Introduction to Additively Manufactured Electronics and what it can do for you

J.A.M.E.S

Table Of Content

1 Additively Manufactured Electronics (AME)

What is AME and what processes are present on the J.A.M.E.S FrAMEwork.

2 Non-technical Benefits Of AME

The logistical, ecological and economical benefits of AME.

3 Lumped AME Filters

Building AME lumped element filters shows the potential of reducing costs, space and weight.

4 3D Wiring Concept

New wiring concepts by AME overcome the limitations of PCB.

5 Merging Mechanical And Electrical Functionalities

Electrify volumes of any shape and rethink the concepts of housings.

6 Heterogeneous Integration Of Unpackaged Chips

Embedding and contacting bare chips using AME, avoiding bond wiring can increase miniaturization.

Abstract

The intention of this document is to give a brief introduction to the Additively Manufactured Electronics (AME) technology and an overview of the currently available (3D-) printing processes for electronics. Furthermore, the paper will highlight the advantages of AME over the traditional printed circuit board (PCB) technology and why it is worth the effort to advance this emergent technology. The identified unique selling points (USPs) of AME will be linked to visionary AME stories on the J.A.M.E.S FrAMEwork, enabling the registered users to permanently track the technology's advancements towards the applicability of the USPs in fully functional products.

Chapter: 1

Additively Manufacturing Electronics (AME)

Additively Manufacturing (AM) or 3D printing denotes any manufacturing process that creates three-dimensional objects by adding layer upon layer of material. For the creation of functional mechanical parts using AM, a variety of materials and processes are available. Some of them have been around for more than ten years, reached a qualification level, and were already used in products.

A rising stream in the domain of additive manufacturing is the field of Additively Manufactured Electronics (AME). Currently, many different definitions are available, which technologies and processes are part of AME, and which are not. In the following, the authors present the definition that guides the roadmap and activities of J.A.M.E.S.

AME encompasses all AM technologies that lead to manufactured structures that provide functionalities needed to realize electronic circuits or electromagnetic structures. This includes not only devices which actively contribute to the electrical functionality (e.g., conductive interconnects, antennas, etc.) but also structures that enable and support this functionality (e.g., heat sinks, housings, and more).

This somewhat general definition does not only include a wide variety of processes but also gives rise to many different fields of application of AME.

In the first step, the authors would like to give a brief overview of the processes that are currently investigated by J.A.M.E.S. It should be noted that this list is not complete and will be subject to constant growth. Therefore, many processes and technologies might be greatly beneficial for AME, although they are not (yet) listed here. The processes listed here are provided by the partners of J.A.M.E.S and are listed in chronological order of the process owners becoming partners of J.A.M.E.S.

The first process available on the J.A.M.E.S FrAMEwork is the Nano Dimension MultiJet process provided by the DragonFly IV printer system. Currently, there are two different inks available. One photopolymer ink, cured by UV light, serves as dielectric substrate material, and one silver nanoparticle ink, cured by an IR lamp supported heat process, provides electrically conductive structures.

Figure 1: Silver nano particles ink for conductive features

The Nano Dimension process enables the realization of three-dimensional electronic devices, which completely overcome the design limitations imposed by the traditional PCB manufacturing process. It is possible to assign each printed three-dimensional voxel to be conductive or nonconductive during the design process.

Another AME process that is available on the J.A.M.E.S FrAMEwork is the microdispensing technology of XTPL. This technology enables users to add very small conductive lines onto existing surfaces. The surfaces do not have to be flat, and line widths of down to 1 um are possible, which gives rise to the possibility of directly contacting bare die chips.

In addition to the AME processes presented above, several ceramic-based processes of the Fraunhofer IKTS are available. The electrification of ceramic materials is promising for applications that need to withstand high temperatures and other rough environmental conditions.

Furthermore, the author will continue to discuss the topic of the potential application of AME technology that arises. A trend to print classical PCB structures has been observed, especially since the advent of AME printers that allow the simultaneous processing of conductive and nonconductive materials. Although the traditional manufacturing process of PCBs imposes some serious limitations on the design process (layer-based design with interconnection by vias). These design limitations are obsolete with AME technology and therefore the authors see no reason to use them.

Thus, the focus of the J.A.M.E.S activities entirely lies on electronic circuits and structures which exceed those limitations as well as use the complete freedom of design that became obtainable through the 3D printing technologies. Another advantage that the J.A.M.E.S FrAMEwork offers is the variety of available processes. Since AME offers a large freedom of design, the combination of different materials and even processes is highly facilitated, so that AME structures can easily combine the advantages of the respective processes. This combination process leads to so-called Hybrid AMEs.

The purpose of this document is to show potential applications and use cases that could vastly benefit from the newly available AME technology. In chapter 2, a list of nontechnical benefits of the AME technology over the traditional PCB process will be presented, while the remaining chapters will show some purely technical USPs of the AME technology. Although these USPs are listed separately in this document, it is certainly possible to include them all together in one single structure in order to draw the most benefit from using the AME technology. Nevertheless, the provided list of USPs is not complete. The basic idea of the J.A.M.E.S FrAMEwork is to assemble as much AME knowledge as possible. Therefore, anyone who has additional USPs, which were not mentioned in this document, is welcome to share their ideas and experiences on the J.A.M.E.S FrAMEwork.

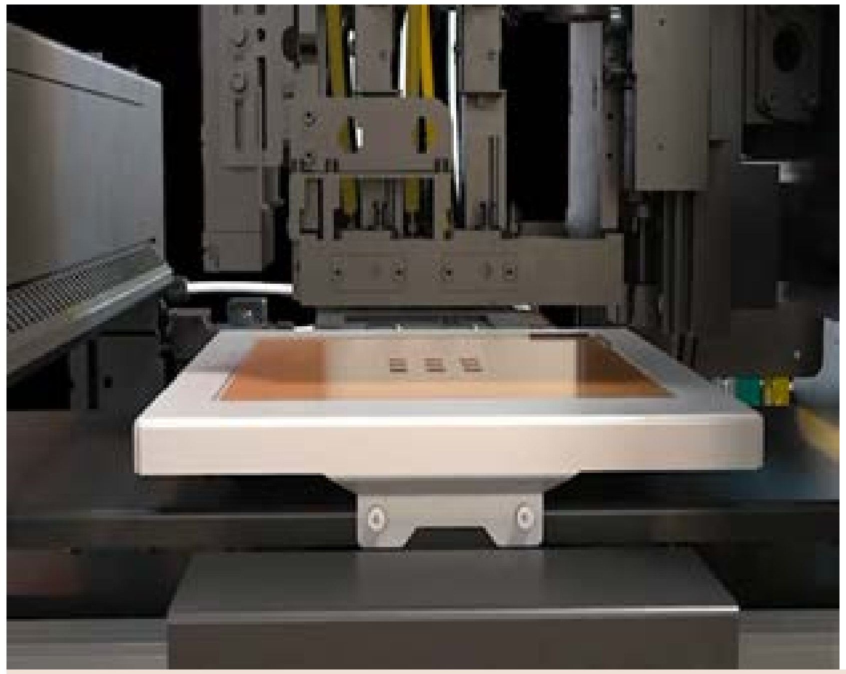


Figure 2: Polymer based ink for insulation and structure

Chapter: 2

Non-technical benefits of AME

This chapter compares AME to the traditional PCB manufacturing process on a non-technical level. The first point to investigate is the sustainability of the AME technology.

Traditional PCBs are typically manufactured in a subtractive process which results in noticeable material waste during the process of etching, drilling, and milling. In contrast to that, AME is a completely additive process. Therefore, material is only added where it is required from a functional point of view. Furthermore, the acids used in the PCB etching process are very harmful to the environment. The AME printing processes do not need the use of such substances and can therefore be considered much more environmentally friendly. From a logistical point of view, there are reasons to use the AME. It is possible to fit an entire AME production within a single lab room, or even a shipping container, giving the possibility to print everywhere around the world without the need to build up a whole manufacturing plant (Infrastructure for the DragonFly IV).

Since the AME technology offers great flexibility in production places, the need for stock keeping is extremely reduced. Hence, if replacement parts are required at remote working places, it is no longer required to keep all sorts of replacement PCBs in stock. But one printer with the respective raw materials is enough, and the replacement electronics can be produced on demand. Considering the actual requirement to establish a fully functional AME manufacturing site are minimal, the AME technology will play a crucial role in establishing the "digital inventory" concept for electronics. Instead of shipping whole PCBs through the globe, it will be enough to send the required production data. The final AME structures can then be realized where they are needed, easing the logistical requirements for electronic components.

Chapter: 3

Lumped AME Filters

Building up RF filters consisting of lumped AME elements is only the second step of the replacement process of commercia-off-the-shelf (COTS) capacitors and coils by 3D printed AME capacitors and coils. The first step consists of replacing those components individually. Just this first step can lead to significant improvements in both performance and logistics. For instance, if there are no more external COTS capacitors or coils required, there will not be the need to procure them and keep a certain amount of them in stock. Instead, it is sufficient to have the respective AME raw materials available, and the required components can simply be included in the print of the overall AME structure.

Furthermore, the AME capacitors and coils can be designed in any shape – of course, within certain limitations – to fit inside the remaining space of the overall design. There is no need to reserve any valuable surface space to place them, but the available surface space will be fully accessible for non-printable components such as transistors, chips, etc. The availability of different 3D printing materials and processes and the ease with which these can be combined will highly increase the performance achievable with AME capacitors and coils. For instance, it will be possible to choose materials with high dielectric constants, such as ceramics, as dielectrics for the capacitors, allowing a significant reduction of size. The same holds true for coils if magnetic materials can be implemented during the printing process.

While those benefits of using AME capacitors and coils individually are already convincing, there are additional benefits when combining those elements to form lumped AME filters. If all the filter elements are printed with one of the AME processes, they will exhibit high reproducibility. Therefore, any additional manual tuning process can be omitted. Since this manual tuning process is the step that makes highly accurate filters awfully expensive, this step can lead to significant cost reductions in producing these types of filters. Moreover, not only the capacitors and coils themselves but also the connections are printed. Thus, it is not necessary to take solder contacts into account, which often leads to unexpected behavior, especially for high frequencies. As a result, the performance of the filters, as well as the frequency range in which they are functional, can easily be extended.

To see the current status of lumped AME filters and to keep track of their future progress, visit the lumped AME filter story on the J.A.M.E.S FrAMEwork.

Chapter: 4

3D Wiring Concepts

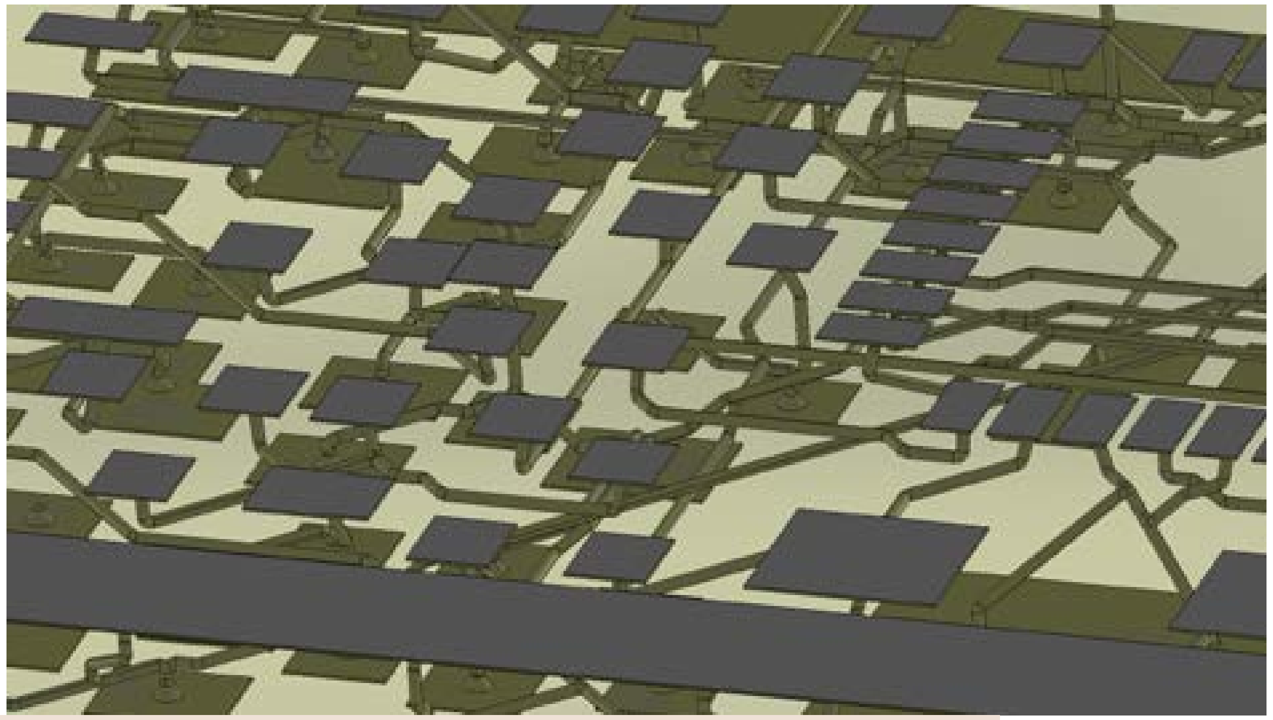


Figure 3: 3D wiring concepts

As stated in the introduction, the traditional manufacturing process of conventional PCBs imposes certain limitations on the design process. It is, for example, necessary to design planar layers. To interconnect these layers, vias will be used, which are vertical lines that are formed through drilling and a subsequent metallization process. To save time and money during the manufacturing process of multi-layer PCBs, the vias are usually created in a late process step and are therefore going through all layers of the board. This however, means that vias are blocking space throughout all available layers, even if the vertical connection is not needed everywhere. Especially if large ball grid arrays (BGA) are involved, the vias block a large amount of space on layers where their connection is in fact not needed, making the PCB much larger and heavier.

Using AME processes, it is not only possible to restrict vias to the layers they really need to interconnect (buried vias), but they allow to get rid of vias altogether by implementing three-dimensional wiring concepts. Instead of drawing planar lines that are interconnected by vias, this innovative technology allows drawing three-dimensional lines connecting exactly those points in space that need to be connected. With this 3D wiring concept it is possible to use the space beneath BGA components for additional lines, which reduces the size and weight of the overall structure.

A further advantage enabled by the AME technology is the possibility to shield the three-dimensionally drawn lines if required. Due to this shielding ability for lines that carry DC or AC signals, it will be possible to highly increase the achievable packing density. Even though the lines are put remarkably close together, the shielding avoids unwanted crosstalk, and the overall structure can shrink even more while simultaneously maintaining full functionality.

When it comes to RF signals, the advantages of AME become even more relevant. Instead of simulating and optimizing via connections from one layer to another to achieve minimum reflections, the RF signal can be carried on a smooth coaxial line from one point to another. Doing so avoids time consuming optimizations and simulations, and results in an exceptionally smooth transmission of the RF signals without significant reflections.

In digital systems, where the signal integrity plays a crucial role, the possibility of printing three-dimensional coaxial lines also leads to significant improvements. The availability of a pure TEM mode, as well as the reflection free transmission of signals over broad frequency bands, promises to yield far greater results in terms of signal integrity.

However, a big challenge that must be faced to realize 3D wiring concepts is the lack of suitable software that enables the user to achieve the 3D wiring in an automatic way. The current work-around to get 3D wired structures is a manual process which is currently very time consuming and prone for design errors. Any software that facilitates the process will be highly welcomed by the AME community.

To keep up to date with recent advancements regarding 3D wiring concepts, have a look at our RF Synthesizer story on the J.A.M.E.S FrAMEwork.

Chapter: 5

Merging mechanical and electrical functionalities

A major advantage that the AME technology provides to its users is the possibility to shape the fully functional structure to any arbitrary volume. In contrast to the traditional PCB technology, which yields flat electronic structures, the AME technology can be utilized to electrify volumes which would not be electrifiable with standard technologies. This advantage has a major influence on the system level design because it allows to fit more electronic functionalities in an arbitrarily shaped housing and the need to squeeze flat PCBs in an aerodynamically shaped volume becomes obsolete.

The next logical step is to no longer include the electronic AME structures in a dedicated housing but to encapsulate all electronic COTS components in one printed AME device, which then no longer requires any additional housing. Thus, the dielectric substrate does not only fulfill an electronic purpose but also must satisfy mechanical requirements that usually are imposed on the housing. The shape of the overall AME structure can thus be defined by the needs resulting from completely different physical domains, for example, aerodynamics. It is also clear the embedding and interconnecting of all the COTS components will be highly facilitated by the availability of the 3D wiring concepts discussed in the previous chapter.

To facilitate the above-mentioned integration of mechanical and electronical functionalities in one single structure, it will be necessary to print the whole AME structure in one single print. This leads to additional advantages on the electronic design side since it will no longer be necessary to interconnect different structures, but it will be possible to omit connectors and connecting wires between the devices. Instead, the required connections between different sections of the AME structure can just be printed and therefore do not need any additional assembly steps.

Figure 4: AME drone

Considering the number of available materials for AME printers is still limited, an effective way to overcome this limitation will be to combine prints from different AME processes. The freedom of design that is available in the AME technology will highly facilitate this integration, leading to hybrid AME structures.

However, the encapsulation of COTS components in the printed structures will also lead to the need of new heat management concepts. If high power components are embedded, it is especially crucial to find a way to get the heat away from the component. Therefore, it is not only a merge of mechanical and electrical but also of thermal functionalities. The advancements and the status of the discussed merge can be tracked by following our AME Drone story on the J.A.M.E.S FrAMEwork.

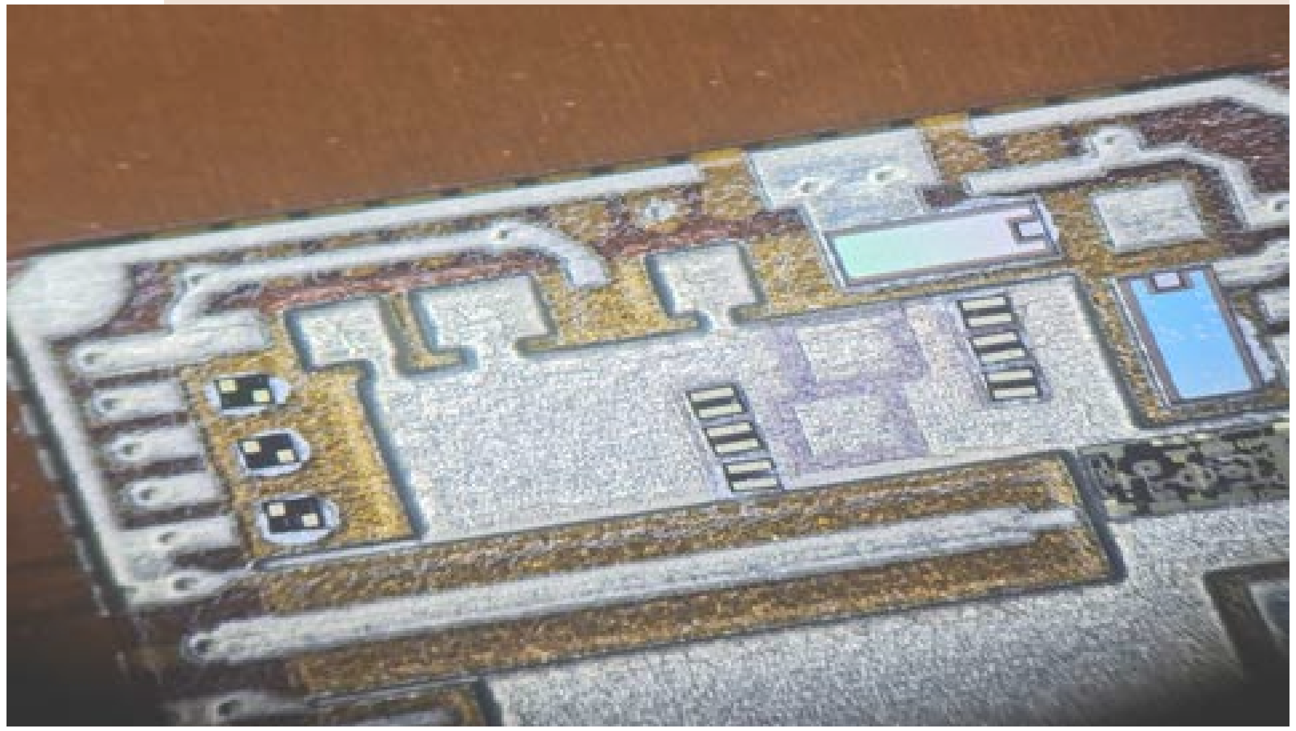
Chapter: 6

3D Heterogeneous integration of unpackaged chips

With the availability of AME processes that allow the creation of exceptionally fine conductive lines, it will be possible to directly contact bare die chips with this printing process and connect it to the remaining AME structure. With this process, the established bond wire process can be omitted. Not only are bond wires in general extremely sensitive to mechanical and thermal stress, but the bond wire process itself is extraordinarily complex and requires a lot of effort and expertise to achieve bond connections that withstand the environmental challenges in the final application. In contrast, contacting the chips with AME processes will lead to a much simpler process resulting in connections that are more robust towards mechanical and thermal stress.

By being able to contact both chips and remaining AME structures, there will be no need for dedicated housings of chips anymore. The bare dies can be directly incorporated into the AME structures, and the form of printed interconnection can be designed according to the respective requirements. If, for example, an RF amplifier is supposed to be connected, the connecting printed line can be designed to be 50 Ohms, resulting in much less reflection. Furthermore, the avoidance of dedicated housings also gives rise to an enormous potential of miniaturization. With the availability of an AME process that can generate exceptionally fine lines, a fan out of the chip connections to a large BGA that is compatible with PCB line and space widths is no longer necessary.

Figure 5: System in package



In addition to the previously mentioned points, a further advantage of using AME to connect bare die chips lies in the possibility of stacking and embedding them in an arbitrary way. With the right AME processes available, it will be possible to place the bare dies in any way and orientation, giving rise to new possibilities in the field of 3D heterogeneous integration and achieving levels of miniaturization which would not be possible with traditional manufacturing technologies.

Besides the availability of suitable underfill material and special pick & place machinery also the heat management will be a crucial issue. However, due to the freedom of design that is provided by the AME technology and the availability of varied materials, the required cooling structure can be directly implemented where they are needed. Additionally, it will be possible to optimize their shape to get the heat away from the critical components in the best way possible. As already mentioned in the 3D wiring concepts section, if the AME printers do not provide suitable materials to realize the cooling structures to print everything at once, the hybrid AME concept can help to overcome this issue.

To be up to date with the advancements in the 3D heterogeneous integration of unpackaged chips, follow our System in package story on the J.A.M.E.S FrAMEwork.

J.A.M.E.S GmbH

Willy-Messerschmitt-Straße 3

82024 Taufkirchen

Germany

Visit our FrAMEwork www.j-ames.com

Follow us on