Patch-monopole monopulse feed for deep reflectors

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A novel design for a simple and compact monopulse feed is presented for illuminating a deep reflector from the primary focal point, e.g. a rotationally symmetric single-reflector parabolic antenna, with a diameter-to-focal-distance ratio of around 0.4. The proposed feed is designed as a multimode circular cavity (cup) antenna. The elliptical patch excites a left-hand-circularly polarised TE_{11} mode for the sum channel. The monopole in the centre of the patch excites the orthogonal, linearly polarised TM_{01} mode for the difference channel. Two prototypes for such a feed were developed and fabricated, where the first was a proof-of-concept device and the second was a computer simulation-optimised version. Both the simulations and the measurements of the optimised prototype are presented.

Introduction: Currently, there are two main approaches to design a monopulse antenna feed. The first is the well-known design using an array of usually four antennas fed by a hybrid network for adding and subtracting the signals to obtain the sum and the difference signals. The sum pattern of the array is usually too narrow to efficiently illuminate a deep reflector with a f/d (diameter to focal distance) ratio of 0.4 or less [1]. The feeding network usually requires bulky waveguides for low insertion losses as required in satellite communications. No matter how small and efficient, the hybrid network [2] remains a limiting factor in the design.

The second approach is to excite at least two orthogonal modes for the sum and the difference channels in a waveguide-horn feed [3]. A good design can integrate the complete sum and difference network in the horn itself. Again, the sum pattern of a multimode horn [4] is usually too narrow to efficiently illuminate a deep reflector with such a low f/d ratio.

To the best of our knowledge, we are presenting a new design for a simple monopulse feed suitable for illuminating a rotationally symmetric, deep parabolic reflector with a f/d ratio of 0.4 from the primary focal point. Our design allows for a less complicated and a more compact and balanced monopulse satellite antenna. Our feed design has an overall diameter of just 0.73λ thus providing a relatively small obstruction with little shading of the antenna aperture. Our prototype was designed, optimised, built and tested for the 2.20–2.29 GHz satellite-downlink band while it can be practically scaled up to at least the X band.

Design: The sum channel is provided by an elliptical radiating patch inside a circular-cup cavity. An air dielectric is used for a high radiation efficiency and wider bandwidth. The patch requires a perfectly balanced feed at two symmetrically-opposed points to avoid any squint of its radiation pattern and unwanted coupling to the difference channel. The shape and size of the patch – an ellipse, a circle with two cuts or a square with two opposed corners cut, all at 45° with respect to the two feed points – is carefully chosen for the desired phase difference of its two fundamental modes to provide a quadrature phase shift for circular polarisation. The sum channel of our feed generates the equivalent of a circularly polarised TE_{11} mode in a circular waveguide [5]. The feed alone generates the left-hand circular polarised antenna (LHCP) to be transformed into the RHCP after reflecting from the parabolic mirror.

The difference channel of our feed is a simple monopole in the centre of the patch, fed by the centre conductor of a coaxial cable passing through both the cup and the patch. The shield of the cable is connected to both the cup and the patch at their centres, where the electric field of the sum channel is equal to zero. Both the cup and the patch act as a ground plane for the monopole. The difference channel of our feed generates the equivalent of a TM_{01} mode in a circular waveguide [5].

The proposed feed is shown in Figs. 1 and 2. The sum channel is designed for the best illumination efficiency of a deep parabolic dish with a given f/d ratio or even better for the best G/T ratio of the whole satellite receiving station. The difference channel is much less demanding, since the bandwidth of the antenna-position control loop is several orders of magnitude smaller than the downlink data bandwidth of the sum channel.

Similar to other monopulse feeds with a single difference channel, our feed only operates with circularly polarised signals. The elevation offset information is obtained by multiplying the sum and the difference channels in phase. The azimuth offset information is obtained by multiplying them in quadrature. Operation with two independent, orthogonally linearly polarised signals is also possible by feeding the patch appropriately.

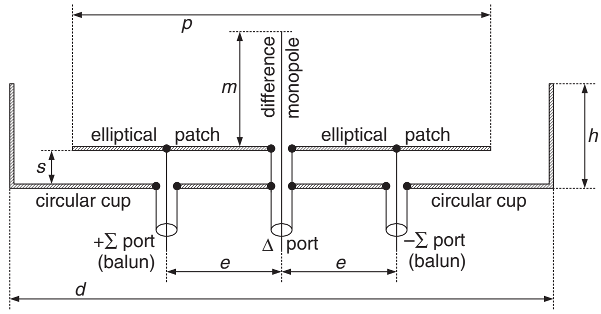

Fig. 1 *Side view of our proposed feed (not to scale)*

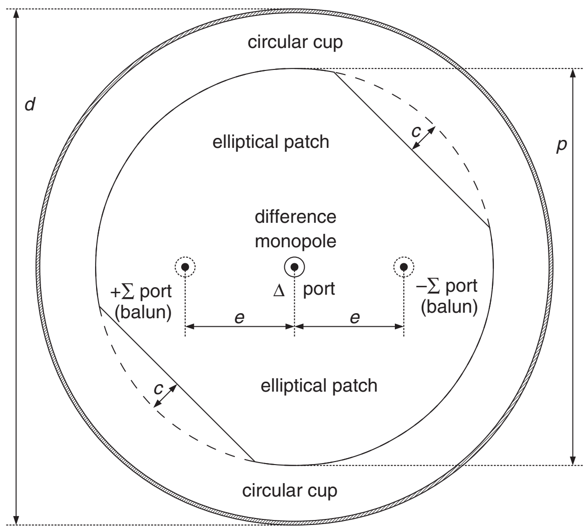

Fig. 2 *Front view of our proposed feed (not to scale)*

Optimisation: The first prototype was designed from scratch and served as a testbed to understand many requirements of such a feed design such as the strictly balanced feed of the sum channel patch. The second prototype was carefully optimised using computer simulation. The optimised dimensions of the monopulse feed are shown in Table 1. The sum balun includes two coaxial lines of lengths 1λ and 1.5λ connected together to a common 50 Ω feedpoint. The difference-monopole impedance match was optimised with a capacitive stub on the feed line.

Table 1: Optimised dimensions of monopulse feed

Dimension	Mark	Length (mm)	Electric length
Cup diameter	d	97.0	0.726λ
Cup height	h	25.0	0.187λ
Patch diameter	p	66.5	0.498λ
Patch cut	c	5.5	0.041λ
Patch height	s	6.8	0.051λ
Patch feedpoint offset	e	12.9	0.096λ
Monopole length	m	27.8	0.208λ (PTFE covered)

A 0.4-mm-thick brass sheet is the main material used for fabricating the antenna since it can be easily soft soldered. All the coaxial lines used for the balun and the matching stubs are semi-rigid coaxial cables with a polytetrafluoroethylene (PTFE) dielectric. The latter also partially covers the monopole for both mechanical strength and a smoother impedance transition. There is an open-ended matching stub for the monopole right outside the back cavity wall realised with an subminiature version A (SMA) tee adapter and an SMA open-end terminator (together accounting for about 15 mm of PTFE in length).

Results and discussion: The impedance matchings of both the sum and the difference ports are shown in Fig. 3 for both the simulation and the measurement. The two additional vertical grid lines represent the operational frequency band. While introducing an unwanted insertion loss, the patch also acts as a bandpass filter for the sum channel, thus releasing the requirements for subsequent filtering in front of the low-noise amplifier. The simulated crosstalk between the two ports is around −40 dB, while the measured value of around −20 dB is still sufficient.

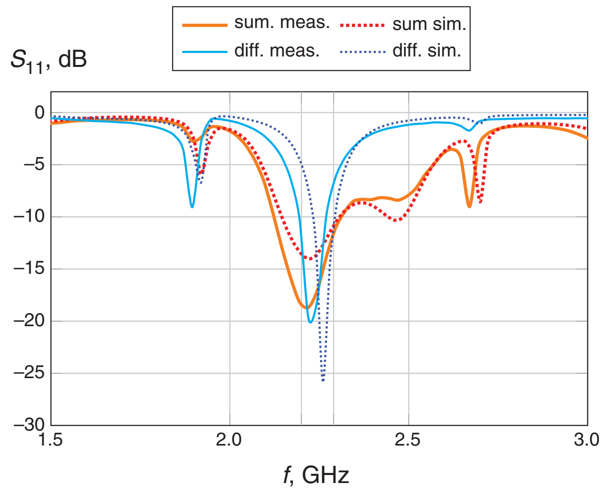

Fig. 3 *Impedance matching of both sum and difference ports*

Two cross-sections of the radiation pattern are shown in Figs. 4 and 5. The corresponding planes are chosen to provide significant information considering the particular design of the described feed. Both planes include the maximum radiation of the sum channel in the *Z*-direction. The dashed lines show the required beamwidth to illuminate a reflector with a f/d ratio of 0.4. The bottom parts of both diagrams are not very accurate since the backward radiation is severely affected by the coaxial cables and the support structure. These small asymmetries in the overall shape of the feed together with the support structure also have a small squint effect on the forward radiation. The measured sum pattern is a little more directional than that predicted, but this may be another artefact of our antenna test range.

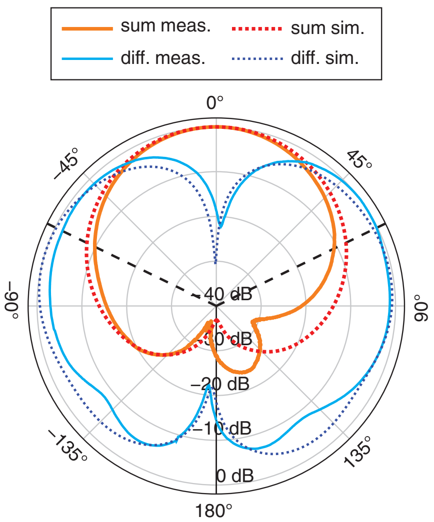

Fig. 4 *Radiation pattern in plane, perpendicular to sum balun*

The simulated radiation efficiency of the sum channel is 95% throughout the desired frequency band and the circular components' ratio achieves its peak of about 35 dB in the middle of the desired band. In the outermost parts of the band, the simulated polarisation loss is around 0.5 dB. In our reverberation chamber, we measured a radiation efficiency of at least 80% for the critical sum channel.

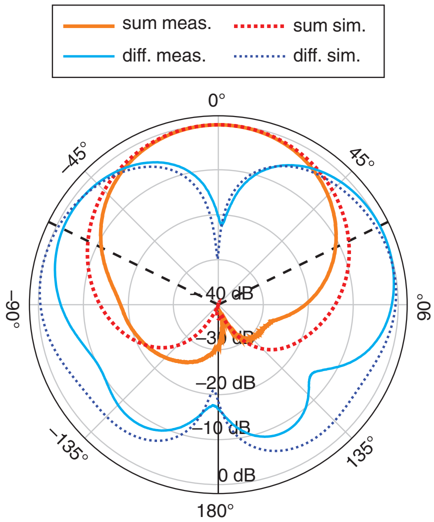

Fig. 5 *Radiation pattern in sum balun plane*

Conclusion: In our Letter, we present a novel *patch-monopole* monopulse feed design, suitable for illuminating a deep parabolic mirror. Two prototypes based on the presented design were optimised, built and measured. Both the simulation results and the measurements show that our feed has at least 100 MHz of usable LHCP bandwidth.

The feed was measured both alone and illuminating a small 60 cm (4.5λ) diameter dish with a f/d ratio of 0.4. For test purposes the sum port was connected to the reference input and the difference port was connected to the test input of a vector voltmeter with a polar magnitude/phase display. The testing showed that the feed is operating as expected.

Our feed design economically extends the monopulse tracking of different targets such as low-Earth-orbit satellites or aerial drones down to very small, compact and inexpensive reflector antennas less than 5λ in diameter. Finally, but not least, due to its simple and inexpensive design, our feed could also be used for indoor tracking, highly directional wireless links or more precise indoor positioning.

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One or more of the Figures in this Letter are available in colour online.

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