessel ID (2, 3 or 4 letter Morse code in a series of 1350 Hz tones), calculates the distance by starting a clock when sending the interrogation to the vessel and stopping it when receiving a reply from the vessel, with the elapsed time minus a reply delay of the vessel's equipment (50 μs for mode X and 56 μs for mode Y) multiplied by the speed of light and divided by 2 (go time and return time).

The heading is automatically calculated by the aircraft through by applying the counter heading. The heading is identified with respect to the location of the reference North pulse within the envelope of the omnidirectional signal amplitude modulated at 15 Hz, at 135 Hz or the combination of both frequencies (see Fig. 3).

Radiation pattern. [7]

Moog Incorporated (2017) states that "The antenna radiation pattern is mechanically or electronically rotated at a rate of 900 rpm or 15 revolutions per second. Rotation is always clockwise as viewed from above. Considered independently, the cardioid pattern results in a 15 Hz AM signal from the TACAN pulse train, while the 9-lobe pattern results in a 135 Hz AM signal (15 Hz x 9) from the TACAN pulse train."

Installation Considerations and Restrictions of the TACAN System [7]

Moog Incorporated (2017) states that "To achieve proper system performance and to avoid damage to the TACAN receiver due to reflected powers or any other radiating elements, the TACAN system antenna must be installed in accordance with the following requirements (see Fig. 5):

- The antenna must be located at the top of the vessel's mast. If the vessel has two masts, the antenna must be located at the top of the highest mast.
- The mast structure where the antenna is installed has to support the weight of the antenna without bending.
- The antenna must be above any radar antenna to prevent interference with the TACAN system.
- As far as possible, the base of the antenna should be at least 3 meters above other metal objects located at specific distances from the antenna, as indicated below:
  - All metal objects within a radius of 4.6 meters from the antenna.

Fig. 3. TACAN indicators on board the aircraft. [7].

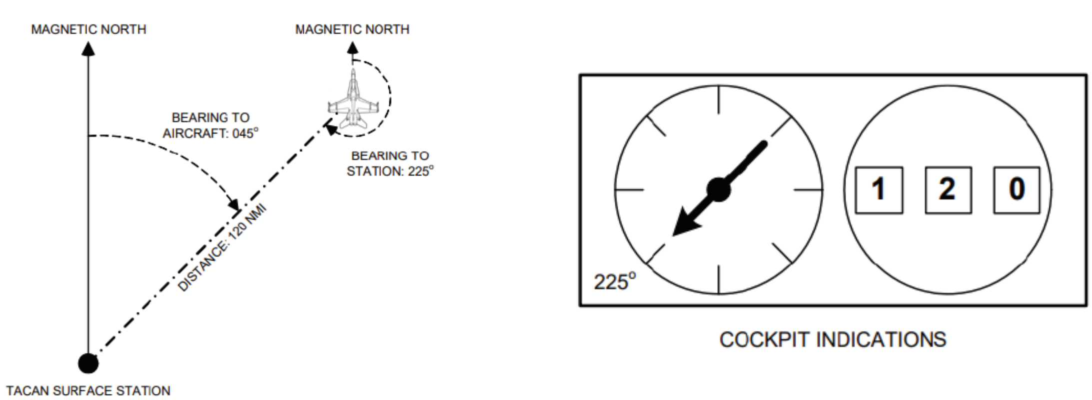


Fig. 4. (Left) Antenna radiation pattern. (Right) Information transmitted by the antenna when using combined modulation at 15 Hz and 135 Hz [7].

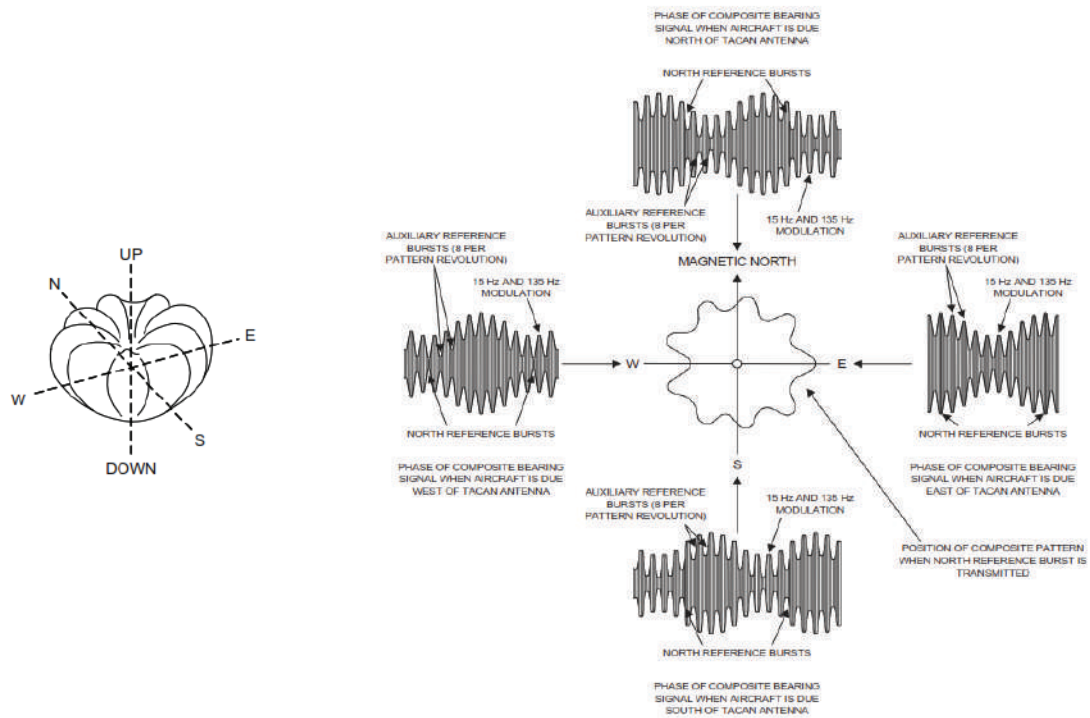
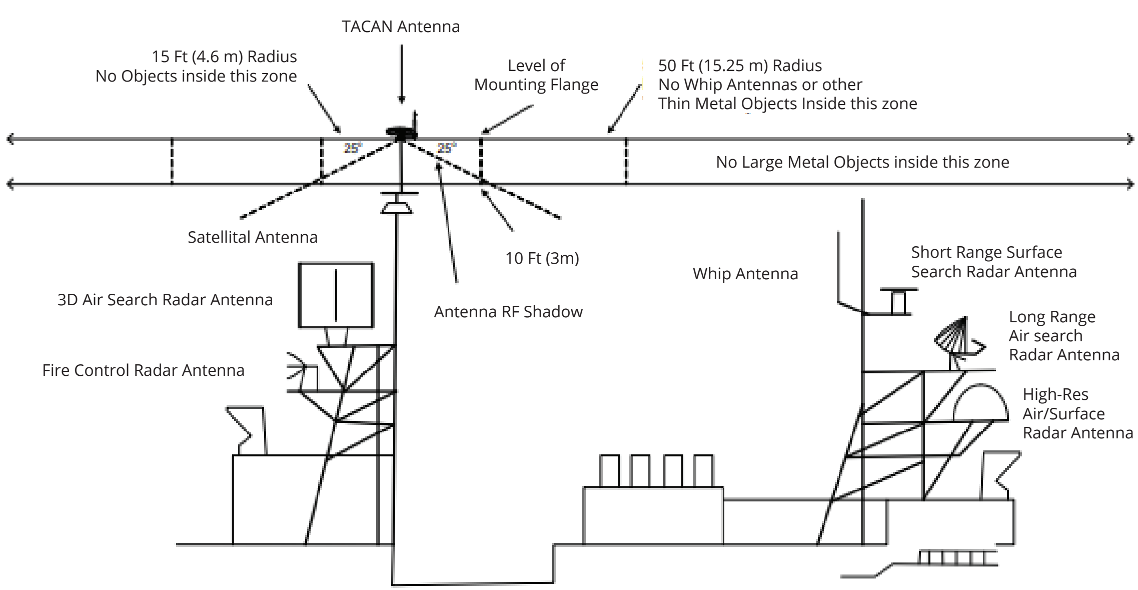


Fig. 5. Installation Restrictions of the TACAN System [7].



- Whip antennas and similar thin metal objects within a 15.2 meter radius of the antenna.
- Large objects within a 15.2 meter radius around the antenna.

EXCEPTION. Objects within the RF shadow of the antenna are exempt from meeting the

Table 1. Ratio of azimuth reference pulse to modulation envelope.

Position of the aircraft relative to the vessel	Position of the North Reference pulse (Positive signal detected)
North	Positive to negative through zero
East	Positive peak
South	Negative to positive through zero
West	Negative peak

distance requirements described above. The RF shadow extends from 25° to 90° below the horizontal plane of the antenna base (see Fig. 5).”

On the other hand, Table 2 shows the minimum separation distances between the TACAN system antenna and the respective electromagnetic hazards listed below, according to [7].

Table 2. Distances for HERP, HERO and HERF risks [11].

RISK		Distance
HERP	Staff	0.5 m
	Susceptible ammunition	1.6 m
HERO	Unstable or unreliable ammunition	6.6 m
HERF	Fuels and lubricants	N/A

Direction Finding - DF

Direction Finding is part of one of the sub-areas of Electronic Warfare (EW) called EW Support Measures (ESM), which aims to detect, identify, find and/or locate intentional or unintentional sources of electromagnetic radiation [9].

This information is used in Signals Intelligence (SIGINT) to analyze and identify intercepted communications, including frequency, bandwidth, modulation (waveform) and polarization. Signals Intelligence is in turn divided into:

- Electronic Intelligence (ELINT). Analysis of information provided by electric fields (electric charges and currents) and magnetic fields. An important electronic system analyzed by ELINT is, for example, radar systems.
- Communications intelligence (COMINT). Analysis of information coming from all kinds of communications (telephone, radio, Internet, etc.).
- Telemetry Intelligence (TELINT). Detection and analysis of images, measurements and radiations both in space and on surface by means of visible and infrared spectrum optical images.

The DF equipment that will be installed on the POC can perform COMINT in the VHF (30-300 MHz) and UHF (300-3000 MHz) frequency bands. To perform its function, it has two antenna arrays (each array has 5 directional antennas distributed in 360°) for each of the 2 frequency bands with highly sensitive receivers located on the mast to reduce signal losses (see Fig. 6). It also has a differential GPS system, which provides conventional GPS positioning by correcting satellite transmission errors.

Up next there is an example of a typical HMI of the spectral diagram in a direction finder (see Fig. 7) , the horizontal axis shows the frequencies and the vertical axis shows both the perceived power in dBm and the marking in degrees of where the emission of the electromagnetic waves received in the DF is perceived.

The sensitivity of the receivers to differentiate low power intensity signals of the order of nanowatts (nW) is evident. The above, with respect to the noise floor which is in the order of picowatts (pW).

Fig. 6. DF COMINT system receiving antenna. Source: Megalitec S.A.S.

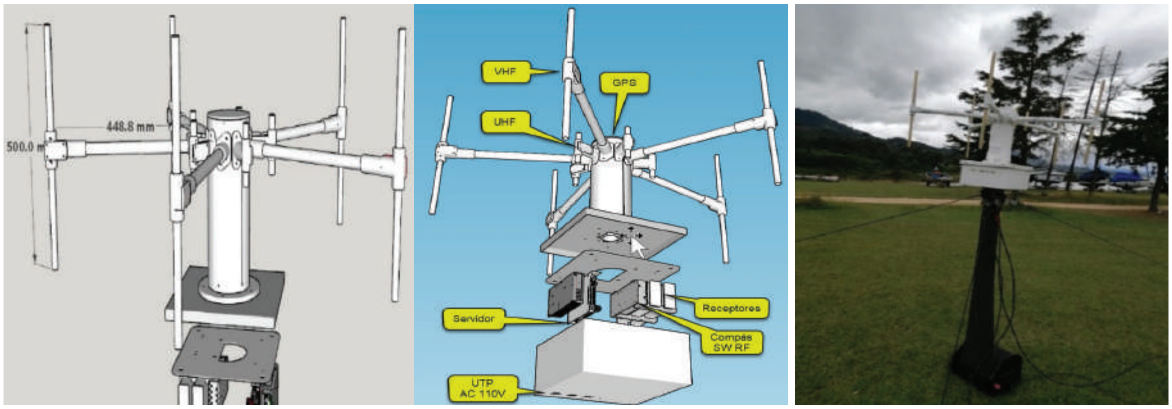
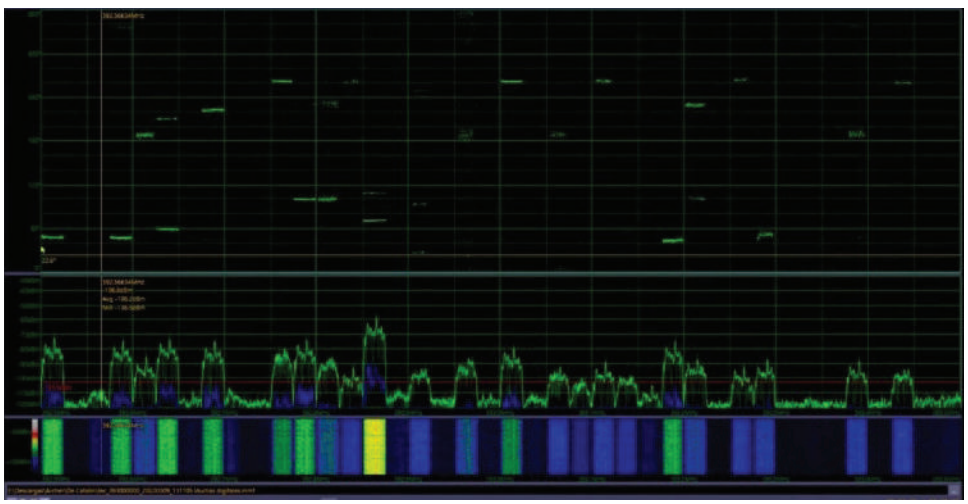


Fig. 7. Typical DF Human Machine Interface (HMI). Source: Megalitec S.A.S.



Technical Coexistence on other vessels

To better understand the complexities of integrating these systems, ships where similar systems coexist have been studied. In particular, the antenna arrangements on frigates and destroyers of the U.S., U.K. and French navies have been analyzed. These ships have implemented various strategies to mitigate electromagnetic interference and optimize system performance. In this study, different types of configurations were identified, where the TACAN system is predominantly installed at the top of the main mast of the unit (see Fig. 8).

On the U.S. Arleigh Burke-class ship, for example, the TACAN and DF antennas are located at different levels of the mast to minimize interference. The French Navy's FREMM-class frigates use RF-absorbing materials and segmented mast designs to ensure electromagnetic compatibility (EMC). These technological solutions were analyzed and adapted to the specific characteristics of the POC, aiming to develop an integration strategy that guarantees the operability and safety of navigation and combat systems. In these ships, the TACAN system coexists with ESM equipment by taking advantage of the TACAN's RF shadow to position the ESM antennas below the TACAN antenna (see Fig. 9).

Fig. 8. Two-masted ships. Italian destroyer “Durand de la Penne”[10] and Japanese “Asagiri” [11].

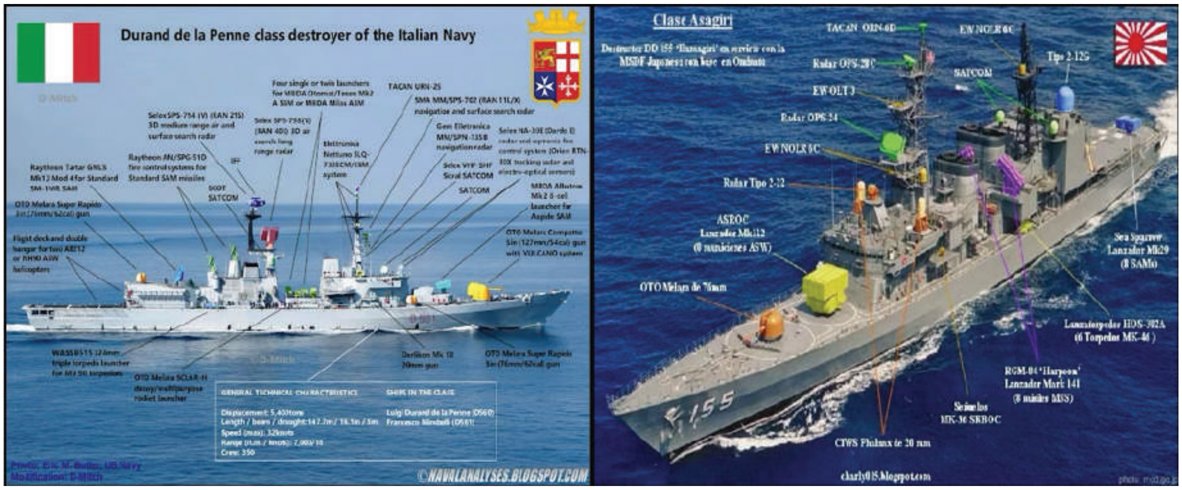


Fig. 9. American Arleigh Burke-class destroyer [11] and Canadian Halifax-class frigate [10].

Installation of both systems (Technical Coexistence)

When discussing the technical feasibility of installing both systems on the same mast, the question arises as to which equipment should be placed at the top of the mast. If the DF is placed above the TACAN, there would be not only a strong electromagnetic interference (EMI) in UHF frequencies, but also the risk of failure of the DF receivers due to the power radiated by the TACAN system.

On the other hand, if the TACAN antenna is installed at the top, the technical considerations mentioned above (see Fig. 5) can be used as an advantage, particularly the exception to the restrictions generated in the TACAN RF shadow area, taking into account that the antenna radiation pattern (see Fig. 4) deploys the maximum power upwards and has a power null at 25° below horizontal.

Installation of the DF concentric to the mast below the TACAN system

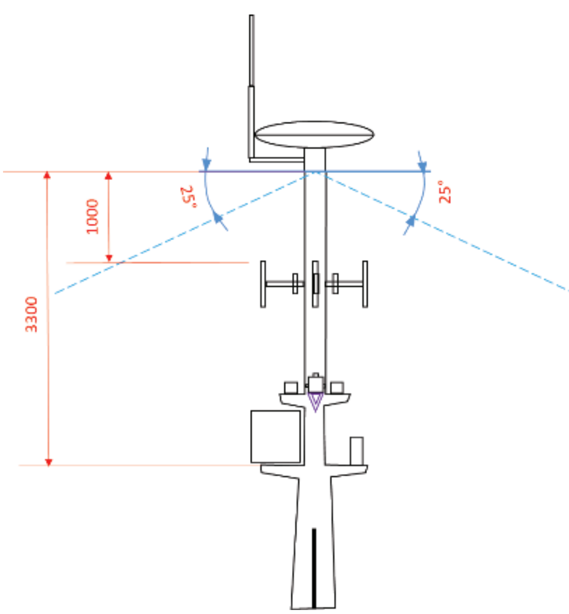
In order not to generate EMI effects on the systems, the DF installation was designed concentric to the mast just below the location of the TACAN system antenna (see Fig. 10), taking advantage of the exception to the restrictions generated in the TACAN RF shadow area, taking into account that the radiation pattern of the antenna (see Fig. 4) deploys maximum power upwards and has a null power at 25° below horizontal. Therefore, the design constraint is to avoid the exit of the upper part of the VHF antennas (the largest) from the TACAN RF shadow.

To achieve this, the center of the VHF radiating elements must be separated from the DF by at least 50 cm below the base of the TACAN antenna, according to equation (1). The final design of this alternative (see Fig. 10) provides 360° unobstructed mast coverage for proper TACAN system performance. However, according to the DF manufacturer, this solution does not allow placing the GPS antenna or the replacement of the GPS antenna with its equalization antenna (see Fig. 11).

Installation of the DF with support forward of the mast under the TACAN system

As an alternative, based on the manufacturer's recommendation and taking into account the

Fig. 10. Top TACAN system design and concentric DF on the mast. Based on GEDIN-COTECMAR design.



$$Z_{min} = long_{arm} * \tan(25°) + \frac{long_{ant}}{2} \tag{1}$$

$$= 508.14\,mm * 0.47 + 250\,mm = 49\,cm$$

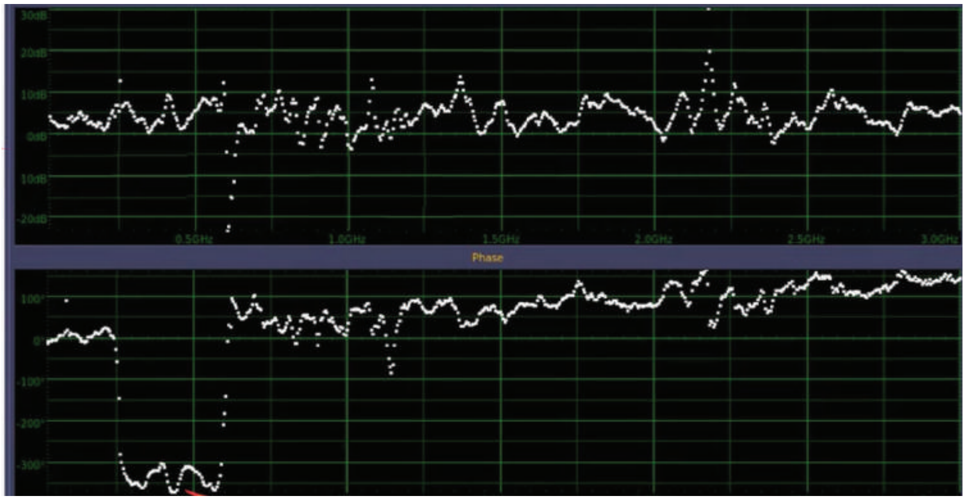
Fig. 11. DF system equalization antenna. Source: Megalitec S.A.S.

simulations performed by the manufacturer, it is proposed to place the antenna arrays on a support forward of the mast [12]. The effect of the mast on the antennas was simulated and mitigated by the manufacturer by equalizing the received signal in the antenna arrays (see Fig. 12), preventing the mast from influencing the antenna radiation pattern. The above, taking into account that the mast behaves as a passive element within the antenna array.

As a result of these simulations, it was determined that a minimum distance of 2.5 meters from the mast to the center of the antenna array was required and together with the antenna equalization, the influence of the mast on the antenna array was mitigated (see Fig. 12).

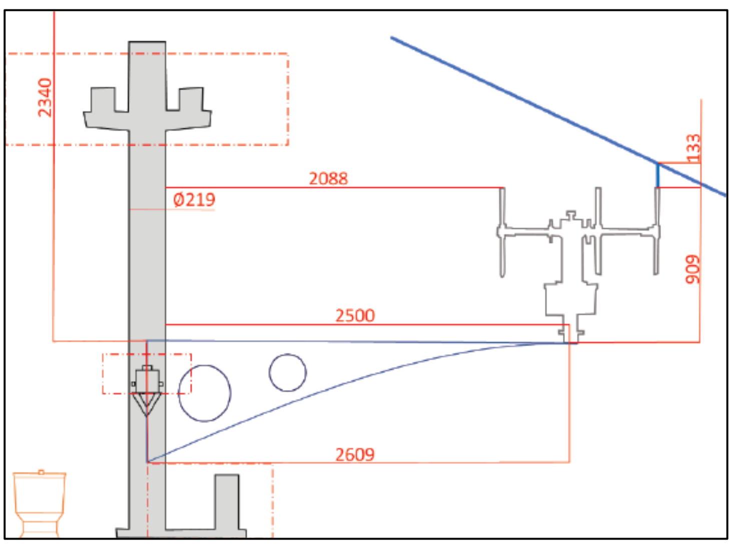
On the other hand, in order to ensure that the larger (VHF) antennas do not leave the RF shadow of the TACAN, the DF antenna support must be installed at least 2.34 meters away from the TACAN antenna base, according to equation (2).

Fig. 12. (Up) DF equalization (Down) Effect of the mast on the received signal. Source: Megalitec S.A.S.



$$Z_{mín} = \left[\frac{w_{mast}}{2} + l_{base} + l_{arm}\right] * \tan(25°) + h_{ant} = (0.1m + 2.5m + 0.5m) * 0.47 + 0.9m = 2.34m \qquad (2)$$

Fig. 13. Final design coexistence of TACAN system and DF antenna. Based on GEDIN-COTECMAR design.

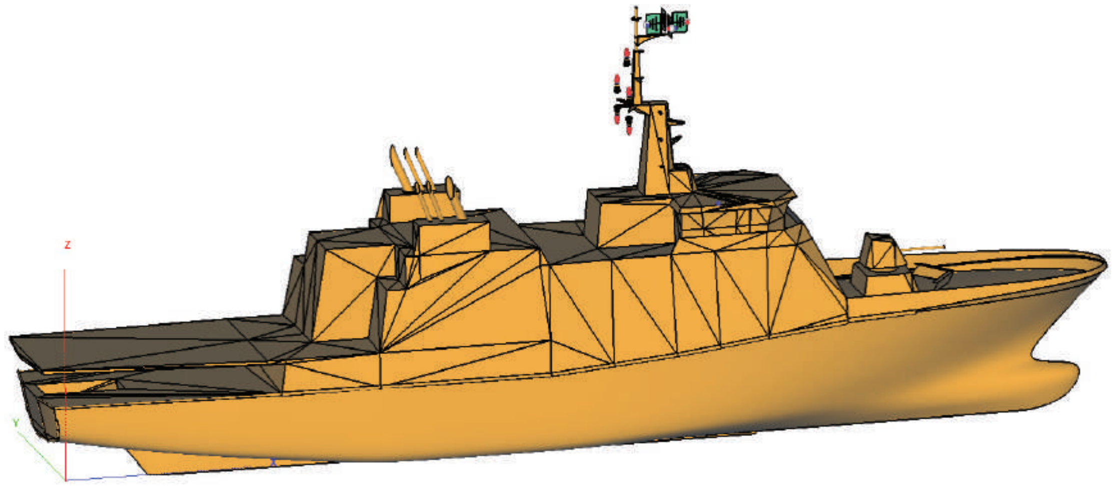


Electromagnetic Compatibility Verification

As part of the design and construction process of the Colombian Patrol Vessel (POC), an Electromagnetic Compatibility Study was carried out together with COTECMAR and Universidad de Los Andes. For this study, the ship's structure was modeled and the radiating elements were characterized using Altair's Feko simulation software [13, 14, 15] in order to provide the ship with an antenna configuration (Integrated TopSide Design - ITD) to enable the use of the electromagnetic spectrum and the protection of non-ionizing radiation emissions (RADHAZ), in accordance with NAVSEA standards [16, 17].

This tool allows using multiple solution methods based on frequency and time domain

Fig. 14. POC Model [19].



in a hybrid approach, in order to perform the analysis of electromagnetic problems efficiently regardless of the electrical size and complexity of the material [18]. In the specific case of a ship, it is necessary to make a large model (order of meters) and parameterize small antennas (order of centimeters). The following figure shows the solid model of the POC (see Fig. 14) developed by COTECMAR and Universidad de Los Andes, together with the parameterization and location of the antennas on the POC mast.

Conclusions

- TACAN and DF systems can coexist on a single mast based on the restrictions established in the paper, taking advantage of the RF shadow provided by the TACAN when installed at the top of the mast.
- It is recommended to install the TACAN and DF systems based on the design (see Fig. 13), preventing the DF antennas from leaving the RF shadow of the TACAN system, according to the relevance established in [6].
- This design prevents the direct radiation of the TACAN system antennas on the DF system. However, it is recommended not to use both systems simultaneously for an optimal performance in the search and localization of signals performed by the highly sensitive receivers of the DF system.

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