Advanced Conformal Load-Bearing Antenna Structures

Richard L. Chaney, Douglas R. Hackler, Dale G. Wilson, Brian N. Meek
American Semiconductor, Inc.
3100 S. Vista Ave., Ste 230, Boise, ID, USA, Phone: 208-336-2773
www.americansemi.com

Abstract: *Conformal Load-bearing Antenna Structures (CLAS) replace separate aircraft structures and antenna components with the antenna embedded in the aircraft structure, providing multiple functional and form factor benefits for both aircraft and antenna systems. This paper discusses American Semiconductor's CLAS technology that incorporates large form factor printed electronics with high performance ICs into flexible hybrid systems for improved functionality CLAS systems.*

Keywords: FleX; flexible; CLAS; conformal; antenna; flexible hybrid system; multifunctional aircraft structures; MAS; structural health monitor; SHM; fly-by-feel

Introduction

Just as shifting from fabric and wood to metal monocoque construction during the 1930s produced a quantum leap in aircraft performance, so the adoption of multifunctional aircraft structure offers the potential to radically alter the capabilities of military air vehicles.[1] Conformal Load-bearing Antenna Structures (CLAS), as the name implies, replace separate aircraft structures and antenna components with the antenna embedded in aircraft structural components. There are multiple benefits of this approach, such as reducing space requirements, weight, drag, and signature while improving antenna performance and structural efficiency. In addition, studies have suggested that a single CLAS can replace multiple traditional antennas and that less than ten multifunctional apertures, distributed appropriately around an aircraft, could replace all existing antennas.[2]

The unique and compelling technology incorporated in American Semiconductor's CLAS approach utilizes flexible hybrid systems for improved functionality. Flexible hybrid systems (FHS) combine flexible printed electronics and high performance flexible ICs into a single system that delivers the best of both technologies. The flexible printed electronics deliver large form factor antenna elements, wiring and interconnects, and sensors. FleX™ Silicon-on-Polymer™ delivers integrated circuit (IC) functions in a flexible form factor that is compatible with the printed electronics.

The benefits of flexible hybrid systems are clear. Combining printed electronics with FleX ICs creates very thin, very flexible circuits and systems in a form factor that is compatible with conformal requirements. The FHS overcomes limitations that prevent the independent technologies from fulfilling complete system requirements. Specifically, FleX ICs provide the ability for localized signal processing and control. Local signal processing greatly improves the antenna performance reducing signal loss from long transmission lines. In addition, local processing allows the use of data communication protocols between sensors and controllers. This offers significant reduction in antenna weight and space consumption by eliminating the individual cables required to directly connect each antenna and sensor to central processing. CLAS also reduces drag and signature requirements by incorporating the antenna into the aircraft rather than in protrusions from the aircraft.

Flexible Hybrid Systems

Flexible Hybrid Systems are a combination of flexible printed materials and flexible silicon-based ICs that creates a new class of flexible electronics, as illustrated in Figure 1. This fusion of technologies is desirable as it combines the most compelling features of the individual technologies while eliminating the limitations of each.

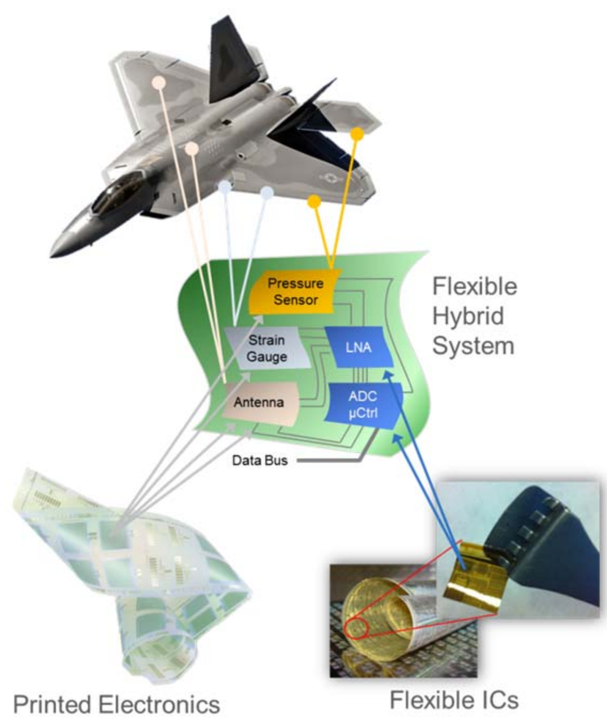

Figure 1: Flexible Hybrid System Example

Printed technologies are relatively mature in the flexible electronics area, and new advances continue to be made. Printed electronics have many desirable features. One of the most compelling features of printed electronics is the large format possible. Printing can be done on roll-to-roll production lines on material several feet wide by hundreds of feet long, producing large form factor sensors or sensor arrays, potentially covering entire aircraft wing structures. Additionally, printed electronics are relatively low cost.

The limitation that must be overcome with printed electronics is that the electron mobilities of printed transistors are low and the feature sizes are much larger than silicon ICs. Printed transistors are useful in large, low density applications such as displays, but cannot be used for viable high performance IC applications such as microprocessors or memory. This has traditionally been a limitation for printed electronics, but is overcome in Flexible Hybrid Systems.

FleX™ Silicon-on-Polymer™ is a proprietary process to transform standard silicon wafers into flexible wafers. American Semiconductor has demonstrated its revolutionary FleX process for creating flexible, ultra-thin, single-crystalline CMOS with multi-layer metal interconnects.[3] CMOS is first fabricated using a standard SOI process on 200mm wafers and then the silicon substrate is removed. The FleX process removes all of the handle silicon and adds a polymer mechanical substrate to create ultra-thin flexible wafers as shown in Figure 2. The FleX wafers may be used at the wafer-scale or diced into individual FleX ICs as shown in Figure 3. FleX provides IC functionality that is orders of magnitude faster than printed transistors.[4] FleX is a post-fab process that can be applied to any SOI CMOS wafer and has been demonstrated on three different CMOS processes from two different CMOS wafer foundries. FleX delivers fully functional, flexible wafers with a final silicon thickness of less than 200nm. FleX has been demonstrated with functional CMOS ICs successful launched into space in June 2012 under the NASA RockSat program.

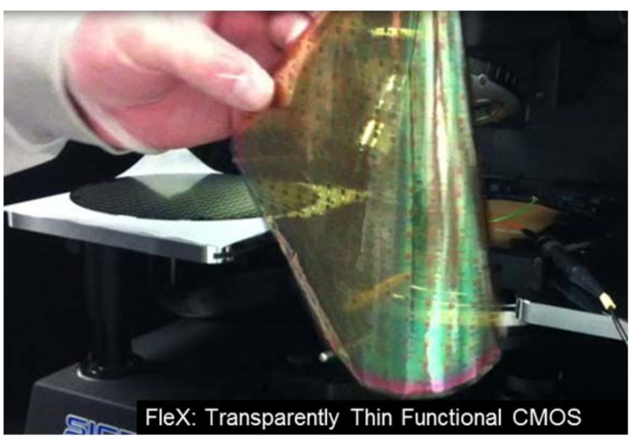

Figure 2: FleX Wafer – 130nm CMOS

Flexible Hybrid Systems have been created as prototypes and conceptualized for high volume manufacturing. Prototyping can be rapidly accomplished using a variety of low-cost printing techniques combined with FleX ICs, as illustrated in Figure 4.

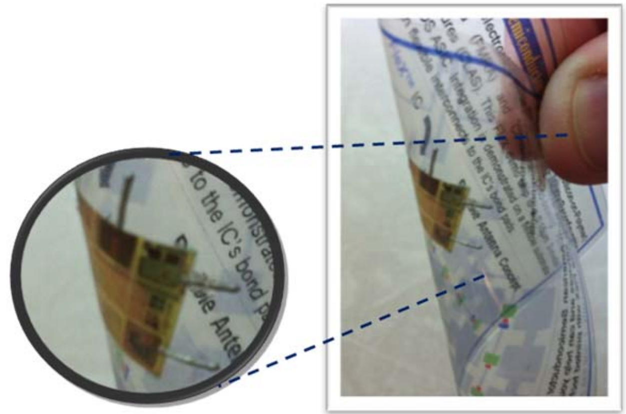

Figure 3: FleX ICs

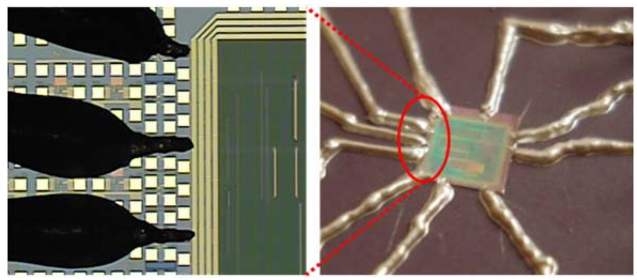

Figure 4: Conformally Attached FleX IC Prototype with Direct Write Flexible Interconnects

High volume manufacturing for Flexible Hybrid Systems has been conceptualized where a FleX IC integration station is added in a roll-to-roll printed electronics line, as shown in Figure 5. The example shows the FleX die integration at the end of the process, although it could feasibly be added at any point in the line as the product requires. With this methodology, Flexible Hybrid Systems can be produced in high volume at low cost.

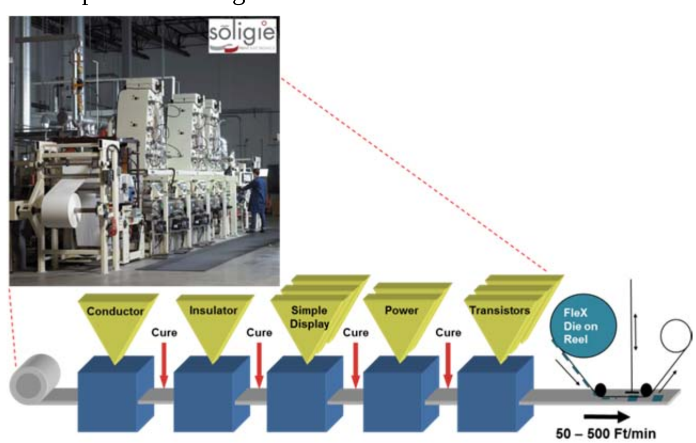

Figure 5: Flexible Hybrid Manufacturing Line

Conformal Load-bearing Antenna Structures

A CLAS prototype has been developed under a Phase I SBIR with Air Force Research Laboratory. The general architecture of the antenna is shown in Figure 6, where the top image illustrates the degree of flexibility and thinness of the antenna. The antenna prototype utilizes a seven layer flexible printed circuit board with three metal layers and four dielectric layers. The entire antenna structure was printed, including the antenna array, ground plane, and interconnects.

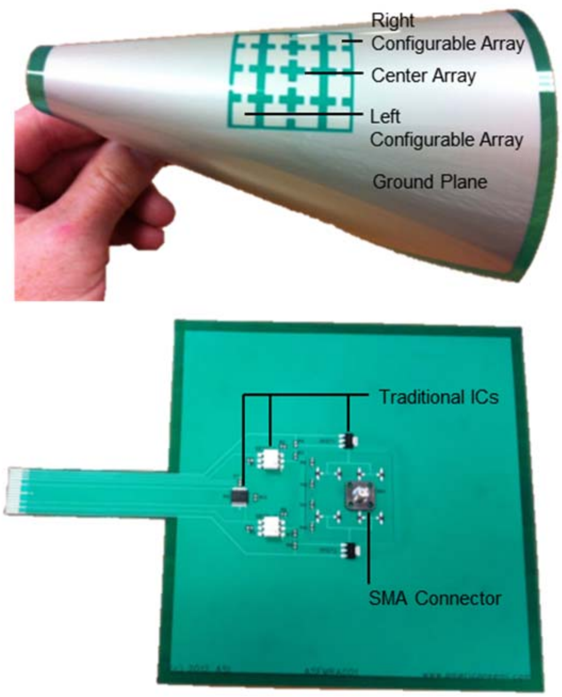

Figure 6: Phase I Conformal Load-bearing Antenna Structure as a Flexible Hybrid System Prototype

The antenna prototype in Figure 6 was fabricated using traditional rigid ICs. Although this approach was useful for demonstrating functionality when the antenna was held flat, mechanical testing demonstrated poor mounting and interconnect characteristics of rigid IC packages on flexible substrates which underscored the benefits of FleX ICs in flexible applications.

A CLAS prototype was developed where the flexible antenna was embedded into a structural laminate, as shown in Figure 7. Due to the transparent material of the inner laminate the image looks as though the antenna was mounted to the inside of the structure. In reality the antenna was mounted to the outer material and covered with the inner material, completely embedding the antenna into the structure. The CLAS prototype was formed into an approximate 6.5 inch radius of curvature to simulate the conformal requirements of a small UAV.

Additional CLAS prototypes were built using a variety of flexible dielectric materials for testing and performance characterization. Antennas were tested flat, conformally mounted, and in the structural laminate. Antennas were tested for S11 and some for S21. The test results allowed development of accurate CLAS models to enhance future programs, including different dielectric materials, antenna layouts, and structural integration effects.

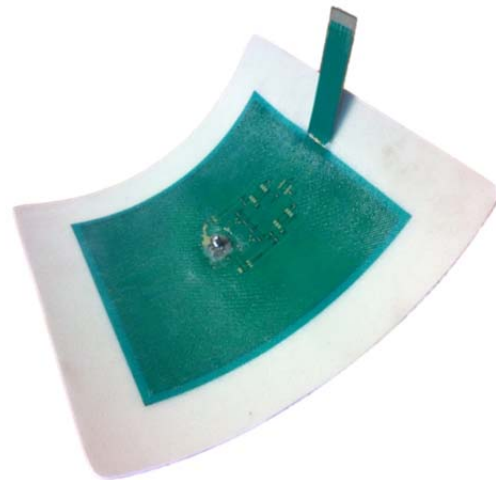

Figure 7: Phase I Flexible CLAS Prototype Embedded in a Structural Laminate

A planned Phase II program will develop an antenna prototype optimized for flexible and conformally mounted applications. This includes replacing the rigid ICs in the antenna with FleX ICs, incorporating an improved flexible dielectric between the antenna and ground plane, and optimizing the antenna design based on the dielectrics, structural material, radius of curvature, and other factors affecting antenna performance. This will result in a thinner, more flexible antenna that can be more optimally integrated into the structural components of the target UAV. Additional CLAS prototypes will be built and integrated into a UAV as illustrated in Figure 8.

Figure 8: CLAS Integrated into a UAV Airframe

In addition, American Semiconductor and Jazz Semiconductor Aerospace & Defense have partnered to provide proven foundry processes in FleX so designers may immediately recognize their ICs in a flexible format.

Extending CLAS Technology

CLAS is one implementation of multifunctional aircraft structures (MAS). MAS hold the potential to drastically alter and improve the capability of air vehicles by integrating functional systems as a part of the airframe structure. MAS takes a large step toward allowing aircraft to be designed around mission requirements rather than by platform limitations.[5] The approach taken by American Semiconductor to create its CLAS is directly compatible with manufacturing advanced MAS sensors and localized processing capability required for structural health monitoring (SHM) and fly-by-feel (FBF) applications.

SHM embeds strain gauges, temperature sensors, pressure sensors, and other sensors into the structural components of aircraft. SHM would enable aircraft maintenance based on need rather than by schedule, potentially saving millions of dollars across a fleet. Additionally, SHM improves safety by monitoring the aircraft dynamically, in flight and on the ground, providing valuable lifetime information which can be critical as assets are often operated beyond their designed lifetimes.

FBF embeds sensors and control into flight surface structures. This provides information that cannot be obtained today, such as the stagnation point of the wing in real time. This information can be used to improve flight performance and efficiency and paves the way to smart, reconfigurable flight surfaces, much like birds use their feathers to optimize flight.

The Flexible Hybrid technology demonstrated in CLAS extends to a wide variety of applications. Embedded flexible sensors and ICs can improve the functionality and lower the cost of wearable, surgical, or implantable medical devices. Flexible Hybrid technology can improve secure documents such as smart cards and secure documents while lowering the manufacturing cost. Flexible Hybrid systems hold the potential to revolutionize consumer devices such as phones, tablets, and other devices.

Conclusions

Multifunctional aircraft structures are desired by aircraft designers as a means to revolutionize flight. MAS adoption has been limited by the electronics being incompatible with flexible and conformal formats. Flexible Hybrid technology solves these issues, combining printed electronics with flexible ICs to deliver large form factor sensor systems while reducing power consumption and weight with increasing functionality and performance. Conformal Load-bearing Antenna Structures offer significant improvements for both UAVs and manned aircraft, while demonstrating the leading edge of Flexible Hybrid adoption.

Acknowledgements

American Semiconductor, Inc. would like to acknowledge Air Force Research Laboratory, Wright-Patterson AFB, for supporting CLAS development under the Phase I SBIR "Conformal Load-bearing Antenna Structure" program.

References

1. Callus, Paul. "Novel concepts for Conformal Load-bearing Antenna Structure" Defence Science and Technology Organisation (DSTO). February 2008.
2. Lockyer, A.J., Alt, K.H., Kudva, J.N., Kinslow, R.W., M.D. and Goetz, A.C., "Conformal load-bearing antenna structures (CLAS): Initiative for multiple military and commercial applications", SPIE Conference on Smart Structures and Materials, SPIE Volume 3046, San Diego, California, USA, 4-6 March 1997, pp. 182-196.
3. Chaney, R., Hackler, D. "Performance Electronics Integration in Flexible Technology". GOMAC, March 2010. url: www.americansemi.com/GOMAC2010_28-18.pdf
4. Hackler, D., "High Performance Electronics Integration in Flexible Technology". 2011FLEX (Flexible Electronics and Displays Conference), February 2011. url: http://www.americansemi.com/AmericanSemiconductor_2011FLEX.pdf.
5. Air Force Research Laboratory, "Transforming the future of warfare with unmanned air vehicles", AFRL Horizons Technical Articles Online, VA0209, September, 2002. www.afrlhorizons.com/Briefs/Sept02/VA0209.html
6. US Patents 6580137, 6919647, 7015547, 7019342, 7154135, 7154135, and 7518189. Other US and foreign patents pending.
7. Chaney, R, et. al. "Pliable Smart Sensor System". GOMAC, March 2012. url: www.americansemi.com/GOMAC2012_31.9.pdf