Low Cost, Short Lead-time Feed Chain Components for Multi-beam Antennas

Paul Booth, Malcolm Skeen, Simon Stirland

Astrium Ltd,
Gunnelswood Road, Stevenage, SG1 2AS, United Kingdom
`paul.booth@astrium.eads.net`

Abstract—**A novel manufacturing process for satellite antenna feed chain components is presented. The process allows batches of components to be manufactured quickly and economically when compared to conventional techniques. It is suited to waveguide components and allows complex parts to be realised monolithically. RF measurements are presented for a batch of Ka-band OMTs and some of the design constraints discussed.**

Index terms—**Feeds, Antenna accessories, Satellite antennas, Waveguide components, Manufacturing**

I. INTRODUCTION

Ka-band broadband internet/data missions are an important developing sector of the commercial satellite telecom market with many requiring the use of multi-spot beam systems and frequency re-use to provide the required 2-way broadband capacity. The multiple spot beams are typically generated using a number of single-feed-per-beam (SFB) antennas on the spacecraft with each SFB consisting of a single offset reflector system fed by a cluster of feeds, each feed generating a single beam. The reduction of manufacturing cost and lead-time is of great importance for such systems, which may have up to 100 beams.

A typical feed chain for a Ka-band SFB antenna system consists of a feed horn, polariser and OMT with suitable waveguide transitions incorporated in between. Using traditional methods such as machining, spark-erosion or electroforming, costs and lead-time can be very high. Within a feed chain, the Ortho Mode Transducer (OMT) is amongst the most complex to manufacture.

II. MANUFACTURING PROCESS DESCRIPTION

The manufacturing process selected was Selective Laser Sintering (SLS) which is a form of additive layer manufacture. It works by building up parts in layers of sintered powder. A layer of powder (thermoplastic polymer or metal) is spread over a build area and sintered by a laser selectively scanning over the surface of the powder layer, the laser being directed by a computer guided mirror. The next layer of powder is then added and the process repeated. Layers down to 0.02mm in depth (depending on process and material) ensure a precise representation of the modelled part. More recently, metal powder processes have tended towards Selective Laser Melting (SLM), which gives higher finished material density and fewer internal voids. Disadvantages with the SLS/SLM process are that the surface finish is dictated by powder size (typically 20µm for metals producing a surface finish in the range 5-10µm Ra), and the number and type of materials available. Metallic materials available are typically as given in Table I. The manufacturing technique is developing rapidly with more materials being introduced as new components and applications increase.

TABLE I
MATERIAL PROPERTIES

Material	Advantages	Disadvantages
Titanium	Strength to mass ratio	Density Poor thermal and electrical conductivity
Tool Steel	Strength	Density Poor thermal and electrical conductivity
Cobalt-Chrome	Strength	Density Poor thermal and electrical conductivity
Stainless Steel	Strength	Density Poor thermal and electrical conductivity
Aluminium Alloy	Low density Good electrical and thermal conductivity	Large particle size (poor detail definition)
Nickel Bronze (EOSINT DM20)	Good thermal conductivity Fine details achievable	Density Poor electrical conductivity

The material chosen for this application was DM20, a nickel bronze. This was selected after discussions with the manufacturer as fine details could be reproduced with tighter tolerances than the other materials. It is also quite a good thermal conductor which is important in large feed arrays. Aluminium alloy was considered but the processing is not sufficiently mature and the particle size was too large to allow detail definition. The high density of DM20 is offset by the fact that only the external ports require flanges. There is no need for flanges to bolt component parts of the OMT together.

A consequence of the poor electrical conductivity of DM20 is that the part must be plated with copper or silver. An electroless process must be used as the complex geometry of the OMT precludes the use of an electrode necessary for electrolytic plating.

The SLS process produces a component surface finish that is both rough and porous. At Ka-band frequencies, the skin depth in silver is less than 0.5µm. The decision was taken to accept the increase in loss due to the surface roughness as there were no suitable processes found that would reduce this to below 0.5µm and maintain fine detail. Much above this figure, the loss does not increase significantly with increased roughness.

III. DESIGN DESCRIPTION

The OMT is based around the Bøifot junction. A previous OMT design had been produced using conventional machining techniques, a picture of which is shown in Figure 1. This was the starting point for the SLS design. The OMT was designed to operate with one polarisation for transmit bands and receive bands on the orthogonal polarisation. Such feeds are used for 75% to 95% of the beams in Ka-band SFB antennas. The transition from the OMT to the polariser was also included as this reduces the parts count for the overall feed chain.

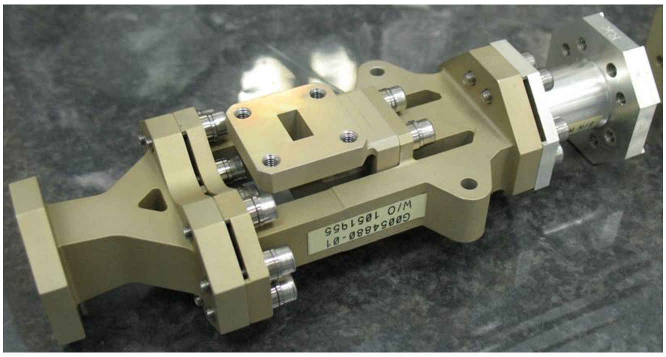

Figure 1. The conventionally machined OMT on which the design is based

A large part of the design effort was spent modifying the original concept to take into account requirements of the manufacturing process. One of the key drivers is the need for the structure to be self-supporting. This means that the build orientation, which is vertical, must be chosen to minimise overhangs. Where overhangs exist, the angle should be less than 45º from vertical. There are certain areas where this may not be possible so support structures can be incorporated that are removed later. Any support structures must be easily accessible so ideally should only occur on external features. Figure 2 highlights some of these features. Electrical modelling was performed using CST. A number of iterations were made to take into account comments and recommendations from the manufacturer.

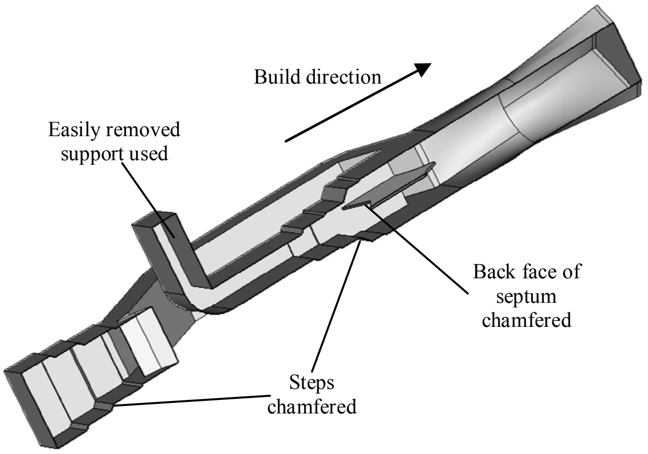

Figure 2 Sectioned OMT model (CST) showing build features

IV. RESULTS

Nine OMTs were built in one batch using the SLS process. Of these, five were finished fully to a standard to allow RF tests to be performed, the remaining four being used as mechanical and plating samples or test pieces. A photograph of one of the OMTs can be seen in Figure 3. S-parameter measurements of all five OMTs and PIM measurements of one OMT are presented. One of the OMTs was built into a feed chain and results for this are also presented.

Figure 3 Photograph of one of the manufactured OMTs

A. Cost and schedule reduction

The manufacturing cost of the finished part is one fifth that of the conventional OMT. Part of this is achieved from the fact that a batch of nine OMTs were built in one build run. The cost is expected to reduce for larger quantities but is partially limited by the number of components that can be built in one batch. However, if only one component was produced per build run the costs are expected to be less than a quarter that of the conventional OMT.

Schedule reduction was also impressive. The nine OMTs can be manufactured in less than six weeks. This includes inspection and material quality tests and plating. For larger quantities, where a number of build runs are required, the time between batches is expected to be less than one week. This assumes batches of nine and plating baths that can handle all nine components at the same time. Conventional machining techniques would require a number of machines operating in parallel to achieve such short timescales. Casting of components, where possible, will still have a lower unit cost for large quantities (greater than 100 units) but the investment cost is high.

B. S-parameter measurements

S-parameter measurements were made using a network analyser. The effects of the transitions between the calibration ports and the actual OMT ports have been removed from the measurements. Figure 4 to Figure 9 show the port return loss, ohmic loss and port to port isolation for five OMTs.

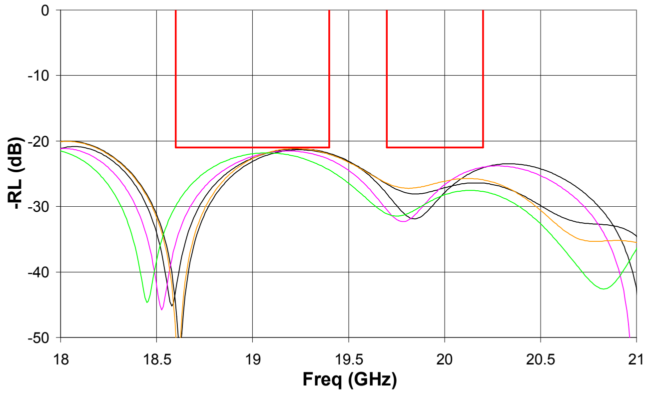

Figure 4 Transmit port return loss

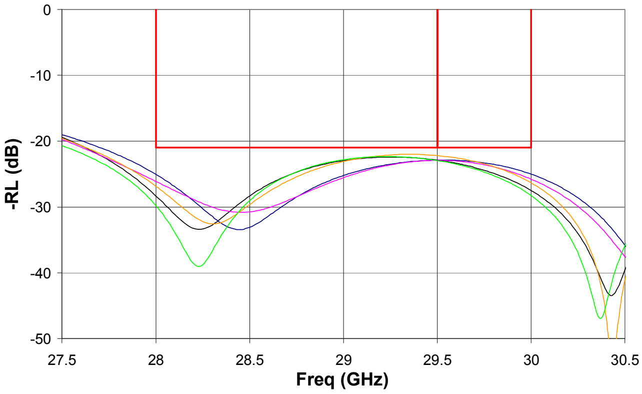

Figure 5 Receive port return loss

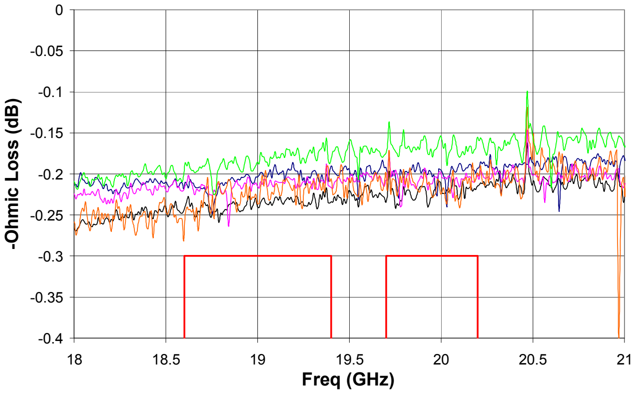

Figure 6 Transmit port to common port loss

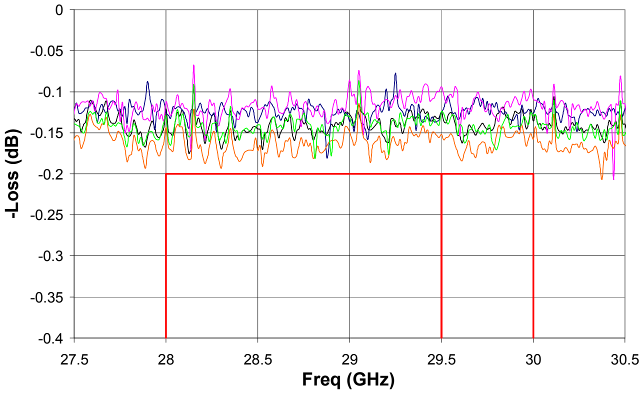

Figure 7 Receive port to common port loss

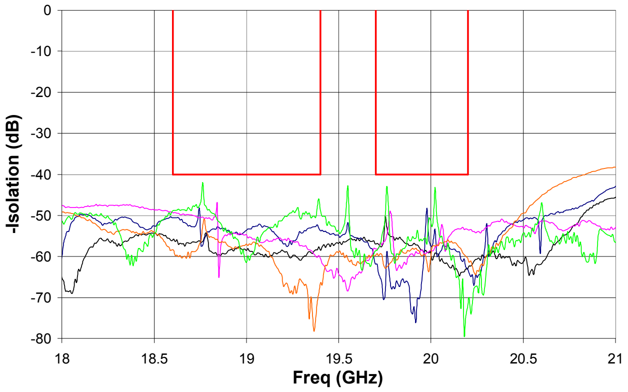

Figure 8 Transmit port to receive port isolation, transmit band

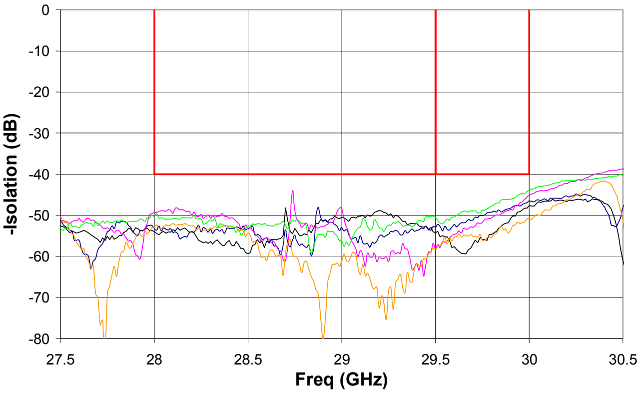

Figure 9 Transmit port to receive port isolation, receive band

C. *PIM results*

The OMT was tested for PIM. The results may be seen in Table II. Two equal power carriers of 150W were injected. Third to seventh order products were measured between 17.3 and 18.3GHz, which is one the receive bands for Ku-band satellite missions. 9th and 11th order products were measured between 28 and 30GHz, the receive band for this particular OMT and its intended antenna. The noise floor of the measurement system was below -145dBm.

TABLE II
RESULTS OF THE PIM MEASUREMENTS

PIM order	Level detected
3rd	-124dBm
5th	Below noise floor
7th	Below noise floor
9th	Below noise floor
11th	Below noise floor

In a Ka-band system, the lowest order PIM product is likely to be 9th. Lower orders only need to be considered for mixed band missions.

D. *Feed chain results*

The OMT was assembled with a polariser and a horn to make a feed chain. This may be seen in Figure 10. This was tested for port return loss, port to isolation and in an antenna test range for patterns and axial ratio.

Figure 10. A feed chain incorporating an SLS manufactured OMT

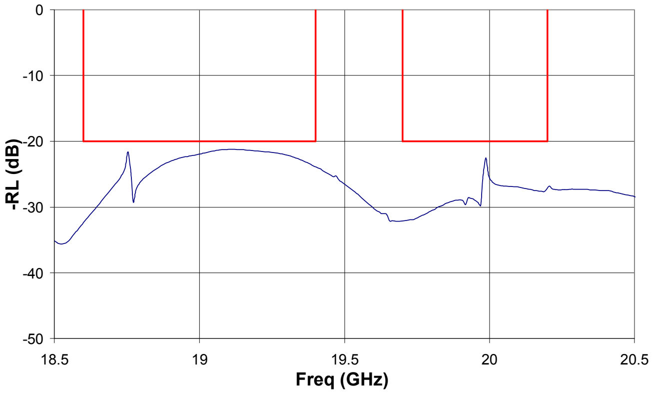

Figure 11 Feed chain transmit port return loss

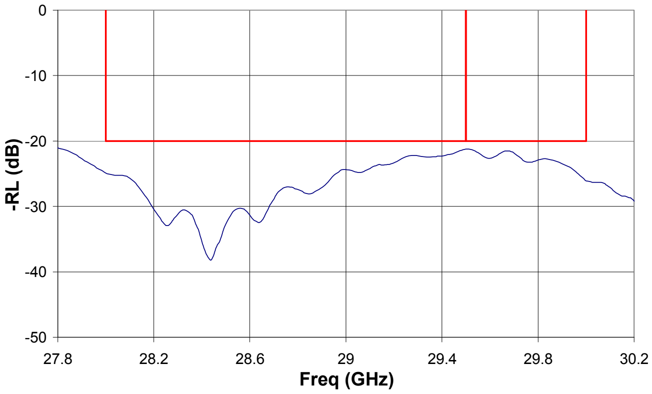

Figure 12 Feed chain receive port return loss

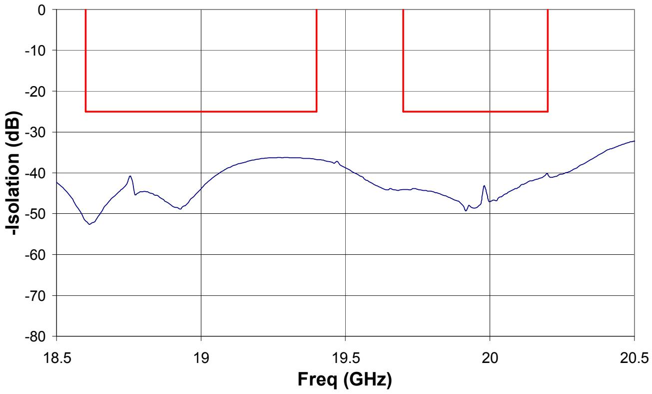

Figure 13 Feed chain transmit port to receive port isolation, transmit band

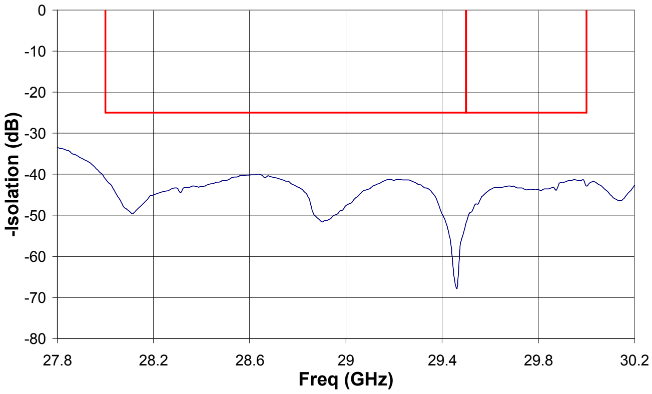

Figure 14 Feed chain transmit port to receive port isolation, receive band

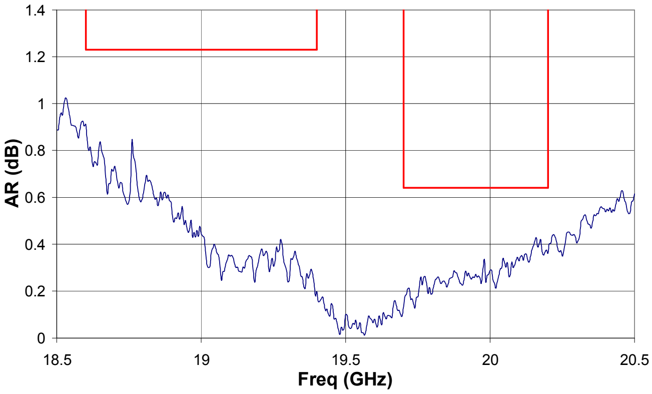

Figure 15 Feed chain boresight axial ratio, transmit band

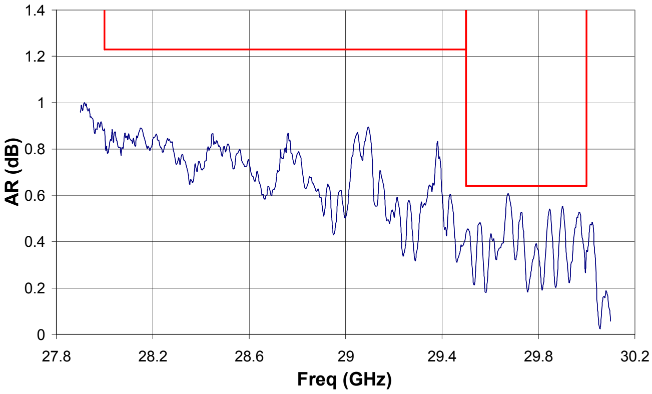

Figure 16 Feed chain boresight axial ratio, receive band

Patterns were measured at band edges and frequencies where spikes in S-parameter were noticeable. The measurements showed that there was no noticeable degradation in performance between a feed chain using a conventionally manufactured OMT and the SLS manufactured OMT.

V. Future Developments

As the SLS/SLM process develops it is expected that the applications will increase. There is currently ongoing work in the use of silver as the build material which could alleviate the need for plating. The process will be even more attractive for satellite components when aluminium alloys can be used. Indeed, for certain RF components it may be practical to produce these in aluminium alloy now.

The OMT described herein is currently undergoing a rigorous flight qualification programme that requires three batches of nine OMTs to be produced.

VI. OMT.Conclusions

A manufacturing technique that can reduce cost and lead times for feed chain components has been presented. The technique requires a number of design considerations to allow the components to be realised. These have been implemented to produce a batch of Ka-band OMTs. Measurements have shown that the OMTs would be suitable for use in multi-beam antennas.

VII. Acknowledgements

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