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Novel Packaging Approaches for Miniature Antennas

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ABSTRACT
We introduce a new type of miniature Bluetooth antenna known as a DC inductive shorted patch antenna (DSPA). It is fabricated as a single layer flex circuit wrapped around a high temperature foam substrate. The DSPA has a low 2.2 mm profile, an electrically small footprint of 9x12.6 mm, and it is surface mountable directly on a metal ground plane. In this paper, we report not only on the electrical performance of this Bluetooth antenna, but we introduce a new packaging concept in which the antenna contains an embedded Bluetooth radio LTCC MCM. The result is an integrated radio and antenna package, which is surface mountable. Antenna performance is reported for the integrated package.

Key Words: Bluetooth antenna, DCL shorted patch antenna, Bluetooth MCM

1. INTRODUCTION

The mobile wireless industry is under unprecedented pressure to bring products to market sooner, at a lower cost, smaller in size, with increased performance and more features. This has forced a trend to further integrate functions and reduce part count, often resulting in massive efforts to modularize the electronics using approaches such as Multi-Chip-Modules (MCM's). To further improve on size and industrial design of wireless portable devices, internal antennas are quickly becoming the preferred solution.

The application of engineered materials such as frequency selective surfaces (FSS's) allows the realization of a variety of high performance electrically small antennas. These materials provide a new degree of design freedom resulting in the creation of low-profile antennas that can be surface mounted directly on a ground plane, constructed with low cost materials such as FR4 and flex, and require minimal labor. Assembly onto the main PCB of the product is done simply by use of standard surface-mount reflow techniques. These antennas exhibit very little frequency detuning due to changes in ground plane size, or proximity of components or users. (i.e., in-situ performance) This makes them particularly well suited for applications such as Bluetooth, which are intended for use in a multitude of different environments – ranging from ground planes the size of a thumbnail for products such as wireless hands-free kits, to huge ground planes for applications such as printers or even vending machines. Very low profile Bluetooth devices for "wearable" applications integrated into clothing or accessories also become more practical.

Traditionally, the antenna has always been a separate component, whether it was an internal antenna or external antenna, but this new class of antennas can ultimately be fabricated as an integral part of the RF module. These antennas provide a new opportunity for an even greater level of RF integration, and, as shown in this paper, antennas of this type have been fabricated with a complete Bluetooth RF MCM system embedded inside the antenna! Using new, engineered materials, antennas can be designed to accommodate both passive and active RF components within their form-factor without any significant degradation of antenna performance.

2. BLUETOOTH ANTENNA

A new type of miniature printed antenna known as a DC inductive shorted patch antenna (DSPA) is described. This antenna has a metal pattern of etched inductors and capacitors, which are derived from the periodic structure of a DC inductive (DCL) frequency selective surface (FSS). When DCL FSS materials are used in printed antenna designs, they perform the function of an electromagnetic slow wave structure [1,2]. The net result is an electrically small antenna, of largest dimension $\lambda/10$, whereby the size reduction is achieved without the cost and weight of dielectric loading.

Figure 1 shows the top and bottom views of a Bluetooth DSPA. This antenna is a surface mountable component with nominal dimensions 2.2 x 9 x 12.6 mm, and a mass of 0.12 grams. It is fabricated by wrapping a flexible substrate of single sided copper clad polyimide around a syntactic foam core. The foam is a lightweight two-part epoxy, which will survive temperatures of reflow solder processes. Note that the antenna contains its own ground plane, and it is designed to be reflow soldered directly to a metal surface of a PCB.

The return loss for this antenna is shown in Figure 2. This DSPA has been optimized for performance at the 2.4 GHz Bluetooth band, however, it also has a second resonance near 5.3 GHz. It is a dual band antenna, but the focus of this paper is on the Bluetooth band. The nominal impedance bandwidths are 125 MHz, 220MHz, and 300 MHz for a minimum return loss of -10 dB, -6dB, and -3dB.

Figure 3 shows the antenna efficiency as measured in e-tenna's Satimo spherical near field scanning antenna range [3]. The peak antenna efficiency is near –2.6 dB, or 55%. This measurement was made with a 45mm square test ground plane, as shown in Figure 7(b). This ground plane is a .031" FR4 PCB with a microstripline on the underside. Antenna patterns are omni-directional for small ground planes, and defined by the size and shape and integration details for larger platforms.

One of the notable features of the DSPA is that its resonant frequency is relatively insensitive to environmental factors, including the ground plane size. Figure 4 shows a summary of ground plane size experiments in which the 250 mm square copper ground plane is the baseline. Deviations are measured relative to this size as the area is reduced down to 15x20 mm. The shift in resonant frequency is 3 MHz or less for sizes as low as 30mm square. Even for the electrically small size of 15x20 mm ($.12\lambda$ x $.16\lambda$ at 2.4 GHz), the net shift is only 31 MHz. Resonant frequency of the DSPA is also expected to be insensitive to the arrangement of nearby surface mounted components. In addition, return loss experiments with a surrogate human head have shown a net frequency shift of 15 MHz between the free-space and on-head environments.

To gain an appreciation for the repeatability of the DSPA design using flex-on-foam construction, a sample of 10 antennas were hand assembled. The tabulated summary of resonant frequency, bandwidth, and height are shown in Figure 5. The key parameter is resonant frequency, which had a relatively small standard deviation of only 14 MHz.

3. BLUETOOTH MCM

The Bluetooth MCM is a complete radio system solution made by Ericsson Microelectronics. Physically, it is a 10.5 x 15.5mm LTCC package, which contains all RF components plus the baseband, memory, crystal, software and firmware. Figure 6 shows a view of the front and back of this Bluetooth transceiver MCM.

4. INTEGRATED BLUETOOTH RADIO AND ANTENNA

Our goal was to evaluate the impact on antenna performance for the case where the Bluetooth MCM is embedded inside of the DCL shorted patch antenna (DSPA). Foam was used to over-mold a portion of the Bluetooth MCM footprint. It was machined to a given thickness, and the flex circuit containing the antenna was wrapped around the assembly and attached with a pressure sensitive adhesive. Figure 7(a) shows the final result. The total package height is 3.0 mm.

This integrated radio/antenna was surface reflow soldered to a 45 mm square ground plane shown in Figure 7(b). Return loss and range measurements were made with this size of test fixture. The return loss, shown in Figure 8, reveals resonant frequencies to be near 2380 MHz and 5150 MHz. This is a shift of only 3.5% relative to the DSPA without an embedded Bluetooth MCM, and the design can easily be adjusted to be on frequency.

The most significant factor after integration is the impact of the MCM on antenna efficiency. This is plotted in Figure 9. The DSPA alone measured a peak efficiency of 55% (-2.6 dB), while the antenna wrapped around the Bluetooth MCM exhibited a peak efficiency of near 47%, a surprisingly small difference of only 0.7 dB.

5. FUTURE PRODUCT

A packaging vision for a future Bluetooth radio module with an integrated antenna is shown in Figure 10. The entire LTCC footprint has a foam over-mold, and the flex circuit attaches to the BGA along opposite ends. The antenna is a metal pattern on the top of the integrated MCM. The RF feed and ground connections are printed on the flex circuit as demonstrated above.

6. CONCLUSIONS

In this paper we have introduced the concept of a low cost, dual-band, flex-on-foam antenna for Bluetooth and 802.11 applications. This antenna is electrically small given that its largest dimension is $\lambda/10$ at its low band resonance. Size reduction is achieved without any dielectric loading, but instead by designing the antenna with built in inductors and capacitors to act as a slow wave structure. Such internal loading allows the resonant frequency to be quite insensitive to proximity effects and to changes in ground plane size and component layout. But most unique is the ability of this class of low profile antenna to be surface mounted directly onto a ground plane. Thus, the real estate on the opposite side of the PCB can be used for additional components.

The next step demonstrated in Bluetooth system integration was to wrap the antenna around an LTCC-based MCM Bluetooth system. The LTCC circuit then becomes the floor of the electromagnetic cavity for the antenna. Tests in the Bluetooth band indicate that the change in resonant frequency is on the order of –3.5% compared to the same antenna without the MCM radio, and that the degradation in antenna efficiency was on the order of only 0.7 dB due to the integration of the radio module. Peak antenna efficiency was still on the order of 47%, even with the embedded Bluetooth radio module.

The integration of all RF functionality into a single multi-chip module, including the antenna, is the ultimate reduction in size and cost of an RF subsystem. This also simplifies packaging and assembly, resulting in improved reliability. A single solution that is tolerant to changes in its environment will also reduce design cycles and accelerate time to market, a must for companies competing in wireless consumer electronics markets.

7. REFERENCES

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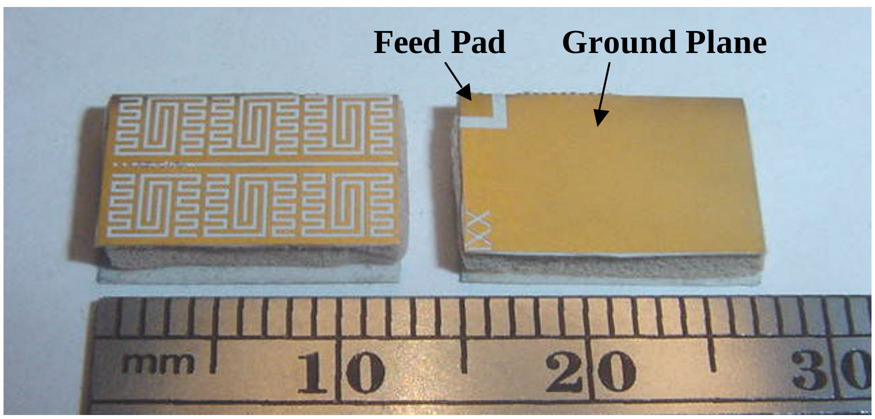


Figure 1. A low cost DCL shorted patch antenna for Bluetooth applications. A top view is shown at left, and the bottom view is shown at right.

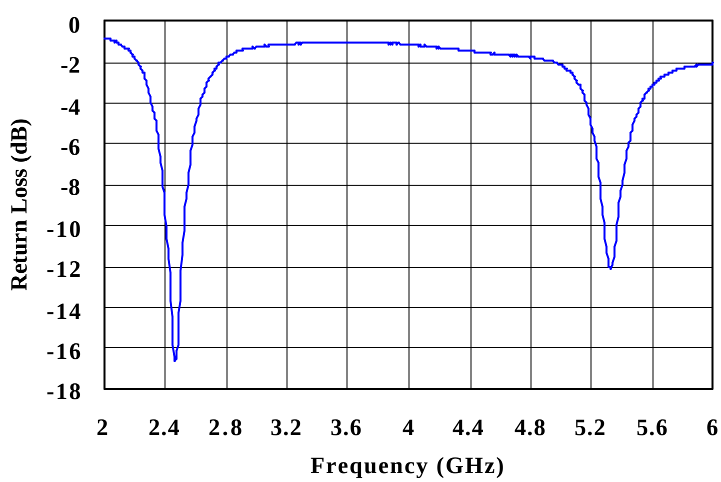


Figure 2. Typical return loss for the Bluetooth DCL shorted patch antenna, as shown in Figure 1, when mounted on a 45 mm square ground plane (see the ground plane in Figure 7(b)).

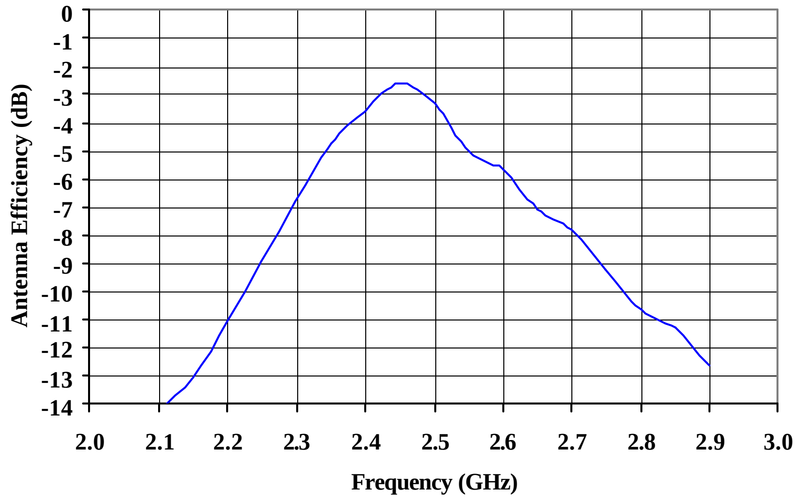
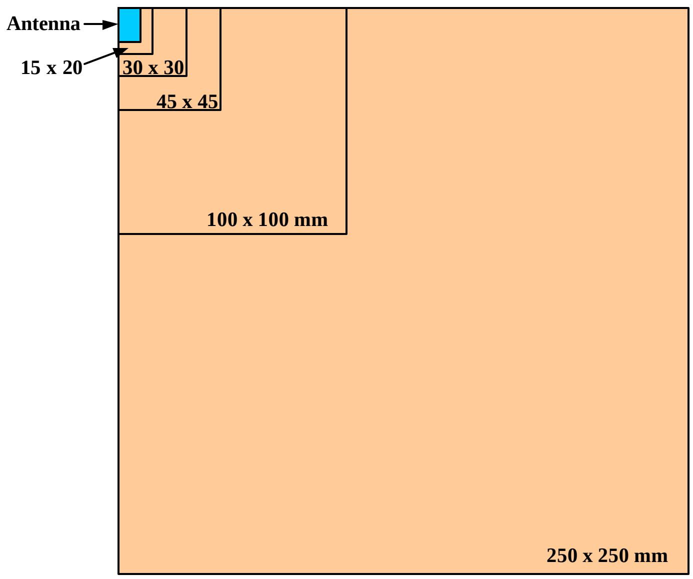


Figure 3. Typical measured antenna efficiency for the Bluetooth DCL shorted patch antenna, as shown in Figure 1, when mounted on a 45 mm square ground plane (see the ground plane in Figure 7(b)).



Ground Plane Size (mm)	Resonant Freq (GHz)	Freq. Delta (GHz)	S11 Null (dB)	-3dB Low (GHz)	-3dB High (GHz)	-3dB BW (GHz)	BW Delta (GHz)
250X250	2.458	0.000	-14.5	2.302	2.634	0.332	0.000
100x100	2.457	-0.001	-12.0	2.318	2.622	0.304	-0.028
45x45	2.460	0.002	-13.8	2.298	2.629	0.331	-0.001
30x30	2.460	0.002	-8.9	2.344	2.604	0.260	-0.072
15x20	2.489	0.031	-11.2	2.360	2.647	0.287	-0.045

Figure 4. This summary of the ground plane size experiments reveals less than 3 MHz of frequency shift for ground plane sizes equal to or greater than 30 mm square.

Sample	Resonant Freq (GHz)	S11 Null (dB)	-3db Low (GHZ)	-3db High (GHz)	-3dB BW (GHz)	Height (Mils)
XXIB-001	2.465	-16.7	2.285	2.680	0.395	87
XXIB-002	2.450	-45.0	2.260	2.670	0.410	89
XXIB-003	2.429	-27.4	2.248	2.632	0.385	91
XXIB-004	2.420	-21.4	2.255	2.612	0.357	89
XXIB-005	2.435	-24.8	2.287	2.612	0.325	86
XXIB-006	2.436	-28.0	2.272	2.617	0.345	88
XXIB-007	2.440	-33.6	2.275	2.635	0.360	85
XXIB-008	2.457	-17.5	2.265	2.652	0.388	88
XXIB-009	2.435	-22.0	2.267	2.615	0.348	87
XXIB-010	2.468	-33.9	2.275	2.642	0.368	87
Mean	2.444	-27.0	2.269	2.637	0.368	88
Std Dev	0.014	7.8	0.011	0.022	0.024	1.540

Figure 5. Sample to sample variation for 10 hand assembled DCL shorted patch antennas.

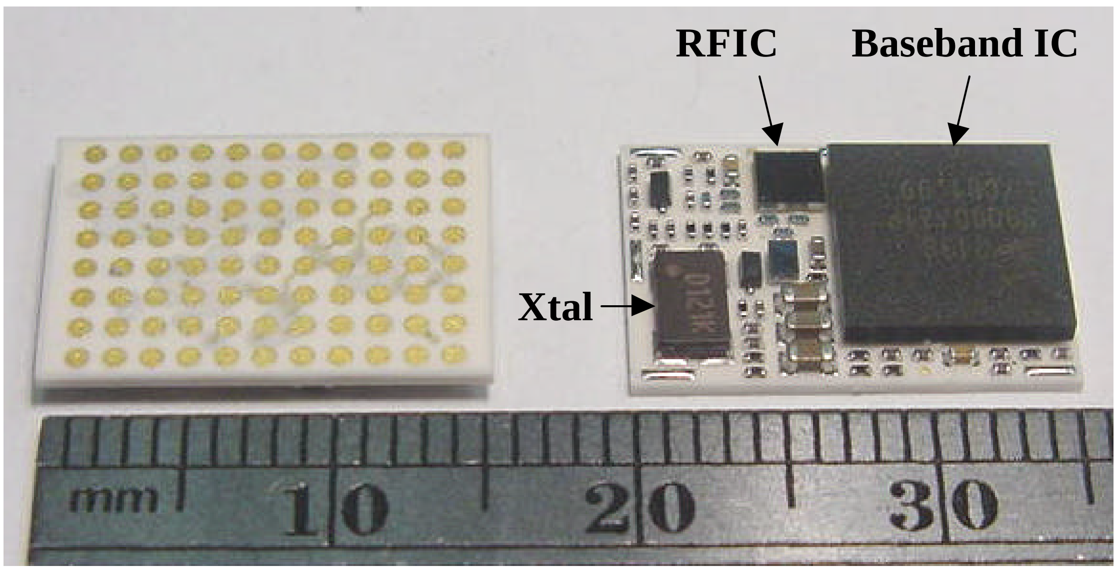
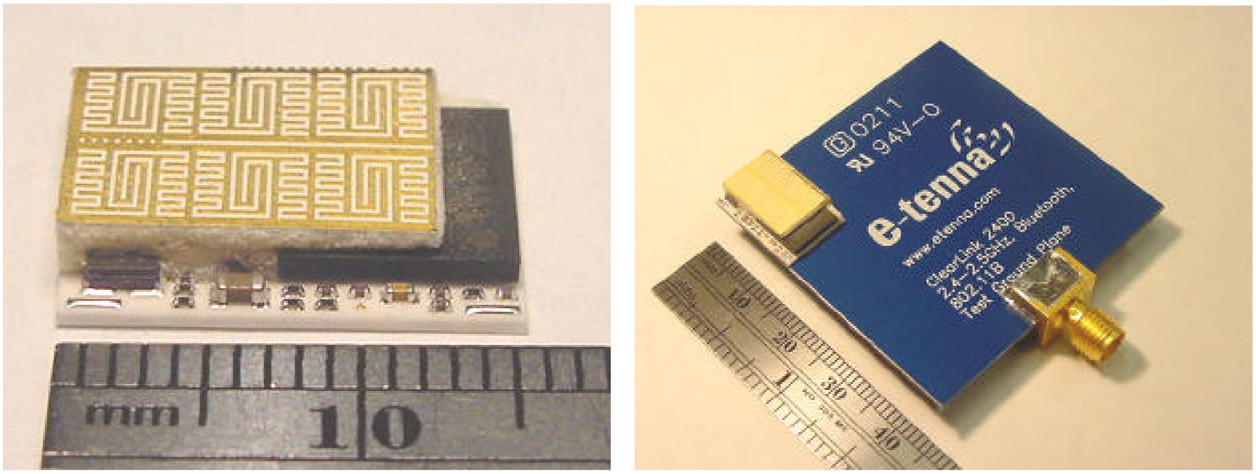


Figure 6. An Ericsson Bluetooth MCM.



(a) **(b)**

Figure 7. (a) A DCL shorted patch antenna with an embedded Bluetooth MCM, (b) Integrated antenna and Bluetooth MCM mounted on a 45 mm square ground plane. This size ground plane was used for all measurements presented in this paper except for Figure 4. Note the antenna is mounted directly on a metal surface.

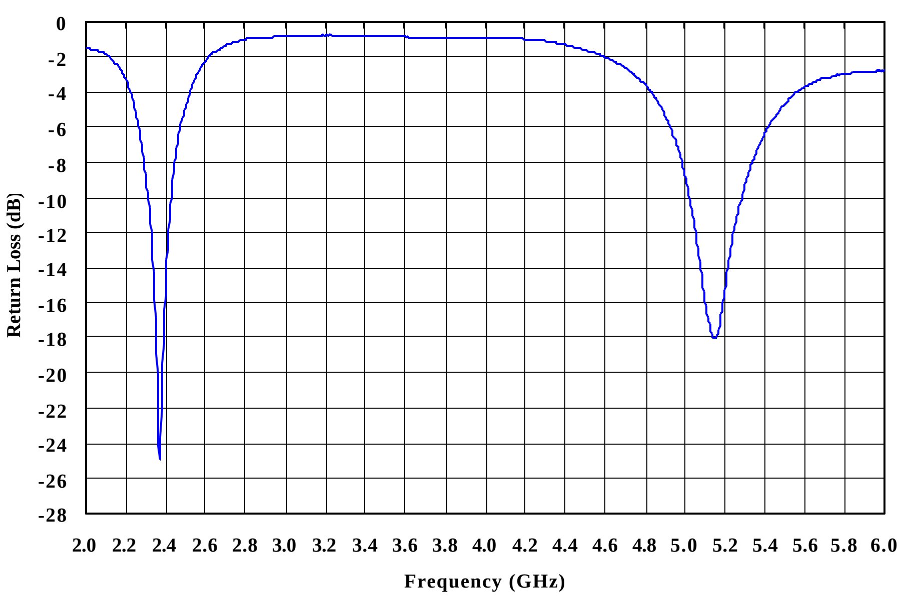


Figure 8. Return loss for the DCL shorted patch antenna with an embedded Bluetooth MCM.

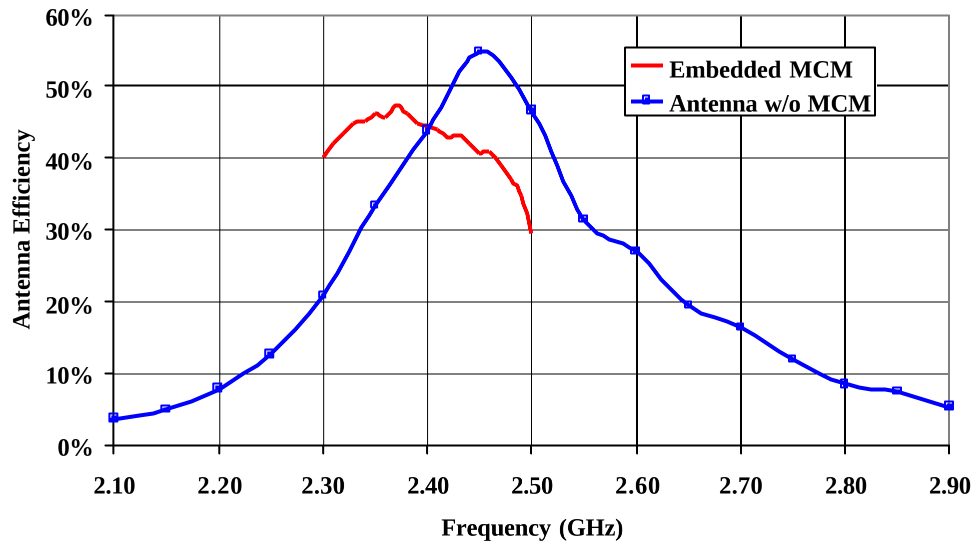


Figure 9. Measured antenna efficiency of the DCL shorted patch antenna with and without an embedded Bluetooth MCM.

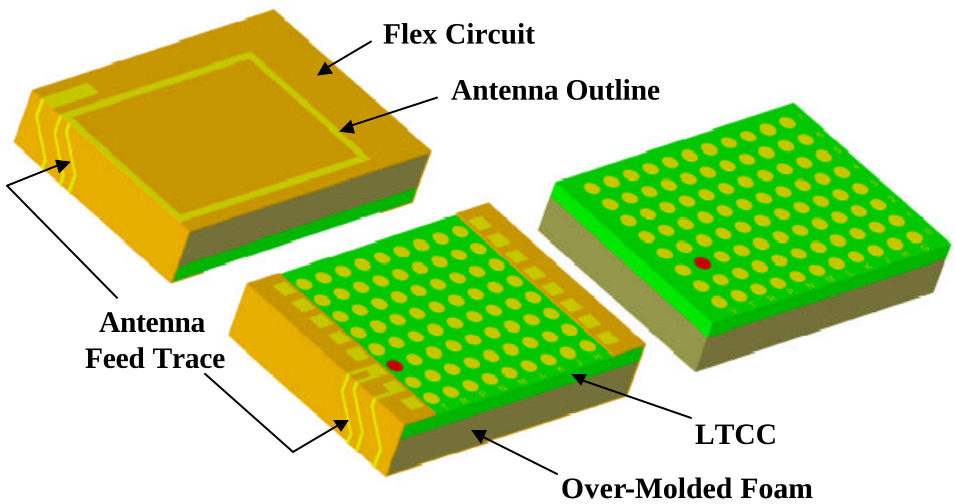


Figure 10. Package integration concept for a complete Bluetooth MCM including an integrated antenna.