Lightweight Waveguide and Antenna Components Using Plating on Plastics

Lightweight Waveguide and Antenna Components Using Plating on Plastics

Erik G. Geterud*, Pontus Bergmark†, Jian Yang‡,

*GlobalView Systems, Hökegårdsgatan 14B, SE-431 38 Mölndal, Sweden. Email: erik.geterud@globalviewsystems.co.uk
†Art and Technology, Letsegårdsvägen 35, SE-427 40 Billdal, Sweden. Email: artotechnology@gmail.com
‡Chalmers University of Technology, SE-41296 Gothenburg, Sweden. Email: jian.yang@chalmers.se

***Abstract*—We present three methods for producing lightweight waveguide- and antenna components by autocatalytic electroless copper plating on plastics. Waveguides for the Ku-band are manufactured throught; 1) extrusion of ABS plastics; 2) 3D printing with Stereolithography (SLA) polymers and; 3) composite forming in Particle Pressure Chamber (PPC). The three methods covers applications from prototypes to mass production, from in house applications to space approved extremes. In previous autocatalytic methods it has been difficult to exceed 2 μm copper layer but in this work we utilize a method of autocatalytic electroless plating on plastics for unlimited thickness but here stopped at a 4-5 μm thick glossy copper layer. Measurements on conductivity and attenuation have shown that the performance is approaching that of standard aluminium waveguides with 0.0375 dB/cm loss, but with reduced weight and lower cost if made in series. Refined waveguide samples will be measured for the conference presentation.**

***Index Terms*—Chemical processes; Composite materials; Fabrication; Metallization; Microwave measurements; Stereolithography**

I. Introduction

Low weight is an attractive feature in many antenna- and microwave component applications, such as in mobile- and aerospace scenarios. Metal plating on plastic (PoP) components to produce highly conductive surfaces is an advantageous approach to achieve this. For serial production plated plastic components there are choices less costly and less energy consuming than its metal counterparts. The commercial methods of PoP was first developed in the 1960's mainly for the automotive industry due to the low cost and advantages in aesthetics and weight [1], [2]. This followed the discovery that the Butadiene blocks in the copolymer ABS (Acrylonitrile-Butadiene-Styrene) can be chemically etched resulting in pores on micrometer level with active sites that can be plated with conductive metal. In theory any metal can be deposited on plastics but Nickel- and Chrome plating dominates. The first electrical use of plating on plastics was for electromagnetic shielding to minimize interference between devices. Plating on plastics has been used for injection molded waveguide filters [3] and power combiners [4]. Also, injection molded planar arrays have been plated for 12 GHz satellite TV reception [5] and 58 GHz radio links [6]. The PoP technology is also applicable to the hat-fed reflector [7]–[9] and the Eleven feed [10], [11], especially for low frequency applications. One potential application of PoP technology is plastic plating gap-waveguide [12]–[14]. In this paper we present the procedure of the technology and measurements on examples of copper plated plastic waveguides.

II. Waveguide and Antenna Production

Long waveguide sections are favorably produced through extrusion of ABS or ABS/PC (Poly-Carbonate) blends. After evaluation of materials for the extrusion- and plating process, the ABS material Terluran HI-10 from BASF [15] was chosen. The waveguide tubes are square for dual polarization and with inner side dimension of 16.4 mm and 0.8 mm wall thickness. The tubes are cut in suitable lengths when leaving the extruder by a moving cutting blade. The capacity of the waveguide extrusion considered is approximately 125 m/h. One alternative method of increasing interest is Stereolithography (SLA) and other types of 3D-printing. By this method very complex 3D-shapes can be generated directly, from CAD data, when prototypes and small series are required. SLA is an additive manufacturing method where a photopolymer, or resin, is cured by a UV-laser to build the structure layer by layer. The structure is generated from a triangular mesh and the tolerances depends on the SLA machine used but typically the layer thickness may be 0.05-0.15 mm (z-direction) and the accuracy 0.01-0.02 mm (x-y-direction). Fig. 3 shows some examples of plated waveguide parts manufactured through SLA. Other examples of metallized SLA-structures are the horn array for 35-39.5 GHz [16] and the corrugated horn for 75-110 GHz [17]. The results are encouraging as the tolerance requirements for such high frequencies are critical on both the SLA-structure and metallization. To 3D-print (lightly) conductive structures it was presented to use thermoplastic composites loaded with amorphous carbon [18]. Proposed applications are electronic sensors and of interest is also the improved thermal characteristics of the carbon loaded material. For larger series production rotational- and injection molding etc. are alternatives.

Another alternative to thermoplastic extrusion is forming of pre-impregnated (prepreg) material in an autoclave. Autoclaves are commonly used with high pressure air or gas as the pressurizing medium in the composite industry. In such autoclaves there are hazards from leakage, high auxiliary material costs and long process times. This has created a need for out of autoclave processing of composites. Here we have used a new technology, a developed Particle Pressure Chamber (PPC) that have eliminated these drawbacks with in addition favorable thickness tolerances and smooth surfaces. PPC can form composites in complex shapes and cavities that can be metallized and used in temperature extremes and with high mechanical strength.

III. Plating on Plastics

In general the polymer surfaces are relatively inert with few sites for binding to an applied metal film. The surface can be activated in different ways, e.g., by introducing acids, basic-polar- or functional groups. A chemical treatment, e.g., an etching by chromium salt, is established for thermoplastics containing butadiene blocks. We have used this treatment successfully with the PPC also for a group of thermosets that contains polybutadiene, e.g., as in impact resistant CFRP (Carbon Fibre Reinforced Plastics).

Plating on plastics can be divided into two main categories: A) Electroplating and; B) Electroless plating.

A. Electroplating

The electroplating process, so-called electrodeposition, requires an applied electrical current. The part to be plated is the cathode of the circuit and a DC current is applied to the anode. Commonly is also pulse plating used with pulses of alternating DC current with shorter or longer durations from milliseconds to seconds. The whole circuit is placed in an electrolyte with metal salts and other ions to support the flow of electricity and metal build up. The process is analogous to a Galvanic cell operating in reverse.

B. Electroless plating

Electroless plating, also known as autocatalytic plating, does not require an external electrical current to be applied. The reaction is accomplished when hydrogen is released by a reducing agent, e.g. sodium hypophosphite, and oxidized, thus producing a negative charge on the surface of the part. A limitation with this method has been that it was slower than electroplating and that the build up layer was limited to a few μm. Advantages are lower setup costs and the freedom in plating all kinds of geometries, including complex cavities.

The method of electroless plating used in this work consists of the following steps. 1) Etching; 2) Activation; 3) Acceleration; 4) Copper deposition; 5) Protective surface coating, as shown in Fig. 1. After each step there is a water rinse. With electroless plating it is possible to stream the electrolyte on the inside only for closed geometries as cavities and waveguides, Fig. 2. This is saving material cost and weight on the final product.

In addition to the structures in extruded ABS the electroless plating process was used successfully for the 3D printed SLA structures and CFRP structures made in PPC, Fig. 4. CFRP is often used in space applications due to its light-weight, high strength and stable thermal performance.

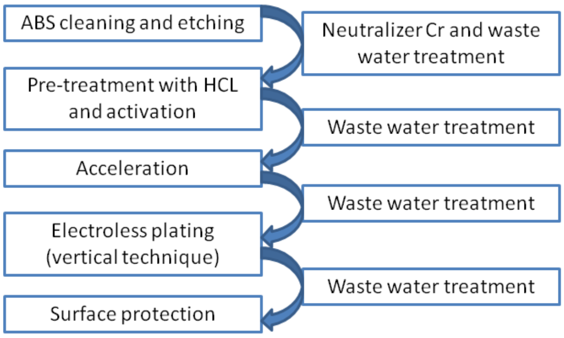

Fig. 1. Plating scheme presenting the main process steps.

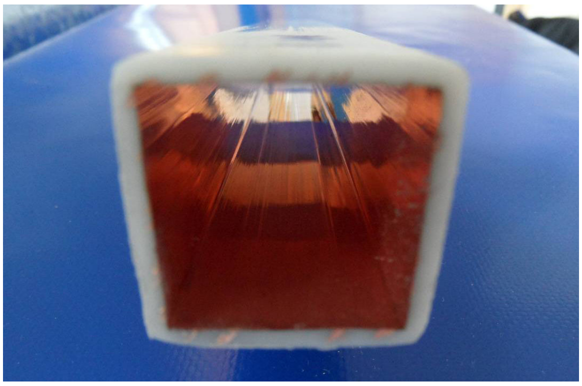

Fig. 2. Plastic (ABS) waveguide with copper plated inner surface.

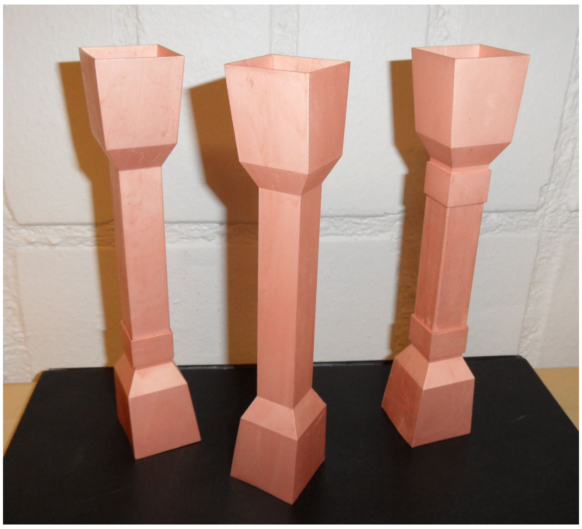

Fig. 3. 3D-printed plated waveguide parts.

IV. The plating process

The settlement of copper from a plating bath is a surface reaction that is a competition between a number of parallel reactions that change over time with change in concentrations and other destabilization reactions at the surface and in the liquid. The waveguide tubes were plated on the inside only which is achieved by having the first bath with the activator

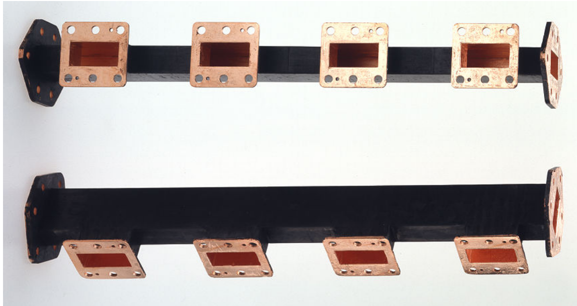

Fig. 4. Waveguide-coupler of metallized Carbon Fiber Reinforced Plastic (CFRP).

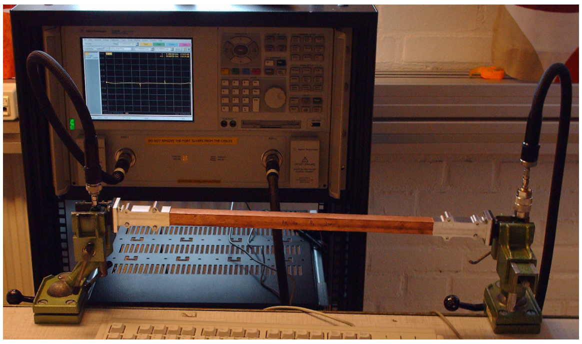

Fig. 5. Measurement setup for waveguide transmission.

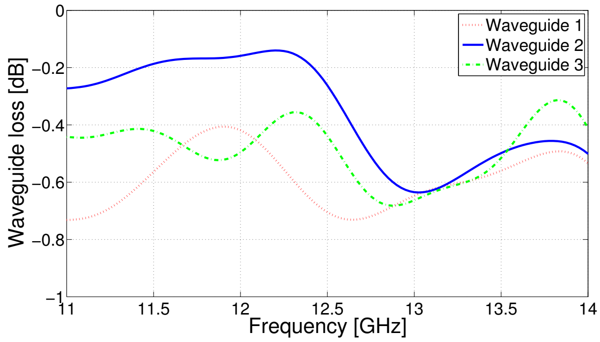

Fig. 6. Measured transmission loss in three plated waveguide samples of equal dimensions and 20 cm lengths.

in contact with the inside surface only. The tubes could be sealed in one end and then filled with the activator followed by a water rinse. The selected plating technique allows the entire tube do be dipped in the baths following the activator bath without precipitates or contaminations on the outer surface. The plating steps coming after the activator bath, goes on only the inside surface. Masking of the structure could thus be eliminated after the activator bath which considerably simplifies the plating. The baths contains reactive substances and after every step in the process the tubes shall be rinsed. It is important that the following bath not becomes contaminated. Also, the concentrations of the specific substances must be monitored continuously. Outside a specific concentration window the bath can precipitate uncontrollable or otherwise jeopardize the waveguide quality. With the narrow tube dimensions agitation of the baths needs to be more intensive and a streaming bath is favorable. The flow speed must not be too high since for instance the reaction for copper plating then becomes too much reduced. The process is in addition to waveguide plating also suitable for plating of cavities. The deposition rate of electroless copper is 4-6 μm/h depending on bath age and working conditions. Due to its good stability, the bath is particularly suitable for the processing by streaming through the waveguide tubes.

V. Waveguide Surface Evaluation

The analysis were performed at Volvo Research at Chalmers Scientific Park in Gothenburg. The inspected tubes copper surfaces are generally glossy and even. The unevenness observed emanated from the extrusion process as small ridges and tracks along the feed direction. When occasionally less successful results were observed as rough, non glossy metallized surface the reason was identified as insufficient circulation in the baths leading to low local concentrations of active materials inside the tubes. This may cause precipitation of copper particles that adhered loosely to the surface and made it rough. Appropriate rinsing is another important aspect of successful plating. Temperature cycling of 50 times between the extremes +60°C and 25°C, with the cycle time 40 min, was done and controlled by temperature sensors. Test of adhesion was done following the standards DIN 53151 (cross-cut test) [19] , and ASTM D 3359 (adhesion by tape test) [20]. The overall appearing result from the tests was classified 5B which means that no copper at all came loose in the test. The further evaluations were ocular, by microscope and by 3D tests of the surface. Measurements of the copper thickness were done on polished cross section samples by use of optical microscope at 10 locations along the cross sections of the waveguides. The thicknesses were even for the samples and varied between 4-5 μm.

VI. Waveguide Measurements

When the waveguides have been plated they are visually inspected and the conductivity is measured using a multimeter. Furthermore, the reflection coefficient S_{11}, and transmission coefficient S_{21} is measured using an Agilent E8363B VNA. Two adaptors are used to match between the coax to WR-75 transition and the extruded waveguides. The waveguides are 200 mm long and measurements are done in the band 11-14 GHz. S_{11} and S_{21} is measured with the waveguide between the adaptors, as shown in Fig 5, and with the adaptors directly attached without the waveguide in between. The waveguide loss is calculated, and plotted in Fig. 6.

VII. Conclusion

A method of metallizing plastic waveguide- and antenna components through autocatalytic electroless copper plating has been developed. Initial measurements on three waveguides samples show waveguide loss of $\leq$ 0.0375 dB/cm. It is assumed that the loss is partly ohmic but that also the attachment of waveguide to the adaptor may include a small air gap which results in fluctuation of the measured result. For the conference presentation further measurements on new waveguide samples will be made with minimized air gaps. For certain specialized applications, e.g. in space, where low weight, strength and stable thermal performance is critical we can chose to manufacture CFRP components in PPC and metallize them as an alternative to the lower cost ABS. SLA have been identified as a suitable method of rapid and lightweight 3D-prototyping of antenna- and microwave components when metallized. The plating on plastics method is applicable for various antenna configurations such as planar arrays, slotted antennas, horns and reflectors.

ACKNOWLEDGMENT

The authors would like to thank Polybase AB [21] for waveguide extrusion, Prototal AB [22] for SLA waveguide prototyping, and Atotech GMBH [23] for assisting with the plating.

REFERENCES

[1] W. G. Simpson, *Plastics: Surface and finish*. The Royal Society of Chemistry, 1995.

[2] R. R. Smith and T. D. Lewis, "Metal plating of abs and other plastics," *The production engineer*, vol. 46, no. 9, pp. 526–534, 1967.

[3] H. Asao, N. Yoneda, M. Mukuda, and K. Yamasaki, "Metal-plated plastic waveguide filter using injection molding process," *IEEE MTT-S Int. Microwave Symposium Digest*, vol. 2, pp. 941–944, 2003.

[4] H. Asao, H. Kazuhisa, M. Mukuda, and N. Yoneda, "Ku-band power combiner composed of metal-plated plastic waveguide hybrid," *IEEE MTT-S Int. Microwave Symposium Digest*, vol. 2, pp. 625–628, 2004.

[5] M. Shelley and N. Dang, "Use of metallised plastics in high volume antenna applications." Low Cost Antenna Technology (Ref. No. 1998/206), IEE Colloquium on, London, 24 Feb. 1998, pp. 7/1–7/5.

[6] R. Dolp, W. Mayer, and W. Grabherr, "Industrialization of a 58 GHz high gain flat panel antenna design using injection molding technique." 29th European Microwave Conference, Munich, 5-7 Oct. 1999, pp. 13–15.

[7] M. Denstedt, T. Ostling, J. Yang, and P. Kildal, "Tripling bandwidth of hat feed by genetic algorithm optimization," in *2007 IEEE Antennas and Propagation Society International Symposium*. IEEE, 2007, pp. 2197–2200.

[8] E. Geterud, J. Yang, T. Östling, and P. Bergmark, "Design and optimization of compact wideband hat-fed reflector antenna for satellite communications," *IEEE Trans. Antennas Propagat.*, vol. 61, no. 1, pp. 125–132, Jan. 2013.

[9] W. Wei, J. Yang, T. Ostling, and T. Schafer, "New hat feed for reflector antennas realised without dielectrics for reducing manufacturing cost and improving reflection coefficient," *IET Microwaves, Antennas & Propagation*, vol. 5, no. 7, pp. 837–843, 2011.

[10] J. Yang, M. Pantaleev, P.-S. Kildal, and L. Hellner, "Design of compact dual-polarized 1.2-10 GHz Eleven feed for decade bandwidth radio telescopes," *IEEE Trans. Antennas Propagat.*, vol. 60, no. 5, pp. 2210–2218, 2012.

[11] J. Yin, J. Yang, M. Pantaleev, and L. Helldner, "The circular Eleven antenna: A new decade-bandwidth feed for reflector antennas with high aperture efficiency," *appear in IEEE Transactions on Antennas and Propagation*, vol. 61, 2013.

[12] P. Kildal, E. Alfonso, A. Valero-Nogueira, and E. Rajo-Iglesias, "Local metamaterial-based waveguides in gaps between parallel metal plates," *IEEE Antennas and Wireless Propagation Letters*, vol. 8, pp. 84–87, 2009.

[13] A. Zaman, J. Yang, and P. Kildal, "Using lid of pins for packaging of microstrip board for descrambling the ports of eleven antenna for radio telescope applications," in *2010 IEEE and Propagation Society International Symposium (APSURSI)*. IEEE, 2010, pp. 1–4.

[14] H. Raza and J. Yang, "Compact uwb power divider packaged by using gap-waveguide technology," in *Antennas and Propagation (EUCAP), 2012 6th European Conference on*. IEEE, 2012, pp. 2938–2942.

[15] BASF, "Terluran HI-10," September 2012. [Online]. Available: http://www.basf.com

[16] L. Schulwitz and A. Mortazawi, "A compact millimeter-wave horn antenna array fabricated through layer-by-layer stereolithography." IEEE Antennas and Propagat. Soc. Int. Symp., 5-11 July 2008.

[17] P. Timbie, J. Grade, D. V. Weide, B. Maffei, and G. Pisano, "Stereolithographed mm-wave corrugated horn antennas." 36th Int. Conf. on Infrared, Millimeter and Terahertz Waves (IRMMW-THz), 2011.

[18] S. J. Leigh, R. J. Bradley, C. P. Purssell1, D. R. Billson, and D. A. Hutchins, "A simple, low-cost conductive composite material for 3d printing of electronic sensors," *PLOS ONE*, vol. 7, 2012.

[19] Deutches Institut fur Normung, November 2012. [Online]. Available: http://www.din.de

[20] ASTM Standards Worldwide, November 2012. [Online]. Available: http://www.astm.org/Standards/D3359.htm

[21] Polybase AB, September 2012. [Online]. Available: http://www.polybase.se/

[22] Prototal AB, December 2012. [Online]. Available: http://www.prototal.se/

[23] Atotech Deutschland GMBH, September 2012. [Online]. Available: http://www.atotech.com/