Doctrinal Points of Interest Covering Antennas, the Propagation of Radio Waves, and High Frequency Radio Technology in the Employment of Communications During Jungle Operations in the Information Age

Conhecimentos de Interesse da Doutrina Sobre Antenas, Radiopropagação e Tecnologia de Rádios HF no Emprego das Comunicações em Operações na Selva na Era da Informação

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ABSTRACT

The hypotheses of employment in the Amazon have in common the need to operate in the ubiquitous jungle biome. One of the main obstacles to the operations in this scenario is the difficulty of communications, very dependent on HF or satellite radio. In this work, the main goal was to discuss potential knowledge of interest to the doctrine in order to help updating the current publications relating to the use of HF radio communications in jungle operations. For this purpose, the procedures adopted in practice by the military organizations more directly involved with operations in the jungle were identified and analyzed. Moreover, some relevant technical concepts were presented and discussed, taking into account the state of the technique of the current generation radios as well as the state of the art relating to antennas and modeling of wave propagation in forests. Besides the complementary knowledge of potential interest to the doctrine discussed in this work, another result that stands out is the confirmation of the hypothesis that the related current doctrine is outdated. Finally, it was also corroborated that communication by HF radio is still perceived as essential to operations in the jungle, even when satellite communication is available.

Keywords: Command and Control. Communications. Doctrine. HF Radio. Jungle Operations.

RESUMO

As hipóteses de emprego na Amazônia têm em comum a necessidade de operar em ambiente de selva, bioma onipresente na região. Um dos principais óbices para as operações nesse cenário é a dificuldade de comunicações, muito dependente do meio rádio, seja via satélite, seja por rádios HF. Este trabalho discute potenciais conhecimentos de interesse da doutrina para a atualização das publicações doutrinárias referentes ao emprego das Comunicações por rádio HF em operações na selva. Para tal, os procedimentos adotados na prática pelas OM mais diretamente envolvidas com operações na selva foram identificados e analisados. Mais ainda, foram apresentados e discutidos conceitos técnicos pertinentes, levando em consideração o estado da técnica dos rádios da atual geração, bem como o estado da arte referente às antenas e à modelagem da propagação de ondas em ambiente de floresta. Além dos conhecimentos de potencial interesse doutrinário discutidos, complementares ao constante nos manuais, destaca-se ainda como resultado deste trabalho a confirmação da hipótese de desatualização da doutrina vigente correlata. Por fim, verificou-se também que a comunicação por rádio HF continua percebida como indispensável às operações na selva, mesmo quando a comunicação via satélite é disponibilizada.

Palavras-chave: Comando e Controle. Comunicações. Doutrina. Operações na Selva. Rádio HF.

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1 INTRODUCTION

The Brazilian Amazon area has a significant mineral resource and biodiversity potential that for many years has been drawing the eyes of the international community. Ensuring the presence of the State in this region is, therefore, of strategic interest.

Towards the end of the eighties the Brazilian Amazon grew in importance as focus of the planning actions of the Brazilian Army (EB). The actions directed to drug trafficking on the borders with neighboring countries and the growing environmental concerns of the international public opinion were some of the factors a relevant change of direction at that time.

It can be said that the prospective scenario assessed by the EB for that region started to gain strength at the highest power decision making levels. In reality, in the current model of management of Brazilian Defense issues, the Amazon-related concerns are explicitly stated in the highest level reference documents: The National Defense Policy - PND (BRASIL, 2013b) and the National Defense Strategy – END (BRASIL, 2013a). Specifically, the END is quite clear about the strategic significance of the Amazon and it also underscores the need to prepare qualified jungle troops capable of adjusting to the ubiquitous hostile environment existing in that region (BRASIL, 2013a).

In the context of Ground Force (F Ter) operations, the Jungle Operations are those carried out by a force of any level in order to fulfill a tactical mission, and whose deployment area is predominantly covered by humid tropical forest (BRASIL, 1997c). Support to combat in the jungle requires special attention to communication needs. Decentralized actions and the significant distance between maneuvering elements make these needs even more critical (BRASIL, 1997c). In this scenario, communication by radio is vital in view of the limitations posed to the use of other means of communication in this environment, particularly by the physical surroundings (BRASIL, 1997a).

Whenever feasible, communication via satellite radio is advisable, but as a rule, the most reliable means is the HF radio. Indeed, as determined by the Provisional Instructions on Jungle Operations (BRASIL, 1997c), precisely for its higher efficiency in jungle, HF radio communications are increasingly relevant, even for smaller units, such as combat groups, platoons and marine corps units.

As evidenced in the EB manuals applicable to the subject (BRASIL, 1997a; 1997b; 1997c) the Ground Military Doctrine – DMT incorporates theoretical and HF radio technology knowledge that was acquired along the seventies and eighties. Nonetheless, this does not mean that a final solution has been devised for the obstacles faced by radio communications during jungle operations. In fact, the limitation imposed by the jungle is physical and, as such, it cannot be changed. Hence, jungle operations depend on technological advances in the development of radios increasingly capable to minimize the effects of the dense plant coverage, so as to enable the most reliable communications possible with the equipment that is available.

An important break of paradigm in the radio technology occurred in the nineties: the digitalization of communication. Certain general performance improvements were then announced for military radios, as for example, the robustness of digital sound or automatic link establishment (ALE) in HF radios, just to mention two of them (HARRIS CORPORATION, 2000; 2005). More recently, the Software Defined Radio – SDR (TUTTLEBEE, 2002) broadened the scope of potential radio performance improvements also in the field of military communications.

Nonetheless, by reading the current manuals it can be evidenced that the potential gains from radio digitalization are still to be fully incorporated to the doctrine related to the of use of communications and, most of all, with respect to support to jungle operations. It is true that considerable efforts towards the reformulation of the general doctrine are now underway, in the current context of the Process of Transformation of the Army. Today, the efforts of the Army Doctrine Center (C Dout Ex) are focused on the production of the two higher level manuals: Fundamentals and Concepts (BRASIL, 2012b; 2014b). Subsequently, it is expected that the 3rd and 4th level of doctrine publications (tactical, standards/ procedures) will be revised, including the current communication campaign manuals (BRASIL, 1997a; 1997b).

The objective of this work is to discuss the potential knowledge of interest to the doctrine that governs the use of Communications by HF radios in Jungle Operations in the current Information Era. In order to achieve this goal, initially this article presents an analysis of the current doctrine and of the procedures for use of HF radio communications currently adopted by the military organizations more directly involved in jungle operations, Next, comes the identification of some of the technical concepts that supplement those currently existing in the corresponding doctrine, taking into consideration the state of the technique of current radios and the state of the art of wave and antenna propagation, especially in the more critical environments of dense forests. The scope of the study was limited to the portable radio sets for jungle operations by smaller units, that is, equipment in groups 4 and 9, and possibly those in the groups 1 and 2 that are used in that environment. The general frequency range discussed is the HF range (3 – 30 MHz), going down to 1.6 MHz (MF) and up to 50 MHz (low VHF).

2 THE CURRENT DOCTRINE RELATED TO THE USE OF HF RADIO COMMUNICATION IN JUNGLE OPERATIONS

The current doctrine applicable to the use of HF radio communication in jungle operations is stated in three Brazilian Army manuals: C 11-1 Use of Communications (BRASIL, 1997a); C 24-18 Use of Radio in Campaign (BRASIL, 1997b); and IP 72-1 Jungle Operations (BRASIL, 1997c). It can be seen that all of these manuals are over 18 years old and were not subject any revision.

2.1 C 11-1 The Use of Communications

In Manual C 11-1, the subject of interest is approached in chapter 7 – Communication in Operations with Special Characteristics, Article IX – Communication in Special Environmental Conditions, in section 7-18 – Communication in Jungle Operations. These are the some of the most relevant general considerations: the effects of humidity and excessive heat on communication equipment and their electronic circuits; limitations to or impossibility to use vehicles as there are no roads; marked attenuation to which radio signals are subject because of the dense plant coverage; and the need to use higher power radio sets and special antennas to cover the large distances that typically exist between the different elements of maneuver.

Specifically about the radios, the C 11-1 mentions that resources of any kind and any type of equipment available should be employed to overcome the unfavorable environmental conditions. And more, radio operators must be qualified and trained to receive weak signals, select appropriate sites to install the radio stations and to build antennas from improvised means (BRASIL, 1997a).

2.2 C 24-18 Use of Radios in Campaigns

As expected, manual C 24-18 (BRASIL, 1997b) offers a more detailed guidance on radio use. Chapters 4 and 5 talk about wave propagation and antennas in general. In section 4.6, the manual approaches the issue of propagation in natural environments, and the forest areas are mentioned in item d, which is partially reproduced below, with text highlights introduced by the author:

> (1) In forested areas the **most important hindrance factor** to the establishment of tactical links in VHF and above is **attenuation by vegetation**. Particularly in the Amazon region, noise in HF may reach values capable causing received signal degradation. For links inside the jungle or on river bank regions, **the adequate frequency band goes from 8 MHz up to 15 MHz**. The "**propagation mechanism**" is called "**lateral wave**". In this model, the wave skims over treetops and accompanies the highest trees, as a "guide", enabling **ranges of around ten (10) kilometers for dozens of watts** power. Antennas should be of the vertical type.
> (2) An alternative for the use of higher frequencies is **to install an antenna on the treetops**. This type of link requires the other point to use the same mode of installation, or can be used for ground-helicopter or ground-aircraft connection.
> (3) **To cover larger distances, the propagation mechanism is the inospheric wave (skywave)**. This range may not be desirable for operations of smaller units and in well defined areas.
> (4) As to equipment, the following precautions should be enforced:
> […]
> (5) for long distance links look for a clearing to establish the link. Even in HF, forest attenuation may prevent link establishment (BRASIL, 1997b, p. 4-19 - 4-20. Text highlighted by the author).

2.3 IP 72-1 Jungle Operations

The provisional instructions IP 72-1 (BRASIL, 1997c) are other important sources of information about the current doctrine are. Chapter 1 provides the following definition of Jungle: areas of equatorial forests or dense tropical forests with humid or super humid climate. The concept of JUNGLE OPERATIONS is also defined: river bank, airmobile and air-ground operations against irregular forces or a group such forces, carried out to accomplish a tactical mission in a jungle area.

Chapter 2 of the IP 72-1 defines the specific operational environment of the Amazon jungle, the scenario to which the manual applies. Physiographic, psychosocial, political, economic and military aspects of the jungle are presented. The physiographic, relief and plant coverage aspects are the most relevant to the context of this article.

The relief of the Amazon jungle has a feature that is mostly unknown by the general public. The thick forest coverage makes the generation of accurate and precise topographic data representing the area relief below the treetops practically impossible. However, all those who operate in the region are well aware that this terrain is quite undulated, forming small valleys with up to 40m differences in elevation, which are generally called “socavões” (BRASIL, 1997c).

As to the plant coverage, the main aspects presented in the manual are reproduced below:

> (1) Despite lacking a uniform aspect, the Equatorial forest is the dominant feature of the area.
> (2) Generically speaking, the Equatorial forest can be divided into two main types: the Firm ground forest and the Floodable land forest
> (3) The Firm Ground forest extends over areas that cannot be reached by flood waters and represent

> the typical Amazon forest, with tall trees with intertwined tops that block sunrays. Below this coverage the environment is humid and dark.
> […]
> (4) Although growing at different ground levels, looking for sunlight the trees grow until their tops are level with the others.
> […]
> (5) The floodable Land forest grows on the banks of the main rivers of the Amazon Plain, and is called floodplain forest or igapó. In a flood plain forest the ground is relatively clear and plant coverage also includes large trees, which distinguishes it from the igapó forest formed by thicker and smaller tree coverage (BRASIL, 1997c, p. 2-2 - 2.3).

Last, in its chapter 8, about combat support, section 8-3 mentions the subject of support to communications. Here two aspects must be highlighted. First, the larger than usual demand for communications that results from a decentralization of actions and the significant distances between the elements of maneuver. Last, mention is made to the relevance of HF radio communication because of its higher effectiveness in jungle areas, including for smaller units (combat groups, platoons and marine corps companies).

3 PROCEDURES ADOPTED BY JUNGLE MILITARY ORGANIZATIONS (OMS)

The growing demand for strategic relevance of the Amazon resulted in the allocation of significant resources to the F Ter to afford it improved conditions to carry out its mission in that region in the course of the last 20 years. It can be hoped, therefore, that some of the scientific-technological advances of this period were incorporated into part of the procedures adopted in practice by the operators to increase the effectiveness of the jungle operations,.

To analyze these procedures, a questionnaire was prepared to evaluate up to what point the current doctrine is updated, and to identify the leading procedures enforced in practice by individuals with the required experience. The questionnaire form was submitted to a group of about 280 student-officers at the ECEME. It was requested that just the officers with experience in HF or VHF operation in a jungle environment were to complete the questionnaire. Participant identification was not requested and respondents were just asked to state the name of the jungle OM where they had served and for how long.

A group of 15 officers who met the research criteria answered the questionnaire, that is, a little over 5% of the considered universe. The experiences reported ranged, in general, from 2 to 6 years. Table 1 shows the results obtained for the first aspect mentioned by the questionnaire: which is the level of update and the scope of the current doctrine in the relevant context. From this survey it was evidenced that with respect to the use of HF radio communications in the jungle the current doctrine is outdated and incomplete.

Table 1. Answers to questionnaire questions about the level of update of the current doctrine

Opção	Qte	%
a) Totally outdated – everything written there is now ineffective.	1	6,67
b) Outdated and incomplete – just a small part of what is written is still effective and, to a great extent, the procedures adopted in practice are not described in the current doctrine.	**11**	**73,33**
c) Updated but incomplete – most of what is written is still effective but, to a great extent, the procedures adopted in practice are not described in the current doctrine.	2	13,33
d) Updated – most of what is written is still effective and just a few procedures adopted in practice are not described in the current doctrine.	0	0,00
e) Fully updated – There's nothing to be added to or changed in current manuals.	0	0,00
f) I have no opinion on the subject/I prefer not to voice an opinion.	1	6,67

Source: Created by author

In the next question respondents were asked to identify the most important procedures currently adopted in practice and that should be included in an update of the current manuals, according to the scope of this work. It was evidenced that the new features existing in the digital radios are part of the demands and the routine of the jungle OMs employing portable HF or VHF radios in forests. There is also a feeling that training aiming at optimal use of such features should get to the "tip of line", once in current operations the frequency of communication of small units with the decision making levels is gradually increasing. Actually, the process of DMT transformation foresees battlefield digitalization as one of the implications with the strongest impact on operations (BRASIL, 2014c). In the current DMT scenario, to a higher or lesser degree, all combat units need to use devices with data transmission capabilities, including images, geographic locations and even videos. A full list of the suggested procedure is provided in Dias (2014).

Besides the technological aspect, the answers to the questionnaires pointed also to the significance of having the conceptual specificities of antennas and radio propagation in the jungle environment included in the doctrine, as in manual C 24-18 (BRASIL, 1997b). It is important then to make sure that the update of the pertinent manuals also includes the scientific advances in these fields in the course of the two last decades, some of which are closely linked to the aspect of radio digitalization.

4 SUPPLEMENTARY FUNDAMENTALS OF ANTENNAS AND RADIO PROPAGATION FOR USE IN PORTABLE HF RADIOS IN FORESTS

Identification and modeling of the mechanism of radio wave interaction with the plant coverage in a forest is not a simple task. This problem can be broken down into two parts. The first one involves wave propagation in the environment. The other aspect is related to coupling of transceiver radio antenna with surrounding objects close by (mostly trees), and how this affects communication performance.

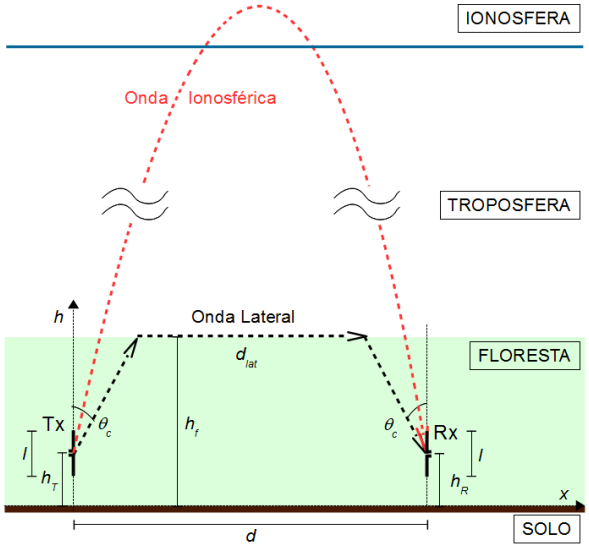
4.1 Radio Wave Propagation

As discussed in current manuals (BRASIL, 1997a; 1997b; 1997c), jungle operational environments pose serious restrictions to communication support to military operations. Actually, the additional demand for more efficient communications to compensate for the long distances involved and the absence of roads is hindered by the obstacle posed by the performance drop to which communication is subject because of the surrounding environment. Nonetheless, the radio is the best means of communication available during these operations, be it through a satellite link, ionospheric refraction or lateral waves.

To Brazil, broad an unrestricted availability of satellite communications is still a political and strategic challenge and, consequently, by its Armed Forces. In a few years the Defense and Strategic Communications Geostationary Satellite (SGDC) may reduce this long standing vulnerability (BRASIL, 2013c). However, while this status quo is not changed, the HF radio continues to be the safest means of communications critical to jungle operations.

Communication by waves reflected off the ionosphere is critical to jungle operation. However, for communications between small units across shorter distances (of up to a few or a few dozens of kilometers) ionospheric refraction is not the most favorable method for the establishment of communications in all cases. Tamir (1967) approached this issue from a theoretical stand point, showing that, in this scenario, in most examples of practical uses of HF/VHF, lateral wave is the mechanism of choice for distances of up to 10km and, even beyond this reference distance, its magnitude is comparable to that of a skywave. It should be noted that in this distance range, the ionospheric mode is almost vertical, with low maximum use frequencies limited to just a few MHz during the day. This mode is represented by the acronym NVIS (Near Vertical Incidence Scattering), from which even the name of certain antennas for tactical radios is derived (HARRIS CORPORATION, 2005). Figure 1 illustrates the importance of both mechanisms of propagation in the scenario of interest.

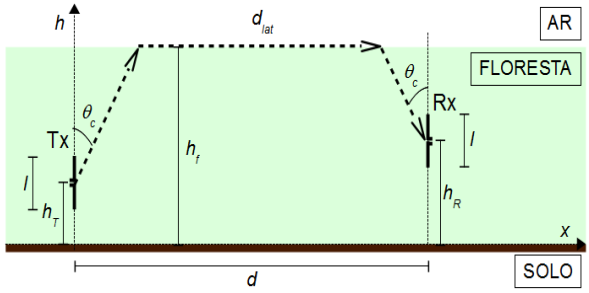
Figure 1. Predominant modes of propagation for HF links in forests: lateral wave and sky wave



Source: Assis (2012, p. 38).

Tamir (1967; 1977) produced a theoretical model of HF and VHF wave propagation in forests and his assertions were validated by field measurements, thus making his model a recurrent reference on this subject. Tamir sees the forest as a homogenous layer with losses, existing between ground and air, with the transmission antenna inside the forest, and propagation assessed based on lightning theory (BALANIS, 1989). Based on the analysis of the propagation mechanisms he stressed the relevance of the lateral wave. This component results from refraction of the wave transmitted from inside the forest off the forest-air interface, with angles of incidence higher than or equal to the corresponding critical angle (θ_c), as represented in Figure 2.

Figure 2. Concept of lateral wave, showing the most significant path of propagation (dashed line)

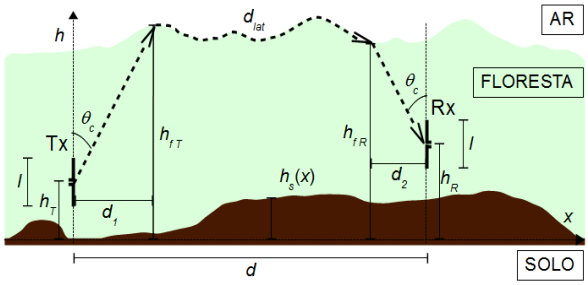


Source: Adapted from Melo et al. (2011, p. 148).

In Brazil several field works were carried out to study radio communication in the Amazon jungle, especially in the eighties, as for example by Dal Bello (1984), Pinto Filho (1986) and Cavalcante et al. (1982). The most important results of an institutional research project of the EB, the M11.14, were published by Dal

Bello and Assis (1992a; 1992b). The Tamir model was used in these studies as the basis for comparison with obtained results, and good consistency was found, that is, its effectiveness for the scenario of interest was evidenced. More recently, this model was revisited in Dias et al. (2010; 2011a; 2011b) and Melo et al. (2011) adding the aspect of relief height variation to the analysis, as shown in Figure 3. Also, a general revision of wave propagation in forests in the HF and VHF ranges was recently published by Assis (2012).

Figure 3. Concept of lateral wave heuristically adapted to real terrains, indicating the most significant path of propagation (dashed line)



Source: Adapted from Melo et al. (2011, p. 148).

In the current context of wireless digital communications, just the analysis of wave propagation with respect to the range is not enough. The quality of the received signal and, consequently, of the information transmitted, be it sound or data, is also influenced. For a more comprehensive approach to this aspect, the propagation channel should be considered in its two observation scales. While large scale analysis provides information generally best known to radio operators, especially the range, small scale analysis produces less well known statistical parameters such as: delay power profile; rms delay spread and coherence bandwidth, among other (SKLAR, 1997; 2001; RAPPAPORT, 2002). Knowledge of these small scale statistical moments provides important inputs to the selection of the mitigation techniques appropriate to digital wireless communication systems, such as error correction coding, spatial diversity, adaptive equalization, spectral spreading, use of adaptive antennas, etc. (SKLAR, 2001) which are found in most of current more complete radios.

There are in the literature several works discussing channel variations in forests, and most of them are based on experimental data, even if in higher frequency bands (VHF a SHF). Other authors evaluate aspects related to channel time variation (DAL BELLO; SIQUEIRA; BERTONI, 2000; MATOS, 2005; MATOS; SIQUEIRA, 2009); and several others also discuss the multipath effects, particularly when potentially causing frequency selective fading (SAVAGE et al., 2003; MENG; LEE; NG, 2007). Anyhow, there are still few references about propagation channel response variation in forests, especially in those existing in our operational environment where lateral wave is the dominant mode of propagation or, at least, is competing with the NVIS.

4.2 Antennas

In Antenna Theory, the basic parameters reflect antenna performance in both of its functions: as a circuit element and as an irradiating element. Standing wave ratio and antenna efficiency are two parameters that represent antenna behavior as a circuit element. The irradiation aspect is represented, among others, by radiation diagram and gain. In both cases, antennas are generally characterized presuming that they are free standing, that is, free from influence from objects around it. The space around the antenna where the presence of objects has a greater impact on its behavior is called near-field region (BALANIS, 2005).

The literature available about the effect of objects on the near-field region of the antenna is abundant for systems operating at higher frequencies, such as the UHF and the SHF. There are many references about the effects from the ground, walls and metallic structures. Recently more studies are focusing on the effects of human body coupling with the antennas of portable terminals, such as cell phones and smartphones, for example (VOLAKIS; CHEN; FUJIMOTO, 2010). However, there is almost nothing about the effect of plant coverage coupling with antennas.

In the systems operating in the HF and VHF range (wavelengths from 100m to 1m, respectively), the trees around the operator in a dense forest tend to be in the near-filed region of the antenna. Antenna coupling with obstacles close by may lead to a non negligible change in performance originally planned for the antenna, consequently, compromising the radio performance itself.

The HF/VHF employed in forest operations have features that favor portability to the detriment of performance. Power supply is a critical aspect (use of batteries), as well as equipment total weight and antenna malleability, which should allow operator movement without significant hindrance. In most cases, all these requirements lead to the use of electrically short (low efficiency) antennas, thus limiting even more the maximum radio range. It should be noted that the same antenna can be electrically short for a lower frequency range, but resonant for a higher range. For example, a 15m long dipole antenna is resonant at 10 MHz (wavelength λ = 30 m), but is short for 3 MHz (λ = 100m).

Electrically short antennas present several performance limitations. With respect to the irradiation aspect, they lack capacity to present directive diagrams and, as a result, directivity is low. Radiation efficiency is low, under 50%, which reduces antenna gain even further

(gain = directivity x radiation efficiency). As to impedance adaptation, the low radiation resistance values (of a few ohms or fractions of ohms) prevent the antenna from presenting a self-resonant behavior. The use of impedance adapters is a technique that reduces this weakness, but poses limitations deriving from the Theory of Circuits itself (VOLAKIS; CHEN; FUJIMOTO, 2010).

Most of the radio sets already feature some kind of impedance adaptation to improve antenna performance across the whole frequency band specified by manufacturers. The most commonly used and lower cost technique is the use of passive impedance-matching devices (filters), designed to adapt a specific antenna to radio output frequency (typically 50 ∧) in the desired range. This coupler may be built-in the radio or come with the antenna. Such method causes flexibility losses when the use of different antennas is necessary in the operation. A specific coupler is need for each antenna.

A more sophisticated solution that uses more space and is not passive (requires power to operate) is provided by the impedance matching networks. These devices contain a filter bank for impedance adaptation for filter selection according to the impedance of the antenna that has been connected. The search for the best performance adaptation may be limited to just a few options and carried out by manual switching, or offer a larger set of options to be engaged automatically, based on some optimization algorithm. Typically, for operations in the jungle, albeit desirable, this type of equipment represents a considerable burden that compromises portability, either by its very weight or by requiring an additional power source. An example of specifications can be found in Harris Corporation (2011).

Antenna interaction with the surrounding elements is an additional degradation factor, which is sometimes overlooked by equipment manufacturers who issue specifications assuming a free space condition. Some recent works have attempted to evaluate, although in a preliminary manner, if this interaction could be negligible (ALEM, 2011; ALEM; SANTOS; DIAS, 2012; DIAS et al., 2012). In more favorable conditions of medium density tropical forests results point to a limited influence of a potential coupling between the antenna and the surrounding woods on the impedance adaptation of elementary antennas (single pole and dipole antennas). However, there was no opportunity to evaluate if this behavior is confirmed in the more strict conditions of a very dense forest.

The state of the technique in current radios brings several important aspects to be considered for a doctrine update. Some of these factors are, again, related to technical concepts, particularly about the antennas. The following chapter discusses these issues based on the specifications of the last generation of portable military equipment currently available in the market.

5 STATE OF THE TECHNIQUE OF PORTABLE HF RADIO SETS

When the word digitalization is mentioned, data transmission is the first functionality of communications that comes to mind. Notwithstanding, with respect to the evolution of radio communications, digitalization went beyond that. It has permeated from encoding of the most important information originally transmitted, voice and even the principles of the Theory of Communications, such as modulation, for example. Conventional telephony was one of the segments to first benefit from voice digitizing potential by using the vocoders that have optimized the use of the restricted channel available to transmit information, enabling to increase the number of users per channel without significant loss of voice quality. The 2nd generation mobile phones (TDMA, CDMA, GSM) started to use this capability to transmit digitized voice, as seen all along the nineties when this segment experience a spectacular growth. This mobile telephony of the nineties also incorporated new radio transmission architecture features deriving from the use of digital modulation and multiple access techniques, which, in their essence, were also digital.

The military HF and VHF radios also profited from the same advancements deriving from the digitalization processes that telephony went through in the nineties. On the wake of the significant architecture transformation, advances came also for important functions, among which are the security of communications (COMSEC) and the security of transmissions (TRANSEC), with important consequences for the Electronic War Theory as a whole. Particularly, the HF radios gained an additional functionality that for a long time operators had been wishing to get: Automatic Link Establishment (ALE), an extremely useful feature given the well known ionospheric layer time variations (HARRIS CORPORATION, 2000; 2005).

By the dawn of the new millennium, the evolution of radio digitalization was embodied in the radio software-defined radio concept. Several works had been published since the nineties, but it was just in the early days of this century that the main ideas became more evident. In essence, the RDS concept leads to maximum replacement of the functions previously carried out by dedicate or specific hardware by an architecture similar to that of a computer whose main software executes the functionalities of a radio, as shown in Figure 4. In its most ambitious version, besides the microprocessor that carries the software with the radio functions, the only remaining hardware parts would be the high speed A/D and D/A converters, the antenna or system of antennas and the so-called front/end RF, where some RF signal amplification, filtering and/or shaping is required before digitalization at reception, or upon conversion into RF signal at transmission (TUTTLEBEE, 2002).

The architecture of a RDS enables new and previously unthinkable functionalities for the conventional architecture. For example, the same equipment can operate in different frequency bands inside a very wide band. Operators can choose the most appropriate modulation or waveform for a given operational scenario, among those available in the equipment, as changing from a waveform to another requires a mere software operation. Now, data transmission does not require external modems, as in most of the conventional radios, once this function is included in the list of possibilities of the RDS. If desirable, network integration, even with access to the internet, is yet another feature available in these pieces of equipment.

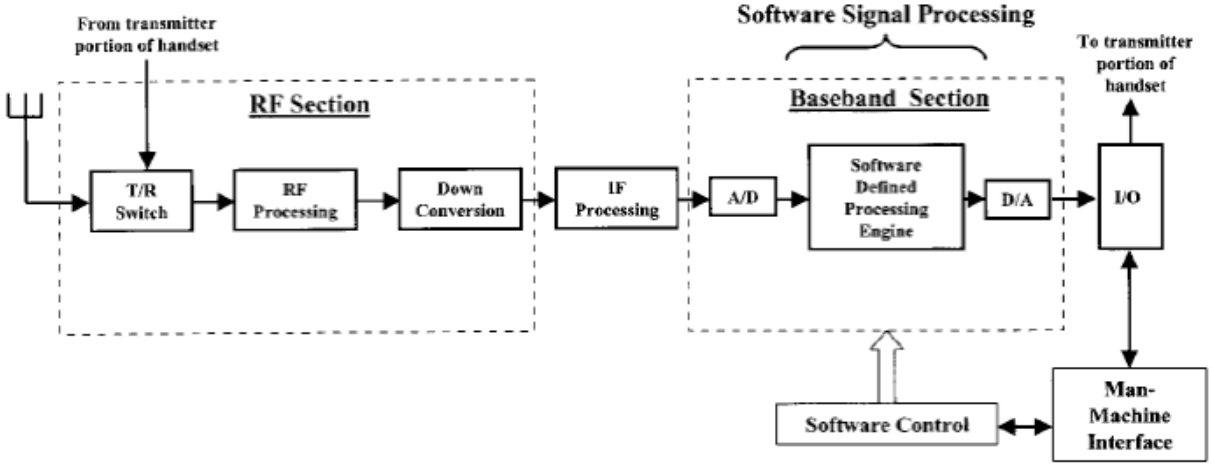
As to antennas, impedance matching may also be built-in the radio, with software capable of adapting this function to the different operating conditions, or to different types of antenna and use bands. The architecture of a RDS requires and facilitates the use of multi-band or ultra wideband antennas, or even the so-called reconfigurable antennas (adaptable to the desired band). In other words, there is an important potential change related to the choice and the use of RDS antennas, which must be understood by operators if an actual effectiveness of operations is to be achieved, even when the most elementary antennas such as the dipole and single pole antennas are used.

Nowadays people are already talking about a concept even more advanced than the RDS, which is the Cognitive Radio (MITOLA et al., 2010). This RDS development incorporates equipment capability to automatically and dynamically scan the environment around it and select frequencies and waveforms to operate. In reality, this concept adds some functionalities to the RDS concept, with some impact in its architecture because of this capability to scan the electromagnetic spectrum in a very wide band.

With respect to F Ter radio communications it is important to underline the current role of the Army Communications and Electronic War Center – CComGEx. This Center is nowadays the agency responsible for the procurement and the distribution of radio sets for most of the OMs all around Brazil. Based on the information collected from its website (BRASIL, 2014a), the F Ter was and continues to be provided with modern equipment such as the M3TR, from Rhode & Schwartz, and the Falcon II (HF and low VHF) and III (VHF and low UHF) lines manufactured by Harris Corporation. These pieces of equipment can be classified as software-defined radios. Particularly, mass procurement of most part of this equipment was carried out in the last few years, according to the demand foreseen by the Army Strategic Projects, especially the SISFRON, the RECOP and the PROTEGER (BRASIL, 2014d). The troops of the CMA, CMN and CMO are already successfully using the Falcon II and III equipment, even if not necessarily utilizing their full potential, but going way beyond what the current doctrine foresees. Data transmission, network connection, COMSEC and TRANSEC are some examples of functions reported to be currently in use by the operators in informal accounts.

From this discussion, and comparing it to the content of chapters 3 and 4, it can be inferred that the state of the technique of current radios is a critical factor to be considered when planning for an update of the doctrine pertaining to the use of HF radios in jungle operations. In fact, the procedures adopted in practice by the troops already take all this into account, and will thus facilitate the design of other corresponding doctrine products.

Figure 4. Typical RDS block diagram.



Source: Tuttlebee (2002, p. 13).

6 CONCLUSION

In face of the current process of Brazilian Army transformation, where the doctrine is one of the vectors that has been subject to marked changes and updates, and in view of the significance of the Amazon in the political-strategic context of Brazilian nation defense, the main focus of this article was the doctrine of employment of HF radio Communications in Jungle Operations. The starting assumption was the outdated status of the current doctrine based on manuals whose last editions date from 1997. Besides attempting to confirm this assumption, knowledge of interest to the doctrine was also discussed as potentially usable in the process of preparation of new manuals applicable to the Command and Control combat function, which are planned for the next few years. In this discussion, special emphasis was given to the scientific-technological aspects, such as the state of the technique of the current generation of radios, as well as to the state of the art of antennas and wave propagation modeling in forest environments.

Once the main aspects of the current manuals related to the relevant subject were presented, an analysis was carried out of the degree of doctrine update based on a field survey carried out with officers with experience in the operations of interest. The starting assumption was confirmed by survey results revealing that the doctrine is outdated and incomplete. Important information was also collected by the survey about the leading procedures adopted in the practical use of HF radios in jungle operations, which could be useful for use in the future manuals pertaining to the relevant subject.

Less obvious theoretical aspects of HF wave propagation in forests and antennas in these environments were also presented to broaden the range of CID potential. The lateral wave and skywave mechanisms, already underlined in the current doctrine, were revisited and commented. Similarly, additional technical information on typical antennas for the scenario were also discussed, as for example, the impact on communication performance from the use of electrically short antennas and the need to investigate the influence of electromagnetic coupling between the antenna and the forest elements surrounding it, which still is not fully understood.

The importance of the impact of digitalization to which radio architectures were subject in the course of almost two decades motivated the following discussion about the state of the technique of current portable HF radios. The current F Ter doctrine already foresee battlefield digitalization as a reality, but this still is not detailed in all the manuals, as the formal doctrine update just started in 2013, with the establishment of the C Dout Ex. Last generation equipment existing in the market and already available to the Brazilian Army, such as the Falcon II and III families and the Harris Corporation products were developed in that context, following and, at the same time, shaping the doctrine updates of the most modern and operative AFs in the world, the US armed forces. And, despite the lack of already updated formal doctrine manuals, as evidenced by the survey, the jungle troops have been successfully adapting to the evolution of radios along the years. With the required formal adaptations, the procedures already adopted in practice will certainly be present in the new manuals related to the Command and Control combat function foreseen for the near future.

REFERENCES

ALEM, R. A.; SANTOS, J. C. A.; DIAS, M. H. C. Medidas de impedância de uma antena monopolo HF/VHF em trecho de mata atlântica. In: MOMAG 2012: 15º Simpósio Brasileiro de Microondas e Optoeletrônica e 10º Congresso Brasileiro de Eletromagnetismo, Ago 2012, João Pessoa. **Anais...** São Paulo: SBMO e SBMag, 2012. v. 1. p. 1-5.

ALEM, R. A. **Análise e projeto de antenas para sistemas de comunicações táticas pessoais em florestas**. 2011. Dissertation (Master in Electircal Engineering)-Instituto Militar de Engenharia, Rio de Janeiro, 2011.

ASSIS, M. S. Radio wave propagation in the Amazon jungle: a tutorial. **Revista de Tecnologia da Informação e Comunicação**, v. 2, n. 1, p. 37-44, out 2012.

BALANIS, C. A. **Advanced engineering electromagnetics**. New York, EUA: Wiley, 1989. 981p.

_____. **Antenna theory**: analysis and design. 3. ed. New York, EUA: Wiley, 2005. 1136p.

BRASIL. Exército. **Manuais e normas**. Brasília, DF, 2014a. Available at:<http://www.ccomgex.eb.mil.br/index.php/pt_br/manuais-e-normas>. Accessed on: Mar 24, 2014.

_____. **C 11-1**: emprego das comunicações. 2. ed. Brasília, DF, 1997a.

_____. **C 24-18**: emprego do rádio em campanha. 4. ed. Brasília, DF, 1997b.

_____. **EB10-IG-01.005**: instruções gerais para a organização e o funcionamento do sistema de doutrina militar terrestre (SIDOMT). Brasília, DF, 2012b.

_____. **EB20-IR-10.003**: instruções reguladoras para a gestão do conhecimento doutrinário. Brasília, DF, 2014b.

_____. **EB20-MF-10.102**: doutrina militar terrestre. Brasília, DF, 2014c.

_____. **Escritório de projetos do Exército**: indutores da transformação do Exército. Brasília, DF, 2014d. Available at:<http://www.epex.eb.mil.br/>. Accessed on: Sept 8, 2014.

_____. **IP 72-1**: operações na selva. Brasília, DF, 1997c.

BRASIL. Ministério da Defesa. **Estratégia nacional de defesa**. Brasília, DF, 2013a.

_____. **Política nacional de defesa**. Brasília, DF, 2013b.

_____. **Retrospectiva**: 2013 foi ano de conquistas e realizações para o Ministério da Defesa. Brasília, DF, 2013c. Available at:<http://www.defesa.gov.br/noticias/8391-defesa-retrospectiva-2013-foi-ano-de-conquistas-e-realizacoes-para-o-ministerio-da-defesa>. Accessed on: Sept 8, 2014.

CAVALCANTE, G. P. S.; ROGERS, D. A.; GIAROLA, A. J. Analysis of electromagnetic wave propagation in multilayered media using dyadic green functions. **Radio Science**, v. 17, n. 3, p. 503-508, 1982.

DAL BELLO, J. C. R. **Propagação de ondas eletromagnéticas na floresta amazônica**. 1984. Dissertation (Master In Electrical Engineering)–Instituto Militar de Engenharia, Rio de Janeiro, 1984.

DAL BELLO, J. C. R.; ASSIS, M. S. Comunicações táticas na região amazônica: projeto M.11.14: propagação de ondas eletromagnéticas na região amazônica: **Revista Militar de Ciência e Tecnologia**, v. IX, n. 3, p. 12-20, 3º Quad 1992a. 1a Parte.

_____. Comunicações táticas na região amazônica: projeto M.11.14: propagação de ondas eletromagnéticas na região amazônica. **Revista Militar de Ciência e Tecnologia**, vol. IX, no. 4, pp. 7–19, 4º Quad 1992b. 2a Parte.

DIAS, M. H. C. **Emprego das comunicações por rádio HF em operações na selva na era digital**: conhecimentos de interesse da doutrina sobre equipamentos atuais, antenas e propagação de ondas. 2014. 66 f. EWnd of Course Paper (Specialization in Military Sciences)–Escola de Comando e Estado-Maior do Exército, Rio de Janeiro, 2014.

DIAS, M. H. C.; ALEM, R. A.; SANTOS, J. C. A. Análise crítica do modelo de Tamir para predição de alcance de rádio-enlaces em florestas. In: 9th International Information and Telecommunication Technologies Symposium (I2TS 2010), Dec 2010, Rio de Janeiro. **Proceedings...** Rio de Janeiro: UNIRIO, 2010. v. 1. p. 1-7.

DIAS, M. H. C.; MELO, M. A. K.; FARIAS, P. A.; SA, H. A.; MARQUES, A. A.; MOREIRA, L. H. A field assessment of HF/VHF wire antenna impedance changes in rain forests. In: 6th European Conference on Antennas and Propagation (EUCAP), Apr 2012, Praga. **Proceedings...** Praga: EuRAAP, 2012. v. 1. p. 934-938.

DIAS, M. H. C.; ROTAVA, A.; ANDRADE, F. G.; ALEM, R. A.; MELO, M. A. K.; SANTOS, J. C. A. Path loss measurements of HF/VHF land links in a Brazilian atlantic rainforest urban site. **IEEE Antennas and Wireless Propagation Letters**, v. 10, p. 1063-1067, 2011a.

_____. Análise da perda de percurso de rádio-enlaces táticos num bosque de mata atlântica. In: XIII SIMPÓSIO DE APLICAÇÕES OPERACIONAIS EM ÁREAS DE DEFESA (SIGE 2011), 2011, São José dos Campos. **Anais...** São José dos Campos: ITA, 2011b. v. 1. p. 1-6.

DAL BELLO, J. C. R.; SIQUEIRA, G. L.; BERTONI, H. L. Theoretical analysis and measurement results of vegetation effects on path loss for mobile cellular communication systems. **IEEE Transactions on Vehicular Technology**, v. 49, n. 4, p. 1285-1293, Jul 2000.

HARRIS CORPORATION. **Especificação técnica do acoplador automático de antenas RF-5382H-CU001, para os rádios da família Falcon II**. Rochester, EUA, 2011. Available at:<http://rf.harris.com/media/rf-5382h-cu001_tcm26-9111.pdf>. Accessed on: Mar 23, 2014.

_____. **Radio communications in the digital age**: HF technology. 2. ed. Rochester, EUA, 2005. v. 1. 94p.

_____. **Radio communications in the digital age**: VHF/UHF technology. Rochester, EUA, 2000. v. 2. 108p.

MATOS, L. J. de. **Influência da vegetação na dispersão dos sinais rádio-móveis**. 2005. PhD Thesis (PhD ub Electrical Engineering)–Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, 2005.

MATOS, L. J. de; SIQUEIRA, G. L. Time and frequency dispersion parameters measurements at 1.88 GHz in a vegetated channel. **Journal of Communication and Information Systems**, v. 24, p. 24-29, 2009.

MELO, M. A. K.; SANTOS, J. C. A.; DIAS, M. H. C. On the use of Tamir's model for site-specific path loss prediction of HF/VHF systems in forests. In: SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC 2011), Nov 2011, Natal. **Proceedings...** Natal: UFRN, 2011. v. 1. p. 147-151.

MENG, Y. S.; LEE, Y. H.; NG, B. C. Wideband channel characterization in a tropical forested area. In: Microwave Conference (APMC 2007), 2007, Bangkok. **Proceedings...** Bangkok: IEEE, 2007. p. 1-4.

MITOLA, J.; ATTAR, A.; ZHANG, H.; HOLLAND, O.; HARADA, H.; AGHVAMI, H. Achievements and the road ahead: the first decade of cognitive radio. **IEEE Transactions on Vehicular Technology**, v. 59, nr. 4, p. 1574-1577, 2010.

PINTO FILHO, R. C. **Propagação de sinais radioelétricos na floresta amazônica**: dimensionamento de sistema. 1986. Dissertation (Master in Electrical Enginnering)–Instituto Militar de Engenharia, Rio de Janeiro, 1986.

RAPPAPORT, T. S. **Wireless communications**: principles and practice. 2. ed. New Jersey, EUA: Prentice Hall, 2002. 736p.

SAVAGE, N.; NDZI, D.; SEVILLE, A.; VILAR, E.; AUSTIN, J. Radio wave propagation through vegetation: factors influencing signal attenuation. **Radio Science**, v. 38, n. 5, 2003.

SKLAR, B. Rayleigh fading channels in mobile digital communication systems: characterization. **IEEE Communications Magazine**. v. 35, n. 7. p. 90–100, Jul 1997. Part 1.

_____. **Digital communications**. 2. ed. New Jersey, EUA: Prentice-Hall, 2001. 1079p.

TAMIR, T. On radio wave propagation in forest environments. **IEEE Transactions on Antennas and Propagation**, v. AP-15, n. 6, p. 806–817, Nov 1967.

_____. Radio wave propagation along mixed paths in forest environments. **IEEE Transactions on Antennas and Propagation**, v. AP-25, n. 4, p. 471–477, Jul 1977.

TUTTLEBEE, W. **Software defined radio**: enabling technologies. West Sussex, ENG: John Wiley and Sons, 2002. 440p.

VOLAKIS, J.; CHEN, C.-C.; FUJIMOTO, K. **Small antennas**: miniaturization techniques & applications. New York, EUA: McGraw-Hill, 2010. 428p.

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(1) Conception and Research Planning or Data interpretation;
(2) Composing;
(3) Relevant critical review;
Based on these criteria, the contribution of the authors of this manuscript was:

Maurício Henrique Costa Dias - 1, 2, 3
Felipe Drumond Moraes - 1, 2, 3

Received on February 22, 2013
Accepted on May 13, 2015