A HIGH-GAIN USER TERMINAL ANTENNA FOR LAND-MOBILE BI-DIRECTIONAL SATELLITE COMMUNICATIONS IN KA-BAND

H. Bayer, A. Krauss, R. Stephan, and M. A. Hein

RF and Microwaves Research Laboratory, Ilmenau University of Technology, P.O. Box 10 05 65, 98684 Ilmenau, Germany, Email: hmt@tu-ilmenau.de

ABSTRACT

The growing interest in bi-directional mobile satellite communications in Ka-band necessitates the development of dedicated antenna systems and feeds. In this paper we describe a mobile satellite communications terminal with a cassegrain reflector antenna fed from a multimode monopulse tracking system for circular polarisation at the satellite downlink frequency of 20 GHz. The structure is operational at 30 GHz as well, to cover the uplink frequency range. The antenna system is mounted on a high-performance mechanical positioner to facilitate a fast compensation of the movements of the carrier vehicle. This work contributes to the development of a satellite terminal for mobile communications in disaster scenarios [1].

Key words: Satellite Terminal Antenna; Multimode Monopulse Tracking; Cassegrain Reflector Antenna.

1. INTRODUCTION

Land-mobile satellite antennas such as introduced in [1–5] need to track the satellite direction during the movement of the carrier vehicle. One possibility to monitor the movement is to use highly precise inertial systems based, e.g., on optical gyro systems. These devices are mostly large, heavy, and expensive, thus not optimal for a mobile system. In our case, the antenna terminal will be equipped with a very lightweight and compact MEMS inertial measurement unit which is supported by a TM01 multimode monopulse tracking system [6, 7]. This feed system provides left- and right-handed circular polarisation, for the downlink frequency range from 19.7 to 20.2 GHz as well as for the uplink range from 29.5 to 30.0 GHz. Figure 1 is a photograph of the mobile satellite antenna terminal comprising a Ka-Band satellite reflector antenna mounted on a high performance mechanical positioner.

Figure 1. Photograph of the high-gain antenna terminal outdoor unit for mobile satellite communications in Ka-band.

2. SETUP OF THE ANTENNA TERMINAL OUTDOOR UNIT

2.1. Antenna Positioner

The mechanical positioner employed in the mobile satellite terminal is capable of moving the antenna in two axes respectively azimuth and elevation. Since the antenna facilitates circular polarisation the polarisation tracking becomes obsolete. The two axes of the positioner are moved by direct drive motors, which facilitate a large torque and highly precise positioning simultaneously. The positioner can move a payload of 12 kg with an angular acceleration of more than 300°/s^2 and an angular speed of more than 300°/s in both axes. Due to a backlash-free operation and by employing precise angle sensors the positioning accuracy reaches about 1 arcsec which corresponds to 0.3 × 10^-3 degrees. Another benefit of these special mo-
tors is a low level of abrasion which leads to low maintenance efforts. The peak power consumption is about 250 Watts per axis if the maximum payload is accelerated with 300°/s². During a controlled movement of the antenna compensating the movements of the carrier vehicle the power consumption is significantly lower.

2.2. Cassegrain Reflector Antenna

The antenna we are using for our mobile satellite terminal is a weight-optimised graphite antenna fabricated by QuinStar Technology, Inc. [8]. The cassegrain type reflector antenna is suitable for the use at Ka-band frequencies and is equipped with a self-made dual-band multimode monopulse tracking feed to generate satellite tracking information. Figure 2 shows a photograph of the 60 cm antenna in the anechoic chamber at Ilmenau University of Technology. Here we can measure complex antenna patterns employing frequency converting techniques for frequencies up to 75 GHz. The antenna pattern measurements for the electrically large Ka-Band antenna were performed by means of spherical near-field scans using the far-field transformation algorithm of the measurement software provided by the supplier [9].

Figure 3. Schematic E-field patterns of the TE_{11} mode for signal transmission in circular polarisation (left-hand part) and the TM_{01} mode for tracking signal generation (right-hand part) in a circular waveguide.

Figure 4. Dual-band multimode monopulse tracking coupler for Ka-band up- and downlink frequencies.

2.3. Dual-Band Multimode Monopulse Feed System

The tracking concept implemented is based on the multimode monopulse technique which uses higher-order waveguide modes to identify the satellite direction [7]. According to [1, 4], the tracking feed excites the TM_{01} mode in a circular waveguide for the tracking information, and the TE_{11} mode in dual polarisation at two frequencies for bi-directional communications. Figure 3 indicates the E-field patterns of the two modes used for the tracking system. The TE_{11} mode generates a narrow pencil-shaped beam for the communications channel while the TM_{01} mode results in a conical pattern with a deep notch in boresight direction, which leads to the absence of received power if the antenna points precisely to the satellite.

To generate tracking signals when the antenna points aside from the satellite, the signals from the two receiver branches exciting the TE_{11} and TM_{01} modes are compared in phase and amplitude using a phase discriminator. The amplitude difference is a measure for the absolute amount of depointing, and the phase difference contains information on the direction of the misalignment. Due to the fact that the tracking signals are generated in the intermediate frequency range, a high tracking bandwidth can be achieved.

2.4. Transceiver Frontend

The multimode monopulse tracking system requires two frequency synchronous downconverters for the two signal paths - one for the TE_{11} mode for communications and one for the TM_{01} mode for tracking. In our terminal we employ two low-cost 3 W transceiver from ViaSat, originally used for fixed Ka-Band satellite terminals. These converters use free running local oscillators, hence they are not working synchronous. For a frequency synchronous operation we coupled both local oscillators directly at 5.3 GHz via a coaxial cable. This technique additionally facilitates the use of an external local oscillator to provide a highly frequency-stable conversion.
2.5. Phase Discriminator

The tracking signals for the control cycle are derived from the amplitude and phase difference of the two signals received from the $\text{TE}_{11}$ and $\text{TM}_{01}$ modes. This comparison is achieved using a phase discriminator at the intermediate frequency band from 0.95 to 1.95 GHz. The functional principle of this device is depicted in Figure 5. Two copies of the received signals are mixed. To obtain an error signal for one plane, the received signals from the $\text{TE}_{11}$ and the $\text{TM}_{01}$ modes are mixed directly, whereas the error signal in the orthogonal plane is generated by mixing the signal from the $\text{TE}_{11}$ mode with a $90^\circ$ phase shifted version of the $\text{TM}_{01}$ mode signal. After low-pass filtering, the phase discriminator provides DC voltages proportional to the misalignment of the antenna over a certain angular range of deviations, depending on the beamwidth of the antenna used. The coordinate system orientation of the tracking signals depends on the phase difference between the feed branch for communication in circular polarisation and the $\text{TM}_{01}$ tracking branch and can be corrected using phase shifters or a coordinate transformation after digitalisation. These two voltages can be fed into a control cycle for the mechanical positioner, to keep the direction of the antenna towards the satellite constant during the movements of a carrier vehicle.

Figure 5. Block diagram of the multimode monopulse tracking principle including the feed network for the mode coupler (left-hand part) and a phase discriminator (right-hand part) to generate the tracking signals.

Figure 6 shows a photograph of the phase discriminator for L-Band intermediate frequency. It employs a power splitter with an amplifier at its input ports, to compensate for dissipation losses. The copies of the two input signals are filtered and amplified before the I/Q mixer module. The output signal amplitude can be set via a differential amplifier to adjust it to the adjacent signal processing unit.

3. MEASUREMENTS

3.1. Antenna Pattern

Figure 7 depicts the measured radiation pattern for the high-gain antenna fed by the $\text{TE}_{11}$ communications mode and the $\text{TM}_{01}$ tracking mode considering left-handed circular polarisation (LHCP) at 20.1 GHz. The antenna has a measured gain of 38 dBi and a half-power beamwidth of 1.6° at 20 GHz. The radiation pattern generated by the $\text{TM}_{01}$ mode has a deep notch in boresight direction whereas the $\text{TE}_{11}$ mode results in a pattern that has its maximum gain in this direction.

Figure 7. Measured radiation pattern of the high-gain antenna for the $\text{TE}_{11}$ mode (blue solid) and the $\text{TM}_{01}$ mode (orange dashed) for LHCP at 20.1 GHz.

Figure 8. Measured radiation pattern of the high-gain antenna for RHCP at 29.8 GHz.
The transmit radiation pattern for RHCP is shown in Figure 8. The measured gain in the transmit band at 29.8 GHz is about 40 dBi with a half-power beamwidth of 1.2°. At this frequency we achieved a sidelobe suppression of more than 18.5 dB.

3.2. Tracking Signals

Figs. 9 and 10 depict the measured error voltage patterns for an angular misalignment of the antenna in the azimuth-elevation plane relatively to the satellite direction. The error voltages are crossing zero when the antenna points exactly to the signal source or too far away from it. Between -1° and +1°, the voltages vary nearly linear, and can be used for a feedback control loop with differential part to drive the mechanical positioner. The lock-in range covers approximately 4 degrees. Outside the lock-in range the movements of the carrier vehicle will be compensated using an inertial measurement unit. The measurements were performed at the Fraunhofer satellite communications test facilities in Ilmenau. The testbed facilitates the simulation of mobile scenarios with the satcom terminal on a motion emulator and a dummy satellite payload on a 50 m antenna mast in a distance of 100 m.

4. CONCLUSIONS

A mobile satellite communications terminal outdoor unit for recovering communications infrastructure in disaster scenarios has been described. The 60 cm high-gain reflector antenna is mounted on a high-precision two-axes mechanical positioner to track the satellite direction during the movements of the carrier vehicle. A compact TM01 multimode monopulse tracking feed has been successfully developed, designed, manufactured, and tested.

5. ACKNOWLEDGMENTS

We gratefully acknowledge M. Huhn and M. Zocher for technical assistance as well as Dr. Christian Volmer for scientific support and Mario Lorenz for performing tracking measurements. This work has been funded by the DLR on behalf of the German Federal Ministry of Economics and Technology (grant no. 50YB0913). This research has been conducted within the framework of the project MoSaKa (Mobile Satellite Communications in Ka-band).

REFERENCES


