HIGH PERFORMANCE BROADBAND FEEDS FOR ECONOMICAL RF TESTING IN COMPACT RANGES

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ABSTRACT

Compact test ranges are worldwide used for real-time measurements of antenna and payload systems. The Compensated Compact Range CCR 75/60 and 120/100 of Astrium represent a standard for measurement of satellite antenna pattern and gain as well as payload parameter due to its extremely outstanding cross-polar behavior and excellent plane wave field quality in the test zone. The plane wave performance in the test zone of a compact test range is mainly dependent on the facilities reflector system and applied edge treatment as well as on the RF performance of the range feed.

To provide efficient and economic testing and maintaining the needed measurement accuracy the existing standard set of high performance single linear feeds covering the frequency range from 1 - 40 GHz had been extended to operate simultaneously in dual linear polarization. In addition several customer specific range feeds had been developed, manufactured and validated. More detailed information and achieved test results for the new high performance range feeds will be presented.

Keywords: Compact Ranges, Feed Design

1 Introduction

Highly accurate antenna measurements for space programs require calibrated test facilities and the application of highly accurate components in the RF test setup. As the range feeds of test facilities are key components, determining significantly the measurement accuracy, detailed analyses and developments in feed design were performed in order to improve the performance.

In order to provide efficient and economic testing the operational frequency ranges have already been extended to operate simultaneously in dual linear polarization. For several customers specific range feeds have been developed, manufactured and validated. Further, the frequency ranges of the test objects are covering the bands from typically L- up to Ka-Band for which the test facilities and related equipment have to be prepared. For example, a dual band dual circularly polarized M/K-band feed covering the frequency bands from 10.7 - 12.8 GHz and 17.2 - 18.4 GHz had been developed to allow RF measurements of satellite antennas in Tx- and Rx frequency band without changing the test setup configuration [1]. Typical design drivers had been the axial ratio (XPD) better 0.25 dB, return loss and port to port isolation.

Other examples for such customer specific range feeds are a set of dual circularly polarized feeds covering the extended Tx & Rx C-band range from 3.7 GHz – 4.8 GHz and from 5.7 GHz – 7.5 GHz respectively and the Ka-Band. Moreover, for low frequency applications, a dual linear polarized UHF Probe had been designed and manufactured for an application within a Galileo test campaign [2].

2 Requirements

Derived from previous mentioned statements, the requirements for range feeds of antenna test facilities can be summarized as follows:

- Covering of a wide-band frequency range
- Overall frequency range from L- to Ka-Band (and even higher) with scaled feed (see Figure 1)
- Dual band applicability to provide efficient payload test capability
- Simultaneous polarization applicability
- High polarization purity

Figure 1 – Typical standard set of CCR range feeds from 1 GHz up to 40 GHz
3 Descriptions of Feeds

This section gives an overview of the design and measurement results of a set of feed systems created for the use in test ranges. The particular feeds are developed for certain frequency bands covering a range from UHF to Ka-band.

3.1 Dual Circular High Performance Wideband Ku-band Feed Chain

Antenna tests on spacecraft level are complex and time consuming tasks. Recording and post-processing of the measurement data can be automated and state-of-the-art measurement concepts provide possibilities for reduction of cost and duration of the measurement [3, 4]. However, even automated measurements need a very accurate alignment between the satellite and the coordinate system of the test facility. If the test set-up has to be changed because of a change of applied frequency band, the extensive and time consuming alignment and calibration process must be repeated. Therefore the use of wide band feed probes for test facility is of high interest since it allows frequency changes without re-alignment. In the future the number of dual-band satellite antennas with additional high cross-polar requirements will increase, e.g. for M/K-band for FSS/BSS services or in K/Ka-band for broad band services. Hence there is a demand on feed probes for test ranges to cover both polarizations over both frequency bands with high polarization purity.

In this chapter a dual band dual circularly polarized M/K-band feed chain which was designed to be used as a test antenna in compensated compact ranges is presented (see Figure 2). The feed chain consists out of a corrugated horn design with optimum illumination of the CCR reflector system, a six-port turnstile junction that separates the two bands, magic-Ts, branch guide couplers and a septum polarizer to create circular polarization and diplexers to combine both bands again.

![Figure 2 - M/K-band dual circular feed chain](image)

For this application an axial ratio lower than 0.25 dB is required in a frequency range from 10.7 - 12.8 GHz and 17.2 - 18.4 GHz. This allows performing measurements in both bands with only one alignment and calibration campaign performed. Based on an accurate component design and analysis a complex system analyses has been applied to predict accurately the performance of the feed chain assembly including possible interferences between the components. The component and system design and analysis were performed using commercial design and analysis software, i.e. CST and Microwave Design Studio [5] and the MICIAN software suite [6] as well as an in-house program based on mode-matching and method of moments.

These accurate analysis tools in conjunction with an advanced design optimization process had been a key in order to enable for the optimization of this complex feed system and finally meet all the challenging requirements. Especially the axial ratio requirements had been achieved over the entire frequency band, whereas the worst case value of 0.25 dB had been measured at a few frequency regions only, while for the majority of the entire band the axial ratio was less than 0.2 dB. The port-port isolation was measured to be higher than 28 dB and the return loss is lower than -20 dB.

3.2 Dual Linear High Performance UHF Probe Antenna

The Galileo IOV program requires that the flight antennas performance has to be measured at payload level. The antennas vary in frequency from UHF through L to C-band; 400 MHZ to 6 GHz. Related antenna measurements will be undertaken in the spherical near field antenna range at Astrium’s Portsmouth site. The UHF antenna measured is the search and rescue antenna operating at 406 MHz. Good measurement accuracy at this frequency is difficult to achieve because chamber limitations influence performance. To try and minimize errors and thus improve accuracy a dual linear probe has been chosen as the source probe. This type of probe has previously demonstrated low cross polar performance in this environment at L-band frequencies. The use of dual linear polarization allows the probe to be stationary and the polarization switched during measurement eliminating rotational alignment errors. Alternative source antennas, log periodic and open ended waveguide, were considered but discounted on pattern performance.

Within this chapter the design and manufacturing of a dual linear polarized high performance UHF Probe antenna, which was contracted to the Astrium RF Test Center in Ottobrunn, will be described. The main requirement for this test probe is a very low cross polar performance of better than -40 dB and an accurate determination of the radiating characteristic over a
specified field of view. Caused by the limitations of the range positioner regarding moveable mass and bending moment the weight of the probe was limited to 35 kg.

The probe antenna consists out of a scrimp horn (see Figure 3) generating the required pattern, a four-port probe excitation section and a feeding network consisting of two 3dB / 180 deg hybrids to generate the dual linear polarization. Caused by the necessary dimensions of the scrimp horn and the mass limitation an alternative manufacturing process had been applied using fiberglass laminate structures covered by electrically conductive paint.

![Figure 3 - CATIA model of the analyzed Scrimp horn design](image)

The calibration data of the probe is usually acquired by a highly accurate measurement of its radiating characteristic. For the application in the frequency range of 400 MHz the possibility to perform a measurement with the required accuracy is very limited, since at this frequency range interferences from the environment cannot be sufficiently well suppressed. Therefore the so called “hybrid design- and verification process” has been applied in order to generate the necessary probe antenna data. This process is based on an accurate measurement of the feeding network in combination with a full wave analysis of the radiation characteristics of the horn using a validated analysis process.

### 3.3 Circular Polarized Feeds for C- and Ka-Band

In order to expand the equipment and also to improve the performance of a compensated antenna test range for accurate measurements of modern satellite antennas a set of circular polarized feed chains were designed. The developed feed chains cover three typical frequency bands: C-band transmit (Tx) 3.7 GHz – 4.8 GHz, C-band receive (Rx) 5.7 GHz – 7.5 GHz and Ka-band Rx 28.4 GHz – 31 GHz.

For the C-band feed chains a return loss of higher than 19 dB, a port-to-port isolation of at least 20 dB and an axial ration 0.25 dB (Tx) and 0.2 dB (Rx) in bore sight direction are required. These feed chains consist out of an axially corrugated horn and a feeding coupler network. The input section of the horns is excited by 4 probes which are joined to the coupler network by Type-N/SMA connectors. The network is composed of two 180°-hybrids and a 90°-coupler in order to generate the circular polarization. A typical C-band feed chain is shown in Figure 4.

![Figure 4 - C-band feed chain for Rx with mounting structure](image)

The requirements of 21 dB for return loss and 0.2 dB for axial ratio for the Ka-band feed chain are quite similar as for the C-band feed chains. There is simply a stronger specification for the port-to-port isolation of 25 dB. The main elements of the Ka-band feed chain are an axially corrugated horn, a septum polarizer and a square-to-circular transition. The Ka-band feed chain is shown in Figure 5.

![Figure 5 - Ka-band feed chain in mounting structure](image)
The feeds offer an excellent broad-band behavior to match with state-of-the-art test range performance in view of a uniform and frequency independent co-polar pattern and outstanding cross-polar purity. All feeds are furnished with a standardized mechanical interface.

4 Measurement Results

This chapter concentrates on the measurement results of return loss, port-to-port isolation, axial ratio and farfield pattern results of the different feed chains.

4.1 Dual Circular Wide Ku-band Feed Chain

After the successful design of the components for the polarizer network the design of a waveguide routing for the entire feed system was carried out. The interaction of each component of the feed system was minimized through the detailed system analysis.

Figure 6 reflects the developed wide Ku-band (M/K-band) dual circular feed chain consisting of 34 individual components. The feed chain design was a considerable challenge with respect to the electrical performance as well as the mechanical accommodation.

Figure 6 - Dual circular wide Ku-band feed chain in mounting structure

The developed dual band dual circular polarizer network is available for the ground feed system as well as for the space programs. The feed chain can be easily adapted to space programs through an adaptation of a horn for the demanded illumination.

Figure 7 illustrates a comparison of the feed system performance between prediction and measurement. The RF performance validates the complex design process and analysis results. The return loss and isolation show the excellent agreement between prediction and measurement in spite of the numerous components of the feed chain. Return loss and port-to-port isolation is better than 20 dB and 28 dB. A really local rising of the return loss at Rx band is caused by the slight interaction between combining diplexer and coaxial adaptor at feed chain feeding port.

Figure 7 - Return loss and port-to-port isolation of the wide Ku-band feed chain for Tx/Rx-band

Figure 7 shows the measured axial ratio performance of the complete feed chain in both bands. The measured axial ratio of the feed chain confirms the remarkable performance of each key component for Tx and Rx circular polarization (see Figure 8). Due to the very low cross polarization of the feed horn, hybrid and septum polarizer the axial ratio was achieved less than 0.2 dB over the entire specified frequency bands only with local exception at the lower Rx edge band.

This measurement feed has been successfully used at Thales-Alenia-Space CCR in Cannes, France, for testing of dual circular wide Ku-band communication satellites.
Due to the low operating frequencies the horn has an aperture with a diameter of about 1250 mm and is approximately 940 mm long. The strongly specified mass requirement has prohibited a conventional horn body composed of metal sheets. Therefore an alternative manufacturing process was applied using fiberglass laminate structures.

For a proper electrical functionality the inner of the horn body is covered by an electrically conductive paint. Figure 9 shows the UHF probe antenna during free space return loss measurements.

The measured return loss of the feeding network is depicted in Figure 10. The hybrid design- and verification process is based on a system analysis model, where the measured results are included by TOUCHSTONE file blocks for a realistic excitation of the probe antenna. The pattern results are shown in Figure 11.
With the used fiberglass technology a horn design could be achieved which is compliant to the strongly restrictive mass specification. The measurement results of the feeding network shows a very good performance. The hybrid design and verification process allows a realistic simulation and analysis of the farfield pattern. All other specifications were fulfilled.

4.3 Circular Polarized Feed Chains for C- and Ka-Band

Because of the high amount of measured data only some selected curves of the three feed chains will be presented. Figure 12 shows the return loss of the C-band Tx feed chain at the LHCP port. The axial ratio of the C-band Rx feed is shown in Figure 13.

The measurement results of the C- and Ka-band feed chains are of very good performance. With some local exceptions the curves for return loss, isolation and axial ratio are compliant to the specifications. Other characteristics like the maximum amplitude and phase taper are also in good agreement with the specifications.

5 Conclusions

High performance broadband feed systems are key elements of RF-test facilities providing excellent measurement accuracies for spacecraft antenna and payload testing. Astrium GmbH, Ottobrunn, is in the unique position to offer both, advanced feed system design as well as high performance RF-testing in a consolidated environment. The well-proven design processes for spacecraft antenna / feed systems as well as the long-term experience in antenna measurements have finally stimulated the range feed developments for Astrium needs, but also for customer specific purposes. The feed systems presented in this paper cover the frequency spectrum from UHF to Ka-band. Most of the applications are optimized for testing of satellite and ground station communication antennas in a compensated compact range with stringent requirements on the co- and cross-polar measurement accuracy. However, there are also products available for other applications such as an UHF probe dedicated to e.g. navigation antenna measurements in a spherical near-field facility. All test results have demonstrated an excellent agreement with the predictions.

6 REFERENCES


