77GHz MMIC Transceiver Modules with Thick-Film Multi-Layer Ceramic Substrate for Automotive Radar Applications

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Abstract **— A 77GHz MMIC transceiver module has been developed for automotive radar applications by using a low-cost thick-film multi-layer ceramic substrate. The module accommodating all MMIC-based transceiver functions in a single-cavity housing for improved manufacturability can be either assembled with built-in Tx/Rx antennas or mounted on external antenna sheet, depending on required antenna beam width. The module, measuring 25x25x3.4mm^3 with 3.3g in weight, has demonstrated >150m target detection capability when evaluated in a radar system, compatible with our current production-type radar.**

I. INTRODUCTION

Millimeter-wave radars have been long awaited and finally started to introduce into commercial markets, targeted for various types of automotive applications which include forward-looking radars for adaptive cruise control and collision warning, pre-crash sensors, side sensors and blind sensors for increased driving safety[1][2].

77GHz radars, however, in some cases have received unfavorable reputation for their rather high cost when compared with lower frequency counterparts or laser radars, despite of their superb performance. Significant R&D efforts, therefore, have been focused on cost reduction of transceiver modules along with size reduction and improved detection capabilities[3].

This paper describes a newly developed transceiver module which employs a thick-film multi-layer alumina substrate combined with a single-cavity housing structure to achieve low manufacturing cost with rf performance compatible with more expensive metal-based modules. Section II describes the design of the new transceiver module. Measured characteristics of the transceiver are shown in Section III, compared with design simulations. Discussion is also given in the section on radar system performance using the transceiver to demonstrate the module's potential for a multitude of vehicular applications.

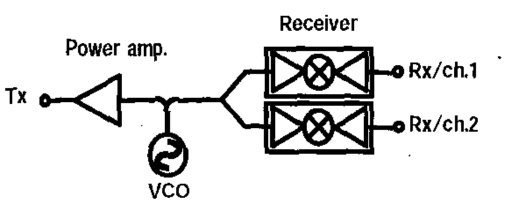

Fig.1. A block diagram of MMIC transceiver module for a 77GHz monopulse radar.

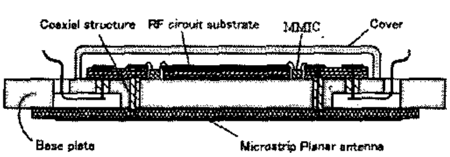

Fig.2. A cross-sectional view of the first generation of 77GHz MMIC transceiver module with metal-based housing. 20x60x5mm^3

II. DESIGN OF TRANSCEIVER MODULE

Fig.1 shows a block diagram of a fully MMIC transceiver module for a two-frequency-CW monopulse scheme employed for our radar system[4]. A part of signal from a VCO is fed to a transmitting(Tx) antenna through a power amplifier, the remain part being delivered to two receivers to serve as LO signals. A reflected signal from a target into a two-channel receiving(Rx) antenna is mixed with the LO signals to generate two-channel

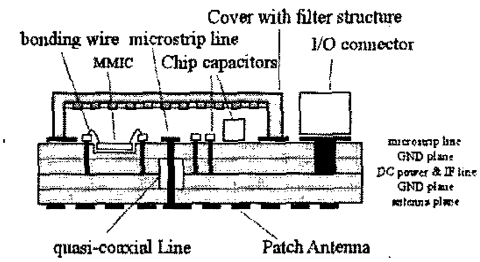

Fig.3. A cross-sectional view of a 77GHz MMIC transceiver module newly developed with thick-film multi-layer ceramic substrate.

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monopulse outputs from which the azimuth angle of the target is calculated[4].

As shown in Fig.2, the existing design of our production-type transceiver assembles the Tx/Rx functions, excluding antennas, in metal-based module housing which is then incorporated into a one-body antenna/transceiver(A/T) by sharing a metal base plate with a planar antenna sheet. The transceiver module part measures 20x60x5mm^3[4].

Although this transceiver configuration offers good rf performance and reliability at competitive manufacturing cost, a further drastic cost reduction may require elimination of assembly of a circuit substrate, an antenna sheet and other components onto a metal base.

Fig.3 depicts a cross-sectional view of the newly developed 77GHz transceiver module with built-in antennas by using a thick-film four-layer alumina substrate. MMIC chips which forms Tx/Rx functions of Fig. 1 are imbedded in the top substrate layer and wire-bonded to microstrip lines for interconnection laid out on the top substrate surface. Chip components such as capacitors for bias circuits are surface-mounted by a reflow process.

Connections to antennas patterned on the bottom surface of the module substrate is made through a quasi-coaxial line with its center conductor formed by stacked through-via's. DC bias lines and output IF frequency lines are laid out on the 3rd metal layer from the top to be led to an I/O connector.

Each signal layer is isolated from the others by inter-layer ground planes. The entire rf functions are hermetically sealed with a either metal or ceramic lid which forms a single cavity housing for manufacturing ease. Cavity resonances and rf interference are suppressed by band-stop filter characteristics built into the inside surface of the lid[4]. The transceiver module typically measures 25x25mm^2 in area.

When a system application requires a narrow Tx or Rx beam or a larger antenna area, the antenna layer can be fabricated on a separate large ceramic substrate or on an other form of dielectric sheet to surface-mount the transceiver module.

III. Measured Performance of Transceiver

A. Characteristics of Transceiver Constituents

Fig. 4 plots the measured attenuation characteristics of different lengths of 50 ohm microstrip lines on the thick-film alumina substrate. A rather significant attenuation of 1.6dB/cm at 77GHz is considered still useable and manageable for a transceiver module since an interconnection will hardly exceed 3mm in length.

Fig. 5 shows the measured S parameters of an MMIC power amplifier imbedded in a module cavity. It favorably compares with a on-wafer measurement, showing no significant degradation in performance.

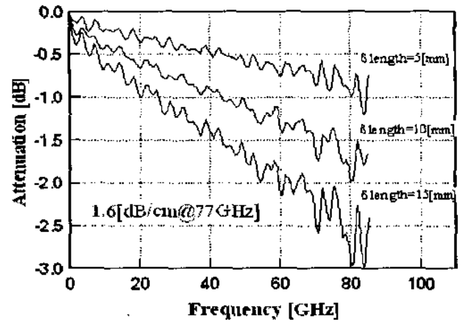


Fig.4. Measured attenuation characteristics of 50-ohm microstrip lines of three different lengths on the thick-film multi-layer ceramic substrate.

Fig. 6(a) depicts a simulated electromagnatic field distribution in a quasi-coaxial line which interconnects a transceiver with a built-in antenna on a bottom substrate layer. The sizes of openings in three layers of ground planes are optimized for impedance matching within a frequency range of interest. Fig.6(b) plots simulated performance of the quasi-coaxial structure as a function of frequency. Also plotted in the figure is that of a similar structure designed for a soft dielectiric antenna sheet with a low dielectric constant around 2.2. A comfortable bandwidth is seen to be achieved in both cases. Fig.7 shows a measured insertion loss of two microstrip-coaxial-microsrip transitions connected in a back-to-back configuration, from which an insertion loss of less than

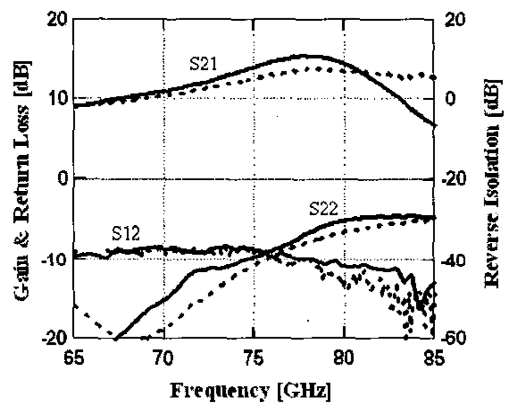
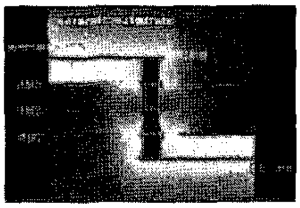


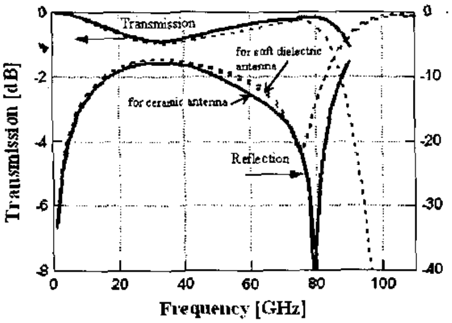
Fig.5. Measured S-parameters of a MMIC power amplifier imbedded in ceramic substrate(solid line), compared with on-wafer measured results(dashed line).

2dB at 77GHz is deduced for a single transition. The measured frequency dependence favorably agrees with simulation which ignores conductor loss in the quasi-coaxial region.

Fig.8 plots measured isolation between the Tx and the Rx ports of a transceiver module with filtering lid described in Fig.3, which clearly shows an band-stop characteristics having a cutoff frequency around 75GHz. The isolation at 76.5GHz is limited to 70dB due to the measurement system used for this evaluation. A result of a more stringent evaluation is shown in Fig.9, where the isolation behavior with a filtering lid is measured as a function of Tx to Rx distance, compared to those with commercially available absorbers mounted in a module or with a plane metal lid as reference. It should be noted that the filtering lid holds better than 100dB isolation even down to a 10mm distance while the absorbers significantly degrade to a 40dB range.



(a)



(b)

Fig.6. (a) A cross-sectional view and simulated electromagnetic distribution of a microstrip/quasi-coaxial/microstrip transition for interconnection to antenna and (b) simulated performance of the transition designed for a built-in ceramic antenna and for a soft dielectric antenna.

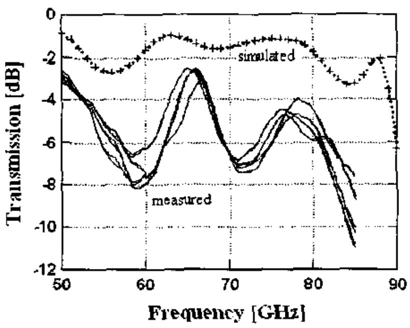


Fig.7. Measured insertion loss of a back-to-back connection of quasi-coaxial transitions, compared with simulation.

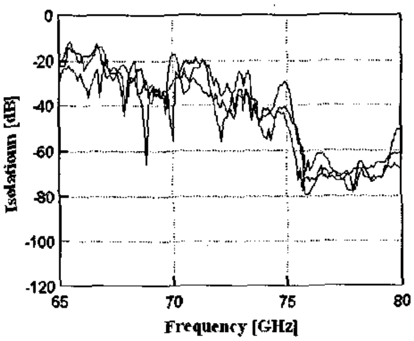


Fig.8. Measured Tx-to-Rx isolation of a multi-layer-ceramic transceiver module.

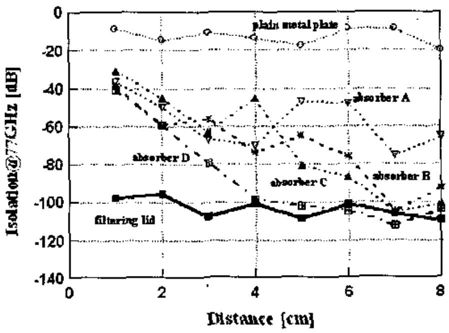


Fig.9. Isolation characteristics of a filtering lid at 77GHz, compared with other schemes, as a function of distance between a Tx and an Rx ports

B. Performance of Transceiver

A photograph of a transceiver module with a lid removed is shown in Fig.10(a), where four MMIC chips are clearly seen along with a transition from microstrip to Tx coaxial line located on the right and those to two Rx lines located on the left.

Fig. 10(b) shows a bird's-eye view of a completed transceiver module covered with a filtering lid. The module measures $25x25x3.4mm^3$ with 3.4g in weight. The lid can be made of either metal or matalized ceramic.

Fig.11 shows a photograph of an experimental antenna/transceiver radar unit where a transceiver module with a multi-layer alumina substrate is surface-mounted onto a sheet of planar antenna substrate which is mechanically supported and reinforced by an FR4 board. The FR4 board can be utilized for mounting low-frequency components such as power supply circuits, analog/digital signal processing units in the future.

An A/T unit shown in Fig. 11, equipped with Tx/Rx monopulse antennas for covering a 30deg azimuth angle range, was tested in a radar system for preliminary evaluation of basic performance.

Fig.10. A photo of a completed 77GHz MMIC transceiver module newly developed with thick-film multi-layer ceramic substrate. (a) with filtering lid removed and (b) with lid sealing the rf section. 25x25x3.4mm^3

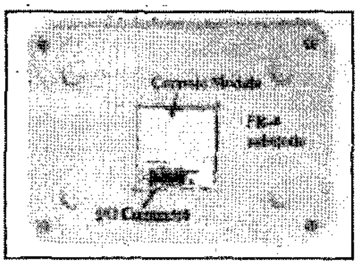


Fig.11. A 77GHz A/T unit with a multi-layer-ceramic transceiver module. The module is surface-mounted on an antenna substrate mechanically supported by an FR4 board.

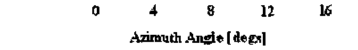


Fig.12. Measured maximum detection range(solid line) of a 77GHz radar system equipped with an multi-layer ceramic transceiver module as shown in Fig. 11. The radar covers a 30deg azimuth angle with a target moving at 2m/sec. The dashed line shows a prediction from the antenna gain.

Fig.12 plots the maximum detectable target range measured at each azimuth angle off boresight for a target moving at about 2m/sec, extrapolated from S/N data actually taken up to 150m. Also plotted by a dotted line is a maximum range estimated from the gain characteristics of the Tx/Rx antennas, showing a good agreement with the measurement. The observed maximum range is dictated by a noise figure of receiver channels of the A/T unit. The unit transmits about 10dBm and dissipates a DC power of 0.9 W.

The results also demonstrate that the A/T unit newly developed with multi-layer ceramic substrate is fully capable of detecting passenger cars with 10-20dBsm RCS over 150m in a normal driving conditions, compatible with our current version of A/T unit with metal-based housing.

IV. Conclusion

A 77GHz MMIC transceiver module has been developed for automotive radar applications by using a low-cost thick-film multi-layer ceramic substrate. The module accommodates all MMIC-based transceiver functions in a single-cavity housing with a filtering lid for manufacturing ease. It can be either assembled with built-in Tx/Rx antennas or mounted on an external antenna substrate. The module has demonstrated >150m target detection capability compatible with our current production-type radar when evaluated in a radar system.

References

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