Applying both Traditional and Fuzzy Methods for Mobile Satellite Antenna Control System Design with Tracking Loop Gain Parameter Variations

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Abstract - This research applied both traditional and fuzzy methods for mobile satellite antenna control system design. The detailed block diagram of a satellite antenna tracking system is very lousy; it is very difficult to obtain the key parameters for analyses and simulation. Thus a simplified model of antenna pitching or yawing control system is applied to speed up the design and obtain the key parameters. Firstly, the antenna tracking and the stabilization loops were designed according to the traditional bandwidth and phase margin requirements. However, the performances would be degraded if the tacking loop gain is reduced due to parameter variations. On the other hand a PD type fuzzy controller was also applied for tracking loop design. It can be seen that the system performances obtained by the fuzzy controller were better for both low and high antenna tracking loop gains, and the tracking loop gain parameter variations effect can be reduced.

Index Terms - Antenna tracking loop, stabilization loop, PD type fuzzy controller, PI compensator.

1 Introduction

In order to cope with the satellite Ka-band and broadband mobile communication requirements, the capacity is five times of Ku-band before. The mobile antenna needs to lock on the satellite in spite of disturbances, thus the performances of antenna tracking as well as stabilization loops of Ku-band should be raised [1-3], and e.g. the tracking rate, pointing precision as well as stabilization should be upgraded. The traditional PI (Proportion and Integration) compensator was applied for the tracking and stabilization loops design of mobile antennas to lock on the satellites [4]. The fuzzy controller was applied for the tracking loop design [5], and the relationship functions of Gaussian distribution were applied for six degrees of freedom simulation, thus the computation loading was very large. In addition, the noise and wind disturbance was taken into antenna design consideration.

This paper applied both traditional and fuzzy methods [6-7] for mobile antenna control system design. Firstly, the antenna tracking and the stabilization loops were designed with the traditional bandwidth and phase margin requirements. Then applying a simplified model for the antenna control system design, both time and frequency domain analyses are studied to obtain the key parameters of antenna tracking and stabilization loops. The stabilization loop was designed by using proportion and PI compensators for comparison. Noted the performances with PI compensation method were better. However, if taking tracking loop gain degradation effect into consideration, then the performances becomes worse for the cases of lower tracking loop gains.

Thus this research proposed an intelligent control law by using both traditional and fuzzy controllers. The results show that the performances are better, and the tracking gain parameter variation effect can be reduced. By the way to reduce computer loading for practical implementation, the simplified triangular distribution relationship functions of the fuzzy controller was applied.

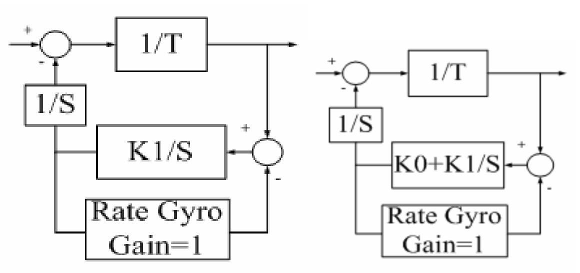
The organization of this paper is as follows: the first section is introduction. The second one is for traditional design of antenna tracking and stabilization loops. The antenna performance analyses with a traditional design are given in Section 3. The fuzzy controller design and performance analyses are given in Section 4. The last part is the conclusions.

2 Traditional Antenna Tracking and Stabilization Loops Design

The detailed block diagram of a satellite antenna tracking system is very lousy [8]. It is very difficult to obtain the key parameters for analyses and simulation. Thus in general a simplified model of antenna pitching or yawing control system is applied to speed up the design and obtaining the key parameters, in which the tracking loop is modeled as a simple gain, and the stabilization loop is replaced by a pure integration, or PI compensators as in Figs. 1 (a) and (b). Then this research made the time and frequency domain analyses firstly, to obtain the key parameters of antenna tracking and stabilization loops. The tracking loop time constant (T) is set as 0.1 seconds of the practical value.

2.1 Stabilization Loop with Pure Integration Compensator

Firstly, the stabilization loop is designed with pure integration compensator. Let the integrator gain (K1) of stabilization loop be 25, 50, 75 and 100, respectively, then the Bode plots are in Fig.2. The gain margins are ∞. Although the phase margin would be increased with larger K1, the increasing rate approaches saturation for K1=100.



(a) (b)

(a) Pure integration compensator
(b) PI compensator.

Fig. 1 Simplified block diagrams of antenna Stabilization loop with (a) pure integration compensator, and (b) PI compensator.

2.2 Stabilization Loop with PI Compensator

Secondly, the PI compensator is applied for the stabilization loop design. The gains of the proportion and integration terms are denoted as K0 and K1, respectively. Fig. 3 shows the Bode plots for several K0's with T=0.1 and K1=100. The phase margin is larger for K0=5. Fig.4 shows that the phase margin is insensitive with K1 (T=0.1 and K0=5), but the steady-state error can be eliminated with the larger K1's. By some trial-and-error one can see that the phase margins are larger (132° and 133°) for the cases with K0=5, K1=50, T=0.1 and K0=5, K1=25, T=0.2, respectively. The former is chosen for faster response.

3. Antenna Performance Analyses with pi Compensator

In this section the antenna performance is analyzed by simulation as in Fig.5. The input line-of-sight angle is a triangle one with amplitude and period respectively as 1 radian and 5 seconds. It can be seen that the gimbal angle can track with the input line-of-sight angle as in Fig.6, thus the performance is very good.

However, in general there is tracking loop gain parameter variation effect. The simulation results with this effect are shown in Figs. 7 and 8 for the parameter T changing from 0.1 to 1 and 1.5, respectively. It can be seen that the tracking performances of gimbal angles are reduced. Thus the traditional method would not be applied for the systems with lower tracking loop gains.

4. Fuzzy Controller Design and Analyses

4.1 Fuzzy Controller Relationship Functions Design

In this section a Proportion and Derivative (PD) type fuzzy controller [6-7] is applied in the tracking loop

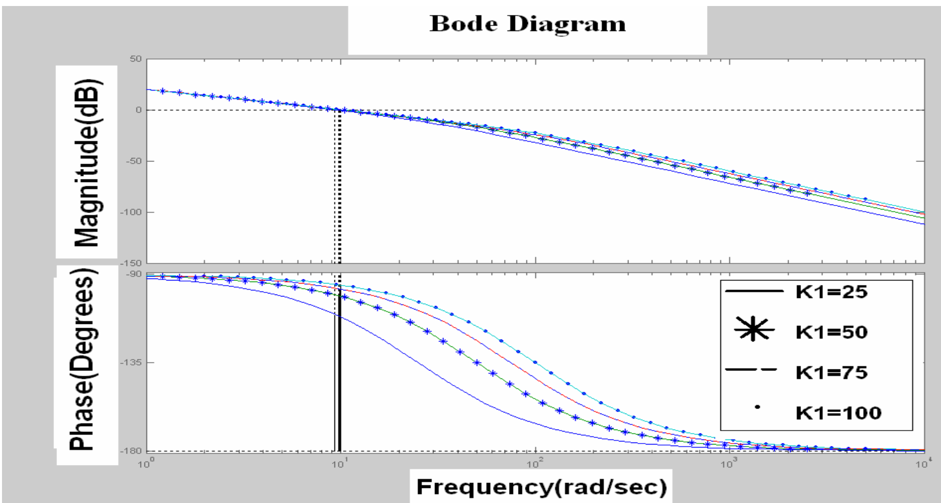


Fig.2 Bode plots for K1 are as 25, 50, 75 and 100, respectively.

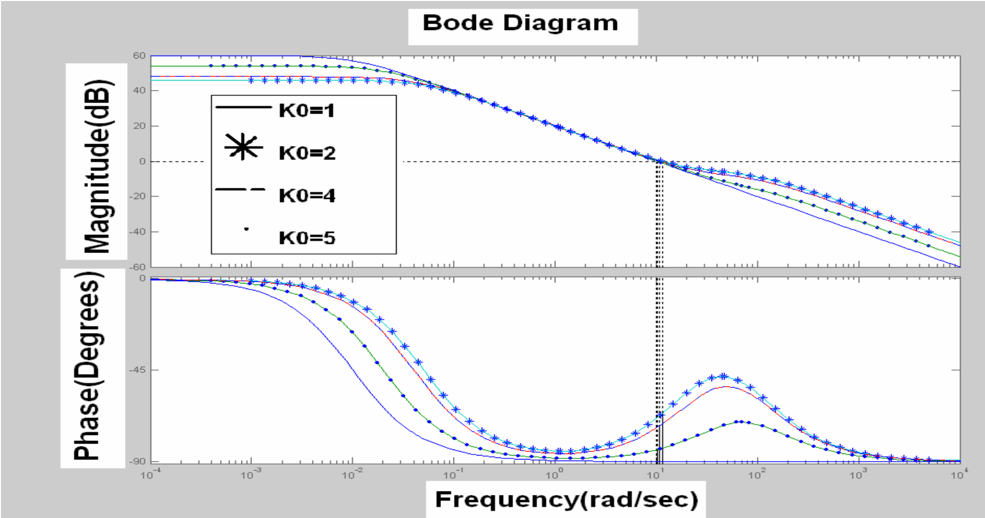


Fig.3. The Bode plots for several K0's with T=0.1 and K1=100.

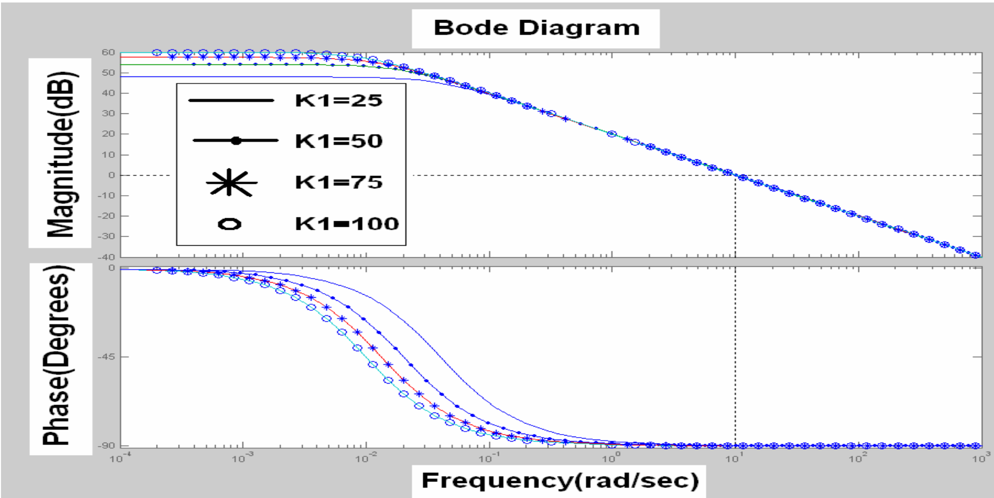


Fig.4 Bode plots for several K1's with K0=5.

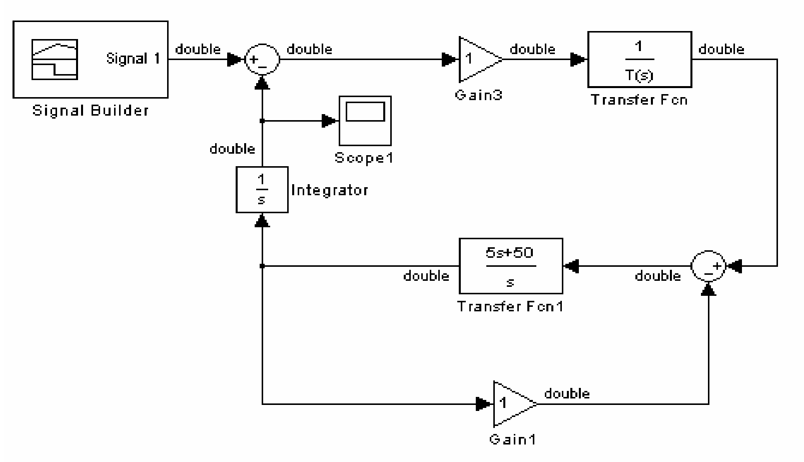


Fig.5 Block diagram of traditional system design.

and with the PI compensator in the stabilization loop as in Fig.9. It is well-known that fuzzy controller is based on the IF-THEN RULE as follows:

R1: IF E is NB AND ΔE is NB THEN U is NB,
R2: IF E is NB AND ΔE is ZE THEN U is NM,
R3: IF E is NB AND ΔE is PB THEN U is ZE,
R4: IF E is ZE AND ΔE is NB THEN U is NM,
R5: IF E is ZE AND ΔE is ZE THEN U is ZE,
R6: IF E is ZE AND ΔE is PB THEN U is PM,
R7: IF E is PB AND ΔE is NB THEN U is ZE,
R8: IF E is PB AND ΔE is ZE THEN U is PM,
R9: IF E is PB AND ΔE is PB THEN U is PB,

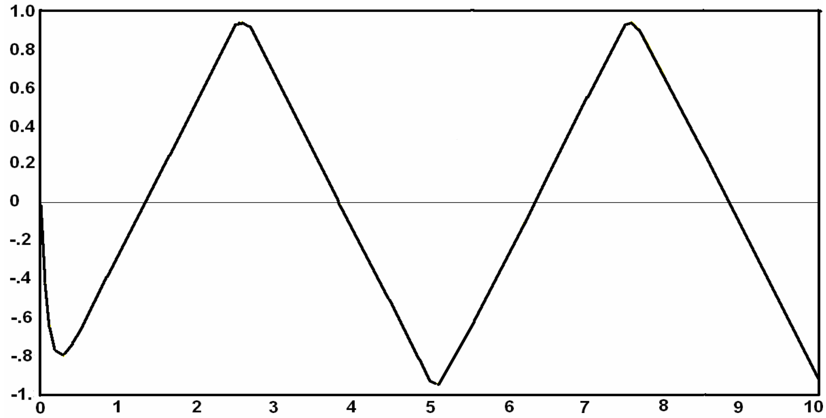


Fig. 6 Gimbal angle output with T=0.1.

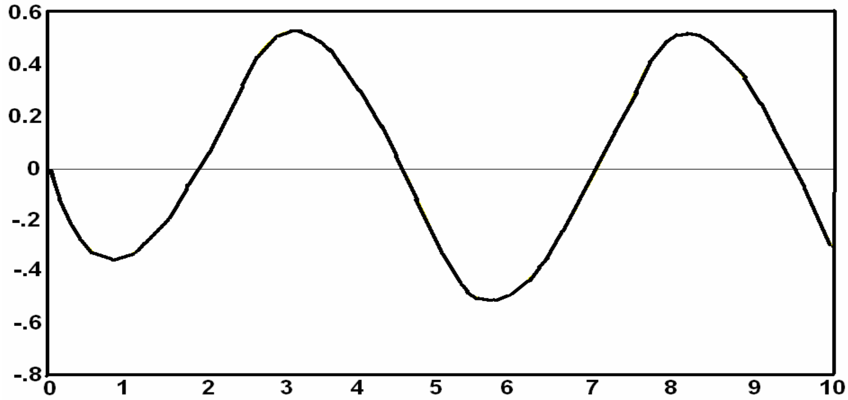


Fig.7 Gimbal angle output obtained by traditional method with T=1.

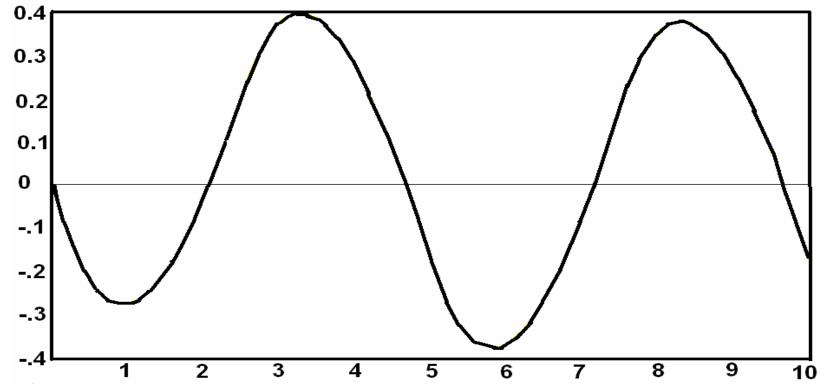


Fig.8 Gimbal angle output obtained by traditional method with T=1.5.

where NB, NM, NS, ZE, PS, PM, and PB respectively stand for negative big, negative middle, negative small, zero, positive small, positive middle, and positive big.

The detailed cross reference rules for the inputs and output of fuzzy controller are defined in Table 1. According to fuzzy control design method the relationship function parameters of boresight error E, ΔE (deviations of present E and the previous E), and U (control input) are defined at first, which are listed in Table 2. To reduce the computation time the triangular distribution functions are applied in fuzzy controller relationship functions calculation instead of using the traditional Gaussian ones.

4.2 Performance Analyses with Fuzzy Controller

Then the antenna performance is analyzed by simulation. Figs. 10, 11 and 12 show the antenna tracking responses for T to be as 0.1, 1 and 1.5, respectively. It can be seen that the results are better than those obtained by using only the traditional PI compensators for all the three values of T.

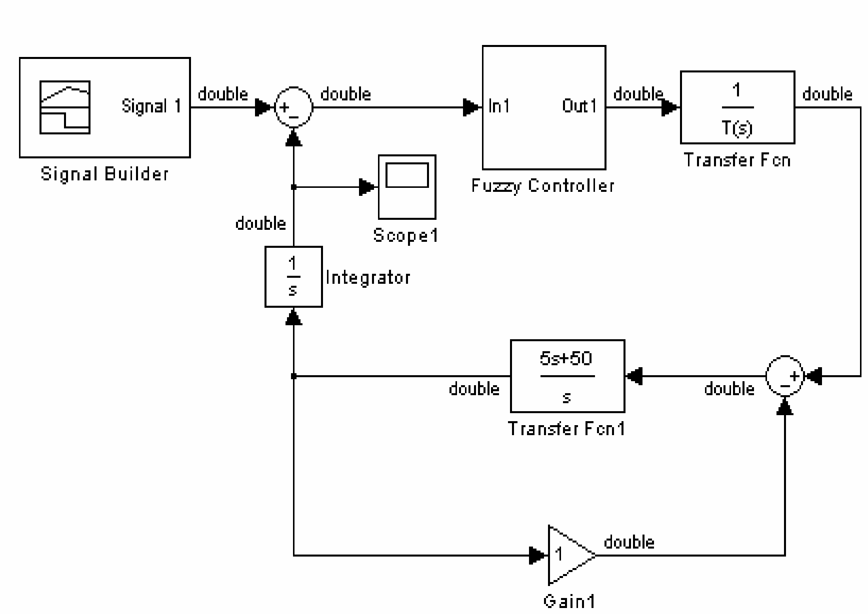


Fig.9 A fuzzy controller is applied in the tracking loop design and with the PI compensator in the stabilization loop.

Table 1 Fuzzy controller cross reference rules.

E/ΔE	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NM	NM	NS	NS	ZE
NM	NB	NM	NM	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PS
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PM	PM	PB
PB	ZE	PS	PS	PM	PM	PB	PB

4 Conclusion

This research applied both the traditional compensator as well as the fuzzy control methods for mobile satellite tracking antenna system design. Since the detailed block diagram of a satellite antenna tracking system is very lousy, it is very difficult to obtain the key parameters for analyses and simulation. Thus, a simplified model of antenna pitching or yawing control system is applied to speed up the design and obtain the key parameters. The antenna tracking and the stabilization loops were designed firstly according to the traditional bandwidth and phase margin requirements. However, the performance would be degraded if the tacking loop gain is reduced due to parameter variations. On the other hand a PD type of fuzzy controller was also applied for the design. It can be seen that the system performances obtained by applying both traditional PI and fuzzy controllers were better for not only lower but higher antenna tracking loop gains. Thus the tracking gain parameter variations effect can be reduced.

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Table 2 Relationship function parameters of E, ΔE and U.

Item	Parameter E	Parameter ΔE	Parameter U
Negative Big (NB)	[-1 -1 -0.75 -0.3]	[-4.5 -4.5 -3.375 -1.35]	[-12 -12 -9.6 -8.4]
Negative Medium (NM)	[-0.75 -0.3 -0.15]	[-3.375 -1.35 -0.72]	[-9.6 -8.4 -7.2]
Negative Small (NS)	[-0.15 -0.1 0]	[-1 -0.5 0]	[-8.4 -4.8 0]
Zero (ZE)	[-0.05 0 0.05]	[-0.25 0 0.25]	[-4.8 0 4.8]
Positive Small (PS)	[0 0.1 0.15]	[0 0.5 1]	[0 4.8 8.4]
Positive Medium (PM)	[0.15 0.3 0.75]	[0.72 1.35 3.375]	[7.2 8.4 9.6]
Positive Big (PB)	[0.3 0.75 1 1]	[1.35 3.375 4.5 4.5]	[8.4 9.6 12 12]

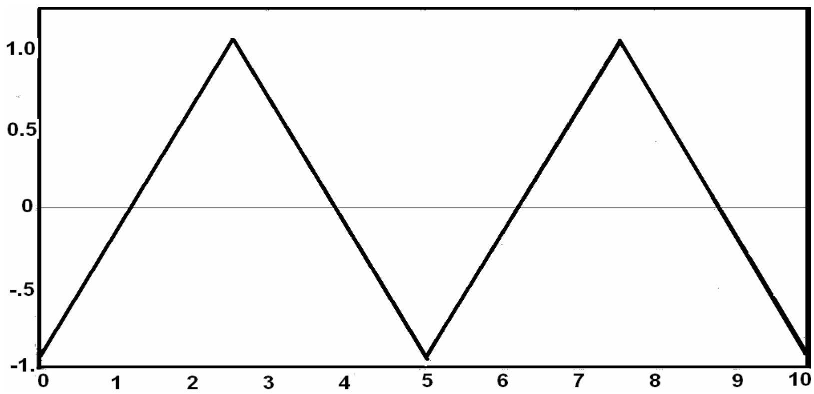

Fig. 10 Gimbal angle output obtained by applying both traditional PI and fuzzy controllers with T=0.1.

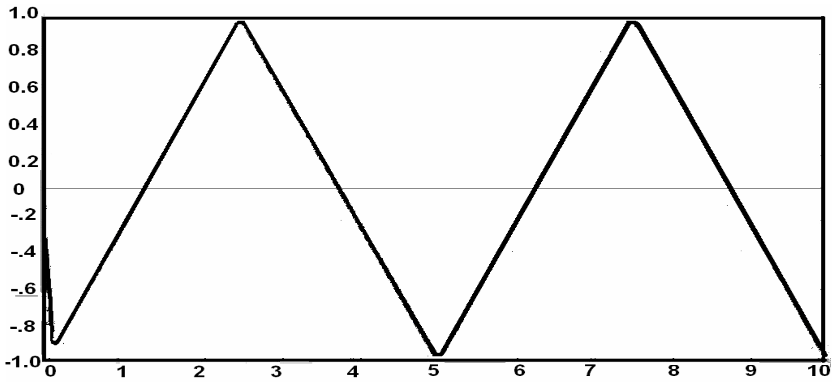

Fig. 11 Gimbal angle output obtained by applying both traditional PI and fuzzy controllers with T=1.

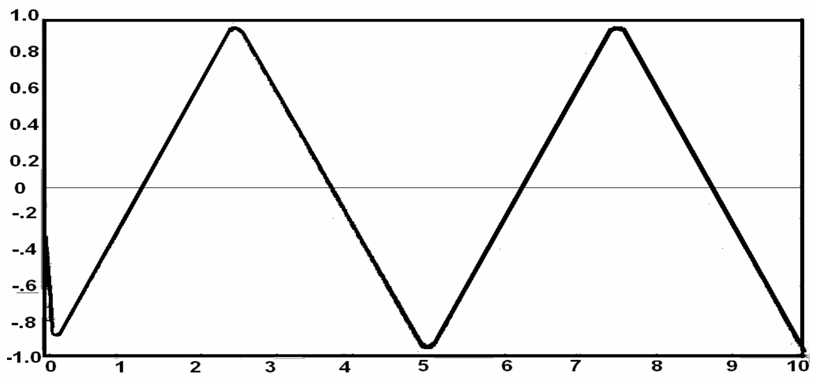

Fig. 12 Gimbal angle output obtained by applying both traditional PI and fuzzy controllers with T=1.5.

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