Electrical Characteristics of Ceramic SMD Package for SAW Filter

Kota Ikeda, Chihiro Makihara
Kyocera Corporation
Semiconductor Component Division Design Center
1-1 Yamashita-cho, Kokubu, Kagoshima, 899-4396, Japan

1. Introduction

With the proliferation of cellular handsets, they are now becoming an indispensable item in our daily lives. Multitude functions and uses of cellular handsets are becoming manifest, resulting in a system that allows exchanging of sounds as well as other various data types. And because the system is changing dramatically and drastically each year, the life cycle for each of the systems is becoming shorter. In this situation, the demands for developing components with added values and performances are accelerating in the market. Needless to say, these demands are seen for SAW filters, where a numerous quantity is adopted in cellular handsets.

Recently, there has been examples where ceramic SMD (Surface Mount Device) packages are not used for SAW filters to protect the SAW device. However, the demand for ceramic SMD packages is still intensified where compact miniaturization, high reliability in harsh environmental conditions, and excellent electrical characteristics are required. Furthermore, modulization or establishing built-in functions using multilayer ceramic technology is attempted, as seen in ceramic duplexers, From the above mentioned advantages, ceramic SMD packages have established a dominating position for SAW filters.

On the other hand, electrical performance required for SAW filters has become more and more severe as further advancements are made in the system. It is essential to investigate the total electrical characteristics including the package. However, the relation between electrical characteristics of SAW filter and the package is not clear at present. Therefore, the circumstances are quite difficult to achieve satisfying electrical characteristics.

This paper will describe several electrical characteristics of ceramic SMD packages for SAW filters, the requirements in a packaging design in terms of electrical characteristics, and items to tackle in the future.

2. Ceramic packages

2-1 Ceramic SMD packages for the cellular handset market

Figure 1 depicts a block diagram of a cellular handset. Various types of ceramic packages, not limited to SAW filter, are widely utilized to achieve compact miniaturization.

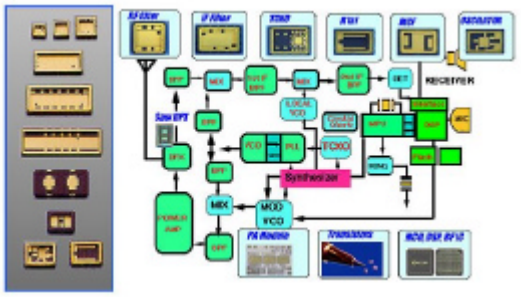


Figure 1: Block diagram of a cellular handset

Figure 2 is a pie graph that illustrates the quantity ratio for each ceramic SMD Package type adopted in cellular handset application. More than 60% is dominated by ceramic SMD packages for SAW filters, and the statistics proves that it is widely adopted.

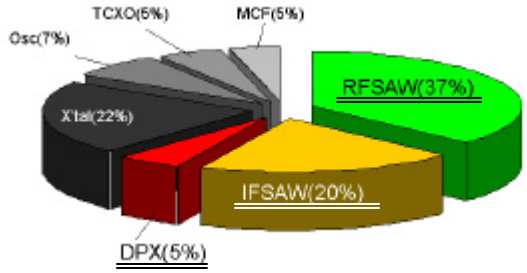


Figure 2: Quantity ratio of Ceramic SMD Packages adopted in cellular handset application

Now, we will briefly describe the structure of ceramic SMD packages for SAW filters. Ceramic SMD packages for SAW filters are manufactured using the ceramic multilayer technology. As Figure 3 depicts, the package consists of 3 to 5 conductor pattern and insulation layers. The conductor pattern layer is consists of; top layer is a seal ring layer for lid seal, middle layer is a bonding finger pattern layer to interface the device I/O`s with the SMD external outputs, and bottom layer is a footprint pattern layer. The conductor patterns in each of the layers are electrically connected by VIA holes and castellations. VIA holes are columnar shaped holes punched on the insulation layers, which are filled-up with conductors. Castellations are semicircular-shaped conductors located on the side of package. This is mainly what composes the ceramic SMD packages structure.

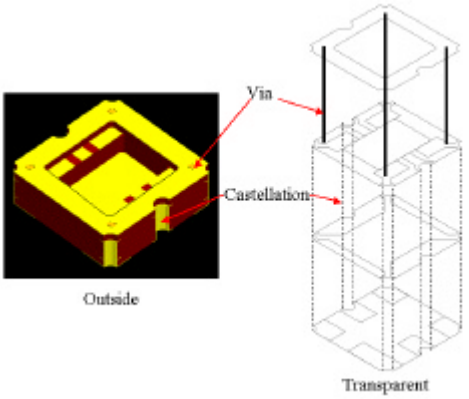


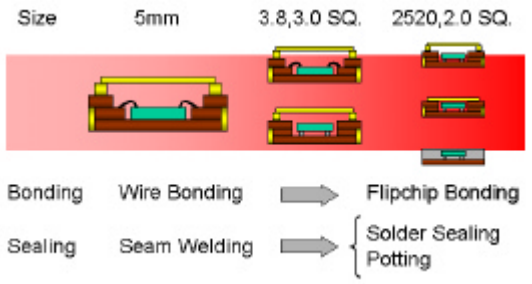
Figure 3: Ceramic SMD package structure for SAW filters

2-2 Market trend of ceramic SMD package configuration for SAW filters

Figure 4 depicts the market trend of ceramic SMD package for SAW filters, which is basically divided into 2 main items; down sizing and high function. There are attempts

to develop a package with OD of 2.5x2.0mm or 2.0mm square compared to the conventional 3.8 mm or 3.0mm square. Other developments involve high functional SAW filter such as duplexer and front-end modules.

(1) Down Sizing



(2) High Function

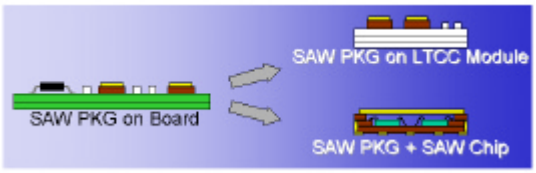


Figure 4: Market trend of ceramic SMD packages for SAW filters

The development of small SAW filters with size of 2.5x2.0mm or 2.0mm square have been reported. Furthermore, many types of packages, including wire bonding, flip chip, and substrate have been introduced. This is because the specifications become more and more diverse as they are in number, and they must be considered together with package configuration. For example, 1st level mounting includes wire bonding or flip chip, and lid sealing includes seam welding, Au-Sn, epoxy, or other methods.

2-3 LTCC (Low Temperature Co-fired Ceramics)

Currently, HTCC (High Temperature Co-fired Ceramics) is the material mainly utilized for SAW filters. Meanwhile, LTCC (Low Temperature Co-fired Ceramics) with copper conductors for internal pattern is now in the limelight.

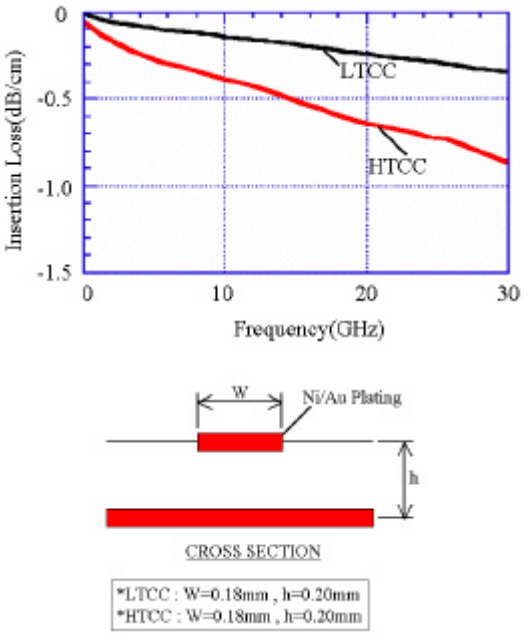


Figure 5: High Frequency Transmission line characteristics at Microstrip line

Figure 5 depicts the transmission line characteristics of LTCC at high frequencies. By adopting copper conductors for internal pattern, results show that the insertion loss is under 0.2dB/cm at 2GHz. A low transmission loss has been proven. This LTCC has been adopted for PA modules in the cellular handset application, as depicted in Figure 6. The size of a typical finished product is 7mm x 7mmx 1mm, composed of 5-6 layers. This PA module incorporates built-in inductor,

capacitor, filter, and coupler to compose impedance matching circuits. LTCC is utilized because each of these functions requires low transmission loss. This "built-in" package design technology is sure to be transferred for the development of high functional SMD packages for SAW filters, which is expected to be required in the future.

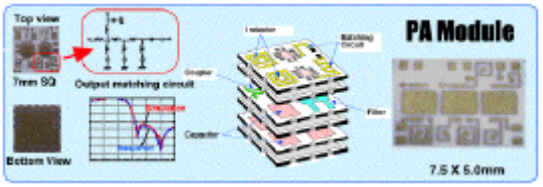


Figure 6: PA Module

3. Electrical characteristics of Ceramic SMD Packages for SAW Filters

The requirements, in terms of electrical characteristics, for SAW filter packages are low transmission loss and high attenuation. To bring forth maximum effect of filter, it is important to maintain minimum transmission loss within the passing bandwidths and high attenuation for out of the passing bandwidths. There are 2 main types of transmission loss caused by the package; loss from conductors and loss from dielectric of ceramic material. At 1-2 GHz, the frequency range that SAW filters use, there is a tendency that the transmission loss derives from the conductors. This loss is consistent with the transmission characteristics illustrated in Figure 5.

Meanwhile, one of the factors in which the package influences the attenuation of filters is the emergence of isolation between the signal line. Isolation characteristics especially have a large effect on the attenuation of filter. An image graph with fluctuation is depicted in Figure 7.

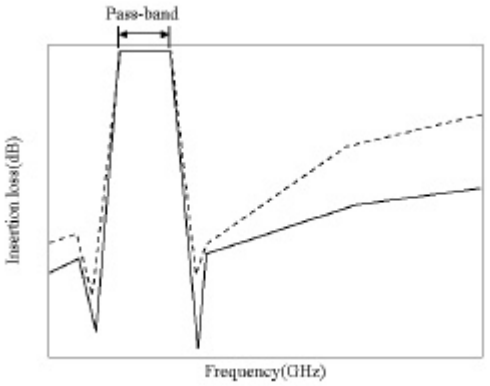


Figure 7: Model of electrical characteristics fluctuation of SAW filters

The isolation of package is generally measured without mounting of devices and the I/O terminals are not connected. Therefore theoretically, the isolation between these I/O terminals should be near infinite. However, these I/O terminals, not connected by direct current, will not show results as the theory would. This is because the electrical radiation at transmission lines in high frequencies and GND noise causes the signals to jump and transmit between the I/O terminals. The package design plays a crucial role in avoiding this phenomenon. Packages are designed for increased isolation by restraining electrical radiation and GND noise.

One example, depicted in Figure 8, is design technology of a high frequency package for 10Gbps transmission switch. To increase isolation, GND VIA holes are allocated along the signal line. This allocation is depended on the signal frequency. By doing so, the route

for signal is increased and GND is reinforced. This new packaging solution will minimize high frequency signal radiation and GND noise figure. As a result, high isolation is demonstrated.

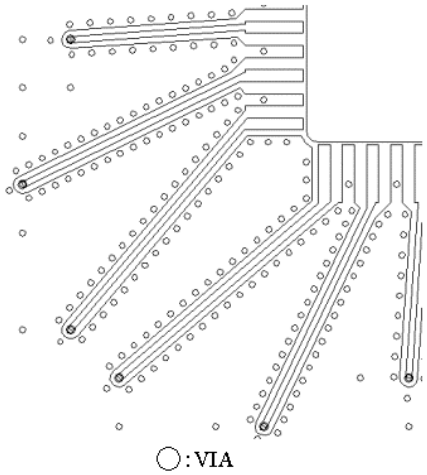
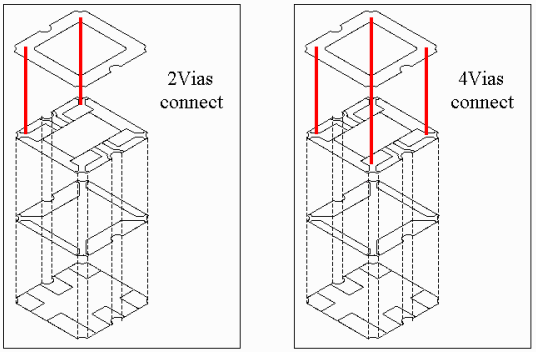


Figure 8: Example of an internal pattern of a high frequency package

Accordingly, attempts to transfer this same design technology to SMD packages for SAW filters had been made, based on the fact that high isolation is achieved by establishing numerous VIA holes. Figure 10 shows the measurements results of isolation between the signal I/O terminals when quantity of VIA holes, which electrically connects seal ring pattern and internal pattern, has been increased from 2 to 4(Figure 9). As hypothesized, the test vehicle with 4 VIA holes demonstrated 60dB or over at broad bandwidths.



Two VIAs connect Four VIAs connect

Figure 9: Perspective sketch of change in quantity of VIA holes

However, at certain frequencies, the test vehicle with 2 VIA holes demonstrated better results.

As mentioned before, it is necessary to maximize the isolation in order to improve attenuation characteristics. Thereupon, the phenomenon of isolation decrease at certain frequencies is especially effective for forming an attenuation pole in regards of the attenuation characteristics of the filter. This attenuation pole becomes an important point for developing a high functional filter. It is vital to investigate the mechanism of why isolation value decreases at certain frequencies.

The cause of the this phenomenon, is related to the quantity of VIA holes of GND, which is greatly influenced by the L and C of GND. Therefore, adjusting the quantity and location of VIA holes and pattern configuration will change the isolation. Then L, C values of GND will change accordingly, which have shown results with deterioration of loss at certain frequencies.

Furthermore, simulation results show that the existing L between wire bonding of oncoming GND is 1-2 nH and existing C of GND and signal I/O terminals is about1 pF. The resonance frequency calculated from these L and C values are estimated to be about 4GHz. Because the decrease in isolation value was also seen near 4GHz in the measurement, there may be a relation to the L and C values. Although this hypothesis is based on lumped constant, it is crucial to get a better understanding of the mechanism of GND in high frequencies by distributed constant for further studies. And by doing so, we can clarify the cause of the fluctuation of isolation.

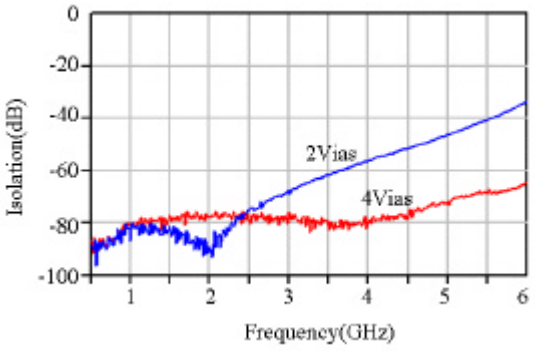


Figure 10:Measurement of Isolation between signal I/O`s

Figure 11 depicts the simulation results of current distribution of a package, with 2 VIA holes from seal ring pattern, illustrated in Figure 9. Leakage is confirmed here in electric currents transmitted through the seal ring and die attach and an unstable GND. Therefore, it is necessary to establish package design technology not simply connecting the GND electrically by direct current method, but through analyzing simulation test results in the standpoint of how a stable GND can be achieved with high isolation.

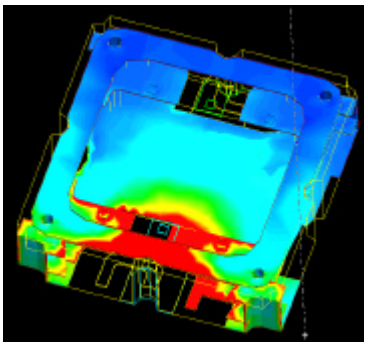


Figure 11: Simulation results of current distribution of 3mmSQ package at high frequencies

In ceramic packages, which can transform dielectric material to insulators, it is difficult to understand the radiation at transmission lines and GND noise by network constant. From this background, the key factor to make further analysis is to make maximum utilization of high frequency simulation tools, including the respect that visual examination is capable.

Another issue is the case where the electrical characteristics results differ due to the difference in ceramic material characteristics. Depending on the package manufacturer, HTCC material, which is generally adopted for SMD packages for SAW filters, has slightly different properties in material, metallization, and so on. For this reason, SAW filters, where very critical characteristics are demanded, with an equivalent package OD, will not have equivalent electrical characteristics in its SAW devices. It is almost impossible to

obtain equivalent electrical characteristics from adopting materials under the name of HTCC, which may have similar material properties.

4. Simulation technology: Electrical characteristics of Ceramic SMD Packages for SAW Filters

As mentioned in the previous section, the electrical characteristics varies according to the package design. Many evaluation samples are produced to fulfill the requirements from the SAW devices, but this accompanies tremendous effort, time, and cost.

From this background, attempts to make electrical characteristics estimations by high frequency simulation technology have begun. The flow of the simulation method is depicted in Figure 12.

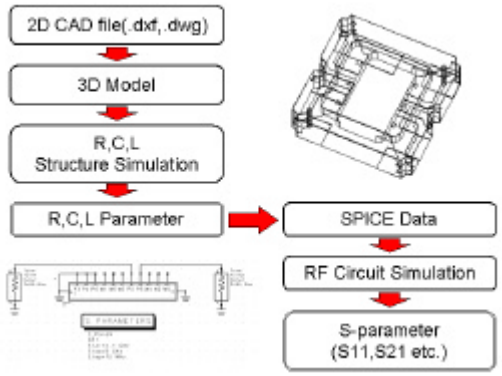


Figure 12: Flow of simulation method

Through this method, first the electromagnetic field simulation of a three-dimensional structure model is used to calculate SPICE data of package including R, C, and L values. These data are then inputted into the RF circuit simulation to obtain the simulation results of high frequency characteristics of the package.

Generally, when conducting analysis of electromagnetic field of high frequencies, S parameter simulator is utilized. However, the S parameter data, compared to the SPICE data, cannot express GND characteristics. Therefore, it is believed to be inappropriate for the simulation of SMD packages for SAW filters, where the variation of the GND characteristics is very important. In SPICE data, on the other hand, the package can abstract the equivalent circuit of R, C, and L values, and can express R, C, and L values of GND by fixed quantities.

Furthermore, in the future it is necessary to make simulation of both the SAW device and package combined. Also In this case, as mentioned before, the S-parameter data is inappropriate at some extents because of its lack of expressing GND characteristics.

For example, when simulation of SAW device and package combined is made, factors such as the location of bonding finger wiring, quantity, and length must be deeply considered. Despite the fact, when S parameter data is used, it becomes very difficult to correctly define each of the GND that are allocated on the package by an electrical aspect.

Figure 13 illustrates an example of S parameter and SPICE symbols derived when each data are inputted into RF circuit simulator. The test vehicle consists of four signal I/O terminals and eight GND I/O terminals. In S-parameter data, only four of

the GND had output. Therefore, the S parameter data does not include the wire bonding of GND, and subtle changes of the SAW filter characteristics cannot be confirmed. On the other hand, in SPICE data, a total of eight terminals including the GND had output. Each bonding terminals of GND and R, C, and L values even of the foot print terminals is capable to be expressed. Therefore, the simulation should be more consistent with the actual state.

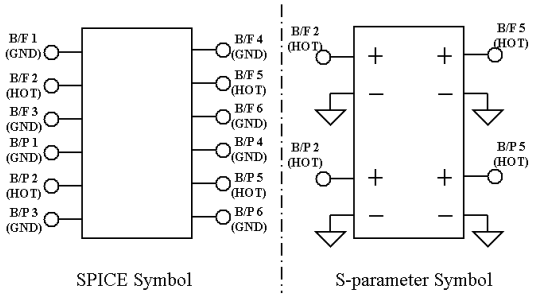


Figure 13: SPICE and S parameter symbols in RF circuit simulator

From the investigations, we found that SPICE data is more effective compared to that of S parameter when making package simulation for SAW filters. By doing so, characteristics of package model, especially GND, will be accurately expressed. As mentioned before, conducting the simulation of SAW device and package combined will enable to make obtain similar results as the actual finalized product. For example, the change in electrical characteristics from modifying internal pattern configuration, quantity or location of VIA hole, etc., can easily be confirmed without actually manufacturing evaluation samples. To have a good command of this simulation is directly related to achieving shorter cycle time in package development.

5. Future investigations

From our investigations, it is understood that the design of GND in a package is the solution to attain the required characteristics of SAW devices. However, presently, the mechanism of characteristic fluctuation is not yet clear. Because of the lack of this understanding, numerous evaluation samples are manufactured and tremendous amount of time must be involved to confirm the electrical characteristics.

The time has now come to establish an environment where manufacturing the samples for confirming electrical characteristics is drastically reduced and to be capable of supplying ceramic SMD packages in a timely manner. As described in the previous section, this ideal environment is realized only by having excellent command of high precision simulation tests. As the first step, electric characteristics of SAW filter packages with a relatively simple structure will be grasped accurately. On top of that, this expertise will be extended to development of high functional packages such as duplexers and front-end modules. There are limitations when confirming characteristics of a package itself, so it is essential to investigate together with the device.

Moreover, from the market trend of cellular handsets market, SAW devices will be

allocated for an even higher frequency of 5GHz. Therefore, packages to meet this requirement must be developed. The frequency, 5GHz, is two times higher than present allocation, and the electrical characteristic requirements are predicted to become more critical.

Figure 14 depicts the results of isolation characteristics to 10GHz using the same test vehicle of which it's results shown in Figure 10. The isolation is deteriorated, as the frequency is higher. Judging from this result, the isolation is under 50dB at 10GHz, and is not acceptable in the market because the results will influence the attenuation of the SAW device.

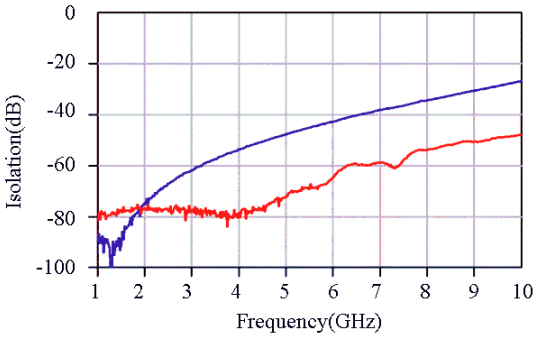


Figure 14: Isolation results between signal I/O`s in 3mm square package

One solution for improvement in this package is to refer to the package designing technology of a RF-BGA package (Depicted in Figure 15) used for over 10GHz in base station applications.

Figure 16 illustrates an example of a design of VIA area of a RF-BGA package. By designing the package to maintain an impedance matching of 50 ohms, easier signal transmission and signal leakage prevention is achieved. This packaging technology can be used as a reference in avoiding deterioration in isolation characteristics, which is an important point for requirements of SAW filters. However, as mentioned before, it is necessary to keep in mind that SMD packages for SAW filters are small, under 3mm in size, and adopting general process technology to this package is difficult. A new processing technology will be needed to do this.

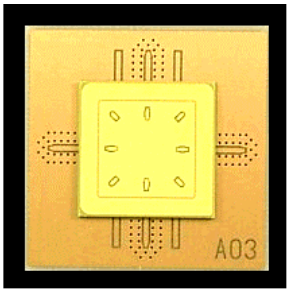


Figure 15: RF BGA for frequencies up to 40GHz

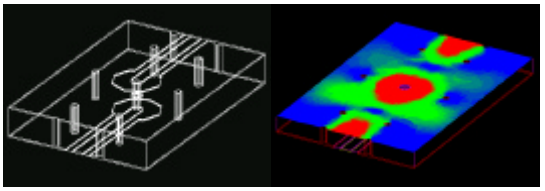


Figure 16: VIA of RF-BGA package and simulation results of its E-vector distribution

6. Summary

With the drastic expansion of cellular handset market, the production capacity status of ceramic packages for SAW filters has increased dramatically. On the other hand, the establishment of package design technology with consideration of its electrical

characteristics has just begun. From the standpoint of package manufacturers, the electrical characteristics of SAW devices are very different compared to that of digital IC or other high frequency devices, which has had considerable amount of handling experience. Consequently, the same design technologies cannot be applied to packages for SAW devices, and the spin off of a newly developed package involves hard work.

This paper has strongly emphasized the importance of considering the electrical characteristics when designing ceramic SMD packages for SAW filters. This is merely from the standpoint of package side. Together it is inevitable to consider the standpoint of the SAW device side; i.e. electrical characteristics of the SAW filter products itself, which we would like to grasp.

The position of SAW filters is put with more importance, where expansion of cellular handset market continues. Moreover the ceramic SMD package is an indispensable component, and plays a major role to achieve the requirements for compact miniaturization, high function, and high frequency. To fulfill the market requirements for cost effective, high performance SAW devices, a closer relation between the maker of SAW device and package is necessary when making package developments.

The activities involving design technology with consideration of the electrical characteristics, introduced in this paper, has just begun. We hope that this wills a trigger for further research and development activities.

7. Acknowledgements

The authors would like to thank Mr. Omori, Fujitsu Media Device Limited, and Mr. Ikata, Fujitsu Laboratories Limited for their continuous technical support.

8. References

[1] K.Ikeda, C.Makihara, KYoshida, and T.Shirasaki; "Development of CSP for Microwave/Millimeterwave Applications"; Oct.1999; Wireless Circuits, Interconnection, and Assembly Workshop 99

[2] T.Shirasaki, C.Makihara, T.Kubo, and K.Tagami; "Functional Multilayer Ceramic Substrate for RF Modules"; Oct.1999; European Microwave Conference 99

[3] S.Morioka and Y.Sawa; "Surface Mount Package for High Frequency band"; Dec.1999; APMC'99 Proceedings; pp 958-961