Folded dipole antenna for CC2400, CC2420, CC2430, CC2431, and CC2480

By G. E. Jonsrud

1 KEYWORDS

- *Radiation Pattern*
- *Line of sight range*
- *CC2400*
- *CC2420*
- *CC2430*
- *CC2431*
- *CC2480*
- *Folded dipole*

2 INTRODUCTION

This application note describes the design of a folded dipole antenna for CC2400, CC2420, CC2430, CC2431, and CC2480. The CC2400 is a true single-chip, general-purpose transceiver for the 2.4 GHz SRD band for data rates up to 1 Mbps. The CC2420 is a true single-chip RF transceiver designed for low power wireless networks operating in the 2.4 GHz SRD band compliant with the ZigBee™/IEEE 802.15.4 standard. CC2430 is a true SoC combining the CC2420 with a single cycle 8051 microcontroller. CC2431 is CC2430 with location engine. The CC2480 is a cost-effective, low power, Z-Accel ZigBee Processor that provides full ZigBee functionality with a minimal development effort.

The design described in this application note is based on the CC2400, but it is possible to tune the antenna impedance so it can be used with CC2420, CC2430, CC2431, and CC2480. The tuning is done by adjusting the value of the inductor placed across the RF pins.

The RF front end consists of three pin connections. Two pins serve as a differential interface shared by the LNA and PA. The third pin changes voltage level in order to provide power to the PA during transmission and ground to the LNA during reception. A differential interface provides a better utilisation of the available supply voltage as well as less parasitic capacitance to ground.

Design criteria for the antenna and the design process are described. Also included are test results and a comparison of the tested antenna to a balun and monopole antenna solution. Gerber files and schematics can be downloaded from www.ti.com/lpw.

Table of Contents

3 ABBREVIATIONS

CC243x	CC2430 and CC2431
CC2480	Z-Accel ZigBee Processor
DC	Direct Current
EB	Evaluation Board
EIRP	Effective Isotropic Radiated Power
EM	Electromagnetic
CC2400EM	CC2400 Evaluation Module
FCC	Federal Communications Commission
FR4	Common PCB material
FSK	Frequency Shift Keying
ISM	Industrial Scientific and Medical
LNA	Low Noise Amplifier
PA	Power Amplifier
PCB	Printed Circuit Board
RBW	Resolution Bandwidth
RF	Radio Frequency
RFC	Radio Frequency Choke
SMA	Common RF connector
SRD	Short Range Device
VBW	Video Bandwidth

4 DESIGN CRITERIA

The following design criteria were important for the antenna design:

- Optimum load impedance for CC2400, 110 + j130 Ohm, differential
- DC-connection between RF pins and TXRX_switch pin
- TXRX_switch pin isolated from RF
- Few components
- Manufacturability
- Low spurious emission
- Low losses
- Omnidirectionality

The optimum termination impedance is a trade-off between optimum source impedance for the internal LNA and optimum load for the internal PA. The TXRX_switch pin level is 0 V in receive mode to provide ground for the LNA and 1.8 V in transmit mode to provide the required supply voltage to the PA. This pin should be isolated from the RF signals by using a shunt capacitor and/or a series inductor (RFC).

Antennas that are electrically short compared to the wavelength tend to be sensitive to component variations in the tuning network. Electrically small antennas may cause yield problems or require individual tuning.

Pay special attention to the harmonic levels for operation in the 2.4 GHz SRD band. Both the second and third harmonic will fall within restricted bands as defined by FCC part 15.

In typical SRD applications, it is desired that the antenna radiates equally in all directions, i.e. that the antenna is omni directional.

A folded dipole is attractive because of its high impedance that makes it easier to match to the optimum impedance for the CC2400. The theoretical impedance is 292 Ohm for a half wavelength folded dipole. A shunt inductor should provide the inductive part of the optimum load impedance while reducing the real part. The folded dipole is a metal loop that will provide DC contact between the RF pins. In addition the mid point of the antenna is virtual ground, meaning that a connection can be made to the TXRX_switch pin without distorting antenna performance. The folded dipole is a resonant structure that should be less sensitive to component variations and provide low losses. The radiation pattern of a folded dipole is omni-directional in the plane normal to the antenna.

5 DESIGN DESCRIPTION

An initial investigation to check the feasibility of the design was performed using the Smith chart. Plotting the 292 Ohm in the Smith chart and adding a 15 nH shunt inductor resulted in 115 + j141 Ohm.

The CC2400EM reference design was selected as the base for the design. The CC2400EM is a radio module with balun and an SMA connector. The balun with the SMA connector is designed to work with 50 Ohm unbalanced devices such as a ¼ wave antenna and most RF instruments

The antenna was implemented on the PCB as part of the layout. The antenna was placed relatively close to the CC2400 to keep the design compact.

The antenna design was simulated before the layout was made. The antenna was designed using an EM simulator and the matching circuit was simulated using a linear simulator and S-parameters from the EM simulation.

The first step in the simulation was to design a folded dipole on a FR4 PCB in front of a ground plane of the same size as the CC2400EM. The length of the antenna was adjusted until the impedance was 290 Ohm. The next step was to add feed lines with pads for a shunt inductor and a transmission line to the virtual ground point of the antenna for DC connection to the TXRX switch pin. The transmission line to the TXRX switch pin was connected to ground during the simulations and was fitted with pads for a series inductor. The inductor pads were defined as ports to make it easy to simulate with various inductors in the following S-parameter simulations. Due to the PCB material and the ground plane, the antenna became shorter than the theoretical half wavelength. Finally, the inductor values were determined using a linear simulator, S-parameters from the antenna simulation and S-parameters for the inductors.

6 SCHEMATICS AND LAYOUT

Figure 1 shows the schematic of the CC2400EM with the folded dipole antenna. Figure 2 shows the board layout. The distance to the antenna and extension of the ground plane behind the antenna are critical parameters. If the PCB is wider than the CC2400EM board, the ground plane, components and tracks should be pulled away from the end points of the antenna.

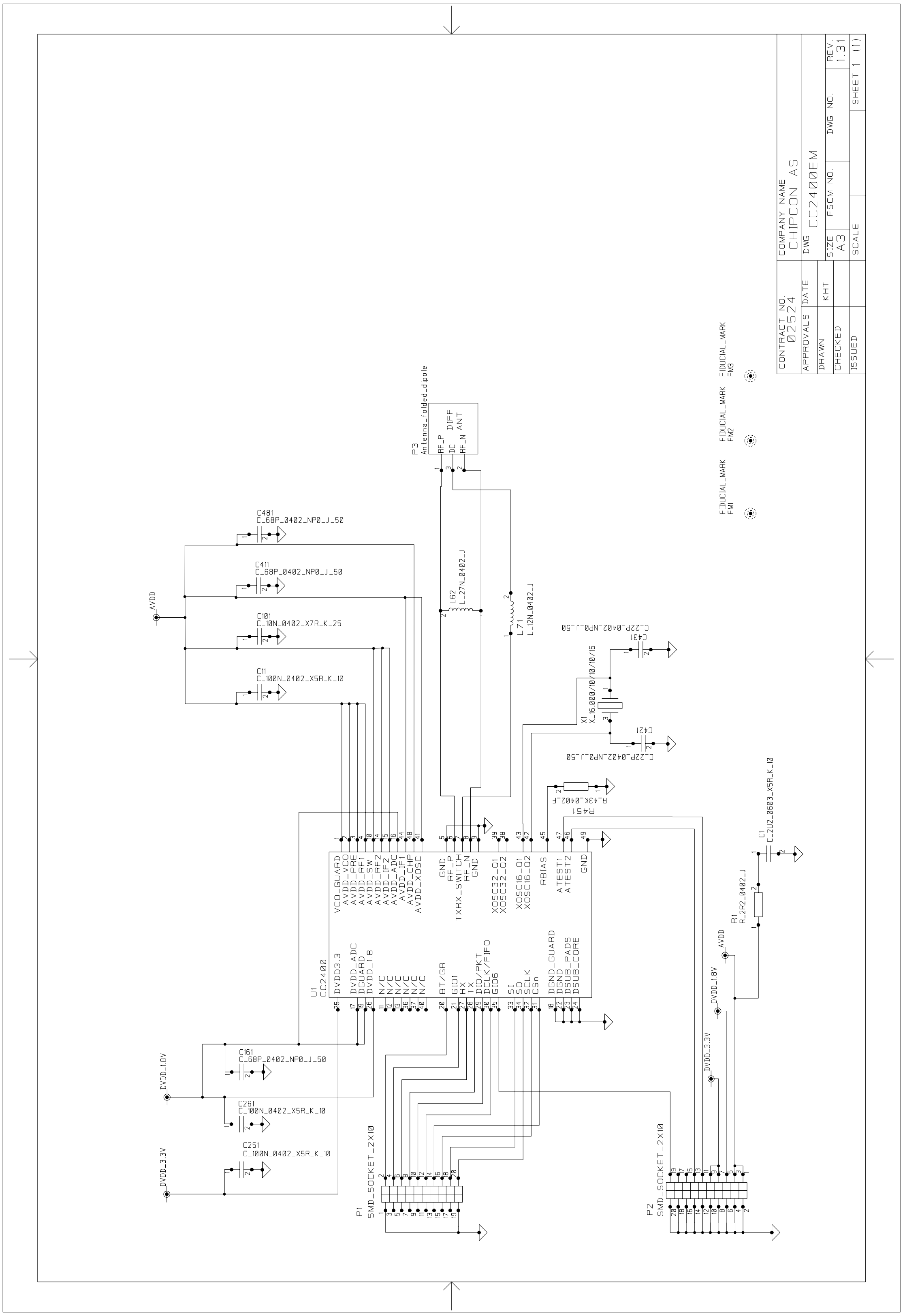


Figure 1: Schematics for CC2400EM with Folded Dipole Antenna

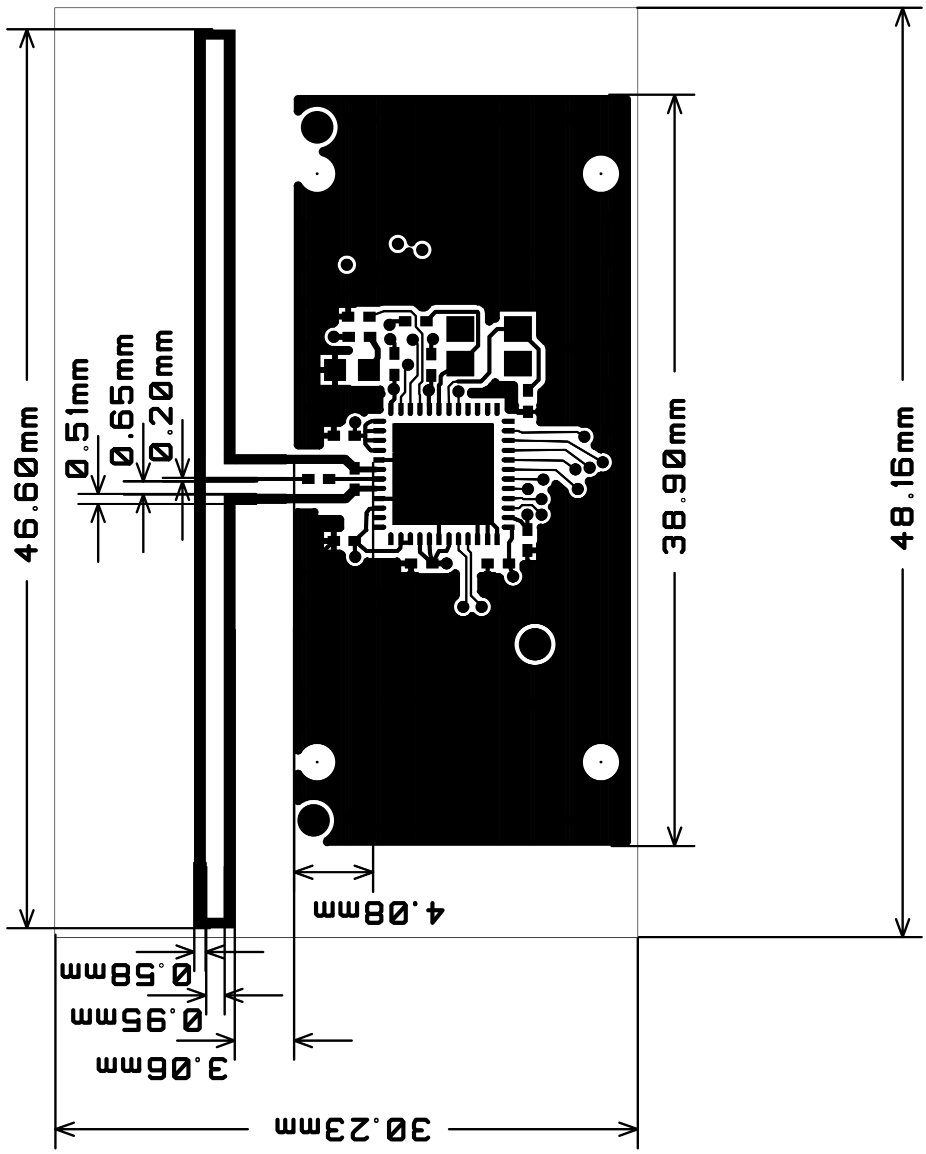


Figure 2: Layout of CC2400EM with Folded Dipole

7 TUNING

The schematic in Figure 1 shows the recommended component values when matching the antenna to CC2400. Since the optimum impedance of CC2420, CC243x, and CC2480 is different from CC2400 is it required to tune the value of the matching inductor (L62) to obtain optimum performance when implementing the antenna with these parts. The optimum load impedance for CC2420, CC243x, and CC2480 is given in the data sheets. The size of the ground plane, encapsulation of the board and objects in the vicinity of the antenna will also affect the performance. Thus, it is important to have the antenna implemented in the environment it is going to be used when performing the tuning. It might also be needed to tune the length of the antenna to obtain optimum performance. The length of the antenna will affect the resonance frequency. Implementations with ground plane size different from the reference design and with encapsulation will most likely require slightly different antenna length to ensure optimum performance in the middle of the 2.4 GHz ISM band. To find the optimum length, test software that steps a carrier across the frequency band can be used. Measuring the radiated power by using max hold on a spectrum analyzer will identify the optimum frequency. If the frequency with highest radiation is too low, the antenna could be made slightly shorter and if the maximum radiation is at a too high frequency, the antenna should be made longer. Tuning of the antenna length could be done using a sharp knife and soldering on copper tape or a small wire.

The purpose of tuning the value of L62 is to maximise output power while maintaining good spectrum properties. Figure 3 shows the spectrum when CC2400 is configured to transmit random data continuously at 1 Mbps. It is measured with a cable between the spectrum analyser and the CC2400EM. The cable and the instrument is 50 Ohm and a good impedance match for the CC2400EM. Figure 3 also illustrates how to judge a good spectrum. The marker measures the difference between the peak power level and the first null. It should be at least 25 dB, typically 28 dB, for no degradation in transmission. The difference in frequency is 760 kHz. It is important to measure with 100 kHz RBW and a 100 kHz VBW. It is also an advantage to apply averaging for the measurements over the air. (Note: The plot uses different settings on RBW and VBW)

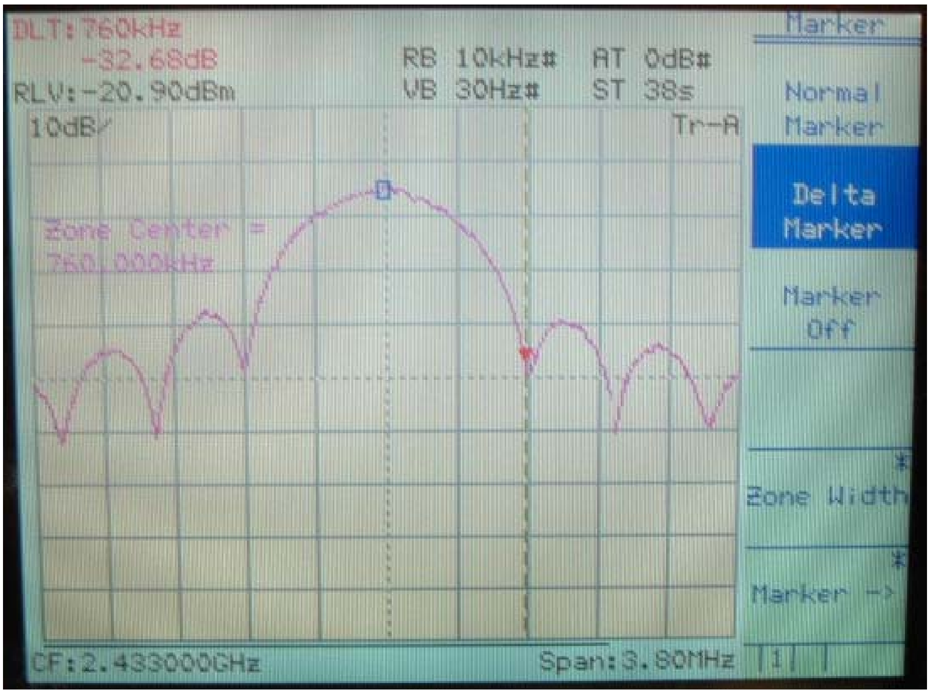


Figure 3: Reference Spectrum for CC2400 at 1 Mbps

Poor matching degrades the output spectrum as illustrated in Figure 4. This measurement is obtained using an antenna connected to the spectrum analyser. The CC2400EM is tested with no antenna connected, i. e. the SMA connector left open. In this case the mismatch occurs due to the open circuit when the antenna is removed from the EM. Transmission is lost even at small distances because of spectrum degradation. The received level is adequate, but the FSK signal is too degraded to be demodulated.

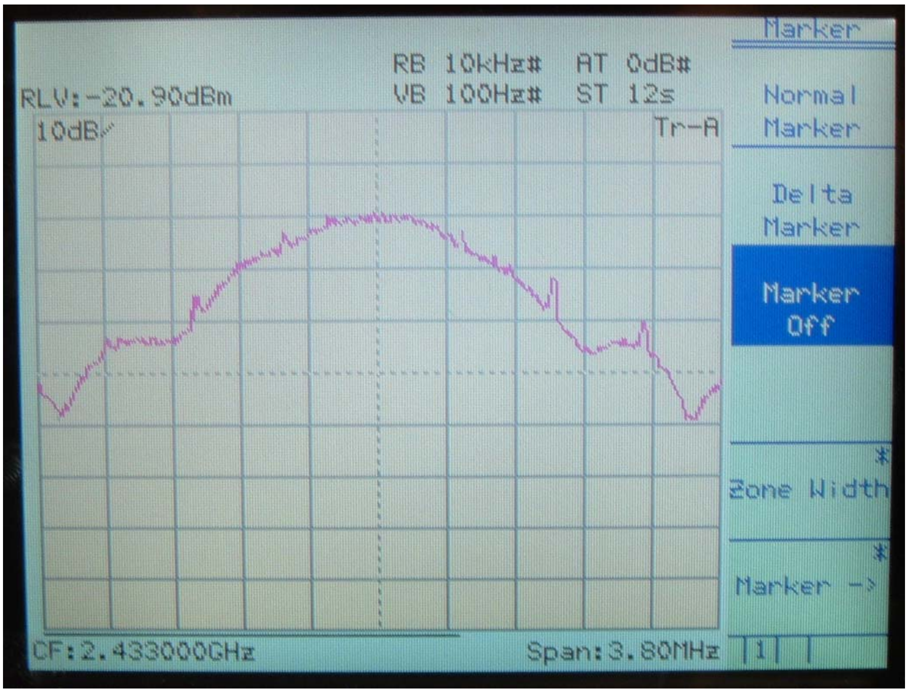


Figure 4: Example of Poor Spectrum. Antenna Removed from EM

The tuning set up is shown in Figure 5. It consists of a whip antenna mounted on a copper sheet and connected to a spectrum analyser. A copper sheet is not required; it was used to have a stable set-up. To achieve reliable measurements, the CC2400EB onto which the CC2400EM to be tested was mounted, was placed in three different positions on the copper sheet. The power received by the whip antenna was read in the three positions and the average was used for comparison of the different configurations. The tuning of the antenna was performed in a laboratory without absorbers or other features for antenna characterisation. It is important to average measurements as small changes in position could give significant changes in received levels due to reflections. The RBW was set to 2 MHz with a 3.8 MHz span and averaging was set to 50 when making power measurements. The spectrum was checked using an RBW = VBW = 100 kHz. The inductor values were stepped up and down and the average power level was recorded as well as the depth of the first nulls in the spectrum.

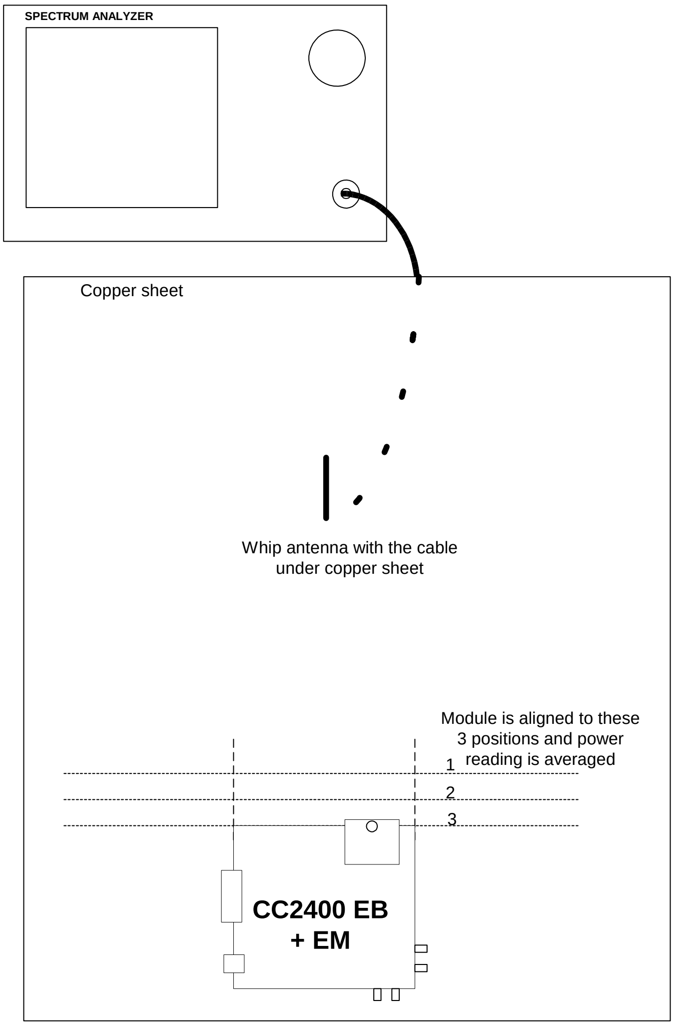


Figure 5: Tuning Setup

8 TEST RESULTS

The folded dipole antenna was tested and compared to the whip antenna that ship with the Chipcon CC24XXDK development kits.

The radiation patterns were tested in an anechoic chamber. All radiation patterns are included in the appendix. The measurements are made for vertical and horizontal polarisations with sweeps made in 3 planes. The output power of CC2400 was programmed to 0 dBm and the measurements were calibrated to show EIRP. The whip antenna (Figure 6) has a vertical orientation when the EB is parallel with the xy-plane. That is why the gain is highest for the plot with vertical polarisation. The folded dipole (Figure 7) has a horizontal orientation and the gain is highest for the plot with horizontal polarisation. The positions of the EB with antennas are shown in Figure 8, Figure 9, and Figure 10.

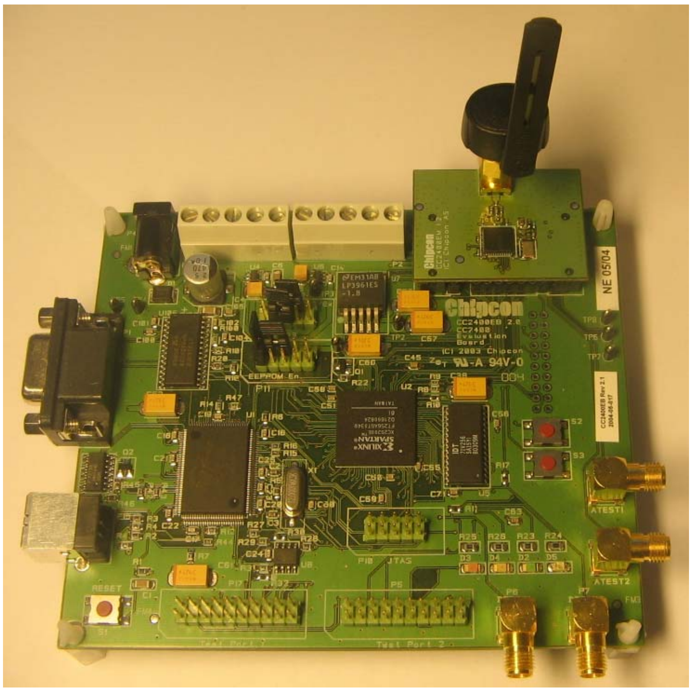


Figure 6: EB with CC2400EM with Whip Antenna

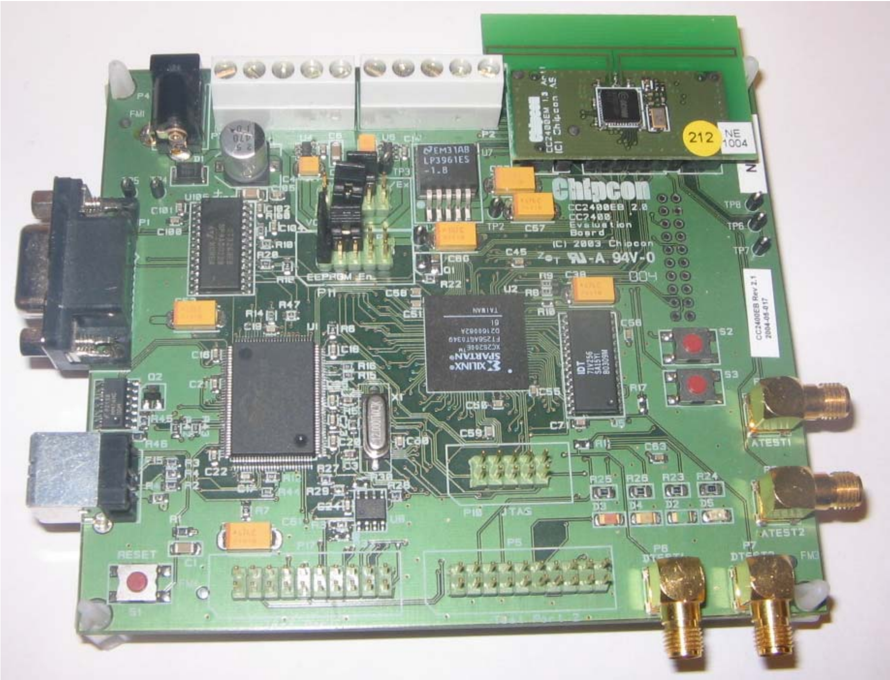


Figure 7: EB with CC2400EM with Folded Dipole Antenna

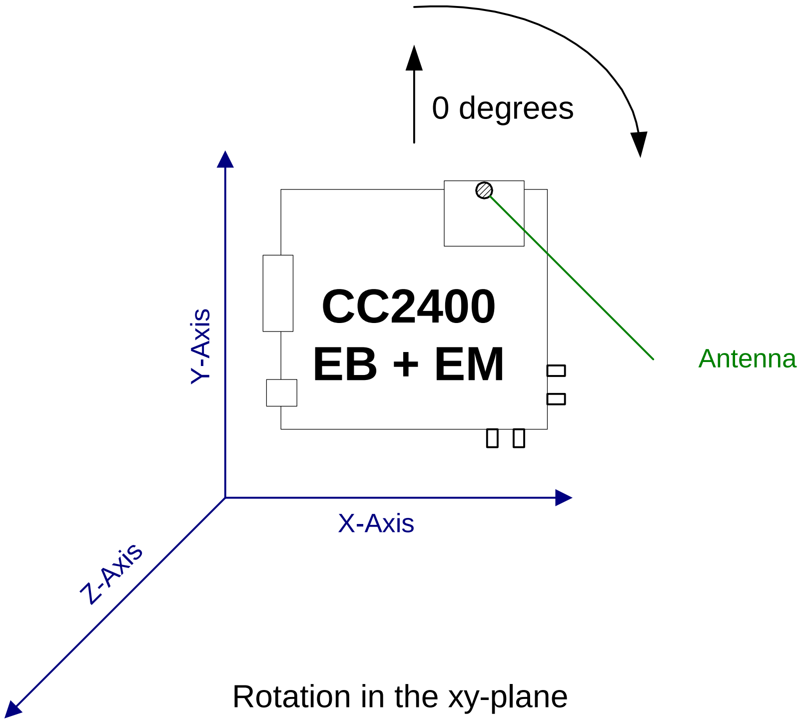


Figure 8: Orientation of Antenna. EM and EB for Sweep in XY-plane

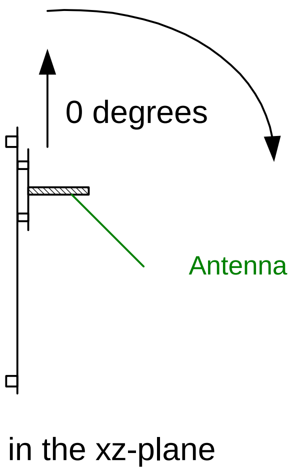


Figure 9: Orientation of Antenna. EM and EB for Sweep in XZ-plane

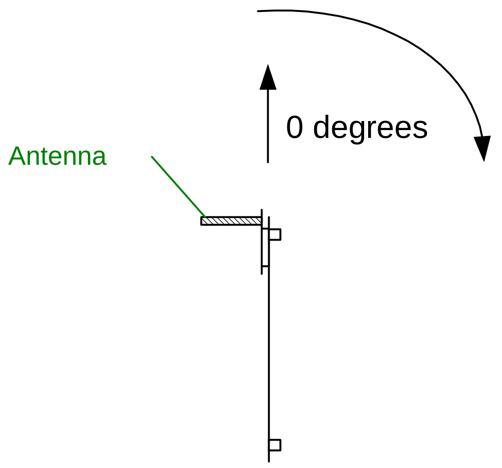


Figure 10: Orientation of Antenna. EM and EB for Sweep in YZ-plane

8.1 SUMMARY OF RESULTS

Table 1 shows a summary of the results associated with the two designs, i.e. for the CC2400EM with balun and whip antenna and the CC2400EM with a folded dipole.

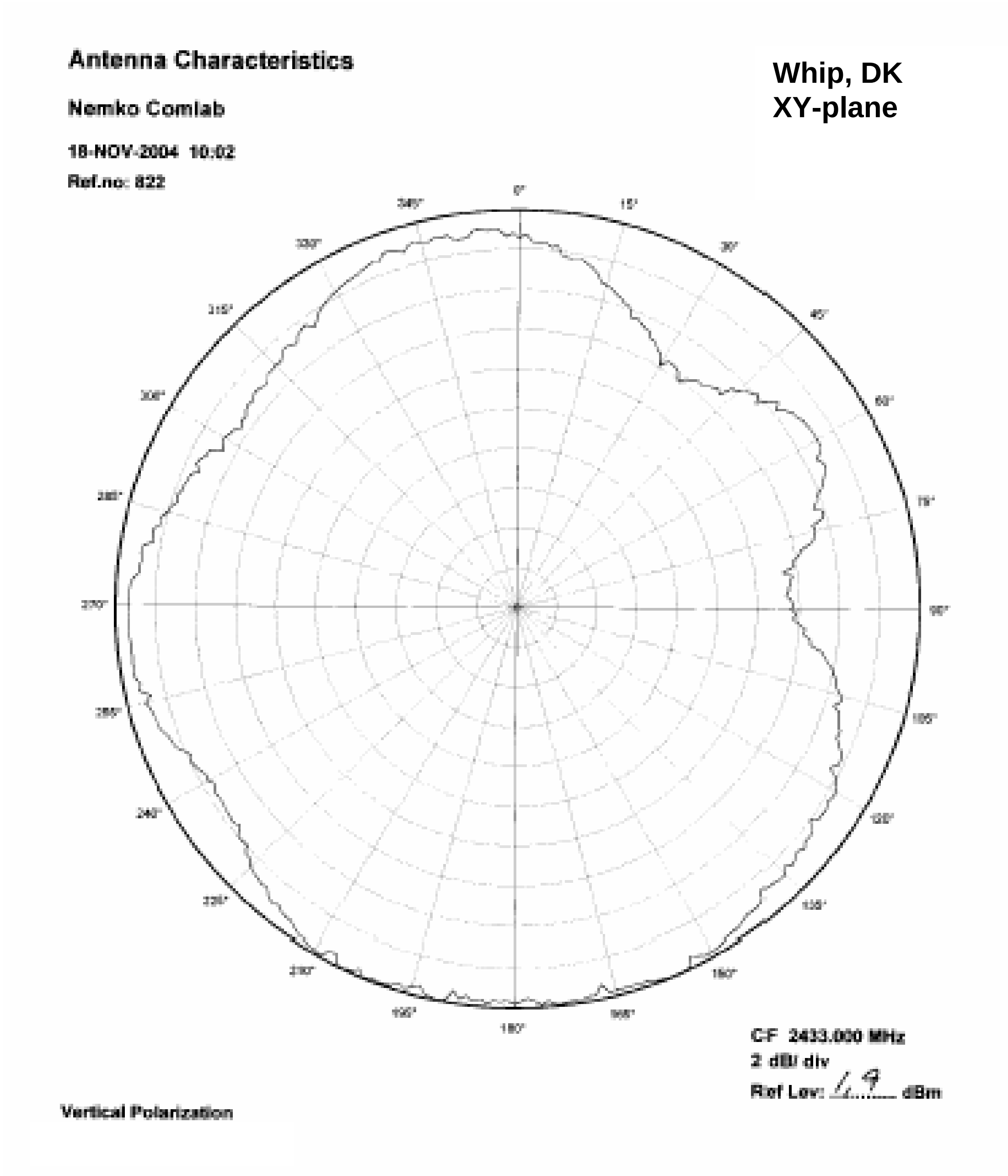
Antenna:	**Whip**	**Folded dipole**
Gain	+ 1.9 dBi	+0.3 dBi
Omnidirectivity	6 dB dip, best case	16 dB dip, best case
Harmonics (FCC part 15, req. max. 54 dBμV/m)	2nd: 52.8 3rd: 49.4	2nd: 52.0 3rd: 51.3
Components	Discrete balun requires 4 inductors and 4 capacitors	Requires 2 inductors
Size including matching network	Without antenna: 8 mm by 4 mm	Antenna and match: 47 mm by 9 mm
Line of sight range outdoors with CC2400	212 meter	157 meter

Table 1: Summary of Results

9 CONCLUSION

The folded dipole is an inexpensive, differential alternative to a balun and single ended antenna.

10 APPENDIX A - RADIATION DIAGRAMS



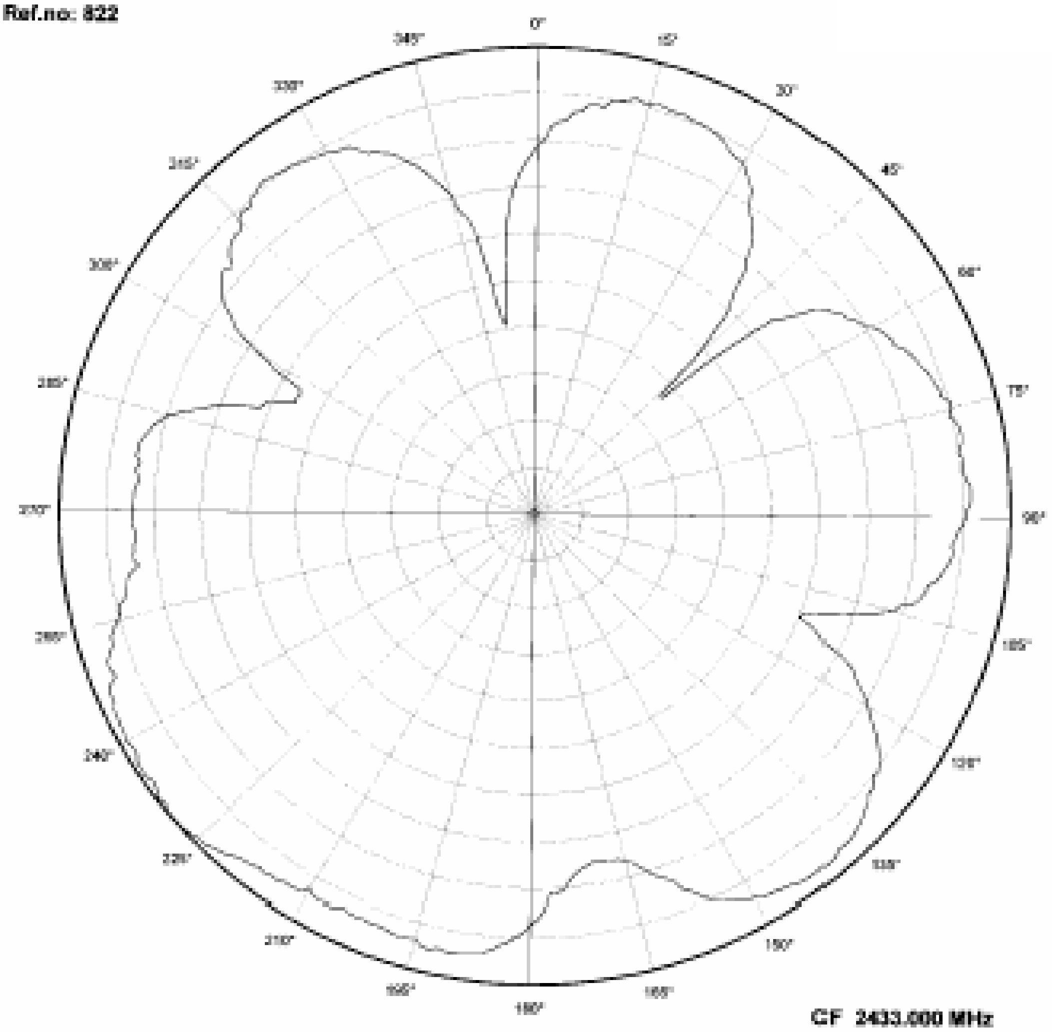
Antenna Characteristics

Nemko Comlab

Whip, DK
XY-plane

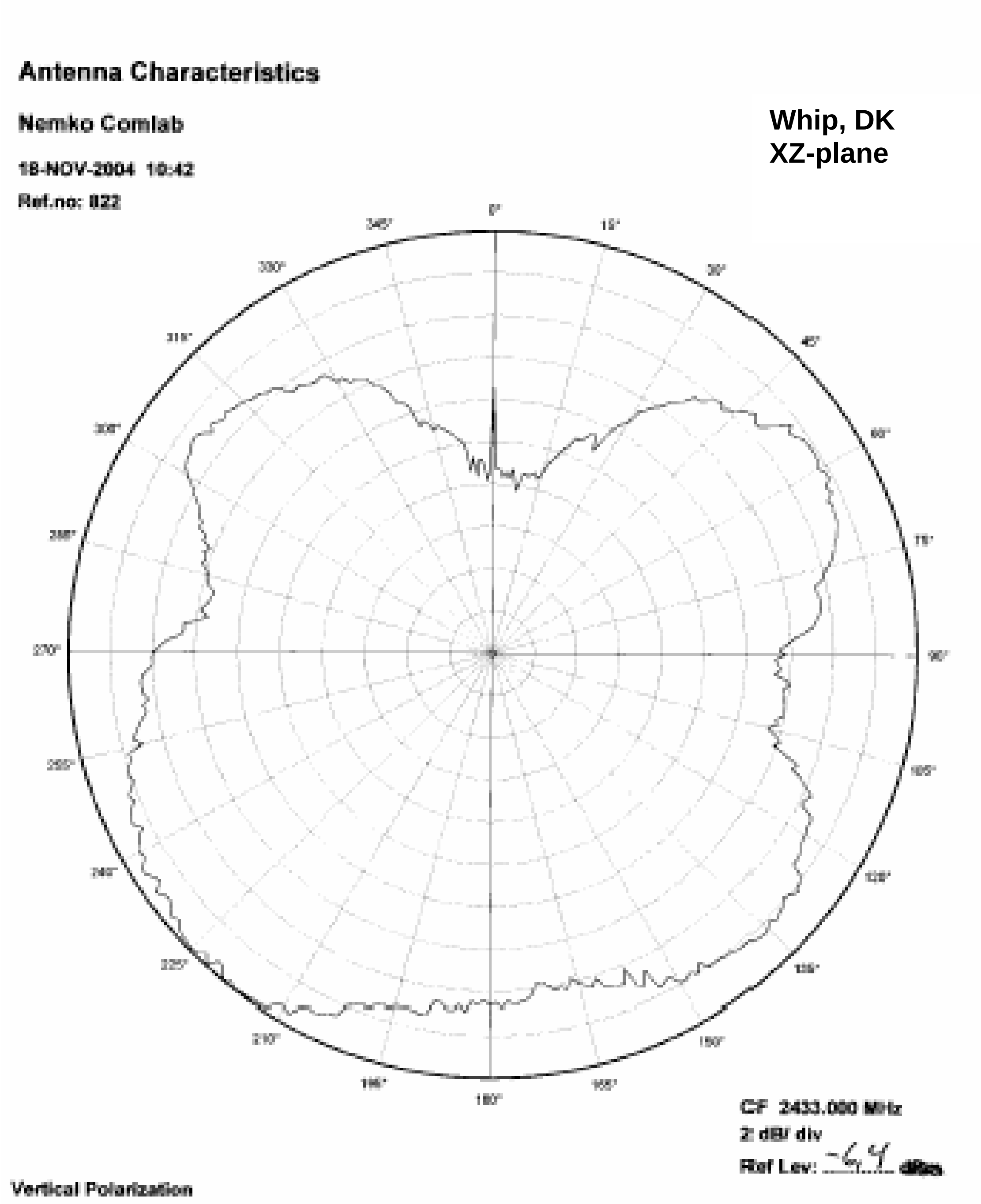
18-NOV-2004 10:03

Ref.no: 822



CF 2433.000 MHz
5 dB/ div
Ref Lev: -43 dBm

Horisontal Polarization



Antenna Characteristics
Nemko Comlab
18-NOV-2004 10:42
Ref.no: 822
Whip, DK
XZ-plane
0°
15°
30°
45°
60°
75°
90°
105°
120°
135°
150°
165°
180°
195°
210°
225°
240°
255°
270°
285°
300°
315°
330°
345°
CF 2433.000 MHz
2 dB/ div
Ref Lev: -64 dBm
Vertical Polarization

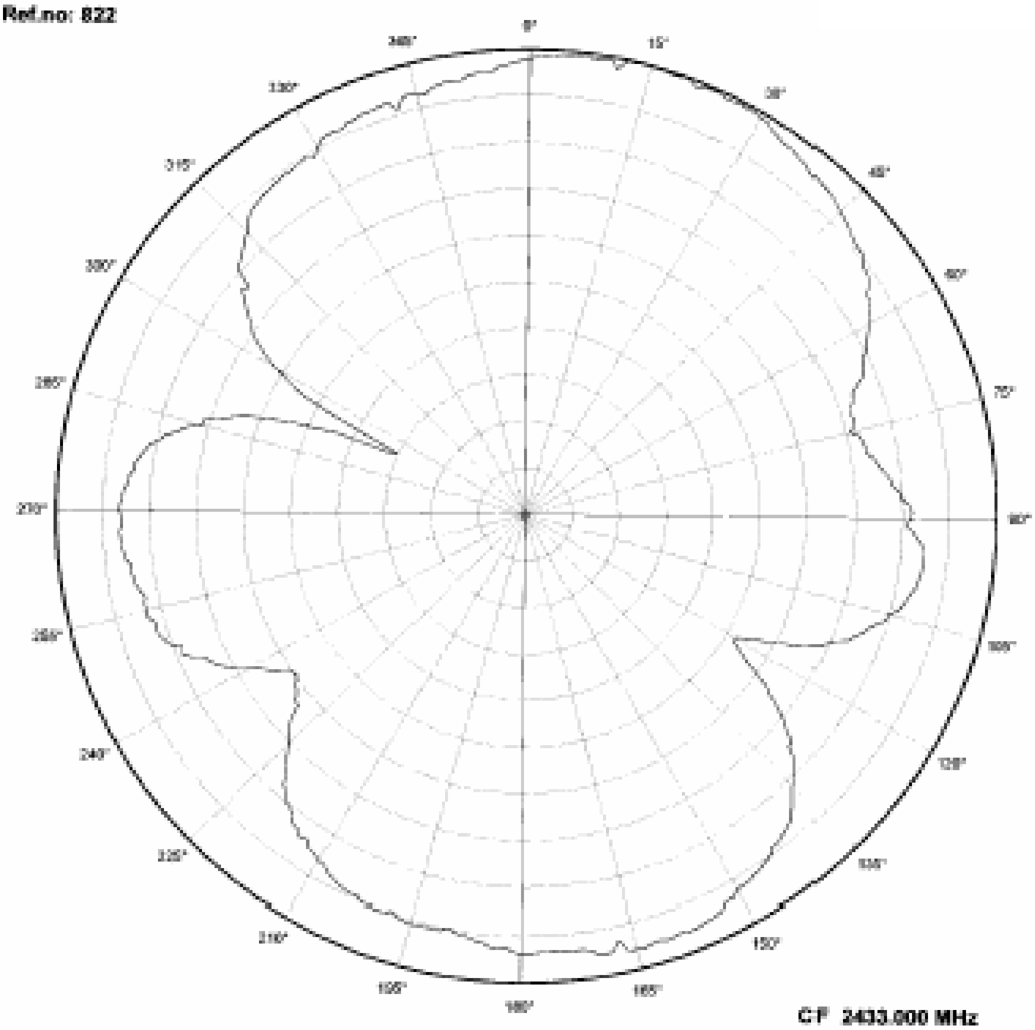
Antenna Characteristics

Whip, DK
XZ-plane

Nemko Comlab

18-NOV-2004 10:30

Ref.no: 822



CF 2433.000 MHz
4 dB/ div
Ref Lev: ..4.1..... dBm

Horisontal Polarization

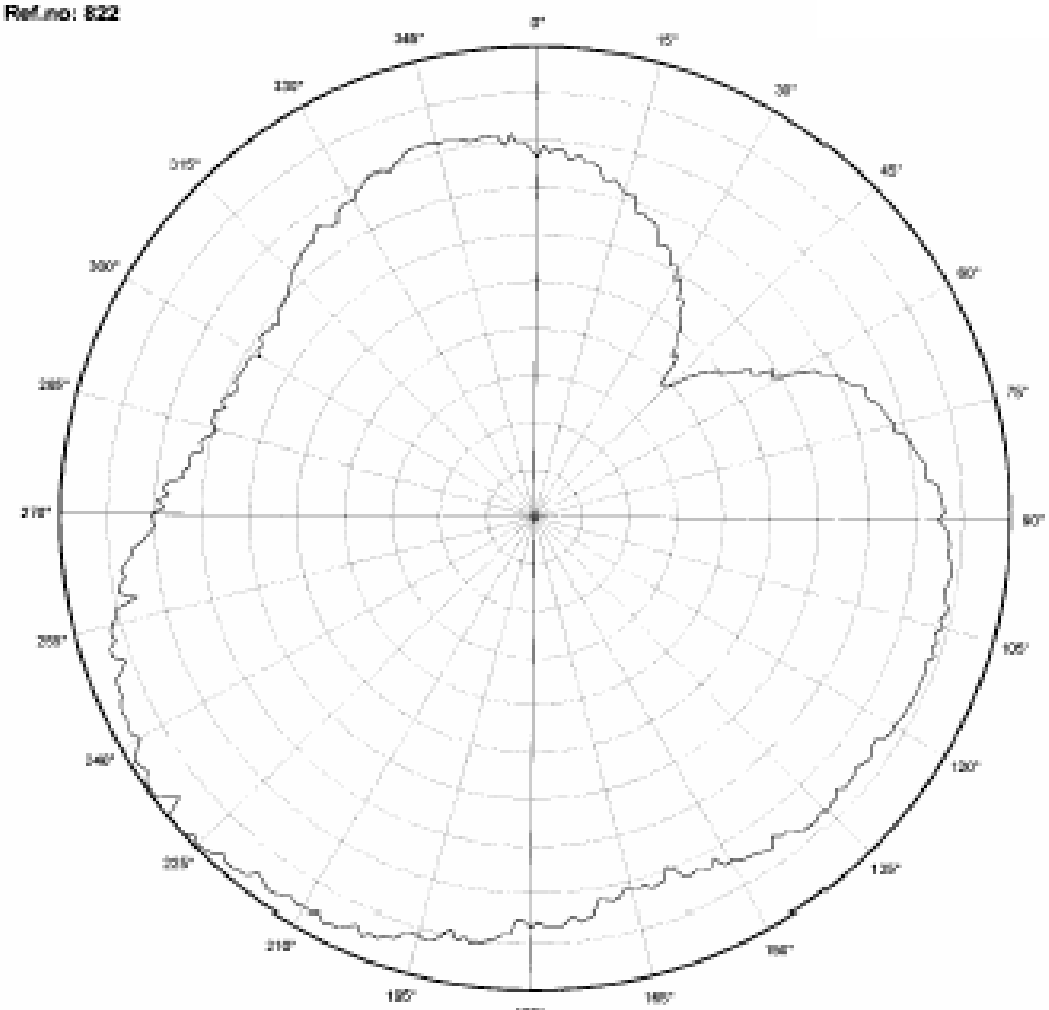
Antenna Characteristics

Nemko Comlab

18-NOV-2004 10:17

Ref.no: 822

Whip, DK
YZ-plane



CF 2433.000 MHz
2 dB/ div
Ref Lev: -3,8 dBm

Vertical Polarization

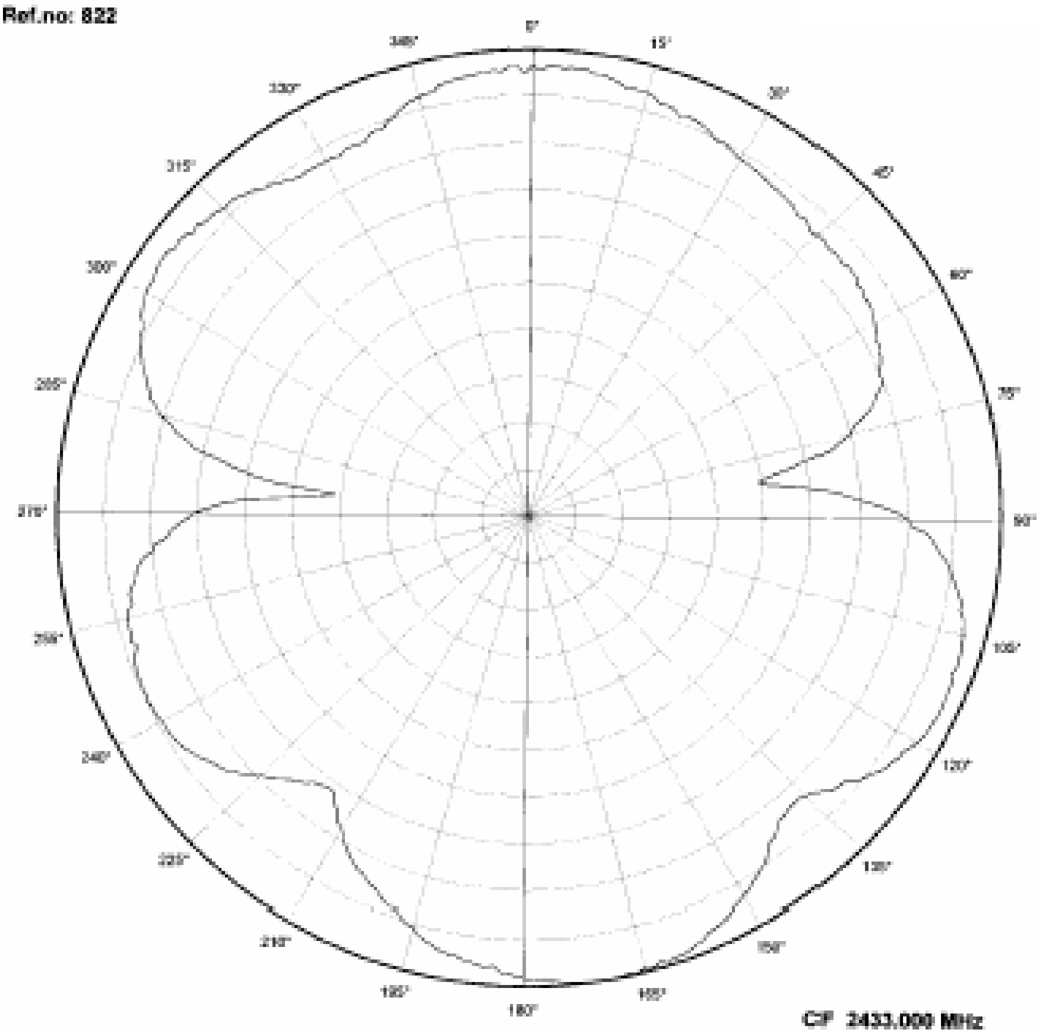
Antenna Characteristics

Nemko Comlab

18-NOV-2004 10:18

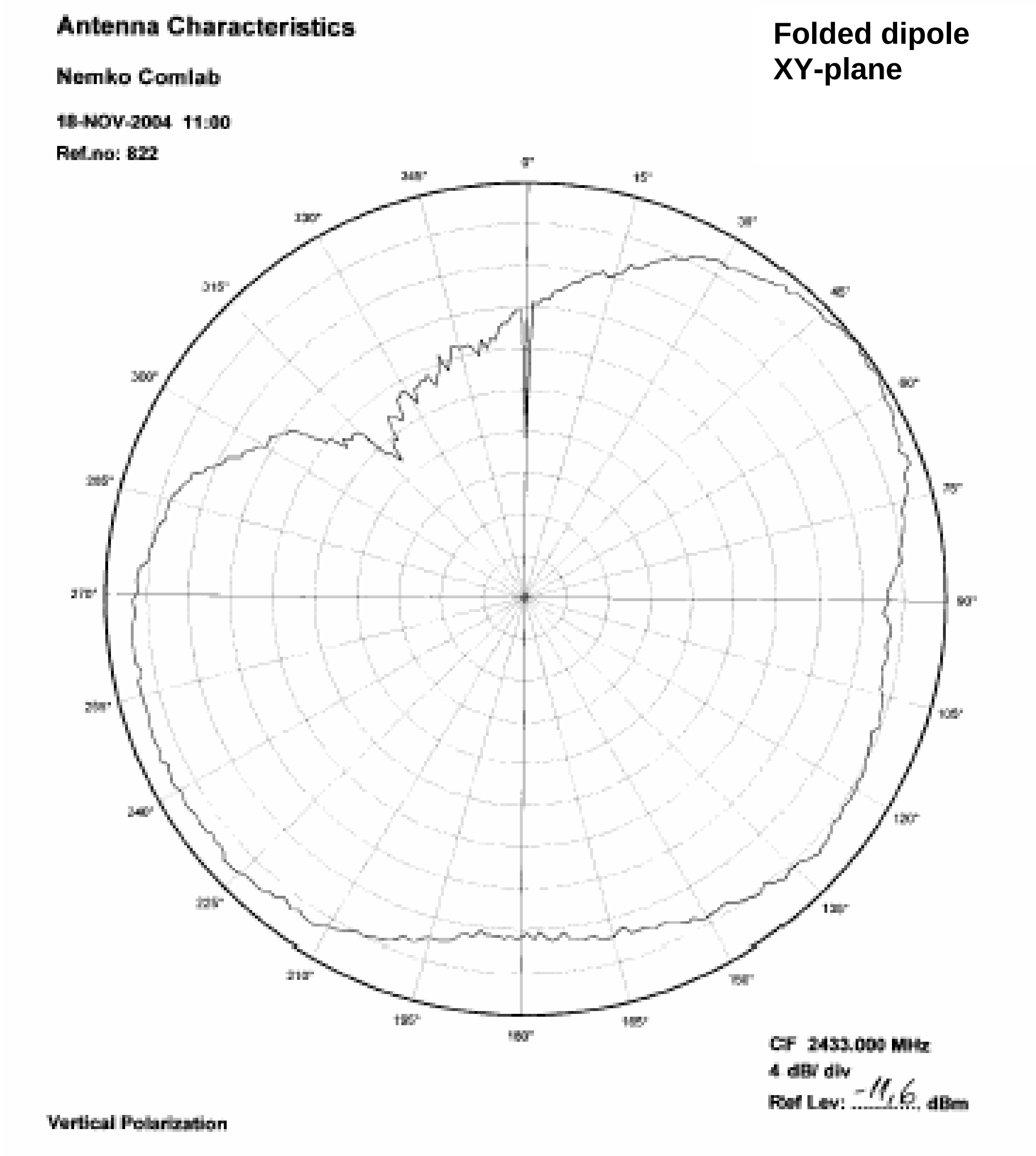
Ref.no: 822

Whip, DK
YZ-plane



CF 2433.000 MHz
5 dB/ div
Ref Lev: 1.9 dBm

Horisontal Polarization


Antenna Characteristics
Nemko Comlab
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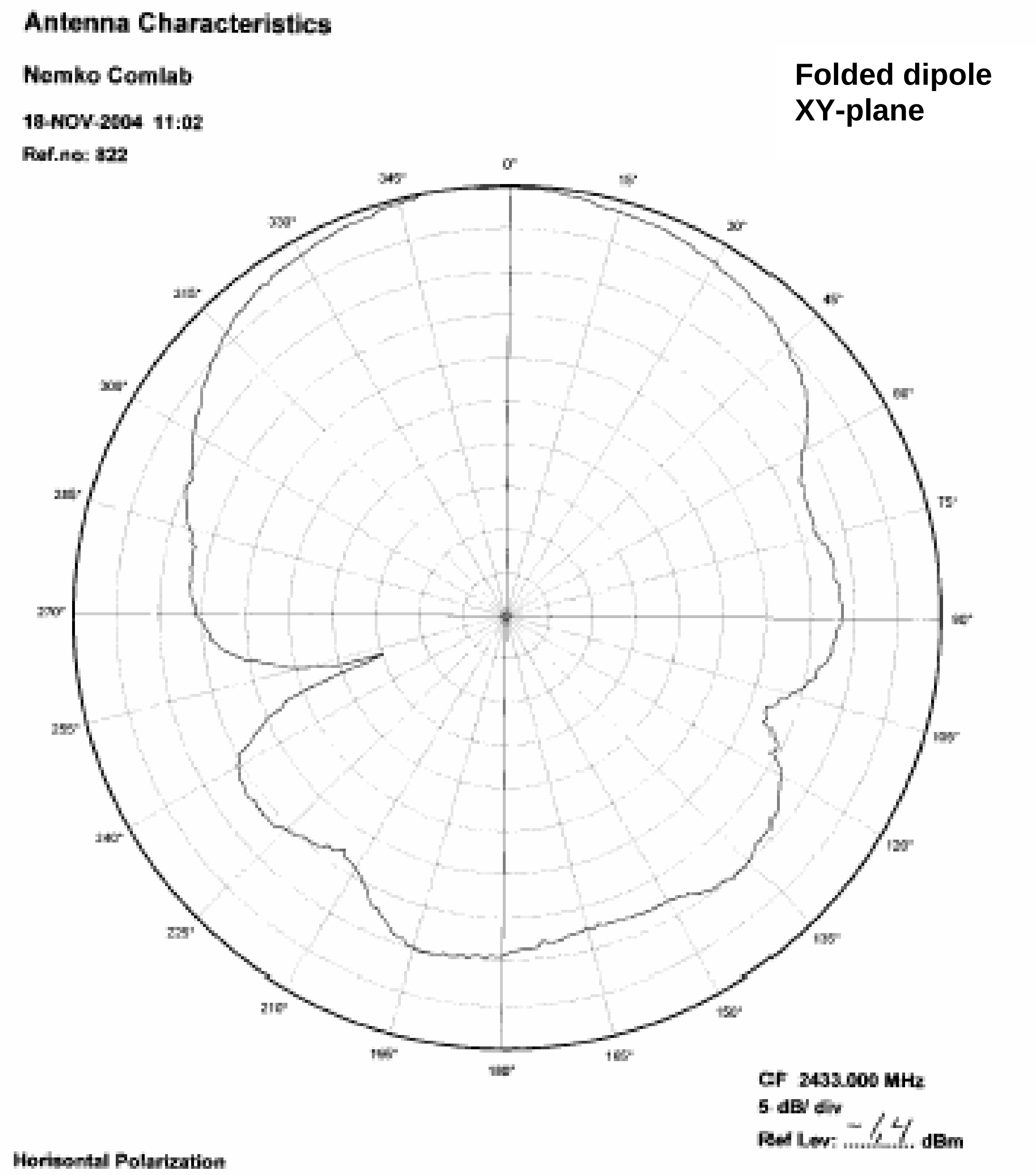
Ref.no: 822
Folded dipole
XY-plane
CF 2433.000 MHz
4 dB/ div
Ref Lev: -11,6 dBm
Vertical Polarization


Antenna Characteristics
Nemko Comlab
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Ref.no: 822
Folded dipole
XY-plane
0°
15°
30°
45°
60°
75°
90°
105°
120°
135°
150°
165°
180°
195°
210°
225°
240°
255°
270°
285°
300°
315°
330°
345°
CF 2433.000 MHz
5 dB/ div
Ref Lev: -14 dBm
Horisontal Polarization

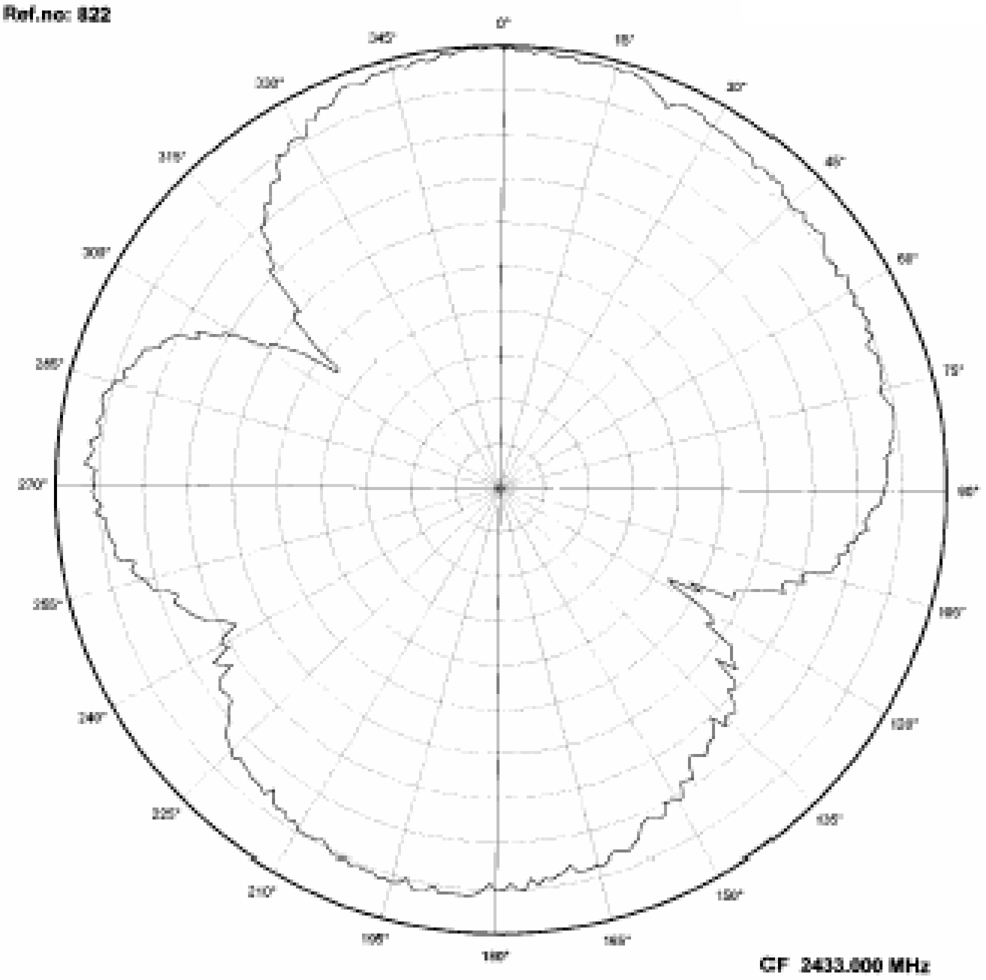
Antenna Characteristics

Nemko Comlab

18-NOV-2004 11:19

Ref.no: 822

Folded dipole
XZ-plane



CF 2433.000 MHz
4 dB/ div
Ref Lev: -16,1 dBm

Vertical Polarization

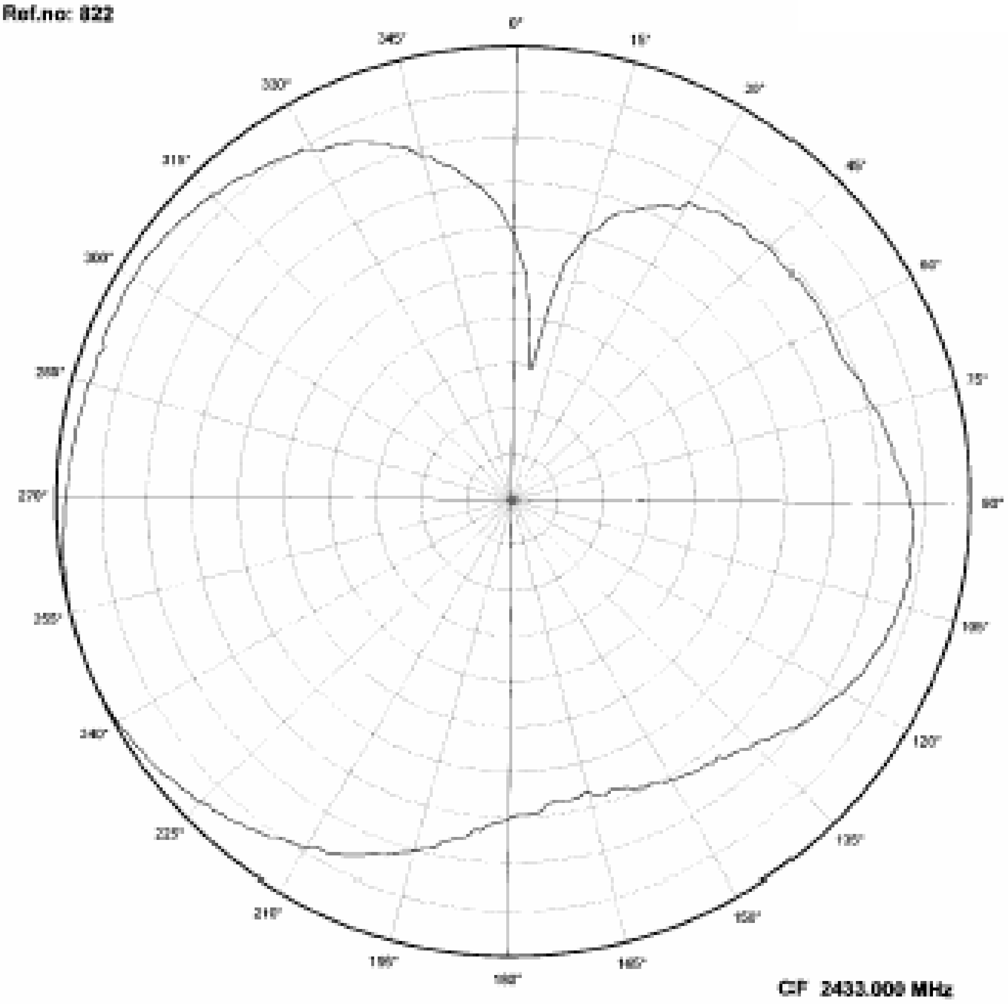
Antenna Characteristics

Nemko Comlab

18-NOV-2004 11:21

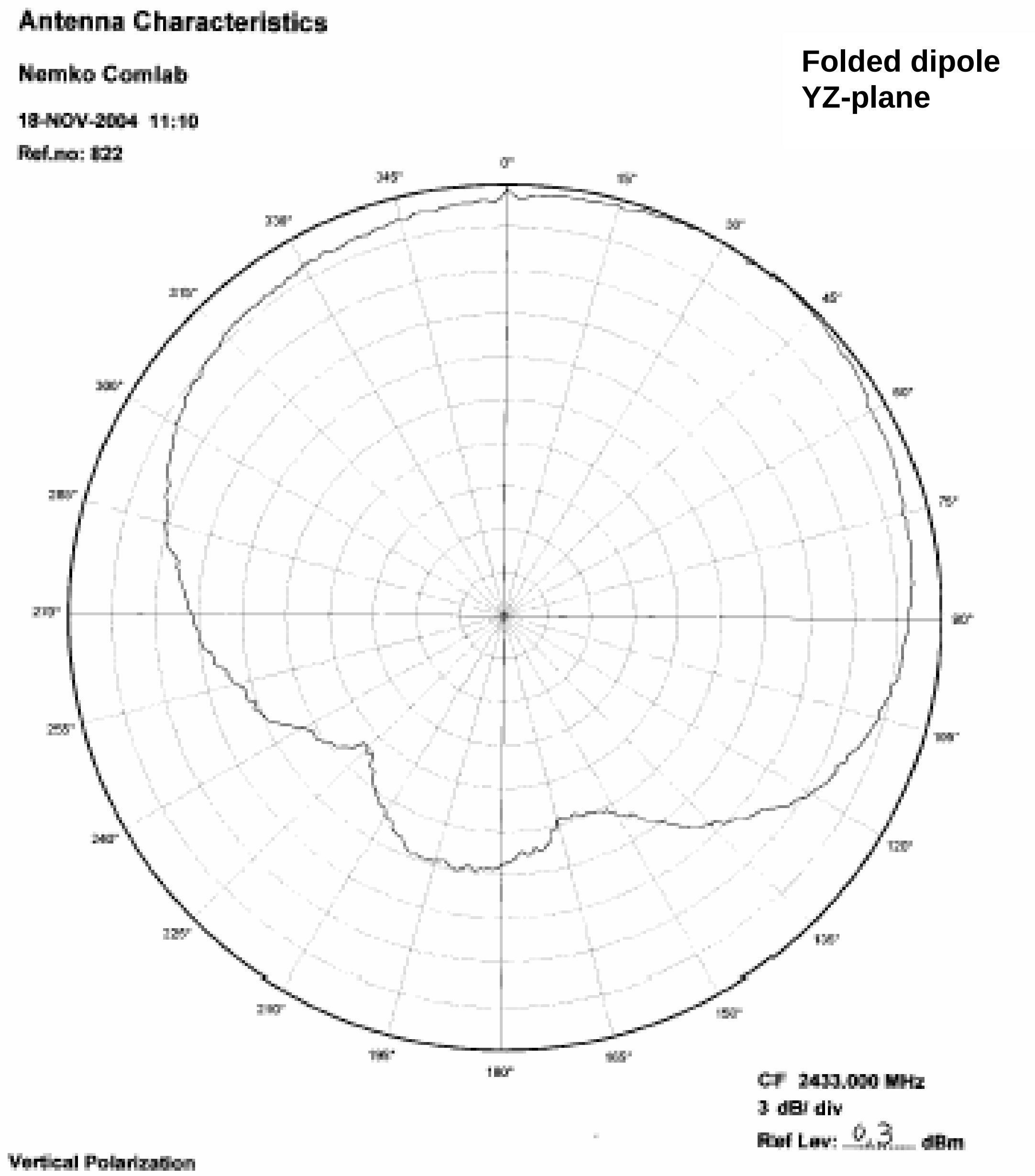
Ref.no: 822

Folded dipole
XZ-plane



CF 2433.000 MHz
5 dB/ div
Ref Lev: -0,4 dBm

Horisontal Polarization


Antenna Characteristics
Nemko Comlab
18-NOV-2004 11:10
Ref.no: 822
Folded dipole
YZ-plane
0°
15°
30°
45°
60°
75°
90°
105°
120°
135°
150°
165°
180°
195°
210°
225°
240°
255°
270°
285°
300°
315°
330°
345°
CF 2433.000 MHz
3 dB/ div
Ref Lev: 0.3 dBm
Vertical Polarization

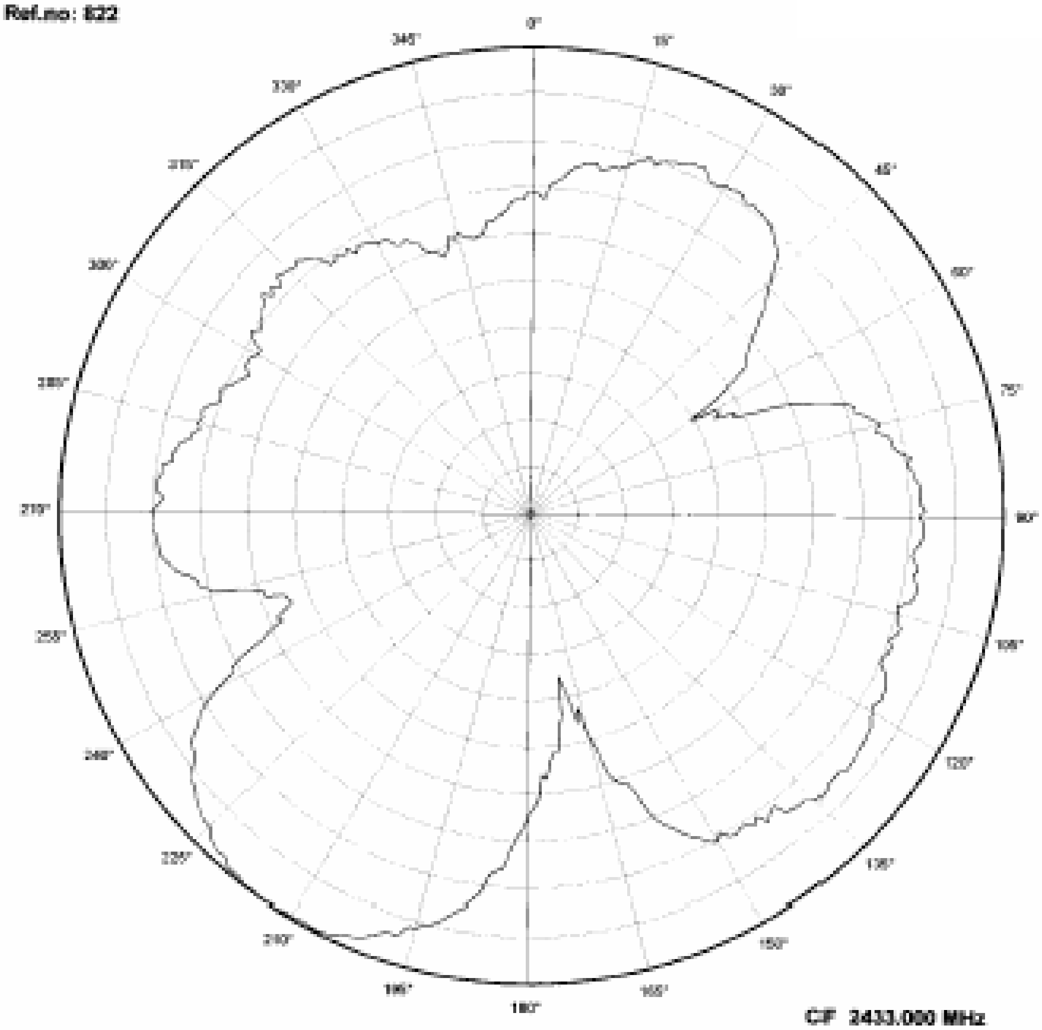
Antenna Characteristics

Nemko Comlab

18-NOV-2004 11:11

Ref.no: 822

Folded dipole
YZ-plane



CF 2433.000 MHz
3 dB/ div
Ref Lev: −10.4 dBm

Horisontal Polarization

11 DOCUMENT HISTORY

Revision	Date	Description/Changes
SWRA093D	2008-04-04	Rename CCZACC06 to CC2480
SWRA093C	2008-02-28	Added reference to CCZACC06
SWRA093B	2007-01-08	Corrected the optimum impedance for CC2400.
SWRA093A	2007-10-23	Added additional information about tuning.
SWRA093	2006-01-09	Initial release.

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