

An uplink power optimization solution for satellite HUBs station based on closed-loop control algorithm

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ABSTRACT

In this paper, we present a power optimization solution based on the automatic power control method using a closed-loop algorithm for the uplink power control device (UPC) of the satellite communication HUB station. The results are evaluated by theoretical analysis and validated by simulation model on Matlab software, finally the model has also been used in the UPC device and tested in practice. The simulation process, and the test is carried out under the impact of varying rainfall on the wave path, the results are compared with the solutions that have been and are being used to demonstrate the effectiveness of the solution. This paper is the research product of the project "Researching, designing and manufacturing the uplink power controller military satellite communication system".

Keywords: HUB station; VSAT; Satellite; Power control; Ku band; Transmission power; Receiver; Uplink; Downlink; Central control; Central processing; Attenuation; Noise; Algorithms; Signal-noise ratio; Heat-noise; Rain.

1. INTRODUCTION

Satellite communication currently has become a popular means of communication in the world, as well as in Vietnam. It can be seen that satellite communications is developing rapidly, with important contributions in many fields of social life, bringing richness in various types of services such as television, data transmission, satellite telephone and so on [1-5]. In satellite communication, power and frequency spectrum resources are valuable resources shared by many large service providers, and shared among terminal stations in the network, with the cost of maintaining power and renting channel is very high. In addition, communication through satellites operating at high frequencies (Ku, Ka) is greatly affected by environmental conditions such as rain path length, precipitation, cloud cover density, fading phenomenon, wave interference, and other types of noise. The above factors cause signal loss, which reduces the efficiency of the system's resource usage, and even disrupts the information connection in the network. One of the important solutions to limit the influence of characteristics of satellite transmission environment is to use automatic uplink power techniques for VSAT terrestrial stations, to ensure optimal distribution of transmi power of the station to maintain the connection, improve the efficiency of spectrum resource exploitation for services in the network.

In the world, many companies provide technical solutions and manufacture power control devices for HUB stations, in which MITEQ is the most popular brand in the Asian market. MITQ provides solutions that are suitable for the environment and geographical conditions in the region, especially the compatibility with systems based on the iDirect network platform. MITEQ's uplink power control (UPC) device has two versions, UPC-A and UPC-2, implementing with a mechanism to sense changes in the transmission line, to issue control commands to the signal attenuator cards (ATT card) using power control algorithms [6]. For UPC-A, which has been used since 2008, it uses an open-loop algorithm. Up to now, a number

of technical problems has appeared, along with technological backwardness, the company has no longer developed this product commercially. In 2014, the company launched a new product line UPC-2 with many improvements compared to the old version, such as diverse connection interfaces, remote monitoring capabilities, and the use of uplink power optimization techniques based on closed-loop algorithm [7]. This algorithm is also used by many companies in the world such as Glowlink, PEAK Communications, Work Microwave, ESA, and so on. However, the companies all have high technology security, their new product lines are very expensive, and has limited compatibility with deployed network infrastructures. From the above problem, the research team has researched the closed-loop power control algorithm, applied it to the actual manufacturing and design of UPC equipment used at HUB stations, ensuring high accuracy, and meet system optimization requirements.

In this paper, we will provide theoretical bases and simulations to demonstrate the adaptability of the closed-loop power control model with the most characteristic influence in satellite transmission environment, that is the loss due to rain and heat noise; simultaneously, the actual product was tested at the satellite HUB station A61, compared with the UPC-A device of MITEQ to confirm the effectiveness of the solution, and the compatibility with the system.

2. POWER CONTROL MODEL CONSTRUCTION

2.1. Control principles

The control of uplink is carried out with caution, especially with large service providers because increasing the transmission power of the ground stations too large will overload the receiver system on the satellite, especially causing interference to other providers and satellites in around [10]. The aim of the HUB station power control determine optimal transmission level (P_{opt}) so that the carrier-noise ratio (C/N_{opt}) on the satellite reaches 90% of the saturation level (C/N_{BH}). In which, C/N_{BH} is calculated by (1),

$$C/N_{BH} = \Phi_{sat} - G_{RX} + (G/T)_{SL} - 10 \lg K \quad (1)$$

Where Φ_{sat} is the saturation power density on the satellite (-90 dBW/m²); $(G/T)_{SL}$ is the satellite receiver antenna quality (2÷6 dB/K); K is Boltzman constant; G_{RX} is the gain of receiver antenna (45 dB).

We get $C/N_{BH} = 95$ dB. The HUB transmission antenna gain following design is $G_{TX} = 60$ dB. The effective isotropic radiated power of the HUB is calculated by (2),

$$EIRP \text{ (dBW)} = P_{TX} + G_{TX} \quad (2)$$

U/L uplink loss in free space ($L_u = 206,8$ dB) at 14.5 GHz. The effective power current density on the satellite in rainy conditions is calculated by (3),

$$\Phi_{hd} = EIRP - L_u - L_{rain} + G_{RX} = P_{TX} + G_{TX} - L_{rain} - 161,8 \quad (3)$$

The uplink C/N_{HD} ratio (U/L) at the satellite receiver input is calculated by (4),

$$C/N_{HD} = \Phi_{hd} - G_{RX} + (G/T)_{SL} - 10 \lg K = 83,8 - L_{rain} + P_{TX} \quad (4)$$

The control models aim to determine the near-optimal transmission power level (P_{OPT}) under random effects of factors on the transmission line, while maintaining the signal-noise ratio at the satellite receiver reached the optimum value ($C/N_{HD} = C/N_{OPT} = 90\% C/N_{BH}$).

2.2. Power control based on open-loop

The open-loop algorithm is a non-closed-loop tuning method – that is, the transmission power correction is not based on the carrier signal strength returned from the satellite to the HUB itself, but on the level of signal which receives a pre-set beacon signal by the VTI satellite control center. Beacon signal strength measurements are averaged and reported once per sampling

interval. Sampling interval allows to smooth the measured D/L signal strength by averaging a series of measurements before assigning the results to the calculation of the correction level per uplink channel (U/L). [12]. The signal loss level set for the first state $A_0 = ACS_n$ is the limit level of the setting on the control unit (Control Unit - CU).

The open-loop control algorithm diagram is implemented in fig. 1.

The control model determines the input voltage level after passing the RF/DC converter block. The voltage level represents the beacon signal reception level at the receiver of the HUB, reflecting the variation of the attenuation on the satellite transmission line. The loss change factor of the instantaneous transmission line in good weather conditions for the beacon signal is calculated according to (5),

$$A_n = ACS_n \left(1 - \frac{DC_{in}}{10}\right) \quad (5)$$

The attenuation factor set up for channel n is calculated according to (6), where ΔFSL is the free-space attenuation difference factor between the U/L carrier and the Beacon signal.

$$ATT_n = A_n + \Delta FSL \quad (6)$$

Compare the calculated loss factor of the n^{th} card (ATT_n) with the value set in the previous control loop (A_0), if there is a difference, control unit will command to increase or decrease the value by C_n . The ATT card has received the new loss level, it saves the result in memory and finishes the process.

2.3. Power control based on closed-loop

The closed-loop algorithm is based on the principle of measuring the signal-noise ratio and interfere by using the U/L carrier signal after returning from the satellite to the receiver. Although the carriers are transmitted on the same transmission line, the losses on U/L and D/L themselves are not the same, so the measured downlink signal-noise (C/N_D) ratio is also different [11].

After each adjustment, a idle period is established. In order to gain high efficiency to the algorithm, the idle period must be greater than or equal to the total period of time that the carrier is transmitted and returned. The closed-loop control algorithm needs to wait for the carrier parameters to be checked on the return path. In satellite communication, as the transmission distance is very long, the latency of carrier transmitting to the geostationary satellite plus its return is approximately 225 ms. Therefore, the idle period is set between 225 ms and 250 ms, which is sufficient for the receiver to check the C/ND ratio and compare it to the optimal level

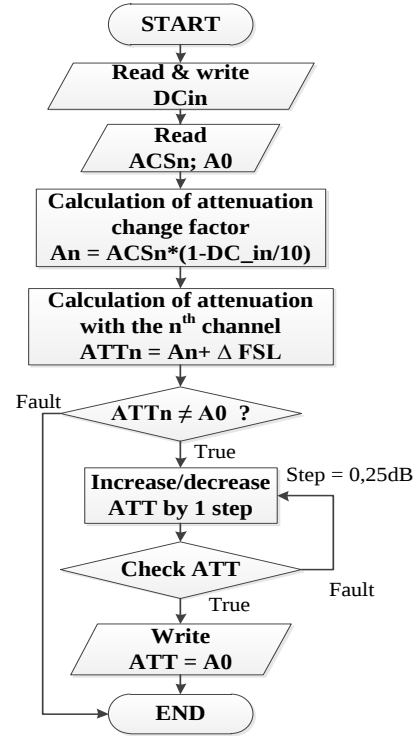


Figure 1. The open-loop power control algorithm diagram.

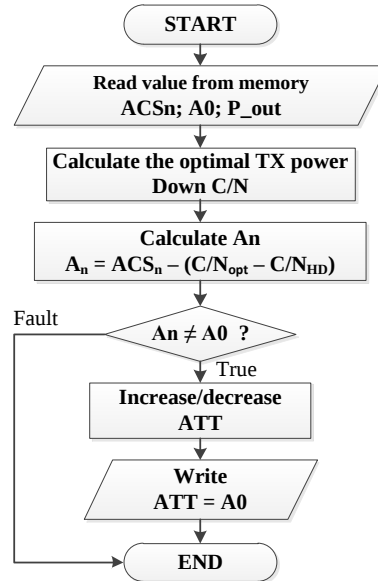


Figure 2. The closed-loop power control algorithm diagram.

(C/N_{opt}). Based on that, the control unit monitors satellite transmission attenuation, leading to the high accuracy of the closed-loop power control model.

The closed-loop power control algorithm is implemented in fig. 2.

From system design parameters such as: G_{RX} is the receiver antenna gain at 14,5 GHz ($G_{RX} = 60$ dB); L_{cable} is the attenuation factor of the cable ($L_{cable} \approx 3,5$ dB); EIRPs is the effective isotropic emission factor from the satellite, EIRPs = 41,46 dBW. The received signal receiving power on the feedback line is calculated by (7),

$$P_{RX} \text{ (dBW)} = EIRPs - L_t + G_{RX} - L_{cable} - L_{rain} = -108,54 - L_{rain} \quad (7)$$

The amount of heat noise ($T_{total} \approx 422^\circ K$). The noise power is calculated according to (8),

$$P_N = 10 \lg k + 10 \lg T_{total} + 10 \lg d = -126,78 \text{ dBW} \quad (8)$$

Thus, the downlink signal-noise ratio when it rains is calculated by (9),

$$C/N_D = P_{RX} - P_N = 18,24 - L_{rain} \quad (9)$$

Optimum D/L signal-noise ratio $(C/N_{OPT})_D = 21$ dB, the attenuation variation coefficient is calculated according to (10),

$$An = ACSn - ((C/N_{OPT})_D - C/N_D) = ACSn - 1,76 - L_{rain} \quad (10)$$

From the loss An will be set on the ATTn control card corresponding to the n^{th} transmission channel, to control the uplink transmission power level of the HUB station close to the most optimum value to ensure high accuracy in power use of the BUC.

3. SIMULATION OF POWER CONTROL MODELS

3.1. Power control model using open-loop algorithm

To evaluate the ability to optimize the transmission power of the HUB, we use the method of simulating parameters on Matlab with function blocks shown in figure (3), the influencing factor on the wave transmission is rainfall (R). To simplify the simulation problem, we give the rain path length (Drain 6 km) and the results of the parameter representation of the deviation of the emission level from the optimal power [8, 9]. Combining formulas (1) and (5), we have the optimal transmission power level is calculated according to (11),

$$P_{opt} = 90\% * C/N_{BH} - 83,8 + L_{rain} = 1,7 + L_{rain} \text{ (dBW)} = 31,7 + L_{rain} \text{ (dBm)} \quad (11)$$

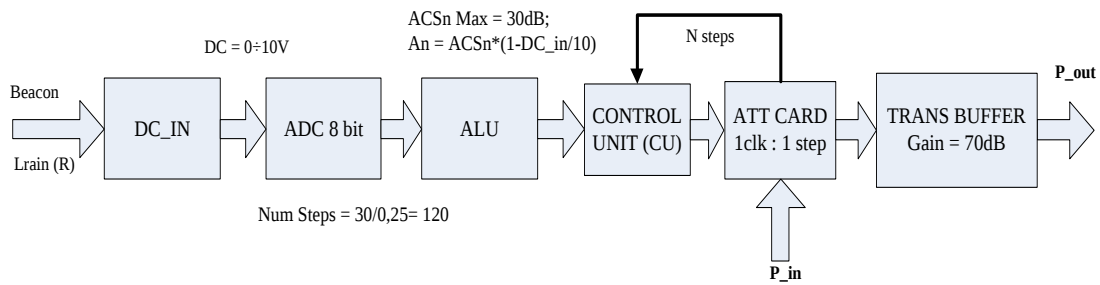


Figure 3. Simulation diagram of the open-loop power control model.

Attenuation offset in free space at U/L frequency (14.5 GHz) vs beacon (11.699 GHz),

$$\Delta FSL = FSL(f) - FSL(Beacon) = 20 \lg(14,5) - 20 \lg(11,699) = 1,86 \text{ dB} \quad (12)$$

Rain loss coefficient: $L_{rain} = \gamma_R \cdot D_{rain} = 0,0996 R^{1,232}$ (dB). From (6), we have the attenuation correction factor on UPC: $An = ACSn - L_{rain} = ACSn - 0,0996 R^{1,232}$. The uplink power of HUB is calculated according to (13),

$$P_{out} = P_{in} + 70 - An \text{ (dBm)} \quad (13)$$

Set the adjustment limit level on the control unit (ACS_n) to 30 dB, input power (P_{in}) to -12 dBm. The offset of the established uplink power vs the optimal power is calculated by (14),

$$\Delta P (\%) = 100\% * (P_{opt} - P_{out})/P_{TU} = 3,7/(31,7 + 0,0996 R^{1,232}) \quad (14)$$

Simulation results of parameters according to rainfall on Matlab software:

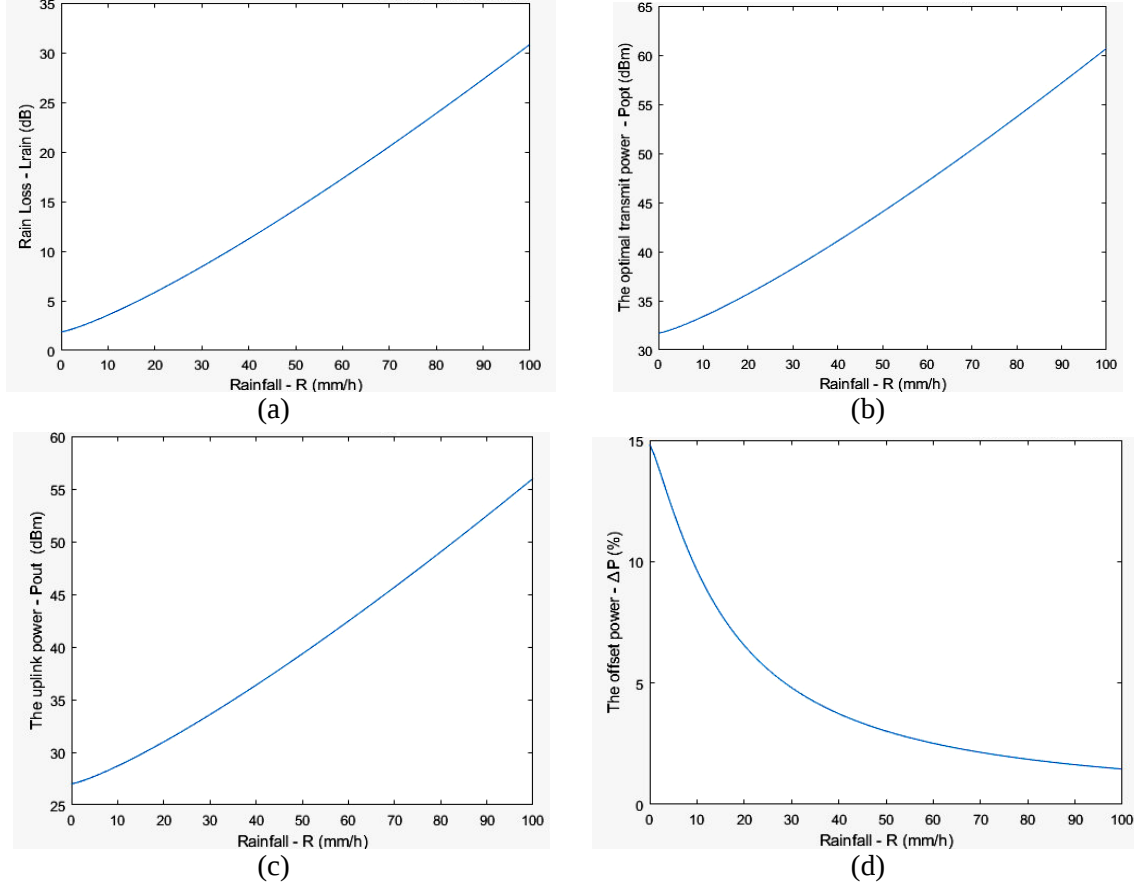


Figure 4. Simulation results on Matlab. (a) Rain loss; (b) Optimal transmission power level; (c) Transmission power setting for the uplink of HUB; (d) Transmission power bias coefficient.

The simulating result of the arguments is depicted in figure 4. In open-loop power control model, there is a significant bias that always occurs between established transmission power in the up-link (P_{out}) and the optimal transmission (P_{opt}) in different scenarios of rainfall. The bias is always high. For instance, in Vietnam, the average rainfall is 50mm/h, so ΔP is above 3%. As the result, the accuracy of open-loop power control model is almost 97%.

3.2. Power control model using closed-loop algorithm

The closed-loop model has a signal feedback path from the transmitting direction back to the receiver expressed by the carrier receiving power (P_{RX}). Therefore, the control unit evaluates loss levels on transmission line, the noise temperature level generated on satellite link, thereby making adjustments to the transmission power for the uplink [11, 12]. At the receiver, a carrier-to-noise ratio meter determines C/N_D. This is the reference parameter for ALU to calculate A_n, based on which the CU makes inferences about the characteristics on the transmission line; Simultaneously issue a command to increase or decrease attenuation levels corresponding for each ATTN transmission channel. Simulating parameters with rainfall from 0÷100 mm/h, ACS_n = 30 dB. Then, the attenuation adjustment level: A_n = 28,24 - 0,0996 R^{1,232}.

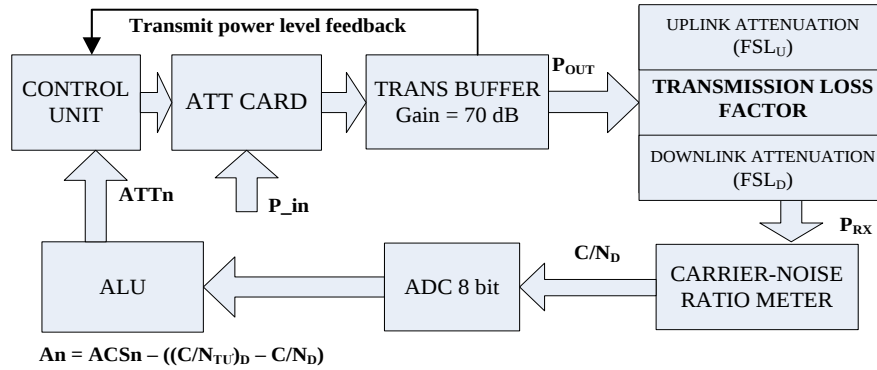


Figure 5. Simulation diagram of the power control model using closed-loop.

After the CU sets the adjustment level on the ATTn card, the tx power for the HUB is calculated by formula (14), we have: $P_{out} = 30,76 + 0,0996 R^{1,232}$ (dBm).

The difference between the uplink power and the optimal power is calculated by formula (15),

$$\Delta P (\%) = 100\% * (P_{opt} - P_{out})/P_{opt} = 0,94/(31,7 + 0,0996 R^{1,232}) \quad (15)$$

Simulation results of parameters according to rainfall on Matlab software:

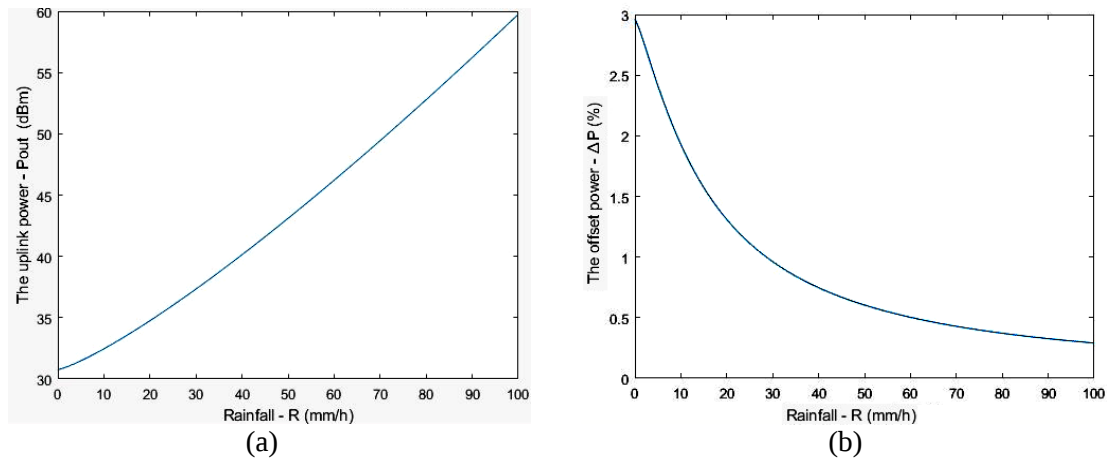


Figure 6. Simulation results on Matlab.

(a) Transmission power setting for the uplink of HUB;

(b) The offset transmission power coefficient.

The simulating result of the arguments is depicted in figure 6. In closed-loop power control model, the established transmission power in the up-link (P_{out}) always follows the optimal transmission power (P_{opt}). The bias power between P_{out} and P_{opt} remains low. For instance, if the average rainfall is 50 mm/h, ΔP goes around 0.6%. This index even goes as low as below 0.5% if the rainfall is 100 mm/h. This means that the accuracy of the closed-loop power control model is significantly high (99.5%).

3.3. Comparison of simulation results

The simulation results have shown that, with a rainfall of 50 mm/h, the closed-loop model has an offset power level about 0.6%, and that of the open-loop model is 3%. In other words, the closed-loop control model has an accuracy of 99.4%, which is significantly higher than the open-loop (97%), so the power optimization solution is using the closed-loop model for the uplink power control system of the satellite HUB station.

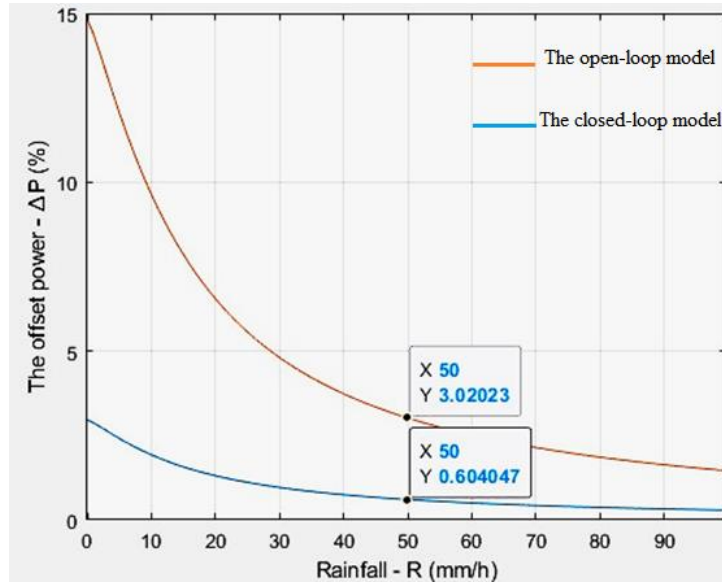


Figure 7. Simulation results of the power bias coefficient of the two models.

4. PRACTICE TEST RESULTS OF CLOSED LOOP POWER CONTROL MODEL

4.1. Product features test

The connection is shown in figure 5. Set up the signal generator with center frequencies are 950 MHz, 1200 MHz and 1700 MHz; transmission power is 0 dBm.



Figure 8. Actual test connection of the UPC.

The control mode setting for channel 3 is auto mode, the attenuation adjustment limit (ACSn) is 15 dB, as shown in figure 8.



Figure 9. Setup for channel 3 of UPC to operate in auto mode with 5 dB loss.

In this case, the output power spectrum of channel 3 has a peak on -8.33 dBm, as shown in figure 9. The attenuation level is set: $L05 = P - P0 = -5.00$ dB.

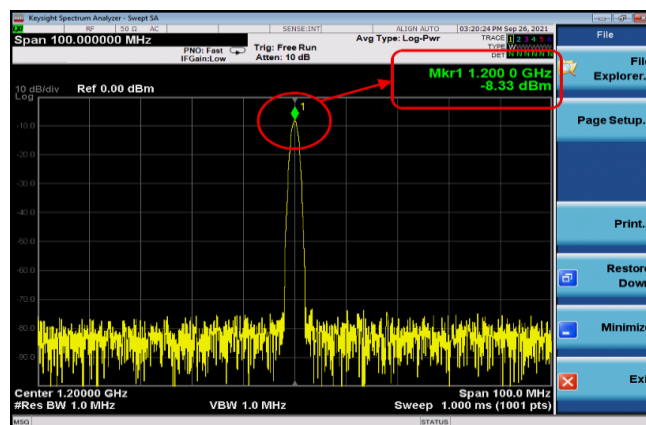


Figure 10. Signal spectrum when the attenuation on the transmission card is 5 dB.

4.2. Test results

The closed-loop power control model was used for the fabrication of UPC devices. The product had been tested in practice at the satellite HUB station (A61) in Xuan Mai - Hoa Binh. The results show that the transmission uplink power of the HUB was automatically adjusted according to transmission attenuation, responds quickly, and adjusts power compensation with high accuracy, especially in the case of heavy rain. The C/N at terminal stations were maintained at an optimal level, and the communication speed was also also suitable for data transmission in the network. Compared with the UPC-A of MITEQ, the research team's product is better about power optimization, and adaptability in rainy conditions.

Table 1. Parameter statistics of terminal stations on iDirect NMS iMonitor operating system.

Solutions	C/N _D ratio (dB)	TDMA lost (Frame/s)	SCPC error (bps)	Ping delay (ms)	Packet loss rate (%)
The UPC of our team	12,0	0	0	240	0,3
The UPC-A of MITEQ	10,5	3	15	268	1,8

The results of testing the power control solution are shown in table 1. Compared with the solution of MITEQ, the UPC of our team gives better system parameters. Therefore, we confirm that the closed-loop power control solution is the optimal power solution for the HUB station, which helps to improve the system quality, and minimize the loss and error of information transmission.

5. CONCLUSION

This paper presented the research results on the uplink power spectrum optimization solution to improve the efficiency of resource usage in the network, while maintaining the stability of the system for using in the HUB station of the satellite communications system. The UPC equipment was tested at the lab of the High-Tech Telecommunication Center. The test process was deployed at the A61 HUB of the 134 Signal Brigade – Signal Corp. The results have shown the feasibility of the closed-loop control model the system's stability, and the efficient use of power and frequency spectrum in the military satellite communication network. The UPC equipment has technical specifications and tactical features meeting the requirements of the system. We can affirm that the product is highly competitive compared to imported equipment, which can completely be put into use for the HUB stations of the satellite communication system in our country.

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TÓM TẮT

GIẢI PHÁP TỐI ƯU HÓA CÔNG SUẤT ĐƯỜNG LÊN CHO TRẠM HUB VỆ TINH DỰA TRÊN THUẬT TOÁN ĐIỀU KHIỂN VÒNG KÍN

Trong bài báo này, chúng tôi trình bày giải pháp tối ưu hóa công suất theo đặc trưng môi trường truyền sóng qua vệ tinh dựa trên phương pháp tự động điều khiển công suất sử dụng thuật toán vòng lặp kín cho thiết bị điều khiển công suất đường lên (UPC) của trạm HUB thông tin vệ tinh. Ngoài việc nghiên cứu cơ sở lý thuyết và đánh giá kết quả bằng mô phỏng mô hình điều khiển công suất trên phần mềm Matlab, mô hình cũng đã được sử dụng vào trong thiết bị UPC và được thử nghiệm thực tế. Quá trình mô phỏng và thử nghiệm được thực hiện trong điều kiện tác động của lượng mưa thay đổi trên đường truyền sóng, kết quả so sánh với các giải pháp đã và đang được sử dụng để minh chứng hiệu quả của giải pháp. Bài báo này là sản phẩm của đề tài “Nghiên cứu, thiết kế, chế tạo thiết bị tự động điều khiển công suất trạm điều khiển trung tâm (HUB) băng Ku của hệ thống thông tin vệ tinh quân sự”.

Từ khóa: Trạm HUB; VSAT; Vệ tinh; Điều khiển công suất, Băng tần Ku; Tuyến phát; Tuyến thu; Đường lên; Đường xuống; Điều khiển trung tâm; Xử lý trung tâm; Suy hao; Tạp âm; Thuật toán; Tỉ số tín trên tạp; Nhiệt tạp âm; Mưa.