Control of Switched Linear Systems via Saturated Input∗

Ni Wei, Qin Huashu, Cheng Daizhan
Institute of Systems Science, Chinese Academy of Sciences, Beijing 100080, P. R. China
E-mail: niw@amss.ac.cn, dcheng@iss.ac.cn

Abstract: In this paper, the problem of satlabilization of switched linear systems via saturated input is considered. Based on different switching law, two control strategies are presented. The first one is based on the minimum dwell time(MDT) switching together with saturated feedback. The second one is designed by state dependent switching and saturated feedback. Illustrative examples are presented to show the validity of the results.

Key Words: Minimum dwell time, Switched linear systems, Saturated input

1 INTRODUCTION

The past decade has witnessed an enormous interest in the research of switched systems. Many results have been developed for stability analysis and stabilization using the tools of common Lyapunov function, multiple Lyapunov functions and the concept of dwell time or average dwell time etc. The reader may refer to [14] for a survey of results in this area.

A very important issue which is always inherent to switched systems is the presence of actuator saturations. Even for switched linear systems, there are relatively few results on the stabilization of such systems [1, 16]. Both in [1] and [16], only the control inputs are utilized to the stabilization of the saturated switched linear systems, that is, the controlled switched system is stable for arbitrary switchings. It’s worth noting, however, that the switching law can also be taken as design object. Two kinds of switching laws are proposed: the MDT-based switching and state-dependent switching.

This paper aims to provide new results on stability analysis and stabilizing control synthesis for a continuous time switched linear system with input saturation. The control synthesis presented in this paper combined the linear state feedback with different switching design. The first switching law is the MDT switching and the second is the state dependent switching.

The rest of the paper is organized as follows. In section 2 the problem formulation is given, a useful lemma is recalled which is used to deal with the saturation nonlinearity, and a fundamental preliminary result is presented which plays a key role in proving the main results of the paper. Section 3 and section 4 present our results about stabilization of switched linear systems via saturated inputs. Two examples illustrating the results are presented in section 5. A brief conclusion is in section 6.

2 PROBLEM FORMULATION AND PRELIMINARIES

The switched linear control system with saturated input considered in this paper can be described as

\[
\begin{aligned}
\dot{x} &= A_{\sigma(t)}x + B_{\sigma(t)}u_{\sigma(t)} \\
x(t_0) &= x_0
\end{aligned}
\]  

where \( x \in \mathbb{R}^n \) is the state, \( u_i = [u_i^1, u_i^2, \ldots, u_i^n]^T \in \mathbb{R}^n \) is the control input, and \( \sigma : [0, \infty) \rightarrow \{1, 2, \ldots, N\} \) is a piecewise right continuous map called switching signal. Suppose the controls are bounded as \( |u_i(x)|_\infty \leq c \) for some given positive number \( c > 0 \), where \( |u_i(x)|_\infty = \max_{j=1}^{\infty} |u_i^j(x)| \). That is, the control \( u_i(x) \) belongs to the admissible control set

\[ A = \{ u(x) \in \mathbb{R}^n | |u(x)|_\infty \leq c \} \]

We use \( \text{sat} : \mathbb{R} \rightarrow \mathbb{R} \) to denote the scaler saturation function, i.e.

\[ \text{sat}(s) = \text{sign}(s) \min\{c, |s|\} \]

where \( c \) is the upper bound of \( \text{sat}(s) \). With a slight abuse of notion and for simplicity, for a vector \( u_i = [u_i^1, u_i^2, \ldots, u_i^n]^T \in \mathbb{R}^n \), we will also use the same \( \text{sat}(u_i) \) to denote the vector saturation function, i.e.,

\[ \text{sat}(u_i) = [\text{sat}(u_i^1), \text{sat}(u_i^2), \ldots, \text{sat}(u_i^n)]^T. \]

With these notions, applying state feedback control law \( u_i = K_i x \) to (1), the system (1) can be written as

\[ \dot{x} = A_{\sigma(t)}x + B_{\sigma(t)}\text{sat}(K_{\sigma(t)}x) \]  

(2)

When there is no saturation nonlinearities in system (1), under the conditions that \( (A_i, B_i) \), \( i \in \mathcal{M} \) are controllable, we can design linear state feedbacks and minimum dwell time switching to make switched system (1) globally exponentially stable. However, when the saturation nonlinearities enter the system, not the whole state space of system (1) can be controlled to the equilibrium. The problem of characterization of the set of all the states that can be steered to the origin by an appropriate choice of admissible control inputs and switching law is under extensive study and still remains open. The objective of this paper is to design admissible control inputs and appropriate switching law which can steer every states in a pre-given subset \( W \) of \( \mathbb{R}^n \) to the origin.

Some notations are introduced. Recall that for a group of points, \( p_1, p_2, \ldots, p_n \), the convex hull of these points is defined as,

\[ \text{co}\{p_k | k = 1, 2, \ldots, n\} = \left\{ \sum_{k=1}^{n} \alpha_k p_k \mid \sum_{k=1}^{n} \alpha_k = 1, \alpha_k \geq 0 \right\} \]

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Let $\mathcal{D}$ be the set of $r \times r$ diagonal matrices whose diagonal elements are either 1 or 0. There are $2^r$ elements in $\mathcal{D}$. Suppose that each element of $\mathcal{D}$ is labelled as $D_k, k = 1, 2, \cdots , 2^r$. Denote $D_k^{-} = I - D_k$ and $\mathcal{K} = \{1, 2, \cdots , 2^r\}, \mathcal{I} = \{1, 2, \cdots , N\}, \mathcal{R} = \{1, 2, \cdots , r\}, \mathcal{L} = \{1, 2, \cdots , l\}$. The following Lemma is useful to place saturation nonlinearities into the convex hull of a group of linear feedbacks.

**Lemma 1** [9] Let $u, v \in \mathbb{R}^r, u = [u_1, u_2, \cdots , u_r]^T, v = [v_1, v_2, \cdots , v_r]^T$. Suppose $\|v\|_\infty \leq c$, then

$$\text{sat}(u) = \text{co}\{D_k u + D_k^- v | k \in \mathcal{K}\}$$

The next lemma is a key in proving the main result of next section.

**Lemma 2** Let $x = A_i x, x \in \mathbb{R}^n, i \in \mathcal{I}$ be $N$ asymmetrically stable linear systems, and $V_i(x) = x^T P_i x, i \in \mathcal{I}$ be the corresponding Lyapunov functions satisfying

$$a_i |x|^2 \leq V_i(x) \leq b_i |x|^2, i \in \mathcal{I}$$

and

$$\frac{dV_i(x(t))}{dt} \big|_{A_i x} = -x^T Q_i x \leq -c_i |x|^2, i \in \mathcal{I}$$

Let $\mu_i = \frac{b_i}{a_i}, \lambda_i = \frac{b_i}{c_i}$, and

$$\tau > \max_{i \in \mathcal{I}} \left\{ \frac{\ln \mu_i}{\lambda_i} \right\}$$

Then for any admissible switching signal $\sigma \in \mathcal{S}[\tau]$, the switched linear system $\dot{x} = A_{\sigma(i)} x$ is globally exponentially stable. The symbol $\mathcal{S}[\tau]$ denote the set of all the switching signals with MDT $\tau$.

### 3 MINIMUM DELLW TIME SWITCHING BASED CONTROL

For given compact subset $W$ of $\mathbb{R}^n$ containing the origin as its inner part, suppose there exist positive matrices $P_i > 0$ such that

$$W \subset \Phi(P_i, 1), i \in \mathcal{I}$$

where $\Phi(P_i, 1) = \{x \in \mathbb{R}^n | x^T P_i x \leq 1\}, i \in \mathcal{I}$. Suppose also there exist a matrix $H_i \in \mathbb{R}^{r \times n}$ such that

$$\Phi(P_i, 1) \subset \mathcal{L}(H_i), i \in \mathcal{I}$$

where $\mathcal{L}(H_i) = \{x \in \mathbb{R}^n | H_i x |_{\infty} \leq c\}$. Then, in view of Lemma 1, we have

$$A_i x + B_i \text{sat}(K_i x)$$

$$\in \text{co}\{A_i x + B_i (D_k K_i + D_k^- H_i) x | k \in \mathcal{K}, i \in \mathcal{I}\}$$

Define

$$Q_i^k = -[A_i + B_i (D_k K_i + D_k^- H_i)]^T P_i$$

$$-P_i [A_i + B_i (D_k K_i + D_k^- H_i)]$$

$$i \in \mathcal{I}, k \in \mathcal{K}$$

and

$$c_i = \max_{k \in \mathcal{K}} \lambda_{\min}(Q_i^k)$$

$$\mu_i = \lambda_{\max}(P_i)/\lambda_{\min}(P_i)$$

$$\lambda_i = c_i/\lambda_{\max}(P_i)$$

Let $\tau$ be a positive number such that

$$\tau > \max_{i \in \mathcal{I}} \left\{ \ln \mu_i / \lambda_i \right\}$$

(4)

We have the following theorem.

**Theorem 1** Let $W$ be a pre-given subset of $\mathbb{R}^n$ containing the origin as its inner point. If there exist matrices $K_i \in \mathbb{R}^{r \times n}, H_i \in \mathbb{R}^{r \times n}$, and positive definite matrices $P_i > 0$ such that

a) $W \subset \Phi(P_i, 1), i \in \mathcal{I}$,

b) $\Phi(P_i, 1) \subset \mathcal{L}(H_i), i \in \mathcal{I}$,

c) $Q_i^k > 0, i \in \mathcal{I}, k \in \mathcal{K}$.

then the switched linear system (1) with initial condition $x_0 \in W$ is exponentially stable for any $\sigma \in \mathcal{S}[\tau]$ with $\tau > \max_{i \in \mathcal{I}} \left\{ \ln \mu_i / \lambda_i \right\}$.

**Proof** We first prove that any trajectory $x(t)$ of system (1) with initial state in $W$ will be in $W$ at any switching time. For any switching signal $\sigma \in \mathcal{S}[\tau]$, let $0 = t_0, t_1, t_2, \cdots$ be the corresponding switching time series. For any $t > 0$, there exists an integer $i$ such that $t \in [t_i, t_{i+1})$. Also suppose that during $[t_i, t_{i+1})$, mode $p(i)$ is active, where $p(i) \in \mathcal{I}$. For the given positive definite matrices $P_i, i \in \mathcal{I}$, let $V_{p(i)}(x) = x^T P_{p(i)} x$ be a Lyapunov candidate corresponding to mode $p(i)$. It obviously that

$$a_{p(i)} |x|^2 \leq V_{p(i)}(x) \leq b_{p(i)} |x|^2$$

(5)

where $a_{p(i)} = \lambda_{\min}(P_{p(i)}), b_{p(i)} = \lambda_{\max}(P_{p(i)})$. It can also be seen from (3) that

$$\hat{V}_{p(i)}(x)$$

$$= 2x^T P_{p(i)} [A_{p(i)} + B_{p(i)} \text{sat}(K_{p(i)} x)]$$

$$\leq \max_{k \in \mathcal{K}} \{x^T [A_{p(i)} + B_{p(i)} (D_k K_{p(i)} + D_k^- H_{p(i)}) P_{p(i)}] x + x^T P_{p(i)} [A_{p(i)} + B_{p(i)} (D_k K_{p(i)} + D_k^- H_{p(i)})] x\}$$

$$= \max_{k \in \mathcal{K}} x^T Q_{p(i)}^k$$

$$\leq -c_{p(i)} |x|^2$$

(6)

By manipulating inequalities (5) with (6) one sees that

$$|x(t)|^2 \leq \mu_{p(i)} e^{-\lambda_{p(i)} (t-t_{i-1})} |x(t_i)|^2$$

By the continuity of $x(t)$, letting $t \rightarrow t_{i+1}$, we can get

$$|x(t_{i+1})|^2 \leq \mu_{p(i)} e^{-\lambda_{p(i)} (t_{i+1}-t_{i-1})} |x(t_i)|^2$$

Iterating the above inequality yields

$$|x(t_{i+1})|^2 \leq \mu_{p(i)} \mu_{p(i-1)} \cdots \mu_{p(0)} e^{-\lambda_{p(i-1)} \cdots \lambda_{p(0)} (t_{i+1}-t_0)} |x(t_0)|^2$$

$$\leq \mu_{p(i)} \mu_{p(i-1)} \cdots \mu_{p(0)} e^{-\lambda_{p(i-1)} \cdots \lambda_{p(0)}} |x(t_0)|^2$$

(7)
Since $\tau > \max_{i \in A} \{ \ln \mu_i / \lambda_i \}$ and

$$\max_{i \in A} \left\{ \frac{\ln \mu_i}{\lambda_i} \right\} > \frac{\ln \mu_{p(i)} + \cdots + \ln \mu_{p(0)}}{\lambda_{p(i)} + \cdots + \lambda_{p(0)}}$$

we have

$$\tau > \frac{\ln \mu_{p(i)} + \cdots + \ln \mu_{p(0)}}{\lambda_{p(i)} + \cdots + \lambda_{p(0)}}$$

or equivalently,

$$\mu_{p(i)} \cdots \mu_{p(0)} e^{-|\mu_{p(i)}| + \cdots + |\mu_{p(0)}|} \tau < 1$$

Thus inequality (7) reduces to

$$|x(t_{i+1})|^2 \leq |x(t_0)|^2$$

This inequality and the assumption $x(t_0) \in W$ imply that at the
switching time $t_{i+1}$, we have $x(t_{i+1}) \in W$.

Then, base on theorem 1, we can conclude from inequalities
(5) (6) and (4) that the switched system (2) is exponentially
stable for any $\sigma \in S[\tau]$ and $x_0 \in W$.

In order to characterize the exponentially stable condition of
the above theorem by means of LMI, we give the following
theorem. For statement ease, we suppose the pre-given
domain $W$ of the above theorem is characterized by a poly-
hedron, that is, there exist $l/l > n$ points $w_1, w_2, \ldots, w_l$ of
$\mathbb{R}^n$, that such the $W = \text{co}\{w_1, w_2, \ldots, w_l\}$.

**Theorem 2** Let $W = \text{co}\{w_1, w_2, \ldots, w_l\}$ be a pre-
assigned subset of $\mathbb{R}^n$ containing the origin as its inner point.
If there exist positive definite matrices $X_i \in \mathbb{R}^{n \times n}$, matrices
$Y_i \in \mathbb{R}^{r \times n}$, and matrices $Z_i \in \mathbb{R}^{r \times n}$ such that the following
LMI’s hold

$$a') \quad \begin{pmatrix} 1 \\ w_l^T \end{pmatrix} X_i \geq 0, \quad i \in I, \quad l \in \mathcal{L}$$

$$b') \quad \begin{pmatrix} 1 \\ z_i^T \end{pmatrix} \geq 0, \quad i \in I, \quad j \in \mathcal{R}$$

$$c') \quad A_i X_i + X_i A_i^T + B_i (D_k Y_i + D_k^{-1} Z_i) + (D_k Y_i + D_k^{-1} Z_i) B_i^T > 0, \quad i \in I, \quad k \in \mathcal{K}$$

where $z_i^T$ is the $j$th row of matrix $Z_i$, then the switched linear
system (2) with initial condition $x_0 \in W$ is exponentially
stable for any $\sigma \in S[\tau]$ with $\tau > \max_{i \in \mathcal{I}} \{ \ln \mu_i / \lambda_i \}$ for
$P_i = X_i^{-1}, K_i = Y_i X_i^{-1}, H_i = Z_i X_i^{-1}$.

**Proof** We first show that the condition $a)$ is equivalent to
condition $a')$. Since $W = \text{co}\{w_1, w_2, \ldots, w_l\}$, the constraint $a)$ is equivalent to

$$w_l^T P_l w_l \leq 1, \quad l \in \mathcal{L}, \quad i \in I$$

Then we can use the standard Schur complements to transfer the
above constraint into the following LMI

$$a') \quad \begin{pmatrix} 1 \\ w_l^T \end{pmatrix} X_i \geq 0, \quad i \in I, \quad l \in \mathcal{L}$$

Next, we show that the equivalence of the constraints $b)$ and
$b')$. Note that $\Phi_i(P_i, 1) \subset \mathcal{L}(H_i)$ if and only if all the hy-
perplane $h_i x = \pm 1, j \in \mathcal{R}$, lie completely outside of the ellipsoid $\Phi_i(P_i, 1)$, i.e., at each point $x$ on the hyperplanes

$h_i x = \pm 1$, we have $x^T P_i x \geq 1$. This means that constraint $b)$ is equivalent to

$$\min_{x} \{ x^T P_i x | h_i x = 1 \} \geq 1, \quad i \in I, \quad j \in \mathcal{R}$$

By using the multiplier method, we obtain

$$\min_{x} \{ x^T P_i x | h_i x = 1 \} = [h_i^T P_i^{-1} (h_i^T)^{-1}, j \in \mathcal{R}, i \in I$$

Consequently, constraint $b)$ is equivalent to

$$h_i^T P_i^{-1} (h_i^T)^{-1} \leq 1, \quad j \in \mathcal{R}, \quad i \in I$$

Also by Schur complement, the above inequality is equiv-
alent to

$$\begin{pmatrix} 1 \\ P_i^{-1} (h_i^T) \end{pmatrix} \geq 0, \quad j \in \mathcal{R}, \quad i \in I$$

Note that $P_i = X_i^{-1}, K_i = Y_i X_i^{-1}, H_i = Z_i X_i^{-1}$.

From this theorem, the stabilizing feedback gain matrices
$K_i, i \in I$ can be obtained from the solutions $X_i, Y_i, Z_i, i \in I$ of the LMI $a'), b)$ and $c')$ by taking $K_i = X_i^{-1}, i \in I$.

4 STATE DEPENDENT SWITCHING BASED
CONTROL

We first introduced the following candidate Lyapunov func-
tion which is crucial for our purposes[7]. For a set of positive
definite matrices $P_1, P_2, \ldots, P_N$, define

$$v(x) = \min_{i \in I} x^T P_i x$$

Obviously, this function is not differentiable everywhere.
Let us recall the class of Metzler matrices denoted by $\mathcal{M}$ and
constituted by all matrices $P \in \mathbb{R}^{N \times N}$ with elements
$\pi_{ij}$, such that

$$\pi_{ij} > 0, \quad \forall i \neq j, \quad i, j \in \mathcal{I}, \quad \sum_{i=1}^{N} \pi_{ij} = 0, \quad \forall j \in \mathcal{I}$$

The next theorem summarizes the main result of this section.

**Theorem 3** For a given compact subset $W$ of $\mathbb{R}^n$, if there
exist matrices $K_i \in \mathbb{R}^{r \times n}, H_i \in \mathbb{R}^{r \times n}$, positive definite
matrices $P_i > 0$, Metzler matrix $I$ and a positive number
$c > 0$ such that

$$a) \quad W \subset \{ x \in \mathbb{R}^n | v(x) \leq c \}$$

$$b) \quad \Phi_i(P_i, c) \subset \mathcal{L}(H_i), i \in I$$

$$c) \quad -Q_i^T + \sum_{j=1}^{N} \pi_{ij} P_j < 0, \quad i \in I, \quad k \in \mathcal{K}$$

then under the state dependent switching law

$$\sigma(x(t)) = \arg \min_{x \in \mathbb{R}^n} x^T(t) P_i x(t)$$

the switched linear system (1) with initial condition $x_0 \in W$
is asymptotically stable.
**Proof** Consider (8) as a candidate Lyapunov function which is not differential for all \( t > 0 \). For this reason we deal with its Dini derivative

\[
D^+ v(x(t)) = \limsup_{h \to 0^+} \frac{v(x(t + h)) - v(x(t))}{h}
\]

For any given \( t > 0 \), suppose at this instance mode \( i \) is active, that is

\[
\sigma(x(t)) = \arg\min_{i \in \mathcal{K}} x^T(t)P_i x(t)
\]

Therefore we have

\[
D^+ v(x(t)) = \min_{i \in \Lambda} \{2x^T(t)P_i[A_i x(t) + B_i \text{sat}(K_i x(t))]\} \leq 2x^T(t)P_i[A_i x(t) + B_i \text{sat}(K_i x(t))]
\]

Since \( \Phi(P_1, c) \subset \mathcal{L}(H_i) \), arguing in a manner entirely similar to that used in Section 3, we may deduce that

\[
2x^T(t)P_i[A_i + B_i \text{sat}(K_i x(t))] \leq \max_{k \in \mathcal{K}} \{-x^T(t)Q_k^i x(t)\}
\]

Thus

\[
D^+ v(x(t)) \leq \max_{k \in \mathcal{K}} \{-x^T(t)Q_k^i x(t)\}
\]

Noting that at time \( t \) mode \( i \) is active, we have, from the definition of switching law (9), that \( x^T(t)P_j x(t) \leq x^T(t)P_i x(t) \) for all \( j \neq i \). Using the inequality (c) we get

\[
D^+ v(x(t)) < -x^T(t)(\sum_{j \in \Lambda} \pi_{ji} P_j) x(t)
\]

\[
< -(\sum_{j \in \Lambda} \pi_{ji})x^T(t) P_i x(t)
\]

\[
= 0
\]

that is, all the trajectories start from \( \Omega = \{x \in \mathbb{R}^n | v(x) \leq c\} \) converge to the origin. Since \( W \subset \Omega \), thus the switched system (1) is asymptotically stable for all initial states \( x_0 \in W \).

Note that \( \Omega \) is the union of all the ellipsoids \( \Phi(P_i, c) \), so the domain of attraction given by theorem 3 is much larger than that of theorem 2 or theorem 1.

However finding the numerical solutions, if any, of the inequality (c) with respect to the variables \( K_i, H_i, P_i, c \) is not a simple task due to the non-convex nature caused by the products of variables. This difficulty can be overcame by working with a subclass of Metzler matrices which have identical diagonal elements. Then constraint (c) has the following form

\[
-Q_k^i + \gamma(P_j - P_i) < 0, j \neq i \in \mathcal{R}, k \in \mathcal{K}
\]

for a certain scalar \( \gamma > 0 \). Manipulating it in a manner entirely similar to the one used in theorem 2, all the constraints can be transferred into a set of LMIs.

**5 ILLUSTRATIVE EXAMPLES**

We use the following example to show the validity of the result in Section 3.

**Example 1** Consider a switched linear control system (1), where \( A_i \) and \( B_i \) are as following

\[
A_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, B_1 = \begin{pmatrix} 0 \\ 5 \end{pmatrix}
\]

\[
A_2 = \begin{pmatrix} -0.8741 & -0.05 \\ -0.1474 & 0.2710 \end{pmatrix}, B_2 = \begin{pmatrix} 1 \\ 1 \end{pmatrix}
\]

Suppose the upper bound of the saturation function \( \text{sat} \) is 1. Let \( W = \{x \in \mathbb{R}^n | x^T P x \leq 0.08\} \), where

\[
P = \begin{pmatrix} 0.0271 & -0.1129 \\ -0.1129 & 0.9094 \end{pmatrix}
\]

is a positive definite matrix. The pre-assigned domain of attraction \( W \) is given in Fig.1. The matrices

![Fig. 1 The pre-given domain of W](image)

![Fig. 2 The graph of \( x_1(t) \) and \( x_2(t) \)](image)

and vectors needed in the Theorem 4 can be chosen as

\[
K_1 = (-2, -1), K_2 = (0.0757, -0.5869), H_1 = (-0.3440, -0.3400), H_2 = (0.1385, -0.9354),
\]

\[
P_1 = \begin{pmatrix} 0.1170 & 0.0627 \\ 0.0627 & 0.0558 \end{pmatrix}, P_2 = \begin{pmatrix} 0.2415 & -1.0062 \\ -1.0062 & 8.1052 \end{pmatrix}
\]
With these datum, we can calculate $c_1 = 1.5612, c_2 = 1.0017, \mu_1 = 9.3900, \mu_2 = 71.6966, \lambda_1 = 9.9967, \lambda_2 = 1.0845, \tau = 3.9395$. The simulation results are given in Fig. 2.

Second example is used to show the validity of the result in Section 4.

Example 2 Consider the switched linear system (1) with

$$A_1 = \begin{pmatrix} 1 & -5/4 \\ -5/2 & -7/4 \end{pmatrix}, B_1 = \begin{pmatrix} 5 \\ -5 \end{pmatrix}$$

$$A_2 = \begin{pmatrix} 1/2 & 1 \\ -1/3 & 0 \end{pmatrix}, B_2 = \begin{pmatrix} 8.2 \end{pmatrix}$$

According to theorem 3, we can choose $K_1 = (-0.7692, 0.0481), H_1 = (-0.7692, -0.1442), K_2 = (0.0610, 1.2756), H_2 = (6.8333, 57.4000), \gamma = 1$ and

$$P_1 = \begin{pmatrix} 1 & 1 \\ 1 & 2 \end{pmatrix}, P_2 = \begin{pmatrix} 2 & 3 \\ 3 & 5 \end{pmatrix}$$

The simulation results are given in Fig. 3.

6 CONCLUSION

In this paper, we consider the problem of control of switched linear systems with saturated input. Two control strategies were presented. The first one is based on the MDT switching together with saturated feedback. The second one is designed by state dependent switching and saturated feedback. Illustrative examples are presented to show the validity of the results.

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