

Introduction

This application note serves as a tutorial for MEMS microphones, providing general characteristics of these devices, both acoustic and mechanical, as well as summarizing the portfolio available from ST.

MEMS microphones target all audio applications where small size, high sound quality, reliability and affordability are key requirements. Based on MEMS (Micro-Electrical-Mechanical Systems) sensor technology, our microphones meet price points set by traditional electric condenser microphones (ECM), while featuring superior reliability and robustness. MEMS microphones from ST are designed using common techniques but also with industry-unique and innovative packaging that offers slimmer form factors and outperforms traditional devices. Both analog- and digital-input, top- and bottom-port solutions are available. Their best-in-class SNR makes ST's MEMS microphones suitable for applications beyond typical consumer applications, such as phonometers and sound-level meters that require a high dynamic range.

Contents

- 1 Mechanical specifications, construction details 4**

- 2 Acoustic parameters 10**
 - 2.1 Sensitivity 10
 - 2.2 Directionality 10
 - 2.3 SNR 10
 - 2.4 Dynamic range and acoustic overload point11
 - 2.5 Equivalent input noise11
 - 2.6 Frequency response 13
 - 2.7 Total harmonic distortion 14
 - 2.8 PSRR and PSR 14

- 3 MEMS microphone portfolio 15**

- 4 Revision history 17**

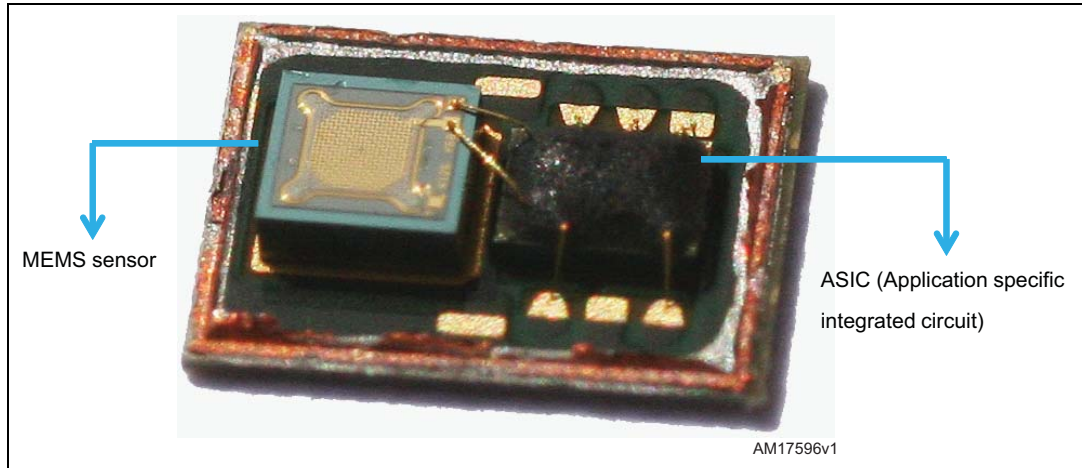
List of figures

Figure 1.	MEMS microphone inside package	4
Figure 2.	MEMS transducer mechanical specifications	4
Figure 3.	Capacitance change principle.	5
Figure 4.	4 x 5 package	5
Figure 5.	3 x 4 package - bottom port	6
Figure 6.	3 x 4 package - top port	6
Figure 7.	Faraday cage in ST's MEMS microphones	7
Figure 8.	RF immunity simulation	7
Figure 9.	EMC test setup	8
Figure 10.	RF test disturbance signal	8
Figure 11.	RF immunity test results	9
Figure 12.	Omnidirectional microphone	10
Figure 13.	A-weighted filter response	11
Figure 14.	Acoustic and electrical relationship - analog.	12
Figure 15.	Acoustic and electrical relationship - digital	12
Figure 16.	MP45DT02 frequency response	13
Figure 17.	MEMS microphone portfolio	15
Figure 18.	MEMS microphone notation	15

1 Mechanical specifications, construction details

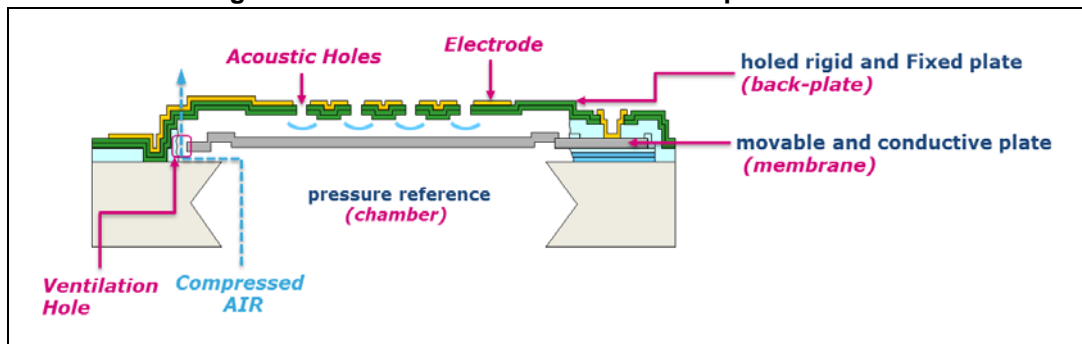
A microphone is a dual-die device consisting of two components, the integrated circuit and the sensor, which are housed in a package using techniques that are proprietary to ST.

Figure 1. MEMS microphone inside package



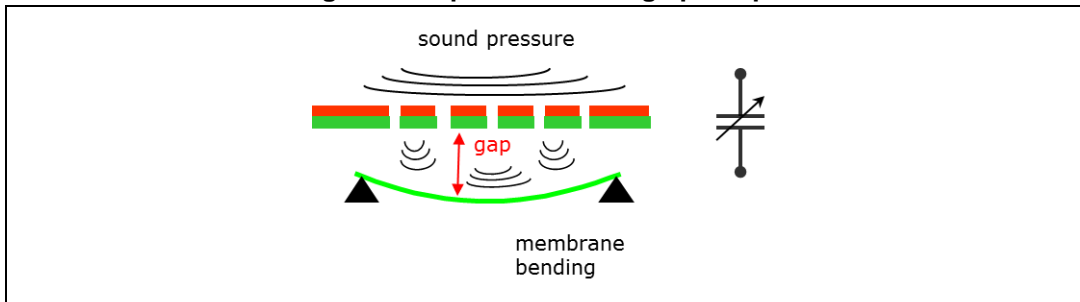
The sensor uses MEMS technology (Micro-Electrical-Mechanical Systems) and it is basically a silicon capacitor. The capacitor consists of two silicon plates/surfaces. One plate is fixed while the other one is movable (respectively, the green plate and the grey one shown in the following figure). The fixed surface is covered by an electrode to make it conductive and is full of acoustic holes which allow sound to pass through. The movable plate is able to move since it is bonded at only one side of its structure. A ventilation hole, allows the air compressed in the back chamber to flow out and consequently allows the membrane to move back. The chamber allows the membrane to move inside but also, in combination with the chamber created by the package will affect the acoustic performance of the microphones in terms of frequency response and SNR.

Figure 2. MEMS transducer mechanical specifications



So basically the microphone MEMS sensor is a variable capacitor where the transduction principle is the coupled capacitance change between a fixed plate (back plate) and a movable plate (membrane) caused by the incoming wave of the sound.

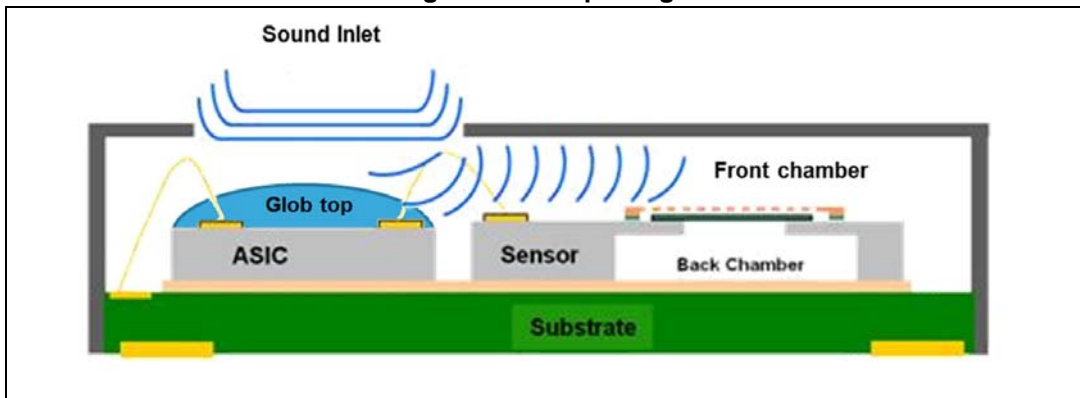
Figure 3. Capacitance change principle



The integrated circuit converts the change of the polarized MEMS capacitance into a digital (PDM modulated) or analog output according to the microphone type. Finally the MEMS microphone is housed in a package with the sound inlet placed in the top or in the bottom part of the package, hence the top-port or bottom-port nomenclature of the package. ST manufactures microphones using industry-wide techniques, but also has developed innovative packaging to achieve improved performance of the microphones. Packaging techniques will be discussed in further detail.

The 4x5 package is widely used to house the digital microphone MP45DT02. It is a common packaging technique in a top-port configuration where the ASIC is placed under the sound inlet with glue on top (glob top) in order to protect the circuit from light and the MEMS sensor is placed beside the integrated circuit^(a). The two silicon components are fixed to the substrate and the pads of the device are on the bottom side. The resonant chambers are identified depending on the position of each chamber with respect to the membrane and the incoming sound. In this case, considering the incoming direction of the sound, the front chamber is created by the package and the chamber inside the MEMS, behind the MEMS membrane, is the back chamber. This configuration allows protecting the MEMS from dust and particles falling into the package but results in a low SNR and frequency response with a peak in the audio band.

Figure 4. 4 x 5 package

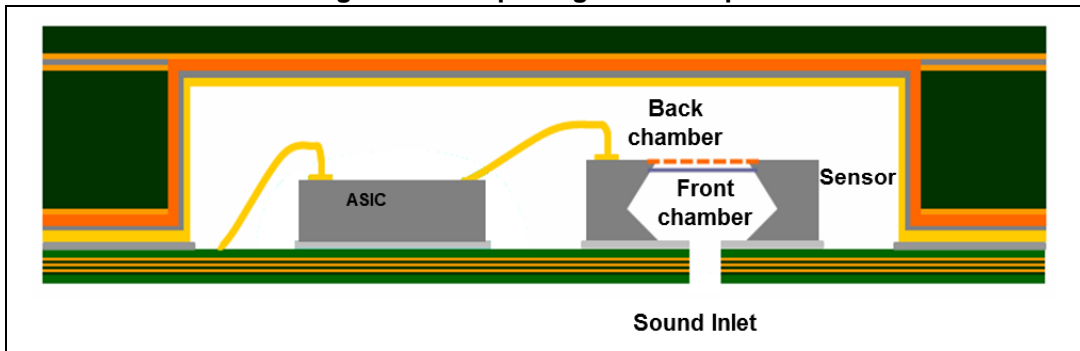


The 3x4 package is used in ST to produce both the bottom- and the top-port digital microphones, MP34DB01 and MP34DT01. Considering the bottom configuration first, this structure is depicted in the following figure. The ASIC and the MEMS sensor are fixed to the substrate and the pads of the device are on bottom side as well. The sound inlet is obtained by drilling the substrate according to the position of the MEMS sensor. The package

a. 4 x 5 microphone with and without glob top are both available.

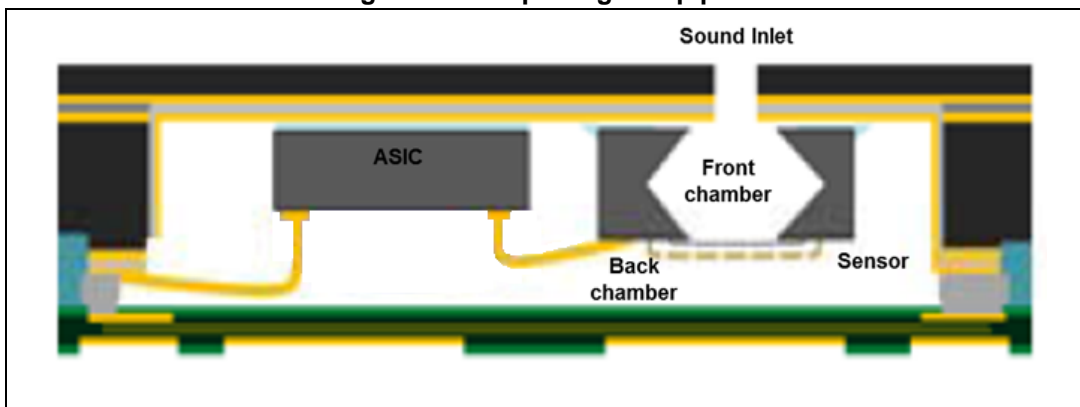
encloses all the components. In this configuration the front chamber is the cavity of the MEMS sensor and the package creates the back chamber. This design optimizes the acoustic performance of the microphone in terms of SNR and also allows obtaining a flat response across the entire audio band. The drawback of this solution is represented by the assembly of this microphone. Usually the bottom-port microphones are soldered on the PCB. The thickness of the board modifies the volume of the front chamber, degrading the flat response of this type of microphone (refer to AN4427, "Gasket design for optimal acoustic performance in MEMS microphones" for details). In order to minimize the artifacts caused by this environment, a flex cable is recommended to be used. Additionally, the bottom-port microphones have a ringed metal pad around the hole. A very careful soldering process is required to avoid dust or soldering paste from entering in the sound port, damaging the MEMS membrane.

Figure 5. 3 x 4 package - bottom port



The 3x4 top-port configuration is basically a mirrored bottom-port microphone. The ASIC and the sensor are placed close to each other, the sensor is still under the sound inlet but these two components are attached to the top of the structure, in other words, the ASIC and MEMS are fixed to the package lid, not to the substrate. The pads are on the substrate and thus on the bottom side of the microphone. This configuration, covered by ST patents, allows optimizing all the benefits of the bottom-port microphone in terms of acoustic performance (i.e. maximized SNR and flat band) and all the benefits related to the top-port configuration during the assembly process.

Figure 6. 3 x 4 package - top port

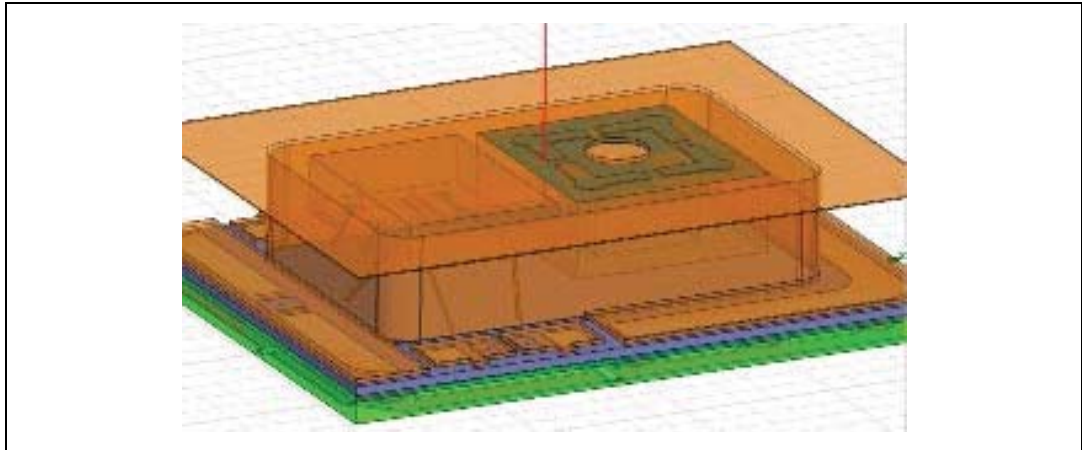


Another package used in ST is a 3.76 mm by 2.95 mm, approximately called 3 by 3. This package is a bottom-port configuration and is used for the analog microphone MP33AB01 which is fully aligned with the digital bottom-port device. Summarizing, it has the same

package construction and the same performance. This is the best microphone offered by ST in terms of SNR.

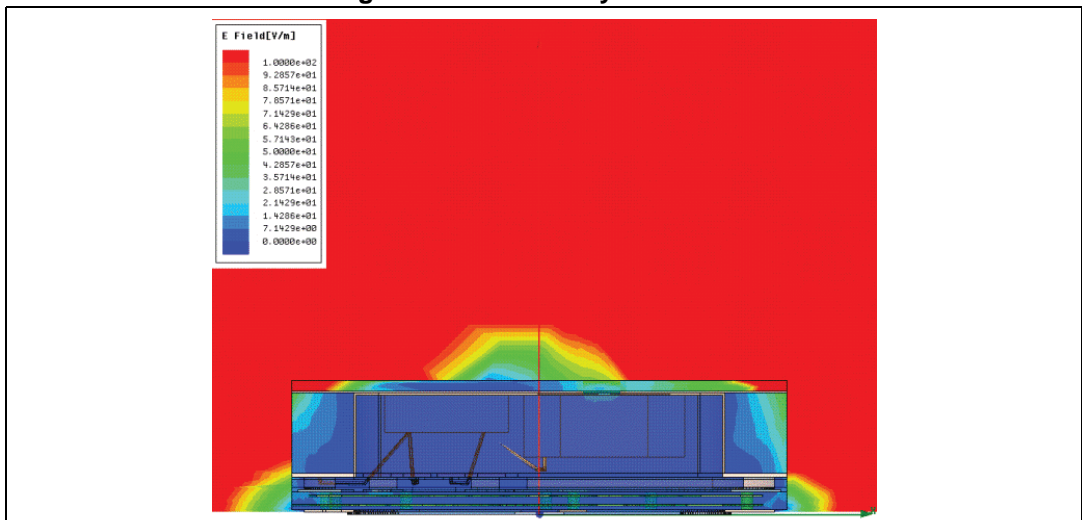
MEMS microphones housed in a plastic package are protected from radiated disturbances by embedding in the plastic package a metal shield which serves as a Faraday cage. The model in the following figure shows how the Faraday cage is implemented in ST's plastic packages.

Figure 7. Faraday cage in ST's MEMS microphones



The next figure shows the simulation of an electric field in open space. By applying an electric field source outside the microphone package, the Faraday cage is able to considerably attenuate the field inside the microphone structure. The temperature grade of the E field is an easy way to plot the results.

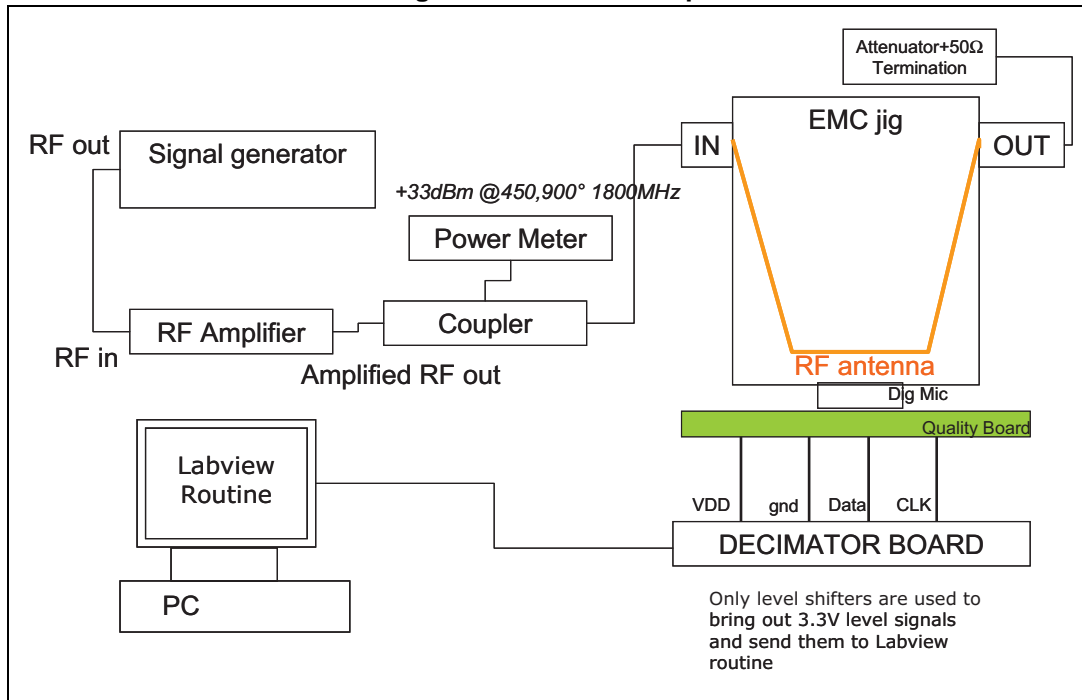
Figure 8. RF immunity simulation



In addition to the simulation, ST has a dedicated test to evaluate immunity, "Microphone durability to EMC disturbances (Digital Microphone EMC Immunity Test Rev0.3)".

Microphones are subjected to RF disturbances using a proper jig with the following setup.

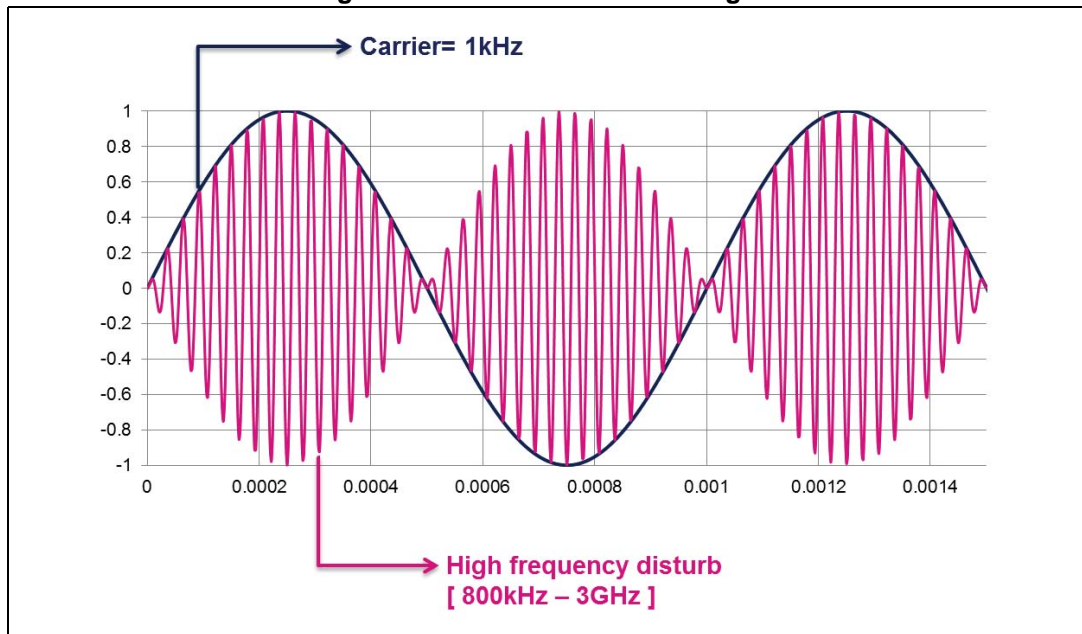
Figure 9. EMC test setup



Basically the test consists of placing the microphone under an antenna radiating a disturbance signal of 1 kHz AM modulated in the range [0.8, 3] GHz. The RF amplitude differs depending on the frequency range according to the following criteria:

- +33dBm in the range [0.8, 2.4]
- +17dBm in the range [2.4, 3.0]

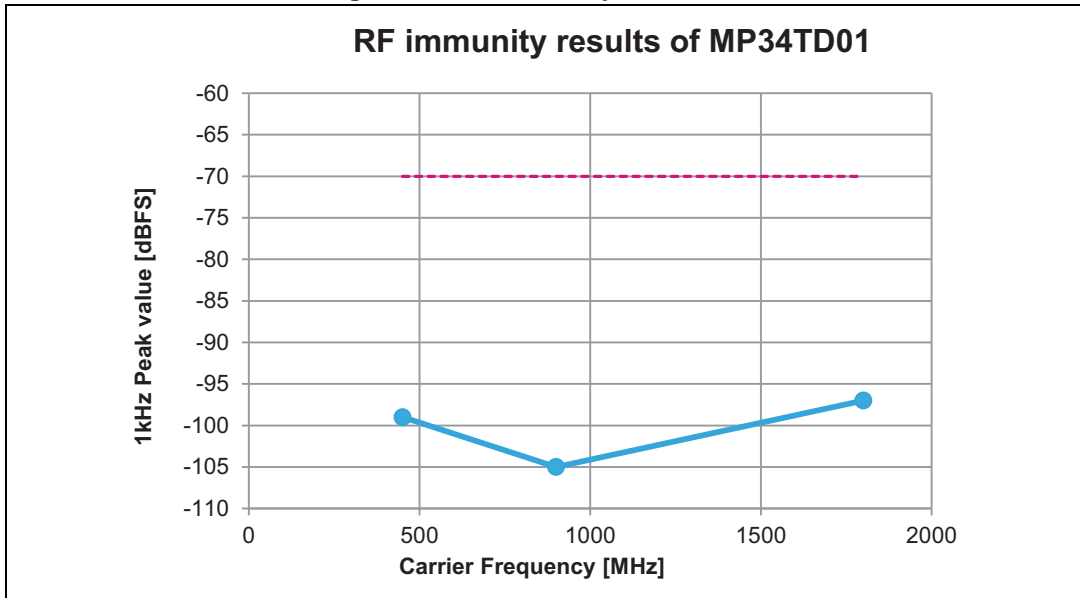
Figure 10. RF test disturbance signal



The carrier of the disturbance is 1 kHz since it is an audio signal. Hence, the RF immunity of the microphone is evaluated by measuring the residual of the carrier at the output of the

microphone. The next figure shows the result of the peak at 1 kHz measured when applying the RF disturbance on top of an MP34DT01.

Figure 11. RF immunity test results



2 Acoustic parameters

2.1 Sensitivity

The sensitivity is the electrical signal at the microphone output to a given acoustic pressure as input. The reference of acoustic pressure is 1 Pa or 94 dB SPL @ 1 kHz. The sound pressure level, expressed in decibel, $dB SPL = 20 \cdot \log(P/P_0)$ where $P_0 = 20 \mu Pa$ is the threshold of hearing. $20 \cdot \log(1 Pa / 20 \mu Pa) = 94 \text{ dB SPL}$

- For analog microphones the sensitivity is expressed in mV_{RMS}/Pa or dBV/Pa
- For digital microphones the sensitivity is expressed in dBFS

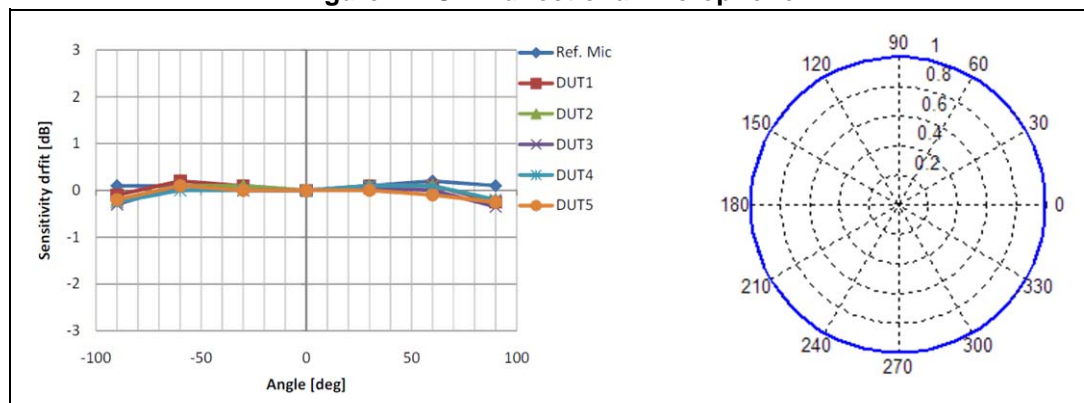
$dBV \neq dBFS$. It is not correct to compare different units. As given in the above equations, dBV is in reference to $1V_{RMS}$ instead of dBFS where the reference is the digital full scale.

2.2 Directionality

The directionality indicates the variation of the sensitivity response with respect to the direction of the arrival of the sound. MEMS microphones from ST are omnidirectional which means that there is no sensitivity change to every different position of the source of the sound in space. The directionality can be indicated in a Cartesian axis as sensitivity drift vs. angle or in a polar diagram showing the sensitivity pattern response in space.

The following figure depicts the directionality in these two reference systems.

Figure 12. Omnidirectional microphone

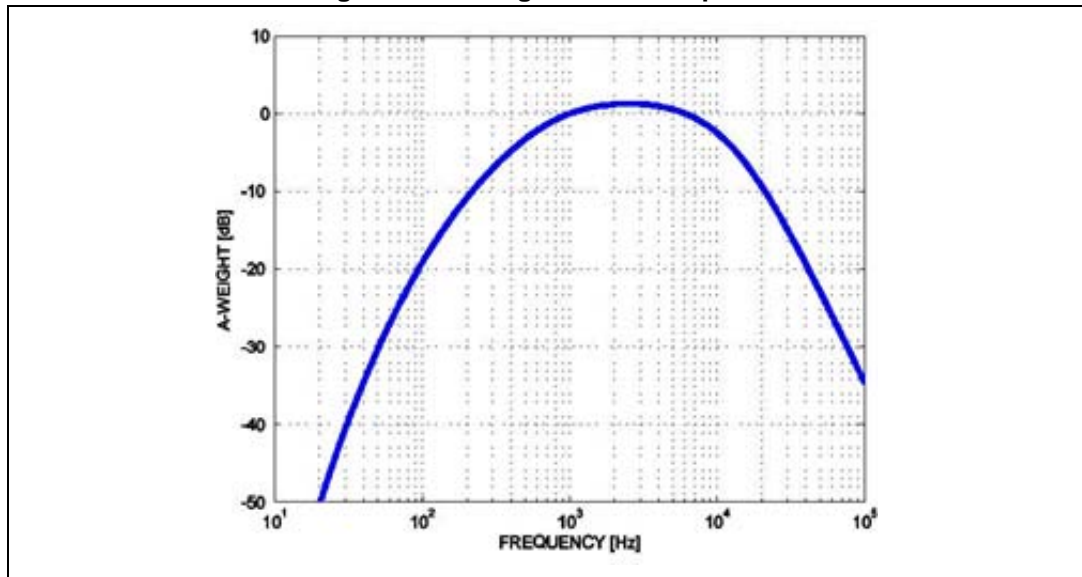


2.3 SNR

The signal-to-noise ratio specifies the ratio between a given reference signal to the amount of residual noise at the microphone output. The reference signal is the standard signal at the microphone output when the sound pressure is 1 Pa @ 1 kHz (microphone sensitivity). The noise signal (residual noise) is the microphone electrical output at silence.

This parameter includes both the noise of the MEMS element and the ASIC. Concerning this sum, the main contribution to noise is given by the MEMS sensor, the integrated circuit contribution can be considered negligible. Typically, the noise level is measured in an anechoic environment and A-weighting the acquisition. The A-weighted filter corresponds to the human ear frequency response.

Figure 13. A-weighted filter response



2.4 Dynamic range and acoustic overload point

The dynamic range is the difference between the minimum and maximum signal that the microphone is able to generate as output.

- The minimum signal is the smallest audio signal that the microphone can generate distinctly from noise. In other words, the minimum signal is equivalent to the residual noise.
- The maximum audio signal is that which the microphone can generate without distortion. It is also called acoustic overload point (AOP). Actually, the specification allows up to 10% in terms of distortion at the acoustic overload point.

2.5 Equivalent input noise

A microphone is a sound-to-electricity transducer which means that any output signal corresponds to a specific sound as input. The equivalent input noise (EIN) is the acoustic level, expressed in dBSPL, corresponding to the residual noise as output.

For example, a digital microphone with a sensitivity of -26 dBFS and a 63 dB as SNR:

Residual noise = -26-63 = -89 dBFS this sum transposed in the acoustic domain is:

EIN= 94-63= 31 dBSPL

The following figures summarize the relationship between the acoustic and electric domains related to each of the parameters listed above. [Figure 14](#) and [Figure 15](#) illustrate this for analog and digital microphones, respectively.

Figure 14. Acoustic and electrical relationship - analog

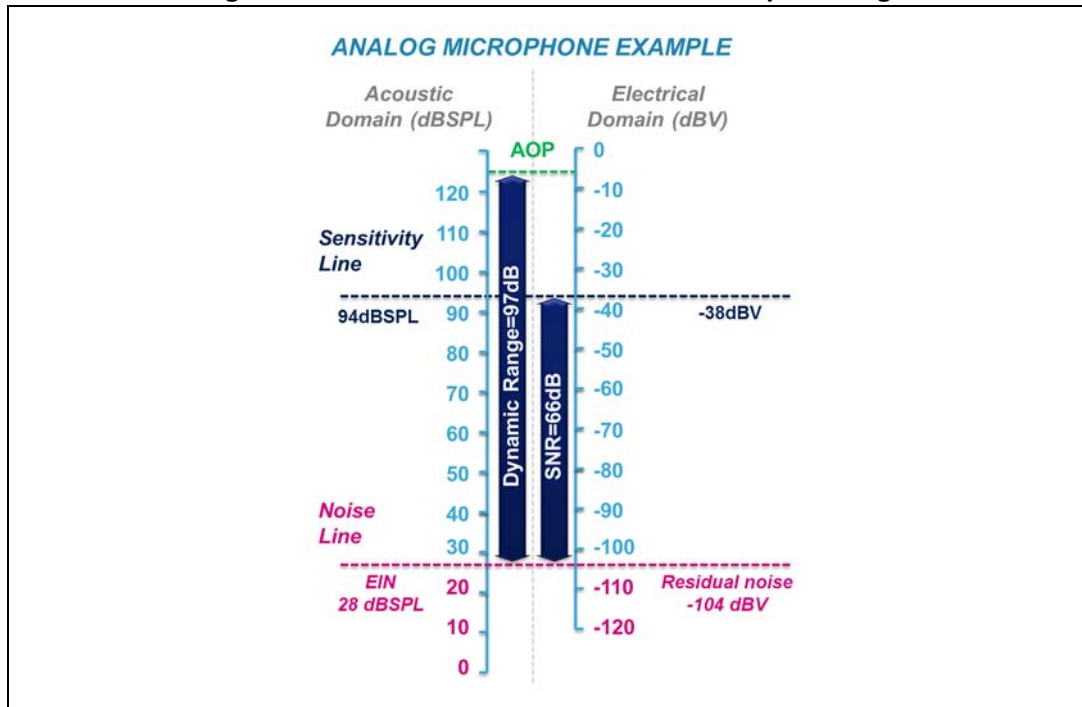
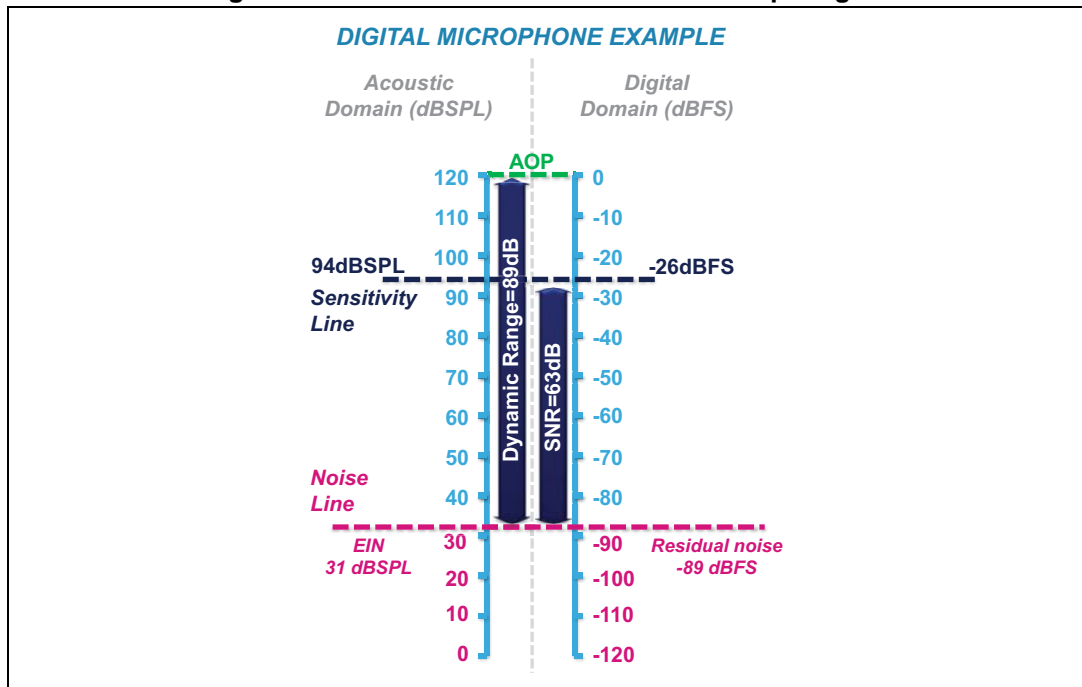


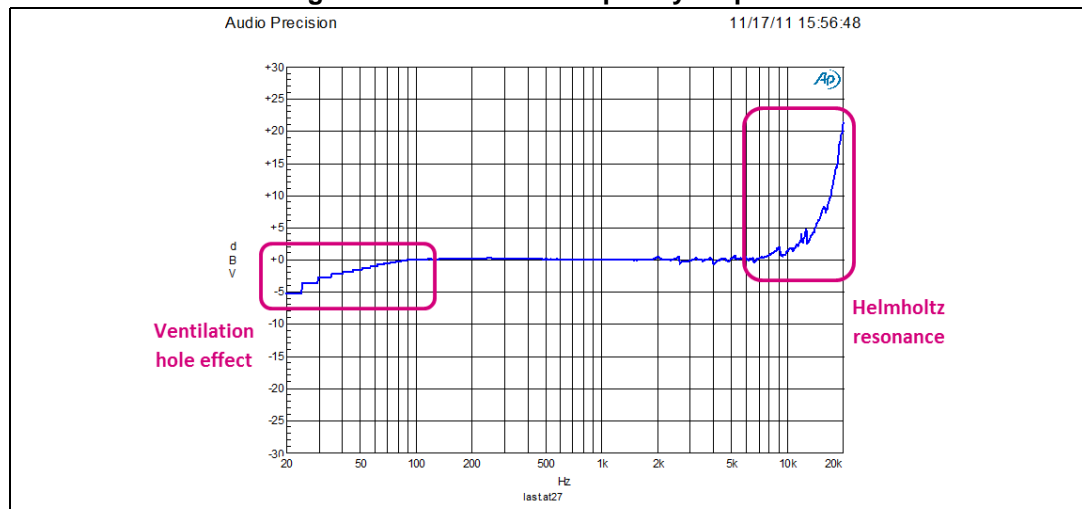
Figure 15. Acoustic and electrical relationship - digital



2.6 Frequency response

The frequency response of a microphone in terms of magnitude indicates the sensitivity variation across the audio band. This parameter also describes the deviation of the output signal from the reference 0 dB. Typically, the reference for this measurement is exactly the sensitivity of the microphone @ 0 dB = 94 dB SPL @ 1 kHz. The frequency response of a microphone can vary across the audio frequency band depending on three parameters: the ventilation hole, the front chamber geometry, and back chamber geometry. The ventilation hole and the back chamber geometry have an impact on the behavior at low frequencies while the behavior at high frequencies depends on the geometry of the front chamber only. Behavior at high frequencies can be a resonance peak caused by the Helmholtz effect. This resonance is the phenomenon of air resonance in a cavity. As a matter of fact, it depends on the dimension of the front chamber of the microphone, representing the sound cavity in which the air resonates. A microphone with a flat frequency response is suitable when natural sound and high intelligibility of the system is required. The following figure shows the response of the MP45DT02. It shows a roll-off at low frequencies and a peak around 18 kHz caused by the large front chamber ^(b) of this microphone.

Figure 16. MP45DT02 frequency response



The frequency response of a microphone in terms of phase indicates the phase distortion introduced by the microphone. In other words, the delay between the sound wave moving the microphone membrane and the electrical signal at the microphone output results in that this parameter includes both the distortion due to the membrane and the ASIC.

b. A detailed explanation of the Helmholtz resonance principle and its effect on the chambers of the microphone is given in [Section 2: Acoustic parameters](#).

2.7 Total harmonic distortion

THD is the measurement of the distortion affecting the electrical output signal of the microphone given an undistorted acoustic signal as input. THD+N is expressed as a ratio of the integer in a specified band of the power of the harmonics plus the power of noise and the power of the undistorted signal (fundamental).

Equation 1

$$THD + N (\%) = \frac{\sum_{n=1}^N Power(Harmonics) + Power(Noise)}{Power(Fundamental)}$$

Typically ST indicates the THD+N measured in the (50 Hz - 4 kHz) band for a given undistorted signal 1 kHz @ 100 dBSPL.

2.8 PSRR and PSR

PSRR indicates the capability of the ASIC to reject noise added to the supply voltage. To evaluate this parameter, a tone of $V_{IN} = 100$ mVpk-pk @ 217 Hz (GSM switching frequency in phone applications) is added to the power supply and then the amplitude of the output is measured. The added noise can be either a square wave or sinusoidal wave. Typically the square wave is preferred since it is the worst case.

PSRR is the ratio of the residual noise amplitude at the microphone output (V_{OUT} @ 217 Hz) to the added spurious signal on the supply voltage. It is typically expressed in dB as given in the equation below:

Equation 2

$$PSRR = 20 \times \text{Log} [(V_{OUT} @ 217 \text{ Hz}) / (V_{IN} @ 217 \text{ Hz})]$$

The capability of the integrated circuit to reject noise added to the supply voltage can also be expressed with another parameter that is the PSR. Basically it is simply a measurement of the output when noise of 100 mVpk-pk @ 217 Hz is superposed to the supply voltage. Consequently expressed in dB as given in the equation below:

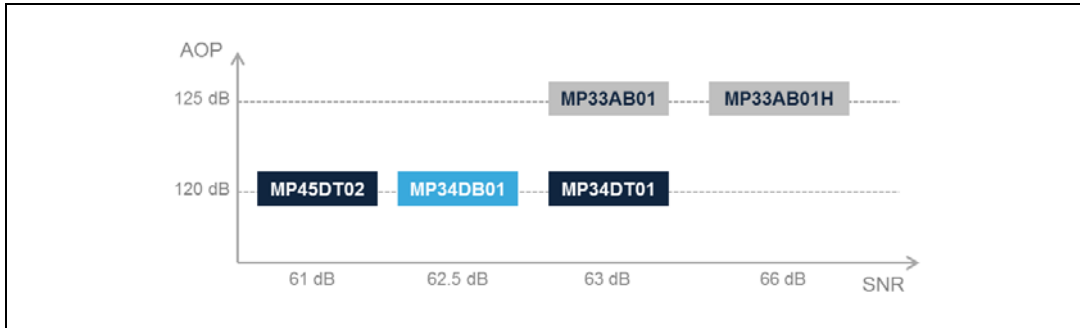
Equation 3

$$PSR = 20 \times \text{Log} (V_{out} @ 217 \text{ Hz})$$

To evaluate either the PSRR or PSR, proper sealing of the sound inlet or measurements performed in an anechoic chamber are recommended to avoid mixing the superimposed noise with that of the noise floor of the output. Finally, in the microphone datasheets PSR is commonly given instead of PSRR.

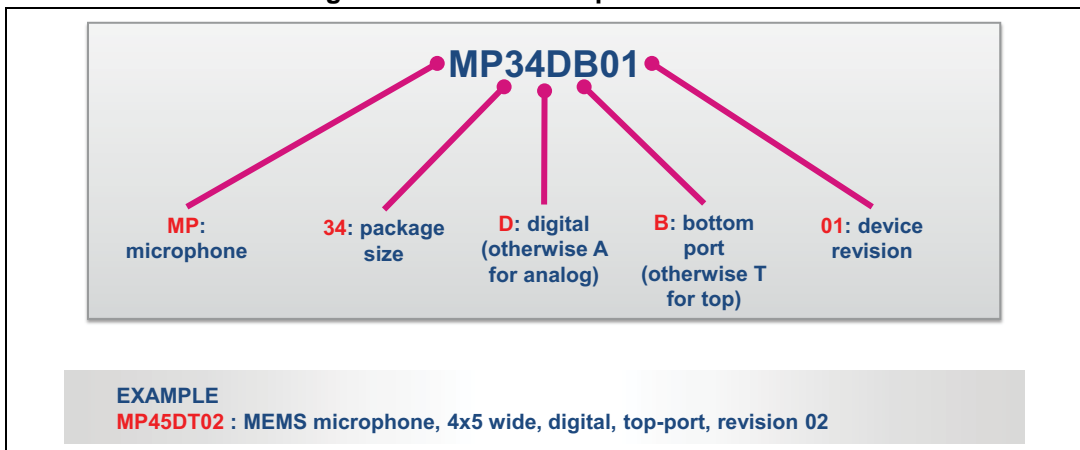
3 MEMS microphone portfolio

Figure 17. MEMS microphone portfolio



ST's portfolio includes digital and analog microphones. The commercial products are named using the notation depicted in the following figure.

Figure 18. MEMS microphone notation



The following table provides a complete overview of the microphones offered by ST. Additionally it serves as a summary for selecting the appropriate microphone among the ST portfolio as the features of both digital and analog microphones are given.

Table 1. Features of MEMS microphones

Parameter	MP45DT02	MP34DB01	MP34DT01	MP33AB01	MP33AB01H
Sensitivity	-26 dBFS	-26 dBFS	-26 dBFS	-38 dBV	-38 dBV
Directivity	Omnidirectional	Omnidirectional	Omnidirectional	Omnidirectional	Omnidirectional
SNR	61 dB	62.5 dB	63 dB	63 dB	66 dB
AOP	120 dB	120 dB	120 dB	125 dB	125 dB
EIN	33 dB	31.5 dB	31 dB	31 dB	28 dB
THD+N	<5% @ 115 dB	<5% @ 115dB	<5% @ 115dB	<5% @ 120dB	<5% @ 120dB
PSR	-70 dBFS	-70 dBFS	-70 dBFS	-75 dBV	-75 dBV
Max. current consumption	650 μ A	600 μ A	600 μ A	250 μ A	250 μ A
Package dimensions	4.72x3.76x1.25 mm	3x4x1 mm	3x4x1 mm	3.76x2.95x1 mm	3.76x2.95x1 mm
Port location	Top port	Bottom port	Top port	Bottom port	Bottom port
Operating temperature	-40°C<T<+85°C	30°C<T<+85°C	30°C<T<+70°C	-30°C<T<+100°C	-30°C<T<+100°C

4 Revision history

Table 2. Document revision history

Date	Revision	Changes
09-Jan-2014	1	Initial release

Please Read Carefully:

Information in this document is provided solely in connection with ST products. STMicroelectronics NV and its subsidiaries ("ST") reserve the right to make changes, corrections, modifications or improvements, to this document, and the products and services described herein at any time, without notice.

All ST products are sold pursuant to ST's terms and conditions of sale.

Purchasers are solely responsible for the choice, selection and use of the ST products and services described herein, and ST assumes no liability whatsoever relating to the choice, selection or use of the ST products and services described herein.

No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted under this document. If any part of this document refers to any third party products or services it shall not be deemed a license grant by ST for the use of such third party products or services, or any intellectual property contained therein or considered as a warranty covering the use in any manner whatsoever of such third party products or services or any intellectual property contained therein.

UNLESS OTHERWISE SET FORTH IN ST'S TERMS AND CONDITIONS OF SALE ST DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY WITH RESPECT TO THE USE AND/OR SALE OF ST PRODUCTS INCLUDING WITHOUT LIMITATION IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION), OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

ST PRODUCTS ARE NOT DESIGNED OR AUTHORIZED FOR USE IN: (A) SAFETY CRITICAL APPLICATIONS SUCH AS LIFE SUPPORTING, ACTIVE IMPLANTED DEVICES OR SYSTEMS WITH PRODUCT FUNCTIONAL SAFETY REQUIREMENTS; (B) AERONAUTIC APPLICATIONS; (C) AUTOMOTIVE APPLICATIONS OR ENVIRONMENTS, AND/OR (D) AEROSPACE APPLICATIONS OR ENVIRONMENTS. WHERE ST PRODUCTS ARE NOT DESIGNED FOR SUCH USE, THE PURCHASER SHALL USE PRODUCTS AT PURCHASER'S SOLE RISK, EVEN IF ST HAS BEEN INFORMED IN WRITING OF SUCH USAGE, UNLESS A PRODUCT IS EXPRESSLY DESIGNATED BY ST AS BEING INTENDED FOR "AUTOMOTIVE, AUTOMOTIVE SAFETY OR MEDICAL" INDUSTRY DOMAINS ACCORDING TO ST PRODUCT DESIGN SPECIFICATIONS. PRODUCTS FORMALLY ESCC, QML OR JAN QUALIFIED ARE DEEMED SUITABLE FOR USE IN AEROSPACE BY THE CORRESPONDING GOVERNMENTAL AGENCY.

Resale of ST products with provisions different from the statements and/or technical features set forth in this document shall immediately void any warranty granted by ST for the ST product or service described herein and shall not create or extend in any manner whatsoever, any liability of ST.

ST and the ST logo are trademarks or registered trademarks of ST in various countries.

Information in this document supersedes and replaces all information previously supplied.

The ST logo is a registered trademark of STMicroelectronics. All other names are the property of their respective owners.

© 2014 STMicroelectronics - All rights reserved

STMicroelectronics group of companies

Australia - Belgium - Brazil - Canada - China - Czech Republic - Finland - France - Germany - Hong Kong - India - Israel - Italy - Japan - Malaysia - Malta - Morocco - Philippines - Singapore - Spain - Sweden - Switzerland - United Kingdom - United States of America

www.st.com