HIGH LEVEL OF INTEGRATION FOR BLUETOOTH MODULES ON LTCC

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Abstract

LTCC (*l*ow *t*emperature *c*o-fired *c*eramic) stands for a ceramic substrate system, which is applied in electronic circuits as a cost-effective and competitive substrate technology with nearly arbitrary number of layers. Printed gold and silver conductors will be used in general. The metallization pastes will be screen printed layer by layer upon the un-fired or "green" ceramic foil followed by stacking and lamination under pressure. The multilayer ceramic stack will be fired (sintered) in the final manufacturing step. The temperature of sintering is below 900°C for the LTCC glass-ceramic. This relative low temperature enables the co-firing of gold and silver conductors. The low line losses as well as the competitive manufacturing costs are an advantage of LTCC for RF and microwave applications. Several LTCC manufacturers like National Semiconductor, Ericsson, Murata and Philips have utilized this technology to launch Bluetooth modules on the market. Their effort results in extremely compact circuits in competitive prices. Today, a class 2 module with 2.5 mW output power is available on an area of about 10 x 12 x 2 mm. The authors have investigated this technology, too and have developed customer driven Bluetooth solutions. Each one is equipped with an integrated antenna, which is printed on the ceramic substrate.

1. Introduction

Bluetooth is a wireless standard for ad hoc networks operating at 2.45 GHz. The envisaged market is for consumer electronics. Up to eight devices are able to build up a communication network to exchange information like data, voice or video between each other. Consumer devices (e.g. mobile phones, cameras, notebooks …) have to be equipped with a Bluetooth Module (BM) to enable the standardized and application dependent data transfer. Each BM consists of the RF-part, base-band circuit, flash memory and a special software. It is obvious that miniaturization and low power consumption are important prerequisites for an integration into mobile devices. The chip manufacturers undertook strong efforts to develop one- and two-chip solutions, where RF-part, base-band and memory are integrated in 1 or 2 IC's. An other potential to miniaturize the BM is to bury the peripheral circuitry into the multilayer carrier substrate. Such components are any R-L-C elements, the RF-balun, the antenna and additional external amplifiers (LNA or PA). LTCC offers excellent capabilities for this purpose: high resolution lines, small pitch distance for BGAs, cavities, printed resistors and a multilayer environment for capacitors, inductors, the antenna and 3D interconnects. The production price is low for high volumes, so that a number of BMs is already offered on LTCC. The authors have investigated available modules on the market and compared their characteristics. They also developed two application driven BMs on LTCC. One was fabricated on Ferro's A6S with the "BlueCore 02" from Cambridge Silicon Radio and the second one utilizes DuPont's tape 951 with Infineon's "BlueMoon 8760". Both LTCC modules are available with and without integrated antenna, which means that an inverted-F antenna structure has been designed for the specific substrate properties and the layer configuration. The following paper will give an overview of the Bluetooth technology, an up-to-date comparison of available modules on the market and considering IMST's developments as example, the integration and miniaturization capabilities will be demonstrated.

2. Bluetooth chips and modules

No doubt, Bluetooth in on its way to play an important role in today's and future consumer applications. There is an increased need for fast, reliable and ad-hoc wireless data transfer from one consumer device to an other. Typical applications are mobile phones, PDAs, notebooks, modems, cameras, printers and other mobile and tabletop equipment. To satisfy the

consumer's needs, Bluetooth modules have to be small and require low power consumption. To ensure compatibility among the different devices, a general standard with application driven profiles has to be implemented into each module. This software (protocol stack) is stored in the memory chip (flash). The flash may be part of the base-band IC or an extra component on the board of the Bluetooth module. Further elements of a Bluetooth application are the radio chip for the transmission and reception of the 2.45 GHz signal, the Tx/Rx switch and the antenna. An example of such a configuration is illustrated in figure 1.

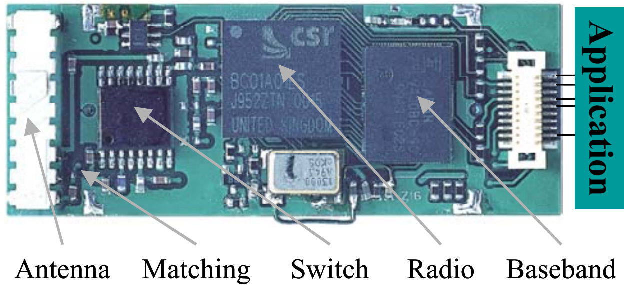

Figure 1: Example of a Bluetooth module

The integration activities of the chip suppliers are preceding very rapidly. In the meantime a number of "single-chip solutions", where radio, base-band and flash are on one IC, are already available on the market. The names of some selected suppliers are Chipcon, Crossbow, CSR, Infineon, Innovent Systems, National Semiconductor, Transilica (Microtune) and Zeevo. However, there are still more "multi-chip solutions" available, while multi-chip does of course not imply a drawback for specific applications. The chips will be mounted on multilayer boards together with additional SMD components. This results in Bluetooth modules, which are ready after flashing the software for integration in consumer devices. Some of the module suppliers decided to use multilayer PCB, while others utilize multilayer ceramic or even both technologies. The following companies offer Bluetooth modules. Those, which are underlined exhibit the advantages of LTCC: ALPS, CSR, Ericsson, Inventel, Mitsumi, Motorola, Murata, National Semiconductor, Philips, Sharp, Taiyo Yuden and Zeevo/azzurri.

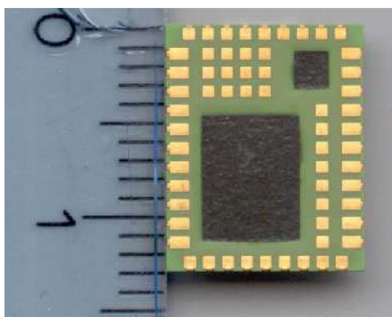

Figure 2: Murata's class2 module on LTCC

The photo in figure 2 shows the backside (with the footprint) of an exciting module on LTCC from Murata. It is extremely small, because some components have been integrated into cavities from the backside using bare-chip mounting. Afterwards the cavities are filled with glob top. Murata explained, that a size reduction of 30% and a weight improvement of 40% could be achieved in contrast to conventional technologies. In addition Murata replaced a number of SMD elements by buried components in LTCC. The good RF performance of the ceramic tape as well as the conductor properties made this advantage possible.

3. BT-module on LTCC with integrated antenna

Knowing the advantages of LTCC and motivated by the successful designs of leading companies the authors started to develop their own application driven Bluetooth modules. The preliminary goal of the effort was the development of a platform for further improvements. This includes an integrated antenna printed on the ceramic tape. The antenna team of IMST [5] has realized an inverted-F structure to achieve the desired radiation pattern. The conductor branches have been folded to reduce the space on the ceramic. Such an integrated antenna has the advantage, that neither an expensive connector or transition to an external antenna is required, nor an SMD antenna has to be mounted onto the board. Figure 1 shows such a component on the left side, which is typically made of multilayer ceramic and multiple folded conductor lines. The authors have made the experience, that the performance of such SMD antennas strongly depends on its environment especially the geometry of the circuitry and the position of the SMD component on this board.

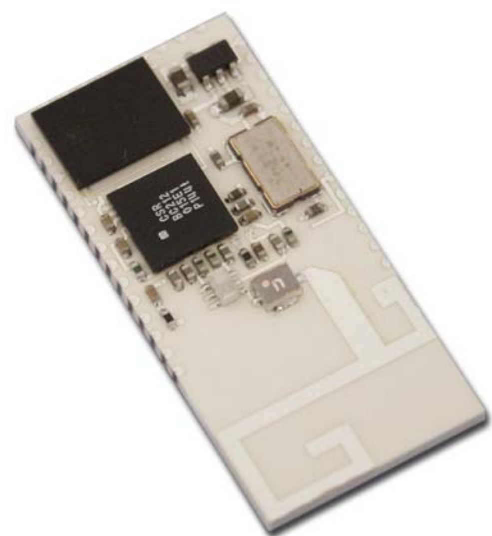

Figure 3: IMST's Bluetooth module on Ferro A6S with BlueCore 02 from CSR and integrated antenna

Figure 3 shows the first LTCC module developed by the authors. The antenna requires about one third of the ceramic substrate. This is somewhat larger than SMD antennas from the shelf, however measurements could demonstrate a better radiation characteristic of the printed structure. The first BT-module was made on Ferro's LTCC tape A6S with silver conductors. Six layers have been used resulting in a total size of 15 x 32 mm including the antenna and 15 x 21 mm without antenna. The single-chip solution "BlueCore 02" from Cambridge Silicon Radio (CSR) has been utilized with an additional flash memory (AMD 8Mbit).

Figure 4: IMST's BT-modules beside a mobile phone with BT-capability

The second BT-module, which has been developed is made with DuPont's LTCC tape 951. Again the antenna is an inverted-F structure like in the first module. Now, the single-chip solution "BlueMoon 8760" from Infineon has been mounted on the multilayer ceramic. This IC has sufficient memory, so that no additional flash chip is required. That's why the second BT-module is smaller. Furthermore the dielectric constant of DuPont's "green tape" 951 is higher (k = 7.8) than the Ferro A6S ceramic (k = 5.9). This results in shorter transmission lines per wavelength. The total circuit size is 14.5 x 28 mm including the antenna and 14.5 x 16.5 mm without antenna. Figure 4 illustrates both LTCC modules next to a mobile phone, which is equipped with Bluetooth hardware for wireless communication and data-transfer with other consumer devices like a headset or a notebook. The authors have implemented a wireless connection between the phone and a notebook for an internet access to demonstrate the ability of the LTCC modules. An evaluation board has been developed to connect the BT-module with the serial port (RS232) of the notebook. Figure 5 shows a photo of the evaluation board with one of the Bluetooth modules.

Figure 5: Evaluation board for LTCC BT-module

4. Acknowledgment

The authors wish to thank the LTCC material suppliers Ferro and DuPont for their support to make the tapes and conductor pastes available. They also delivered design and manufacturing rules and gave helpful hints how to process the materials. Special thanks are given to the chip supplier Cambridge Silicon Radio (CSR) and Infineon for their support of the authors with samples and early information about their chips.

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