A TRI-BAND L, S, C PRIME FOCUS FEED: CONCEPT, DESIGN AND PERFORMANCE

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Octobre 2013

KEYWORDS

Tri-band, L, S, C bands, Multi-band feed, Ground station, Telemetry, Tracking, Single Channel Monopulse (SCM), Flight test

ABSTRACT

The flight test mission services need higher data rates due to increased system complexity and the need for more accurate, higher rate, and better data acquisition. The existing L or S band frequency spectrum allocation was a limiting factor to meet this increased data rate requirement. The World Radio-communication Conference (WRC 2007) attributed new additional frequency spectrum allocations in the C band for Aeronautical Mobile Telemetry (AMT). The international flight test community has taken this opportunity to immediately take advantage of the new C-band range 5091-5250MHz.

This paper presents the multi-band feed product designed by the RF & Antenna Laboratory of ZODIAC DATA SYSTEMS company. This feed is foreseen to be used in prime focus configuration on any diameter parabola dish providing telemetry and tracking channels in three L, S, and C bands.

Here, are described the concept and the technology achieved taking into consideration the performance and industrial constraints. Moreover, this contribution focuses on the electromagnetic simulations of radiating elements, the feed network and RF system integration. This paper is structured as follows: firstly, the objectives and the motivation for developing a prime focus feed which works in L, S, C bands are presented. In particular, the market constraints and approach to find the best solution satisfying the feed RF requirements, and mechanical constraints, such as weight, size and cost, are discussed. The second section describes the 5 step development cycle: principle and technology, design of the telemetry channels and tracking function, cohabitation of the different radiating elements, and problems of the channels isolations. The third section discusses the performance achieved using electromagnetic simulations. The fourth section talks about the integration of RF system feed.

The paper concludes by discussing future work using the same concept that is applied to other telecommunication or telemetry frequency bands.

INTRODUCTION

Today, a majority of users works with S-band and L-band telemetry and they also need tracking function. In most cases, the ground stations for telemetry have an antenna diameter dish which varies between 6 and 14 feet and is mounted on high dynamic pedestals. In the future, the telemetry will be partially done in C-band, but most users will still want to keep S-band and L-band. With this in mind, we envisage the ideal antenna as being able to provide all the telemetry bands L, S and C with tracking function.

The high servo-control dynamic of an antenna involves two mechanical conditions. The first is linked to the weight of mobile components, the feed and struts should be as light as possible. The second talks about the dish diameter: it could be small approximately 6 or 8 feet and the feed size should be as small as possible. Given the RF constraints providing the telemetry channel and tracking function in three bands, this presents a real challenge for antenna designers. So, what is the best technical solution that will satisfy the requirements? and what is the best compromise between the complexity and the price?

MARKET CONSTRAINTS AND APPROACH

Before evaluating tri-band feed solutions, the two antenna configurations are briefly described. The first is the Cassegrain dichroic sub-reflector configuration. It requires that one of two feeds has to provide two bands L and S at prime focus, and the second C band in Cassegrain configuration. Furthermore, it should be noted that the sub-reflector could present problems by the small dish diameter. Moreover, the dichroic sub-reflector is costly. The second antenna configuration is the prime focus antenna configuration which is lower cost than the Cassegrain antenna, but the feed needs to provide tri-band in the same box.

Thus, we need to define the most simple antenna structure and meet the minimum specifications. The proposed prime focus feed design is optimal for F/D=0.4: parabola dish diameter D $\geq$ 4 feet and F = focal length. This feed is able to work simultaneously in three bands: C-band, bandwidth = 5%, S-band, bandwidth = 10%, and L-band, bandwidth = 12%. The feed has to receive the telemetry data (sigma channel) and perform auto-tracking using Single Channel Monopulse (SCM) and with a good tracking slope (delta channel). The feed must work in two circular polarizations left and right hand. For mechanical considerations, the feed must be compact and light.

To identify the best design solution of the tri-band feed, we have outlined the four main principles used for generating the sigma and delta channels from literature and illustrated in Figure 1:

- Solution 1: uses an array of four radiating elements: the same radiating array can synthetize sigma and delta.
- Solution 2: uses an array of four radiating elements for delta, and a single radiating element for sigma.

- Solution 3: This differs significantly and uses multiple coaxial mechanical radiating cavities: the sigma signal is generated with four orthogonal probes and the delta signal is generated with eight probes at 45 degrees.
- Solution 4: consists of one printed radiating element to generate the sigma channel and eight printed radiating elements to generate the delta channel.

With Solutions 1 and 2, it is not possible to correctly synthetize the delta radiation patterns to have a good illumination of the parabola dish (F/D=0.4). This is true especially for the upper frequency band. The network factor of the four elements is too high for geometrical reasons. The third solution using coaxial cavities radiating elements is reasonable and should achieve good RF performances closed to horn characteristics. However, the complexity and the tuning are difficult. Moreover, the weight and the size are not really compatible with the specifications. The fourth solution provides good dish illumination and good characteristics in terms of weight and size and thus seems to be the best compromise. In spite of sub-optimal performances, overall it is sufficient for telemetry applications.

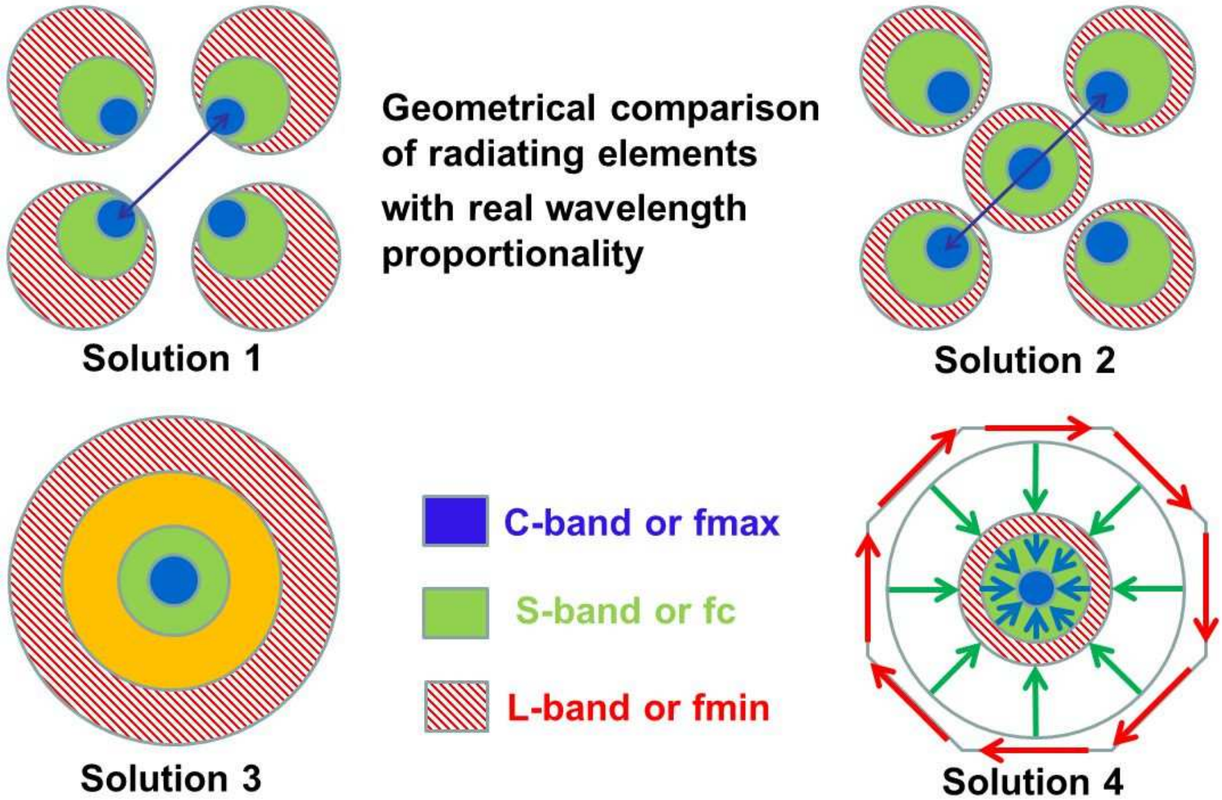

Figure 1

PRINCIPLE AND TECHNOLOGY AND PHASES OF DEVELOPMENT

To design this complex antenna structure, we have used the following methodology. Phase 1 begins by focusing the development on the sigma channel, for one band frequency, the highest band, i.e. the C-band. Then in the second phase, the sigma design for the other bands is deduced using a homothetic function. The overall sigma design is located at the center of the feed along the propagation axis.

The third phase is the design of the array that generates the delta channel or tracking function, for one frequency band. In the fourth phase, the delta design for the other bands is deduced using a homothetic function. To do this, it is necessary to integrate the three arrays of eight elements with different geometry in the same volume. The solution is to optimize the constant dielectric and other geometrical parameters. Finally, the fifth and last phase consists of analysis and optimization of the isolation between the sigma and delta channels in the same band. Several iterations were needed to reach the required performance levels.

Here, the sigma and delta radiating elements are described. For the sigma channel that receives the telemetry data, we have chosen the aperture coupled patch [1] compatible with the frequency bandwidth. The elements are printed on high quality RF substrate. All the sigma elements are placed at the center, with the sigma element for the C-band being in the upper position, the sigma S-band element in the middle position and the sigma L-band element at the bottom, as shown in Figure 2. The radiating element of the delta is a simple single half printed patch. To generate the complete delta pattern, we use the equivalent of waveguide TE21 modes, shown in Figure 3, by using of eight elements placed at 45° following a central symmetry. The amplitude and phase are realized with a network feed composed of hybrid couplers in a microstrip technology. This complete design, including multi-band sigma and delta functions described above, was patented [2].

We remark that the phase center for each band is not located at the same point. It is possible to evaluate the axial defocusing. We chose the phase center for the upper frequencies, i.e. C-band in order to optimize the performance in this band and to minimize the phase default in other bands. The displacement in L-band is of $0.15*\lambda_{L\text{-band}}$ and $0.12*\lambda_{S\text{-band}}$. So, we can consider that the axial defocusing is minimized.

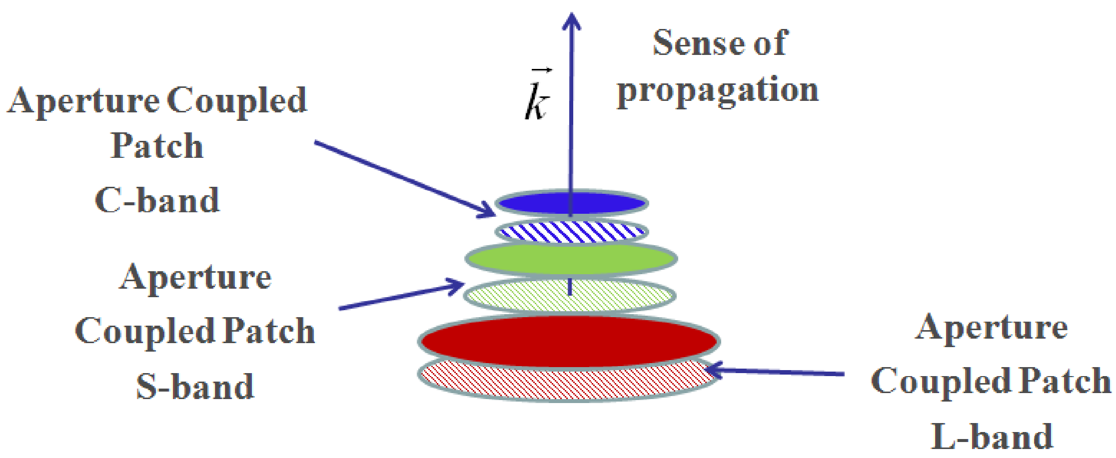

Figure 2

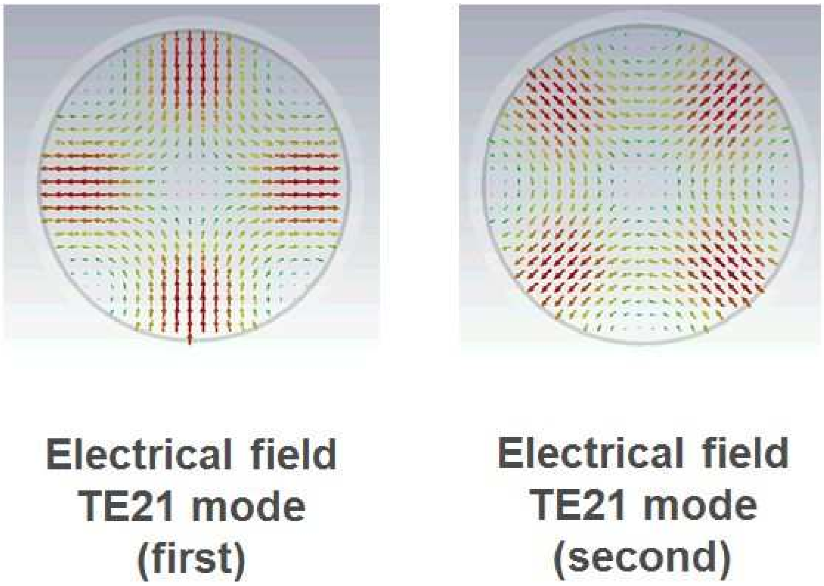

Figure 3

RESULTS OF ELECTROMAGNETIC SIMULATIONS

To design all the radiating elements and RF devices, we have used the CST Micro Wave Studio software. This software is based on one Finite Integral Technique (FIT) to solve the Maxwell’s Equations. The FIT with advanced techniques gives a good simulation accuracy results. The transient solver works properly with hexahedral meshing, but it should be used with caution due to the geometry of this design.

Despite of the time domain solver, the resonant structures, the aperture coupled patch or other printed patch, it was necessary to split the development into several simulation models in order to minimize the simulation time. For global analysis of all bands, it is strongly recommended to use parallel computing: up to 10 ports by band and up to 12 ports for all bands.

The final results of S-parameters are really good. About the adaptation of the radiating elements impedance, the return loss is good for all sigma channels L, S and C, and it is reasonable for all delta ports. After many runs of optimization, the isolations between delta and sigma channels are better than 15dB in each band, and the isolations between different frequency bands are better than 20dB.

The optimization of sigma radiation patterns has been done without major difficulties. But, for the delta radiation patterns, the optimization has been more difficult due to isolation and geometry issues. The sigma and delta patterns for the C-, S-, and L-band are illustrated in figures 4, 5 and 6 respectively.

In synthesis, once the S-parameters performance has been reached with a good field distribution, i.e. illumination of angle at -10dB closed to 128°, we can expect a good optical efficiency. The global efficiency of the tri-band L-S-C antenna station is estimated to between 60 and 70%. The radiation patterns of the sigma and delta are detailed by 2D plots in the Figures 4 to 6.

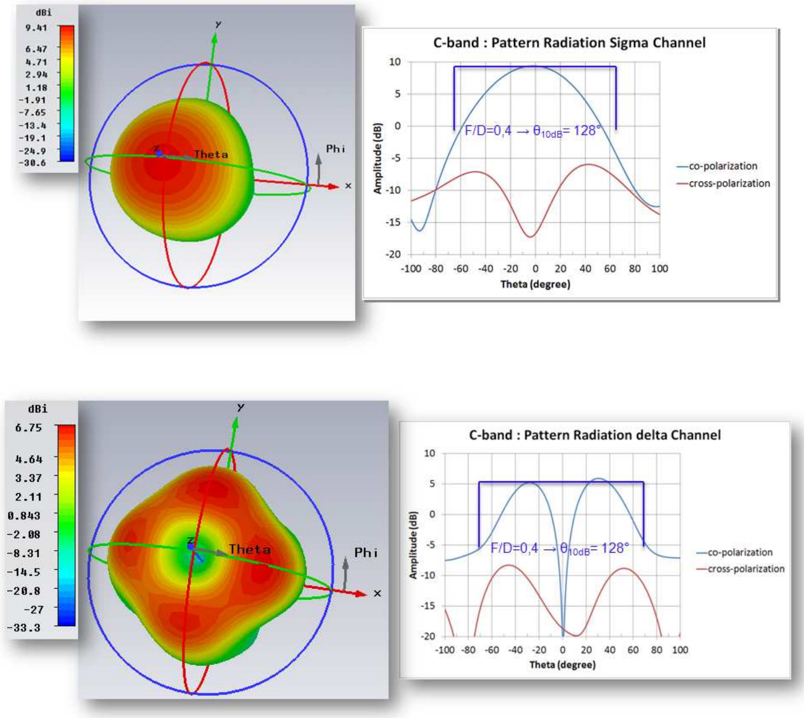

Figure 4

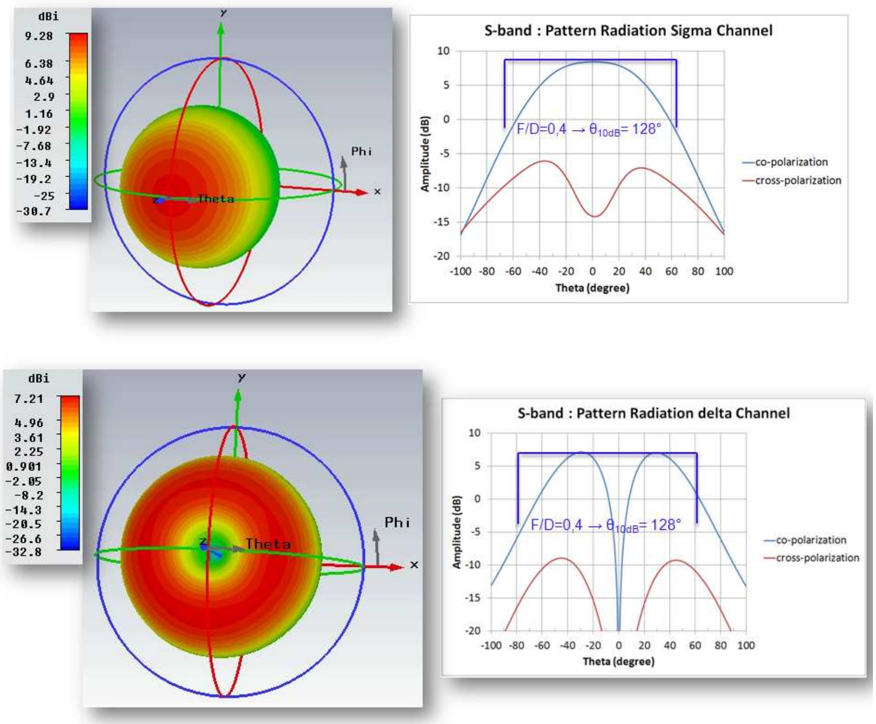

Figure 5

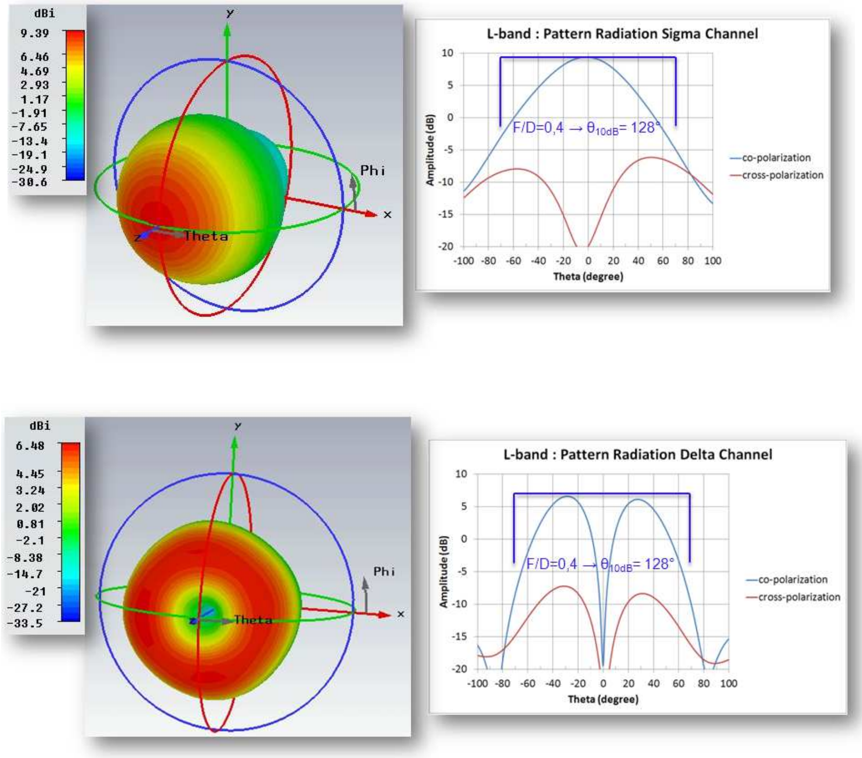

Figure 6

RF SYSTEM INTEGRATION OF FEED

To understand the RF system integration of this tri-band feed, Figure 7 illustrates the complete chain. This chain starts from the head feed, radiating elements sigma and delta through to the telemetry and tracking ports with two polarizations, the right (RHCP) and left hand (LHCP). Each feed network has two sigma RHCP and LHCP ports and two delta RHCP and LHCP ports: each independent active module is connected at these four ports. The active modules are composed of filters, low noise amplifiers, modulators and couplers, and are specific for each band. The modulators and couplers allow the Single Channel Monopulse. The triplexers are connected to the outputs of the active modules. The triplexers are mandatory, as it is not possible to route six RF channels through the pedestal azimuth rotary joint. Moreover, the tri-band receiver, like RTR (Radio Telemetry Receiver), is already available on the market with the capability to accept tri-band signals on its RF input ports.

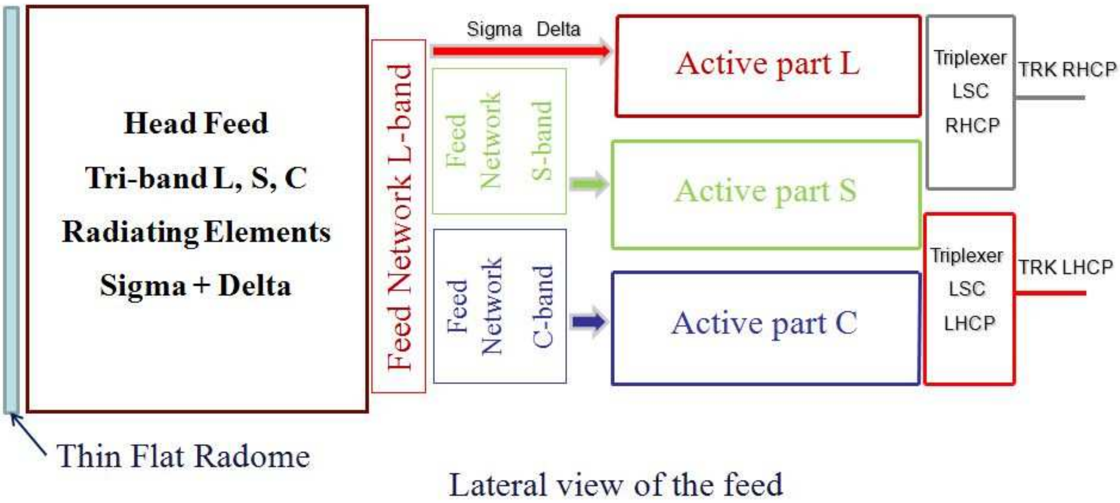

Figure 7

CONCLUSION

With accurate simulations, we can conclude that with this design the overall required performance for L-S-C bands are achieved. This allows a true simultaneous tri-band L S C feed for flight test applications to be designed. The difficulties of creating connections between some of the critical radiating elements and feed network have been solved. Globally, the design of and the integration of the complete RF system feed is valid and satisfies the mechanical constraints.

The two main aspects of this design are to keep the maximum symmetrical figures of radiating elements and take apart the aerial port perturbations. From this design, it is possible to consider others frequencies but the designer needs to assume the available bandwidth of aperture coupled patch and to assume the losses involved by the technology and complexity of design. RF losses are important but not critical for flight test applications as is the case for telecommunications applications.

ACKNOWLEDGMENTS

The author wishes to acknowledge all the RF and Antenna team of ZODIAC DATA SYSTEMS and the support of the CST Company. The collaboration between David CHAIMBAULT, Fabien PELEAU and Alain KARAS, has been invaluable and have enabled this contribution and overcome many design challenges.

REFERENCES

[1] Jie Lu, A High-Isolation Dual Polarization Microstrip Patch Antenna With Quasi-Cross-Shaped Coupling Slot IEEE Transactions on Antennas and Propagation

[2] Tri-band feed for parabolic antenna, patent n°1355655