Highly Efficient Monopulse tracking feed subsystem for unmanned aerial vehicle

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Abstract— **A monopulse tracking subsystem for unmanned aerial vehicle is described. It is composed of a septum polarizer and a TM01 circular waveguide mode tracking coupler. The tracking coupler utilizes only two parallel slots for sensing TM01 mode which made the system more compact along with a very small size. The whole monopusle tracking subsystem was designed, fabricated and tested for the Ku-band (14.4-15.5). It provides an excellent return loss > 28dB, an axial ratio better than 0.45dB and an isolation between the sum and the difference signals more than 50dB.**

Keywords-component; Tracking feed system; Tracking monopulse; mode coupler

I. INTRODUCTION

In the current satellite communications, large base station antennas with narrow microwave beams are used to communicate with satellite. In order to point these narrow beams at the satellite, several tracking techniques have been implemented. The most effective tracking techniques used a pattern having a null in the direction of the communications beam peak which is compared to the communications or sum pattern to yield a tracking error signal. This pattern is called a difference pattern and it is often generated in the antenna using higher order modes to perform the tracking task.

Generally, they use the circular waveguide TE21 or TM01 mode or both of them to generate the difference signal. The choice depends on the communication system requirements. These systems also utilize the TE11 mode for the main signal (sum). The output of the higher order mode coupler will sense any small changes in the pointing angles (azimuth and elevation). Deviations in amplitude and phase of these modes with respect to those of the reference mode TE11 depend on the variations in the pointing angles. This information is supplied to the electronic unit which feeds the azimuth and elevation antennas motors for the correction of the pointing errors. An interesting survey of different configuration that realize the tracking sensing by coupling holes or slots to detect the TE21 mode and that are carried out by using the coupled mode theory is found in [1]-[7]. Many structures have been proposed in the literature to fulfil different requirements for the sum and the difference signals by using TM01 mode as a coupling mode are reported in [8]-[11]. A design configuration use both TE21 and TM01 to achieve the difference channel along with TE11 as a main signal (sum) can be found in [12]-[13]. However, the use of a great number of slot or holes in the coupled lines makes the device very bulky and increase the design and the construction cost and therefore deteriorate the whole performances of the subsystem.

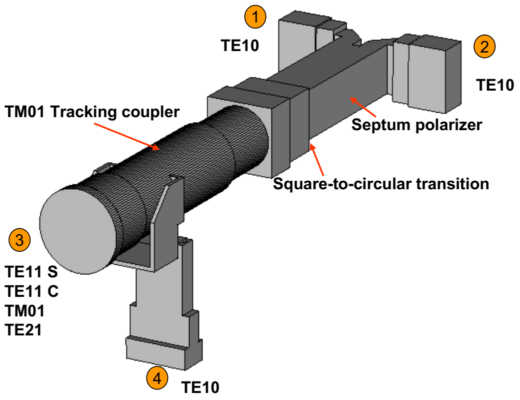


Fig. 1 3D view of the whole monopulse tracking feed subsystem

Other configuration that uses dielectric resonant ring to reduce the size of the structure is reported in [11], but the principal disadvantage of this configuration is the high level of losses and the critical control of the dielectric properties especially in the cryogenic environment. In this paper, we present the design, construction and test results of a compact and robust monopulse tracking coupler, which uses only two parallel slots for sensing TM01 mode, together with a septum polarizer for the Ku-band (14.4-15.5GHz). An external view of the whole subsystem formed by the tracking coupler and the septum polarizer is shown in the fig.1. When an incoming circular wave is received by the antenna, the output level of the communication signal is maximum with the antenna pointed in the source direction while a null is obtained in the higher order mode, as we can observe in the radiation pattern of the fundamental mode (TE11) and the tracking mode (TM01) shown in fig.2. The mode detection is performed by resonant slots cut in a transversal manner in the circular waveguide. These coupling slots must be in the direction of the magnetic field near the waveguide walls. The theoretical analysis of the tracking coupler is carried out using the theoretical description of resonant slots cut longitudinally or a transversally in the waveguide walls reported in [14]-[15].

The output signal from the mode sensor depends on the polarization of the incident electric field of the beacon signal and on the angular error deviation of the antenna axis fig.3. Suppose incident electric field on the antenna amplitude Eo and making an angle φ with respect to the y-axis direction (vertical reference for the antenna feed). The output from the mode sensor of TM01 exposed to the Ex and Ey components given by (1)-(2):

$$E_1 = \Delta_{el} E_y - \Delta_{az} E_x \qquad (1)$$

$$E_1 = \left(\Delta_{el} \cos\varphi - \Delta_{az} sen\varphi\right) E_o \qquad (2)$$

Where Δaz is a coefficient depending on the azimuth error deviation and Δel is a coefficient depending on the elevation error deviation.

To detect the azimuth and elevation error signals separately we have to use also a second mode sensor for the mode. Combining then the outputs of the two sensors in phase quadrature, the total output is given by the equation (3) [14]. Then the azimuth and elevation error signals in phase quadrature are processed and consequently separated in the tracking receiver system. For circular polarized beacon signals the Ey and Ex components are in phase quadrature, and the output of a single sensor is sufficient to extract the tracking information like in our present case.

$$E_1 = \left(\Delta_{el} + j\Delta_{az}\right) E_y \qquad (3)$$

II. TRACKING COUPLER SUBSYSTEM DESIGN AND SIMULATION

The fig.1 shows the Tracking system designed using conventional mode matching and FET integrated in MwWizard-Mician [16]. This design contains also a septum polarizer to obtain the sum signal with an orthogonally circularized polarization (RHCP and LHCP) and a tracking port to extract the difference signal using TM01 mode sensing. The design band is 14.4 to 15.5 GHz, the diameter of the circular common waveguide is 20.24 mm, and the three rectangular waveguide ports use WR62 standard waveguide dimensions (15.8x7.9 mm). The monopulse tracking system has four physical ports as it can be observed in the fig.1, but presents eight electrical terminals, since it has five electrical terminals in the circular waveguide output, the fundamental mode TE11 s,c, and the higher order modes TM01, TE21s,c. Because of design requirements we made a compact, simple and small device in spite of the electronic complexity required in order to treat these signals. Since the polarization of the incoming signal is circular, a single higher order mode sensor is needed, in this case the TM01.

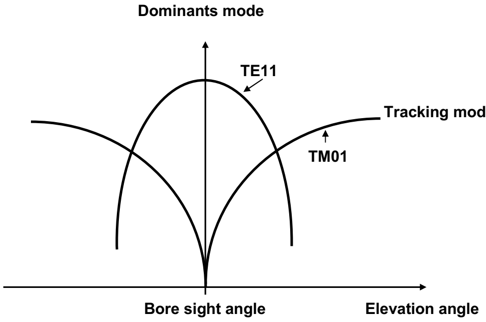


Fig. 2 Sum and difference channel patterns

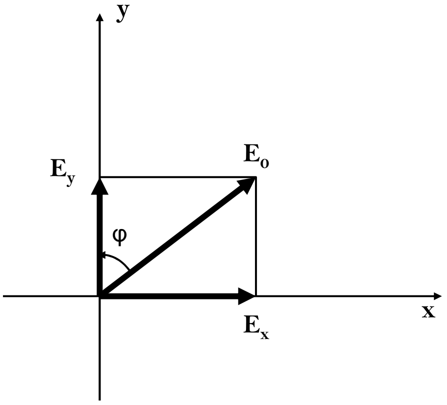


Fig. 3 Linear incident electric field

In the output circular waveguide that will be connected to the antenna the diameter of this guide is enough to allow the higher order modes propagation, so we can get the TM01 mode through these two parallels slots. The signals coming from these two slots are combined using a reduced height H-plane T junction, and finally a multi step transition is needed to assure the output in a standard waveguide WR62. The Fig.4 shows a view of the tracking coupler. The monopulse tracking subsystem is required to receive in right-hand, from 14.4 to 14.85GHz, and to transmit in left-hand from 15 to 15.5GHz. The structure dimensions were optimized to allow circular TE11 mode propagation in both bands and TM01 mode propagation in the receive band in the circular waveguide that will be converted to the TE10 rectangular standard waveguide WR62 (port3).

Furthermore between the septum polarizer and the tracking coupler the circular waveguide input diameter is smaller than the output one to avoid higher order mode propagation, that is, the cutoff frequency of these modes is maintained above the frequency operation band. The overall length of the monopulse tracking feed subsystem is 130mm.

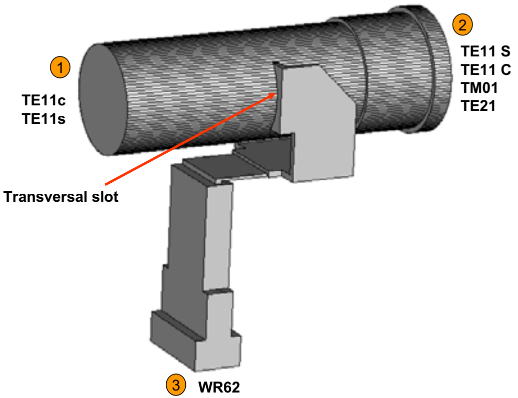
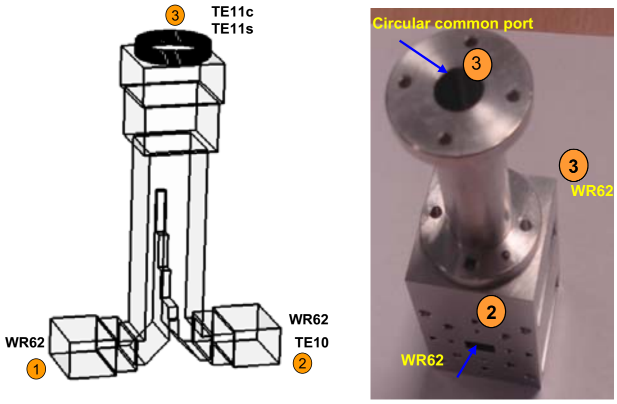


Fig. 4 3D view of the tracking coupler

The septum polarizer is a very good solution over a moderate bandwidth because of its simple and compact design. The septum polarizer is a device that handles the task of both the OMT and the polarizer and is widely used in satellite and radio astronomy subsystems. A prototype together with an internal view of the septum polarizer is shown in the fig.5. As we can observe this polarizer is made in a square waveguide; therefore a circular to square transition is needed.

III. EXPERIMENTAL RESULTS OF THE TRACKING SUBSYSTEM

To validate the previous concepts, a prototype of the monopulse tracking subsystem for the Ku band (14.4-15.5GHz), where the tracking frequency band is 14.4-14.85GHz, have been fabricated and tested. The prototype has been fabricated using the classical validated manufacturing technique of milling (CNC) as a two individual bodies. Aluminium 6061 was chosen as the body material for its availability, excellent properties, and easy of surface treatment. Measurements have been taken with a two port network analyzer PNA, from Agilent Technology, by carrying out a WR62 TRL calibration. During the measurement processes we have used a radiating load that must be matched not only for the TE11 mode but also for the TM01 tracking mode.



(a) (b)

Fig. 5 Ku-band Septum polarizer. (a) 3D internal view, (b) Machined prototype

The fig.6 shows an internal view of this radiating load along with the simulated reflection coefficients of both TE11 mode and TM01 mode respectively. The return loss of both modes was better than 35dB in the whole frequency band. Furthermore, a high performance circular-to-rectangular (WR62) transition was fabricated for the measurement purpose.

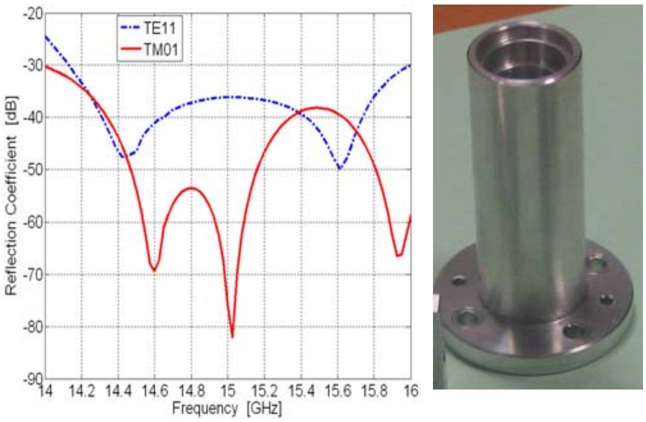


Fig. 6 Simulated reflection coefficients of both Te11 and TM01modes in the input of the radiating load

Fig.8 shows the measured reflection coefficients (of the sum signal) and isolation between port 1 and port 2 (according to fig.1) along with their respective simulation generated by µWave-Wizard [16]. Furthermore Fig.9 shows a measurement vs. simulation plot for the overall axial ratio. The axial ratio was computed by measuring the amplitude and phase difference for the two orthogonal TE11c/s circular waveguide modes (sum).

Finally Fig.10 shows the reflection coefficient of the tracking port (port 4) as well as isolation between the sum and difference signals (port 1 or port 2 from one hand and port 4 from other hand). As it can be seen from the fig.8, the return losses of the fundamental modes in both senses of polarization is better than 28dB and the isolation between the rectangular ports of the septum polarizer is always better than 40dB in whole band. The axial ratio as it can be seen in fig.9 is around 0.45dB which confirm the high purity of the circular polarization of the main signal (sum). The return loss of the tracking port 4 is superior to 22dB and the isolation between the sum and difference signals is extremely low, of the order of -50dB (fig.10). Therefore, the TM01 tracking mode is transformed, with high coupling efficiency, to the TE10 rectangular standard waveguide mode in port 4. We can note also, from the fig.8, that TE11s is not affected by the transversal slots of the tracking coupler. The prototype of the whole monopulse tracking subsystem is shown in the fig.10.

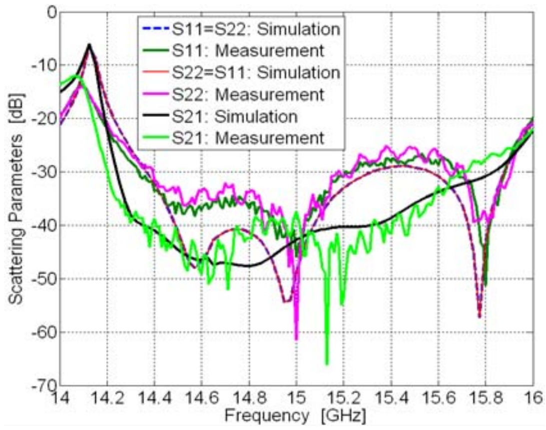


Fig. 7 Match of the two rectangular standard ports of the sum signals and the isolation between them (the ports numeration is according to the fig.1).

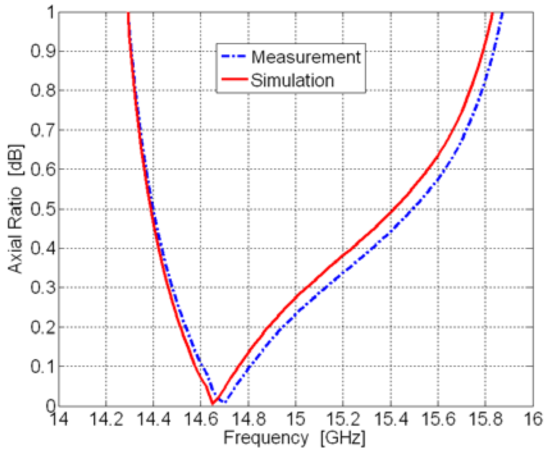


Fig. 8 Axial ratio of one sense of the circular polarized sum signal

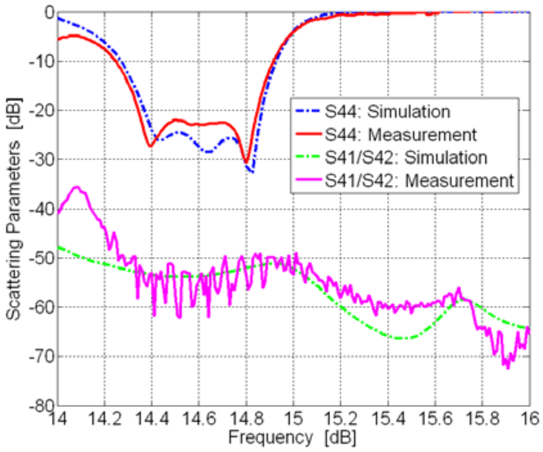


Fig. 9 Match of the tracking ports (difference signal), and isolation between the sum and difference channels

IV. CONCLUSIONS

A compact monopulse tracking feed subsystem has been designed, and tested, taking into account dimension constraints for easy and low-cost production. It presents very good performances with a return loss of the sum signal of better than 28dB, an insertion losses less than 0.15dB, and an axial ratio of around 0.45dB in the frequency bandwidth 14.4-15.5GHz. The measurement of the difference signal exhibits a return loss better than 22dB, an insertion loss less than 0.12dB, along with a high level of isolation from the sum signal. These monopulse tracking subsystem is well-suited to high coupling efficient and compact applications with good performances and good manufacturability mechanical tolerances. Especially, this device will be another alternative option for tracking the motion of unmanned aerial vehicle.

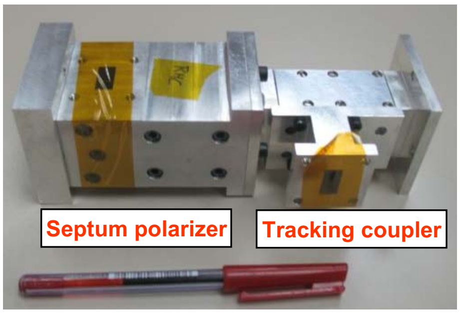


Fig. 10 An assembled prototype of the whole monopulse tracking feed subsystem

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