Magnetic Sensor Hardware Design Layout Guideline

MEMSIC Inc.
Application Engineering Department

Revision History

Revision	Date	Author	Comments
1.0	2009-11-1	Liu Baipo	Initial Draft
1.1	2009-11-25	Liu Baipo	Add the sch section
1.2	2010-01-08	Liu Baipo	Update the power line measurement result
1.3	2010-02-23	Liu Baipo	Update the schematics to support all MEMSIC magnetic sensors
2.0	2010-03-13	Liu Baipo	Update the description for the guide
2.1	2010-05-18	Liu Baipo	Delete the appendix
2.2	2010-05-18	Liu Baipo	Add the real phone for speaker mag field
2.3	2010-08-18	Liu Baipo	Add the keypad metal dome analysis
2.4	2010-10-12	Liu Baipo	Change description of the current safe distance
2.5	2011-01-18	Liu Baipo	Add the shield can analysis SUS304
2.6	2011-01-24	Liu Baipo	Add the shield can analysis SUS301
2.7	2011-5-14	Liu Baipo	Add the battery safety distance
3.0	2013-12-23	Sun Xiang/Zha Mingang/Hu Yong	Change the sensor to 3416&3516 and rewrite the article
3.0.1	2014-6-11	Sun Xiang/Zha Mingang	Update the soft-iron materials parts
4.0	2014-07-22	Hu Yong	Change the sensor to 3524 and rewrite the article
4.0.1	2014-10-29	Xiang Sun	Add Nc pin and Test pin recommend circuit
4.0.2	2015-11-4	Xiang Sun	Update the NC,Test and vpp pin configuration
4.0.3	2015-11-13	Xiang Sun	Add the compatible design for YAS537 and MMC3530KJ
5.0	2016-1-5	Xiang Sun	Add the application of MMC3630KJ

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1 Introduction

The document introduced how to design an electronic compass into a smartphone. A smartphone magnetometer measures the sum of the geomagnetic field plus magnetic interference generated by ferromagnetic components on the smartphone PCB. This interference contains permanent hard iron and induced soft iron components. These components may contain different materials from different suppliers. So the recommendations provided by the document are for reference only. Therefore, the designs may vary in each actual project.

2 Magnetic Field Of The Smartphone

The magnetic field contains the geomagnetic field and magnetic interference generated by ferromagnetic components on the smartphone PCB. The magnetometer is based on the geomagnetic field test to determine the direction. Therefore, engineers should place the magnetometer away from sources of magnetic interference on the smartphone PCB to minimize the interference of hard iron and soft iron.

2.1 Hard Iron Interference

Hard iron magnetic fields are generated by permanently magnetized ferromagnetic components on the PCB, such as bar magnet. Figure 2.11 shows magnetic measurements result with no interference. Figure 2.12 shows magnetic measurements result with hard iron interference. We can found hard iron interference only shift the center of the circle away from the origin and not distort the shape of the circle.

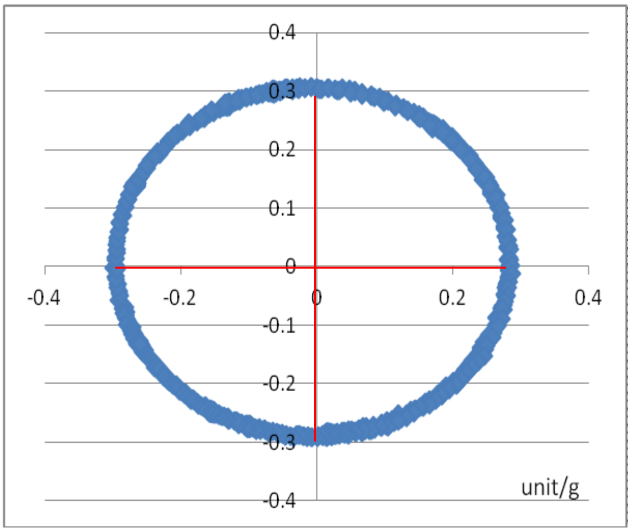

Figure 2.11: No Interference

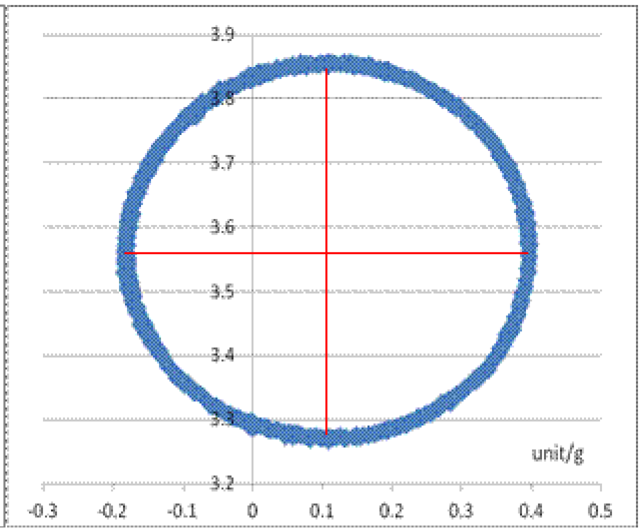

Figure 2.12: Hard Iron Interference

2.2 Soft Iron Interference

Figure 2.21 shows magnetic measurements result with both hard iron and soft iron interference. Because hard iron interference only shift the center of the circle away from the origin and not distort the shape of the circle, soft iron interference can warp the circle into an elliptical shape.

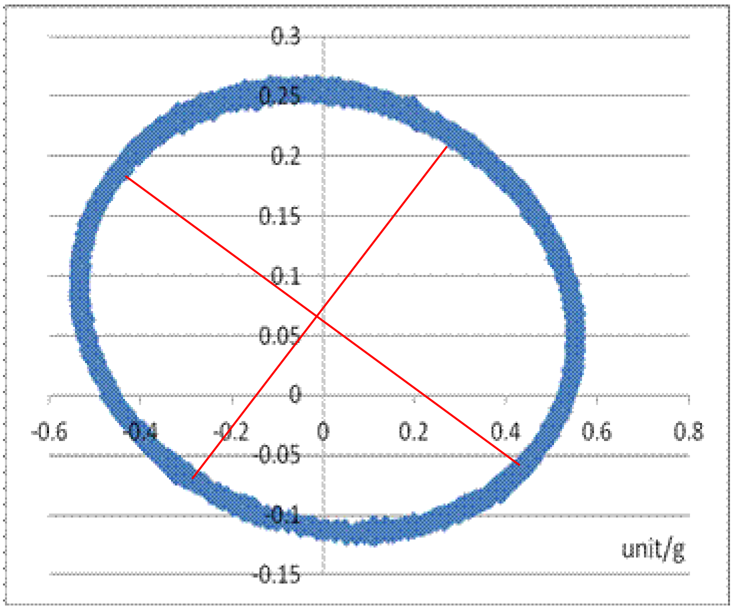

Figure 2.21: Hard Iron And Soft Iron Interference

2.3 PCB Currents Interference

Fixed currents will generate fixed magnetic field, therefore, fixed currents is equal to hard iron. Calibration program may attempt to remove these fields inference, but the best way is to minimize these fields inference. We have the measured data on the current trace in the PCB.

Battery Working Current	Magnetic Strength (Gauss) vs Current Line		
	on the wire	0.5cm	1cm away
0	0.46	0.46	0.46
100	0.52	0.48	0.47
200	0.59	0.51	0.49
300	0.70	0.54	0.50
400	0.79	0.57	0.51
500	0.90	0.58	0.53
600	1.0	0.61	0.54

Table 2.31: Magnetic Field of the current trace

But usually, the current is not constant in the phone, it is always changing. The changing current will make a lot of noise. That means calibration will need more time and the heading error will be worse. We will give the safety distance of a changing current in Chapter 4.

2.4 Material Selection

Materials using iron, cobalt, nickel and their alloys when unmagnetized belong to soft iron interference, when magnetized belong to soft iron and hard iron interference.
Materials that can be placed in the proximity of the magnetometer include brass, aluminum, copper, gold,

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silver and titanium.

2.4.1 Magnetic Measurements Of Material

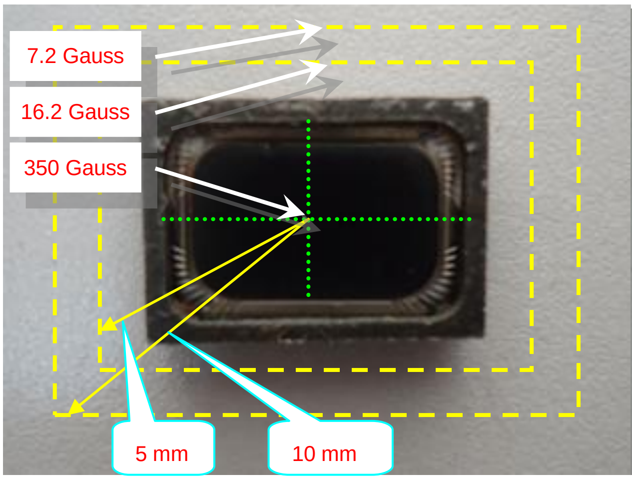


Figure 2.4.11: Magnetic Measurement of Loud Speaker

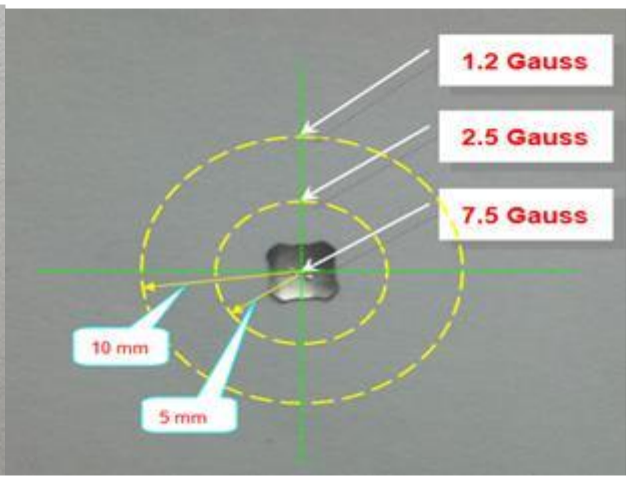
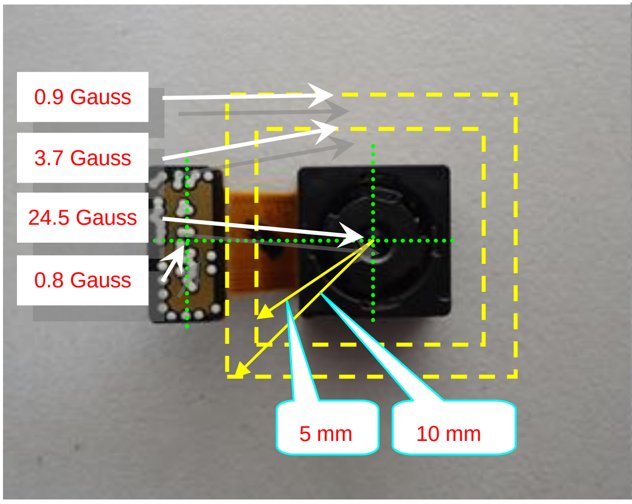


Figure 2.4.12: Magnetic Measurement of the magnetized keypad metal dome



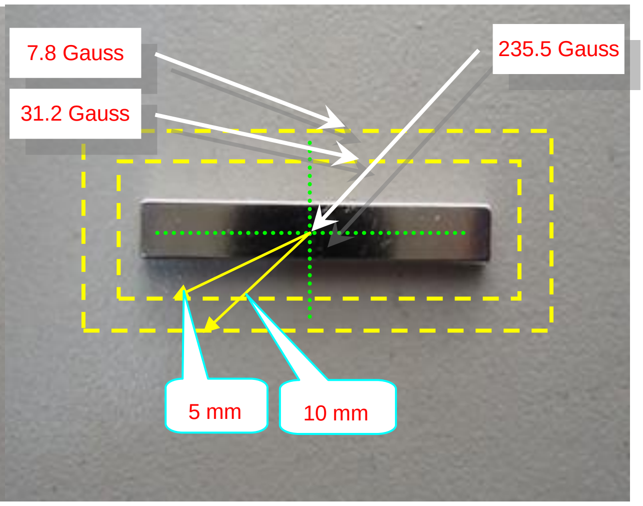


Figure 2.4.13: Magnetic Measurement of Camera

Figure 2.4.14: Magnetic

Measurement of Bar magnet

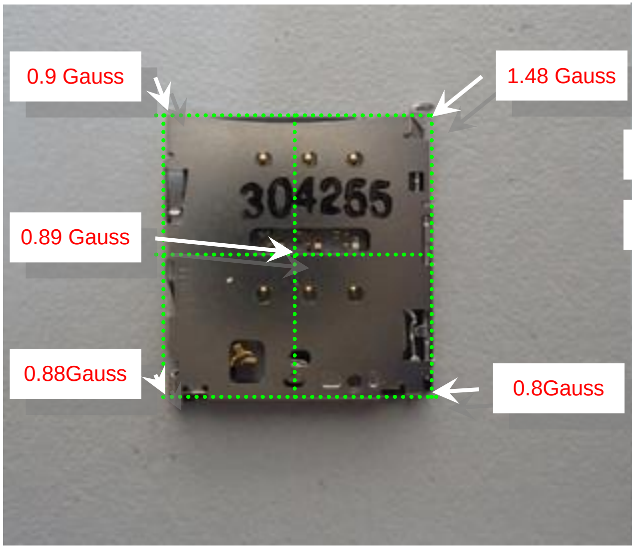


Figure 2.4.15: Magnetic Measurement of SIM card slot

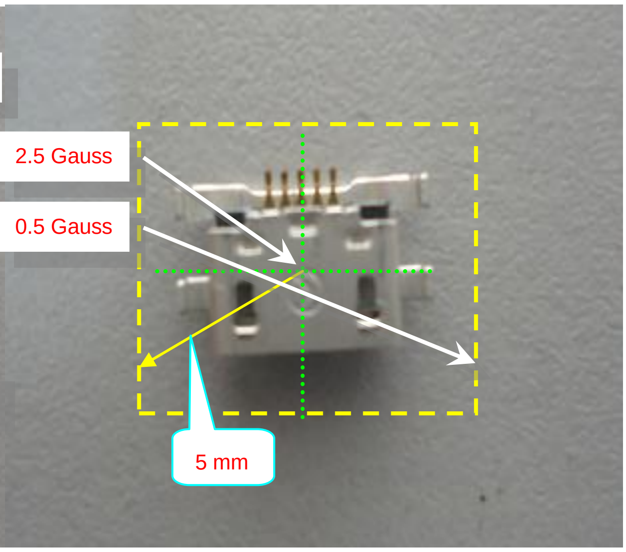


Figure 2.4.16: Magnetic Measurement of Mini USB

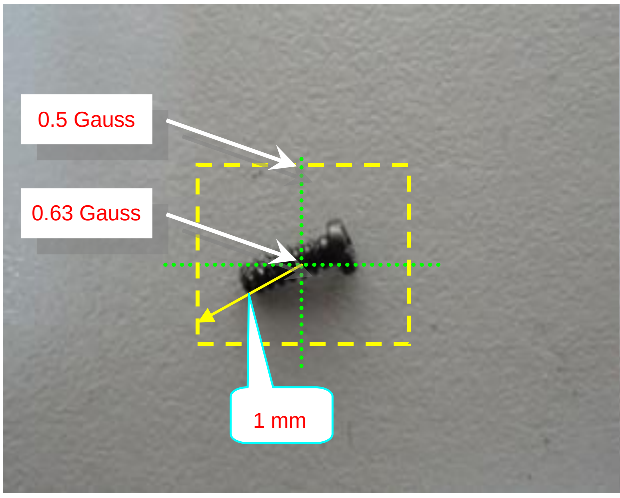


Figure 2.4.17: Magnetic Measurement of Screw

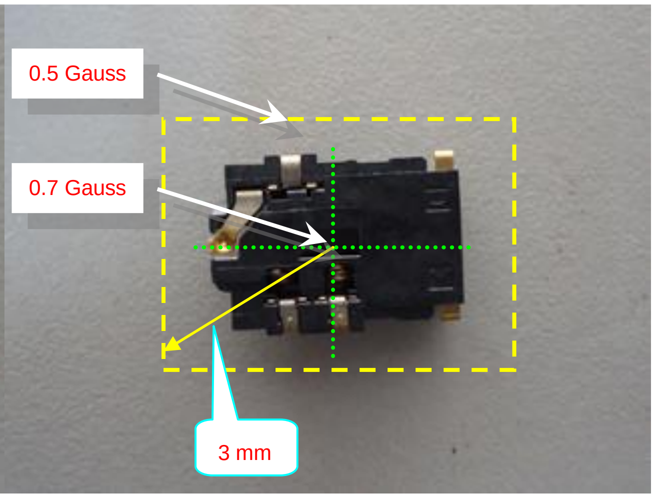


Figure 2.4.18: Magnetic Measurement of Headphone Jack

2.4.2 Magnetic Measurements Of Smartphone

Figure 2.4.21: The magnetic measurements of smartphone

3 PCB Layout Considerations

Rule 1 Get proper distance from the variable magnetic source.

The magnetic sensor is designed to measure the static magnetic field strength, such as geomagnetic field in e-compass application, which is consistent & static along the time.

In electronic device like cell phone, there are also some internal static magnetic field strength come from some components that are nearby the magnetic sensor. Those static magnetic field strengths will also attract the magnetic sensor as well as the geomagnetic field. In actual e-compass application, those internal magnetic strength offsets could be eliminated as long as the e-compass algorithm is running for calibration, which will make the e-compass accurate to detect the geomagnetic orientation correctly.

Some components, such as speaker, vibrator, auto-focus camera module, will generate variant magnetic field strength when they are working. Those magnetic strengths are not consistent, so the e-compass calibration algorithm will not be able to calibrate them correctly. So when then those components and e-compass are working together, the accuracy of e-compass will be affected.

Therefore, the magnetic sensor need keep a safety distance from those components that will generate variant magnetic strength.

Rule 2 The magnetic field should be in the sensor's best linearity range.

Generally, the magnetic field can not beyond the sensor's measurement range. If the magnetic field beyond the measurement range, the sensor's reading will not accurate enough due to the linearity error is out of control.

Rule 3 Can not block the geomagnetic field from the sensor.

If the geomagnetic field cannot completely reach the magnetic sensor, the accuracy of e-compass will be affected.
Generally the soft-iron materials can change the direction of the magnetic field. If we use the soft-iron materials cover the magnetic sensor, the geomagnetic field will be changed direction by the soft-iron component and cannot completely reach the magnetic sensor.
The soft-iron can be magnetized by the other magnetic field, when the external magnetic field is removed, the soft-iron's magnetic field will disappear by time. For example the pure iron, Fe-Si alloy, Fe-Al alloy, permalloy, ferrite bead and so on. Different materials have different magnetic field disappear time, some materials can have a over 20 Gauss magnetic field for over 10 minutes. The same material will have different magnetic fields in different area, the edge area and the bent area will have bigger magnetic field than the middle area and the flat area.

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4 Safety Distance

Magnetic Parts	Safety Distance(mm)	Level	Reason
Loud Speaker	15~20mm	Prefer [1]	Rule1&2
Voice Receiver	18~23mm	Prefer	Rule1&2
Vibrator	20~25mm	Prefer	Rule1&2
Camera	15mm	Prefer	Rule2
100mA current trace	12mm	Prefer	Rule1
10mA current trace	8mm	Prefer	Rule1
Shield Case[3]	10mm (7mm for compromise[4])	Recommendation [2]	Rule2&3
SIM Card Holder	8mm (6mm for compromise)	Recommendation	Rule2
0603 Capacitor	8mm (6mm for compromise)	Recommendation	Rule2
Keypad Metal Dome	10mm	Prefer	Rule2
2032 cell battery	8mm	Prefer	Rule2&3
AA battery	15mm	Prefer	Rule2&3

Table 4.1: Safety Distance with Magnetic Parts

Notes:

1. **Prefer** means if the distance is less than the safety distance, the eCompass performance may be reduced.
2. **Recommendation** means those parts will not impact the eCompass performance. The closer placement only increase the internal magnetic field strength, it can be calibrated to zero by the algorithm. But we recommend to keep a bigger distance if the space is free.
3. The material of the shield case is SUS304 as the reference here. We have a sample phone using the SUS304 and covered the magnetic sensor. SUS304 is a low magnetic field stainless steel. After the cold mechanical process, it will generate the magnetic field. So do not use the cold mechanical process area to cover the magnetic sensor. But we are not always know the material of the shield case, in case of the shield case contain the soft-iron, we do not recommend covering the magnetic sensor by the shield case.
4. **Compromise** means if there is no more space to meet the recommended distance, we can use this value. This only increased the internal magnetic field, it can be calibrated to zero by the algorithm.
5. Most of the materials above will both have hard iron and soft iron effect. The magnet has hard iron effect only. If some materials have only hard iron effect, the effect should better less than 8 Gauss.
6. We only tested 10mA and 100mA current trace. If the current is higher, the distance should be bigger.
7. Some materials, like the metal supporting LCD, can have an over 20 Gauss magnetic field after magnetized in the edge area, so the magnetic sensor should better be away from these area.

5 Shield Can Analysis

Cover the magnetic sensor is not recommended.
If there is no choice but to cover the magnetic sensor by shield can, following rules can be followed initially. But the test must be performed to evaluate the real shield can interference.

5.1 SUS304

A flat piece of SUS304 stainless steel can not be magnetized.
If the SUS304 was bent to a 90 degree or a wave shape, the bent area can be magnetized.
The magnetic sensor should keep the safety distance with the bent area.

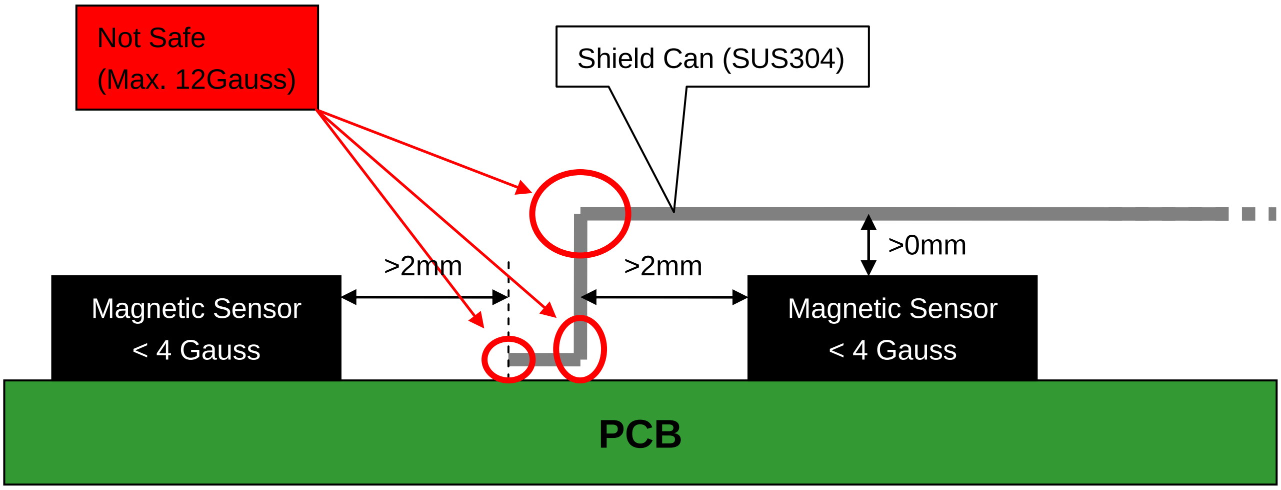


Figure 5.1: Placement IN/OUT the Shield Can

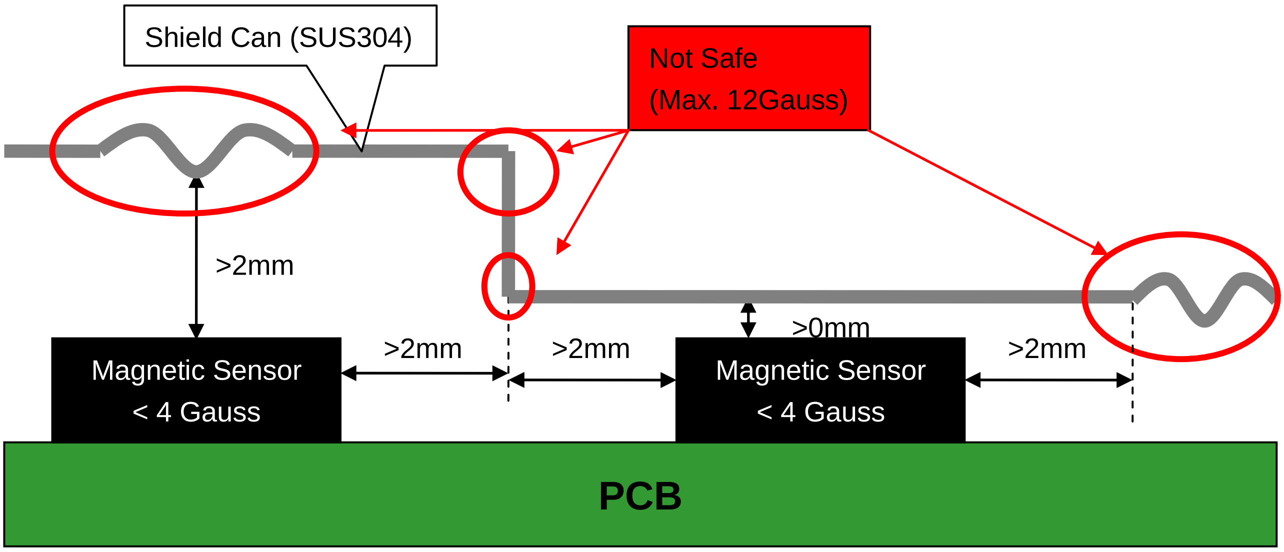


Figure 5.2: Placement in the Shield Can

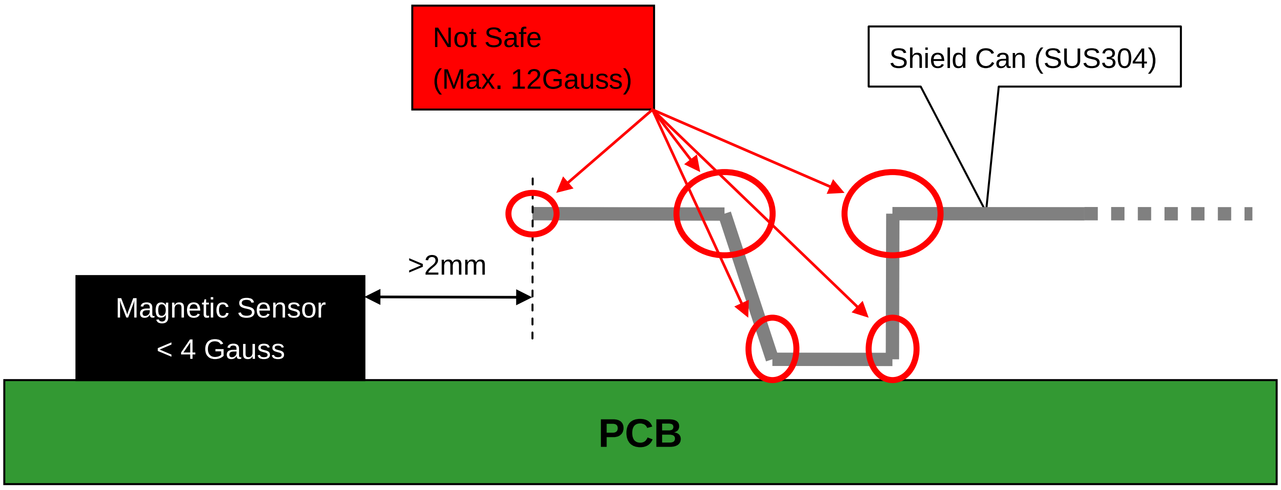


Figure 5.3: Magnetic Sensor do not Need the Protect of Shield Can

5.2 SUS301

The whole SUS301 material can be magnetized.
The magnetic sensor should keep safety distance with the whole SUS301 shield can.
SUS301 is not recommended to be the shield can with magnetic sensor together.

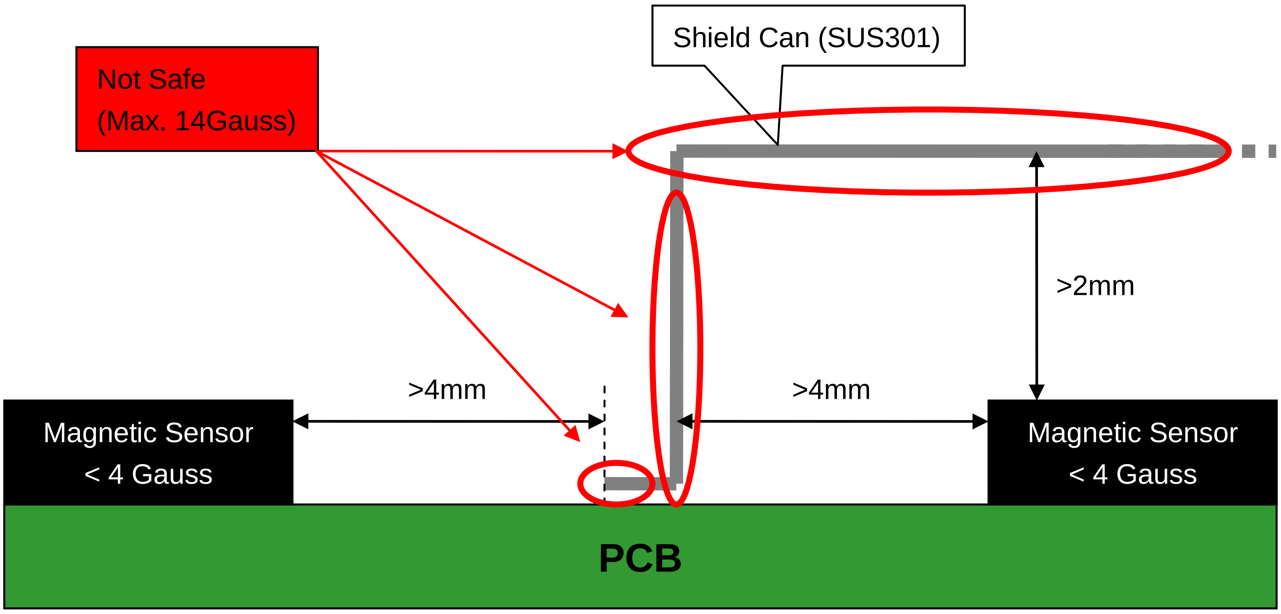


Figure 5.4: Placement IN/OUT the Shield Can

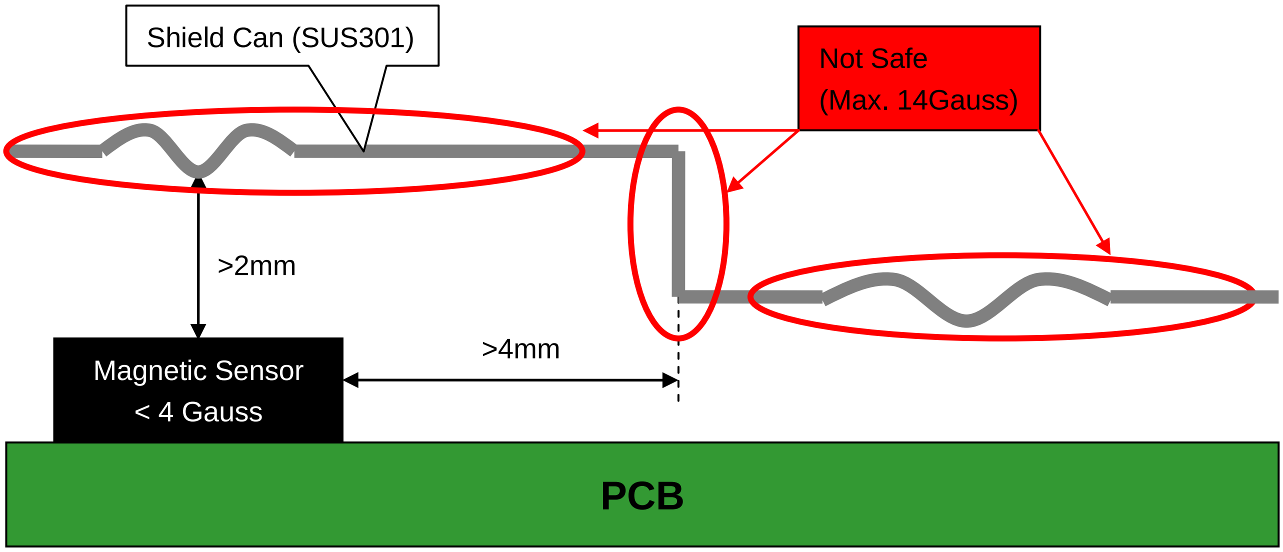


Figure 5.5: Placement in the Shield Can

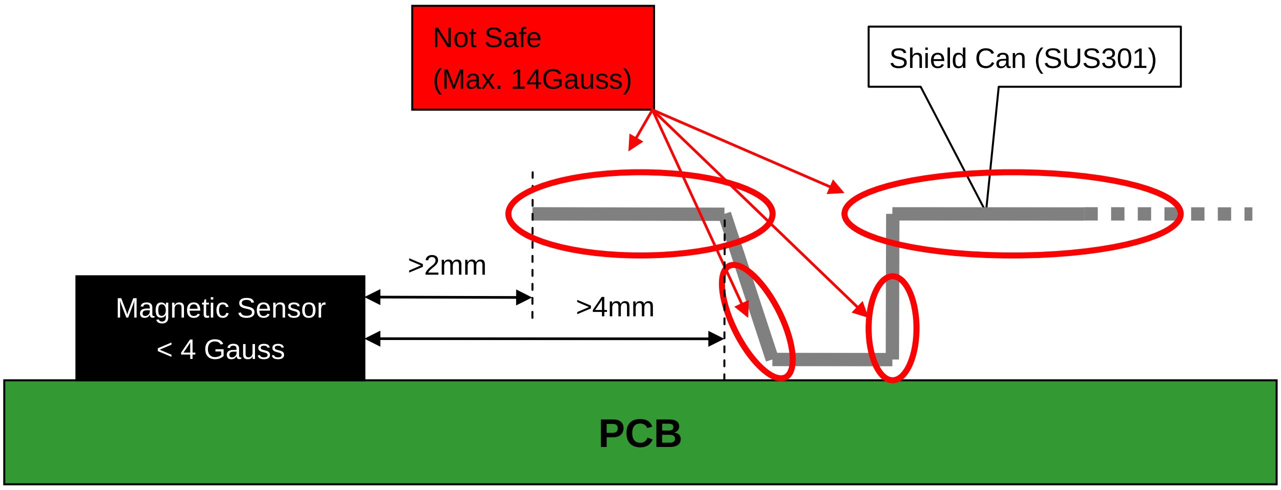


Figure 5.6: Placement beside the Shield Can

6 Compatible design

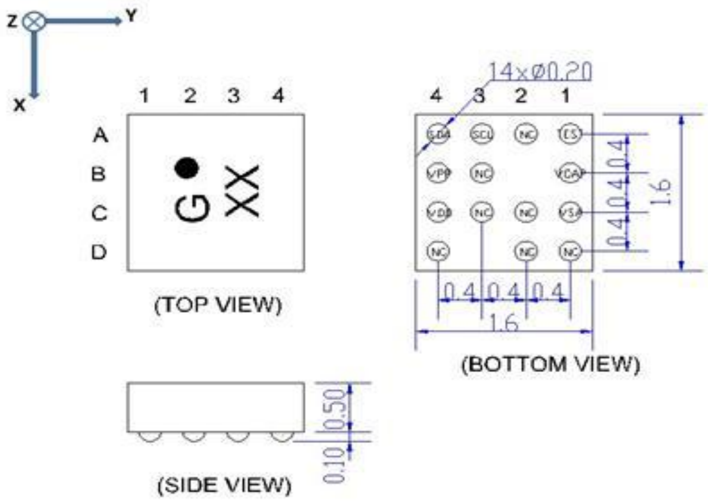
6.1 MMC35240PJ

6.1.1 MMC35240PJ Pin Description: BGA Package

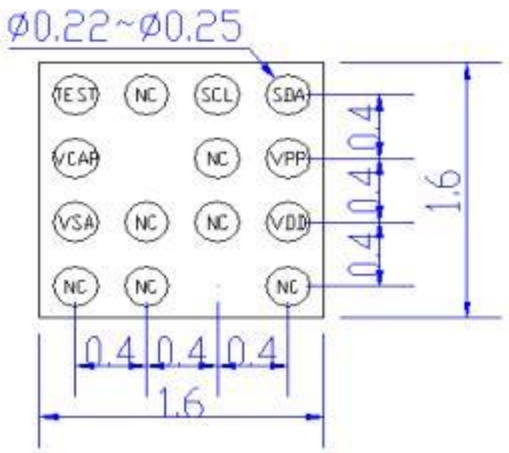
Pin	Name	Description	I/O
A1	TEST	Factory Use Only, Leave Open/Not connected	NC
A2	NC	Not Connected	NC
A3	SCL	Serial Clock Line for I^2C bus	I
A4	SDA	Serial Data Line for I^2C bus	I/O
B1	VCAP	Power Supply for SET/RESET Coil	P
B3	NC	Not Connected	NC
B4	V_{pp}	Factory Use Only, Leave Open	NC
C1	VSA	Connect to Ground	P
C2	NC	Not Connected	NC
C3	NC	Not Connected	NC
C4	VDD	Power Supply	P
D1	NC	Not Connected	NC
D2	NC	Not Connected	NC
D4	NC	Not Connected	NC

6.1.2 MMC35240PJ BGA package

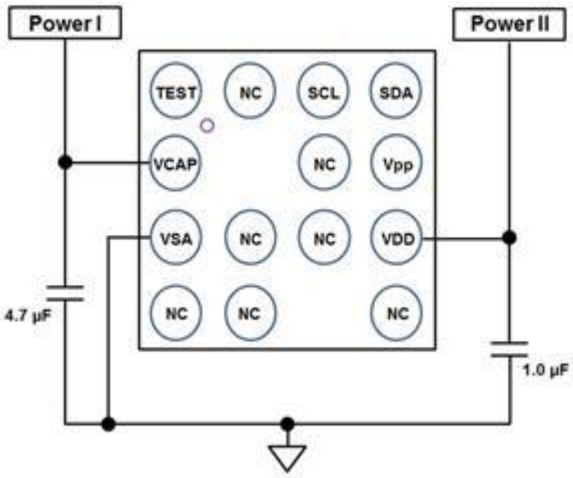
[mm]



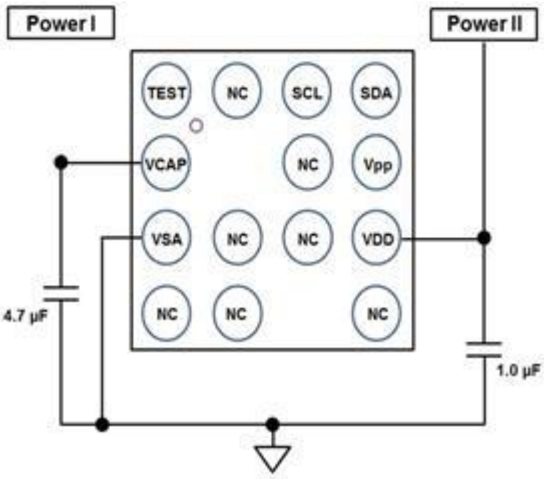
Recommend land pattern [mm]



6.1.3 MMC35240PJ application circuit



Dual supply



Single supply

For NC pins, they can be connected to VDD or Ground directly.

For Test and Vpp pin, we suggest to keep these pin floating.

If Test pin is connected to GPIO directly. Customer need to configure the GPIO into the input or high z pin.

See the following table for operating in different supply modes.

Power Supply Options	Dual Supply	Single Supply
Power I	2.6 V – 3.6 V	N/A
Power II	1.62 V – 1.98 V	1.62 V – 1.98 V
VCAP	Connected to Power I	Connected to Ground through a 4.7 µF Cap

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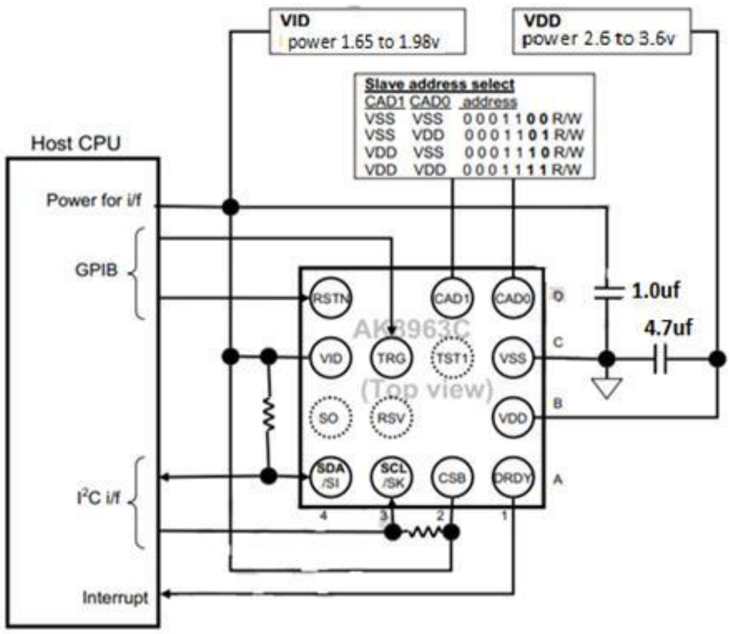
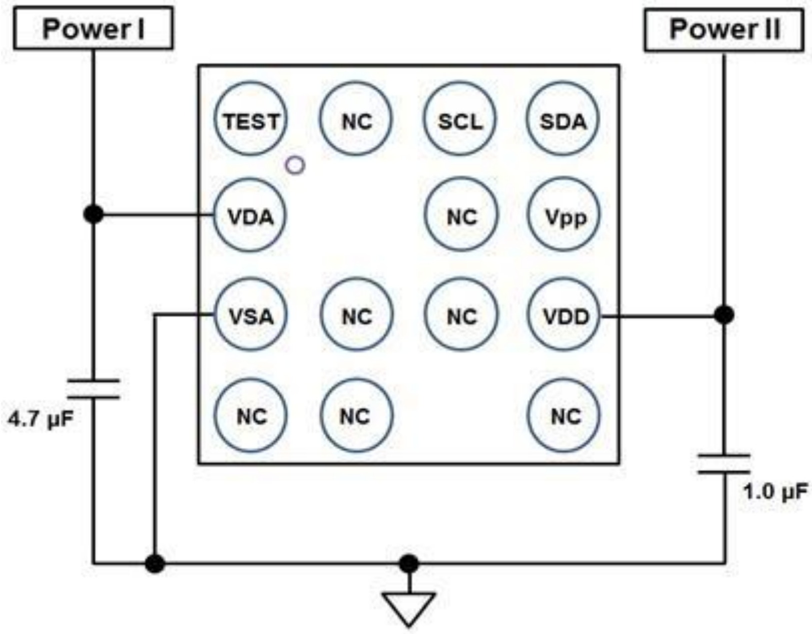
6.1.4 Compatible design for MMC35240PJ and AK8963C/AK09912



AK8963C/AK09912				MMC35240PJ		
I/O	Description	Name	Pin	Name	Description	I/O
O	Data Ready output pin	DRDY	A1	TEST	Factory Use Only, Leave open/not connected	NC
I	Chip select pin for 4-wire SPI	CSB	A2	NC	Not Connected	NC
I	Control data clock input pin	SCL	A3	SCL	Serial Clock Line for I2C bus	I
I/O	Control data input/output pin	SDA	A4	SDA	Serial Data Line for I2C bus	I/O
_	Analog Power supply pin.	VDD	B1	Vcap	Power Supply	P
O	Reserved	RSV	B3			
O	SPI Mode: serial data output pin	SO	B4	Vpp	Factory Use Only, Leave Open	NC
_	Ground Pin	VSS	C1	VSA	Connect to Ground	P
O	Test Pin, No connected or connect to VSS	TST1	C2	NC	Not Connected	NC
I	External trigger pulse input	TRG	C3	NC	Not Connected	NC
_	Digital interface positive power supply pin	VID	C4	VDD	Power Supply for I2C bus	P
I	Slave address input pin	CAD0	D1	NC	Not Connected	NC
I	Slave address input pin	CAD1	D2	NC	Not Connected	NC
I	Reset pin. Connect to VID when not in use	RSTN	D4	NC	Not Connected	NC

Note: If MMC35240PJ'sTest pin is connected to interrupt pin of MCU, the interrupt pin needs to be configured to input or high z.

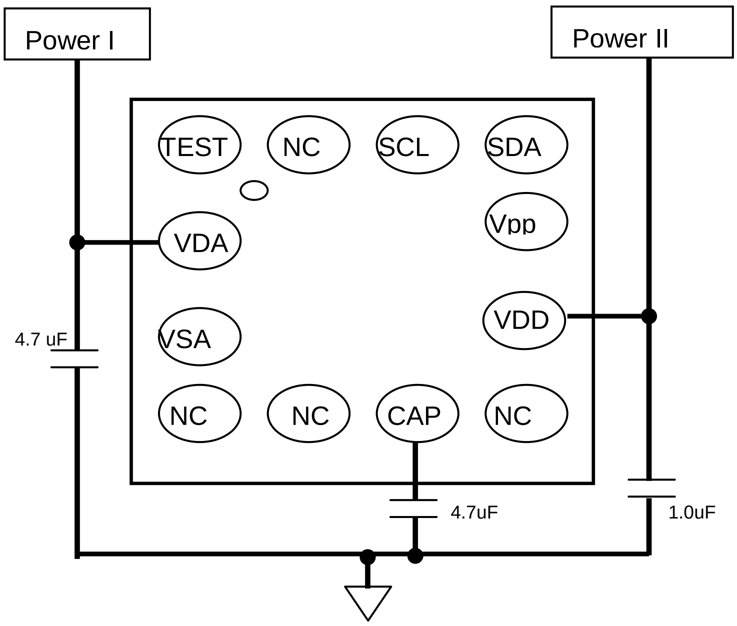
6.1.5 Compatible design for MMC35240PJ and MMC3516XPJ



The range of power supply:

Power Supply Options	Dual Supply
Power I	2.6 V – 3.6 V
Power II	1.62 V – 1.98 V

6.1.6 Compatible design for MMC35240PJ and MMC3416XPJ



The range of power supply:

Power Supply Options	Dual Supply
Power I	2.6 V – 3.6 V
Power II	1.62 V – 1.98 V

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6.2 MMC3530KJ

6.2.1 MMC3530KJ BGA package

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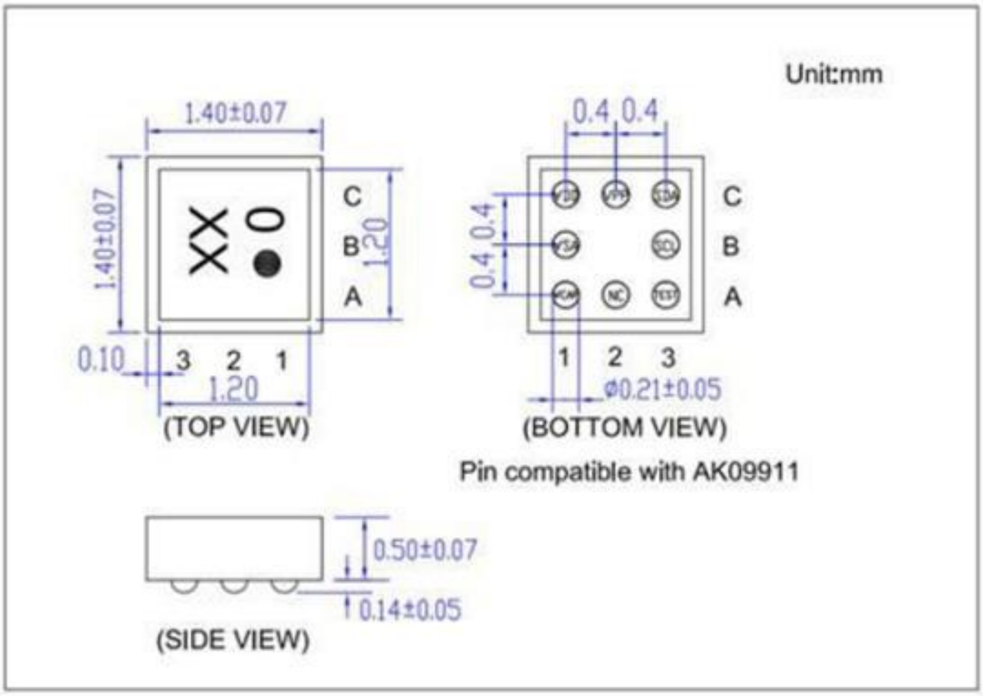

Recommend land pattern

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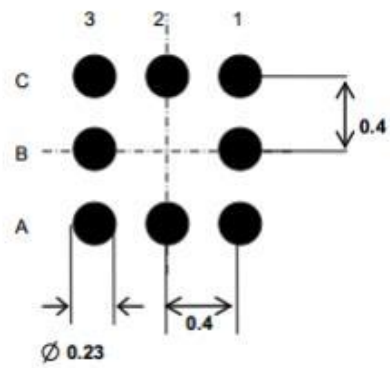
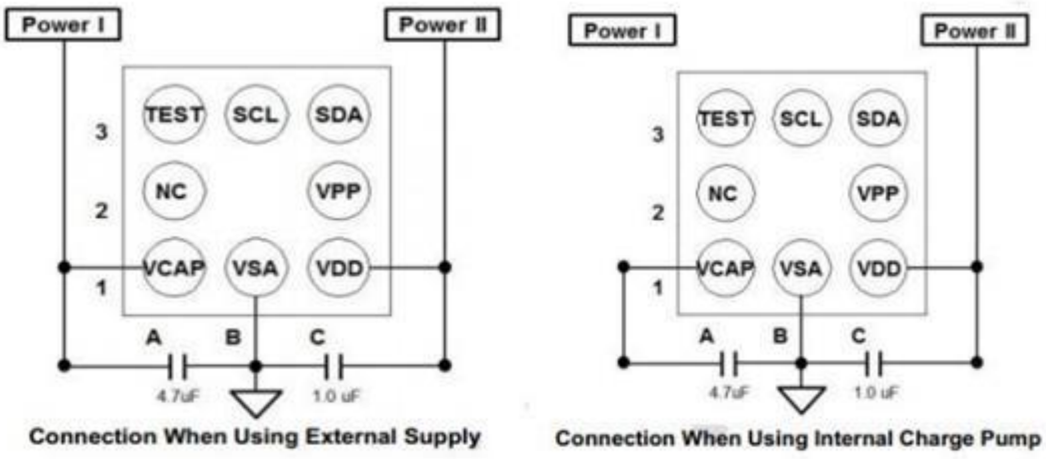


6.2.2 MMC3530KJ application circuit



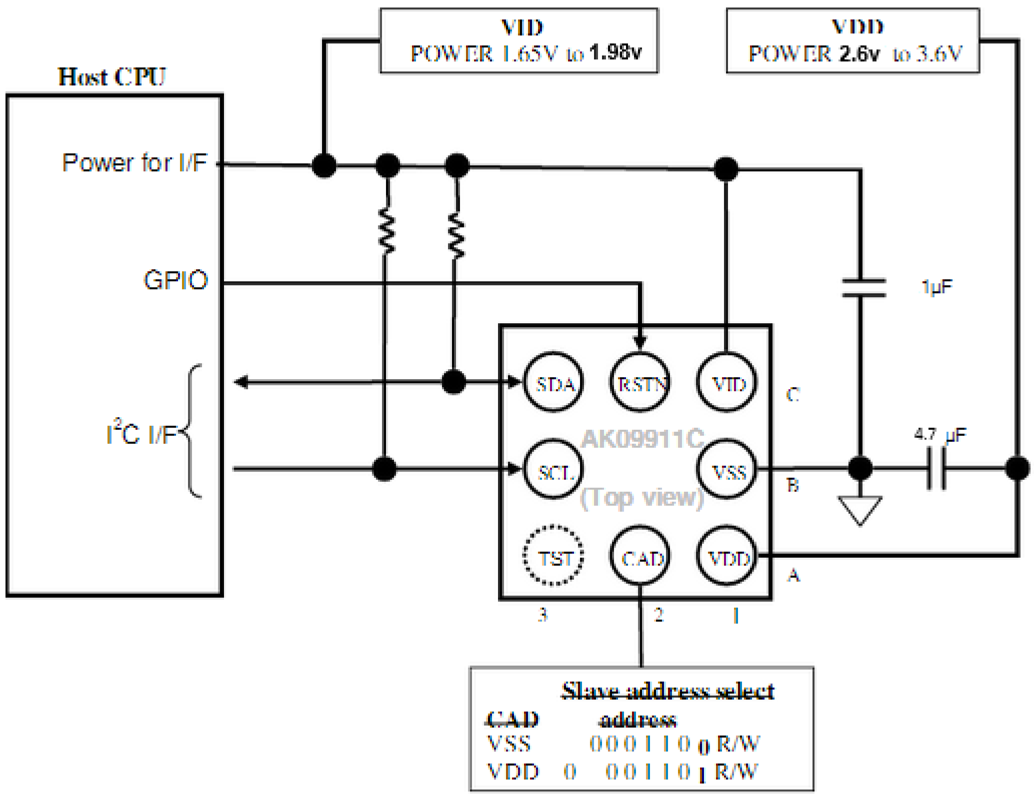
For NC pins, leave them open

For Test and Vpp pin, leave them open

See table below for operation in different supply modes

Power Supply Options	Dual Supply	Single Supply
Power I	2.6 V – 3.6 V	N/A
Power II	1.62 V – 1.98 V	1.62 V – 1.98 V
VCAP	Connected to Power I	Connected to Ground through a 4.7 μF Cap

6.2.3 Compatible design for AK09911 and MMC3530KJ

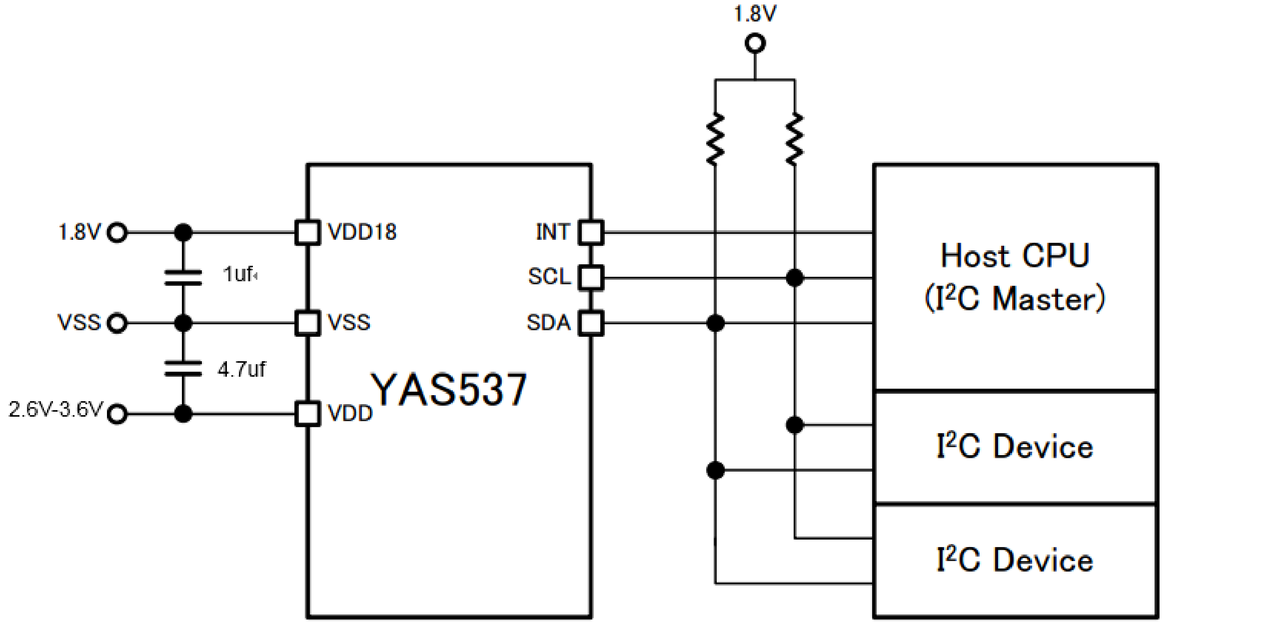


Pins of dot circle should be kept non connected.

AK09911				MMC3530KJ		
I/O	Description	Name	Pin	Name	Description	I/O
P	Positive power supply pin	VDD	A1	VCAP	Power supply for set/reset coil	P
I	Slave address input pin	CAD	A2	NC	Not Connected	NC
I/O	Test pin	TST	A3	TEST	Factory use only	NC
P	Ground pin	VSS	B1	VSA	Connect to ground	P
I	Control data clock input pin	SCL	B3	SCL	Serial Clock Line for I2C bus	I
P	Digital interface positive power supply pin	VID	C1	VDD	Power supply	P
I	Reset pin	RSTN	C2	VPP	Factory use only	NC
I/O	Control data input/output pin	SDA	C3	SDA	Serial Data Line for I2C bus	I/O

Note: If MMC3530KJ's VPP pin is connected to GPIO of MCU, the GPIO needs to be configured to input or high z.

6.2.4 Compatible design for YAS537 and MMC3530KJ



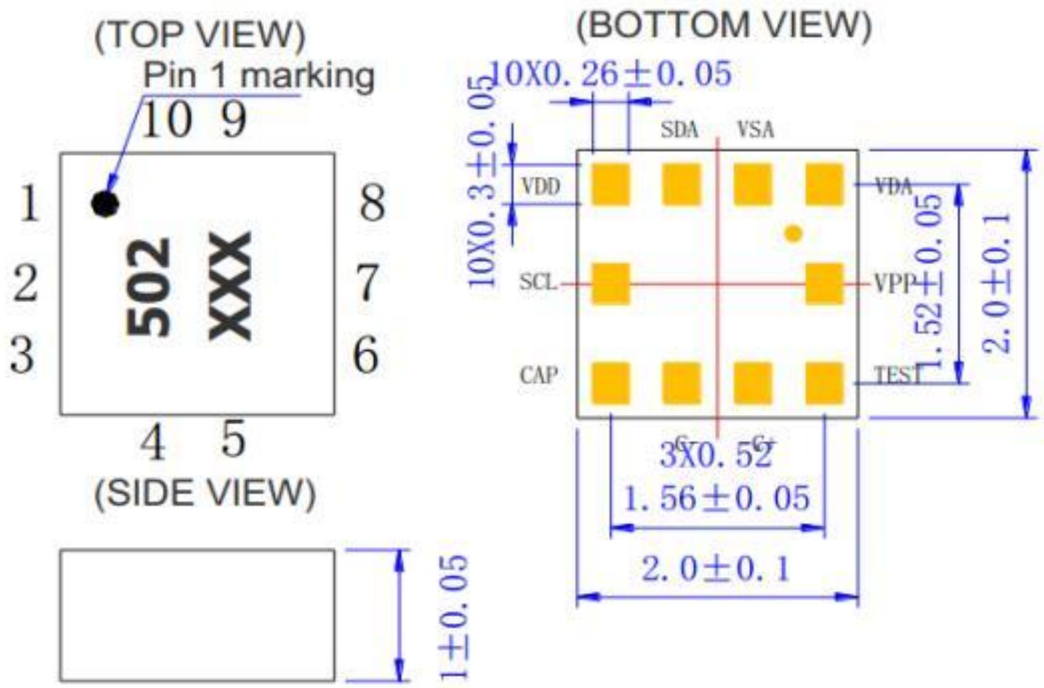
YAS537				MMC3530KJ		
I/O	Description	Name	Pin	Name	Description	I/O
P	power	VDD	1A/A1	VCAP	Power supply for set/reset coil	P
-	N.C.	NC	2A/A2	NC	Not Connected	NC
O	Interrupt signal output	INT	3A/A3	TEST	Factory use only	NC
P	Ground pin	VSS	1B/B1	VSA	Connect to ground	P
I	I2C serial clock	SCL	3B/B3	SCL	Serial Clock Line for I2C bus	I
P	power	VDD18	1C/C1	VDD	Power supply	P
-	N.C.	NC	2C/C2	VPP	Factory use only	NC
I/O	I2C serial data	SDA	3C/C3	SDA	Serial Data Line for I2C bus	I/O

Note: If MMC3530KJ'sTest pin is connected to interrupt pin of MCU, the interrupt pin needs to be configured to input or high z.

6.3 MMC3316xMT

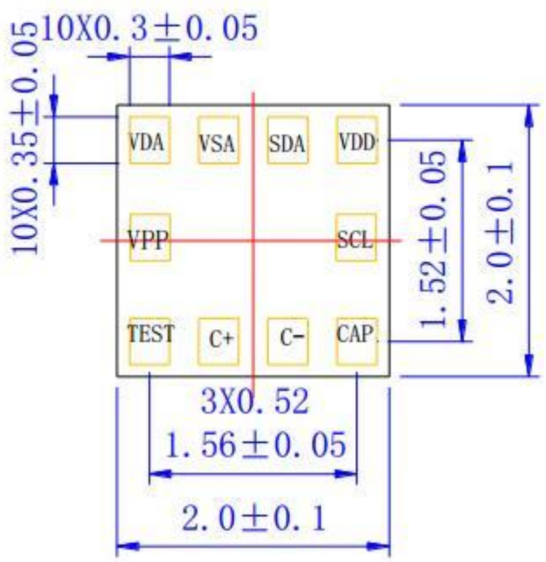
6.3.1 MMC3316xMT LGA package

[mm]

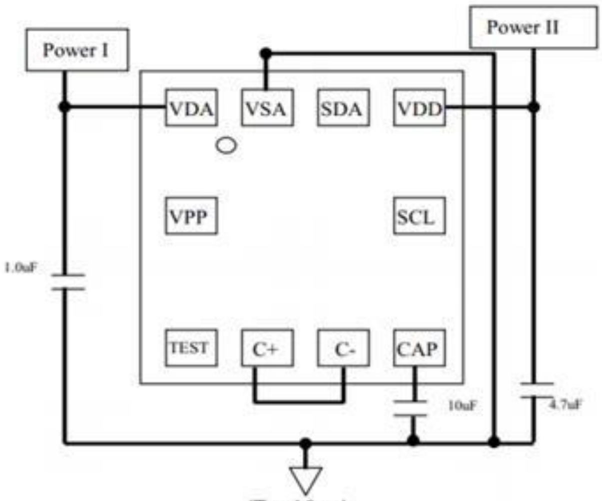


Recommend land pattern

[mm]



6.3.2 MMC3316xMT application circuit

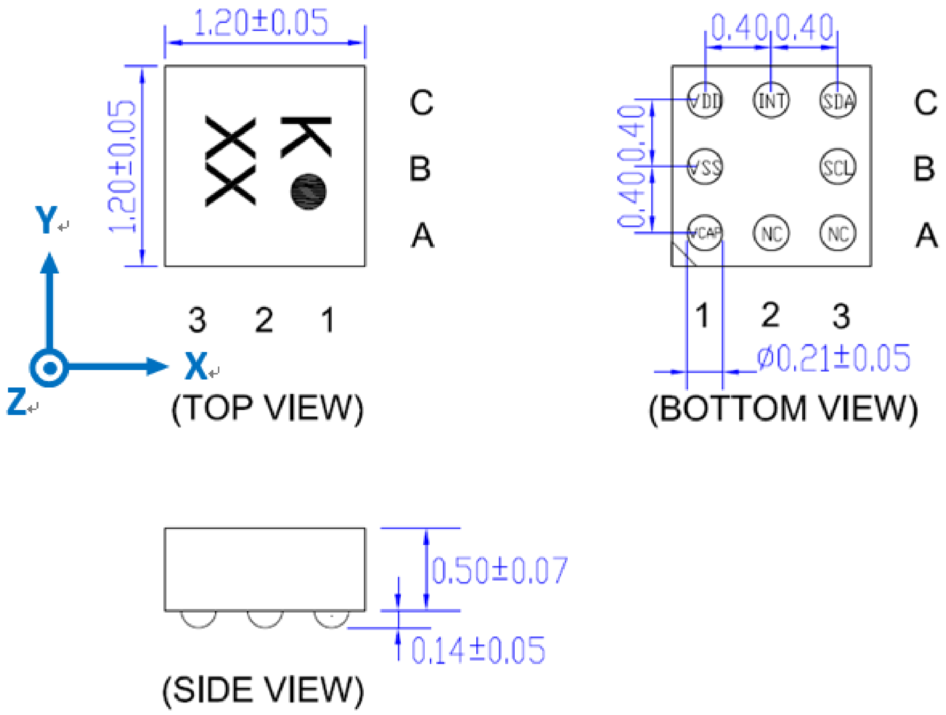


The range of power supply

Power Supply Options	Dual Supply
Power I	1.62 V – 3.6 V
Power II	1.62 V – 3.6 V

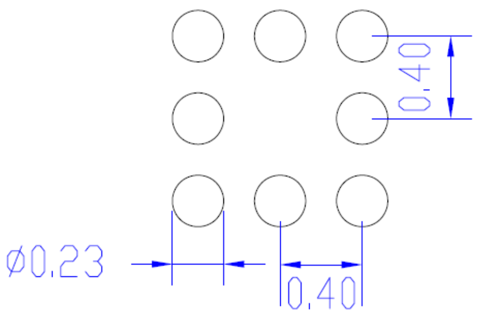
6.4 MMC3630KJ

6.4.1 MMC3630KJ BGA Package

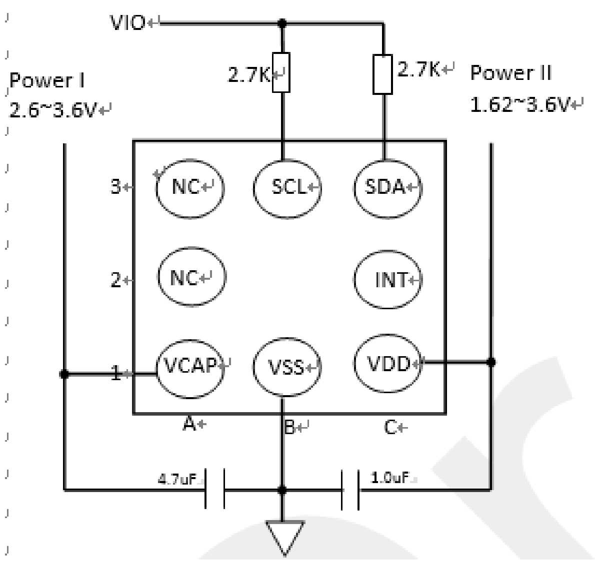


Land pattern

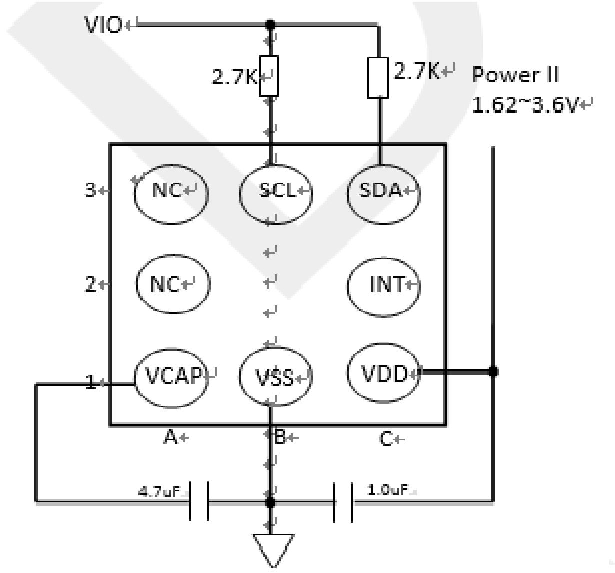
Unit:mm



6.4.2 MMC3630KJ application circuit



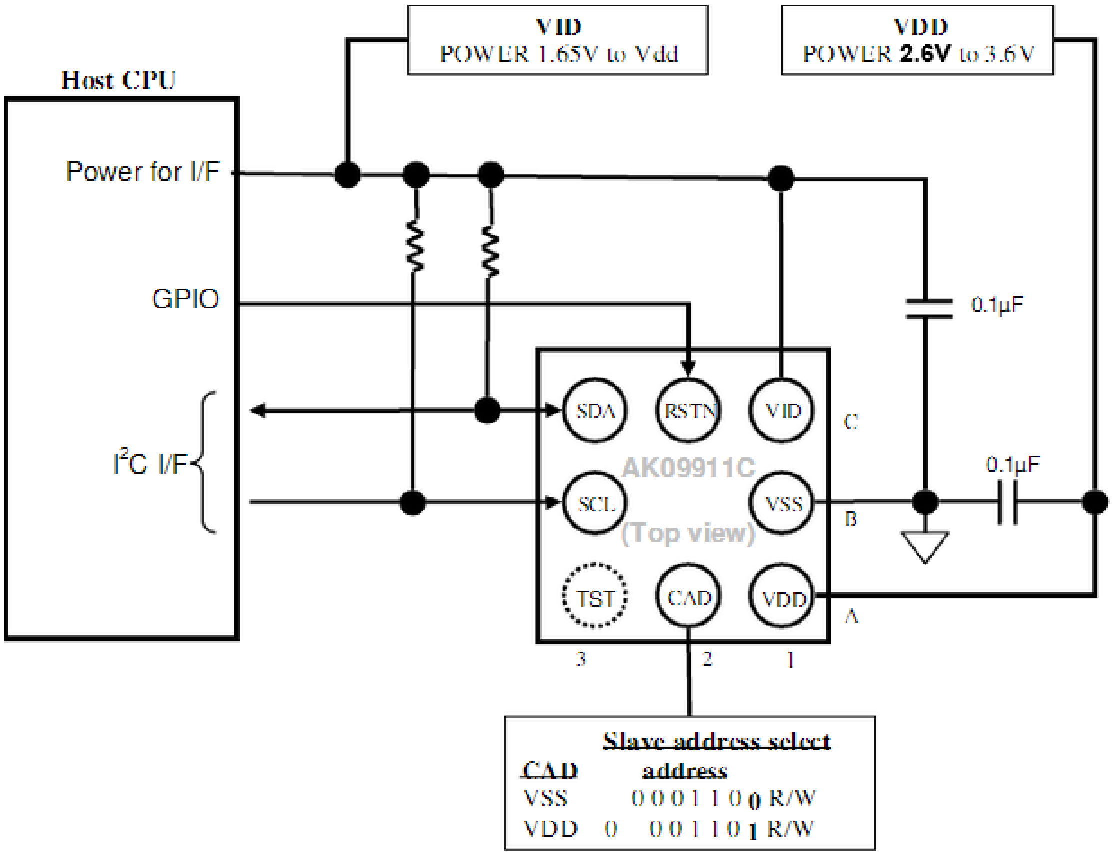
Dual supply connection



Single supply connection

Power Supply Options	Dual Supply	Single Supply
Power I	2.6V ~3.6V	NA
Power II	1.62V~3.6V	1.62V~3.6V
VCAP	Connected to Power I	Connected to Ground through a 4.7 µF Cap

6.4.3 Compatible design for AK09911 and MMC3630KJ



Pins of dot circle should be kept non-connected.

AK09911				MMC3630KJ		
I/O	Description	Name	Pin	Name	Description	I/O
P	Positive power supply pin	VDD	A1	VCAP	Power supply for set/reset coil	P
I	Slave address input pin	CAD	A2	NC	Not Connected	NC
I/O	Test pin	TST	A3	NC	Not Connected	NC
P	Ground pin	VSS	B1	VSA	Connect to ground	P
I	Control data clock input pin	SCL	B3	SCL	Serial Clock Line for I2C bus	I
P	Digital interface positive power supply pin	VID	C1	VDD	Power supply	P
I	Reset pin	RSTN	C2	INT	Interrupt output	O
I/O	Control data input/output pin	SDA	C3	SDA	Serial Data Line for I2C bus	I/O

Note: If MMC3630KJ's INT pin is connected to GPIO of MCU, the GPIO needs to be configured to input.

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