PACKAGING SOLUTIONS IN SPACE MCM's AND MHIC's

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ABSTRACT

Since 90's MCM, MIC's, and MHIC's have been developed by several technological approaches for space application. Alternatives in the packaging solutions through thick film hybrids and thin film MIC have been found to increase integration level and reliability of space components. For analog and digital hybrids thick film MCM technology evolution was driven by high resolution printing and fine line etching of top layers. Thin film multilayer technologies employing photosensitive polyimide and sputtered SiO_2 as dielectric have been evaluated to achieve line/gap structures of 25 μm as well embedded NiCr resistors. LTCC MCM's using etched thin film fine lines have been evaluated. GaAs discrete and MMIC dices take relevant role in hermetic cavities development for MHIC's in C-X-Ku- Ka bands. Last prototyping and space qualification work is going to develop high-tech mixed solutions hybrids based on LTCC with thin film metallizations for MW applications, and HTCC with fine lines for MCM's.

INTRODUCTION

Microelectronics is a growing technology in Space Applications because it continues to evolve and expand to meet the needs of spacecraft designers reducing weights and HW volumes, increasing reliability, keeping high performances for the devices at low recurring costs and reduced lead times. To-day satellite applications, mainly for commercial communication services, ask for complex digital and microwave functions integration as well as OBDH's (on board data handling units), Front Ends, Receivers, Down Converters, Channel Amplifiers, SSPA (Solid State Power Amplifiers) etc.. Integration process is widely implemented through hybrid technology resulting in smaller dimensions, greater current densities and larger use of automation. Ceramic circuit technologies are becoming more significant as electronic equipment needs grow more demanding, especially in harsh environment; thick and thin film hybrids continue to find new market opportunities which seem continually emerging. Thin film multilayer approach based on photosensitive polyimide and magnetron sputtered SiO2 as dielectric has been evaluated for high density MCM's using same die technology domain. Microwave technology found large applications field mixing basic thin film technology on 99.9% Al_2O_3, laser weldable Kovar and aluminium packaging solutions, weldable feedthroughs, ceramic microstrips and Ka ceramic launchers out of hermetic cavity, custom designed GaAs MMIC's.
The third rapidly growing technology is low temperature co-fired ceramic (LTCC) well suited for joining microwave and digital function integration on the same module. New advances in materials and processes (such as thin layers , low dielectric constant materials and tape on carrier) are greatly increasing the applicability of this circuit technology. LTCC can also be combined with photo patterned material (thin or thick film) to take advantage of the best characteristics of all involved technologies. Thermal constrains for power MCM's drive to the use of suitable HTCC's multilayers with the same requirements for I/O pitches of large surface mounted dies and then similar thin film patterning /LTCC technology combinations. Space qualification campaigns have been the main achieved steps to gain hi-rel devices manufacturing capabilities through the most of listed technologies with clear evidence of future improvements in new Capability Approval works.

MULTICHIP MODULES (MCM's) TECHNOLOGY DESCRIPTION

Thick film technology

Thick film is a reliable technology for space applications, but limits in printing definition of fine structures reduce the field of application for hybrids containing one or more chips with high pin number i.e. MCM. MCM approach allows a high grade of integration, that leads to size and weight reduction of satellite units. Often chips with high pin function (some hundreds of I/O signals) like ASIC's cause an excessive increase of local interconnection density, and bonding with microwires from die pads to substrate is not easy. This difficulty is avoided if bond pad pitch on thick film substrate is strictly equal to pad pitch on ASIC's. If this goal is achieved wire bonding is made easier because distance of bond pads from pads of die is minimum and equal for all connections. Alenia Aerospazio has developed and qualified for space application a process, which is an improvement of basic thick film technology, that allows high resolution structures. This high resolution is achieved through an etching of screen printed top layer. The etching technique consists of printing the entire surface of the substrate with conductive (gold) thick film paste and, after firing, performing a "thin film technology lithography" by means of wet etching. Wet etching gives shrinkage of lines width (respect to nominal mask) of about double the fired gold thickness. The wet etching can give line width close to nominal provided that the mask is compensated (1). This technology allows the manufacturing of Hi-Rel multilayers for MCM's with line/gap structures of 70 μm nominal (71.1±2.9μm) (2). Photo 1 is an example of a MCM manufactured employing this technique.

Thin film Multilayer technology

Thick film multilayer, even with fine line structures on the top layer, encounters a limitation in further integration. This is due to the fact that via connection between layers can't be reduced without impact on the reliability. MCM multilayer substrate made by thin film technology allows such desired higher level of integration (see for example Photo 5). Today this is the most advanced technology for the manufacturing of MCM substrates. Alenia Aerospazio has made some experience also into this field developing MCM by the use of polyimide or SiO2 as dielectric (3)(4). The main features of the experimented solutions on to the Alenia substrates are: substrate made in Al_2O_3 or Si, dielectric interlayer made by RF sputtered SiO_2 (1μm) or spin coated photosensitive polyimide (6μm), NiCr/Pd/Au thin film metallization with fine lines down to 25μm, buried NiCr resistor with meanders of 25μm line width.

Thin film Microwave Integrated Circuits (MIC's)

Another extensive application of photosensitive polyimide is the field of thin film MIC's. These circuits employ packaged components mounted a thin film alumina containing also integrated NiCr resistors. Such resistors during thermal cycles under biasing conditions are prone to electrolytic corrosion. Photosensitive polyimide employed as a coating on NiCr resistors acts as a highly efficient moisture barrier. That results in a high reliability of NiCr resistors when they are submitted under bias to condensed moisture (3).

MHIC's TECHNOLOGY DESCRIPTION

The microwave hybrids are based on the extensive use of GaAs MMIC (designed by Alenia Aerospazio) brazed, together with thin film ceramic substrates, onto a metallic carrier by AuSn eutectic to obtain subassembly with specific electrical function. These low TCE carriers (Kovar or CuW) are housed in aluminium alloy packages. The packages are hermetically sealed by laser welding. This mechanical structure presents a high thermal expansion mismatch between subassemblies and the aluminium body. For this reason it is required to apply special technical solutions to withstand 500 thermal cycles between −55 and +125°C as required by ESA qualification specifications. For the cleaning before sealing of such complex shape cavities it has been developed and qualified another original technical solution (4) to overcome the difficulties of more classical cleaning processes. Subtechniques like fine lines (down to 20μm nominal:19.93±1.76μm), metallized holes and other standard thin film technologies, joined to a wide spectrum of assembly solutions, allowed us the development of different products.

Ku LNA

This is a fully integrated Ku front-end that performs the downconversion of the incoming signals in Ku band frequency down to 140 MHz IF signal (7). The LNA section is fully MMIC based. Three MMIC LNA are cascaded to provide a typical gain of 38 dB and 2 GHz bandwidth. Each active stage of MMIC is made with a 0.25μm pseudomorphic HEMT process. The image reject filter uses GaAs Schottky beamlead diodes to convert RF signal down to IF. The package is in aluminium and was designed in order to avoid possible resonances.

FSS RECEIVER

A hybrid hermetic module mostly MMIC based has been designed to integrate low noise amplifier (14 GHz), mixer and IF circuits (12GHz) (7). The low noise amplifier section uses as first stages discrete HEMT to achieve the best noise figure performances. A hybrid mixer uses GaAs Schottky beamlead diodes to convert RF signal down to IF. The IF section is composed by different MMIC circuits cascade which provides the required gain and gain control dynamic. See Photo 2.

BFN
This hybrid is an analog Beam Forming Network that is part of a S-Band Receiving Phased Array Antenna. Four MMIC phase shifters and three combiners are packaged together to minimise mass and volume. A multilayer thick film substrate is used for digital circuit and the top layer also contains a RF ground plane electrically connected to the bottom using metallized edges. MMIC's and thin film substrate containing RF paths and the combiners are glued with conductive epoxy on the thick film multilayer. A package with ceramic feed-throughs (stripline configuration) for RF input/output has been used (6).

NEW GENERATIONS OF MHIC's

44 GHz low noise preamplifier

MHIC technology has been upgraded to permit the manufacturing of new Ka and millimetric band equipments. A new 44 GHz low noise preamplifier (20 dB gain minimum in 43.5-44.5 GHz bandwidth, 3.5 dB noise figure) has been developed using advanced packaging solution, see Photo 3 . This hybrid integrate microwave and DC (biasing and filters) circuits into a single hermetic housing. These two sections are located in separated cavities to guarantee a good EMI shielding. The electrical interconnection between the 2 cavities is done using coaxial bead feed-throughs. The housing material is Kovar™. The electrical interfaces employ hermetic microstrip to waveguide launcher transition (for the MW I/O port) and hermetic coaxial beads/feedthrough for DC connections. The microwave to waveguide launcher is an alumina substrate hermetically closing a waveguide aperture onto which the launcher is built with a thin film network. Hermeticity is achieved by brazing in inert gas the bottom edges of I/O launchers to the aperture rim, using AuSn 80/20 alloy. This alumina/Kovar hermetic interface has been tested submitting transition samples to 100 thermal cycles, -55/+125 °C. Fine leak test performed before and after thermal cycles measured He leaks in the range of 10^{-9} atm cc/s. Laser welding of two Kovar™ covers (one above MW cavity and one above DC biasing cavity) guarantees total hermeticity.
LNA is composed by the input/output transition and two amplifier sections separated by an isolator. Each amplifier section is composed by discrete GaAs HEMT to achieve state of the art noise figure performances. Active components and thin film alumina microstrip are attached directly onto the package (1st section), to minimise microwave and ribbon interconnection length and ground plane dishomogeneity that typically occur when a carrier approach is used. This packaging solution is possible because package material thermally matches very well with Al_2O_3 and GaAs. The isolator has been manufactured with the deposition of thin film gold microstrip line and pattern and NiCr resistor onto a ferrite substrate. Its back is gold metallized, and epoxy attached onto a carrier. A magnet and a FeSi dish are either glue attached onto the back and the top of the ferrite, respectively.
Thin film adherence on ferrite substrate has been tested (>4.5kg/mm^2). Thermocompression ribbon bonding on the thin film microstrip has been successfully performed. Typically performances of the 44GHz isolator are 1dB insertion loss, 15dB return loss, and 15 dB isolation.
The described technologies have also been used to built a 44 GHz mixer and multiplier. In addition to the performed preliminary evaluation tests, a qualification activity of all the employed materials and subtechniques is in progress.

2nd generation Ku band channel amplifier

The evolution of the previously MMIC-based satellite equipments is the second generation Ku band channel amplifier (10.70 to 12.75 GHz ; selectable gain: 21 to 51 dB; selectable output power level: -7 to +6dBm) (8). In this equipment the electrical design concurs with technological design to achieve impressive results in terms of miniaturisation. Previous design was based on digitally controlled section whose data were memorised in a packaged PROM. It was mounted externally to either microwave hybrid module and hybrid control module. The new project uses an analog circuit for thermal compensation and control linearization. This choice permits to integrate the whole control section in a single MCM which is housed in the same package where the MW section is housed too. So, it was possible to update the project from a composed flight unit to a single hermetic hybrid circuit, reducing mass, material cost, manufacturing lead time and screening sequence. The MCM is a 7 layer thick film substrate, attached on a WCu carrier, with bare Si chips epoxy glued and wire bonded with automatic processes. Thin film tantalum nitride resistor chips are used instead of thick film printed (on dielectric) ones to reduce space and achieve the resistance accuracy (1%) required from the analog control design. MW section is designed as a macro-hybrid with MMIC and alumina thin film substrates (microstrip lines, filter, detector) brazed on open carriers, as a trade-off between the needs of miniaturisation and production yield. High rework capability in case of handling failures during electrical tuning or mounting is permitted. The basic building block of the MW section is a variable gain amplifier (VGA) circuit integrated in a GaAs MMIC design by ALS. This MMIC provides an amplification in conjunction with a gain control function. Control and MW sections are mounted in two separated cavities of a single aluminium package, to avoid the risk of electromagnetic interference between power supply and MW circuits. Filtering feed-throughs provide the electrical connection. RF and DC/control connections are achieved through laser weldable glass-beads feed-throughs and Micro-D connectors respectively, installed by ALS. The use of laser weldable parts was chosen to reach higher efficiency and hermeticity respect to brazing process of glass beads onto aluminium packages.

FUTURE PACKAGING DESCRIPTION AND TRENDS.

Thin film on LTCC.

Alenia Aerospazio has in L'Aquila plant also a Low Temperature Cofiring Ceramic (LTCC) development line, which has already completed an evaluation campaign for MCM applications. The evaluation has been made taking as reference ESA thick film requirements (PSS-01-606). The evaluated LTCC technology presents an upgrading respect to the standard technology. The upgrading consists of the Alenia fine line technology applied on the top layer. New projects are in progress trying to develop higher integration level and low-cost producibility for MW hardware minimising manufacturing and tuning lead times. LTCC technology seems to give good chance to integrate digital/analog low frequency circuits together with MW network and MMIC's in the same substrate. It is possible to manufacture top surfaces of LTCC substrates with thin film technology, that guarantees good MW performances and repeatability, joining solutions and needs with typical attitude of LTTC technology to cover multilayer.
In order to investigate electrical characteristics of Green Tape™ cofiring system supplied by Du Pont, some simple RF patterns have been designed, produced and tested on multilayer samples. Dielectric constant and loss tangent have been verified using a 20 GHz ring resonator. Electrical performances and technological feasibility have been verified by a 20 GHz band pass filter (see Figure 2) and a Lange coupler (see Photo 6) testing campaign.

LTCC channel amplifier.

The Channel Amplifier provides amplification of a 17.5 to 21.5 GHz band signal, allowing selection of either linear gain (20 to 55 dB) or output power level (-13 to +3 dBm) in discrete steps, by means of an external command. If the Automatic Level Control mode is enabled the output level is kept constant by the ALC loop which compensates any input power variation within the loop's range (typically -35 to -50 dBm). ALC function may be inhibited for Fixed Gain (FG) operation depending on the application. Temperature compensation is implemented to guarantee gain stability. It is composed of the MMIC based microwave section and of the command and control section.
The packaging design for the baseline version of the CAMP is a novel concept, although employing subtechniques qualified or being validated in the frame of other Programs. A single LTCC substrate is employed for both RF and control functions. All of the equipment is contained in a Kovar™ housing of dimension 100.0 x 10.0 x 68.3 mm (61.6 x 10.0 x 68.3 mm excluding mounting feet) intended to be stacked in assemblies of three CAMP's minimum.
The housing mechanical drawing is shown in Figure 1. The LTCC substrate is attached to the bottom plane with a conductive film. An inside cover shields the narrow RF strip that is placed near and parallel to the contact surface. The cover's contact is made via screws on three sides. The side overlapping the substrate contacts to ground via a central screw and a longitudinal gasket contacting a strip of ground vias on the substrate. This part of the housing design is the most critical in terms of effect of the packaging on microwave performance because of the potential problems of stray feedback and cavity resonances. The MMIC dice (20 GHz Low Noise Amplifiers, Medium Power Amplifiers and Variable Attenuators designed by ALS, using PHEMT 0.25μm technology) are brazed with eutectic onto small CuW carriers acting as heat sinks and epoxy attached to the bottom plane. The LTCC substrate integrates microstrip interconnections between active chips, plus passive circuitry within the RF strip. DC interconnections to and from the RF strip are buried in the substrate and cross the via wall with local capacitors acting as feedthrough filters. The RF connectors are hermetic SSMA: the coaxial bead is brazed with eutectic alloy onto the housing, and a field replaceable connector with RF gasket is externally assembled. The DC connector is a laser weldable Micro-D.
The Kovar lid is laser welded for hermeticity. The housing is provided with mounting feet and side flanges for stack assembling. A solid model was developed for the housing. The computed mass is 58 grams. The overall equipment mass is predicted below 100 grams.

OBP enhanced

LTCC MCM's with high power densities require an extensive use of thermal vias that can limit the routing of interconnection lines within the multilayer. A possible solution is to employ a ceramic having an higher thermal conductivity. The use of High Temperature Cofiring Ceramic (HTCC) multilayers can supply the appropriate thermal dissipation. To allow high density of die and pads onto the top layer an improvement of the standard HTCC is needed. Alenia Aerospazio has started a feasibility study to apply thin film technology on the blank top layer of HTCC multilayer. The final multilayer with thin film fine lines shall be the substrate/base plate of a MCM package with a Kovar ring frame brazed on it.

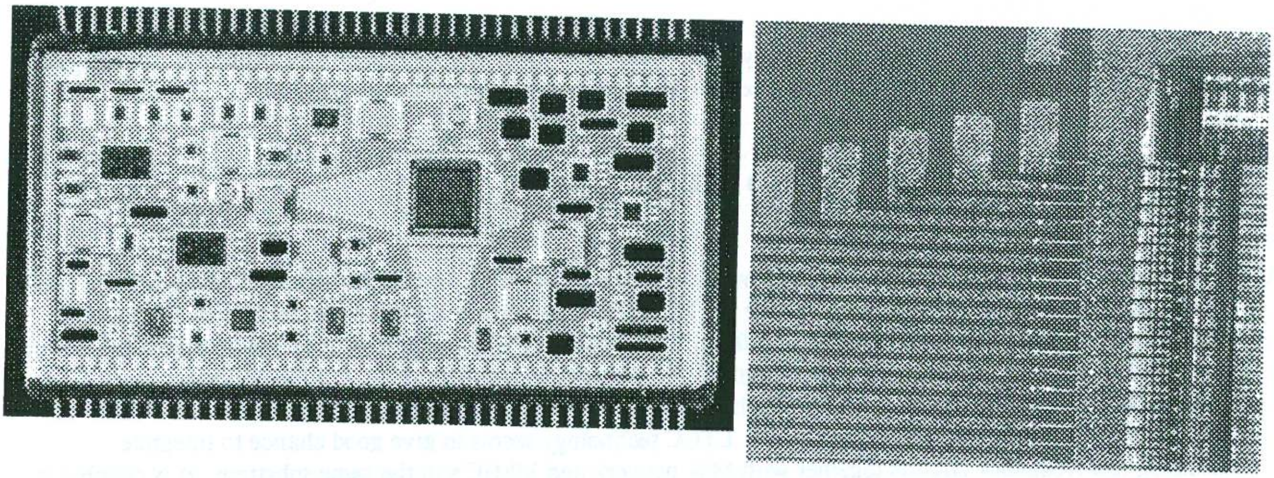

Photo 1: Thick film MCM (left) with detail of Alenia fine line technology (right).

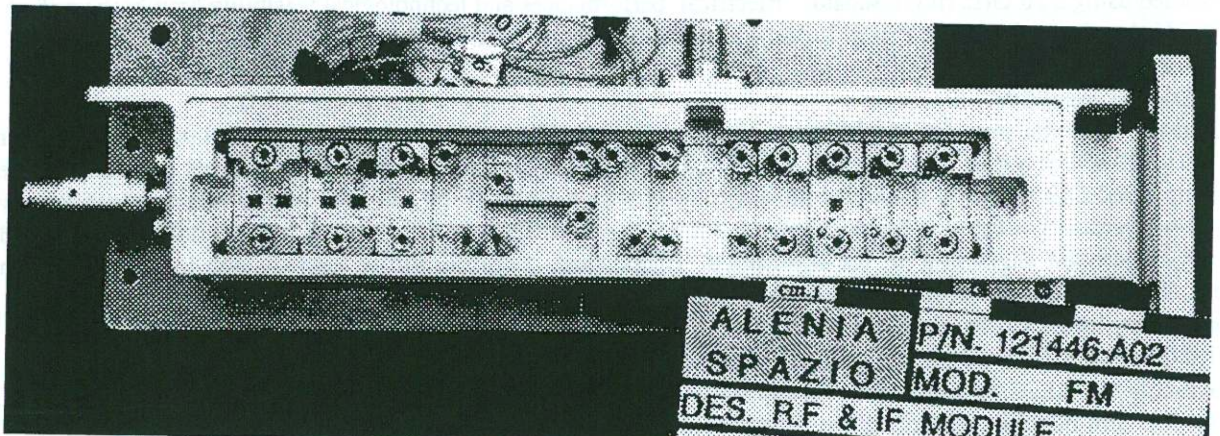

Photo 2: FSS receiver

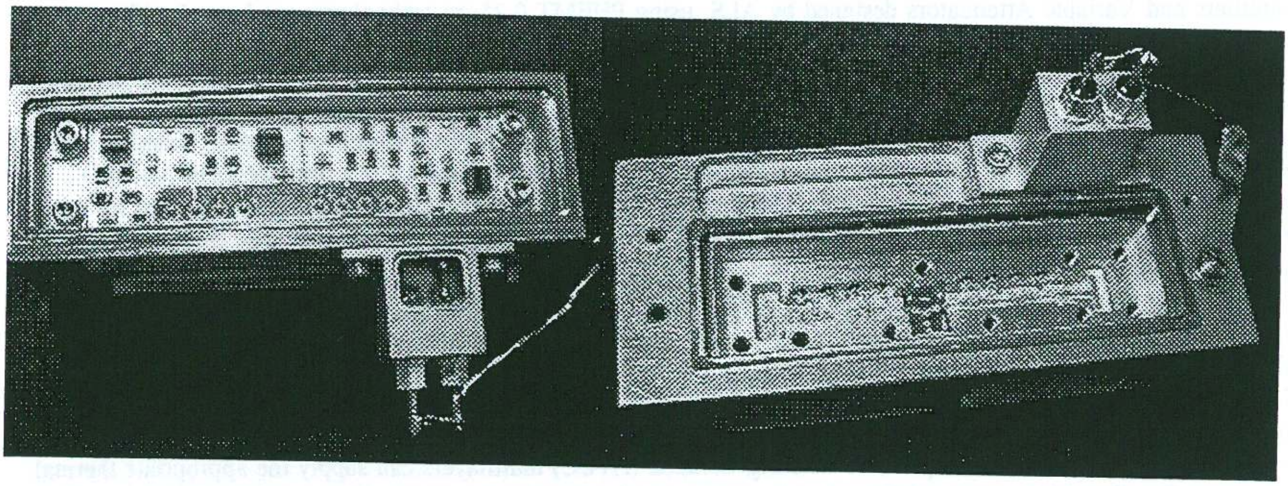

Photo 3: 44 Ghz Pre Amplifier. DC Lateral cavity (left), MW Top cavity (right).

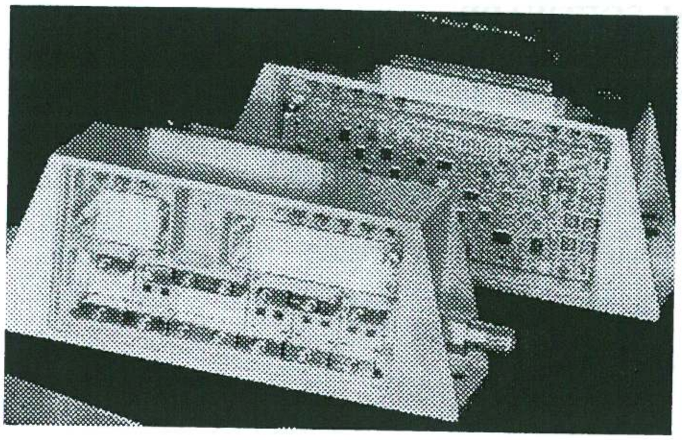

Photo 4: 2nd Generation CAMP

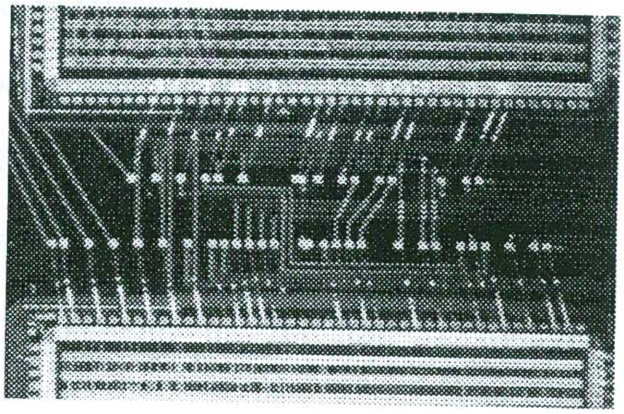

Photo 5: Thin film multilayer MCM detail

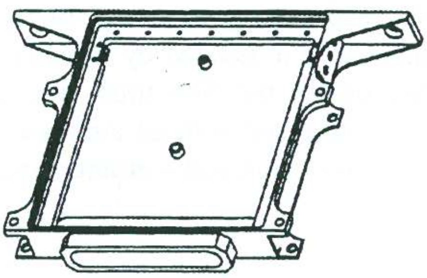

Figure 1: 3rd Generation CAMP housing

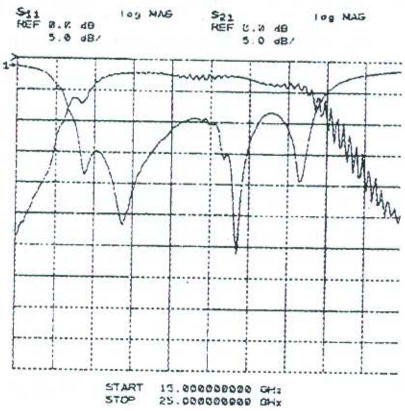

Figure 2: LTCC band pass filter gain and input loss

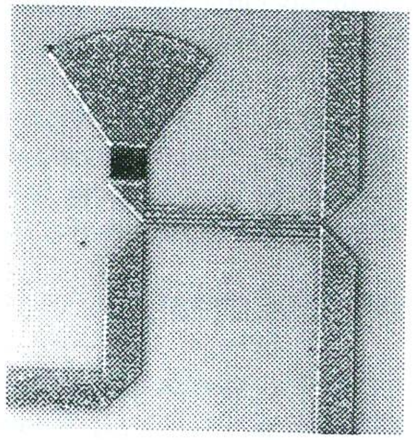

Photo 6: LTCC thin film Lange coupler

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