AN12242

NxH3670 headphone antenna

Rev. 1 — 27 September 2018 | Application note

Document information

Information	Content
Keywords	NxH3670, headphone antenna
Abstract	This document describes antenna design guidelines and evaluation methods using the NxH3670.

Revision history		
Rev	**Date**	**Description**
1.0	20180927	first issue

1 Introduction

This application note is intended as a practical guide to design and validate an antenna for a 2.4 GHz headphone application with radio ICs of the NxH3670. The aim is to provide the required understanding to design such an application specific antenna and to achieve the best performance for RF communication at 2.4GHz.

Notes:

- As a prerequisite, it is assumed that the reader has a basic understanding on how to use a Radio IC of the NxH3670. This application note cannot and does not replace any of the relevant radio IC datasheets.
- As there are many parameters influencing the overall performance, a basic RF knowledge is needed to design an RF antenna.
- Design hints on how to place the components on a PCB are not included.
- All antenna measurements need to be always performed at the final mounting position to consider effects of incorporation into a product.

The guideline covers the following items:

- A detailed description of the antenna structure.
- The antenna performance validation section describes the required tools and measuring setups to determine the antenna parameters obtained with a connected measurement and a radiated measurement in an anechoic room.

1.1 Reference documents

- Data sheet NxH3670

1.2 Reference simulation tools

- CST Microwave Studio: 3D Electromagnetic Simulation Tool

2 Description of the antenna

A circular electronic board that incorporates electronic components and a conductive ground plane form the antenna. The board has a rectangular slot in its ground plane with an open end and a closed end as shown in Figure 1.

The open end is at the edge of the ground plane and the electrical length of the slot is a quarter wavelength of the transmission frequency approximately. The slot is filled with a non-conductive substrate material.

The diameter (Φ) of the circular ground plane equals an electrical length of a halve wavelength of the transmission frequency. In this way, the ground plane acts as an efficient antenna for a relatively large frequency band.

Oval shaped electronic boards can also be used. However, in this document we provide the dimensions for designing a circular conductive board antenna.

The antenna feeding port has two feeding connections, F1 and F2, on opposite sides of the slot near the closed end. One feeding connection is passing the signal from the transceiver to the slot and vice versa. The other connection is providing the connection to ground to allow this unbalanced feeding configuration.

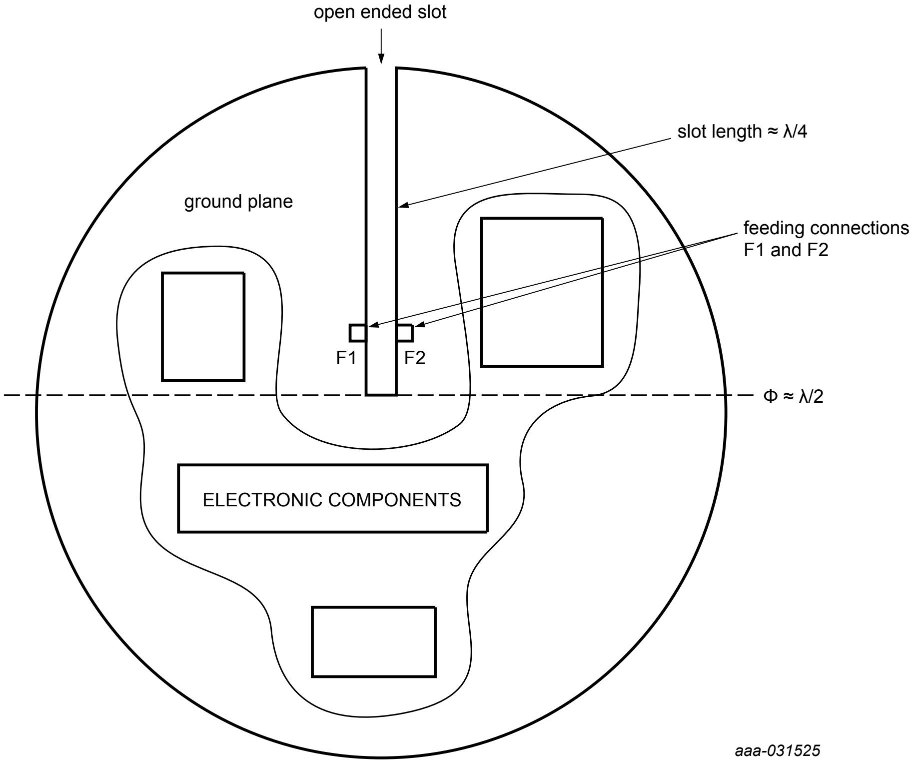


Figure 1. Schematic drawing of the conductive plane antenna

2.1 Antenna layout

In what follows, reported values correspond to an antenna design on an FR4 substrate board of approximately 1 mm thickness. When designing the conductive plane antenna for an operation frequency of 2.45 GHz, the circular board is given a diameter of approximately 50 mm. The straight slot is designed with a length of 19.2 mm and a width of 1 mm. To allow horizontally and vertically polarized antenna radiation, the slot is positioned under an angle of 45 degrees regarding the vertical direction. The radiation pattern is shown in Section 3.2.2.2. The antenna feed point is positioned at a distance of 3.8 mm from the closed end of the slot. Figure 2 clarifies these dimensions.

As the circular board is used to mount electronic components as well, following guidelines must be considered. When more than 2 layers are used in the PCB design, the slot which is copper-free must be repeated as such on all layers. A series of via holes is placed on both sides of the slot with a regular spacing in between them to ensure a good ground connection.

The antenna feeding connection that passes the signal from the balun - connected to the NxH3670 - to the slot is given by the red trace in Figure 2. if necessary, provisions for matching (orange pads) are available to be populated along this trace. The second feeding connection, which is the ground, is implemented by a trace (shown in blue on Figure 2) on the opposite side of the slot with via holes connecting to the ground plane. See Figure 3 for a more practical implementation.

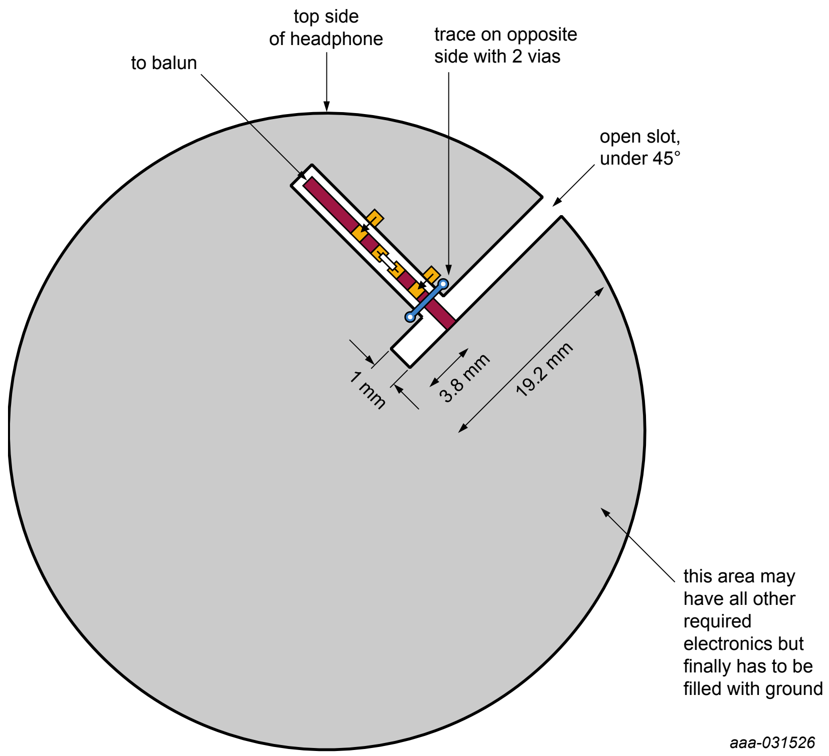


Figure 2. Schematic drawing of the antenna

2.1.1 Design guidelines

2.1.1.1 Assumptions

Carrier frequency: 2400 MHz to 2480 MHz

Radio IC: NxH3670

2.1.1.2 Design targets

Return Loss |S11| ≤ −10 dB from 2400 MHz to 2480 MHz

Bandwidth ≥ 80 MHz

Maximum gain ≥ 0 dBi for the vertical and the horizontal polarization

The antenna must support the vertical polarization and the horizontal polarization.

2.1.1.3 Material

- Dielectric material = FR4 1080
- Dielectric constant = 4.2
- Manufacturer: Shenzhen Multilayer PCB Technology Co, Ltd.
- Substrate thickness: 1.1 mm
- Multilayer printed circuit board
- Cu thickness: 17.5 µm
- Plated through hole vias at the spiral antenna of 0.4 mm diameter
- via copper thickness: 0.1 mm
- drill size: 0.2 mm

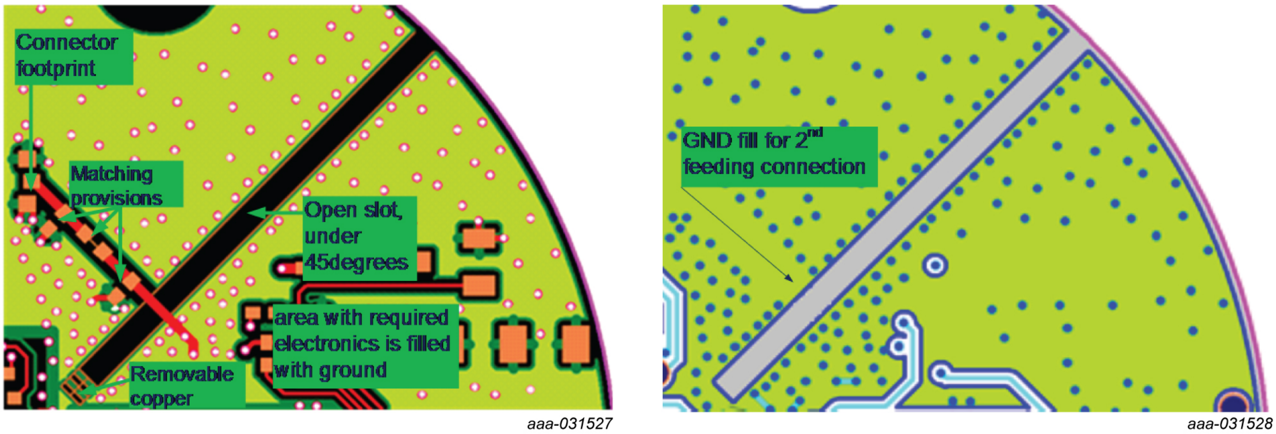
2.1.1.4 Planar Outline

In Figure 3, one can find an outline of the conductive plane antenna. The open slot is copper free on all layers and surrounded by numerous via holes on either side connecting the ground to each of the layers.

The red trace on the top layer in Figure 3 shows the antenna feeding connection that passes the signal from the balun to the slot. We have chosen to provide a connector at the left end of this trace (see connector footprint). If necessary, provide this connector in the layout to allow optimizing the matching of the antenna. Provisions to place matching components are foreseen. At the closed end of the slot, provisions are in place, so copper can be scratched off to make the slot longer, if necessary.

The second feeding connection, the ground, is implemented by a copper fill marked by the arrow in the right outline of Figure 3. To ensure a good ground connection, a series of via holes (up to 50 in total) are placed on both sides of the slot and all layers with a regular spacing in between them. These vias are spaced at about 0.3 mm from the slot.

As can be observed, the area surrounding the electronics should be filled with ground. The board diameter is 50 mm and about 0.4 mm clearance area is provided at the edge of the board.



a. Top layer

b. Bottom layer

Figure 3. Example outline of the conductive plane antenna

2.1.1.5 Stack up

The reference design is using a multilayer PCB with the following stack up. As mentioned before, the slot which is copper-free must be in place on all layers.

Table 1.

NO.	Stackup			Thickness [mm]
1	GTL			0.0175
2	PP			0.15
3	L2T-L3B		1080 FR-4 1080	0.8
4	PP			0.15
5	GBL			0.0175

3 Antenna parameters validation

3.1 Connected measurement

The measurement of the return loss or the $|S_{11}|$ is done in a connected manner. To retrieve the matching components to provide a 50-ohmic antenna input connection, an UFL connector is soldered at the end of the signal trace connecting to the slot as mentioned earlier.

3.1.1 S-parameter measurement

The return loss or $|S_{11}|$ measurement of the antenna in air is given in Figure 5 when the matching network available is not populated with L or C reactive matching components. Only a 0 Ω resistor is connected in series as shown in Figure 4. Attention must be paid to the cable connecting to the UFL connector: the coaxial cable should be kept perpendicular regarding the conductive plane antenna to avoid it from contributing to the radiation of the antenna.

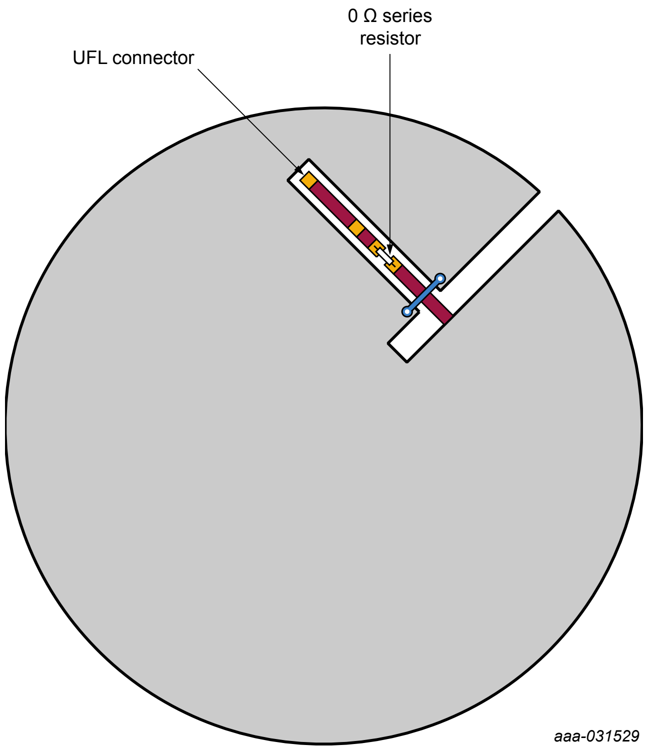


Figure 4. Schematic drawing of the antenna under return loss measurement

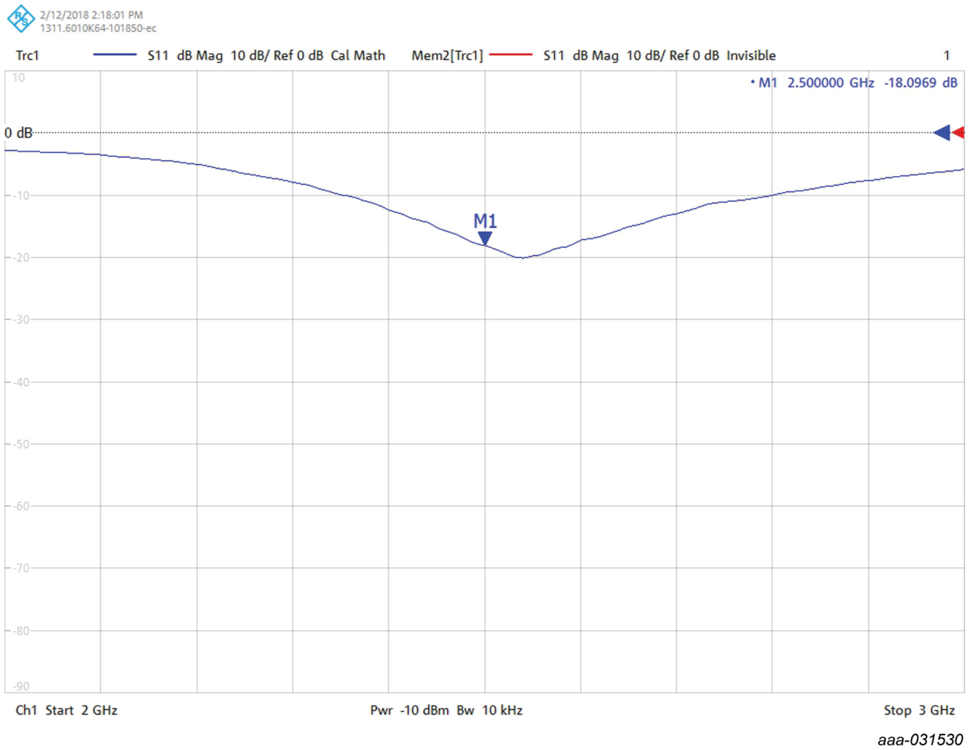


Figure 5. Return Loss of the conductive plane antenna measured in air

$|S_{11}| < -10$ dB at 2.5 GHz for a bandwidth larger than 300 MHz. Hence, the design target is more than achieved. Mounting the antenna in a headphone, near the head of a user, then maintains a good return loss thanks to the wide bandwidth of the antenna.

The Smith Chart in Figure 6 shows that S_{11}= (40 − 4 j) Ω at 2.5 GHz.

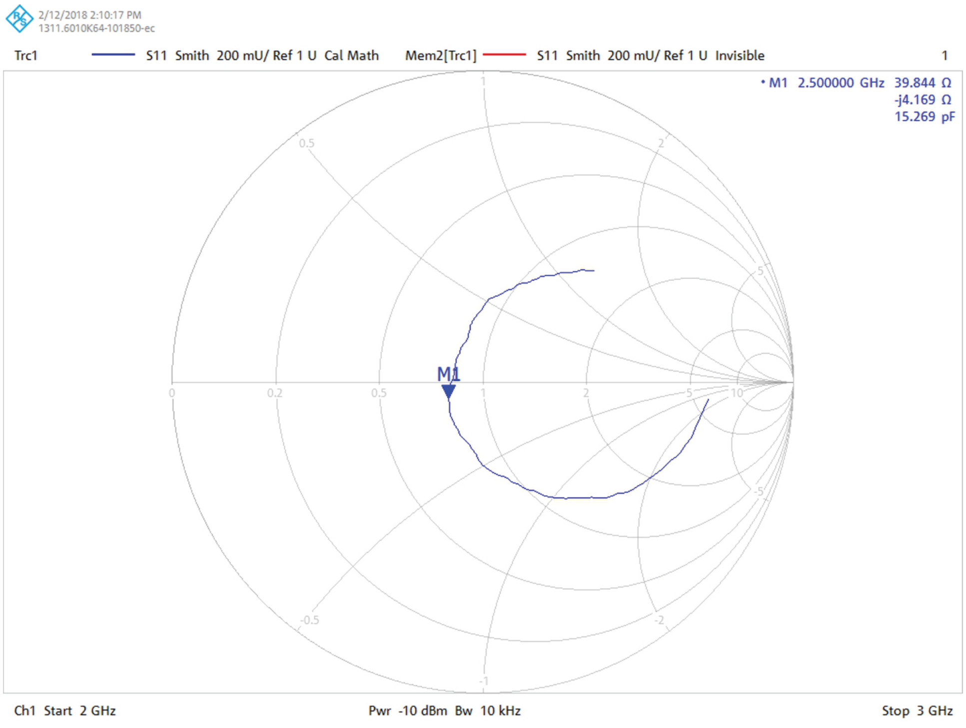


Figure 6. Smith Chart of S11 of the conductive plane antenna measured in air

3.2 Radiated measurements

Since the performance of the antenna must be considered when it is integrated in an actual product, we have opted to incorporate the conductive plane antenna inside a fully functional headphone. It is expected that the conductive parts inside the functional headphone and the speaker, which can be 5 cm in diameter, influences the antenna performance.

Hence, the conductive plane antenna is integrated inside the left earpiece of a functional headphone (see Figure 7). The spacing between the conductive plane antenna and the speaker (Φ = 5 cm) is chosen to be approximately 6 mm. As speaker and antenna are 5 cm in diameter, they are aligned to cover each other.

aaa-031532

Figure 7. The conductive plane antenna integrated in a commercially available headphone

The radiated measurements of the antenna are performed with the headphone on a SAM phantom head (SAM-V4.5BSE by Speag in Figure 8). A receiving horn antenna captures the vertical and horizontal polarization transmitted by the conductive plane antenna.

aaa-031533

Figure 8. Radiated measurements of the antenna inside a headphone on a SAM phantom head mounted in an anechoic room

3.2.1 Radiated antenna bandwidth

Settings of the transceiver:

- Output power: 0 dBm
- Frequency: 2400 MHz to 2480 MHz
- Modulation: off
- Carrier: sweeping
- The antenna supports the required bandwidth from 2400 MHz to 2480 MHz (see Figure 9).

aaa-031534

Figure 9. Received signal strength (dBm) versus frequency (MHz)

3.2.2 Antenna radiation pattern

3.2.2.1 Conductive plane antenna in functional headphone on a SAM head

The conductive plane antenna is integrated in the left earpiece of the headphone and is then mounted on the left ear of the SAM phantom head. Figure 10 depicts the amount of energy transmitted in the vertical and horizontal polarization by the conductive plane antenna as captured by a receiving horn antenna. The yellow shape in Figure 10 represents the SAM phantom head and the black box represents the earpiece with integrated antenna. Antenna radiation patterns are measured in the horizontal plane.

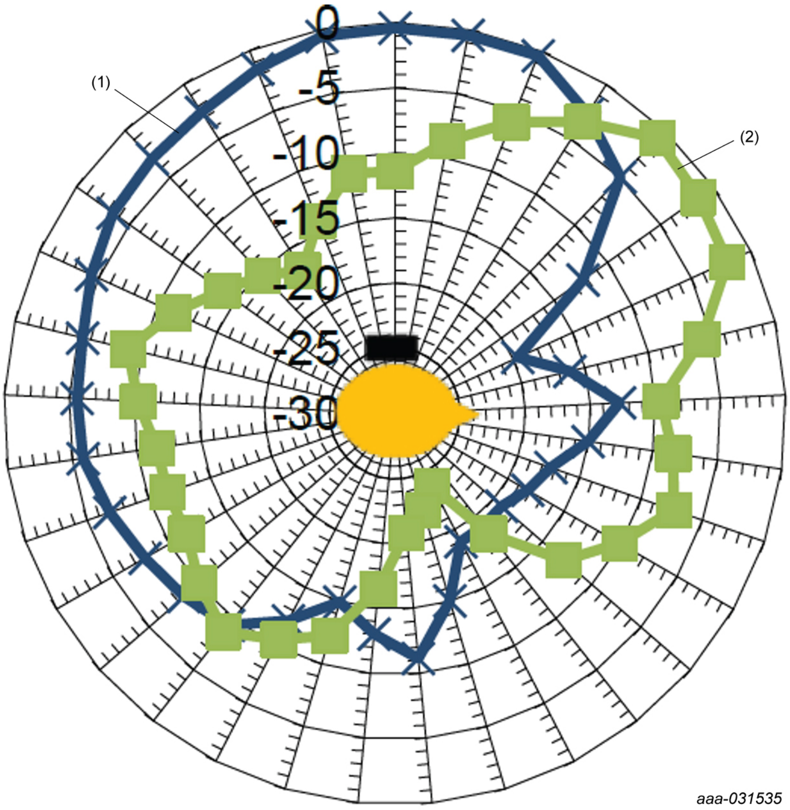
The loss of measuring cables, the horn antenna gain, the path loss in the anechoic room and the input power of the IC are calibrated such that the received signal strength measured by the spectrum analyzer is a measure for the antenna gain in dBi[1] of the conductive plane antenna.

Both polarizations are transmitted and received to a similar extent as can be observed in Figure 10 and in Table 2. The maximum gain is equal in both polarizations and the average gain is the highest in the vertical polarization.

The conductive plane antenna was also measured with the slot positioned vertically and horizontally inside the headphone as opposed to under an angle of 45 degrees. The vertical slot was then yielding dominantly horizontally polarized antenna radiation and the

1 Antenna gain is here defined as the ratio of the power produced by the antenna to the power produced by a hypothetical lossless isotropic antenna, which is equally sensitive to signals from all directions. This ratio is expressed in "decibels-isotropic" or dBi.

horizontal slot vertically polarized antenna radiation. The property of tilting the slot in the head phone product to achieve either or both polarizations is very beneficial.



(1) Vertical polarization

(2) Horizontal polarization

Figure 10. Antenna gain (dBi) in the horizontal plane rotated over 360 degrees

With the SAM phantom head in the setup, one would expect to see absorption by the phantom head tissue and hence no energy at the opposite side of the head. However, the conductive parts inside the functional headphone such as the speaker results in additional antenna radiation at the opposite side of the head. The radiation pattern also shows drops in gain due to reflections.

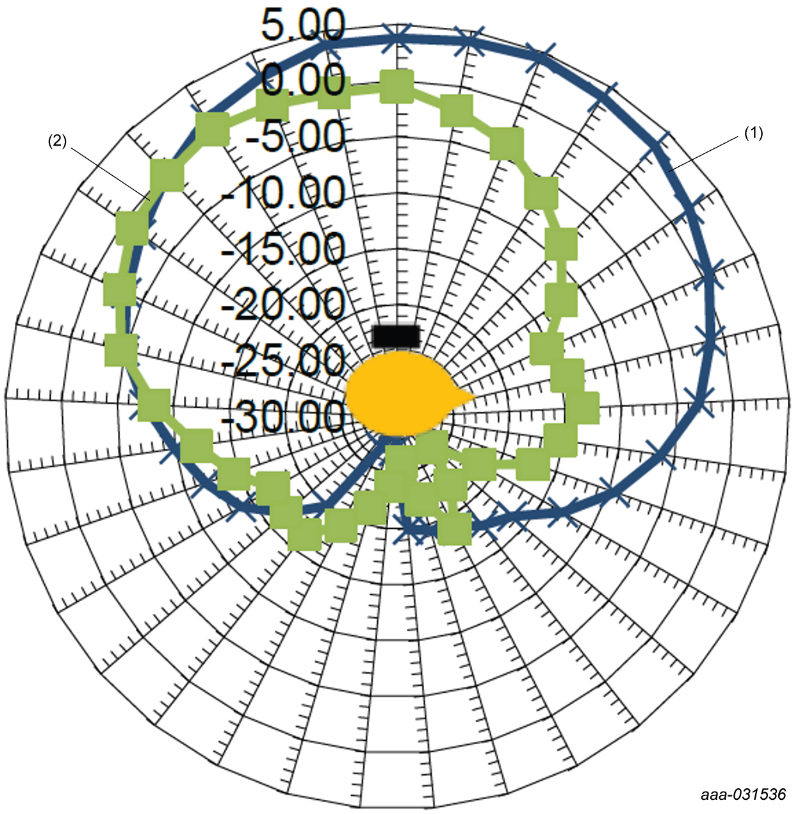
Table 2. Antenna gain (dBi) in the horizontal plane: maximum, minimum and average value over a rotating angle of 360 degrees in the horizontal plane

Gain (dBi)	Vertical polarization	Horizontal polarization
maximum	−0.43	−0.83
minimum	−19.63	−23.73
average	−9.35	−11.13

3.2.2.2 Conductive plane antenna in empty head phone shell on a SAM head

As an illustration, the radiation pattern measured on the conductive plane antenna embedded in an empty head phone without conductive parts is depicted in Figure 11. The purpose is showing that the radiation pattern then does not show energy at the opposite side of the head when there is minimal reflection by the head phone.

The antenna gain is highest perpendicular to the left ear. There is substantially less gain to the back and the front of the user. As can be seen in Figure 11, a severe decrease in performance is found at the other side of the headphone due to absorption by the tissue of the head. As expected, both polarizations are again present in the radiation pattern of the antenna. The energy in the vertical polarization is higher than in the horizontal polarization. The cause can be a slight misalignment when the headphone is on the SAM head.



(1) Vertical polarization
(2) Horizontal polarization

Figure 11. Antenna gain (dBi) in the horizontal plane rotated over 360 degrees

Table 3. Antenna gain (dBi) in the horizontal plane: maximum, minimum and average value over a rotating angle of 360 degrees in the horizontal plane

Gain (dBi)	Vertical polarization	Horizontal polarization
maximum	4.47	0.47
minimum	−33.93	−25.93
average	−8.25	−12.25

3.3 Conclusions on the antenna validation

As can be observed in this section, the antenna design targets are met:

- Return Loss |S11| ≤ −10 dB from 2400 MHz to 2480 MHz

- Bandwidth ≥ 300 MHz
- Maximum gain ≈ 0 dBi for the vertical and the horizontal polarization
- The antenna supports the vertical and the horizontal polarization to a similar extent

The conductive parts inside the functional headphone results in additional antenna radiation at the other side of the head and drops in the radiation pattern.

One can therefore conclude that depending on the headphone design, incorporating this conductive plane antenna results in varying radiation patterns.

When considering a separation from the speaker and other conductive parts, the performance of the antenna reported here is safeguarded.

4 Legal information

4.1 Definitions

Draft — The document is a draft version only. The content is still under internal review and subject to formal approval, which may result in modifications or additions. NXP Semiconductors does not give any representations or warranties as to the accuracy or completeness of information included herein and shall have no liability for the consequences of use of such information.

4.2 Disclaimers

Limited warranty and liability — Information in this document is believed to be accurate and reliable. However, NXP Semiconductors does not give any representations or warranties, expressed or implied, as to the accuracy or completeness of such information and shall have no liability for the consequences of use of such information. NXP Semiconductors takes no responsibility for the content in this document if provided by an information source outside of NXP Semiconductors. In no event shall NXP Semiconductors be liable for any indirect, incidental, punitive, special or consequential damages (including - without limitation - lost profits, lost savings, business interruption, costs related to the removal or replacement of any products or rework charges) whether or not such damages are based on tort (including negligence), warranty, breach of contract or any other legal theory. Notwithstanding any damages that customer might incur for any reason whatsoever, NXP Semiconductors' aggregate and cumulative liability towards customer for the products described herein shall be limited in accordance with the Terms and conditions of commercial sale of NXP Semiconductors.

Right to make changes — NXP Semiconductors reserves the right to make changes to information published in this document, including without limitation specifications and product descriptions, at any time and without notice. This document supersedes and replaces all information supplied prior to the publication hereof.

Suitability for use — NXP Semiconductors products are not designed, authorized or warranted to be suitable for use in life support, life-critical or safety-critical systems or equipment, nor in applications where failure or malfunction of an NXP Semiconductors product can reasonably be expected to result in personal injury, death or severe property or environmental damage. NXP Semiconductors and its suppliers accept no liability for inclusion and/or use of NXP Semiconductors products in such equipment or applications and therefore such inclusion and/or use is at the customer's own risk.

Applications — Applications that are described herein for any of these products are for illustrative purposes only. NXP Semiconductors makes no representation or warranty that such applications will be suitable for the specified use without further testing or modification. Customers are responsible for the design and operation of their applications and products using NXP Semiconductors products, and NXP Semiconductors accepts no liability for any assistance with applications or customer product design. It is customer's sole responsibility to determine whether the NXP Semiconductors product is suitable and fit for the customer's applications and products planned, as well as for the planned application and use of customer's third party customer(s). Customers should provide appropriate design and operating safeguards to minimize the risks associated with their applications and products. NXP Semiconductors does not accept any liability related to any default, damage, costs or problem which is based on any weakness or default in the customer's applications or products, or the application or use by customer's third party customer(s). Customer is responsible for doing all necessary testing for the customer's applications and products using NXP Semiconductors products in order to avoid a default of the applications and the products or of the application or use by customer's third party customer(s). NXP does not accept any liability in this respect.

Export control — This document as well as the item(s) described herein may be subject to export control regulations. Export might require a prior authorization from competent authorities.

Evaluation products — This product is provided on an "as is" and "with all faults" basis for evaluation purposes only. NXP Semiconductors, its affiliates and their suppliers expressly disclaim all warranties, whether express, implied or statutory, including but not limited to the implied warranties of non-infringement, merchantability and fitness for a particular purpose. The entire risk as to the quality, or arising out of the use or performance, of this product remains with customer. In no event shall NXP Semiconductors, its affiliates or their suppliers be liable to customer for any special, indirect, consequential, punitive or incidental damages (including without limitation damages for loss of business, business interruption, loss of use, loss of data or information, and the like) arising out the use of or inability to use the product, whether or not based on tort (including negligence), strict liability, breach of contract, breach of warranty or any other theory, even if advised of the possibility of such damages. Notwithstanding any damages that customer might incur for any reason whatsoever (including without limitation, all damages referenced above and all direct or general damages), the entire liability of NXP Semiconductors, its affiliates and their suppliers and customer's exclusive remedy for all of the foregoing shall be limited to actual damages incurred by customer based on reasonable reliance up to the greater of the amount actually paid by customer for the product or five dollars (US$5.00). The foregoing limitations, exclusions and disclaimers shall apply to the maximum extent permitted by applicable law, even if any remedy fails of its essential purpose.

Translations — A non-English (translated) version of a document is for reference only. The English version shall prevail in case of any discrepancy between the translated and English versions.

Security — While NXP Semiconductors has implemented advanced security features, all products may be subject to unidentified vulnerabilities. Customers are responsible for the design and operation of their applications and products to reduce the effect of these vulnerabilities on customer's applications and products, and NXP Semiconductors accepts no liability for any vulnerability that is discovered. Customers should implement appropriate design and operating safeguards to minimize the risks associated with their applications and products.

4.3 Trademarks

Notice: All referenced brands, product names, service names and trademarks are the property of their respective owners.

Contents

Date of release: 27 September 2018
Document identifier: AN12242