First Development S-Band Antenna System for THAICHOTE Satellite Control Ground Station

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***Abstract*—This paper presents a project based on first development antenna system for ground station in Thailand. The title is called that "Wise Antenna of Transmission Execution & Receiving System" or WATERs. This project is initiated to effort to generate the technology within country. It is expected to approach the optimality and sustainability for Thailand in term of ground station technology. The part of development consists of Radio Frequency and Intermediate Frequency (RF/IF), tracking system and Monitoring and Control (M&C). The system is anticipated to be replaced original system, which has used several years ago, for support THAICHOTE satellite communication and further is for THAICHOTE-2. THAICHOTE is a LEO satellite and sun synchronous orbiting which is moving from north to south while the earth moves from east to west. Therefore, tracking and link system of ground station must be high efficient. It is difficult things which GISTDA team must intensively study original system for new one.**

Keywords—antenna ground station, hexapod pedestal, Stwart platform

I. Introduction

The space technology is increasingly emphasized and activated around the world. Thailand also considers in this issue because space can provide high benefit to people and moreover many people are increasingly interested in space technology. Geo-Informatics and Space Technology Development Agency (GISTDA), who is represented Thailand space agency, is a one organizer that must drive the space industry for support fast growing up. Antenna system, satellite operation center, flight dynamic analysis and mission planning are considered to initiate development for support the future mission and capacity building activities.

In addition, GISTDA has a mission for operating THAICHOTE satellite which is a first Low Earth Orbit (LEO) satellite. Due to type of orbit is a sun synchronous orbit, revolution of the earth is about 100 minutes. It is too fast which ground track is 7 km/s. THAICHOTE has two communicating ways to ground station. These are Tracking, Telemetry and Command (TT&C) and Image telemetry. In part of this paper presents only TT&C infrastructure which provides commanding, verification of satellite's health and status. In addition to that of link, the calculations are used to verify that the signal-to-noise ratio (SNR) of both uplink and downlink must be adequate [1]. The antenna system does not have only link communication. The main part consists of tacking system, monitoring and control (M&C) and radio frequency and intermediate frequency (RF/IF) as shown in Fig.1.

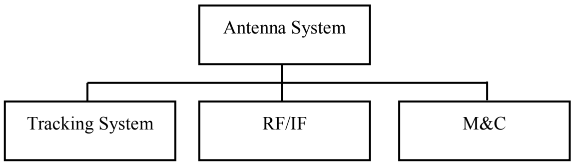

Fig.1 Overview development antenna system

A. RF/IF operation

TT&C operation is performed based on S-Band frequency including 2.035 GHz for uplink and 2.211 GHz for downlink. The both chains perform right hand circular polarization (RHCP) and left hand circular polarization (LHCP) with antenna size is 4.5 m diameter for original system. Downconverter and upconverter are in the system for conversion from either RF to IF or IF to RF. In this case the IF is fixed that 70MHz for support bit rate at 4kbps (uplink) and 400kbps (downlink). Effective Isotropic Radiated Power (EIRP) is minimized by 50dBw while the merit of receiving (G/T) is minimized by 10 dB/k.

B. Tracking system

Tracking system is a hexapod pedestal refers to original system. The antenna is controlled by length of six legs. The top platform can freely move without cable twisting [2]. Hexapod can also be high precision poisoning, higher payload to weight ratio, none cumulative joint error, higher structural rigidity and low inertia hexapod pedestal [3]. Firstly, this technique has been used for flight simulators and continued to manufacturing and medical application [4]. Length legs transfer the antenna to Azimuth (Az) and Elevation (El) angle. These angles will direct main beam to the satellite in each step of time following as program tracking.

C. Monitoring and Control

Generally, the antenna system in the world provides the program for control and monitor. The functionality is that the status of components will check frequently and show on PC via TCP/IP. Moreover, the parameters can be modified via one PC, although the components are far from control room. This is a necessity of M&C. However, this paper does not present the detail about this topic because it is familiar with software engineer.

This paper will explain the overview of system architecture in part II. Tracking system will be explained in the part III and IV for link budget analysis.

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II. THE ANTENNA SYSTEM ARCHITECTURE

Since, GISTDA just operates LEO satellite few years ago, during that the problem has appeared in many times which makes the concerning of sustainability. Capacity building will be the main goal of this development. The principle concept design must be initiated really learning from original system before starting that GISTDA can find the optimal way which is an integrator. In this way, the cost, man power and time are accepted to be done. The one partner is Thai-German Institute (TGI), who is an expertise in mechanical part. TGI team has started to recovery the broken leg in 2014 and this is a chance to study in function of any part. Consequently, TGI can re-design and assemble ball screw, contacting joint, transition system (gear set) and control system. It has installed in GISTDA site at Chonburi, Thailand. On the other hand, in part of algorithm for control length of six legs that is supported by GISTDA. Pointing accuracy will be verified when the control function has completed. By the way, the operation of hexapod depends on six leg lengths which it must be synchronous at all. As a Fig.2, the mechanical parts and hexapod pedestal have combined (a) and the completed tracking system can be shown in drawing assembly (b). In 2016 is anticipated to finish of tracking system. The parabolic antenna for new system was selected 6.1 m. diameters which is a composite material for low weight, ease of fabrication and good corrosion and compromising electrical characteristics [5]. Since, the antenna is bigger, the signal level is higher from gain is increased. This affects branching components that loss and gain must be selected optimally. This project anticipates finishing within 2017 as shown in Fig.3. M&C will be developed during that time after RF/IF has finished.

(a) (b)

Fig.2 (a) hexapod pedestal (b) Drawing assembly

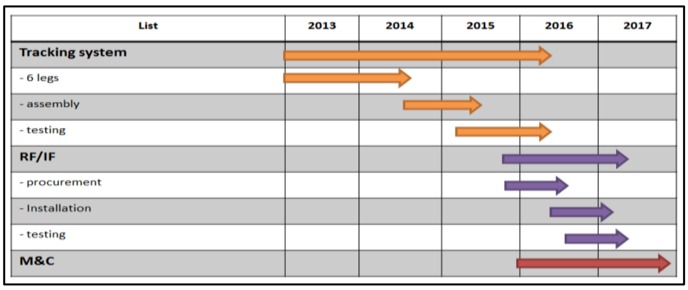
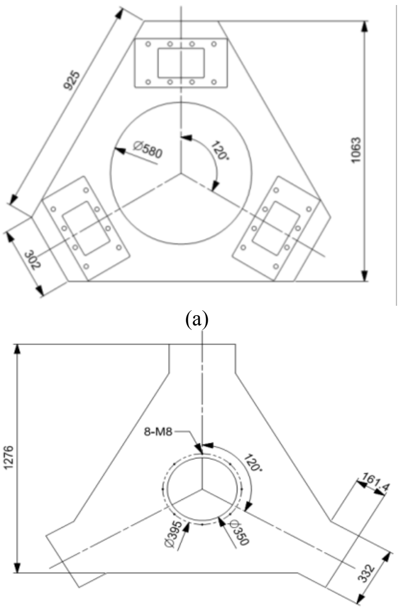


Fig.3 Time Line project

III. TRACKING SYSTEM

The tracking system of this paper presents hexapod application. Nowadays, the most tracking system is 3-axis tracking system which is used only 2 or 3 motors. It is complicate less than hexapod but signal scan or auto tracking is needed for kind of this system. Meanwhile, the auto tracking does not be needed in this project since hexapod pedestal can support as its advantages. First of all, the starting of establishment the algorithm is that the characteristic of antenna must be studied. Base platform must be fixed on the ground while the top platform can be moved freely as 6 degree of freedom (6DOF). Moreover, determination origin at the center of two platforms is 0,0,0 as x,y,z coordinates. Then, the point for mounting between platform and legs that should be found in x,y,z coordinates. Next step, the height (*h*) and radius (*r*) must be found that is a key of characteristic of hexapod as shown in Fig.5 by *h* is the needs of high level of center antenna and *r* is the maximum of distance between center of base platform and center of antenna when EL is equal to zero.



(a)

(b)

Fig.4 (a) Base Platform (b) top platform

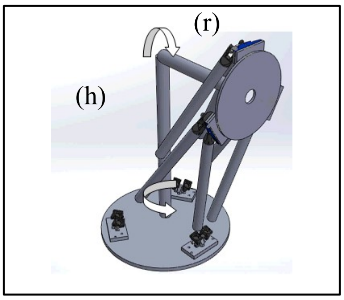


Fig.5 Determination parameter r and h

When the position of mounting between legs and platform is known in term of x,y,z that the definition of rotation matrix for top platform must be found for responsibility of their applications. In this case, the center of parabola is defined constantly in height because of avoidance error from dynamic range of high level antenna. Even though it moves to anywhere, it will be constant at height. Then, the rotation matrix is defined in equation (1) by sources from two angles Az and El. The Az is represented by sweeping angle from north 0^o through east, south and west until 360^o. Meanwhile, El is represented by vertical angle from 0^o to 90^o. The operation Az and El must be computed before operation date that it is propagated by flight dynamic department. When, r has defined maximum 1,095 mm at zero of elevation. The initiation of computation must be used 0,0,r for multiple matrix (1) by equation (2) to find P_{x0},P_{y0},P_{z0}. The P_{x0},P_{y0} will be continued to substitute in equation (3) for finding leg length by P_{z0} has fixed that equals to 2175 mm. This paper has simulated by VBA in Excel Program for verification the algorithm. For Example, as shown in Fig.6 has shown the moving of top platform when it is ordered Az=0^o,El=90^o (Fig.6(a)), Az=0^o,El=10^o (Fig.6(b)) and Az=45^o,El=10^o (Fig.6(c)) for top view. As Fig.7, it has shown the characteristic of six leg lengths when the moving platform is moving around itself at all El = 0^o. As a result from simulation that is the algorithm can be verified it works well by the six leg lengths are synchronous. For Fig.8, it can be also verified that the overhead path which is run from El= 0^o to 90^o at Az=0^o and El=90^o to 0^o at Az=180^o is also synchronous of six leg lengths.

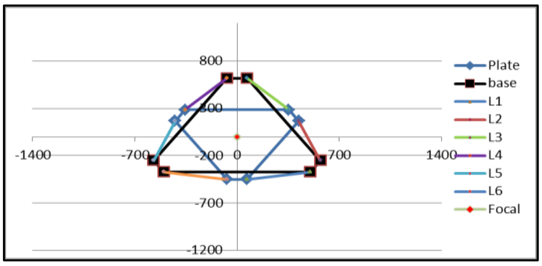
$$\mathrm{Ux} = \cos(-\mathrm{Az})\cos(90 - El)\cos(\mathrm{Az}) - \sin(-\mathrm{Az})\sin(\mathrm{Az})$$
$$\mathrm{Uy} = -\sin(-\mathrm{Az})\cos(90 - El)\cos(\mathrm{Az}) - \cos(-\mathrm{Az})\sin(\mathrm{Az})$$
$$\mathrm{Uz} = -\sin(90 - El)\cos(\mathrm{Az})$$
$$\mathrm{Vx} = \cos(-\mathrm{Az})\cos(90 - El)\sin(\mathrm{Az}) + \sin(-\mathrm{Az})\cos(\mathrm{Az})$$
$$\mathrm{Vy} = -\sin(-\mathrm{Az})\cos(90 - El)\sin(\mathrm{Az}) + \cos(-\mathrm{Az})\cos(\mathrm{Az})$$
$$\mathrm{Vz} = -\sin(90 - El)\sin(\mathrm{Az})$$
$$\mathrm{Wx} = \cos(-\mathrm{Az})\sin(90 - El)$$
$$\mathrm{Wy} = -\sin(-\mathrm{Az})\sin(90 - El)$$
$$\mathrm{Wz} = \cos(90 - El)$$

$$\begin{bmatrix} U_x & V_x & W_x \\ U_y & V_y & W_y \\ U_z & V_z & W_z \end{bmatrix} \qquad (1)$$

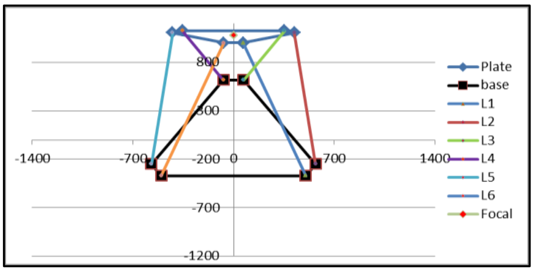
$$\begin{bmatrix} P_{x0} \\ P_{y0} \\ P_{z0} \end{bmatrix} = \begin{bmatrix} U_x & V_x & W_x \\ U_y & V_y & W_y \\ U_z & V_z & W_z \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ 1095 \end{bmatrix} \qquad (2)$$

$$Li^2 = \left(\begin{bmatrix} P_{x0} \\ P_{y0} \\ 2175 \end{bmatrix} + \begin{bmatrix} U_x & V_x & W_x \\ U_y & V_y & W_y \\ U_z & V_z & W_z \end{bmatrix} \begin{bmatrix} bix \\ biy \\ biz \end{bmatrix} - \begin{bmatrix} aix \\ aiy \\ aiz \end{bmatrix} \right)^T \left(\begin{bmatrix} P_{x0} \\ P_{y0} \\ 2175 \end{bmatrix} + \begin{bmatrix} U_x & V_x & W_x \\ U_y & V_y & W_y \\ U_z & V_z & W_z \end{bmatrix} \begin{bmatrix} bix \\ biy \\ biz \end{bmatrix} - \begin{bmatrix} aix \\ aiy \\ aiz \end{bmatrix} \right) \qquad (3)$$

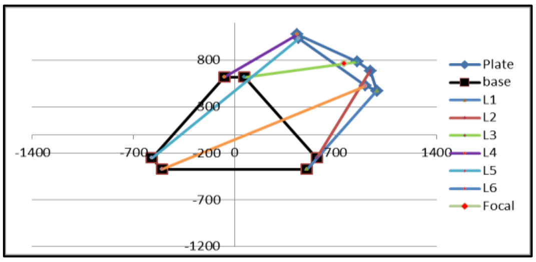
bix = X coordinate of attached point of top platform (i = 1,…,6 leg number)
biy = Y coordinate of attached point of top platform (i = 1,…,6 leg number)
aix = X coordinate of attached point of base platform (i = 1,…,6 leg number)
aiy = Y coordinate of attached point of base platform (i = 1,…,6 leg number)
$biz = aiz = 0$
Li = Leg length



(a)



(b)



(c)

Fig.6 (a) Top view of Hexapod simulation at Az=0^o and El = 90^o (b) Az=0^o and El = 10^o (c) Az=45^o and El = 10^o

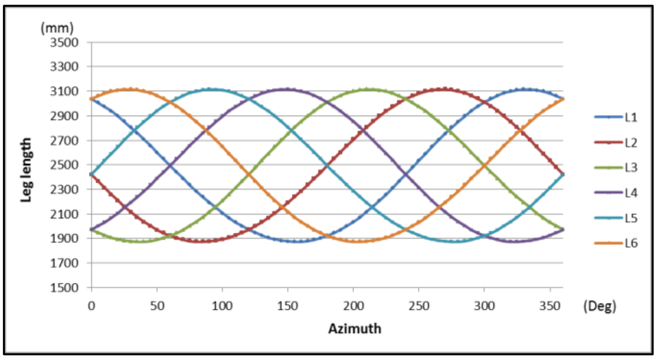


Fig.7 Six leg lengths of circular path (El =0^o and Az 0^o to 360^o)

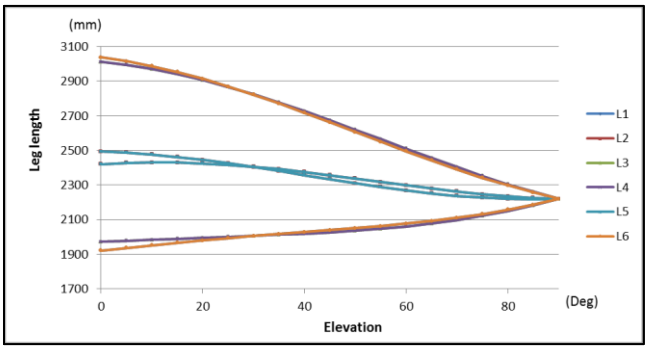


Fig.8 Six leg lengths of overhead path (El = 0^o to 90^o when Az =0^o and El = 90^o to 0^o when Az =180^o)

IV. LINK BUDGET ANALYSIS

The link budget is an important topic of communication which can show the capability of the link that. Moreover, optimality should be parallel with capability. Ground station and satellite can be communicable depend on link designing and generally, ground station mostly installs parabolic antenna because the distance between ground and satellite is too far. Therefore, high gain is needed to support that and it can also be suitable for high bit rate. The selection of components will be significant part of this project because those components must be compatible with encode, decode system and signal level. Hence, the link analysis should be performed to analyze that before procurement process will be started. As an introduction, the mission for new system is for TT&C by S-band. The link design can be descried that it is in requirement based on EIRP and G/T are greater than 50 dBW and 10 dB/k respectively.

In designing uplink chain, the components which are expected to select will not be much different depend on cost investment and signal level. The first, generally, output of baseband is generally released that -20dBm by IF frequency 70MHz. Then, it links to upconverter through cable and there is converted to 2035.96MHz and amplified by upconverter gain about 33dB. The main difference from original system is shorter of RF cable that. The original has wired 300 m. while new system is just only 50 m. It can decrease loss that much. High power amplifier will be selected to be solid state power amplifier (SSPA) types and mostly it can be adjusted the gain from 55dB to 75dB. The computation of gain requirement can be performed in equation (4) and (5) which is included couple loss. In new system, gain SSPA might be adjusted to smaller than the original system because of smaller RF cable loss. This can decrease consumption energy. Moreover, due to parabolic antenna is bigger and then gain can be larger as well which EIRP can reach 59.63 dBW at SSPA gain 62.6dB. Simply, signal level of uplink chain can be figured out in Fig.9. This paper has also compared between new and original system that in Fig.12 which it looks like the signal level is greater for new system.

In part of downlink chain, firstly, EIRP from satellite and free space loss must be estimated from the operation data before performing link analysis. This part will emphasize in the G/T parameter because it is indicator of quality of receiving chain. The equation of G/T can be computed by equation (7) when noise temperature can be computed that in equation (6). Noise temperature of whole system is approximate 146.72 k. Consequently, G/T is estimated that 18.73dB/k. As a result, G/T of new system is better than the original system which is approximate 13 dB/k. For more detail As Fig.10, the explanation of downlink chain is simulated and shown in step of signal level. Moreover, Fig.12 is shown the new system has signal level higher than the original system because RF cable is shorter and antenna size is higher efficiency. Finally, baseband can receive suitable signal level at -25.9 dBm that is related to the limitation of baseband between -20 dBm to -80 dBm.

From signal level analysis, the new system should be stronger in power that however, it can be resisted by attenuator if it is needed. In addition, the signal level can be transferred to analyze the link budget as shown in table I and II. Carrier-to-noise ratio (C/N0) is used to define the status of link margin that it is to optimize between the available and required space by equation (8). The link margin of both has shown that is not so high or low and similar with the original system.

Couple Output =input SSPA + Input losses + Gain + Atten – couple ratio (4)

Output = couple output + couple ratio (5)

$$T_{sys} = T_{ant} + T_{Diplex}\left(L_{Diplex} - 1\right) + T_{LNA}L_{Diplex}$$

$$+T_{cable}\left(\frac{L_{Diplex}}{G_{LNA}}\right)\left(L_{cable} - 1\right) + T_{D/C}\left(\frac{L_{Diplex}L_{cable}}{G_{LNA}}\right) \quad (6)$$

$G/T = G_{antenna}\ (dB) – T_{sys}\ (dBk)$ (7)

Link Margin(dB) = C/No(available) – C/No(required) (8)

T = Noise temperature (k)

G = Gain as a ratio($10^{(dB/10)}$)

L = Loss as a ratio ($10^{(dB/10)}$)

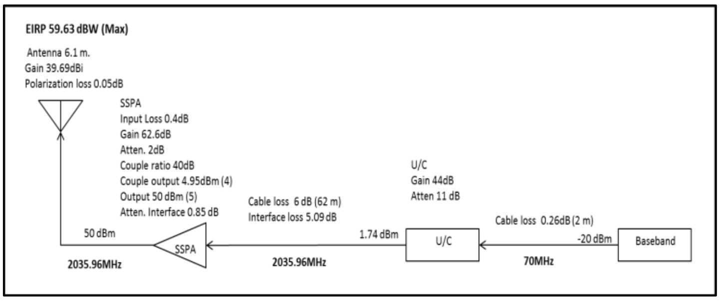


Fig.9 Uplink chain analysis

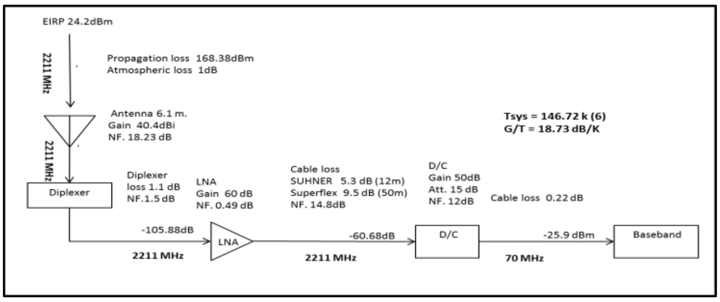


Fig.10 Downlink chain analysis

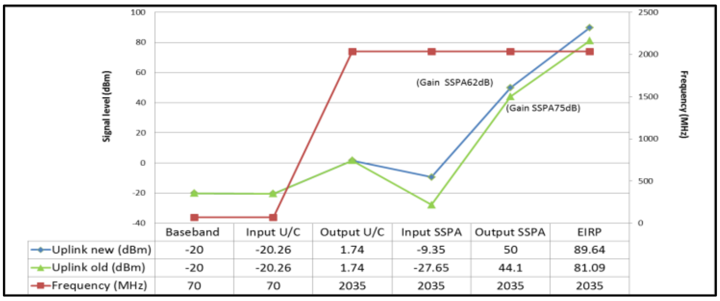


Fig. 11 Signal level and frequency for up link between old and new system

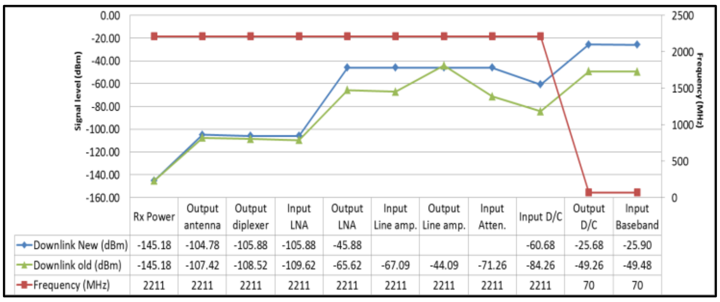


Fig. 12 Signal level and frequency for downlink between old and new system

Table.I Up link margin

TC Link margin			
Frequency	2035.96	MHz	
Bit rate	4	Kbps	
EIRP	53.74	dBW	
G/T	-40	dB/k	
Free space losses	-167.66	dB	
Atmospheric Losses	-1	dB	
On borad losses	-5.4	dB	
Boltzmann's constant	228.6	dB-Hz/k	
C/No (Available)	68.276	dB	
Eb/No for 10-7 BER	11.30	dB	
Bit rate	36.02	dBHz	
Modulation losses	-5.20		
Techno losses wrt theoretical Eb/No	-2.50	dB	
C/No (Required)	55.02	dB	
Link Margin	13.26	dB	

Table.II Downlink margin

TM Link margin			
Frequency	2211	MHz	
Bit rate	400	Kbps	
EIRP	-5.8	dBW	
G/T	18.73	dB/k	
Free space losses	-168.38	dB	
Atmospheric Losses	-1	dB	
Boltzmann's constant	228.6	dB-Hz/k	
C/No(Available)	72.15	dB	
Eb/No for 10-6 BER	6.4	dB	Reed Solomon
Bit rate	56.02	dBHz	
Techno losses wrt theoretical Eb/No	-1.5	dB	
C/No (Required)	63.92	dB	
Link Margin	8.23	dB	

V. Conclusion

Technically, as a result from tracking simulation and link analysis, the new system is highly possible to work well and be compatible with THAICHOTE satellite. It is close to success that GISTDA will have the technology which is generated by themselves. Although this project is just integration system, the advance knowledges can be learned that much from this project such as algorithm hexapod control based on Stewart platform and characteristic of THAICHOTE satellite link. Moreover, the problem during performing can increase the skill to be the good system integrator.

In near future, some methods must be considered for higher level such as forward kinematic, which is a transformation from length of six legs to Az and El for global control loop and function for G/T measurement, which is an automatic function. GISTDA still follows the space technology development.

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