Development of Airborne Antennas for Satellite Communication

Oct 12th, 2015
Mitsubishi Electric Corporation
Table of Contents

1. Introduction
2. MELCO’s antenna heritage for Satellite Communication On The Move
3. Ku band Airborne Antenna Subsystem
   3.1 Overview
   3.2 Technical requirements
   3.3 Elliptical reflector design for low profile
   3.4 Polarization control using electrical phase shifter
   3.5 Accurate tracking system
4. Ku band Helicopter Satellite Communication (Helisat) System
   4.1 Overview
   4.2 Technical requirements
   4.3 Intermittent transmission synchronized with blade rotation
   4.4 Field test of intermittent transmission
   4.5 Satellite tracking and linear polarization tracking
   4.6 Technologies for reducing interference to radio astronomy observations
5. Ka band Unmanned Aircraft Antenna
   5.1 Overview
   5.2 Technical requirements
   5.3 Radiator and Feed
   5.4 Antenna system configuration
6. Conclusion
1. Introduction

(1) Mitsubishi Electric corporation manufactures various types of satellite communication antennas on the move in this decade.

(2) Firstly, we will show you the Ku-band airborne antenna for satellite communication, which we first launched for commercial airplanes in 2004.

(3) Secondly, we will show you the Ku-band satellite communication system on helicopter, which we first launched in 2012.

(4) Lastly, we will show the Ka band Unmanned aircraft antenna, delivered to NiCT.
2. MELCO’s antenna heritage for SOTM

- **Ku-band Airborne antenna (2004-2006)**
- **1m Maritime VSAT (2009-)**
- **1.2m (2011)**
- **Helisat system (2012-) (with 40cm antenna)**
- **Compact SNG on vehicle (2010-) (with 40cm antenna)**
- **0.6m Maritime VSAT (2012-)**

*SOTM : Satellite On The Move*
3. Ku band Airborne Antenna Subsystem
3.1 Overview

- We first developed and started production of Ku-band airborne antenna subsystem for satellite communication on commercial airplane in 2004, giving Broadband internet access to passengers on airplane in flight, being equal to that on ground.

- We delivered 300 units during 2004 to 2006. 150 of them were installed to airplanes before the service company CBB shut down their service in 2006.
3.2 Technical requirements

(1) Low profile antenna for better mountability on airplane
   -Less than 10” in height including Radome
   -Lower sidelobes for meeting the interference specification

(2) Linear polarization tracking and Circular polarization for DBS
   -Linear polarization tracking system should be implemented, corresponding to low profile requirement

(3) Accurate tracking system
   -Azimuth tracking error should be less than +/- 0.13 deg
   -Elevation tracking error should be less than +/- 0.19 deg
   (Approximately 20th part of each beam width)
3.3 Elliptical reflector design for low profile

Aperture size : 600 x 200 mm
Point of the reflector design

● In first place, we designed low profile elliptical aperture antenna based on the geometric optics

● Then, we investigated the reduction of undesirable diffusions to deteriorate the antenna performance by reflector modification technique based on the physical optic theory

See from the direction B

See from the direction A

Copyright © 2015 MITSUBISHI ELECTRIC CORPORATION. ALL RIGHTS RESERVED.
3.3 Radiation pattern of the antenna

Azimuth-plane (Orbital plane)

V-pol., 14.0GHz, narrow range

H-pol., 14.0GHz, narrow range

V-pol., 14.0GHz, wide range

H-pol., 14.0GHz, wide range

ITU-R S.728-1 Specification
3.4 Polarization control
using electrical phase shifter

● Linear polarization radio wave for SATCOM is transmittable. Linear polarization radio wave for SATCOM and Circular polarization for Satellite TV are receivable.

● It was difficult to adopt waveguide polarizer for reducing antenna size, we adopted the digital phase shifter of MMIC for electrical controlled polarizer.
3.5 Accurate tracking system

<<Requirements and problems>>
1. Accurate tracking (AZ < 0.13, EL < 0.19 deg r.m.s) against 1-5Hz aircraft body vibration caused by gust and turning.
2. Aircraft body distortion and vibration between IRU and the antenna located more than 20m away give negative influence on the attitude estimation.
3. IRU data has random time delay

<<Achievement>>
1. Less than 0.04 deg r.m.s in each axis error caused by vibration and distortion is compensated by rate sensor installed near the antenna.
2. Compensation of IRU delay (max 250ms) by using rate sensors installed near the antenna.
3. Stable tracking near zenith direction.
   Keyhole filter and newly developed algorithms

Aircraft attitude $q_A$ (detected by IRU) ≠ Antenna attitude $q_B$
3.5 Accurate Tracking system

Motion table for Tracking test.

(1) Sine wave motion
- 6 deg/sec, 3sec (Roll)
- 2deg/sec, 6sec (Pitch)
- 2deg/sec, 32sec (Yaw)

(2) Ramp motion
- 6 deg/sec, 16sec (Roll)
- 2deg/sec, 8sec (Pitch)
- 2deg/sec, 32sec (Yaw)

(3) Gust
- 6deg/sec (Roll)
- 2deg/sec (Pitch and Yaw)
- 2nd-order BW 2Hz,
  Damping coef. 0.4

<table>
<thead>
<tr>
<th></th>
<th>Requirements</th>
<th>Mesured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nav Track</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AZ</td>
<td>0.13deg rms</td>
<td>0.041deg rms</td>
</tr>
<tr>
<td>EL</td>
<td>0.19deg rms</td>
<td>0.039deg rms</td>
</tr>
<tr>
<td>Step Track</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AZ</td>
<td>0.25deg rms</td>
<td>0.10deg rms</td>
</tr>
<tr>
<td>EL</td>
<td>0.60deg rms</td>
<td>0.14deg rms</td>
</tr>
</tbody>
</table>
4. Ku band Helisat System
## 4.1 Overview

<table>
<thead>
<tr>
<th>System Overview</th>
<th>Helisat System</th>
<th>Conventional Helicopter TV System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Area</td>
<td>Large (depending on satellite beam coverage)</td>
<td>Small (Each relay station covers approx. 50 km)</td>
</tr>
<tr>
<td>Anti Tolerance</td>
<td>No influence of natural disaster on the ground</td>
<td>Relay station or terrestrial line may be destroyed by natural disaster</td>
</tr>
<tr>
<td>Direct communication between helicopters and a base station via satellite (Single hop)</td>
<td></td>
<td>Helicopters to relay stations via microwave. Relay stations to a Head quarter (Ground station) via multiple microwave (terrestrial) or satellite communication (via portable VSAT systems or vehicle mount VSAT systems)</td>
</tr>
</tbody>
</table>
4.1 Overview

Base Station

Ground Station Equipments
- MODEM
- DECODER
- Management Unit

Helicopter Airborne Station

External Equipments
- Antenna
- RFU-OUT

Cabin Equipments
- RFU-IN
- MODEM
- Antenna Control Unit
- ENCODER
- Camera (Option)

HSA40 Equipments
4.2 Technical requirements

(1) Satellite communication system under helicopter blade blocking
   - Transmitting method for avoiding blade blocking
   - Receiving method under blade blocking

(2) Accurate pointing and polarization tracking on helicopter environment
   - Pointing accuracy 0.5deg 0-p
   - XPD more than 21dB

(3) Small aperture for small footprint with meeting the interference specifications
   - 0.4m aperture
   - Meeting the specification of interference on adjacent satellites and radio astronomy observation
4.3 Intermittent transmission synchronized with blade rotation

- Radio waves reflected by the rotor blades may cause interference to other systems. We adopt an intermittent transmission method synchronized with blade rotation.

- Timings and intervals of intermittent transmission are variable with flight attitude. They are calculated using in-flight data of helicopter positions, satellite position and blade cutoff intervals.

Timing chart of intermittent transmission method:

- Magnetic pickup signal
- Blade cutoff intervals (4-blade type)
- Transmission signal
- Blade rotation cycle (e.g. 192ms (312rpm))
- Blocking interval 10 - 30ms (depends on beam direction)
- Send ON and OFF timing margin
- Intermittent transmission cycle

Time (t)
4.4 Field test of intermittent transmission

Field test of intermittent transmission from a real helicopter

Transmitting level

47.7 msec

1.29 msec

1.29 msec
4.5 Satellite tracking and linear polarization tracking

1. ±0.5° (0-p) of tracking accuracy under helicopters’ typical vibration and motion conditions is actualized by combination of rate sensor and beam scan.

2. More than 21dB of XPD is actualized by vibration motion compensation using data from inclino-meter and rate sensor.

3. Cost performance is improved by the composition of inexpensive electronic components compared with an external inertial navigation system.
4.5 Satellite tracking and linear polarization tracking

We evaluated accuracy of the tracking system and found that it meets the most severe requirement for practical helicopter operations.

- Helicopter motion simulations
  (3 axes simultaneous oscillation):
  - Roll ±30deg
  - Pitch ±20deg
  - Yaw ±30deg

※ quoted from a report by Ministry of internal affairs and communications (2009)
4.6 Technologies for reducing interference on radio astronomy observations

Conditions to coexist with radio astronomy observations

PFD @14.0∼14.47GHz within range of radio receiving facilities
-190+0.5θ dBW/m²/150kHz (θ≤40°)
-185 dBW/m²/150kHz (40 <θ≤90°)

-TE112 mode circular cavity resonator to realize ultra narrow guard band and high attenuation filter
-Adopting low thermal expansion coefficient materials to realize temperature resistant property

Measurement result of PFD in surface of the earth
5. Ka band Unmanned Aircraft Antenna

(Delivered to NiCT)
5.1 Overview

(1) We developed the Ka band SATCOM antenna on unmanned aircraft under the order from NiCT. NiCT and we are planning to conduct flight test by the end of this year.

(2) We conducted the antenna design for meeting ESOMP’s frequency ranges, with taking the mountability on aircrafts into consideration.

(3) In the following presentation, we will show you the detail of our design.
5.2 Technical requirements

(1) Low profile antenna for better mountability on aircraft, with - Height (target) : 10”

(2) Wider frequency band (ESOMP compliant)
   - TX frequency range : 27.5 – 30.0 GHz
   - RX frequency range : 17.3 – 20.2 GHz

(3) Light weight for meeting aircraft’s payload limitation
   - Weight (target) : less than 30kg (Antenna unit)

(4) Reduction of the number of units for better mountability on aircraft
   - Fewer indoor units simplify the installation and wiring
5.3 Radiator and Feed

1. Reflector: Low profile by adopting elliptical reflector (minimum diameter of EL swept:235mm)
2. Rx branching filter: Thin profile (25mm) and down size by adopting two-dimensional synthetic circuit with phase shifter and 90 degree hybrid circuit
3. Meeting characteristics within ESOMP spectrum
4. The combination of OMJ, POL and OMT offers the switching function for RHCP and LHCP

<table>
<thead>
<tr>
<th>Items</th>
<th>Measured values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>TX: 27.5～30.0GHz</td>
</tr>
<tr>
<td></td>
<td>RX: 17.3～20.2GHz</td>
</tr>
<tr>
<td>VSWR</td>
<td>TX: less than 1.24</td>
</tr>
<tr>
<td></td>
<td>RX: less than 1.22</td>
</tr>
<tr>
<td>Axial ratio</td>
<td>TX: less than 0.82dB</td>
</tr>
<tr>
<td></td>
<td>RX: less than 1.24dB</td>
</tr>
<tr>
<td>Isolation</td>
<td>TX band: less than 64.3dB</td>
</tr>
<tr>
<td></td>
<td>RX band: less than 54.2dB</td>
</tr>
<tr>
<td>Antenna gain (with feed loss)</td>
<td>39.0dBi @ 30.0GHz</td>
</tr>
<tr>
<td></td>
<td>35.5dBi @ 20.2GHz</td>
</tr>
<tr>
<td>Off-axis EIRP density</td>
<td>ITU-R S.524-9</td>
</tr>
<tr>
<td></td>
<td>(24.5dBW/40kHz)</td>
</tr>
</tbody>
</table>
5.3 Radiator and Feed

Elliptical reflector - Low profile (minimum diameter of EL sweep: 235mm) and wide band (ESOMP compliant)

(a) Radiator overview
(b) Reflection characteristic
(c) Off-axis radiation patterns (RHCP)
5.3 Radiator and Feed

Thin profile and down sized filter with two-dimensional synthetic circuit realizes compliance with characteristics within ESONP spectrum

(a) Block chart

(b) Rear face of the antenna

(c) Photograph and dimensions

(d) Electrical performance

1. VSWR

![Graph showing VSWR values](image)

**TX (17.3 ~ 20.2GHz)**
- Calculated value: less than 1.16
- Measured value: less than 1.20

**RX (17.3 ~ 20.2GHz)**
- Calculated value: 0.07dB
- Measured value: 0.06dB

P.S.: Phase shifter

Feed

Filter

POL/OMT

[Image of antenna components diagram]
5.4 Antenna system configuration

1. Antenna system consists of 2 units; Antenna unit and Antenna Control unit. (MELOCO’s Ku band Airborne antenna system consisted of 7 units)
2. BUC is mounted on the antenna unit for unit reduction.
3. The design to balance weight of feed module and BUC reduces counter weight to realize a compact lightweight antenna.
   
   Weight of antenna unit: 28kg
   Antenna swept diameter: 88.5cm
   Antenna swept height: 25.6cm
6. Conclusions

(1) We showed the several types of satellite communication antennas on the move manufactured by Mitsubishi Electric in this decade.

(2) Firstly, we explained about our Ku-band airborne antenna, especially its low profile and tracking technology features.

(3) Secondly, we explained about our Ku-band Helisat system, especially its technology for avoiding blade blocking.

(4) Lastly, we explained about Ka-band unmanned aircraft antenna, especially its wide frequency ranges meeting ESOMP.

(5) We will conduct the satcom evaluation in flight environment with Ka-band unmanned aircraft antenna by the end of this year.