THE RF MODELLING OF A GENERIC COMMUNICATIONS SATELLITE TRANSPONDER

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Abstract

The increasing complexity of today's telecommunications satellites, due to the incorporation of more and more components, coupled with their operators' desire for increased capabilities is placing increased pressures on the RF modelling of such satellite payloads.

Previously, conventional payloads have been modelled successfully in RF terms by using spreadsheet software tools that allowed predictions to be made with confidence. However some calculations such as spurious signals or inter-modulation levels and locations, phase noise, Bit Error Rate (BER) and interference are more difficult entities to model. It would be an advantage if these quantities could be modelled with some degree of confidence and in this way complement the existing modelling tools and methods.

An approach taken on a theoretical development study here at Astrium Portsmouth has been to create accurate RF models of each piece of equipment at an early stage in the modelling process and to assemble these together into a single chain of a generic payload model. The aim being to upgrade these components as a project evolves. The software tool chosen to model these equipments has been Agilent's Advanced Design System or ADS, which has been shown to be an accurate and flexible software system. When a set of individual equipment models has been created, it is a relatively simple process to connect these together into an overall systems model that links the receive antenna through the RF amplification and conditioning chain to the final transmit antenna. This paper will present some of these generic models, some theoretical results and show the various tools that could be applied to test the functionality of a future payload.

Introduction

A modulated signal that is transmitted from a ground station reaches a communications satellite through a receiving antenna before being initially amplified by a low noise amplifier (LNA). It is then transmitted through filters, up and down frequency converters and on through further amplification with filtering, before finally being transmitted through a high power amplifier (HPA) and filter. This is shown in figure 1. This output signal which is now at a different frequency from that received is eventually emitted by a transmitting antenna towards the earth station. Each component has an associated noise figure with the amplifiers and mixers exhibiting the greatest noise contribution, with the local oscillators and amplifiers having specific phase noise envelopes. The filters give a definitive frequency response at the various stages of the chain. In addition all the individual components have an insertion loss and return loss associated with them.

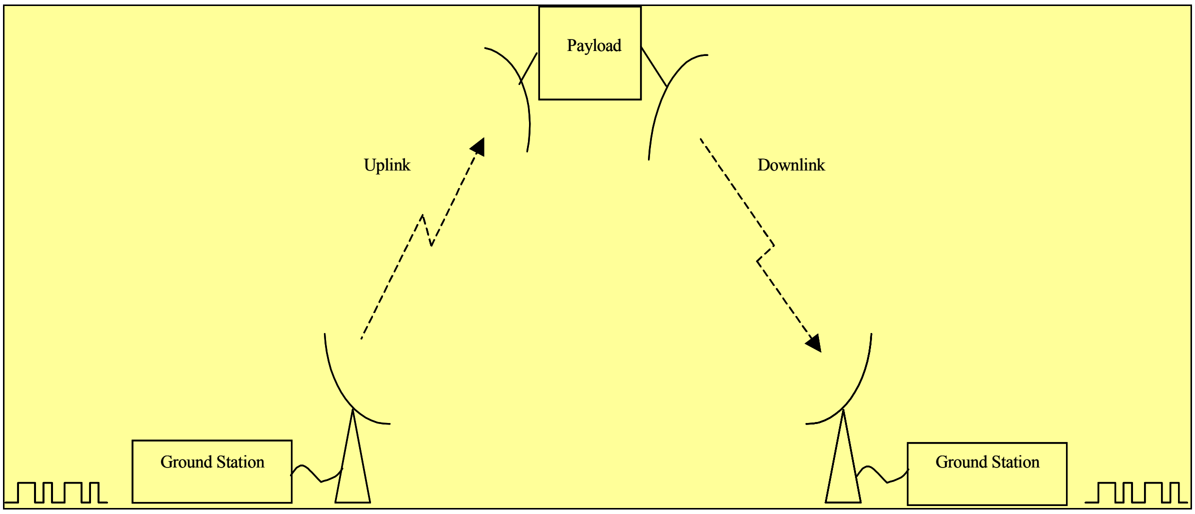

Figure 1 Overview of the satellite link

Previous conventional payloads have been modelled so that gain, loss, noise figure, group delay, AM-AM and AM-PM could be predicted. However, calculations such as spurious signal or inter-modulation levels and locations, phase noise, Bit Error Rate (BER) and spectral leakage interference are entities that need to be modelled to have a good understanding of the satellite payload itself. These constitute the main thrust of the work reported in this paper. The basic parameters of the generic simulation models are listed in table 1.

Parameter	**Value**
Uplink band centred on	14.3 GHz
Downlink band centred on	11.5 GHz
Nominal transponder channel bandwidth	112MHz
Modulation scheme	Direct QPSK as per DVB-S standard
Bit rate	90Mb/s
Spectral filter roll-off factor (α) of the QPSK up-link signal	0.35 as per DVB-S standard

Table 1 The basic parameters of the models and simulations

The Payload Model

The method used called for the creation of a set of accurate RF models of each piece of equipment and then to assemble these together into a single chain payload model. The software tool chosen being ADS of which the company has built up a considerable amount of experience at component level and in radar antennas, [1]. The components have been created using empirically based models when measured data were available on components such as the input and output channel filters and the TWTA amplifier. In most other cases theoretical models of the components have been assembled. For example, amplifiers are defined in terms of their 3rd order intercept and saturated power, whilst filters are defined in terms of well known theoretical pole-zero transmission models that exhibit an associated group delay. In all cases, both the transmission and reflection characteristics of these components have been incorporated into the model. When a set of individual equipment models has been created, it has been found to be a relatively simple process to connect these together into an overall systems model. In addition, as the ADS tool is partly a pictorial based interface where design details of each component can be compartmentalised into different levels of complexity, the result being that it allows the model to be easily accessible and understandable. The top-level generic payload model is shown in figure 2. This somewhat innocent looking diagram masks a set of complicated network models composed of a number of up and down conversions with local oscillators and their respective harmonic frequencies, the first and simplest one being shown in figure 3.

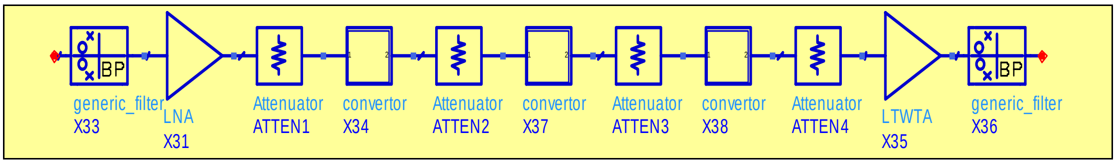

Figure 2 The top-level generic payload model

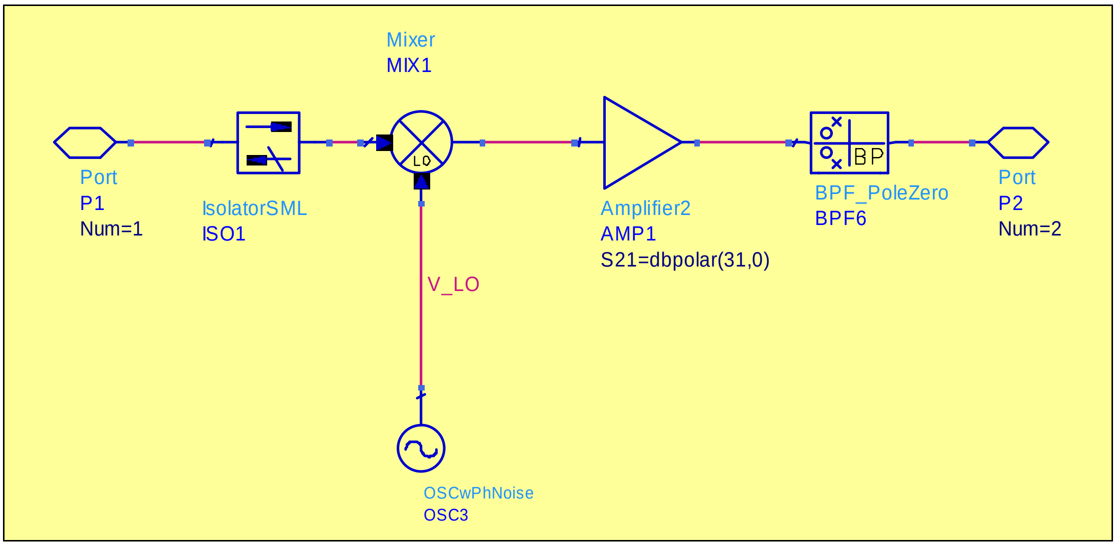

Figure 3 The 1st down conversion module

In addition the component models have the following characteristics:

- Alignment throughout provided by attenuators.
- Input match or return loss defined for all equipments with reference to 50 Ω.
- Output match or return loss defined for all equipments with reference to 50 Ω.
- Filters have phase as well as amplitude defined.
- Amplifiers have their non-linear characteristics defined.

Test Bench

A test bench was assembled that allowed different types of stimuli to excite the payload model, these being RF Budget, S-parameters, Harmonic balance and Envelope simulations. Budget analysis allows the RF signal, gain, signal to noise ratio and noise to be monitored as the signal passes through the payload. S-parameter simulation allows a wide band relative power measurement, which is useful for looking at the overall gain and phase ripple, return loss and group delay. A harmonic balance simulation allows one or more signal tones to be input into the payload under test and analyze the inter-modulated signals that emerge. Finally the envelope simulation allows a modulated signal to be passed through the model so that the signal spectrum and eye diagram can be monitored.

Results of the Simulations

Using the RF Budget simulation, the RF signal gain and the noise figure could be monitored through the payload model as shown in figure 4 and figure 5 respectively. These simulations demonstrate that the RF signal gain is amplified throughout the payload chain and that the noise figure undergoes its greatest increase at the first amplifier. These simulations confirm what may be performed using a spreadsheet approach. In addition, the group delay of the payload is presented in figure 6.

The harmonic balance simulation was used to investigate the inter-modulation products that were generated by the payload when zero, one or two input tones were used as stimuli to the model. When zero input tones were used -but when all the local oscillators were in operation- some non-carrier related spurious inter-modulated output signals were generated and these are presented in figure 7. However, when a single tone was used as an input stimulus the output signals included the inter-modulation terms that are the result of the harmonic signals from the oscillators mixing within the amplifiers, as shown in figure 8. Of great interest is the affect of passing two closely spaced signal tones through the payload model as these will interact within the non-linear amplifier at the output and generate intermodulated frequency tones, figure 9. The amalgamated phase noise through the payload due to the various local oscillators is presented in figure 10. Finally, the output power vs. input power is shown in figure 11.

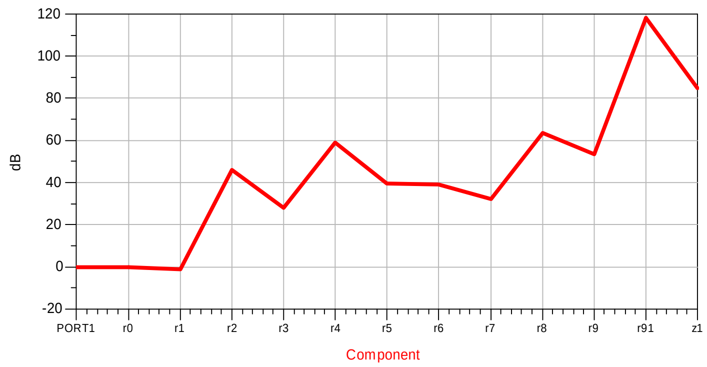

Figure 4 RF signal gain level through the payload

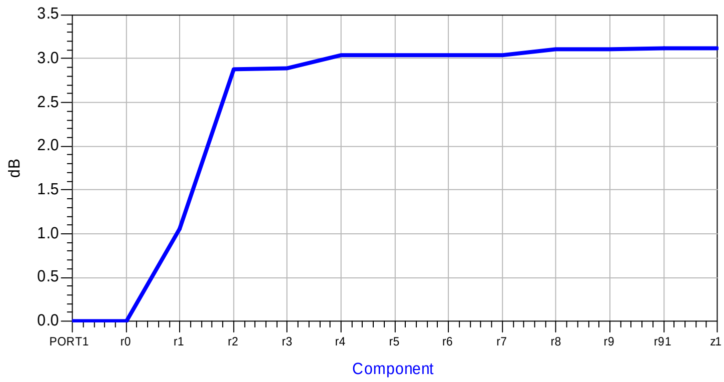

Figure 5 Noise Figure through the payload

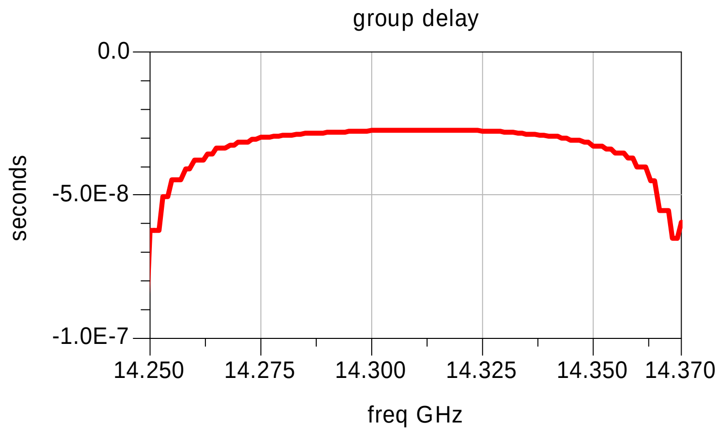

Figure 6 Group delay of the payload

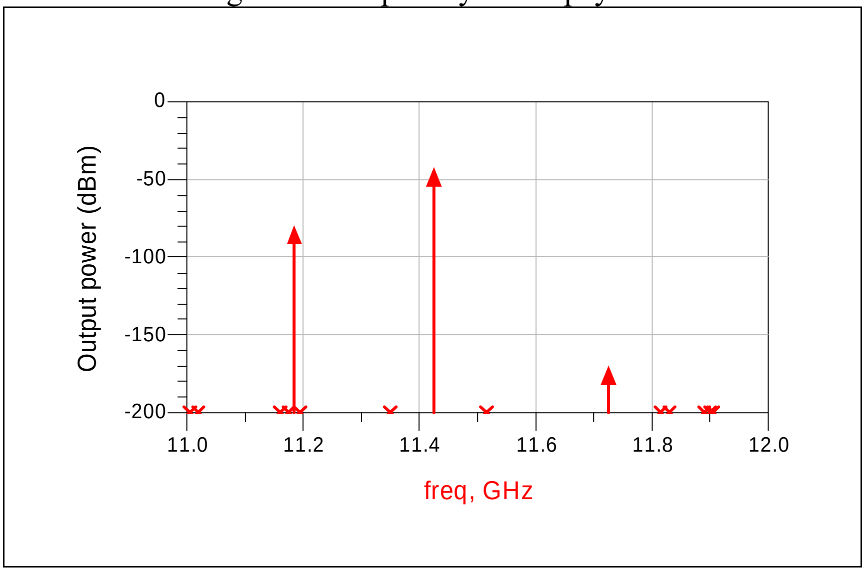

Figure 7 Non-carrier related spurious inter-modulated output signals

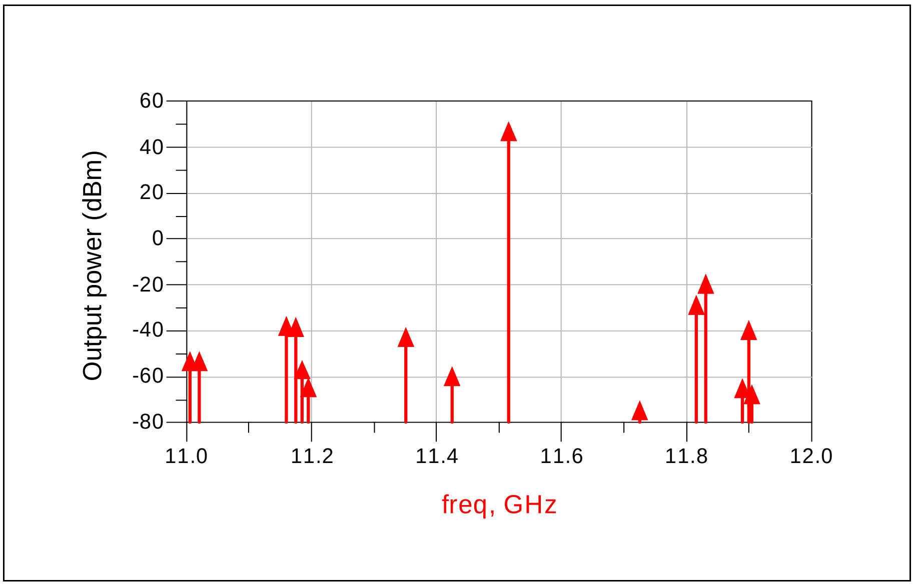

Figure 8 Output carrier related spurious signals from a single input signal

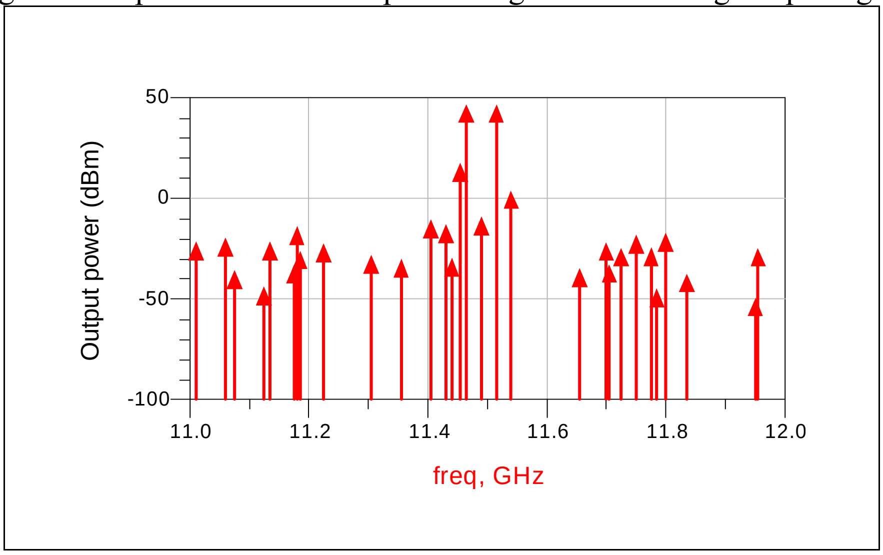

Figure 9 Output twin carriers inter-modulation spurious signals from two input signals

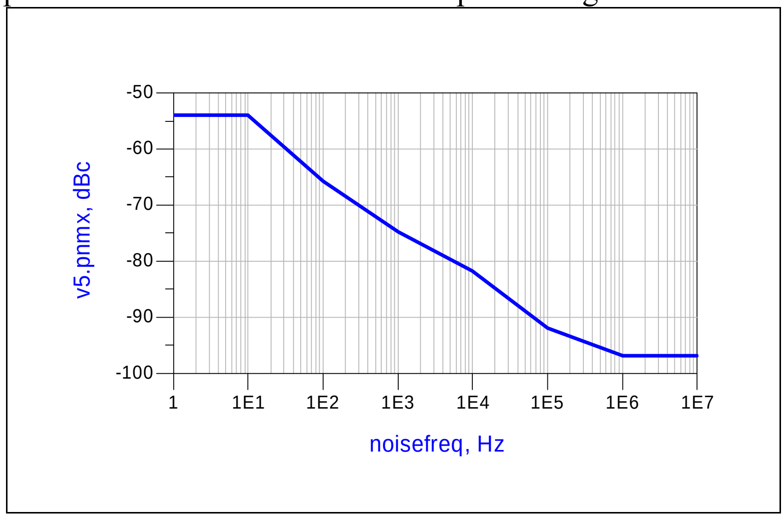

Figure 10 Phase noise of the payload model due phase from each oscillator

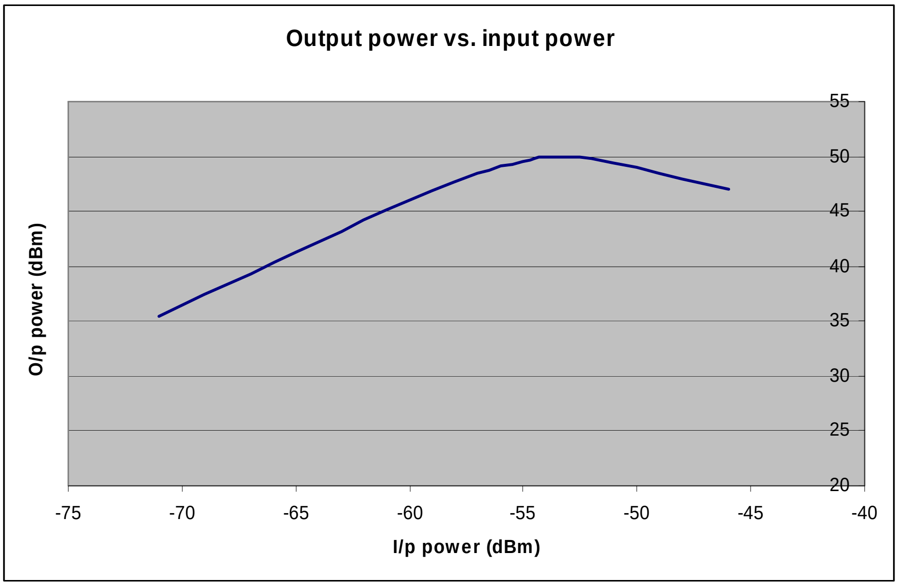

Figure 11 Output power vs. input power of the generic payload

In order to investigate the ability of the generic model to handle real data transmission it was thought advantageous to be able to model modulated signals and then pass these through the payload model. This has been achieved using the Envelope simulation tool. A QPSK modulated signal, figure 12, was generated which was then modified using a square root raised cosine filter to emulate a more realistic traffic scenario. This modulated channel filtered signal is shown in figure 13. The input and output in phase and quadrature phase bit streams may be examined but a more favourable approach is to examine the eye diagram at various locations. The ideal eye diagram and the channel filtered QPSK modulated signals are presented in figure 14 and figure 15 respectively. As the signal passes through the payload model the effects of noise and group delay become apparent before the final amplifier is reached, figure 16. Finally when it has undergone transmission through a ground station raised cosine filter it is presented in figure 17. The corresponding constellation diagram is shown in figure 18. In all cases the open centre of the eye is observable.

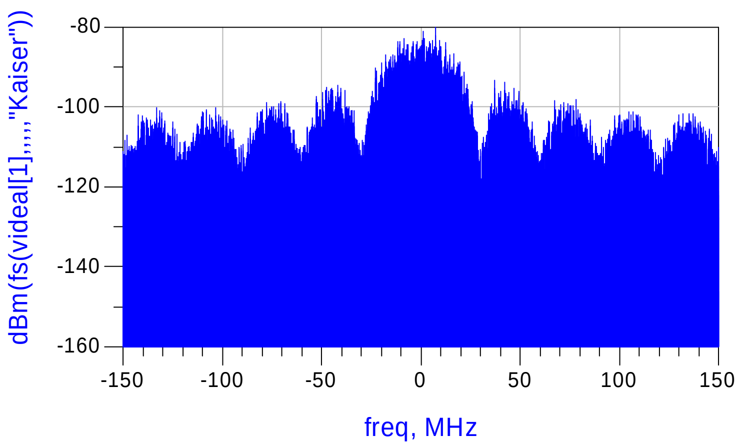

Figure 12 QPSK signal generated by ADS

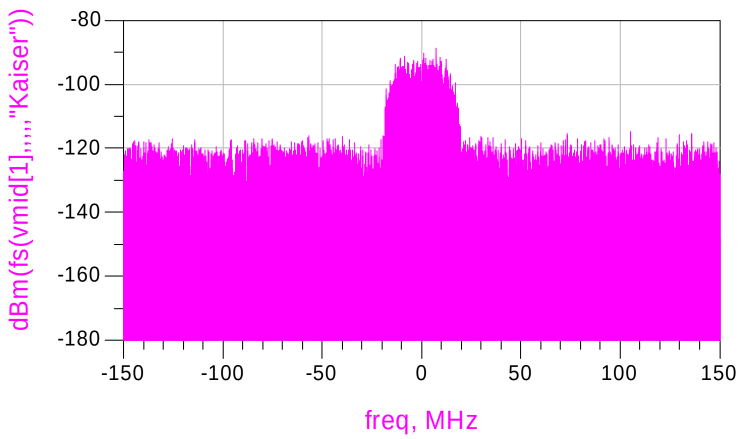

Figure 13 Raised cosine filtered QPSK signal generated by ADS

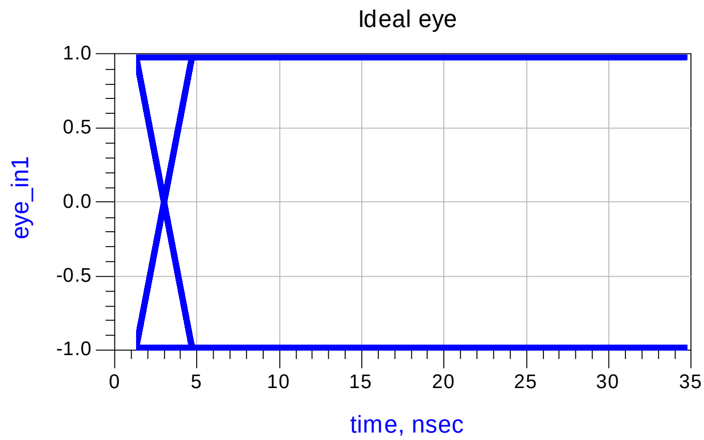

Figure 14 Eye diagram produced from the ideal QPSK signal

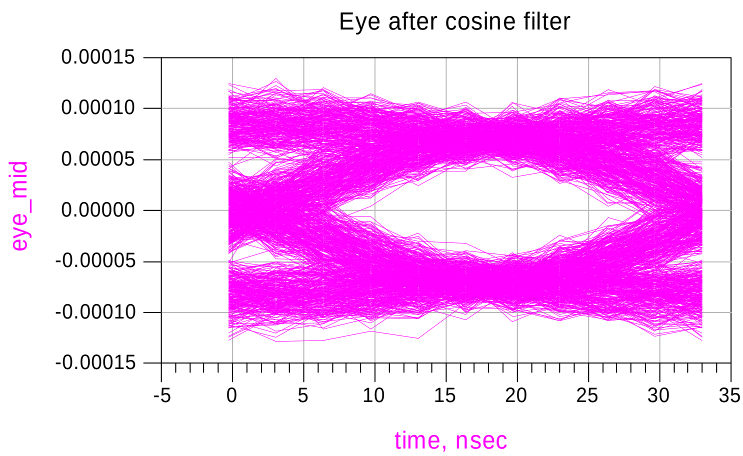

Figure 15 Eye diagram produced by the raised cosine filtered QPSK signal

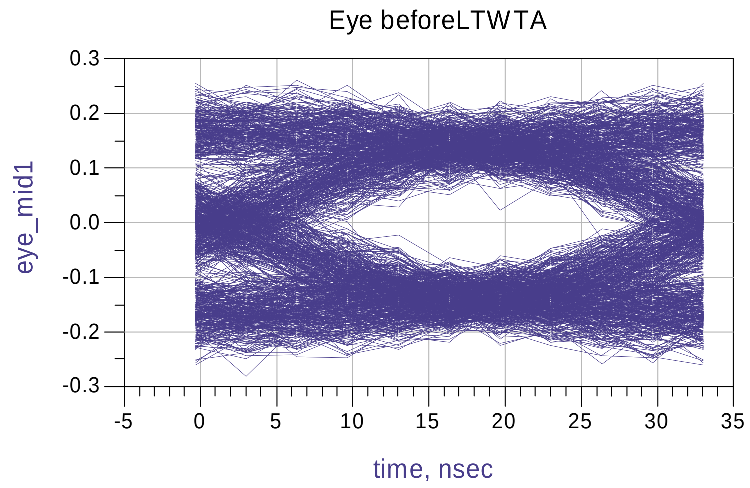

Figure 16 Eye diagram produced by the QPSK signal prior to the LTWTA

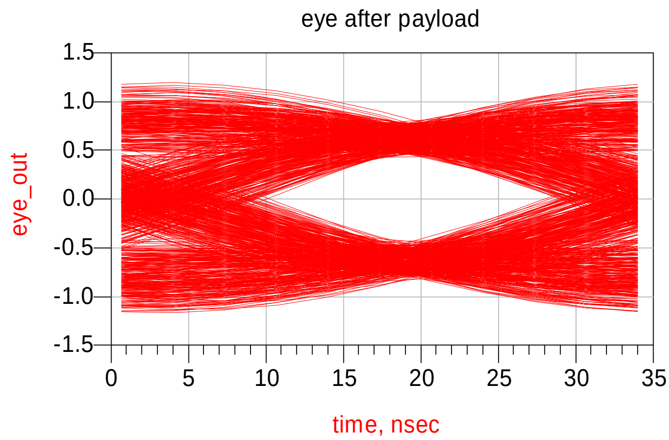

Figure 17 Eye diagram after having passed through the payload and having entered a receiver model

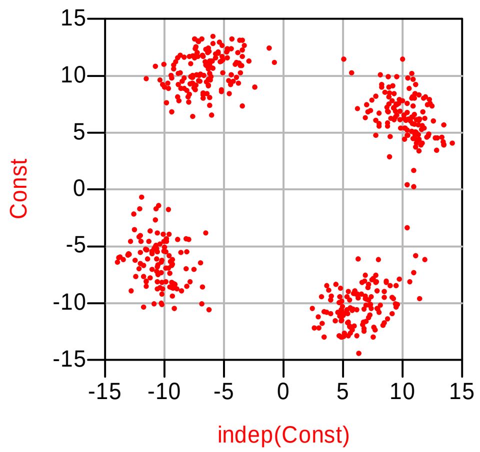

Figure 18 Constellation diagram of the received signal

Conclusion

This paper has described the RF modelling of a theoretical generic communications satellite payload through the use of the ADS RF modelling package. It has described the model, the components used and the various different test stimuli that can be applied to it. Furthermore, it has presented some results that display these features. It has shown that such features as gain and noise figure may be easily tracked through the satellite transponder. It has presented group delay vs. frequency predictions. Intermodulaton signals may be effectively tracked through the payload system with the final stage giving the transmitted levels of spurious signals. Through the use of a modulated signal the eye-diagram has been shown at various stages of the payload. Overall, it has demonstrated that a generic model of this nature could be used to assist in the prediction of different aspects of a satellite payload. Whilst there are no measured results that allow a comparison with the predictions, previous analysis of a single frequency conversion ADS payload model showed good correlation and there is no reason to believe that a future payload model would prove otherwise. Future work that could be very useful would involve passing multiple QPSK signals through the generic payload model in order to calculate adjacent channel interference. It could also assist in deciding the channel-to-channel spacing and their respective guard bands. The incorporation of a receiver ground station model would allow the prediction of Bit Error Rate. It would be a relatively simple addition to input as stimuli 8PSK and other higher order modulation schemes into the model. Also, multi-path analyses due to EMC type effects could be potentially envisaged. It could ultimately prove constructive in investigating a payload under test.

References

[1] 'A RF Model of an Active Array Antenna for a Spaceborne SAR', D. J. Bibby and A. J. Knight, ICAP 2003, Exeter, England.

Acknowledgements

The author would like to give his thanks to Dr. S. V. Potter, Mr S. Hakeem and Mme M. Lassauque for their kind assistance and advice in this work.