

# A Octuple Switching Structure with Code Independent for Frequency Conversion of High Performance D/A Converters

Wang liguo, Wang zongmin, and Kong ying

**Abstract**—A new switching structure for decreasing signal dependent nonlinearity and upconverting in high performance D/A converters is addressed in this paper. The switching which receives a digital data input signal that is defined at data intervals can removing any substantial data dependency from this interaction. The logic circuit controls the switches to be in one of a normal mode or multi-mixer mode that convert the input digital data signal into a mixed analog signal having a mixer frequency that is higher than the data frequency. Simulation results show that the new switch structure most extend the usable frequency spectrum into fifth to sixth Nyquist zone beyond conventional DACs.

**Index Terms**—Differential octuple switching, direct digital modulation, data independent

## I. INTRODUCTION

IN high performance digital-to-analog converters (DAC), noise becomes an ever more limiting consideration as dynamic range increases and/or as minimum detectable signal decrease. One particular source of noise in a mixed digital and analog signal application is effect on critical analog signal paths of the various digital circuit. One commonly used such critical analog signal path is the switch or steering of analog reference signals by control elements, which are themselves activated by digital control signals. In a physically realizable system, it is impossible to completely isolate these digital control signal from analog signals which they are controlling because of coupling through the analog signal control elements [1], and also because digital circuits consume time-varying power and cause time-varying loading [2], IR drops [3], and charge injection, which in turn cause interactions with the overall signal processing circuit. These effects cause changes in reference signals, supply voltages, bias levels, clock phases, transition phase, and substrate effects that in turn corrupt the desired analog signal being processed. Because of inevitable parasitics and non-ideal circuits, this can cause data dependant loading and spurious coupled signal modulation [4]. In this manner the digital signals add noise and/or distortion to the analog signals.

In direct digital modulation systems, the signal is up-converted in digital domain, and the modulated digital is converted into a modulated analog form. In these systems, a digital-to-analog converter (DAC) whose conversion rate is more than the Nyquist rate of the carrier frequency. A

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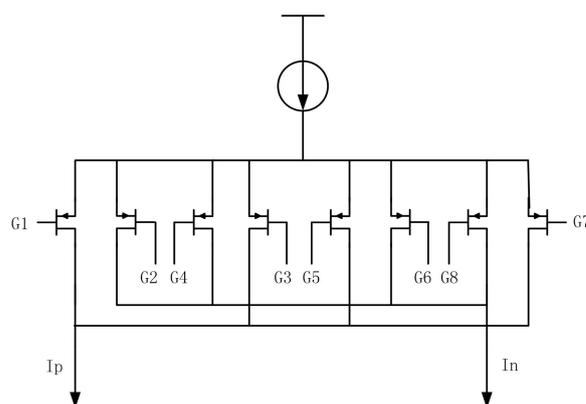


Fig. 1. The structure of octuple switching

wide variety of different electronic device use a system that both converts internal digital signals to analog signals, and then shift the frequency of the resultant analog signal. For example, conventional cell phones often have a digital to analog chip converter chip that converts a digitally processed voice signal into an analog baseband signal for transmission. Before transmission, however, a mixer chip shifts the frequency of the baseband signal to a frequency that facilitates transmission.

An effective switching structure, called differential-octuple switching (DOS) is proposed for the oversampling DAC to meet the requirements for direct digital modulation and data independent. Fig.1 is the circuit based on DOS. Section II gives the structure of octuple switching. Section III discusses the theory of switching. Section IV describes the control circuit of switching. Section V contains some conclusions plus some ideas for code independent of glitch. Section VI presents the primary experimental results of the paper and the section VII is the conclusion.

## II. DIFFERENTIAL OCTUPLE SWITCH

Practically, it is not possible to design a perfect switch used as a 1-bit DAC. Ordinary differential switching is capable of eliminating many nonlinearities caused by imperfect switching but still has some data-dependent nonlinearities [5]. Due to the mixed-signal nature of a DAC, digital data activity on the switch gate will cause interference in the analog output. This becomes an important performance issue as the static and dynamic performance. A special case of data pattern dependent interference comes from the varying gate seen by the final control signal which controls the switch to be on or not. The now popular two transistor switch topology. True and complements of the data are provided to the two inputs

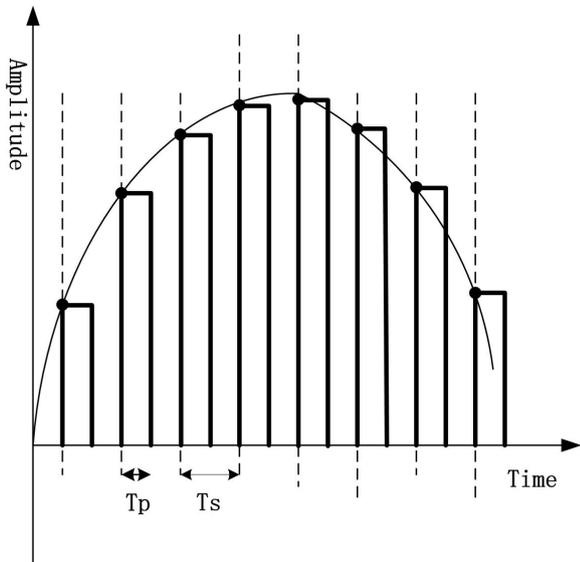


Fig. 2. General wave of DAC output

separately and the DAC output change only when either of them changes. As a multi-bit DAC, the switches changed state will produce glitch through the capacitor between gate and drain but those not changed will not impact on output, then the output glitch depend on data patten.

If, however, the switches act every clock edge or half a clock cycle or a quarter clock cycle, the frequency of this noise will not be in the band of signal but have a certain relationship with the conversion clock frequency. The noise frequency either is as same as the carrier band frequency or twice or four times as high as the carrier band frequency.

This switching is DOC. Fig.1 is the simplified circuit based on DOC. Each switch is controlled by one signal that is come from the logic operation of input data and clock, the switch apparatus has a current source that transmit a current to either one of two differential output nodes Ip and In via one of the eight switches G1-G8. To the end, no more than one of eight switches G1-G8 can be in an “on” state at any single time. For each quarter DAC clock cycle, one of the eight transistors changes their state while the others remain off. The data input to the segment determines whether the current for this segment is re-routed by this switching, thereby changing the differential output current levels, or only routed through a different transistor for an unchanged output.

### III. SWITCHING THEORY

According to the sample theorem, as long as we sample fast enough, digital signal x(n) contains all information of analog signal x(t). If we hope to reconstruct x(t) from x(n) perfectly, we can let

$$g(t) = \frac{\sin(\pi * f_s * t)}{\pi * f_s * t}, x(t) = \sum_{n=-\infty}^{\infty} x(n) * g(t - nT_s)$$

But it is very hard to build an analog circuit that does this. The most practical way of reconstructing the continuous time signal is to simply “hold” the discrete time values that is continued either for full period Ts or a fraction Tp. It is illustrated in Fig.2.

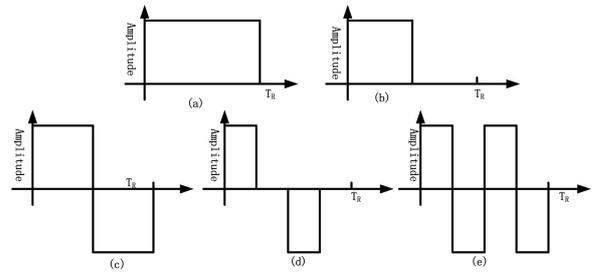


Fig. 3. The time domain wave of switching function (a)zero-order hold pulse. (b)RZ hold pulse. (c)2p2L hold pulse. (d)4p3L hold pulse. (e)4p2L hold pulse

The process of “hold” can be realized through an analog circuit that we can call it switch whose function is the reconstructing. Consider the general case with a rectangular pulse  $0 < T_p < T_s$ , let the rectangular unit pulse is  $h(t)=u(t)-u(t-T_p)$ , the time domain signal follows from convolving the Dirac sequence with it. Because of

$$x(t) = \sum_{n=-\infty}^{\infty} x(n) * h(t - nT_s)$$

$$Hp(f) = T_p \frac{\sin(\pi * f * T_p)}{\pi * f * T_p} e^{-j\pi * f * T_p}$$

then

$$Xp(f) = \frac{T_p \sin(\pi * f * T_p)}{T_s \pi * f * T_p} e^{-j\pi * f * T_p} \sum_{n=-\infty}^{\infty} X(f - \frac{n}{T_s})$$

As to a discrete signal x(n), the spectrum Xd(f) is Periodically spread of spectrum X(f) which is Fourier transform of x(t). So, when we reconstruct the x(t) from x(n), in frequency domain the reconstruction function Hp(f) which we select filters the Xd(f). As follow, we will design the reconstructed function which is realized by DOC and fulfills the reconstruction and upconversion of DAC.

#### A. Zero-Order Hold Pulse

In the normal DAC mode, the reconstruction function of switch is zero-order hold pulse in Fig.3.(a) We let

$$P_{ZRH}(t) = \prod_{(0, T_R)}^1(t) = \begin{cases} 1 & 0 < t < T_R \\ 0 & t < 0 \text{ or } t > T_R \end{cases}$$

then

$$P_{ZRH}(t) = \prod_{(0, T_R)}^1(t) = u(t) - u(t - T_R)$$

Laplace transform

$$L\{ \prod_{(0, T_R)}^1(t) \} = L\{u(t) - u(t - T_R)\} = \frac{1}{s} - \frac{1}{s} e^{-sT_R} = \frac{1 - e^{-sT_R}}{s}$$

Fourier transform

$$F\{ \prod_{(0, T_R)}^1(t) \} = \frac{1 - e^{-sT_R}}{s} \Big|_{s=jw}$$

$$F\{ \prod_{(0, T_R)}^1(t) \} = T_R \frac{e^{jw \frac{T_R}{2}} - e^{-jw \frac{T_R}{2}}}{2jw \frac{T_R}{2}} e^{-jw \frac{T_R}{2}} = P_{ZRH}(w)$$

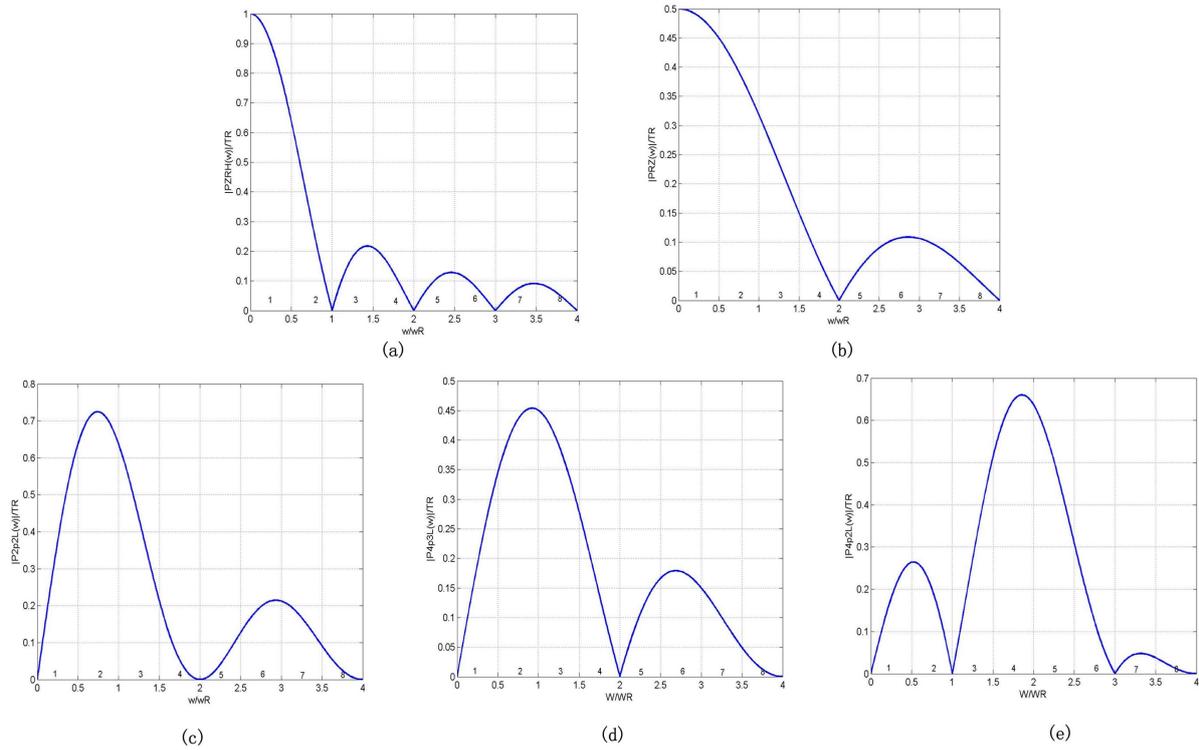


Fig. 4. The wave of switching function in frequency domain (a)zero-order hold pulse. (b)RZ hold pulse. (c)2p2L hold pulse. (d)4p3L hold pulse. (e)4p2L hold pulse

$$P_{ZRH}(w) = T_R \frac{\sin(w \frac{T_R}{2})}{w \frac{T_R}{2}} e^{-jw \frac{T_R}{2}} = T_R Sa(w \frac{T_R}{2}) e^{-jw \frac{T_R}{2}}$$

$$P_{ZRH}(w) = \frac{T_R}{2} \frac{\sin(w \frac{T_R}{4})}{w \frac{T_R}{4}} e^{-jw \frac{T_R}{4}} = \frac{T_R}{2} Sa(w \frac{T_R}{4}) e^{-jw \frac{T_R}{4}}$$

From the figure, we can get when  $w = nw_r (n \in z, n \neq 0)$ , the sample function have zero point and the envelope of function drop at the speed of -20dB/Decade or -6dB/Octant. In Fig.4.(a), number 1 to 8 is the Nyquist zone, the Nyquist frequency is  $wR/2$  and the spectrum is the most strong at 1 Nyquist zone at which the normal DAC work and is the baseband zone. the amplitude of other zones spectrum is force to get more decreased.

From the spectrum of the return to zero in Fig.4.(b), we can see that the width of it increases to double times more than the spectrum of zero-order hold PRZ(w) meanwhile the amplitude decrease to one half. So the spectrum amplitude of first Nyquist zone is restrained but the second and third zone is strengthened relative to the PZRH(w).

**B. Return to Zero Pulse**

We can call the return to zero pulse double phase single polar level(RZ) in Fig.3.(b)

$$P_{ZRH}(t) = \prod_{(0, \frac{T_R}{2})}^1 (t) = \begin{cases} 1 & 0 < t < \frac{T_R}{2} \\ 0 & t < 0 \text{ or } t > \frac{T_R}{2} \end{cases}$$

then

$$P_{ZRH}(t) = \prod_{(0, \frac{T_R}{2})}^1 (t) = u(t) - u(t - \frac{T_R}{2})$$

$$F\{ \prod_{(0, \frac{T_R}{2})}^1 (t) \} = \frac{1 - e^{-s \frac{T_R}{2}}}{s} \Big|_{s=jw}$$

$$F\{ \prod_{(0, \frac{T_R}{2})}^1 (t) \} = \frac{T_R}{2} \frac{e^{jw \frac{T_R}{4}} - e^{-jw \frac{T_R}{4}}}{2jw \frac{T_R}{4}} e^{-jw \frac{T_R}{4}} = P_{ZRH}(w)$$

**C. Biphasic Bipolar Level Pulse(2p2L)**

$$P_{2p2L}(t) = \prod_{(0, \frac{T_R}{2})}^1 (t) - \prod_{(\frac{T_R}{2}, T_R)}^1 (t) = \begin{cases} 1 & 0 < t < \frac{T_R}{2} \\ -1 & \frac{T_R}{2} < t < T_R \\ 0 & \text{others} \end{cases}$$

then

$$P_{2p2L}(t) = u(t) - 2u(t - \frac{T_R}{2}) + u(t - T_R)$$

the wave of time domain is Fig.3.(c), Fourier transform

$$F\{P_{2p2L}(t)\} = \frac{1-2e^{-s \frac{T_R}{2}} + e^{-s T_R}}{s} \Big|_{s=jw} = P_{2p2L}(w)$$

$$P_{2p2L}(w) = \frac{1-2e^{-jw \frac{T_R}{2}} + e^{-jw T_R}}{jw} = \frac{(1-e^{-jw \frac{T_R}{2}})^2}{jw}$$

$$= T_R \frac{\sin^2(w \frac{T_R}{4})}{w \frac{T_R}{4}} e^{j \frac{\pi}{2} - jw \frac{T_R}{4}}$$

$$= T_R Sa(\pi \frac{w}{2w_R}) \sin(\pi \frac{w}{2w_R}) e^{j \frac{\pi}{2} - jw \frac{T_R}{4}}$$

$$|P_{2p2L}(w)| = T_R \sin^2(\theta)$$

here, let  $\theta = \pi \frac{w}{2w_R}, \frac{d(\sin^2(\theta))}{d\theta} |_{\theta = \theta_0}$  then we can get when

$$\theta_0 = \pi \frac{w}{2w_R} \approx 1.1655, |P_{2p2L}(w_0)| = 0.7264T_R$$

So the spectrum in Fig.4.(c) absolutely restrains the DC signal and restrains the first Nyquist zone spectrum in a large degree, but strengthens the second and third Nyquist zone spectrum especially the second Nyquist zone spectrum is strengthened smoothly. To DAC, the realization can be called upconversion.

**D. Quadphase Triple Level Pulse(4p3L)**

The wave of time domain is Fig.3.(d)

$$\begin{aligned} P_{4p3L}(t) &= \prod_{(0, \frac{T_R}{4})}^1(t) - \prod_{(0, \frac{T_R}{4})}^1(t - \frac{T_R}{2}) \\ &= u(t) - u(t - \frac{T_R}{4}) - u(t - \frac{T_R}{2}) - u(t - 3\frac{T_R}{4}) \\ F\{P_{4p3L}(t)\} &= \frac{1 - e^{-s\frac{T_R}{2}} - e^{-s\frac{T_R}{4}} + e^{-3s\frac{T_R}{4}}}{s} |_{s=jw} \\ &= \frac{(e^{s\frac{T_R}{8}} - e^{-s\frac{T_R}{8}})(e^{s\frac{T_R}{4}} - e^{-s\frac{T_R}{4}})}{s} e^{-3s\frac{T_R}{8}} |_{s=jw} \\ &= P_{4p3L}(w) \end{aligned}$$

then

$$\begin{aligned} P_{4p3L}(w) &= \frac{T_R}{2} \frac{\sin(w\frac{T_R}{8})}{w\frac{T_R}{8}} \sin(w\frac{T_R}{4}) e^{j\frac{\pi}{2} - 3jw\frac{T_R}{8}} \\ &= \frac{T_R}{2} Sa(\pi \frac{w}{4w_R}) \sin(\pi \frac{w}{2w_R}) e^{j\frac{\pi}{2} - 3jw\frac{T_R}{8}} \end{aligned}$$

The spectrum of Quad-phase triple level pulse in Fig.4.(d) strengthens the second and third Nyquist zone amplitude smoothly more than Biphasic Bipolar level pulse. So it can realize the function of upconversion better.

**E. Quad-Phase Bipolar Level Pulse(4p2L)**

The wave of time domain is Fig.3.(e)

$$\begin{aligned} P_{4p2L}(t) &= u(t) - 2u(t - \frac{T_R}{4}) + 2u(t - \frac{T_R}{2}) \\ &\quad - 2u(t - 3\frac{T_R}{4}) + u(t - T_R) \end{aligned}$$

Fourier transform

$$\begin{aligned} F\{P_{4p2L}(t)\} &= \frac{1 + 2e^{-s\frac{T_R}{2}} - 2e^{-s\frac{T_R}{4}} - 2e^{-3s\frac{T_R}{4}} + e^{-sT_R}}{s} |_{s=jw} \\ &= \frac{(e^{s\frac{T_R}{8}} - e^{-s\frac{T_R}{8}})^2 (e^{s\frac{T_R}{4}} + e^{-s\frac{T_R}{4}})}{s} e^{-s\frac{T_R}{3}} |_{s=jw} \\ &= P_{4p2L}(w) \end{aligned}$$

then

$$\begin{aligned} P_{4p2L}(w) &= T_R \frac{\sin(w\frac{T_R}{8})}{w\frac{T_R}{8}} \sin(w\frac{T_R}{8}) \cos(w\frac{T_R}{4}) e^{j\frac{\pi}{2} - jw\frac{T_R}{2}} \\ &= T_R Sa(\pi \frac{w}{4w_R}) \sin(\pi \frac{w}{4w_R}) \cos(\pi \frac{w}{2w_R}) e^{j\frac{\pi}{2} - jw\frac{T_R}{2}} \end{aligned}$$

the spectrum of Quad-phase Biphasic level is Fig.4.(e) and strengths the fourth and fifth Nyquist zone amplitude spectrum. So it can realize the function of upconversion higher.

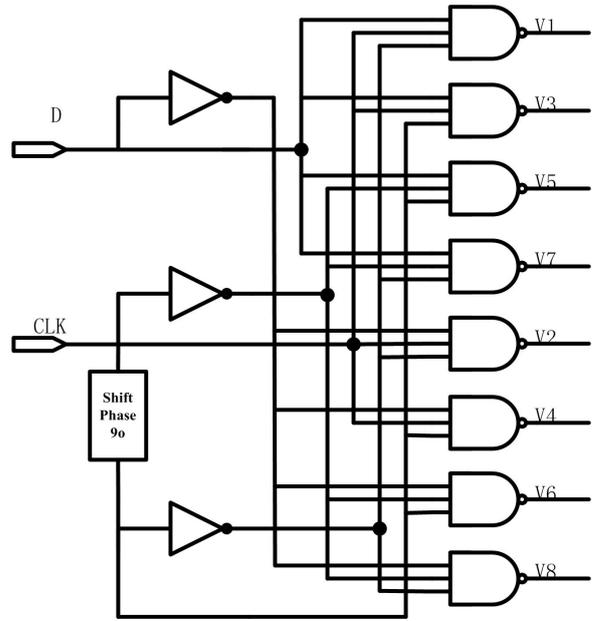


Fig. 5. The control circuit of the switching input signal

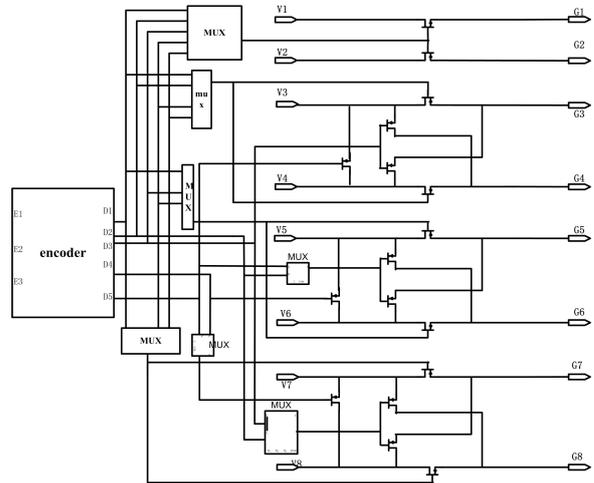


Fig. 6. The control circuit of the switching input signal

**IV. THE CONTROL CIRCUIT OF SWITCHING**

The control circuit of switching decides which switch is “on” state. Because no more than one of eight switches can be “on” state at any single time, for example, if switch G1 is on, and G2-G8 is off. In that case, the current flows to output Ip and the current on output node In is zero. The differential output signal (Ip-In) therefore is +1, when switch G2 is on and others are off. The current therefore flows to the output node In, which produces a differential output signal of -1.

From section III, in this paper, we will introduce five worked modes of DAC. That are separately zero-order hold mode(Normal), return to zero mode(RZ), Biphasic Bipolar level mode(2p2L), Quad-phase triple level mode(4p3L), Quad-phase Bipolar level mode(4p2L). D is the input data, C is clock and the C\_s90 is the result that the clock shifts 90 degree. As to the five modes of zero-order normal, 2p2L, 4p2L, RZ and 4p3L. V1-V8 are the result of operation of C, C\_s90 and D, the arithmetic operators is NAND, see the Fig.5.

The TABLE.I enumerate all the status of the control signal

TABLE I  
=THE RESULT OF FIVE DAC MODES

D C C_s90	1 1 0	1 1 1	1 0 1	1 0 0	0 1 0	0 1 1	0 0 1	0 0 0
V1	0	1	1	1	1	1	1	1
V2	1	1	1	1	0	1	1	1
V3	1	0	1	1	1	1	1	1
V4	1	1	1	1	1	0	1	1
V5	1	1	0	1	1	1	1	1
V6	1	1	1	1	1	1	0	1
V7	1	1	1	0	1	1	1	1
V8	1	1	1	1	1	1	1	0
Normal output	+1	+1	+1	+1	-1	-1	-1	-1
4p2L output	+1	-1	+1	-1	-1	+1	-1	+1
2p2L output	+1	+1	-1	-1	-1	-1	+1	+1
4p3L output	+1	0	-1	0	-1	0	+1	0
RZ output	+1	+1	0	0	-1	-1	0	0

and the output result of five modes. Because the operation mode we design is programmable, we select a 3 to 8 encode to produce five control signals which control separately five DAC modes. The output D1 represents Normal mode. D2 represents the 2p2L mode that we only need to let V5 to G6, V6 to G5, V7 to G8, V8 to G7. D3 represents 4p2L mode that we only need to let V3 to G4, V4 to G3, V7 to G8, V8 to G7. D4 represents 4p3L mode that we only need to link V3 and V4, V7 and V8, let V5 to G6, V6 to G5. D5 represents return to zero mode that we only need to link V5 and V6, V7 and V8. See the Fig.6.

#### V. CODE INDEPENDENT OF GLITCH

While the data do not change in two successive clock cycle, the operation will produce the variational data on the switches, but do not bring the change on the output. While the data change in two successive clock cycle, the switches that change accord with data will bring the change on the output.

From this no matter whether the input data change, the output signal complemental change all the way and do not have any relation with the input data. So the glitch which is correlated to the input data is transformed the glitch at a fixed frequency that is four times of the clock, far from the baseband and be filter.

With this scheme, the disturbances to the circuits of this segment (most particularly to the source node of the switches) or adjacent circuits are data-independent, since one transistor turns on and others turns off each quarter clock cycle. This prevents data dependent pumping of any nodes.

#### VI. EXPERIMENTAL RESULT

The Matlab simulation result of DOC is illustrated in Fig.7. The input signal is the digital sinusoidal

$$f(n) = \sin(\pi * 10^5 * n) + 2$$

whose frequency is 100Khz and the resolution is 10 bit. A 2048 point FFT is calculated based on the output signal. In Fig.7, the normal mode, (a) is wave of the time domain and we can see that the first Nyquist zone spectrum is strengthened from frequency spectrum (b). In the Fig.7, the Biphasic Bipolar level mode(2p2L), (c) is wave of the time

domain and we can see that the spectrum (d) is restrained the first Nyquist zone spectrum in a large degree, but strengthened the second and third Nyquist zone spectrum, so the spectrum is modulated the second and third Nyquist zone. In Fig.7, Quad-phase Bipolar level mode (4p2L), (e) is wave of the time domain and we can see that the spectrum (f) mainly strengthens the fourth and fifth Nyquist zone thus can realize the more high upconversion. In Fig.7, return to zero mode, (g) is wave of the time domain and we can see that the second and third Nyquist zone spectrum is strengthened from frequency spectrum (h) meanwhile the first Nyquist zone spectrum is decrease one half, so the spectrum is modulated the second and third Nyquist zone. In the Fig.7, Quad-phase triple level mode, (i) is wave of the time domain and we can get the second and third Nyquist zone spectrum (j) which is compared with the 2p2L mode is more strengthened, so it can be realization of upconversion.

#### VII. CONCLUSION

A novel switching structure called differential octuple switch able to overcome the output nonlinearities depend on input data and realized to upconversion is proposed. Through the designed control circuit, it can make the DAC worked at five modes whose functions are modulator and we can select anyone to achieve the upconversion of the output signal.

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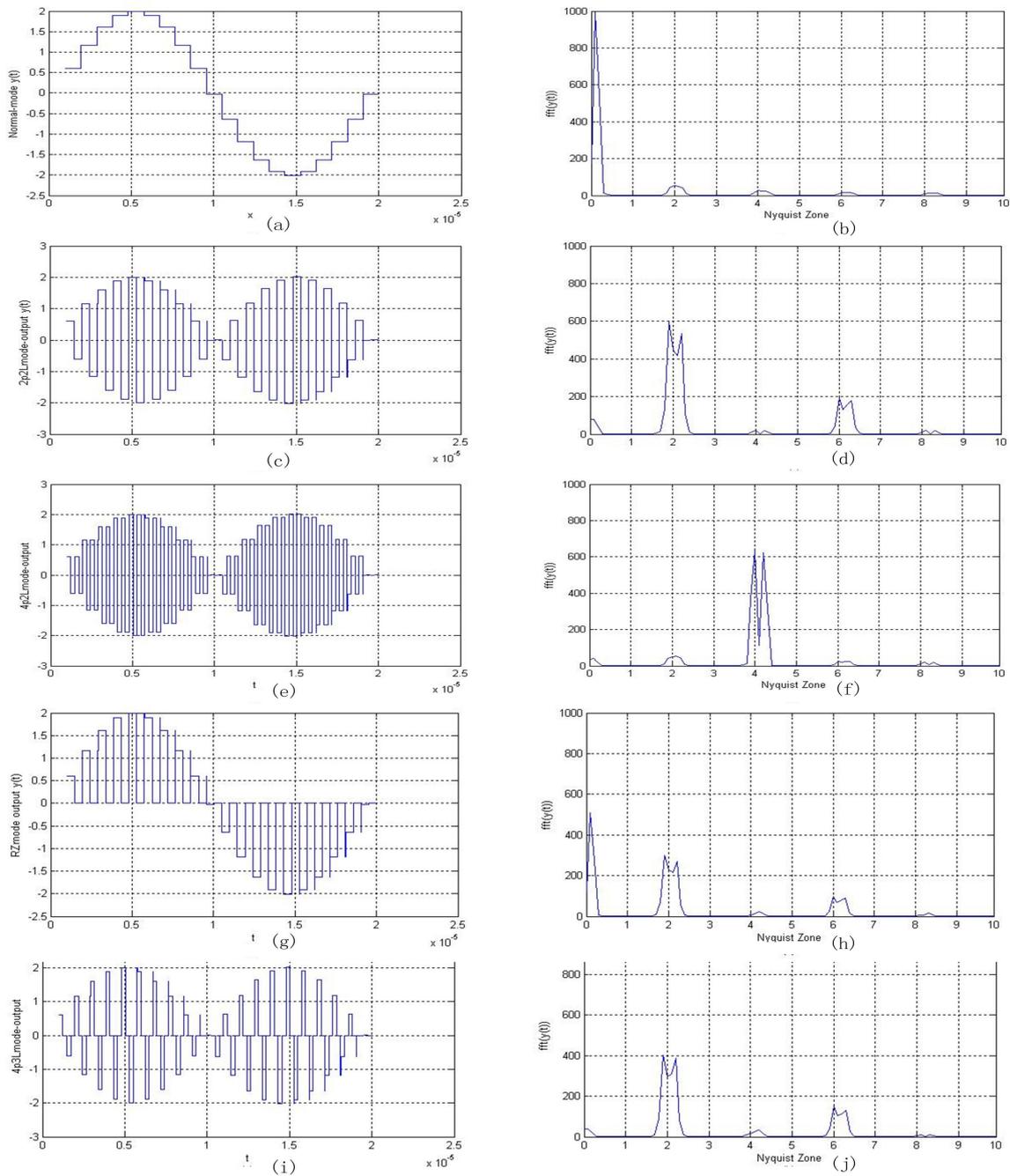


Fig. 7. The time and frequency domain wave of five modes (a)The time domain output of Normal mode. (b)The Fourier transform result of Normal mode. (c)The time domain output of 2p2L mode. (d)The Fourier transform result of 2p2L mode. (e)The time domain output of 4p2L mode. (f)The Fourier transform result of 4p2L mode. (g)The time domain output of RZ mode. (h)The Fourier transform result of RZ mode. (i)The time domain output of 4p3L mode. (j)The Fourier transform result of 4p3L mode