Magnetic Simulator Testbed for APSCO Student Small Satellite Project

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Abstract. The Student Small Satellite (SSS) is a university project of Asia-Pacific Space Cooperation Organization (APSCO), composed by one microsatellite (SSS-1) and two 3U CubeSats (SSS-2A and SSS-2B). Regarding SSS-1 and SSS-2A satellites, the active 3-axis magnetic control strategy has been applied in the Attitude Determination and Control System (ADCS). In this paper, the necessary study for the development of a Magnetic Simulator Testbed for the SSS-1 and SSS-2A satelites was performed using one pairs of Helmholtz coils for each axis of rotation (X, Y, Z). Each pair of coil can generate a sufficiently large and stable magnetic field that simulate the Earth's magnetic field but with a reliable level of accuracy, to perform the ADCS test on the satellites. Matlab software was used to generate the propagation of the orbit, to calculate the Earth's magnetic field around that orbit and simulate a pair of Helmholtz coil in each axis of rotation to reproduce the Earth's magnetic field using the Biot-Savart Law. The results obtained for propagation of the orbit, calculation of terrestrial magnetic field and reproduction of the magnetic field through the Magnetic Simulator Testbed, were very close to the results obtained in important researches previously consulted, giving reliability to this research and allowing an analysis to determine the real physical size that Magnetic Testbed should have. The size determined, is very close to what was expected, allowing to conclude the reliability and viability of the development of the Magnetic Testbed for APSCO SSS Project.

1. Introduction

Asia-Pacific Space Cooperation Organization (APSCO) is an intergovernmental organization who promotes multilateral cooperation, enhances the space application capacity of member states through their universities and promotes the peaceful use of outer space by mankind. The Student Small Satellite (SSS) is a university project composed by one microsatellite (SSS-1) and two 3U CubeSats (SSS-2A and SSS-2B) [1]. Regarding SSS-1 and SSS-2A will have 3 axis Magnetic Attitude control with magnetorquer for stabilization and control in the three axes X, Y and Z. Each magnetorquer will generate a magnetic field that will interact with the Earth's magnetic field to modify its Attitude. The basic information can be seen in table 1. Attitude Determination and Control System (ADCS) is an important
part of a nano-satellite, which usually performs attitude determination, stabilization and acquisition control [2].

In this paper, the necessary study for the development of a Magnetic Simulator Testbed for the SSS-1 and SSS-2A satellites was performed using three pairs of Helmholtz coils, one for each axis of rotation (X, Y, Z) in order to perform the tests of stabilization and attitude control to ensure the proper functioning of the ADCS after putting into orbit. Magnetic Simulator Testbed will simulate the Earth's magnetic field along the same LEO orbit that will have the SSS project, allowing to obtain a clearer vision of what the behaviour of the subsystem will be when it is in orbit, and making the relevant design corrections to ensure its proper functioning after launch.

Matlab software was used in the first stage to generate the propagation of the orbit on the studied satellites and then, it was calculated the Earth's magnetic field around that orbit. To this, the standard World Magnetic Model (WMM) of the United States’ National Geospatial-Intelligence Agency (NGA) [3] was used. Later, in the second stage of the study, Matlab software was used to simulate a pair of Helmholtz coil in each axis of rotation to reproduce the Earth's magnetic field previously obtained in the first stage, using the Biot-Savart Law [4].

The Magnetic Simulation Testbed system (MST), in general, is composed of three modules; the Control Module (CM), the Interface Module (IM), and the Testbed Module (TBM). The CM, is in charge of carrying out the orbit propagation of the SSS-1 / SSS-2A satellites and the calculation of the magnetic field along the orbit, in each moment of time. The IM, is responsible for the connection and exchange of information between the CM and TBM. The TBM will be a hardware of three pairs of Helmholtz coil, one pair for each axis X, Y and Z, this will simulate the magnetic field of the Earth in any direction and orbit, according to calculations generated by the CM. shown figure 1.

![MST Diagram](image)

**Figure 1. Magnetic Simulator Testbed structure.**

For the development of the MST, the mathematical models of Helmholtz Coil and the Earth's magnetic field were studied as well as the propagation of the satellites' orbit to predict the magnetic field that the Earth will have in the orbit of the satellites at each moment of time, in this way will guarantee that the MTB will generate a magnetic field as close as possible to reality to perform the ADCS tests of the SSS APSCO project.

| Table 1. SSS APSCO Project Basic information. |
|-----------------------------------------------|
| Altitude                                      | 500 km          |
| Local time of descending node                 | 10:30AM         |
| SSS-1 Dimension                              | 350*350*650mm   |
| SSS-1 Mass                                    | 30kg            |
| SSS-2A Dimension                             | 100*100*300 mm  |
| SSS-2A Mass                                   | 4 kg.           |
| ADCS Control System (SSS-1 and SSS-2A)        | Magnetic        |
| Inclination                                  | 97.4065°        |
| Eccentricity                                  | 0               |
2. Mathematic Theory

2.1. Satellite orbit propagation

The orbits propagation consists of predicting or estimating the future position of satellites from known ephemeris in a certain period of time. If we know all the orbital elements of a satellite, we will know its orbit precisely and we can make the propagation using the laws of orbital mechanics [5]. The orbital elements that are altered by the chosen propagator are the following [6]:

\[ \Omega = \Omega_0 - 1.5n \frac{R_e^2}{p^2} J_2 \cos(i) \Delta t \]  
\[ \omega = \omega_0 + 0.75n \frac{R_e^2}{p^2} J_2 (5 \cos^2(i) - 1) \Delta t \]  
\[ M = M_0 + (n + 0.75n \frac{R_e^2}{p^2} J_2 (2 - 3 \sin^2(i) \sqrt{1 - e^2}) \Delta t \]  

Where, \( \Omega \) is right ascension of the ascending node (RAAN), \( \omega \) is argument of periapsis, \( M \) is average anomaly.

From the orbital elements we can know thanks to the time laws; the true anomaly of the satellite and with it the position in the plane of the orbit in the perifocal reference system (with the XY plane contained in the orbit and the OX direction pointing perigee) [6]:

\[ r^R = \frac{p}{1 + e \cos(\theta)} \begin{pmatrix} \cos(\theta) \\ \sin(\theta) \\ 0 \end{pmatrix} \]  

To give the location of the satellite, the true anomaly \( \theta \) is used, while the element that has propagated is the average anomaly \( M \). The change between the two is not trivial, and is detailed in figure 2.

Figure 2. Definition of the Eccentric Anomaly.

The relationship between Eccentric Anomaly \( E \) and true anomaly \( \theta \), is given by the equation [5]:

\[ \tan(\theta/2) = \frac{1+e}{1-e} \tan(E/2) \]  

Similarly, by relating \( E \) to \( M \), using geometric relationships and Kepler's second law, we obtain that:

\[ M = E - e \sin(E) \]  

To find the trace, a change of axes is made from the perifocal reference system to the Earth's equatorial inertial reference system [3]:

\[ C^E_P = \begin{pmatrix} \cos(\Omega) \cos(\omega) - \sin(\Omega) \sin(\omega) \cos(i) & \sin(\Omega) \cos(\omega) - \cos(\Omega) \sin(\omega) \cos(i) & \sin(\omega) \sin(i) \\ -\cos(\Omega) \sin(\omega) - \sin(\Omega) \cos(\omega) \cos(i) & -\sin(\Omega) \sin(\omega) + \cos(\Omega) \cos(\omega) \cos(i) & \cos(\omega) \sin(i) \\ \sin(\Omega) \sin(i) & \cos(\Omega) \sin(i) & \cos(i) \end{pmatrix} \]  

When performing a second transformation to the geographic reference system, the transformation matrix is, in this case:
\[
C_E^B = \begin{pmatrix}
\cos(GST_0 + \omega_e t) & \sin(GST_0 + \omega_e t) & 0 \\
-sin(GST_0 + \omega_e t) & \cos(GST_0 + \omega_e t) & 0 \\
0 & 0 & 1 \\
\end{pmatrix}
\] (8)

Once you have the position in these axes, to obtain the trace you only have to change from Cartesian to spherical coordinates, where the two angles give the latitude \(\phi\) and length \(\lambda\) [6].

2.2. Mathematical Model of Earth Magnetic Field

The Earth's magnetic field in general resembles the field around a magnetized sphere, or a dipole. As of 1999, the dipole axis was tilted approximately 11.5 degree from the axis of rotation, and grew at a rate of approximately 0.2 degrees per year [7]. A low intensity of magnetic field at approximately 25 S and 45 W which is known as the Brazilian Anomaly, and a high point of Earth's magnetic field at 10 N and 100 E. Emphasis must also be placed on the growth of global magnetic anomalies (Canadian, Brazilian, Antarctic and East-Siberian) in the Earth’s magnetic reorganization. Its importance since these global anomalies make up a source's magnetic almost independent of main Earth's magnetic field, additionally these anomalies’ magnetic intensity in the world substantially exceeds the entire residual non-dipolar component, what is obtained by subtracting the dipole component from the total magnetic field of the Earth [7-8].

The Earth's magnetic field is a vector magnitude and as such is characterized by its module, its direction and its sense. To module of this vector we call it total force or total intensity \(F\), equivalent to the module of the vector resulting from the vector sum of its three Cartesian components \((X,Y,Z)\) [9]. The geomagnetic field \(B_T\), is a vector magnitude and according to [8] the relations between components and angles are:

\[
H = \sqrt{X^2 + Y^2}
\]

\[
X = H \cos D
\] (10)

\[
Y = H \sin D
\] (11)

\[
tgD = \frac{Y}{X}
\] (12)

\[
B_T = \sqrt{H^2 + Z^2} = \sqrt{X^2 + Y^2 + Z^2}
\] (13)

\[
H = B_T \cos I
\] (14)

\[
Z = B_T \sin I
\] (15)

\[
tg I = \frac{Z}{H}
\] (16)

The Earth’s magnetic field (from the surface of the Earth and up to about 5 times the radius of the Earth) corresponds approximately to the field that generates a magnetic dipole located in the center of the Earth. In the figure 3, shows a simplified diagram of the Earth's magnetic field [8-9].

\[\text{Figure 3. (a) Earth’s magnetic field} \]
\[\text{Simplified diagram. (b) Earth's} \]
\[\text{magnetic field decomposition at a } \lambda \text{ latitude place, in its horizontal} \]
\[\text{components } (B_T)h, \text{ and vertical} \]
\[\text{components, } (B_T)V.\]
The angle that forms the magnetic field vector direction with the horizontal of a place is called the angle of inclination \([9]\). In the same way, the magnetic field can be represented at any point by a three-dimensional vector (usually called B). The F field's intensity (also called Lorentz force) is proportional to the force exerted on the magnet of said compass. We can see this in the figure 4.

This magnetic field is measured in Tesla (T) according with the International System of Units, and in Gauss (G) according with the Cegesimal System of Units. For weak magnetic fields, it is most common use the Gauss. The relationship between these two units is as follows:

\[
1 \text{T} = 1e4 \text{ G}
\]  

\(17\)

![Figure 4](image)

**Figure 4.** Earth’s Magnetic Field Vectors components, H and V are the horizontal and vertical components, respectively.

The Earth's magnetic field is increasing its value as we approach the poles magnetic, while reaching its lowest values at the equator \([10]\), observed in the table 2.

| Place               | \(\mu\text{Tesla} \) | Tesla     | Gaus  |
|---------------------|-----------------------|-----------|-------|
| Poles               | 60\(\mu\text{T} \)   | 6e-5 T    | 0.6G  |
| Ecuador             | 30\(\mu\text{T} \)   | 3e-5 T    | 0.3G  |
| Atlantic anomaly    | 23\(\mu\text{T} \)   | 2.3e-5 T  | 230\(\mu\text{G} \) |

**Table 2.** Magnetic field on the Earth's surface in different units.

2.2.1 The International Geomagnetic Reference Field (IGRF) model. Belonging to the International Association of Geomagnetism and Aeronautics (IAGA) is a mathematical description of the main magnetic field which is widely used in interior studies of the crust, the ionosphere and the terrestrial magnetosphere \([8]\). The IGRF incorporates data from terrestrial, aerial, maritime and satellite exploration observatories \([7]\). The IGRF consists of a series of Gauss coefficients and their secular variations of degree and order from \(n = 1\) to \(n = 13\), since it is accepted that the terms of minor degree represent, to a large extent, the main field coming from the nucleus \([7-8]\).

\[
V(r, \theta, \phi, t) = R \sum_{n=1}^{k} \left( \frac{R}{r} \right)^{n+1} \sum_{m=0}^{n} \left[ g_n^m \cos(m\phi) + h_n^m \sin(m\phi) \right] P_n^m(\theta) \]  

\(18\)

Where, \(R\) is the radius of the Earth which approaches 6371.2 Km, \(r\) is the distance (Km) from the centre of the Earth to the point on which you want to measure the field (altitude), \(\theta\) is the co-latitude (\(\Theta = 90\) - latitude) and \(\phi\) is the longitude, like the figure 5.

![Figure 5](image)

**Figure 5.** Location in spherical coordinates of latitude and longitude.
The Earth’s magnetic field can be obtained from the negative gradient of the scalar function \( V \) as shown in the following equation [7]:

\[
B = - \nabla V
\]  (19)

If the expression given by the previous equation is used, to determine the magnetic field in each of its spherical components, according to [7, 11] we have:

\[
B_r = - \frac{1}{r} \frac{\partial V}{\partial r} = \sum_{n=1}^{\infty} \frac{\left(\frac{R}{r}\right)^{n+2}}{n+2} (n+1) \sum_{m=0}^{n} \left[ g_n^m \cos(m\phi) + h_n^m \sin(m\phi) \right] P_n^m(\theta) \]  (20)

\[
B_\theta = - \frac{1}{r \sin \theta} \frac{\partial V}{\partial \theta} = - \sum_{n=1}^{\infty} \frac{\left(\frac{R}{r}\right)^{n+2}}{n+2} \sum_{m=0}^{n} \left[ g_n^m \cos(m\phi) + h_n^m \sin(m\phi) \right] \frac{\partial P_n^m(\theta)}{\partial \theta} \]  (21)

\[
B_\phi = - \frac{1}{r \sin \theta} \frac{\partial V}{\partial \phi} = - \frac{1}{\sin \theta} \sum_{n=1}^{\infty} \frac{\left(\frac{R}{r}\right)^{n+2}}{n+2} \sum_{m=0}^{n} \left[ m g_n^m \sin(m\phi) + h_n^m \cos(m\phi) \right] P_n^m(\theta) \]  (22)

The three previous equations are tangential components of the Earth’s magnetic field in spherical coordinates for \( B_r \), \( B_\theta \), \( B_\phi \), respectively. To make use of the three equations above, it is necessary to convert them to geocentric inertial components, which can be acquired through the satellite data of a GPS global positioning system, in the following way [8]:

\[
B_x = (B_r \cos \delta + B_\theta \sin \delta) \cos \alpha - B_\phi \sin \alpha
\]  (23)

\[
B_y = (B_r \cos \delta + B_\theta \sin \delta) \sin \alpha - B_\phi \cos \alpha
\]  (24)

\[
B_z = (B_r \cos \delta + B_\theta \sin \delta)
\]  (25)

In the equations (23), (24) and (25), \( B_x \), \( B_y \) and \( B_z \) correspond to the latitude measured in the positive north of the equator and is the local sidereal time of the point of interest.

2.2.2 The World Magnetic Model (WMM). It is the standard model used by the U.S. Department of Defense, the U.K. Ministry of Defence, the North Atlantic Treaty Organization (NATO) and the International Hydrographic Organization (IHO), for navigation, attitude and heading referencing systems using the geomagnetic field [3], it is also used widely in civilian navigation and heading systems. The model, associated software, and documentation are distributed by NCEI on behalf of NGA and is produced at 5-year intervals [8, 3].

2.3. ADCS Testbed Magnetic Field Calculation

To create an ADCS Testbed Magnetic Field that generates a stable magnetic field and simulates the magnetic field of the Earth, a pair of Helmholtz Coil can be used [12]. Helmholtz coils consist of two plates circulars rolled into a conductive material by the which will circulate current in the same direction and that it will generate the almost uniform magnetic field, as can be seen in figure 6 as [11-12]. To determine the magnetic field generated in the Helmholtz pair, we establish the vector that describes the magnetic field \( B^* \) as a function of \( \rho, \phi \) and \( z \); in cylindrical coordinates, that is to say \( B^*(\rho, \phi, z) \).

![Figure 6. Helmholtz Coil configuration for SSS Project’s Magnetic Testbed.](image)

Therefore, for two turns separated from each other put a distance \((d)\), the law of Biot-Savart is written
as follows [12-14].

\[
B_z = \frac{\mu_0 a^2 N}{2} \left[ \frac{1}{\left(a^2 + \left(z + \frac{d}{2}\right)^2\right)^{3/2}} + \frac{1}{\left(a^2 + \left(z - \frac{d}{2}\right)^2\right)^{3/2}} \right]
\]  

(26)

Where \(\mu_0 = 4\pi \times 10^{-7} \text{N/A}^2\) is vacuum's magnetic permeability, \(I\) is Current (Ampere), \(a\) is coil's radius (meters), \(d\) is the separation between coil (meters), \(N\) is coil's number total, \(B_z\) is the magnetic field (Tesla) along the Z axis. For this investigation \(a = b\).

To perform simulation of the magnetic field around the axis of revolution (Z), the equation (27) will be taken, according to those described [13].

\[
B_z(\rho = 0; z) = \frac{8\mu_0 I}{5\sqrt{5} a} \left[ 1 - \frac{144}{125} \left(\frac{z}{a}\right)^4 \right]
\]  

(27)

Finally, to perform the magnetic field simulation around the radial coordinate (\(\rho\)), the equation (28) can be applied, according to what is indicated in [13]. At (27) and (28) are assumed that \(N = 1\).

\[
B_\rho(\rho, z) \rho \ll a = \left(\frac{8\mu_0 I}{5\sqrt{5} a}\right) \left(\frac{288}{125}\right) \left(\frac{\rho}{a}\right) \left(\frac{z}{a}\right)^3
\]  

(28)

3. Simulation and Results

3.1. APSCO Satellite orbit propagation and Earth’s magnetic field calculation

To obtain the propagation of the orbit that will have the satellites SSS-1 / SSS2A of APSCO, simulation was carried out with a Two Line Element (TLE) file that contains the orbital information described in table 1. Later, the magnetic field of satellites around its orbits was calculated using the WMM model. The orbital simulation was carried out with Matlab from 17 May 2019 14:00:00 UTC to 17 May 2019 20:00:00 UTC. The result of the simulation can be seen in the figure 7.

![Figure 7. APSCO Satellite Orbit Propagation and Magnetic Field Results](image)

Additionally, thanks to the simulation performed, it was possible to obtain the rods of the magnetic fields along the orbital line of the satellites of the SSS project.
The figure 8 shows the results of the magnetic fields obtained in nano-tesla on the X, Y and Z axes, the maximum and minimum values obtained can be seen in table 3.

**Table 3. SSS1/SSS2A Magnetic Field on satellite orbit (nano Tesla).**

| Value         | Bx           | By           | Bz           |
|---------------|--------------|--------------|--------------|
| Maximum       | 2.8135E+04   | 1.0448E+04   | 4.6365E+04   |
| Minimum       | -9.2951E+03  | -1.2646E+04  | -5.1846E+04  |

After obtaining the results of the simulation in figure 7, three (03) random measurements were selected to form table 4 with its respective values, which were used to compare these results with those of other investigations. This will allow to verify if the results in the present research are correct.

**Table 4. Satellite Orbit Propagation and Magnetic Field Results Selection.**

| Latitude  | Longitude | Height (Km) | Magnetic Field on Satellite Orbit (nano Tesla) Results |
|-----------|-----------|-------------|------------------------------------------------------|
| -68.178   | 144.91    | 500         | X: -1571.562, Y: 1676.9861, Z: -51558.813, F: 51610.0123 |
| 7.5180    | 45.921    | 500         | X: 27788.4276, Y: 55.6766, Z: 516.9338, F: 27793.291 |
| 40.098    | -59.187   | 500         | X: 18933.7793, Y: 3521.1578, Z: 29246.223, F: 35017.5403 |

From the simulation we can also extract the maximum and minimum values of the magnetic field ($B_T$) on which the satellite will be subjected along its orbit, as shown in table 5.

**Table 5. Maximum and minimum magnetic field (BT) obtained.**

| Value       | $B_T$ (nano Tesla) | $B_T$ (Tesla) | Latitude | Longitude |
|-------------|--------------------|---------------|----------|-----------|
| Maximum     | 51926.54197        | 0.00005193    | -64.57   | 148.220   |
| Minimum     | 20494.51779        | 0.00002049    | -34.09   | -16.263   |

3.2. **ADCS Testbed Magnetic Field Calculation**

A simulation in matlab of a pair of Helmholtz coils was carried out in order to study the magnetic field generated in the center of the coils. Observe figure 9.

**Figure 9.** APSCO ADCS Testbed Magnetic Field Software.
Table 6. Initial data for the simulation of the APSCO ADCS Magnetic Testbed.

| Parameters | Results obtained (Tesla) |
|------------|--------------------------|
| Measurement 1 | Radio (m)= 0.528, N= 230, I (Amp)= 2.5 | 0.001329 |
| Measurement 2 | Radio (m)= 0.105, N= 200, I (Amp)= 0.65 | 0.00155 |

4. Simulation Results Verification.

To ensure that the results obtained in this investigation are correct, they were compared with the results of other previous investigations. In the case of the magnetic calculation in the orbit of the satellite SSS-1/SSS-2A, the results of this investigation observed in table 4 were compared with the results of [16]. For the case of the magnetic field generated by the Helmholtz coils in table 6, they were compared with the results of [11, 15]. The result of the comparison can be seen in table 7.

Table 7. Simulation Results Verification.

| Satellite Orbit Propagation and Magnetic Field Results on satellite Orbit | Basic Information | My Results | External Research Results |
|-------------------------------------------------|------------------|-----------|--------------------------|
| Lat: -68.178, Lon: 144.91, H: 500 Km             |                  | 51,610.0123 nT | 51,651.8 nT a            |
| Lat: 7.5180, Lon: 45.921, H: 500 Km              |                  | 27,793.291 nT | 27,719.2 nT a            |
| Lat: 40.098, Lon: -159.187, H: 500 Km            |                  | 35,017.5403 nT | 35,104.9 nT a            |
| APSCO ADCS Testbed Magnetic Field Simulator     |                  | 0.001329 Tesla | = 10 b Gauss (0.001T)    |
| R= 528 mm, N=230, I=2.5 Amp                      |                  | 0.00155 Tesla | = 11.13 c Gauss (0.001113 T) |
| R= 10.5 cm, N=200, I=0.65 Amp                    |                  |              |                          |

a Data obtained from [16].
b Data obtained from [15].
c Data obtained from [11].

As can be seen in table 7, the results obtained in this research are very close to the results of other investigations, so it can be concluded that the simulations are reliable.

5. APSCO SSS-1/SSS-2A ADCS Magnetic Testbed size determination.

The magnetic field generated from a Helmholtz pair is uniform in a relatively large region of space; this space is considered as spherical whose center is at the midpoint of the segment joining the centers of the coils, and the radius measurement is of the order of half the radius of the coils [13, 17]. Therefore, taking into account the dimensions of the SSS-1/SSS-2A satellites shown in Table 1 and the maximum values of the Earth's magnetic field that will affect the satellites along its orbit, according to table 5, performed simulation in Matlab to determine the real size that the APSCO ADCS Magnetic Testbed must possess in such a way that it is capable of simulating the Earth's magnetic field and allows to perform the attitude control tests to the ADCS subsystem. As for the 3D simulation of the ADCS Testbed, it was carried out, taking as initial values a radius equal to 0.80 meters, separation between each coil equal to the radius, Current intensity of I = 2A, and number of turns 80. The two Helmholtz coils are centered on the Z axis, the first located at Z = (r / a) and the second located at Z = (r / 2), that is, at Z = -0.45 and Z = + 0.45, respectively. The result of the simulation can be seen in figure 10.
three coordinate axes, respectively. The Z axis can be seen in more detail, simulations using the parameters of Table 1, a testbed with radio coils 0.80m was created with a current of 2A and 1 satellite and the stable magnetic field generated between the two Helmholtz coils in greater detail, Figure 1 shows the ADCS Testbed with R=0.80m, I = 2A and
3D Simulation of the APSCO ADCS Magnetic Testbed, Satellite and Stable Magnetic Field Generated.

According to figure 11, is shown each one of the parts of the APSCO ADCS Testbed, APSCO SSS-1 satellite and the stable magnetic field generated between the two Helmholtz coils in greater detail, using the parameters of Table 1, a testbed with radio coils 0.80m was created with a current of 2A and 80 turns, generating a stable magnetic field of 0.000179 Tesla. Also can be observed graphically the result of the simulation in figures 12, 13 and 14. Where the magnetic field generated by the testbed on the Z axis can be seen in more detail, simulation using nineteen contours and the magnetic field on the three coordinate axes, respectively.

Figure 10. 3D Simulation of the APSCO ADCS Magnetic Testbed, Satellite and Stable Magnetic Field Generated.

Figure 11. 3D Simulation of the APSCO ADCS Magnetic Testbed, Satellite and Stable Magnetic Field Generated.

Figure 12. 3D ADCS Testbed with Length of the stable magnetic field, generated on the Z axis.

Figure 13. Graph of the simulation of the Helmholtz Coil using 19 contours.

Figure 14. 3D Magnetic field generated by the ADCS Testbed with R=0.80m, I = 2A and N=80.

Figure 15. 3D APSCO ADCS Magnetic Testbed with X, Y and Z Axis Coils.
On the other hand, in figure 15 the result of the simulation of the APSCO ADCS Magnetic Testbed can be observed with a pair of Helmholtz coil for each axis X, Y and Z, you can also see the six coils, the SSS-1 satellite and the stable magnetic field generated near the center of the coils.

6. Conclusion
As a result of the research and simulation process, the following general conclusions can be reached:

The simulations of Earth’s magnetic field as well as the APSCO SSS-1 / SSS-2A ADCS magnetic testbed, showed that the results of this investigation are very close to those obtained by other investigations, therefore, it can be considered reliable.

The development of the APSCO SSS-1 / SSS-2A ADCS Magnetic Testbed required to perform the Attitude Control tests on the satellites of the APSCO project can be designed with the following specifications: radio 0.8m, N = 80 and I = 2A. This configuration generates a maximum magnetic field of 0.000179 Tesla according to figure 11. This result is much higher than the maximum required in table 5. And the magnetic field intensity within the stable sphere shown in figure 11, can be varied simply by varying the intensity of the current flowing through the Helmholtz coils.

An identical Helmholtz array should be made for each coordinate axis (X, Y, Z), similar to those observed in figure 1 and figure 15.

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