

# Beacon Antenna Controller based on Synchronous Satellite

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Original scientific paper

In order to improve the communication efficiency between beacon antennas of flight recorder and the synchronous satellite, a beacon antenna controller based on synchronous satellite has been designed. The optimal communication antenna selection is realized by calculating the angle between the aircraft and the synchronous satellite using Global Positioning System (GPS) position information and flight attitude. The simulation and experimental results show that reliable automatic switch of the antenna can be realized by the antenna controller which can accurately calculate the angle between the aircraft and the satellite after receiving the position and posture information.

**Key words:** Data processing, Attitude estimation, Antenna switch, Synchronous satellite

**Regulator antene odašiljača zasnovan na upotrebi geosinkronog satelita.** U svrhu unaprjeđenja efikasnosti komunikacije između antena odašiljača snimatelja leta i geosinkronog satelita, sintetiziran je odgovarajući regulator antene odašiljača. Optimalni odabir antene za komunikaciju ostvaren je proračunom kuta između letjelice i geosinkronog satelita uz korištenje informacija o položaju i karakteru leta dostupnih iz globalnog sustava za pozicioniranje (GPS). Simulacijski i eksperimentalni rezultati pokazuju da se pouzdana promjena korištene antene može ostvariti putem antenskog regulatora koji točno računa kut između letjelice i satelita nakon primanja informacija o položaju i karakteristikama leta.

**Ključne riječi:** Obrada podataka, estimacija karakteristika leta, odabir antene, geosinkroni satelit

## 1 INTRODUCTION

The storage testing [1,2] is widely used in various aircraft parameters tests. Improving the retrieve efficiency of the recorder is very important for the weapon tests. Commonly used radar positioning [3,4], GPS [5-7] and radio positioning [8,9] cannot solve the abnormal problems occurred during testing of long-distance aircraft.

By using the wide communication range of satellite, the beacon installed in recorder sends GPS position information to the synchronous satellite in real time, and the satellite will forward it to the ground station to obtain the recorder location in real time, as shown in Fig. 1. The antenna controller plays a very important role to ensure continuous communication between beacon antenna and the satellite as multiple antennas are installed on the aircraft. At present, most antenna controllers are ground based stations, which drive the antenna motor by sending instructions through satellite communications to adjust the azimuth and pitching angles of the antenna to realize the communication of antenna to satellite [10-12]. There is a lack of research on satellite attitude and antenna selection of multiple fixed antennas on the aircraft moving in high-speed.

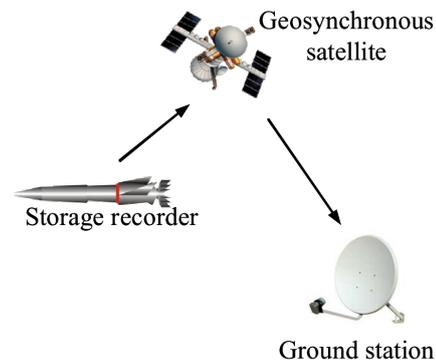


Fig. 1. Flight data recorder positioning system

To solve the above problems, a beacon antenna controller based on synchronous satellite has been designed. Using the aircraft flight attitude and GPS position information, DSP calculates the angle of aircraft to satellite to select the best antenna with satellite communication, realizing automatic switch of antenna.

## 2 ANTENNA CONTROLLER

### 2.1 The relationship between the antenna controller and other devices on aircraft

The relationship of devices on the aircraft is illustrated in Fig. 2. The antenna controller receives aircraft trajectory and attitude information by sensors, and uses the information to calculate antenna switch signal, then sends it to the RF unit to complete antenna switch.

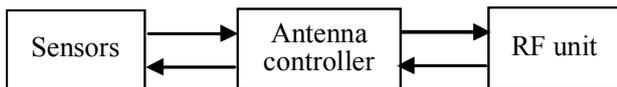


Fig. 2. The relationship of devices on the aircraft

### 2.2 The antenna controller composition

Considering the constraint of aircraft design and communication efficiency between antenna and satellite, four identical antennas are evenly distributed on the surface of the aircraft, as shown in Fig. 3. In order to achieve best communication performance, data need to be sent while the angle between the maximum radiation direction of the antenna and the satellite reaches its minimal value. The angle between the aircraft and the satellite can be calculated according to the aircraft attitude information and GPS position information.

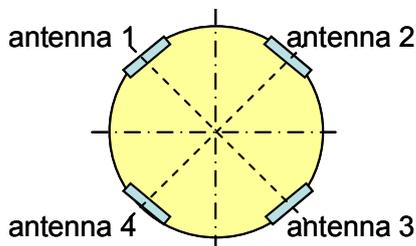


Fig. 3. Antenna layout

The antenna controller contains power conversion unit, data transceiver unit, condition monitoring unit, DSP central control unit and antenna control unit, as shown in Fig. 4. Power conversion unit is used to complete the aircraft power isolation and conversion, and eliminate the influence of the antenna controller to the aircraft. Data transceiver unit is used to obtain GPS position information and aircraft attitude information from the aircraft. Condition monitoring unit is used to feedback the antenna controller state information and master its operative mode. DSP unit takes charge of the angle calculation of the aircraft to the satellite, and selects transmitting antenna by optimization algorithm. Antenna control unit is used to complete the wireless power amplification, data coding and sending.

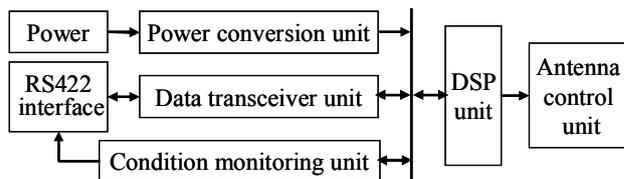


Fig. 4. System block diagram

## 3 BEACON ANTENNA CONTROLLING ALGORITHM

### 3.1 Coordinate system definition

Using satellite to transmit the location information, the satellite and the aircraft have to be in the same coordinate system for calculating the angle between the satellite transient position and antenna.

For satellite, the Earth-centered inertial (ECI) coordinate system [13] is widely used. In the ECI coordinates, satellite orbit parameters include the semi-major axis  $a$ , inclination  $i$ , eccentricity  $e$ , argument of perigee  $\omega$ , right ascension of the ascending node  $\Omega$  and mean anomaly  $M$  [14,15].

For navigation and positioning, the position of the aircraft to the earth usually uses longitude  $\lambda$ , latitude  $\varphi$  and altitude  $H$  to show, namely latitude and longitude coordinates. Figure 5 shows the relationship between the  $(x_1, y_1, z_1)$  Earth Centered Earth Fixed (ECEF) coordinates and the local East-North-Up (ENU) coordinates.

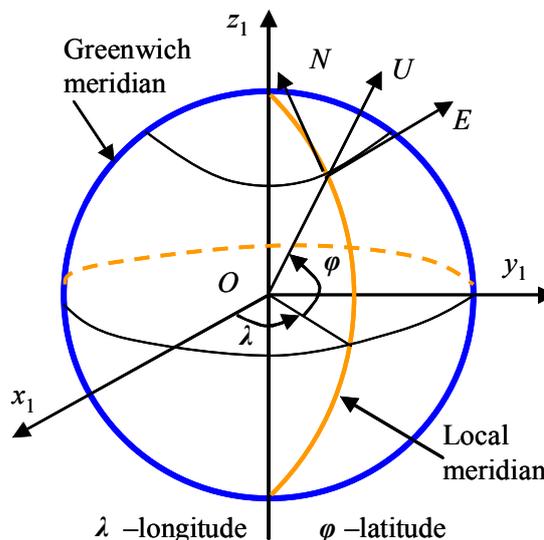


Fig. 5. The relationship between ECEF and ENU coordinates

Figure 6 shows the angle definition of the airplane to the satellite;  $o-xyz$  is the aircraft coordinate system. The

origin  $o$  is the instantaneous centroid of the aircraft. The  $y$ -axis is the vertical axis of aircraft. Its positive direction is towards the aircraft head. The  $z$ -axis is inside vertical symmetry plane of aircraft, and is orthogonal to the  $y$ -axis pointing up. The  $x$ -axis is determined by the right-hand rule. The  $p$  denotes satellite,  $op$  is the line from aircraft to satellite and  $op'$  denotes the projection of  $op$  in  $xoz$  plane.

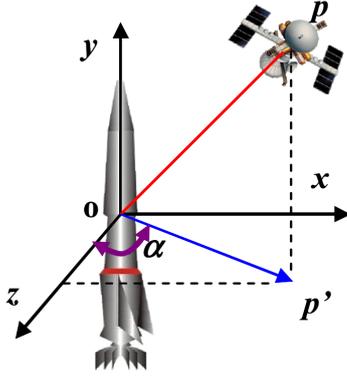


Fig. 6. Aircraft and satellite attachment and projection angle definition

### 3.2 Angle calculation of airplane to satellite

The principle of beacon antenna control is that using  $\lambda$ ,  $\varphi$  and  $H$  and the aircraft attitude parameters (yaw, roll and pitch), DSP unit completes the navigation calculation, realizing the conversion from ECEF to aircraft coordinate system. According to the geometrical relationship in Fig. 6, the angle of airplane to satellite is calculated, realizing the antennae automatic switching. The specific calculation is as follows:

- I. Obtain coordinates in the ECEF from the satellite parameters

According to the classical two-body theory, sometime three-dimensional coordinate  $(x_1, y_1, z_1)^T$  of satellite can be given:

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \frac{a(1-e^2)}{1+e \cos f} \begin{bmatrix} \cos \Omega \cos(\omega + f) - \sin \Omega \sin(\omega + f) \cos i \\ \sin \Omega \cos(\omega + f) + \cos \Omega \sin(\omega + f) \cos i \\ \sin(\omega + f) \sin i \end{bmatrix}, \quad (1)$$

where  $f$  is true anomaly:

$$f = M + \left(2e - \frac{e^2}{4}\right) \sin M + \frac{5}{4}e^2 \sin 2M + \frac{13}{12}e^3 \sin 3M + \dots$$

For synchronous satellite,  $i = 0$ ;  $e = 0$ ;  $\omega = 0$ ;  $M = 0$ , so formula (1) can be written as follows:

$$\begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} a \cos \Omega \\ a \sin \Omega \\ 0 \end{bmatrix}. \quad (2)$$

- II. From ECEF to ENU coordinates

If  $(\lambda, \varphi)$  in the ECEF coordinate are known, the conversion from ECEF to ENU can be given by [16]:

$$\begin{bmatrix} E \\ N \\ U \end{bmatrix} = C_e^g \cdot \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}, \quad (3)$$

where

$$C_e^g = \begin{bmatrix} -\sin \lambda & \cos \lambda & 0 \\ -\sin \varphi \cos \lambda & -\sin \varphi \sin \lambda & \cos \varphi \\ \cos \varphi \cos \lambda & \cos \varphi \sin \lambda & \sin \varphi \end{bmatrix}.$$

- III. From ENU to ENU1 (rising  $H$ ) coordinates:

$$\begin{bmatrix} E_1 \\ N_1 \\ U_1 \end{bmatrix} = \begin{bmatrix} E \\ N \\ U - H \end{bmatrix}. \quad (4)$$

- IV. From ENU1 to aircraft coordinate system:

Aircraft attitude information includes the pitch, yaw and roll angles. Pitch angle, denoted by  $\theta$ , is the angle from  $ox$  axis of aircraft to the ground plane, with its domain being  $-90^\circ \leq \theta \leq 90^\circ$ . Yaw angle, denoted by  $\psi$ , is the angle from the projection of aircraft  $ox$  axis on the ground to the due north, and clockwise is positive, with its domain being  $0^\circ \leq \psi \leq 360^\circ$ . Roll angle, denoted by  $\gamma$ , is the angle from aircraft axis to the vertical plane of containing the body axis, and tilting the aircraft to the right is positive, with its domain being  $-180^\circ \leq \gamma \leq 180^\circ$ .

According to the attitude information, the transformation matrix  $C_g^b$  from ENU1 to aircraft coordinate system is [17]:

$$C_g^b = \begin{bmatrix} \cos \gamma \cos \psi + \sin \gamma \sin \theta \sin \psi & \cos \theta \sin \psi & -\cos \gamma \sin \psi + \sin \gamma \sin \theta \cos \psi & -\sin \gamma \cos \theta \\ \sin \gamma \cos \psi - \cos \gamma \sin \theta \sin \psi & \cos \theta \cos \psi & \cos \theta \cos \psi & \sin \theta \\ -\sin \gamma \cos \psi - \cos \gamma \sin \theta \cos \psi & \cos \gamma \cos \theta & \cos \gamma \cos \theta & \end{bmatrix}. \quad (5)$$

The conversion from ENU 1 to aircraft coordinate system is showed:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = C_g^b \cdot \begin{bmatrix} E_1 \\ N_1 \\ U_1 \end{bmatrix}. \quad (6)$$

V. According to the geometrical relationship in Fig. 5, the angle  $\alpha$  of airplane to satellite can be calculated by:

$$\alpha = \arctan \frac{x}{z}. \tag{7}$$

By Fig. 3 antenna installation position, the angle of the max-radiation of antenna and the aircraft longitudinal axis is fixed, and the max-radiation direction of antenna is in  $xOz$  plane of the aircraft. The angle of the max-radiation direction of antenna to the satellite can be obtained by simple geometric operations.

### 3.3 The realization of the beacon antenna control algorithm

The specific flow chart of the antenna control is shown in Fig. 7. TI company’s TMS320F28335DSP is used, which has the high speed processing capacity of 150MHz, 32-bit-floating-point processing unit, built-in 256K×16 bit FLASH and 34K×16bit SRAM.

DSP receives GPS position and flight attitude information, pre-processes the received data, and calculates the angle of aircraft to satellite, then selects the antenna to send data by the switch module. In order to avoid frequent switch when antenna is in the critical state, the switch hysteresis angle has been used. According to the aircraft flight attitude change estimate, the hysteresis angle is set to 3° (see Fig. 8). Meanwhile, the debounce time delay is used to set the switching time, which means the switching can be confirmed only when the angle is greater than the switch angle for more than 0.5 s. The transmitting antenna is selected through an analog switch.

## 4 THE SYSTEM TEST

With storage recorder, beacon device and antenna controller installed, the aircraft completed the real flight test. Through replaying the recorded data of GPS information, flight attitude information, calculated results, control commands and GPS position information received by the ground station, it is found that it takes less than 50  $\mu$ s to calculate the angle of aircraft to satellite after DSP receives the GPS position information and inertial navigation data. The antenna controller can quickly and accurately complete antenna switch, and send data reliably. In the actual flight process, the changes of the  $\lambda$ ,  $\varphi$ ,  $\theta$  and  $\gamma$  are very small, so the influence to antenna switch can be neglected, the change curves of  $H$  and  $\psi$  are shown in Fig. 9. The calculating results by DSP and the simulation results of STK software of American AGI Company are shown in Fig. 10. The red curve is the calculated result by DSP and the blue curve is the simulation by STK. The test and simulation results show that the maximum angle error is less than 0.05°, which satisfy the requirement of angle accuracy of antenna switch.

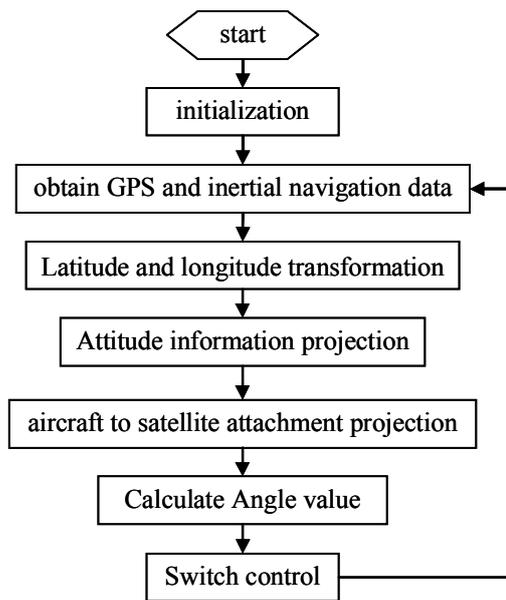


Fig. 7. Flow chart

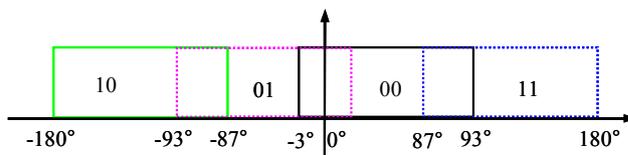


Fig. 8. The hysteresis angle switch controlling

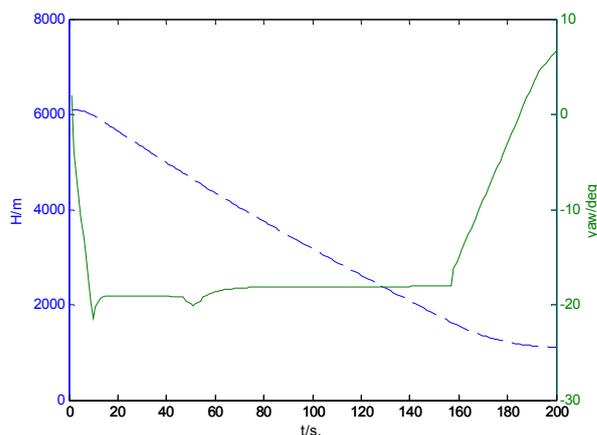


Fig. 9.  $H$  and  $\psi$  changing curves

## 5 CONCLUSION

The paper designed a new antenna controller which can be used in flight recorder positioning system. Using the GPS position information and flight attitude information, DSP can quickly and accurately calculate the angle of air-

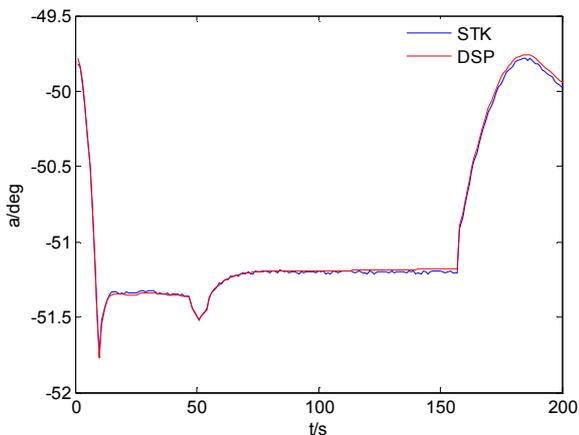


Fig. 10. The calculated curve by DSP and simulation curve by STK

craft to satellite and select the most efficient antenna to communicate with satellite, realizing the automatic switch of antennas. The results of simulation and test show that the system has rapid and accurate antenna switch function. It can be widely used in communications between multiple fixed antennas and satellite.

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