RF MODELLING AND HARDWARE REALISATION OF INPUT AND OUTPUT NETWORKS FOR USE IN A MULTIPORT AMPLIFIER CONFIGURATION

A. Pratt BSc

M M Microwave Ltd, Thornton Road, Pickering, North Yorkshire, YO18 7JB, England

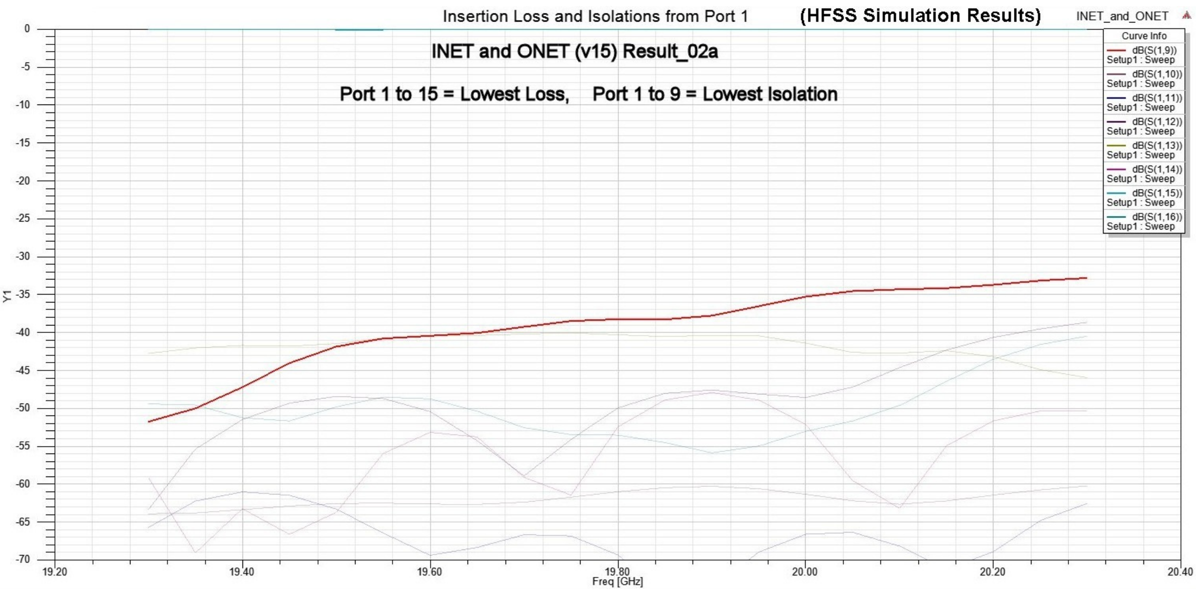
Email: a.pratt@mm-microwave.com

I. INTRODUCTION

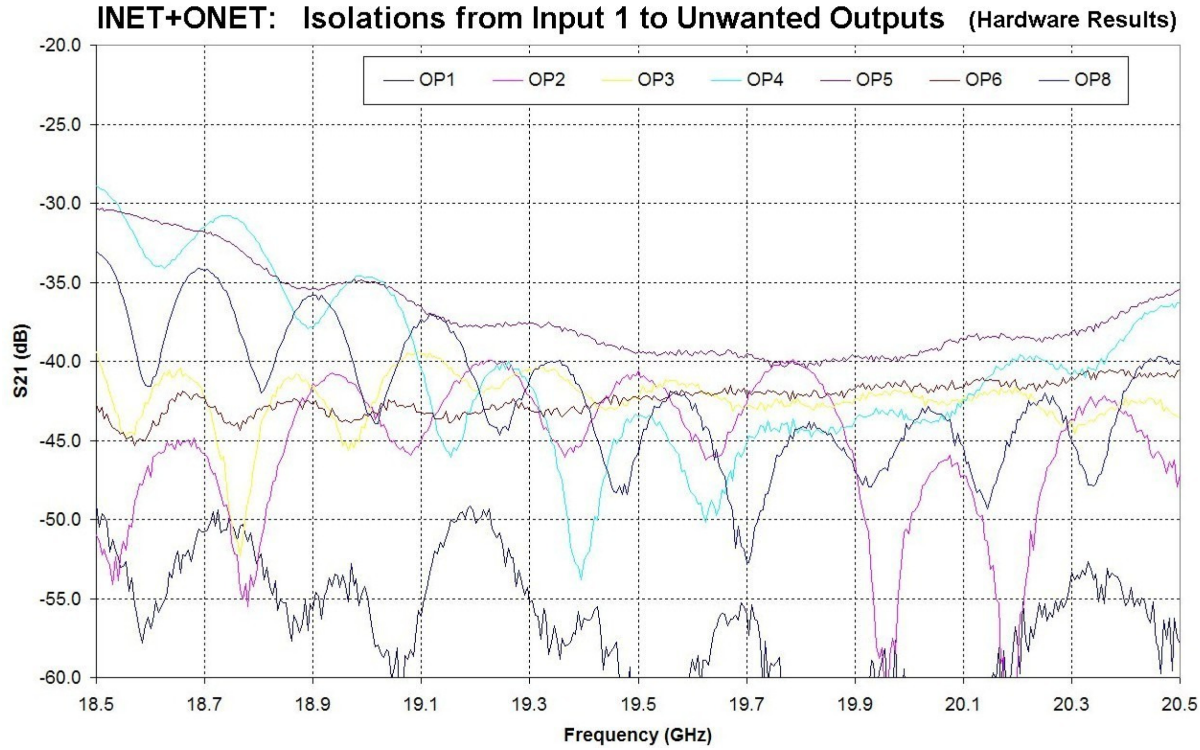
Multiport amplifiers, MPA, at Ka-band for use in Communication Satellites require Input and Output Networks, INET and ONET, with minimum insertion loss. A suitable structure using waveguide technology has been modelled using High Frequency Simulation Software for an 8x8 configuration. The basic building blocks were 3dB hybrid couplers. This was manufactured using high speed machining techniques, and the resulting hardware electrically tested in an INET+ONET configuration. A high degree of correlation was found between the measured and simulation results. The mechanical design was chosen to ensure the placement of the input and output ports were suited to ease of integration with the other components of the MPA system.

II. RESULTS

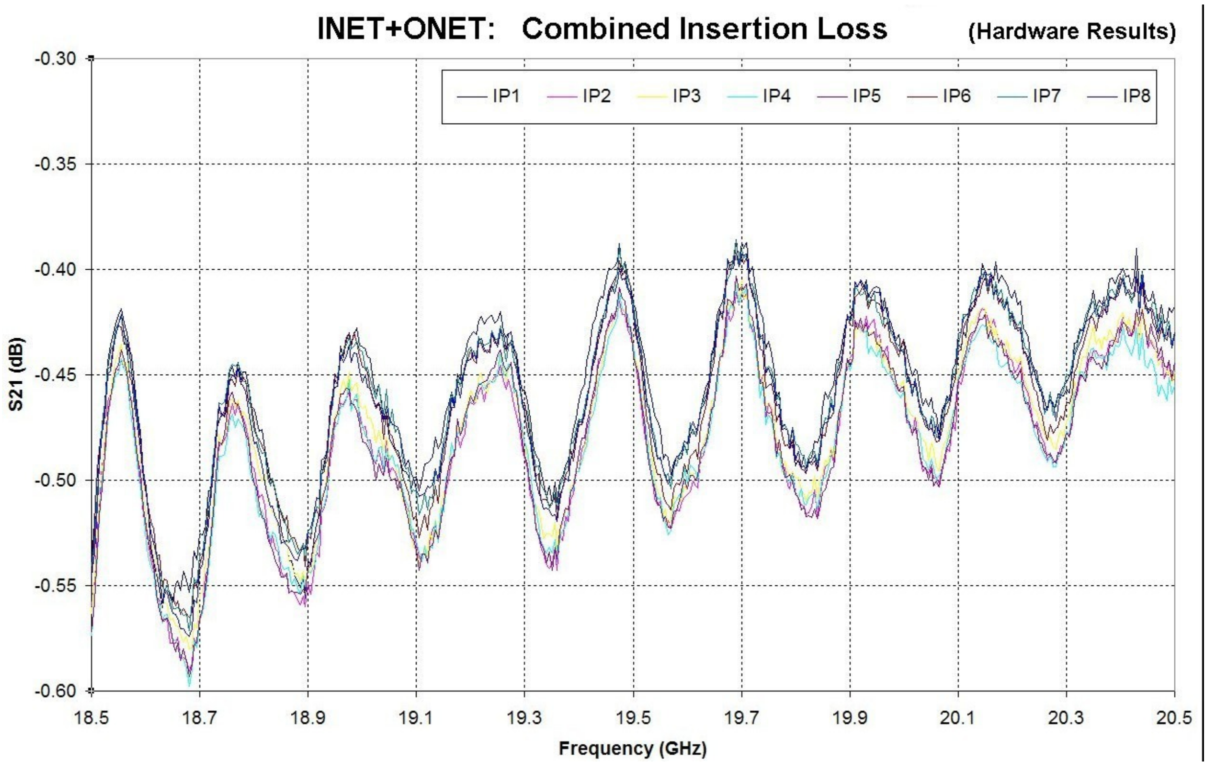
The results from the Ansoft HFSS were plotted over the operating frequency range of 0.8GHz bandwidth, and predict the unwanted Isolation between Output ports will exceed the 30dB minimum requirement.



The measured results on the INET connected to the ONET through eight phase matched waveguide channels were plotted over a wider frequency range to show the lower limit for the 30dB Unwanted Isolation. Over the operating frequency range the results are similar to the predicted values.



The Insertion Loss of the INET+ONET combination was found to be less than 0.55dB over the operating frequency range, which equates to 0.25dB per device when the loss of the interconnecting waveguide is removed.



III. CONCLUSIONS

An INET structure entirely in waveguide was found to exhibit a low insertion loss with a base material of aluminium. This combined with the light weight makes it suitable for use in a satellite communication multiport power amplifier.

The measured unwanted output port isolation was predicted to exceed the 30dB minimum requirement using HFSS with the nominal dimensions. The hardware results were also in excess of 30dB and showed a high degree of correlation with the predicted results. This demonstrated it was possible to manufacture the complete INET using the accuracy of precision high speed milling machines combined with the assembly technique of dip brazing.

The frequency bandwidth over which the Insertion Loss and Unwanted Isolation parameters met acceptable figures of 0.25dB minimum and 30dB maximum respectively, was found to be at least 1.6GHz compared to the operating bandwidth of 0.8GHz.

The mechanical layout showed it was possible to produce hardware which would allow for ease of integration with the power amplifiers, by the appropriate choice of internal waveguide paths and port locations.

INET – Presentation Slide Show Commentary

Slide Number *Commentary*

2. Input and Output passive waveguide networks are used in multi-port amplifiers, MPA, in Communication Satellites. Often referred to as Butler matrices, these networks are required to split and combine the individual channel signals. A waveguide structure is the ideal choice to achieve minimum insertion loss. The passive Input Network, INET, and Output Network, ONET, are identical with interchangeable input and output port designations. The basic building blocks are 3dB hybrid short slot couplers in both sidewall and topwall configurations.

Figure 1 shows the INET schematic for an 8 x 8 structure. A signal applied to any input will appear at every output, with 1/8 power (-9.03dB excluding losses). The phase relation between outputs is shown in Table 1 and is based on multiples of 90degrees as defined by the characteristics of the hybrid couplers.

3. In the MPA, phase matched transmission lines and amplifiers are used to connect the INET to the ONET. Each amplifier handles a portion of all the inputs. There is however only one route through the system for each Input as shown in Figure 2, whose port labels represent the actual interconnections used for measurements of the prototypes. The most important system parameter is the measure of how much signal appears at the other 7 outputs. This is referred to as 'Unwanted Output Isolation'.

4. INETs can be produced with various configurations, with the most common being 4x4 and 8x8. There are also several different topologies for each configuration, but the best choice is one with several degrees of symmetry. An example of a symmetric 8x8 INET is shown in Figure 3. It comprises two 4x4 INETs interconnected by 4 Top-wall couplers.

5. This layout was chosen to design a 8x8 INET in Ka-Band with a minimum bandwidth of 3%. The core of the INET, representing the internal waveguides, is shown in Figure 4. This has an elongated cross-shaped profile. Each coupler was developed with the aid of the electro-magnetic analysis software ANSOFT HFSS. The INET was then assembled in a CAD package with Standard designs for the interconnecting waveguide bends.

6. The plan view of the INET shows the port designations. The inputs are divided into pairs of 4 on opposite sides and the outputs are similarly arranged on adjacent sides to the inputs.

7. The original abstract showed results for the Ka-Band development which was completed in 2012. Further development of a Ku-Band prototype was undertaken in 2013, which was analysed in much more detail and forms the basis of this presentation. The actual hardware is shown in Figure 5 with the same port designations as for the Ka-Band. Analysis of the results for the Ka-band INET showed it was possible to extend the bandwidth, hence the design target for the Ku-Band INET bandwidth was set at ambitious 15%. The measured bandwidth was based on an acceptable value for the specification parameter 'Unwanted

Output Isolation'. This is a measure of the signals which appears at all other seven outputs relative to the 'Low Loss' path through the MPA. The target specification was 30dB minimum in the centre of the band and up to 25dB minimum at the band edges.

8. After optimising the HFSS model for the INET, a 'nominal dimensions' model was analysed. The results in Figure 6 for the Power Split, all 8 output traces, showed a spread of 0.5dB between 11GHz and 12.7GHz, which was a bandwidth of 14.3% (close to the target of 15% minimum). The model has key dimensions adjusted to represent the tolerances expected in manufacture. The corresponding Power Splits are shown for the Lower and Higher Tolerance limits.

9. Figure 7 shows the measured Power Split for the prototype INET. The traces are centred on -9.2dB which gives an insertion loss of 0.2dB.

10. The spread at the band centre is roughly 0.37dB which shows it fits between the Lower tolerance limit and the Nominal dimensions predictions. The spread peaks at 0.75dB at 11GHz.

11. What was of greatest interest was the relationship between the Power Split for an INET and the Unwanted Output Isolations for an INET connected to an ONET. The connection was made using phase matched waveguides with a maximum relative phase error of 0.7° across all 8 interconnections. This comparison shows the predicted Power Splits and corresponding predicted Unwanted Output Isolations.

12. Some analysis of the predicted Isolations was required as shown in Figure 8. Whilst there were 7 Unwanted Isolations only 3 were worth examining, as the other 4 were below -45dB.

13. The two traces which track each other closely have two maximum Isolations at the frequencies corresponding to the two 'zero dB' spreads in the Power Splits.

14. The other worse case trace does not change much with tolerance, apart from a 3dB shift in level close to the centre frequency. This Isolation corresponds to the adjacent ports fed from the same hybrid coupler, where one port is the required output.

15. For the 'Lower Tolerance Limit' the worst case Isolation is for the single trace at the Upper frequency.

16. For the 'Higher Tolerance Limit' the worst case Isolation occurs close to the Centre frequency. All 3 traces are overlapping.

17. There is a direct correlation between Isolation and the spread in the Power Splits. A higher spread gives a lower Isolation. 0.75dB spread is equivalent to 29dB Isolation for the 'Lower Tolerance Limit' at the Upper frequency. 0.7dB spread is equivalent to 32dB Isolation for the 'Higher Tolerance Limit' at the Centre frequency.

18. So how did the measured Isolations compare with the HFSS predictions? Figure 9 shows the results for two Inputs each of which is representative for four Inputs. The results fit

between the ‘Lower Tolerance Limit’ and ‘Nominal Dimensions’ predictions, just like the Power Split results for the individual INET.

19. The pair of tracking traces is almost identical for each Input, but the single ‘worst case’ trace is very different, dipping to -40dB for Input3 but only -30dB for Input 6.

20. The cause was found to be the unbalances in the path lengths as measured by the relative transmission phase results. Experiments with phase shifting shims at the Output ports showed the ‘worst case’ single Isolation trace could be manipulated. This same compensation can be achieved by the external phase shifters in the MPA configuration.

21. The measured Return Losses were also compared with the predicted values. Figure 10 shows the comparisons for the Ku-Band design for both Input and Output Ports. Measured values are on the right. It was very encouraging to measure worst case Return Losses of 25dB for a device with so many internal changes of waveguide size and bends.

22. The same comparison was made for the INET connected to the ONET. Figure 11 shows the target figure of 20dB minimum Return Loss an INET, was achieved for the combination of INET+ONET.

23. Figure 12 shows photographs of the Ka-band INETs manufactured in 2012 with an elongated mechanical structure and bracing ribs to provide stiffening of the assembly. This construction was deemed suitable for a Space application.

24. Figure 13 shows photographs of the Ku-band INETs manufactured in 2013. This compact mechanical design was closer to a square profile. There was no need for additional bracing as the waveguide paths provided this function instead. Although the design was completed using HFSS without any metal models, the low phase unbalance between the individual internal paths could not have been achieved without the close control of tolerances in the manufacture.

25. CONCLUSIONS

An INET structure entirely in waveguide, with a base material of aluminium, was found to exhibit a low insertion loss. This combined with the light weight makes it suitable for use in a satellite communication multiport power amplifier.

The extensive analysis of the Ku-band INET and measurements on the two prototypes, both as INETs and as INET+ONET combinations showed a high degree of correlation between the ‘Unwanted Output Isolation’ and the ‘Power Split’ of the INET.

The measured bandwidth based on the 25dB minimum ‘Unwanted Output Isolation’ was 1.8GHz or 15%, hence the design target was met. This was sufficient to cover the Ku-band requirement with a single INET design.

These prototypes demonstrated it was possible to manufacture the complete INET using the accuracy of precision high speed milling machines combined with the assembly technique of dip brazing. The mechanical layout allowed for ease of integration with the power amplifiers, by the appropriate choice of internal waveguide paths and port locations.

REFERENCES

[1] 'The Short-Slot Hybrid Junction.' H. J. Riblet, Proceedings of the I.R.E., Vol. 40, February 1952.

INET Input Network

ONET Output Network

Matrix whereby all inputs have low loss paths to all outputs.

Usually made as symmetrical structures such as 4 x 4 which is 4 inputs and 4 outputs

Current example is an 8 x 8

In the last few years, the architectural design of satellite communications payloads has benefited from the view point of flexibility, from the adoption of Multiport Power Amplifiers (MPA). Multiport power amplifiers offer a means to combine discrete amplifiers in a way that is reconfigurable and will degrade gracefully in...

An Input Network, INET, has been designed as a waveguide structure with eight inputs and eight outputs. A signal applied to any input will appear at all eight outputs. The network is a passive reciprocal device which can be used as an Output Network, ONET. If eight phase coherent signals are applied to the inputs they will combine and appear at only one output.

An INET and an ONET are used in a multiple power amplifier, MPA, system to provide redundancy in a satellite communication system.

The electrical design of the INET provides the splitting or combining of the RF signals without any crossovers. All the input and output port locations are arranged to ensure a relatively straightforward interconnecting structure can be used to test an INET connected to an ONET.

The internal structure was designed with the aid of High Frequency Simulation Software packages, Ansoft HFSS and CST Microwave Studio, and the predicted responses compared with real hardware measurements.