LMX9838 Placement for RF Performance

National Semiconductor
Application Note 1701
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1.0 Introduction

The National Semiconductor LMX9838Bluetooth®module contains all components for a complete bluetooth node including crystal, loopfilter and antenna. This simplifies the implementation in to the end customer application because it frees the designer from complex external antenna design considerations.

This application note describes how to place the LMX9838 module in to an application so that the internal antenna is optimized for maximum efficiency.

2.0 Field Theory

Of primary interest to the customer is the near field when designing the LMX9838 in to the application. If the application is designed well so that the near field is not severely disturbed then the far field will give good performance.

2.1 NEAR FIELD

The Near Field is the region where the Electric field and the Magnetic field from the antenna can couple to objects placed close to the antenna. A typical Bluetooth antenna (monopole) has predominantly Electric Fields in the Near Field region. For physically small Bluetooth antennas the near field is contained within a few centimeters from the antenna.

The near-field region (also known as the Fresnel Region or near zone) exists within a distance from the antenna defined as:

$$\text{Near Field} = 2D^2 / \lambda$$

where

D = Maximum dimension of the antenna

λ = Wavelength

From the formula we can calculate that for a Bluetooth dipole the near field is contained within an area 6cm from the antenna.

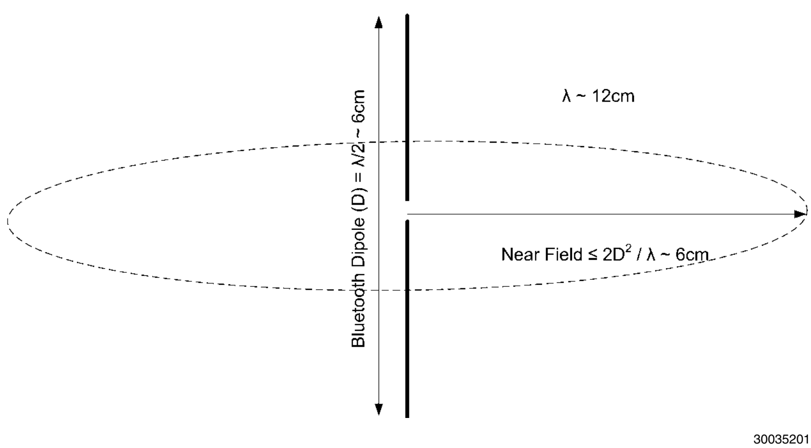

FIGURE 1. Near Field Region For a Bluetooth Dipole

The LMX9838 module uses an internal ceramic antenna and a matching circuit to reduce the size of the antenna relative to the dipole shown in *Figure 1*. Therefore the limit of the near field will be less than that calculated for the dipole and it is recommended to keep objects a distance of 3cm from the antenna for optimum performance.

2.1.1 Field Lines

In the case of the LMX9838 antenna, the predominant electric field lines emanate from the active element of the antenna and couple to the nearby ground plane (as shown in *Figure 2*).

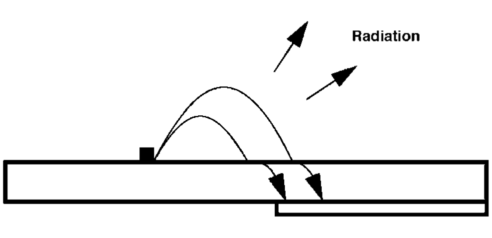

FIGURE 2. Example of Electric Field Lines: Coupling from Active Element of Antenna to Ground Plane

The near field energy is converted to a far field traveling wave. The far field traveling wave is the Electromagnetic traveling

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wave which allows communication between Bluetooth devices.

2.1.2 Detuning Effect

If an antenna (and consequently it's near field) has been optimized for maximum efficiency, then placing an unwanted object in its near field will cause a disturbance of the field pattern and reduce the efficiency of radiation.

The disturbance of the field pattern causes a detuning of the antenna which results in a mismatch in the interface between the radio module and the antenna which consequently has the effect of reduced power transfer in the transmit and receive direction.

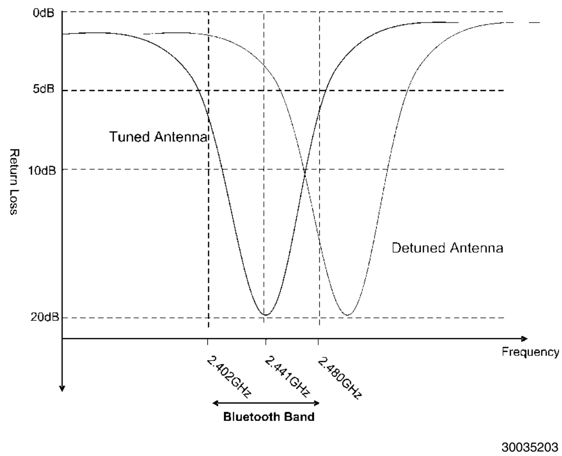

FIGURE 3. Return Loss (S11) of Antenna (Tuned & Detuned)

This effect of detuning can be seen using a network analyzer (as shown in *Figure 3*) where the return loss measured into the antenna source gives a well matched profile, i.e. broad bandwidth centered around the center frequency of the application. Any un-wanted object entering the near field will decentre this return loss profile and may also reduce the bandwidth of operation.

Also, objects that are placed into the near field can cause unwanted field coupling which disturbs the shape of the near field and hence disrupts also the far field pattern. The consequence of all these effects is that the user will see a reduction in range and/or a modification of the far field pattern.

2.2 EFFECT OF DIFFERENT MATERIALS

The detuning effect will be most evident when an unwanted object is placed into the near field where the field strength is maximum. This will cause maximum coupling to the object and major disruption of the antenna match. But also the material from which the unwanted object is made is important. For example conductors such as metals are the worse for causing detuning whereas certain ceramics and plastics may hardly disrupt the field at all.

As an example of this effect, certain outdoor antennas are protected from the weather by a radome which is an enclosure sitting very close to the antenna without disrupting the field. Such structures are made from fiber glass or Teflon which is "invisible" to the frequency of transmission being used.

2.3 FAR FIELD

The far-field region is the region outside the near-field region where the true radiation pattern takes shape. The far field region consists predominantly of the electromagnetic traveling wave. The electric and magnetic near fields are negligible in the far field, consequently objects placed in to the far field have no effect on the radiation efficiency of the antenna.

If the source has a maximum overall dimension D that is large compared to the wavelength, the far-field region is commonly taken to exist at distances greater than $2D^2 / \lambda$ from the source.

$$\text{Far Field} > 2D^2 / \lambda$$

The far-field region is sometimes referred to as the Fraunhofer region, far field, far zone or radiation field.

For a Bluetooth dipole the far field can be calculated as being further than 6cm from the antenna (as shown in *Figure 4*). Because the LMX9838 is physically smaller than the dipole then the far field will be less than calculated for the dipole and it is recommended to keep objects a distance of 3cm from the antenna for optimum performance.

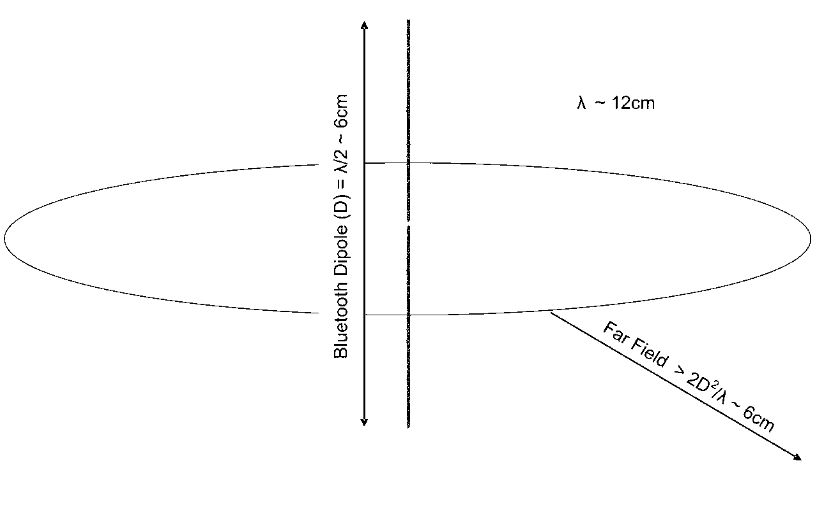

FIGURE 4. Far Field Region for a Bluetooth Dipole

3.0 Antenna Gain, Peak Gain and Average Gain

When antennas radiate, they tend to radiate more in one direction than in another, the intensity of radiation in one particular direction is known as Antenna Gain with the Peak Gain being the direction of highest radiation intensity. Average Gain however is the surface integral of all gain vectors which shows the total amount of radiation emanating from the antenna. Gain is measured relative to a theoretically perfect isotropic antenna which radiates equally in all directions and the unit is therefore dBi, where the "i" denotes "isotropic".

It is a common mistake to think that an antenna with higher Peak Gain is better than an antenna with lower but broader gain pattern. In reality however for most non-line of sight applications, such as Bluetooth, it is the Average Gain that is important.

An example where knowledge of the Antenna Gain might be useful is in a car kit. In this case, for optimal performance, the car kit should be installed so that maximum gain is towards the cabin compartment. It is also important to note that the gain should also be quite wide in to the cabin to give good coverage to the driver and passenger(s). Some experimentation is normally necessary to find the optimal position.

3.1 ANTENNA PATTERN AND 2-DIMENSIONAL CUT

The 3-dimensional shape formed by looking at all gain vectors from the antenna is known as the antenna pattern.

Like all practical antennas, the LMX9838 gain varies depending on the angle from the antenna.

Figure 5 through *Figure 7* show 2-dimensional cuts through the radiation pattern with the receiver rotating counterclockwise around the antenna in the centre of the chart.

Assuming the part is mounted in the horizontal plane (like most IC's on a board) then the gain of the antenna can be summarized as follows:

- It radiates best above & below the plane of the board, not in the exact plane of the board.
- It radiates best to horizontally polarized antennas
- It radiates best in the direction away from the antenna side of the board

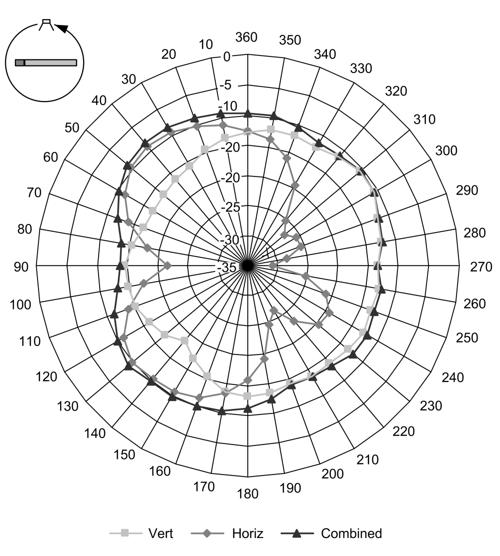

FIGURE 5. Radiation Pattern Starting from Top, Antenna to the Left

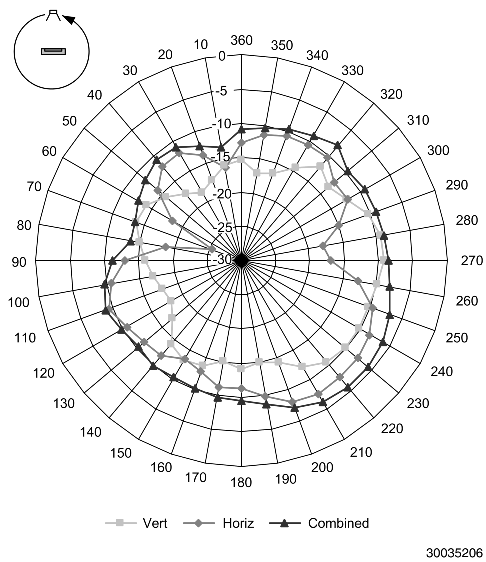

FIGURE 6. Radiation Pattern Starting from Top, Antenna Up

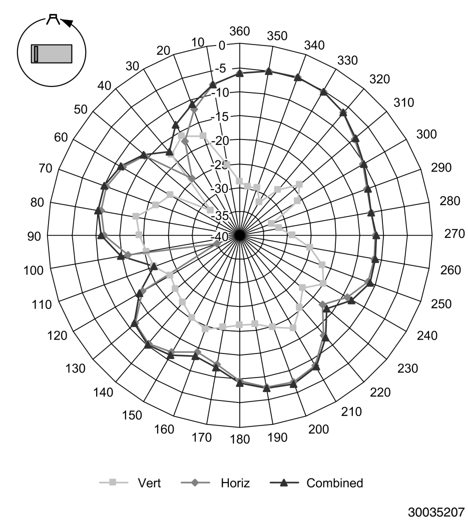

FIGURE 7. Radiation Pattern Starting from Right Plane to LMX9838, Antenna to the Left

3.2 POLARIZATION

All electromagnetic radiation propagates with a certain polarization since it is a TEM or transverse electromagnetic wave, the angle of photon vibration is called polarization. There are many types of polarization, from plane polarized to circular and elliptical. Small antennas such as the one for the LMX9838 tend to have more or less random or undefined polarization and thus it is of no great issue for these types of antennas. Larger antennas however can have a better defined polarization and there it becomes a more relevant parameter.

4.0 Physical Placement of LMX9838

4.1 MOUNTING LMX9838 ON PCB

For optimum antenna performance, the part should be placed on the FR4 PCB as shown in *Figure 8*. The recommended dimensions of the ground plane and the minimum distance to nearby objects are specified so as to optimize the antenna field pattern and efficiency.

It is recommended that the "PCB area without any metal" should not contain any ground plane or signaling lines. The ground plane is also part of the antenna and using the recommended ground plane dimensions will optimize the radiated performance.

If possible, objects should be kept more than 30mm away from the antenna end of the module. This recommended distance applies to the front, above, below and to the sides of the module. This distance can be relaxed to the rear of the device. Within this described region the near field of the antenna is strong and objects (especially metallic) may degrade the performance of the antenna. This 'near field' effect is a physical limitation of all antennas and is not specific to this product.

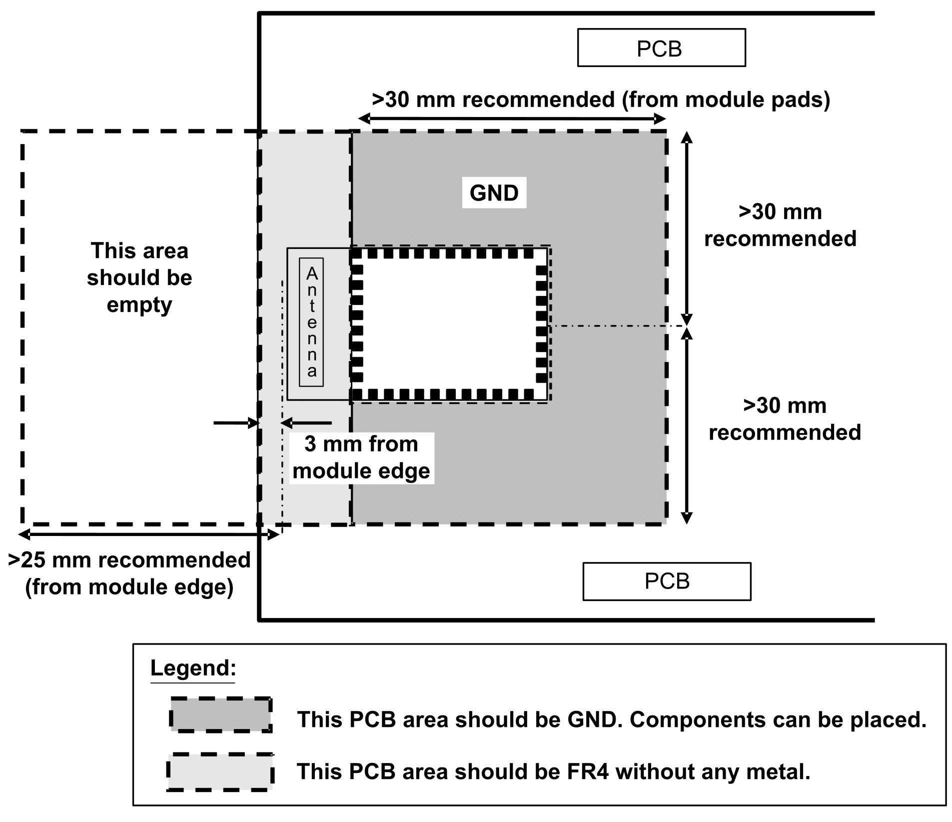

FIGURE 8. Placement of LMX9838 on the PCB and Recommended Grounding and Clearance

4.1.1 FR4 Thickness

The resonant frequency and therefore the performance of the LMX9838 antenna over the Bluetooth band is influenced by the thickness of the FR4 PCB (Printed Circuit Board used). It is recommended to use the FR4 PCB with a thickness between 30 mil (0.76mm) to 100 mil (2.54mm). Optimum antenna performance is achieved using 60 mil (1.52mm).

4.1.2 Proximity Effects

Objects such as speakers or metal casings coming in to the near field of the antenna will modify the field pattern and degrade performance. Therefore it is recommended to keep metal objects no closer than 3cm away from the antenna end of the LMX9838 module.

5.0 Design Steps & Debugging

Most customer applications are systems which means that the application will consist of sub-systems (as shown in *Figure 9*). These sub-systems are connected to each other using defined interfaces. Also these sub-systems may be different types of technology, for example the application may consist of the Bluetooth module (LMX9838) as well as a customer designed digital and analog part.

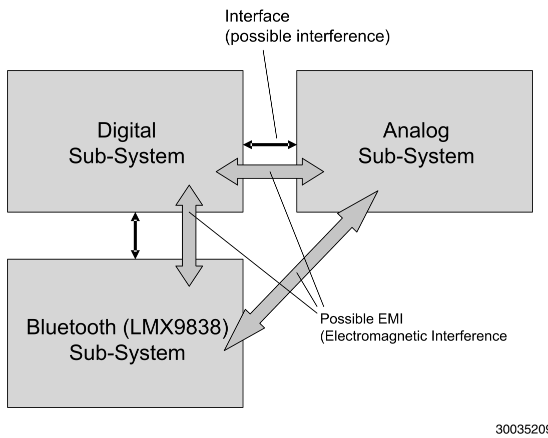

FIGURE 9. Example of a System (i.e. Customer Application) and its Sub-Systems

5.1 PROTOTYPE DESIGN

It is recommended when designing such an application to prototype the individual sub-systems and thoroughly test the interfaces. The sub-systems can then be connected and the overall system performance measured. If the sub-systems have been prototyped on individual bread-boards then this minimizes interference between the sub-systems and the final system acts as a reference design for the maximum achievable performance.

5.2 APPLICATION DESIGN

Most customer applications have all of the sub-systems placed on a single PCB (Printed Circuit Board) and designed to minimize space. Very often, on the first design the performance is not as good as expected. The reason is normally because of unexpected interactions between the sub-systems due to the compact nature of the design.

5.3 DEBUGGING

At this point the designer needs to isolate the problem(s). A methodical approach is recommended here, the prototype design can be used to compare performance:

- Separately power up each sub-system on the board and test the interfaces. This should isolate any problem on the sub-system.
- Connect sub-systems and test the interfaces. This should isolate any unwanted interactions between the sub-systems.

The main points to look for are EMI (Electromagnetic Interference) between the sub-systems, interference be-tween sub-systems via the ground plane and interference via the interfaces.

5.3.1 EMI (Electromagnetic Interference)

For example, the electric fields from the LMX9838 antenna may couple in to the digital and analog sub-systems and these may need shielding. Also, sub-systems generating strongly interfering electric fields can couple in to the LMX9838 causing performance degradation, in this case the sub-system causing the interference should be shielded.

Therefore shielding a sub-system can prevent interference into other sub-systems as well as preventing susceptibility to interference from the other sub-systems. Note that the LMX9838 cannot be shielded as it contains the antenna.

5.3.2 Interference via Ground Plane

If all sub-systems are placed on a single ground plane then circulating currents can cause interference and un-predictable behavior. This tends to occur from a noisy digital section to a sensitive audio or Radio Frequency part.

Having separate ground planes for each sub-system can prevent this effect (as shown in *Figure 10*).

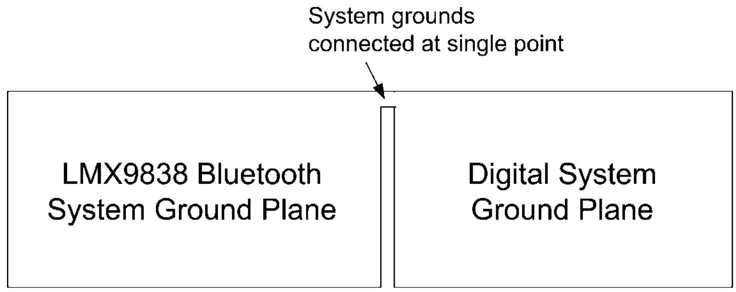

FIGURE 10. Sub-system Ground Planes

The ground planes should not overlap and should be positioned as close as possible to each other. They should be connected together at a single point.

6.0 Bibliography

[1] AN-1587: LMX9838 Design Guide

5.3.3 Interference via Interfaces

Often unwanted high frequency signals can be transmitted down the interface and filtering can be used to reduce this effect.

Notes

Notes

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