International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R M.2200
(11/2010)

Characteristics of amateur radio stations in the range 415-526.5 kHz for sharing studies

M Series

Mobile, radiodetermination, amateur and related satellites services

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Reports

(Also available online at http://www.itu.int/publ/R-REP/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	**Mobile, radiodetermination, amateur and related satellite services**
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management

***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2012

REPORT ITU-R M.2200

Characteristics of amateur radio stations in the range 415-526.5 kHz for sharing studies[1]

(2010)

Objective

This Report describes the transmission characteristics of amateur radio systems most likely to be employed in amateur radio operations at frequencies in the 415-526.5 kHz range including analyses of antenna systems likely to be used in the amateur service at these frequencies.

TABLE OF CONTENTS

Page

[1] This Report has been prepared in support of World Radiocommunication Conference 2012 (WRC-12) Agenda item 1.23. In the event that WRC-12 does not make an allocation to the amateur service in this band, the Report will be suppressed.

1 Introduction

Recommendation ITU-R M.1732 describes the characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies. This Report provides typical transmission modes and characteristics of stations in the amateur service that could be deployed in the range 415-526.5 kHz. It also provides simulations of radiation patterns of antennas that could be deployed in this range.

2 Related ITU-R Recommendations

Recommendation ITU-R M.1732 – Characteristics of systems operating in the amateur and amateur-satellite services for use in sharing studies.

Recommendation ITU-R M.1798 – Characteristics of HF radio equipment for the exchange of digital data and electronic mail in the maritime mobile service.

Recommendation ITU-R M.1677 – International Morse code.

3 Abbreviations

ADSL	Asymmetric digital subscriber line
DSL	Digital subscriber line
EZNEC	A simplified antenna simulation program based on NEC
FEC	Forward error correction
NBDP	Narrow-band direct printing
NEC	The numerical electromagnetics code: Antenna modelling software package
PACTOR	Packet teleprinting over radio
PSK31	Phase shift keying 31.25 Hz
QPSK31	Quadrature phase shift keying 31.25 Hz
WSPR	Weak signal propagation reporter

4 General

Amateur stations generally do not have assigned frequencies but dynamically select frequencies within a band allocated to the amateur service using a listen-before-talk protocol. Many bands allocated to the amateur service are shared with other radio services and amateur operators are aware of the sharing conditions. Amateur stations in the range 415-526.5 kHz could perform a variety of functions similar in nature to those performed in other bands allocated to the amateur service, such as training, communication between amateur stations, disaster relief communications and technical investigations in radio techniques for personal as opposed to pecuniary interest.

Given the modest size of the proposed allocation (about 15 kHz), amateur transmissions in the range 415-526.5 kHz would likely make use of radiotelegraphy and a variety of data transmissions.

5 Transmission modes in the range 415-526.5 kHz

5.1 Morse code

Morse code (CW) or continuous-wave, *Emission Mode A1A*, is radiotelegraphy accomplished by keying a carrier on and off in accordance with the international Morse code.

While varying with the keying speed, the necessary bandwidth of conventional CW signals can be taken as 150 Hz or less. An allocation in the range 415-526.5 kHz would likely make considerable use of very-slow-speed CW (Slow Morse), the necessary bandwidth of which may be as small as 1 Hz.

Morse code is defined in more detail in Recommendation ITU-R M.1677.

5.2 Narrow-band direct printing radiotelegraphy

Narrow-band direct printing (NBDP), *Emission Mode F1B*, is the modern amateur radio implementation of traditional commercial narrow-band direct printing and has the following characteristics:

– Frequency-shift keying (FSK) with a spacing of 170 Hz between the lower (SPACE) and the upper (MARK) frequency.

– A transmission capability of 60 words/min[2].

– Encoding using the five-level Baudot (ITA2) code.

NBDP, which requires a necessary bandwidth of 250 Hz, will fit within the proposed allocation of about 15 kHz. A commercial implementation of NBDP for LF and VLF frequencies using an 85 Hz shift could be used by the amateur service in the range 415-526.5 kHz.

PACTOR is a further enhancement of NBDP utilizing both automatic repeat request (ARQ) and FEC. PACTOR 2, *Emission Mode J2D*, has a necessary bandwidth of 375 Hz and will likely find application in the band 415-526.5 kHz.

The PACTOR mode, specifically the PACTOR-III Protocol, is described in Recommendation ITU-R M.1798.

---

[2] Each word assumed to be five characters in length; each character requiring five bits to encode. Allowing for space characters, start and stop bits, etc. the resulting bit rate is 45.45 bit/s – often quoted as 45.45 Bd.

5.3 Narrow-band phase shift keying modes

Phase-shift keying 31.25 Hz (PSK31), also frequently referred to as binary phase shift keying (BPSK), *Emission Mode G1B,* is a data transmission mode involving shifting the phase of a steady carrier by 180º while suppressing most of the undesirable distortion artefacts. In operation, each transmission begins with a carrier that has a continuous sequence of phase reversals at 31.25 Hz. Un-encoded, this would result in a continuous string of binary zeroes. As the operator types text, the bit stream is encoded using a scheme of variable-length bit sequences, whereby the most common characters have the shorter bit sequences.

The necessary bandwidth for PSK31 is 60 Hz, and uses no error-correction; however, a variant called quadrature phase-shift-keying (QPSK31) provides some FEC. This would be more attractive for an amateur service in the range 415-526.5 kHz because of its better performance under fading conditions.

PSK31 is a data mode that is implemented in software. This has allowed narrower-bandwidth variants such as PSK08, PSK02, etc., to be readily implemented. For example, PSK08 operates at one quarter the speed, i.e. approximately 8 symbols/s, with the necessary bandwidth reduced pro rata.

5.4 MFSK and FDM modes

There are a number of digital modes used by stations in the amateur service that employ multiple frequency-shift keying (MFSK), orthogonal multiple phase-shift keying or frequency-division multiplexing (FDM) of multiple carriers. These include modes such as Olivia. Olivia is a recent digital protocol, which has the promise of permitting reception of text transmissions under very adverse receiving conditions such as signals significantly below the noise floor.

Amateurs have studied sky-wave propagation near to 500 kHz through the experience of two-way communications, and also through the use of beacon transmitters. Recently, amateur beacons in several countries using the WSPR operating mode recently developed by amateurs, have been used successfully. WSPR uses a narrow bandwidth (~6 Hz) MFSK signal that can be successfully decoded and quantified under weak signal conditions (−30 dB SNR in 3 kHz bandwidth) making it well suited for use by amateur stations with low e.i.r.p. Each station alternates between transmit and receive time slots, so that signals may be monitored on all paths between the active beacon stations. Received signal data from all stations is automatically logged and uploaded to a publicly accessible online database for further analysis. Apart from WSPR's contribution to analyzing propagation conditions, its use to optimize transmitter antenna performance whilst operating at low transmitter bandwidth and e.i.r.p. is of significant benefit.

6 Characteristics of radiated signal

6.1 Overview

Amateur radio operators will be especially challenged by the large dimensions of antenna structures theoretically required and often employed in commercial installations in the range 415-526.5 kHz.

So as to better understand the characteristics of transmit antennas that might be employed in the amateur service in this frequency range, representative antenna types were analyzed using EZNEC pro/4 software. The antennas studied included two that could be constructed in limited space and two variations of an antenna requiring more substantial space. A detailed analysis of the antenna simulations and the results obtained for each antenna appear in Annex 1.

The antenna types studied are:

– A short vertical antenna with six ground radials.

– A short vertical antenna in the shape of an inverted L, also using six ground radials.

– An inverted L antenna of moderate size using sixteen 30 m ground radials.

– An inverted L antenna of moderate size using sixteen 15 m ground radials.

6.2 Summary

The following table summarizes the gain, efficiency and bandwidth of each of the simulated antennas.

TABLE 1

Small and moderate antennas in the range 415-526.5 kHz

Antenna	Effective gain[3] (dBi)	Input power (W)	Efficiency (%)	Bandwidth (kHz)
Short vertical/6 radials	−11.8	476.4	4.20	1.21
Electrically small inverted L/6 radials	−9.96	319.2	6.27	2.00
Moderate inverted L/30 m radials	−5.56	71.8	27.90	150.7
Moderate inverted L/15 m radials	−6.27	84.5	23.70	176.2

Gain shown in Table 1 includes losses in the tuner and transmission cable as well as the antenna gain. Efficiency defined in the foregoing is calculated by expressing the ratio of an assumed 20 W e.i.r.p. over the transmitter power required to achieve it after accounting for tuner loss, transmission cable loss and the antenna gain.

The 3 dB bandwidth of the antenna emissions is shown in Table 1. The first two antennas from Table 1 are electrically small and have bandwidths between 1.21 kHz and 2.0 kHz. The third and fourth antennas, however, are physically much larger and have dimensions which approach one-quarter wavelength.

The circuit bandwidth for these antennas is calculated using definitions of circuit Q and bandwidth using the following methodology:

– First the antenna input impedance is calculated with the aid of a 3D antenna simulator. Zin = Rin +jXin.

– Then, the Q of the circuit is calculated by assuming that Xin is resonated with a reactance of – jXin (usually an inductor). Q = Xin/Rin. This approximation is valid for small antennas operating over a very limited band of frequencies.

– Then the 3 dB bandwidth is calculated from the Q and operating frequency.

The following example calculation is for a short (much less the one quarter wavelength high) vertical antenna (see § A2.1). This antenna has an input impedance of 9.2 − j3816 Ω. Hence the Q is approximately 414 and the circuit bandwidth is 1.2 kHz for an operating frequency of 500 kHz.

[3] Effective gain refers to the achievable gain from the antenna taking into account relative inefficiencies, resonance, etc.

Large antennas that have dimensions approaching one quarter wavelength have input impedances that are quite different, with larger input resistance and smaller input reactance. The large antenna examples in the Annex of this Report are not resonant, but operate close to resonance. For example, antenna A3.1 has an input impedance of 14 − j47 Ω when mounted over lossy ground. Hence the Q is approximately 3.32 and the circuit bandwidth is 150 kHz for an operating frequency of 500 kHz.

It should be noted that the simple algorithm used here does not apply to resonant antennas, where the reactive portion of the input impedance equals zero. In this case, the antenna simulation must be done over a large frequency range from which the bandwidth can be deduced.

Three additional antennas were analyzed only to determine their bandwidths. The bandwidths were determined as follows:

TABLE 2

Antenna	**Bandwidth (kHz)**
30 m vertical with 16 radials	1.31
15 m vertical with 16 radials	0.41
Inverted-L 21m Vertical, 60 m Horizontal	8

Since the efficiency of antennas of the type studied is closely related to the size of the ground radial system, a further analysis was done using the small vertical antenna to demonstrate the effect of varying the number of radials. The results are summarized in Table 3.

TABLE 3

Gain vs. number of radials

Number of radials	**Gain (dBi)**
1	−18.19
2	−15.76
4	−13.17
6	−11.85
8	−11.03
12	−10.07
16	−9.52
24	−8.92
32	−8.59

Gain can also be improved by using longer radials; however, the example of the moderate size inverted L antenna detailed in the Annex shows an improvement in gain of only 0.7 dB in going from 15 m to 30 m radials.

6.3 Conclusions

Transmitting antenna systems of the type which might be employed in the amateur service in the range 415 to 526.5 kHz would be relatively inefficient (in the range 1 to 20%). While the gain of antenna systems in this range can be improved by using a more elaborate system of ground radials, to reduce the ground system losses, the improvement is in the order of 3 dB and the incremental improvement in gain drops off rapidly once an adequate number of radials have been provided. The efficiency of these antennas is greatly influenced by the surrounding environment, particularly the presence of trees and buildings, which typically have similar height dimensions to the antenna itself. This is not normally an issue for non-amateur MF installations as the antenna sites are carefully chosen to avoid these problems. It has been found that an antenna in a typical residential environment can have its loss resistance increased, and efficiency reduced, by an order of magnitude compared to a similar antenna erected in an open field. Measurements suggest that these efficiency reductions occur as a combination of electrical losses, and reduction in effective height of the antenna caused by a screening effect of objects surrounding the antenna.

At the power levels authorized for station operation in the amateur service by most administrations, radio amateurs could be expected to achieve only modest levels of effective radiated power in the 500 kHz range.

6.4 Receive antenna design

The ambient noise level near to 500 kHz includes natural background noise and impulsive thunderstorm static, but also in many locations a major contribution from manmade noise sources, including power supply switching transients, noise from wired data systems such as ADSL/DSL, and low level noise sidebands from high power broadcast and utility transmitters. Signal-to-noise ratios are often poor as a result, and amateurs have invested considerable effort in the design of receiving antenna and systems to mitigate this.

Many amateurs have used compact receiving antennas using small loops and E-field probes. With care, these antennas can be designed with noise figures below the ambient noise floor, suitable filtering (selectivity) and dynamic range. These compact antennas can be positioned to take advantage of locally low levels of noise field strength, or combined in arrays to implement noise cancelling schemes or produce steerable directional nulls. One particularly important and unexpected aspect of self learning is that amateurs have had to become adept in techniques to decouple receiving antennas and transmission lines from local noise sources, developing new noise reduction techniques, including optical isolation of antenna feed lines.

Diversity reception and remote operation of active antennas is likely to be significant in the use of frequencies between 415-526.5 kHz in support of emergency communications.

7 Reference material

The following reference material lists a number of sources of further information on the history, use and technical characteristics of these modes.

ARRL HF Digital Handbook, American Radio Relay League, ISBN: 0-87259-103-4, 4th Edition 2007.

Radio Communications Handbook, 10th Edition, Chapter 10 Low Frequencies 136 kHz and 500 kHz. Radio Society of Great Britain, ISBN 9781-9050-8654-2.

Digital modes (RAC) http://www.rac.ca/opsinfo/infodig.htm.

Ham radio operating modes http://www.ac6v.com/opmodes.htm.

PSK31 http://mars.superlink.net/~driller/page2.htm#PSK31.

Ham radio digimodes
http://www.electronics-radio.com/articles/ham_radio/digimodes/digital-modes-summary.php.

Annex 1

Analysis of antenna systems likely to be employed in the range 415-526.5 kHz in the amateur service

A1 General

The following input data was used in the simulations listed below:

– the ground type is "average";

– the radials are 0.4 m below ground.

The relationship between e.i.r.p., gain and transmitted power is:

$$P_T\,(\text{dBW}) = \text{e.i.r.p.} - G_T\,(\text{dBi})$$

where G_T is the antenna gain accounting for all losses (ground, wires, cables, and antenna tuner) and P_T is the power supplied by the transmitter.

A2 Examples of electrically small transmit antennas suitable for limited space

A2.1 Short vertical antenna

The short vertical antenna performance calculations are simulated according to the assumptions below:

– Antenna height = 15.24 m.

– Radial length = 7.62 m.

– Radial wire diameter = 2 mm.

– Simulated gain = −11.7 dBi.

– Tuner loss = 1.58 dB.

– Cable loss[4] = 0.5 dB.

– Total loss = 2.08 dB.

– Effective gain = −13.78 dBi.

– e.i.r.p. = 13 dBW.

– Transmitter power = 26.78 dBW (476.4 W)[5].

– Polarization: Vertical.

– Beamwidth = 47.5º.

– Elevation = 21º.

Figures 1 and 2 show the antenna geometry and elevation plot for the simulations parameters for the short vertical antenna.

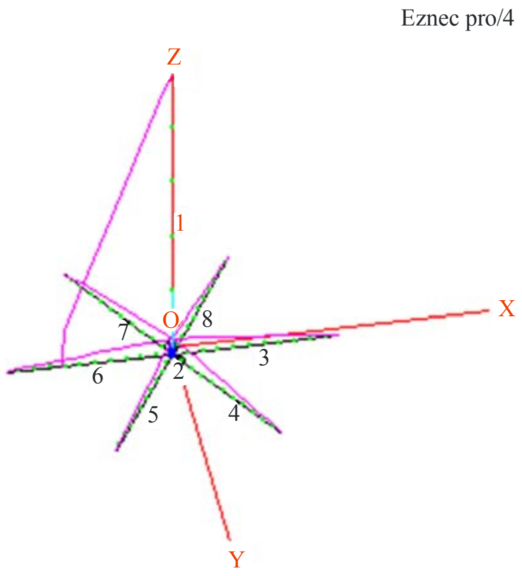
---

[4] Cable loss is highly dependent on system architecture including cable length, thus the value can range typically between 0.2 and 3 dB.

[5] Required transmitter output power, expressed in W, to attain e.i.r.p. of 20 W (13 dBW).

FIGURE 1

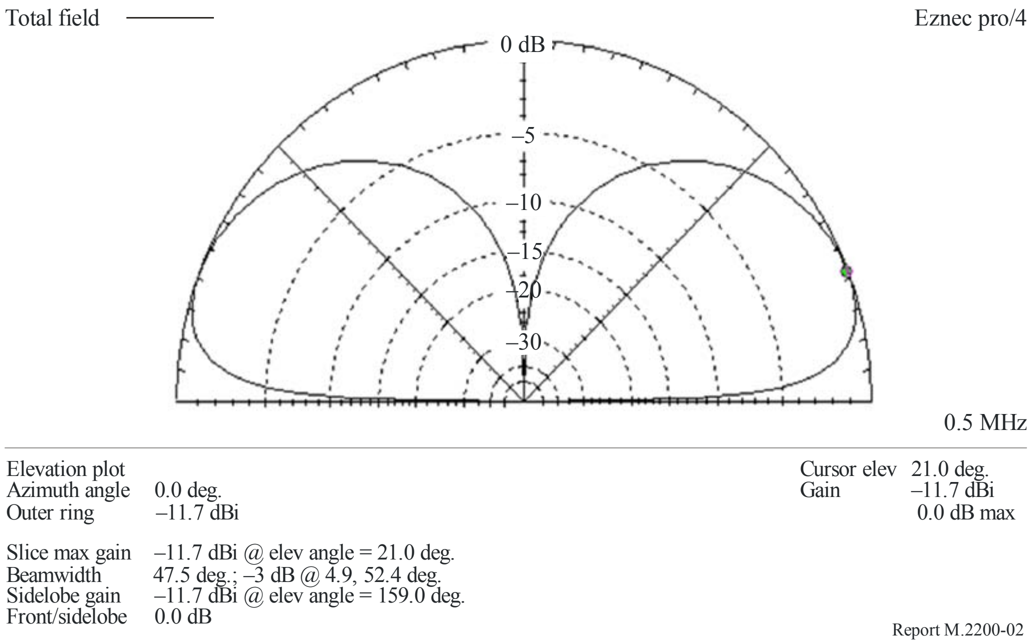
Antenna geometry: short vertical antenna, 7.62 m radials (6 ground radials)



Report M.2200-01

FIGURE 2

Elevation plot (total field): short vertical antenna, 7.62 m radials (6 ground radials)



Report M.2200-02

A2.2 Electrically small inverted L antenna

The electrically small inverted L antenna performance calculations are simulated according to the assumptions below:

– Antenna height = 15.24 m.
– Horizontal section = 7.62 m.
– Radial length = 7.62 m.
– Simulated gain = −9.96 dBi.
– Tuner loss = 1.58 dB.
– Cable loss = 0.5 dB.
– Total loss = 2.08 dB.
– Effective gain = −12.04 dBi.
– e.i.r.p. = 13 dBW.
– Transmitter power = 25.04 dBW (319.2 W).
– Polarization: Vertical with a very small horizontal component.
– Beamwidth = 47.7º.
– Elevation = 21º.

Figures 3 and 4 show the antenna geometry and elevation plot for the simulations parameters for the electrically small inverted L antenna.

FIGURE 3

Antenna geometry: electrically small inverted L antenna, 7.62 m radials (6 ground radials)

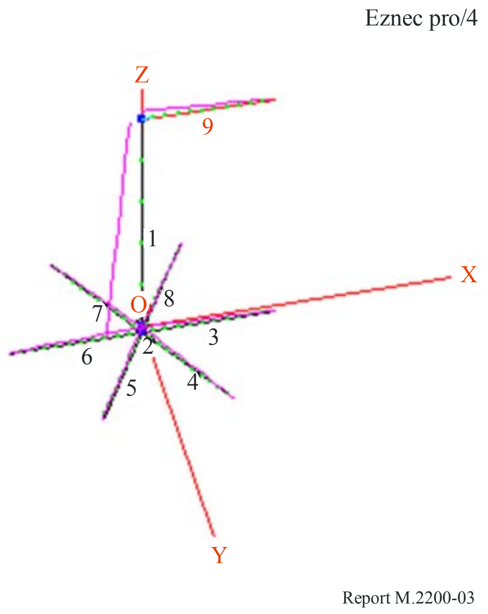
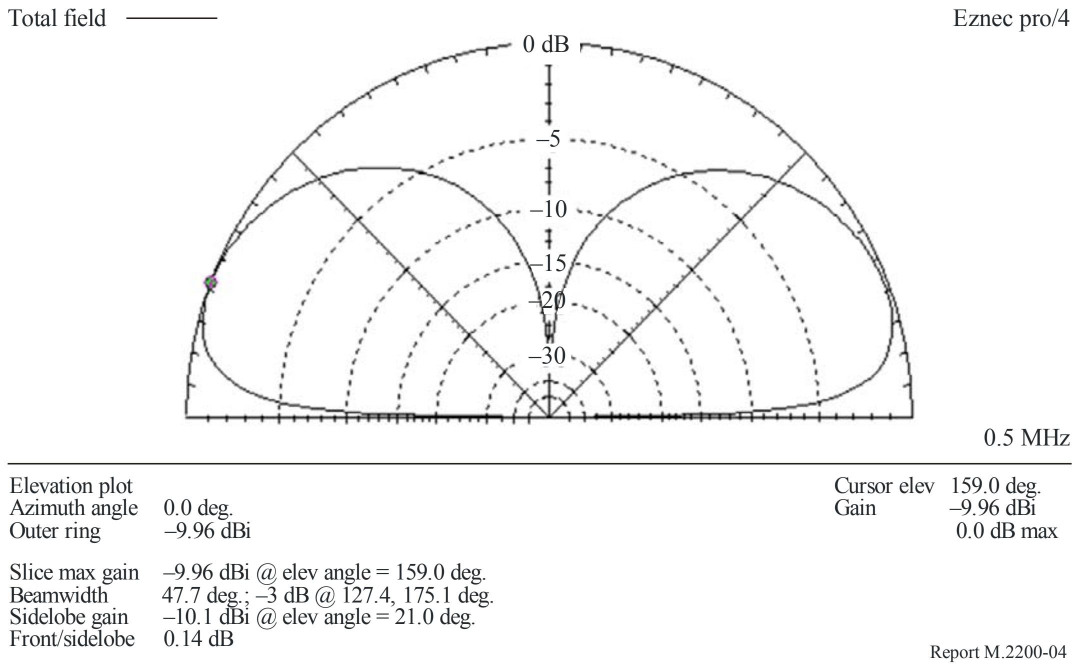


FIGURE 4

Elevation plot (total field): electrically small inverted L antenna, 7.62 m radials (6 ground radials)



A3 Examples of moderate-sized antennas suitable for locations with increased space availability

Two versions of this antenna using different radial length were simulated with EZNEC Pro/4. The following parameters are common to both antenna versions:

– the e.i.r.p. equals 13 dBW;

– the ground type is "average";

– wire diameter 1.63 mm;

– radials are 0.40 m below ground.

A3.1 Inverted L using 30 m radials

The performance of an inverted L antenna with 16 ground radials each 30.48 m are simulated according to the assumptions below:

– Antenna height = 21.34 m.

– Horizontal section = 119.79 m, oriented along the x-axis.

– Radial system = 16 ground radials each 30.48 m long.

– Simulated gain = −3.48 dBi (maximum).

– Tuner loss = 1.58 dB.

– Cable loss = 0.5 dB.

– Total loss = 2.08 dB.

– Effective gain = −5.56 dBi.

– e.i.r.p. = 13 dBW.

– Transmitter power = 18.56 dBW (71.77 W).

– Polarization: Vertical/horizontal depending on the azimuth angle.

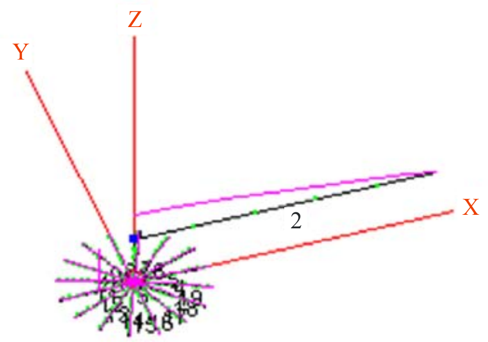
– Beamwidth = 161.6º.

– Elevation = 32º.

Figures 5 to 8 show the antenna geometry and elevation plot for an inverted L antenna with 16 ground radials each 30.48 m.

FIGURE 5

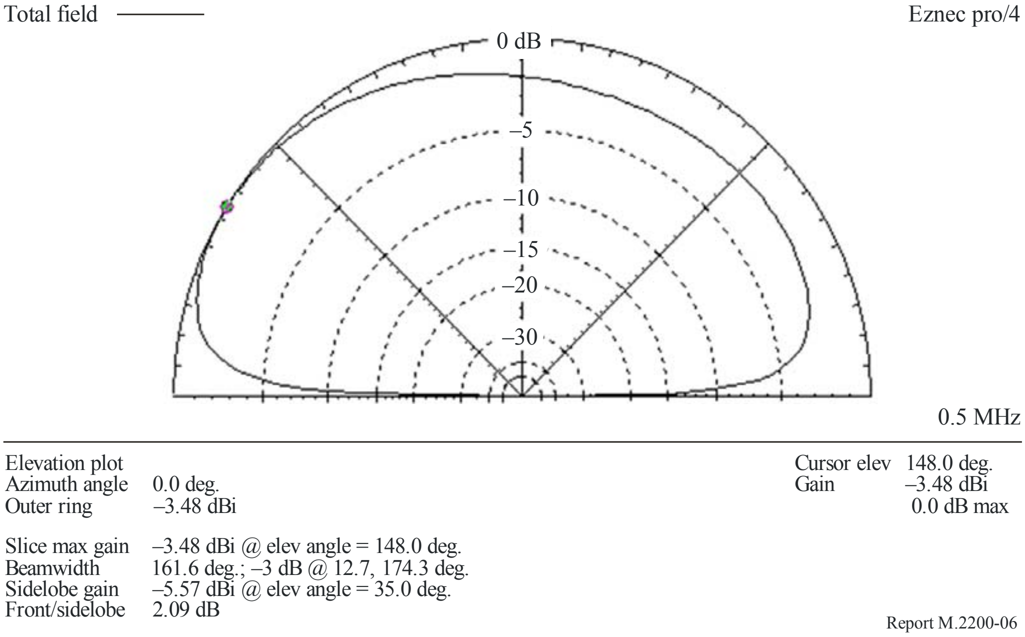
Antenna geometry: Inverted L antenna, 30.48 m radials (16 ground radials)



Report M.2200-05

FIGURE 6

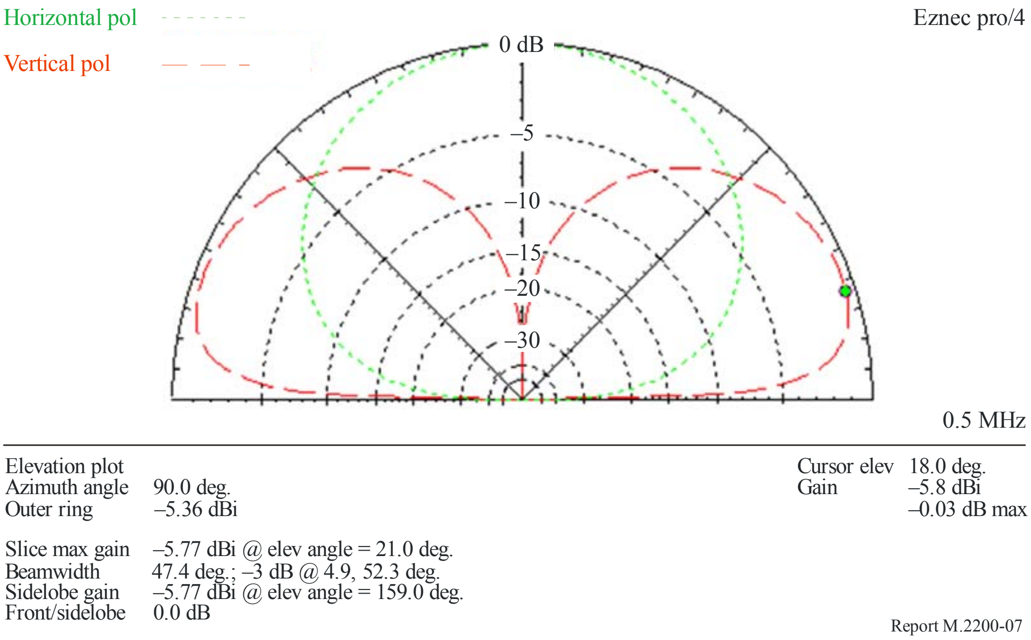
Elevation plot (total field): Inverted L antenna, 16 ground radials, 30.48 m long
Azimuth angle = 0º (end fire)



Report M.2200-06

FIGURE 7

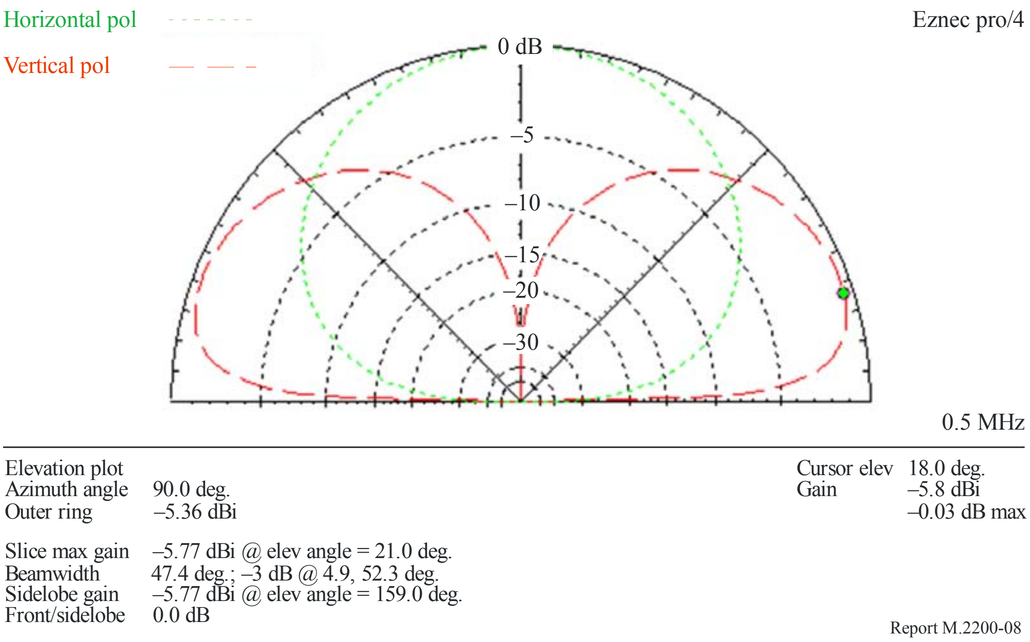
Elevation plot horizontal and vertical polarization: Inverted L antenna, 16 ground radials, 30.48 m long Azimuth angle = 90º (broadside)



Report M.2200-07

FIGURE 8

Elevation plot horizontal and vertical polarization: Inverted L antenna, 16 ground radials, 30.48 m long, Azimuth angle = 90º (broadside)



Report M.2200-08

A3.2 Inverted L using 15.24 m radials

The performance of an inverted L antenna with 16 ground radials each 15.24 m long are simulated according to the assumptions below:

– Antenna height = 21.34 m.

– Horizontal section = 119.79 m, oriented along the x-axis.

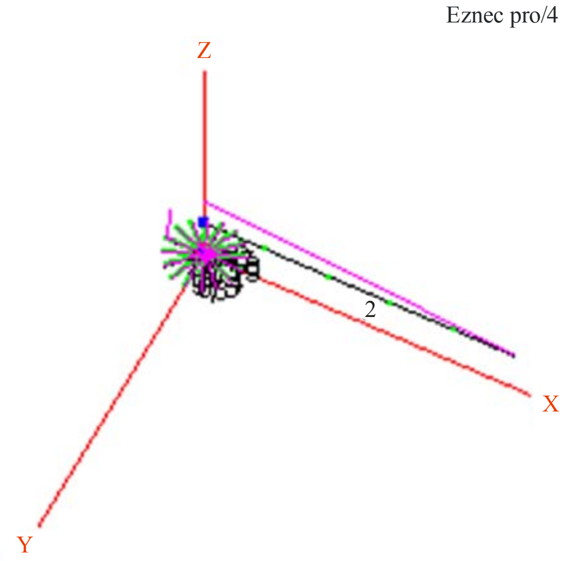
– Radials = 16 ground radials each 15.24 m.

– Simulated gain = −4.19 dBi (maximum).
– Tuner loss = 1.58 dB.
– Cable loss = 0.5 dB.
– Total loss = 2.08 dB.
– Effective gain = −6.27 dBi.
– e.i.r.p. = 13 dBW.
– Transmitter power = 19.27 dBW (84.5 W).
– Polarization: Vertical/horizontal depending on the azimuth angle.
– Beamwidth = 160.8º.
– Elevation = 32º.

Figures 9 and 10 show the antenna geometry and elevation plot for an inverted L antenna with 16 ground radials each 15.24 m long.

FIGURE 9

Antenna geometry: Inverted L antenna, 16 ground radials, 15.24 m long



Report M.2200-09

FIGURE 10

Elevation plot total field: 16 ground radials, 15.24 m long,
Azimuth angle = 90º (broadside)
Maximum gain 0.7 dB less than the system having 30.48 m radials