empfasis

A publication of the National Electronics Manufacturing Technology Center of Excellence

Volume 3 Number 2

In this Issue

New JSF RF Tuner System Decreases Cost and Increases Bandwidth

Figure 1-1: The F-35 Joint Strike Fighter will benefit from the new SiGe/LTCC RF Tuner.

The F-35 Joint Strike Fighter (Figure 1-1) is among the many Navy and Air Force combat planes that rely on economical, lightweight, and reliable electronics to meet their missions. The RF Tuner System is a prime example where the blend of new material and manufacturing technologies can reduce cost and increase bandwidth capabilities. This is achieved by utilizing a system on chip (SOC) design that requires the attachment of a silicon germanium (SiGe) die to a high temperature co-fired ceramic (HTCC). The SoC design allows for monolithic integration of high Q passives and active circuits. The SiGe integrated circuit technology allows for increased operating speed, increased functionality, and a higher level of integration that results in reduced size and weight. The higher circuit density HTCC module, which benefits from lower losses, is a suitable substrate for RF and microwave packages.

This tuner was developed for the F-35 Joint Strike Fighter (JSF), but has applicability to multiple naval and air force platforms, can result in substantial cost savings and increased capabilities. Space savings is also critical, as the controls on the cockpit (Figure 1-2) which provide the pilot enhanced warfighter capabilities, require higher density electronic circuitry to achieve the increased functionality. The technology to develop this common and modularized RF tuner required a combination of both material research and manufacturing process development. The formulation and application of a conductive resin system was critical to the success of the project. This formed the focus of the manufacturing studies designed to optimize the production of the HTCC module. The final composition of the conductive epoxy resins will ultimately dictate the parameters of operation at the various manufacturing stages. A separate article will discuss the technology development and characteristics of the resins used for the RF tuner module in more detail.

The production of the RF tuner is not trivial from a manufacturing perspective. The features and tolerances necessary to leverage the miniaturization

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Message from the Director

The Electronics Manufacturing Productivity Facility (EMPF) has a track record of providing technology assessments for the Navy that entail nearly all elements of electronics manufacturing technologies. The EMPF uses technology roadmaps from trade organizations and research consortia, assessments of the technology maturity via current government and industrial definitions for TRLs and MRLs, and assessments on how the manufacturing or electronics technology aligns with industry standards and best practices. The objective of the assessments is to determine and predict the relative success the technology has in reaching maturity and what will be required to achieve maturity and the acceptance of the technology by the electronics industry which will directly determine the availability and affordability of the technology to the Navy when it is needed.

The EMPF has generated innovative investment recommendations that have created transformational improvements in affordability, supportability, and performance on key platforms within the Navy ManTech Strategy. These investment recommendations were developed through a proactive involvement and strong relationships with acquisition PMs and industry partners. The EMPF has developed and maintained relationships with most major SYSCOMS and PEOs sufficient to understand their priorities and ensure that transitions are being planned and executed. The quality of these recommendations have either met or exceeded the Navy's expectations as evidenced by direct feedback from the weapon system stakeholder.

Through resource leveraging, the continued use of proven and effective processes, and the introduction of new and innovative strategies, the Electronics Manufacturing Technology COE will remain at the forefront of manufacturing technology innovation and maximize Navy ManTech's return on their critical technology investments.

Michael Frederickson

New JSF RF Tuner System Decreases Cost and Increases Bandwidth (continued from page 1)

benefits of the SiGe/HTCC module require strict manufacturing guidelines and the development of state of the art processes. There are multiple processes associated with the improvement of the new RF tuner, but there are three areas where substantial ManTech effort is being applied:

1. substrate attach process
2. substrate preform process
3. epoxy dispense process

As mentioned previously, the success of these processes is predicated on the uniformity and consistency of both the conductive epoxy and substrate epoxy.

Substrate Attach

The substrate attach (i.e. die attach) process requires controlled lamination conditions where the (conductive) epoxy squeeze out is minimized or regulated. Additionally, lamination further functions to eliminate substrate decoupling from the SoC module. The current method of removing excessive resin bleed requires a costly manual operation which can be variable due to human error. One way to resolve this issue is to optimize the lamination process by controlling conditions such as pressure, temperature ramp, lamination temperature, and cool down rates within very tight tolerances. This requires lamination presses that can maintain a level of precision and accuracy at relatively low pressures and temperatures. Most production lamination equipment is designed for pressing multilayer circuits which often require greater force to achieve the higher pressure (350 psi) needed over a large area. A lamination procedure requiring presses with large platen areas would not typically be applied in a process to assemble HTCC modules. The ability to control ram force below 1000 lbs. within 5% tolerance is challenging and demands process and material optimization.

Under the JSF ManTech program, there are continuing efforts to optimize the lamination parameters using hydraulic vacuum presses designed for better granulation and control at the lower pressures and temperatures. The engineering team has been able to control the amount of resin bleed consistently within a few mils, thus reducing the amount of labor for cleaning excessive resin.

Substrate Preforms

Crafting a resin film preform to attach the substrate most typically involves a die cutting process in which the dimensions of the preform match the shape of the substrate. Under less stringent tolerances, the use of die cutting is an economical way of creating the preform. However, under very tight tolerance conditions, and in the case of the RF tuner, it was discovered that die cutting or manual cutting involved too many trimming operations that consumed a great deal of labor hours. The tolerance specifications required for the dimensions of the preform were less than the width of the blade used to cut the preforms. During the lamination cycle, any resin bleed could adversely affect peripheral features such as pads that would subsequently require cleaning prior to assembly. To alleviate this possibility, the preforms could be designed with dimensions smaller than the outline of the adjacent substrate in order to avoid excessive bleed. However, to ensure that the preform maintains a consistent dimension, a UV laser with a small spot size and high velocity can be utilized to cut precise preforms rapidly. The lasing process should safeguard against damage to the preform, such as excessive carbonizing of the edges. There are several variables that can be controlled to optimize the laser for dimensional consistency and speed. Parameters such as pulse frequency, pulse width, residence time, velocity, power intensity,

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and pulse repetition can typically be adjusted to produce the right balance of speed and accuracy. Keep in mind that the mechanical platform plays an important role in defining the tolerances of the preform. Where the laser can be programmed to ablate at the proper conditions, the mechanical platform must be well calibrated to move at the precise locations, typically as a step and repeat process for multiple preforms.

Conductive Epoxy Dispense

The SiGe and HTCC are part of the enabling technology that allows the JSF RF Tuner System to increase bandwidth performance and reduce footprint size. The circuit features on the modules can be less than 100 microns. By any measure, this presents an engineering challenge to maintain low resistance and consistent resin dispensing through the module. A slight increase in resistance to any pad can result in higher inductance and impedance mismatch. The importance of the resin composition in shaping the physical properties cannot be overestimated. A good deal of engineering resources were allocated to developing the right chemistry to meet the specifications for the RF tuner. In addition to utilizing the appropriate resin chemistry, the engineer must optimize the dispensing process. For this project, needle and other dispensing methods are being evaluated for present and future applications.

The needle dispensing process is commonly used for all manners of inks and resins, but because of the higher viscosities associated with conductive polymers and resins, fine dispensing can be a technically difficult challenge. The prospects of decreasing pitch and pad sizes, which comprise a strategic part of the RF tuner development, makes needle dispensing increasingly difficult. An alternate method that is currently being developed is an automated jetting process that can dispense very small amounts of resins suitable for the fine pitch features of the RF tuner. The criticality of using a jetting system becomes more apparent as the features get smaller. Some of the process conditions to consider include: resin viscosity, pneumatic pressure, spray pattern, print speed, and tip diameter. There are still a number of technical challenges to resolve using the jetting process such as potential bleed out, offset height limitations, uniform resistivity, and shorting between features. But the benefits of developing a spray or jetting system capable of depositing a consistent volume of conductive resins has far reaching benefits for electronic warfare (EW) efforts.

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Figure 1-2: Smaller electronic circuitry is required to achieve increased functionality in the F-18 cockpit.

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Conclusion

In addition to the implementation of the new SiGe/HTCC RF Tuner System to the JFS platform, the developed conductive resin will be commercially available at the conclusion of this project for use in multiple platforms. Under this ManTech project, much of the process development has been centered on manufacturability of the SiGe/HTCC tuner, with subsequent actions to document and validate the reproducibility of the results. The outcome to the Navy, and more broadly to the DoD warfighter efforts, will be a set of established guidelines and practices that include the design, materials, tooling, and processes needed to produce high yielding RF circuits using system on chip technology with SiGe chips at a reduced cost.

For more information on the manufacturing of RF tuners please contact the EMPF by phone at 610.362.1320 or via email at info@empf.org.

Carmine Meola
R&D Projects Manager

Contact the EMPF Helpline

Your direct connection to electronics manufacturing support! Experienced engineers and technicians are available to assist you in solving your manufacturing problems, answer your equipment questions, brief you on the latest processes and materials used in electronics manufacturing, or direct you to other sources for problem resolution or support services.

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New Conductive Epoxy Resin Leads to Cost Reduction of RF Tuner Systems for JSF

Figure: 2-1: Preflight checks are performed in the cockpit of this F/A-18C Hornet.

Advancements in electronics miniaturization enable a smaller Joint Strike Fighter (JSF) RF Tuner System to be incorporated into the compact space of the F-35 (Figure 2-1). A new conductive epoxy is being developed to satisfy the finer pitch/tighter spacing requirements. Current methods using conductive epoxy for component attach are limiting the use of smaller components for more dense integration, due to this tighter spacing. The manufacturing process is dependent on both the conductive epoxy formulation and the deposition process.

Epoxy resins are usually available as two part compounds that start curing upon mixing, but single part materials that can be cured thermally or with UV exposure, are also available. In general, epoxy resins exhibit good abrasion and chemical resistance, as well as reasonable humidity resistance.

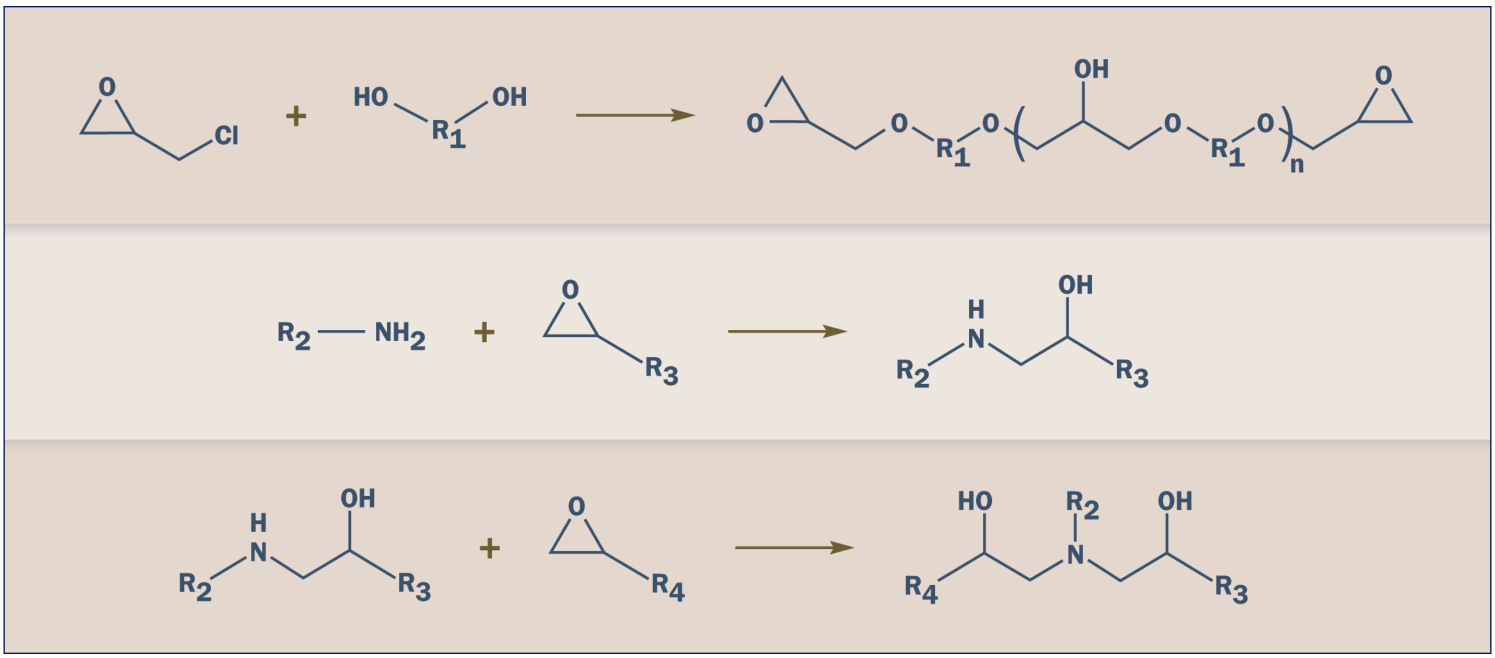

Figure: 2-2: Synthesis of epoxy resin.

Figure 2-2 shows an example of epoxy synthesis and polymerization, where epichlorohydrin reacts with a dialcohol [$R_1(OH)_2$] to form a diepoxide. In the next step, the epoxide groups react with amines to form an adduct. If the amine from step 2 is a primary amine, R_2-NH_2, then it is theoretically capable of reacting with another epoxide group.

Current Methodology

The smallest volume that is currently producible is a dot in the range of 5.9×10^{-7} in^3 or 9.7×10^{-6} mLl (approximately 0.015" in diameter and a conical height of approximately 0.010"). The system used for dispensing is a Newport 175 dispenser equipped with a DL Technology Auger Pump with a 27 gauge x 0.625" long EFD needle. The pump has a 16 pitch carbide lead screw with a thread depth of 0.011". Figure 2-3 shows an example of the conventionally dispensed epoxy next to a placed component.

Producing smaller epoxy features with the conventional method is a function of the needle size used in the dispensing process. The silver filler size for current conductive epoxy materials average 0.0008 to 0.0012". A 27 gauge needle (OD = 0.016" and ID = 0.0075") is the lower limit before the needle will clog completely or produce a resin rich dispense that lacks the silver filler.

The distance of the substrate from the dispense needle tip is also critical to the reproducibility of the dispense process. The texture or morphology of the substrate surface affects the results.

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Development Approach

In order to use conductive epoxy as the component attach method for more densely packed assemblies, either a new epoxy material with smaller silver fillers, a new application technique, or a combination of the two would be necessary. With the current method, an extensive amount of manual labor is required to touch up epoxy patterns and ensure full epoxy coverage without shorting.

A multipath approach was taken with regards to improving the epoxy application process.

1. A new material was pursued that would have the same electrical, thermal, and mechanical properties as the currently used epoxies with much smaller fillers
2. The new material would be applied using current techniques (DL auger pump) to determine the limits of pattern size and reproducibility
3. Formulate a material with small fillers and lower viscosity than current materials, which would allow the material to be mechanically jetted onto a substrate
4. Formulate a material with could be atomized and aerosol jetted onto a substrate

This multipath approach included separate test methods for evaluating the material properties and improvements in the application process.

Formulation Development

The current silver filled epoxy material has relatively high thermal and electrical properties, fair mechanical strength, and low modulus. Since the new application methods and materials differ widely, the test criteria are based on volume size and reproducibility, as well as the ability to access deep channeled packages.

The formulation process for the conductive epoxy involved incremental changes in a variety of parameters, such as solvent type, amount of solvent, size of the silver fillers, and additives to control cure rate and wetting.

Separation of the filler particles from the resin would lead to undesirable thermal and electrical properties. A resin system was selected that would keep the silver particles suspended with the assistance of a coating on the particles.

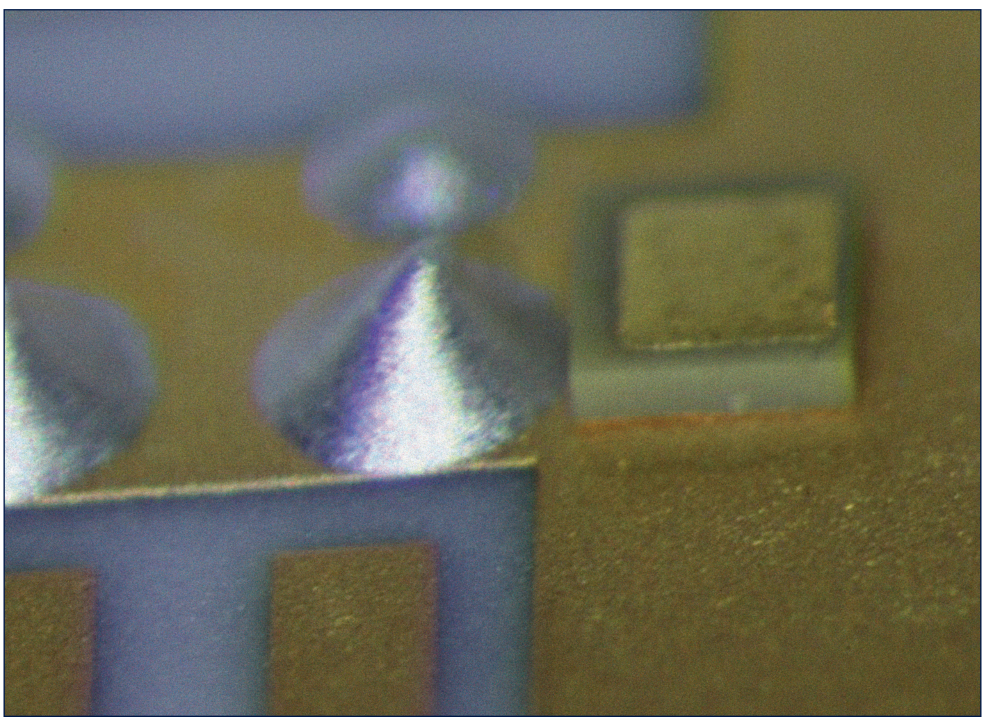

Figure: 2-3: Image of conventional dispensed epoxy. Courtesy of BAE Systems.

Solvent was added to lower the viscosity of the resin system and allow nebulization and jetting deposition methods. Issues encountered were solvent separation, component wetting, resin bleed out, and overspray. These issues were addressed by changes to the solvent and adduction of the hardener. Adduction is the product of the reaction of an epoxy resin with an amine, where the amine adduct having active hydrogen of the residual amino groups is formed, as seen in step 2 of Figure 2-2.

The electrical and mechanical properties of the materials were tested. If the material did not perform as desired, the testing was stopped and the material was reformulated. A final formulation was selected which had different amounts of solvent to adjust the viscosity as needed for either the aerosol jet or auger dispense.

Testing

The test specimens were bare alumina substrates patterned with silver loaded adhesives in long lines and small (0.020" x 0.020") squares with the squares having 0.010" spacing. The material bleed out between sites was tested using resistance measurements and optics. The volume of the squares and bond line of the long lines determined reproducibility.

Substrates were used to establish a baseline for close pitched small patterns and changes in resistance over thermal cycle. The conductive epoxy material was dispensed as a matrix of dots as close as possible to 0.015" pitch, as well as a series of continuous lines. The dots were used to establish pattern bleed between sites and the lines were used to monitor for any change in resistance that resulted from thermal cycling.

Metal tabs were placed in conductive epoxy and cured at 150°C for 90 minutes and the resistance was checked post cure. Samples of metal tabs were tested using die shear. The remaining samples were subjected to thermal cycling from -55°C to +100°C with die shear and resistance tests after 50, 100, 250, and 500 cycles.

Substrates were cured and resistance measured between dot patterns and for each length of line. Substrates were subjected to thermal cycling

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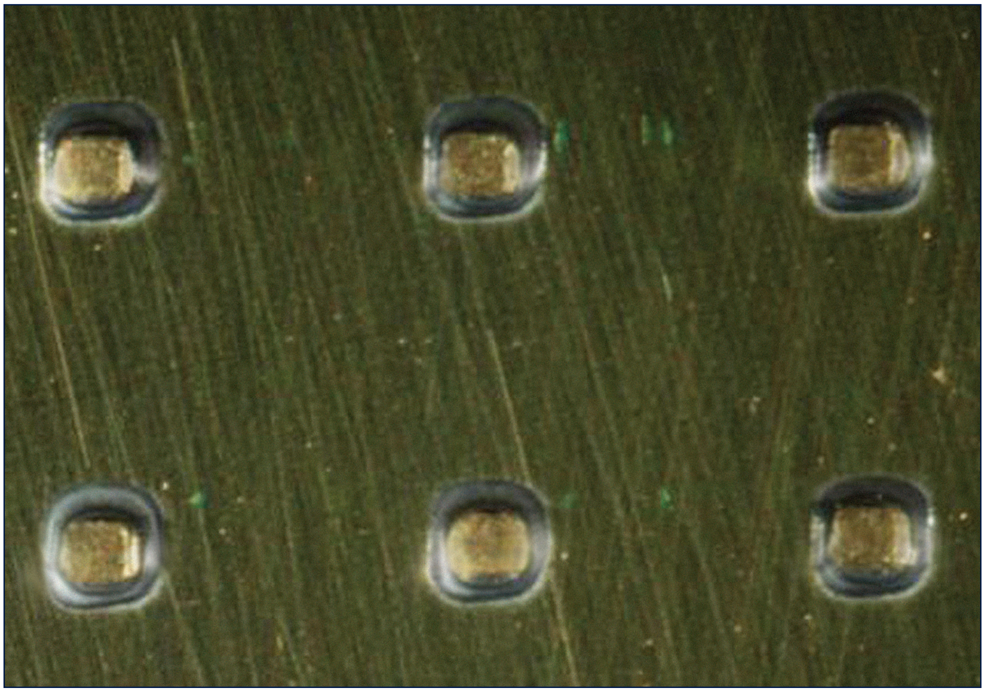

Figure: 2-4: Optical image of metal tabs placed in aerosol jetted conductive epoxy. Courtesy of BAE Systems.

from -55°C to +150°C for up to 1000 cycles with measurements taken after each 100 cycles. All measurements were performed with the conventional material used as a baseline standard.

Application Process Development

The standard deposition process of using an auger pump was one method that was evaluated. Epoxy was dispensed using 27 and 32 gauge needles. The 32 gauge needle provided better control, but both had the problem where the distance variation between the substrate and needle tip resulted in area and volume variation.

A mechanical jetter was evaluated and was able to dispense the nanoparticle-sized silver filler epoxies. The main issue was with standoff heights greater than 0.015" causing a sharp falloff in pattern shape with a reduction in accuracy. Testing of the standoff heights needed to dispense into a channelized package and developing a nozzle to allow access within a channeled package, were not successful.

An aerosol jetter was also evaluated. It was able to dispense and meet the standoff heights necessary with 5 mm for common areas and 15 mm for channels present in certain packages. Progress is continuing to reduce the overspray observed with the 15 mm standoff height by using higher droplet velocities and adjusting the resin composition.

Figure 2-4 shows an example of metal tabs placed and cured in the newly formulated conductive epoxy material.

Summary

The development of the new nanoparticle silver filled conductive epoxy resin has been patterned in more discrete areas which will assist in the miniaturization of the JSF RF Tuner System. After the completion of this ManTech program, the new epoxy system is expected to be commercially available for use on other systems. The use of the new epoxy system, as well as other program efforts, will lead to a reduction in cost in the JSF RF tuner systems.

For more information about the development of nanoparticle silver filled conductive epoxy that can be aerosol jetted, please call 610.362.1320, email helpline@empf.org or visit www.empf.org to contact the EMPF.

Sean Clancy, Ph.D.
Research Associate/Chemist

Services and Training Overview

Empfasis **is a publication of the National Electronics Manufacturing Technology Center of Excellence** **Volume 3 Number 2**

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1 International Plaza, Suite 600
Philadelphia, PA 19113

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