

## OVERVIEW

The  $\Sigma$ DECO SM5864AP D/A converter is a high-speed converter for digital audio systems fabricated using NPC's molybdenum-gate CMOS process. A selectable operating frequency and balanced outputs allow the  $\Sigma$ DECO SM5864AP to be adapted to a wide range of applications.

The  $\Sigma$ DECO SM5864AP is designed to be used with a digital eight-times oversampling filter and has two serial inputs for left- and right-channel data. The serial input data format consists of 20-bit words in 2s complement, with the most significant bit first.

The  $\Sigma$ DECO SM5864AP linearly interpolates the input signal at a high multiple of the original sampling frequency and then requantizes the resulting signal. A fourth-order noise shaper is used to remove most of the quantizing noise before the signal is output as a pulsewidth-modulated (PWM) waveform. Quasi-symmetrical PWM outputs allow the use of low system clock frequencies.

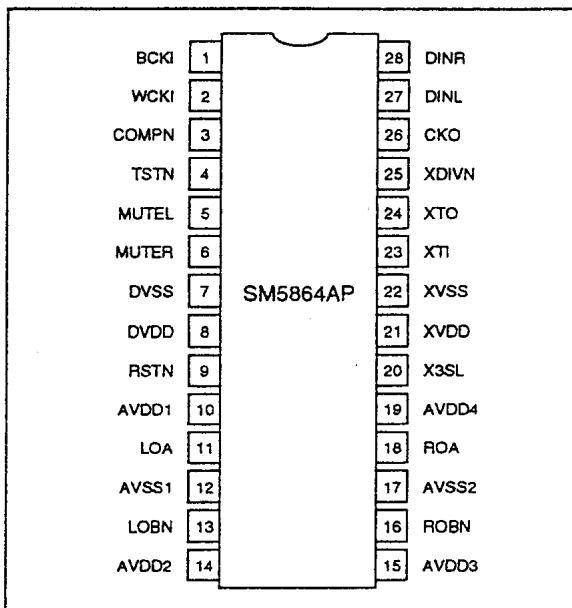
The  $\Sigma$ DECO SM5864AP has a complementary output mode that produces a single low-distortion, high-linearity output channel.

The  $\Sigma$ DECO SM5864AP operates from a single 5 V supply and is available in 28-pin plastic DIPs.

## FEATURES

- Two-channel D/A converter
- Designed for use with a digital eight-times oversampling filter.
- Quasi-symmetrical PWM outputs
- High-accuracy pulsewidth-modulated output
- 384fs, 768fs, 512fs or 1024fs selectable system clock frequencies
- On-chip crystal oscillator circuit
- Fourth-order, 32fs noise shaper
- TTL-compatible inputs and outputs
- Molybdenum-gate CMOS process
- Single 5 V supply
- 28-pin plastic DIPs

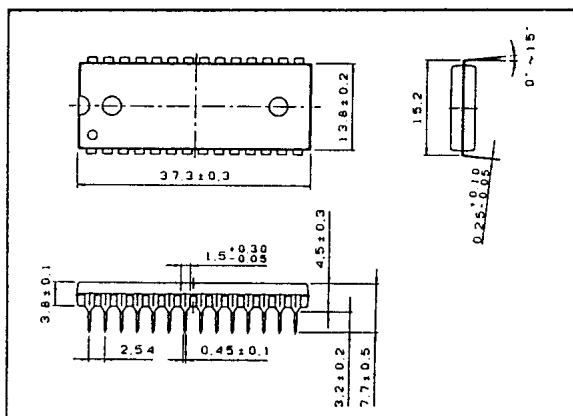
## PINOUT



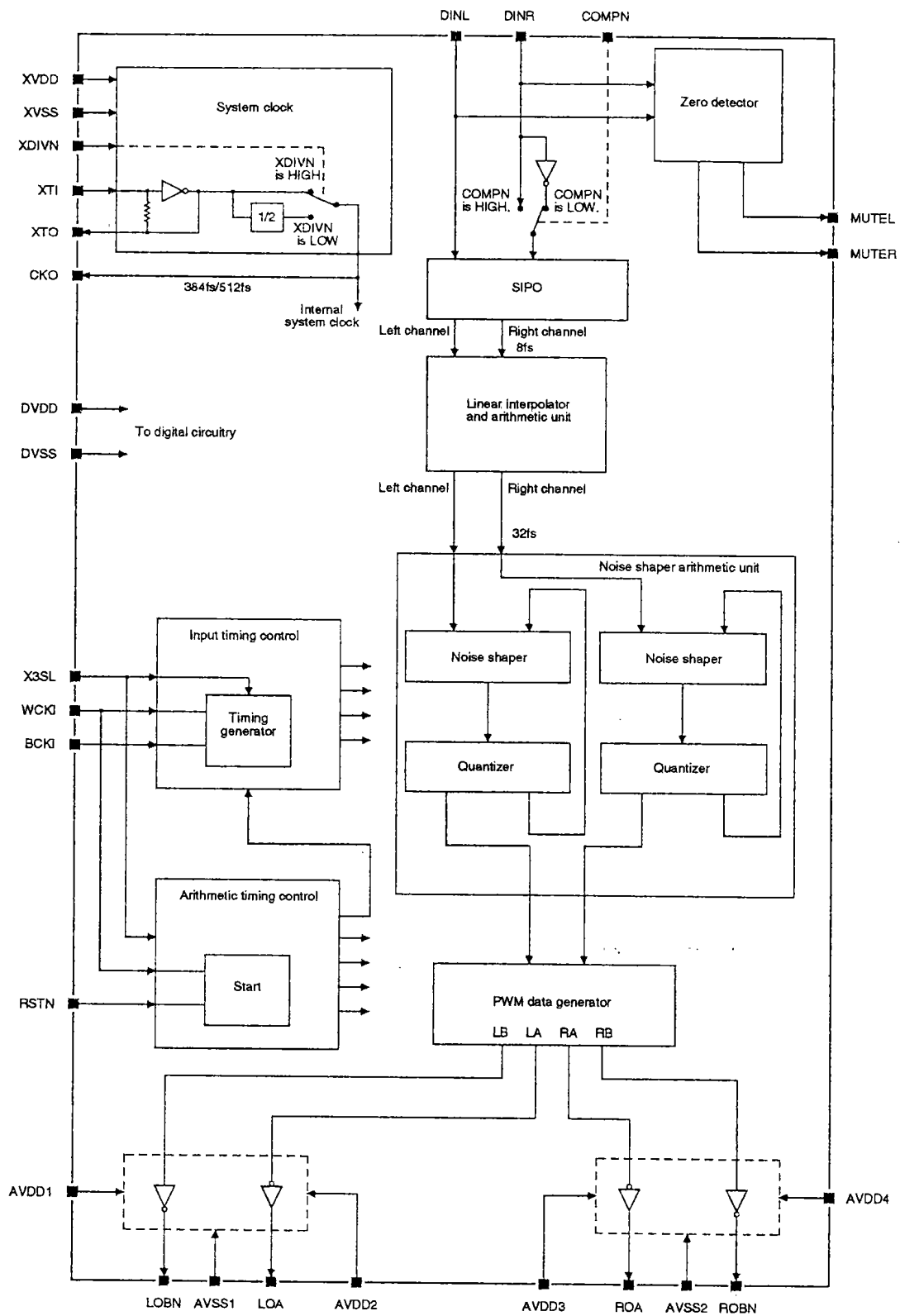
## PACKAGE DIMENSIONS

Unit: mm

Plastic DIP28



## BLOCK DIAGRAM



## PIN DESCRIPTION

| Number | Name   | Description                                                                                                                   |
|--------|--------|-------------------------------------------------------------------------------------------------------------------------------|
| 1      | BCKI   | Bit clock input. Data is latched into the input shift registers on the rising edge of BCKI. Internal pull-up resistor         |
| 2      | WCKI   | Word clock input. Words are latched into the converter input registers on the falling edge of WCKI. Internal pull-up resistor |
| 3      | COMPEN | PWM output mode select input. Internal pull-up resistor                                                                       |
| 4      | TSTN   | Test input. Tie HIGH or leave open. Internal pull-up resistor                                                                 |
| 5      | MUTEL  | Left-channel mute control output                                                                                              |
| 6      | MUTER  | Right-channel mute control output                                                                                             |
| 7      | DVSS   | Digital ground                                                                                                                |
| 8      | DVDD   | Digital supply                                                                                                                |
| 9      | RSTN   | Reset input. Active-LOW. Internal pull-up resistor                                                                            |
| 10     | AVDD1  | Analog supply 1                                                                                                               |
| 11     | LOA    | Left-channel positive PWM output                                                                                              |
| 12     | AVSS1  | Analog ground 1                                                                                                               |
| 13     | LOBN   | Left-channel negative PWM output                                                                                              |
| 14     | AVDD2  | Analog supply 2                                                                                                               |
| 15     | AVDD3  | Analog supply 3                                                                                                               |
| 16     | ROBN   | Right-channel negative PWM output                                                                                             |
| 17     | AVSS2  | Analog ground 2                                                                                                               |
| 18     | ROA    | Right-channel positive PWM output                                                                                             |
| 19     | AVDD4  | Analog supply 4                                                                                                               |
| 20     | X3SL   | Clock frequency select input. Internal pull-up resistor                                                                       |
| 21     | XVDD   | Clock supply                                                                                                                  |
| 22     | XVSS   | Clock ground                                                                                                                  |
| 23     | XTI    | Crystal oscillator or external clock input                                                                                    |
| 24     | XTO    | Crystal oscillator output                                                                                                     |
| 25     | XDIVN  | System clock frequency select input. Internal pull-up resistor                                                                |
| 26     | CKO    | 384fs or 512fs clock output                                                                                                   |
| 27     | DINL   | Left-channel serial data input. Internal pull-up resistor                                                                     |
| 28     | DINR   | Right-channel serial data input. Internal pull-up resistor                                                                    |

**Note**

fs is the sampling rate. fs is normally 44.1 kHz for CD data.

## SPECIFICATIONS

## Absolute Maximum Ratings

| Parameter                                     | Symbol                                                 | Rating                                           | Unit   |
|-----------------------------------------------|--------------------------------------------------------|--------------------------------------------------|--------|
| Supply voltage range                          | DV <sub>DD</sub> , AV <sub>DD</sub> , XV <sub>DD</sub> | -0.3 to 7.0                                      | V      |
| Input voltage range for all inputs except XT1 | V <sub>IN1</sub>                                       | DV <sub>SS</sub> - 0.3 to DV <sub>DD</sub> + 0.3 | V      |
| XT1 input voltage range                       | V <sub>IN2</sub>                                       | XV <sub>SS</sub> - 0.3 to XV <sub>DD</sub> + 0.3 | V      |
| Power dissipation                             | P <sub>D</sub>                                         | 250                                              | mW     |
| Operating temperature range                   | T <sub>opr</sub>                                       | -20 to 80                                        | deg. C |
| Storage temperature range                     | T <sub>stg</sub>                                       | -40 to 125                                       | deg. C |
| Soldering temperature                         | T <sub>SLD</sub>                                       | 255                                              | deg. C |
| Soldering time                                | t <sub>SLD</sub>                                       | 10                                               | s      |

## Recommended Operating Conditions

T<sub>a</sub> = 25 deg. C

| Parameter                   | Symbol                                                                                                                                                                                                                                           | Rating       | Unit |
|-----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------|------|
| Supply voltage              | DV <sub>DD</sub> , AV <sub>DD</sub> , XV <sub>DD</sub>                                                                                                                                                                                           | 5            | V    |
| Supply voltage range        | DV <sub>DD</sub> , AV <sub>DD</sub> , XV <sub>DD</sub>                                                                                                                                                                                           | 4.75 to 5.25 | V    |
| Supply voltage differential | DV <sub>DD</sub> - XV <sub>DD</sub> ,<br>DV <sub>DD</sub> - AV <sub>DD</sub> ,<br>XV <sub>DD</sub> - AV <sub>DD</sub> ,<br>DV <sub>SS</sub> - XV <sub>SS</sub> ,<br>DV <sub>SS</sub> - AV <sub>SS</sub> ,<br>XV <sub>SS</sub> - AV <sub>SS</sub> | -0.1 to 0.1  | V    |

## Note

All power supply pins (VDD and VSS) should be connected to the same external power supply.

## DC Electrical Characteristics

DV<sub>SS</sub> = AV<sub>SS</sub> = XV<sub>SS</sub> = 0 V, DV<sub>DD</sub> = AV<sub>DD</sub> = XV<sub>DD</sub> = 4.75 to 5.25 V, T<sub>a</sub> = -20 to 80 deg. C unless otherwise specified

| Parameter                        | Symbol            | Condition                                                                                                                         | Rating                 |     |                     | Unit            |
|----------------------------------|-------------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------|-----|---------------------|-----------------|
|                                  |                   |                                                                                                                                   | min                    | typ | max                 |                 |
| Digital circuitry supply current | I <sub>DD</sub>   | DV <sub>DD</sub> = AV <sub>DD</sub> = XV <sub>DD</sub> = 5 V,<br>f <sub>XT1</sub> = 49.2 MHz, no load. XDIVN is LOW. X3SL is LOW. | -                      | 22  | 35                  | mA              |
| Analog circuitry supply current  | I <sub>DDA</sub>  |                                                                                                                                   | -                      | 2.5 | 5                   | mA              |
| Clock circuitry supply current   | I <sub>DDX</sub>  |                                                                                                                                   | -                      | 8   | 15                  | mA              |
| LOW-level input voltage          | V <sub>IL2</sub>  | See note 1.                                                                                                                       | -                      | -   | 0.5                 | V               |
| HIGH-level input voltage         | V <sub>IH2</sub>  |                                                                                                                                   | 2.4                    | -   | -                   | V               |
| XT1 LOW-level input voltage      | V <sub>IL1</sub>  | External clock input                                                                                                              | -                      | -   | 0.3XV <sub>DD</sub> | V               |
| XT1 HIGH-level input voltage     | V <sub>IH1</sub>  |                                                                                                                                   | 0.7XV <sub>DD</sub>    | -   | -                   | V               |
| XT1 AC input voltage             | V <sub>INAC</sub> | AC coupled input                                                                                                                  | 0.3XV <sub>DD</sub>    | -   | -                   | V <sub>pp</sub> |
| PWM LOW-level output voltage     | V <sub>OLA</sub>  | I <sub>OL</sub> = 2 mA. See note 3.                                                                                               | -                      | -   | 0.3                 | V               |
| PWM HIGH-level output voltage    | V <sub>OHA</sub>  | I <sub>OH</sub> = -2 mA. See note 3.                                                                                              | AV <sub>DD</sub> - 0.3 | -   | -                   | V               |
| LOW-level output voltage         | V <sub>OL1</sub>  | I <sub>OL</sub> = 1.6 mA. See note 2.                                                                                             | -                      | -   | 0.4                 | V               |

# CMOS LSI $\Sigma$ DECO SM5864AP

| Parameter                     | Symbol    | Condition                        | Rating |     |     | Unit    |
|-------------------------------|-----------|----------------------------------|--------|-----|-----|---------|
|                               |           |                                  | min    | typ | max |         |
| HIGH-level output voltage     | $V_{OH1}$ | $I_{OH} = -0.4$ mA. See note 2.  | 2.5    | —   | —   | V       |
| CKO LOW-level output voltage  | $V_{OL2}$ | $I_{OL} = 1.6$ mA                | —      | —   | 0.5 | V       |
| CKO HIGH-level output voltage | $V_{OH2}$ | $I_{OH} = -0.4$ mA               | 2.5    | —   | —   | V       |
| LOW-level input current       | $I_{IL2}$ | $V_{IN} = 0$ V. See note 1.      | —      | 10  | 20  | $\mu$ A |
| XTI LOW-level input current   | $I_{IL1}$ | $V_{IN} = 0$ V                   | —      | 10  | 20  | $\mu$ A |
| XTI HIGH-level input current  | $I_{IH1}$ | $V_{IN} = X_{VDD}$               | —      | 10  | 20  | $\mu$ A |
| Input leakage current         | $I_{LH}$  | $V_{IN} = D_{VDD}$ . See note 1. | —      | —   | 1   | $\mu$ A |

## Notes

1. DINL, DINR, BCKI, WCKI, COMPN, TSTN, RSTN, XDIVN, X3SL
2. MUTEL, MUTER
3. LOA, LOBN, ROA, ROBN

## AC Electrical Characteristics

$DV_{SS} = AV_{SS} = XV_{SS} = 0$  V,  $DV_{DD} = AV_{DD} = XV_{DD} = 4.75$  to  $5.25$  V,  $T_a = -20$  to  $80$  deg. C unless otherwise specified

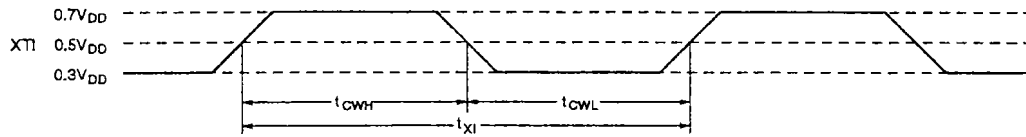
## System clock

| Parameter                            | Symbol | Condition                                   |                             | Rating |      |       | Unit |
|--------------------------------------|--------|---------------------------------------------|-----------------------------|--------|------|-------|------|
|                                      |        |                                             |                             | min    | typ  | max   |      |
| Clock frequency                      | fosc   | Crystal oscillator connected to XTI and XTO | X3SL and XDIVN are HIGH.    | 2.0    | 16.9 | 20.0  | MHz  |
|                                      |        |                                             | X3SL is HIGH, XDIVN is LOW. | 4.0    | 33.9 | 39.5  |      |
|                                      |        |                                             | X3SL is LOW, XDIVN is HIGH. | 4.0    | 24.6 | 27.5  |      |
|                                      |        |                                             | X3SL and XDIVN are LOW.     | 8.0    | 49.2 | 51.5  |      |
| External clock LOW-level pulsewidth  | tcwl   | X3SL and XDIVN are HIGH.                    |                             | 23.0   | 29.5 | 250.0 | ns   |
|                                      |        | X3SL is HIGH, XDIVN is LOW.                 |                             | 12.0   | 14.7 | 125.0 |      |
|                                      |        | X3SL is LOW, XDIVN is HIGH.                 |                             | 16.5   | 20.3 | 125.0 |      |
|                                      |        | X3SL and XDIVN are LOW.                     |                             | 8.3    | 10.1 | 62.0  |      |
| External clock HIGH-level pulsewidth | tcwh   | X3SL and XDIVN are HIGH.                    |                             | 23.0   | 29.5 | 250.0 | ns   |
|                                      |        | X3SL is HIGH, XDIVN is LOW.                 |                             | 12.0   | 14.7 | 125.0 |      |
|                                      |        | X3SL is LOW, XDIVN is HIGH.                 |                             | 16.5   | 20.3 | 125.0 |      |
|                                      |        | X3SL and XDIVN are LOW.                     |                             | 8.3    | 10.1 | 62.0  |      |
| External clock period                | tphi   | X3SL and XDIVN are HIGH.                    |                             | 50.0   | 59.0 | 500.0 | ns   |
|                                      |        | X3SL is HIGH, XDIVN is LOW.                 |                             | 25.3   | 29.5 | 250.0 |      |
|                                      |        | X3SL is LOW, XDIVN is HIGH.                 |                             | 36.5   | 40.7 | 250.0 |      |
|                                      |        | X3SL and XDIVN are LOW.                     |                             | 19.5   | 20.3 | 125.0 |      |

## Note

Typical ratings are based on 44.1 kHz (X3SL is HIGH) and 48.0 kHz (X3SL is LOW) sampling frequencies.

### Clock timing waveform



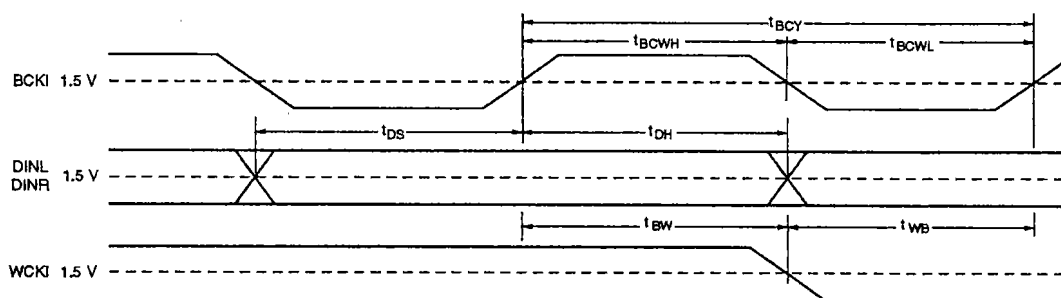
### Reset timing

| Parameter                  | Symbol     | Condition                    | Rating |     |     | Unit    |
|----------------------------|------------|------------------------------|--------|-----|-----|---------|
|                            |            |                              | min    | typ | max |         |
| Reset LOW-level pulsewidth | $t_{RSTN}$ | At power-up                  | 1      | —   | —   | $\mu$ s |
|                            |            | At times other than power-up | 20     | —   | —   | ns      |

### Serial input timing

| Parameter                  | Symbol     | Condition | Rating |     |     | Unit |
|----------------------------|------------|-----------|--------|-----|-----|------|
|                            |            |           | min    | typ | max |      |
| BCKI LOW-level pulsewidth  | $t_{BCWL}$ |           | 30     | —   | —   | ns   |
| BCKI HIGH-level pulsewidth | $t_{BCWH}$ |           | 30     | —   | —   | ns   |
| BCKI period                | $t_{BCY}$  |           | 60     | —   | —   | ns   |
| DINL and DINR setup time   | $t_{DS}$   |           | 20     | —   | —   | ns   |
| DINL and DINR hold time    | $t_{DH}$   |           | 20     | —   | —   | ns   |
| BCKI to WCKI delay time    | $t_{BW}$   |           | 30     | —   | —   | ns   |
| WCKI to BCKI delay time    | $t_{WB}$   |           | 20     | —   | —   | ns   |

### Serial input timing waveform



## AC Analog Characteristics

$DV_{DD} = AV_{DD} = XV_{DD} = 5\text{ V}$ ,  $DV_{SS} = AV_{SS} = XV_{SS} = 0\text{ V}$ ,  $XDIVN$  and  $X3SL$  are HIGH, external crystal oscillator clock input,  $f_{osc} = 16.9344\text{ MHz}$ ,  $T_a = 25\text{ deg. C}$

| Parameter                           | Symbol    | Condition                                                  | Rating |        |       | Unit      |
|-------------------------------------|-----------|------------------------------------------------------------|--------|--------|-------|-----------|
|                                     |           |                                                            | min    | typ    | max   |           |
| Total harmonic distortion and noise | THD + N   | $f = 1\text{ kHz}$ , $V_I = 0\text{ dB}$                   | —      | 0.0015 | 0.002 | %         |
| Output level                        | $V_{OUT}$ | $f = 1\text{ kHz}$ , $V_I = 0\text{ dB}$                   | 1.8    | 2.0    | 2.2   | $V_{rms}$ |
| Dynamic range                       | D.R       | $f = 1\text{ kHz}$ , $V_I = -60\text{ dB}$                 | 95     | 98     | —     | dB        |
| Signal-to-noise ratio               | S/N       | $f = 1\text{ kHz}$ , $V_I = 0\text{ to }-\infty\text{ dB}$ | 100    | 104    | —     | dB        |
| Channel separation                  | Ch. Sep   | $f = 1\text{ kHz}$ , $V_I = -\infty\text{ dB}$             | 85     | 95     | —     | dB        |

### Note

Parameters measured in accordance with EIAJ Standard CP-307.

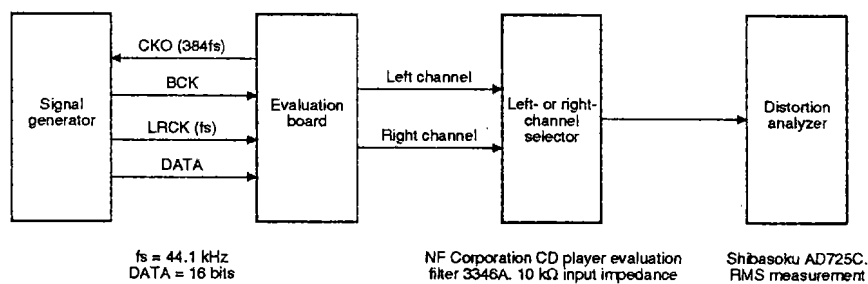
## Measurement Circuits

### Measurement conditions

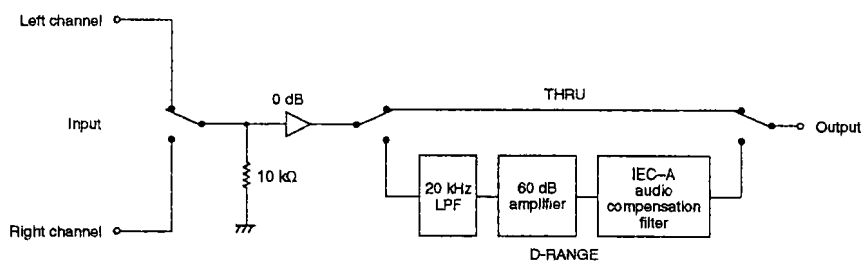
| Parameter                           | Symbol    | 3346A channel selector position | AD725C distortion analyzer setting                                                              |
|-------------------------------------|-----------|---------------------------------|-------------------------------------------------------------------------------------------------|
| Total harmonic distortion and noise | THD + N   | THRU                            | 20 kHz lowpass filter is ON.<br>400 Hz highpass filter is OFF.                                  |
| Output level                        | $V_{OUT}$ |                                 |                                                                                                 |
| Dynamic range                       | D.R       | D-RANGE                         | 20 kHz lowpass filter is ON.<br>400 Hz highpass filter is OFF.<br>JIS* A-weighted filter is ON. |
| Signal-to-noise ratio               | S/N       | THRU                            |                                                                                                 |
| Channel separation                  | Ch. Sep   | THRU                            | 20 kHz lowpass filter is ON.<br>400 Hz highpass filter is OFF.                                  |

\* Japanese Industrial Standard

### Measurement circuit block diagram



### Channel selector internal circuit

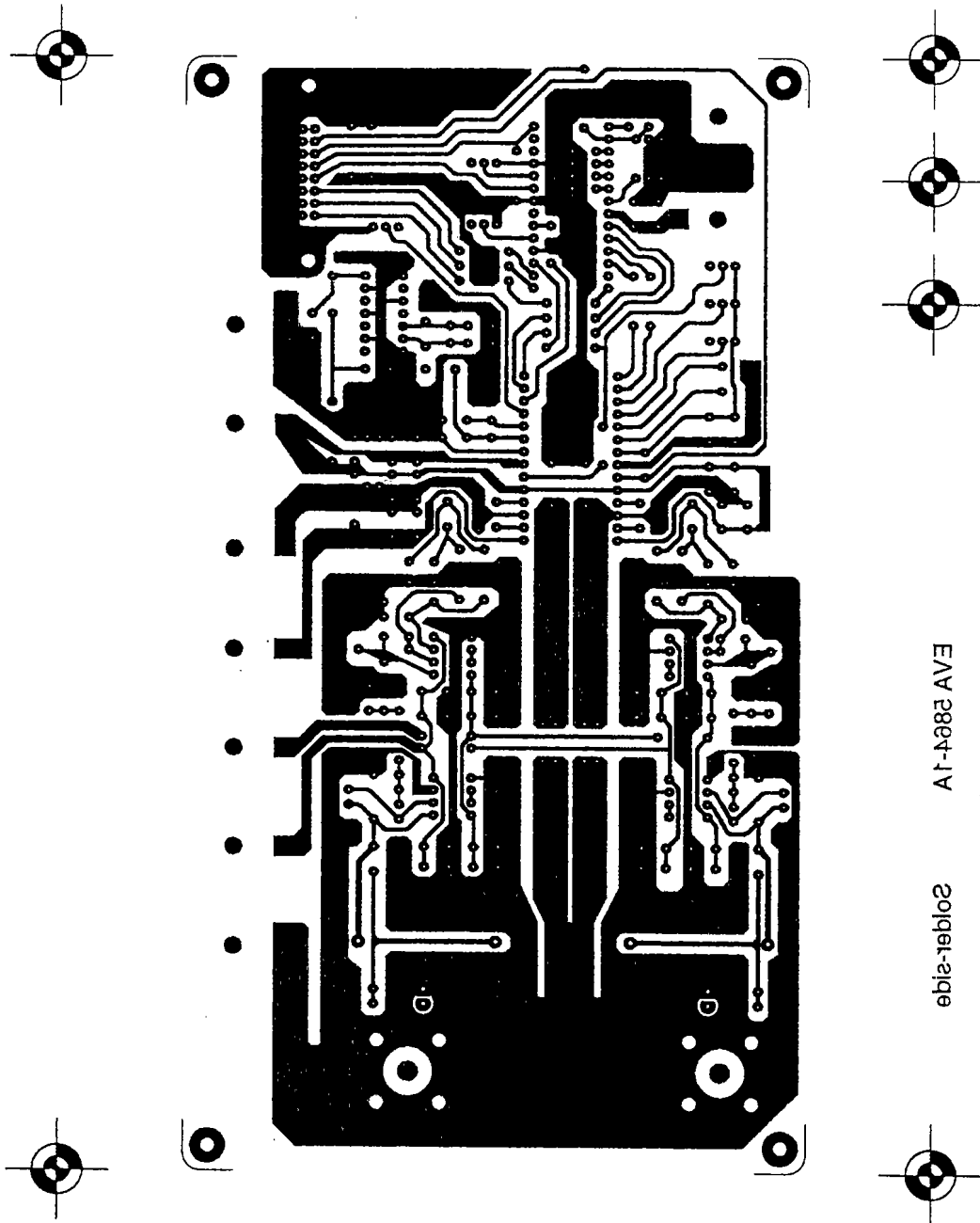






PCB pattern

The following figure has been reduced by 30%.



## FUNCTIONAL DESCRIPTION

### System Clock

XDIVN and X3SL select the system clock frequency as a function of the sampling rate, fs. The

effect of XDIVN and X3SL on the system clock and CKO output frequencies is shown in table 1.

Table 1. System clock selection

| X3SL | XDIVN | Clock frequency | CKO output frequency |
|------|-------|-----------------|----------------------|
| LOW  | LOW   | 1024fs          | 512fs                |
| LOW  | HIGH  | 512fs           | 512fs                |
| HIGH | LOW   | 768fs           | 384fs                |
| HIGH | HIGH  | 384fs           | 384fs                |

As the stability and signal-to-noise ratio of the system clock greatly affects the AC analog characteristics, care should be taken to ensure that the clock is free from jitter.

The system clock can be controlled by a crystal oscillator, connected as shown in figure 1. Capacitors C1 and C2 should be chosen to match the crystal oscillator used. The system clock can also be supplied externally as shown in figure 2. When using this method, XTO should be left unconnected.

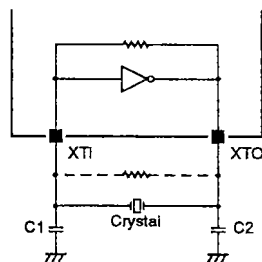


Figure 1. Crystal oscillator connections

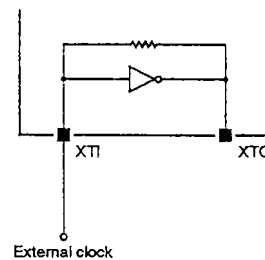


Figure 2. External clock input

### Output Modes

The  $\Sigma$ DECO SM5864AP has two output modes, normal and complementary. When COMPN is HIGH, normal mode is selected.

The device then converts and outputs both the left and right channels as shown in figure 3.

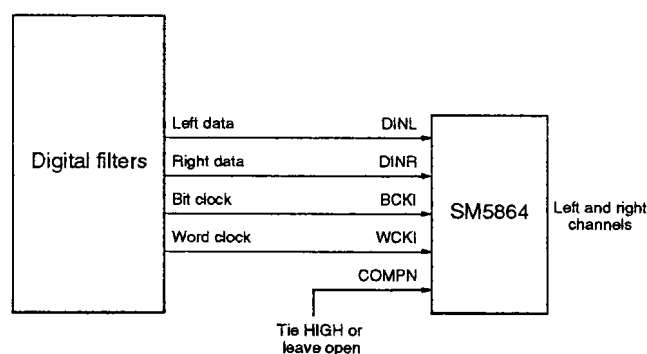


Figure 3. Normal output configuration

When COMPN is LOW, complementary mode is selected and the  $\Sigma$ DECO SM5864AP converts only one channel. Two devices are needed to process

both the left and right channels as shown in figure 4. This configuration results in improved distortion and interchannel crosstalk characteristics.

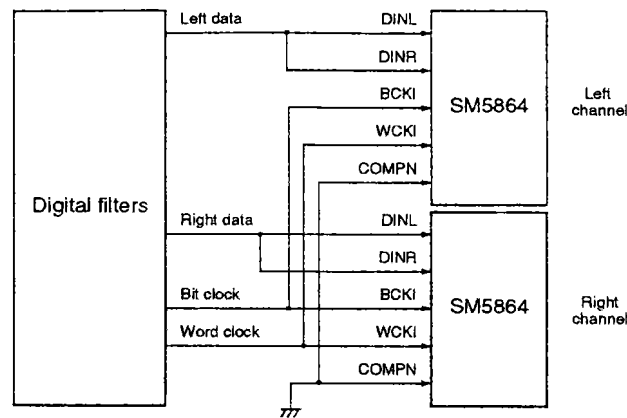


Figure 4. Complementary output configuration

### Pulsewidth Modulation Waveforms

The signals output by the  $\Sigma$ DECO SM5864AP are quasi-symmetrical. Each individual output signal is not symmetrical about the center of the output

pulses, however the difference signals (LOA – LOBN) and (ROA – ROBN) are symmetrical as shown in figure 5.

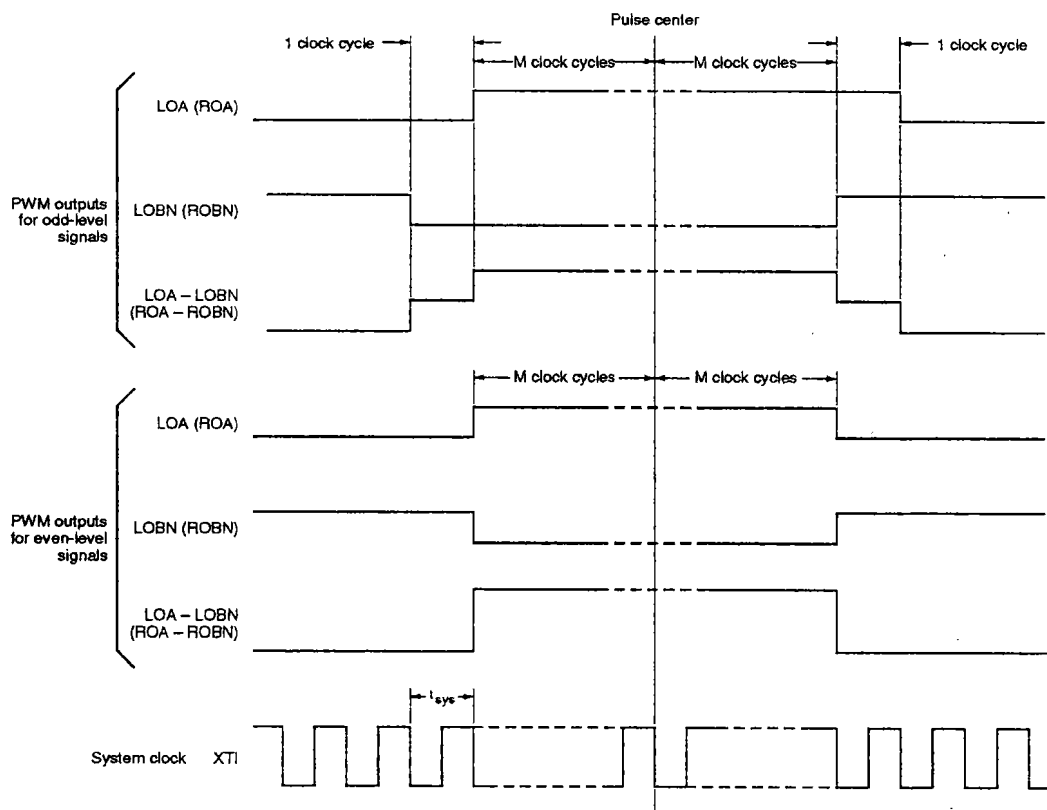


Figure 5. PWM output waveforms

## Reset

At power-on, or after a change in system parameters, the input data timing may be corrupted. A LOW-level pulse on RSTN will resynchronize the  $\Sigma$ DECO SM5864AP with the preceding over-sampling filter stage.

Upon reset, the following takes place:

1. The internal timing is resynchronized on the falling edge of the 65th cycle of WCKI after RSTN goes HIGH.
2. The PWM outputs are muted with a 50% duty cycle signal from the time when RSTN goes LOW until the rising edge of the 96th cycle of WCKI after RSTN goes HIGH.

## Mute Detection

When the serial input data on DINL and DINR remains zero for  $2^{21}$  consecutive bits, the cor-

responding mute output (MUTEL or MUTER) goes HIGH. Note that the two least significant bits of each word are ignored. If the data remains zero for a further  $2^{21}$  bits, the PWM output changes to a 50% duty cycle waveform, suppressing unnecessary noise. A 50% duty cycle waveform corresponds to the analog ground level after lowpass filtering. For a 44.1 kHz sampling rate and 18-bit word length,  $2^{21}$  bits correspond to a period of approximately 330 ms. Muting operates independently for each channel.

## Linear Interpolator

The linear interpolator oversamples the 8fs input signal at the 32fs noise shaper operating frequency. The frequency characteristic of the linear interpolator is shown in figure 6.

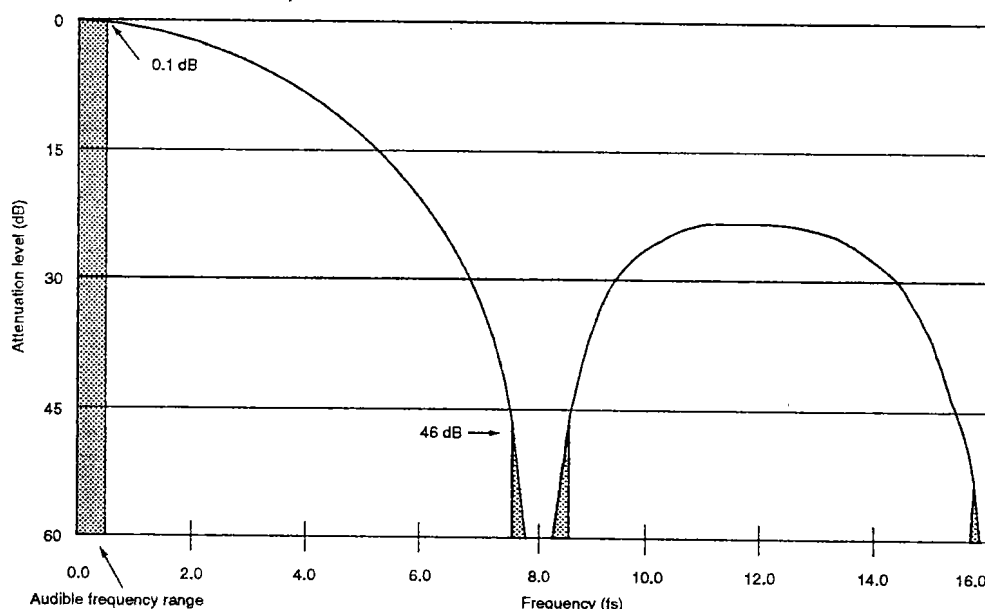


Figure 6. Linear interpolator frequency characteristic

## Noise Shaper

A fourth-order noise shaper is implemented on the  $\Sigma$ DECO SM5864AP to eliminate quantization noise in the audio band. The noise shaper uses an NPC proprietary technique which shifts the zero point of the quantization noise processed by the noise

shaper. Figure 7 shows the quantization noise component of the signal before the PWM output stage relative to the quantization noise of a non-oversampled 16-bit signal.

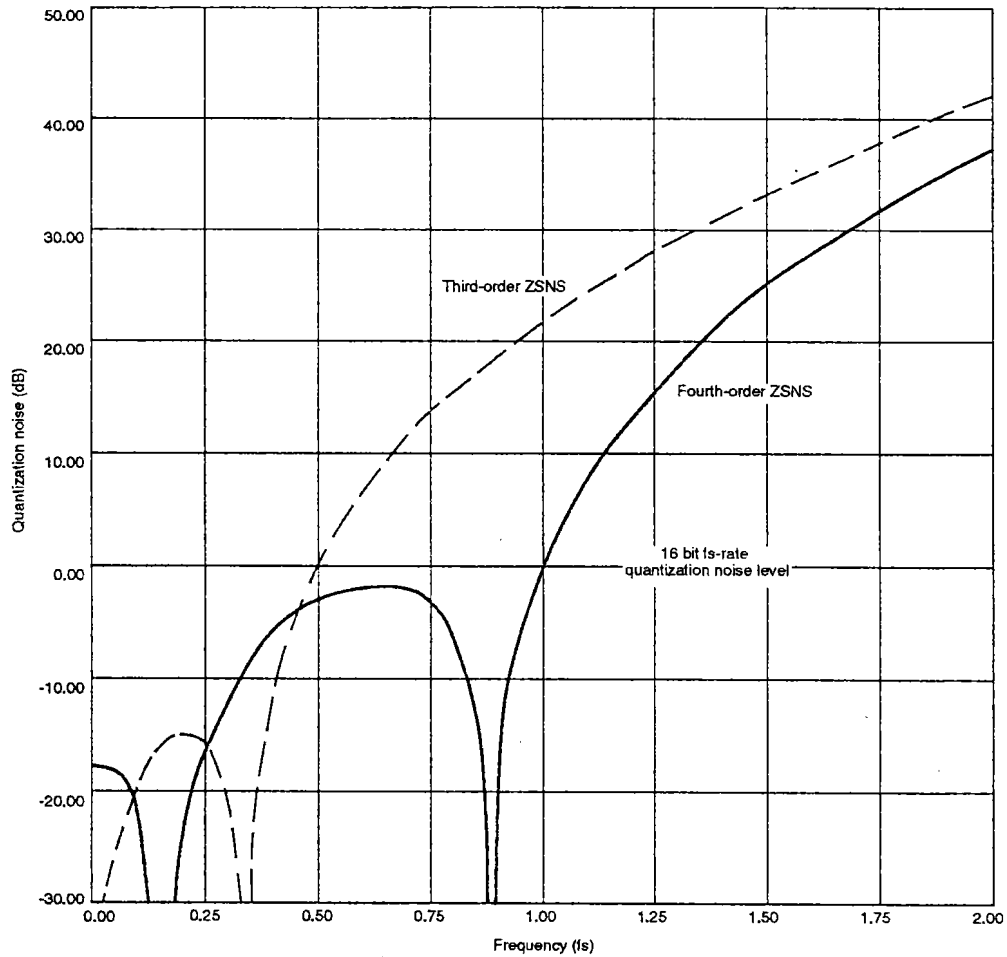


Figure 7. Noise shaper characteristic

## DATA FORMAT WAVEFORMS

## Audio Data Input

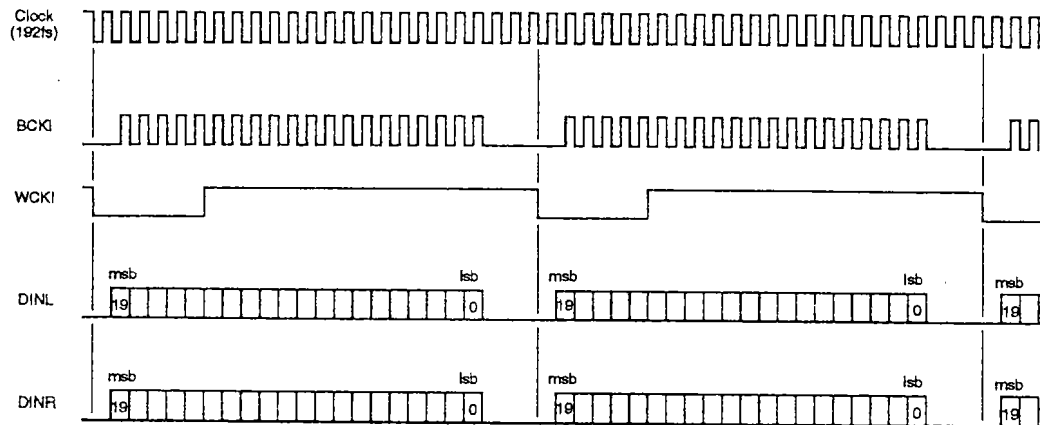


Figure 8. Audio data format 1

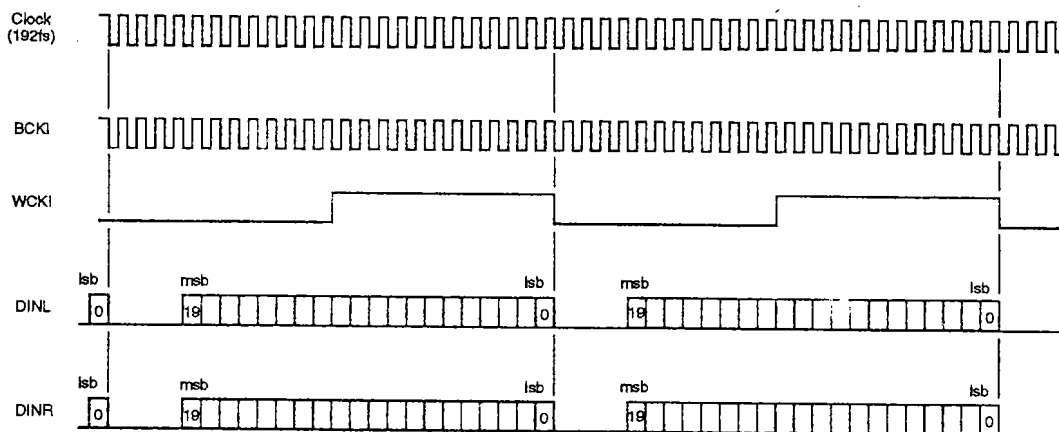


Figure 9. Audio data format 2

## APPLICATION NOTES

## Input Interfaces

## Interface to SM5813 digital eight-times oversampling filter

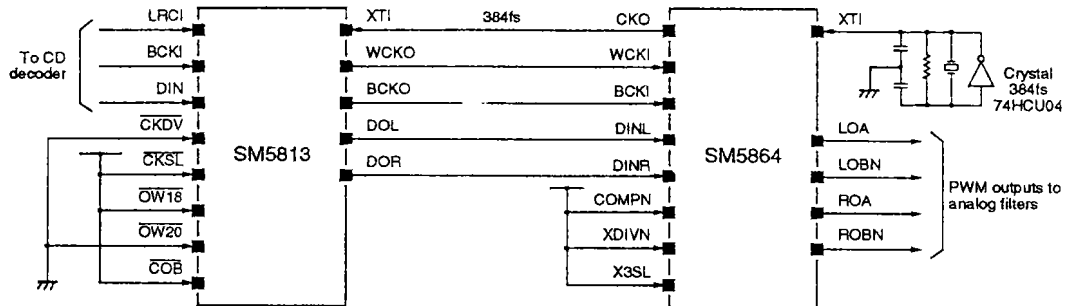


Figure 10. SM5813 interface 1

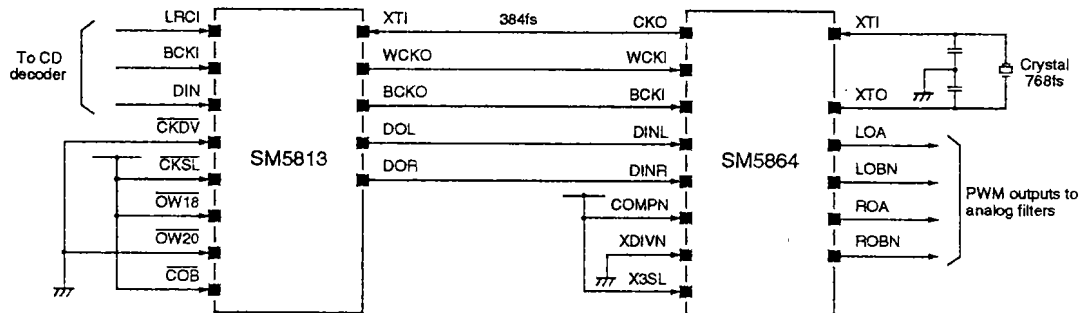


Figure 11. SM5813 interface 2

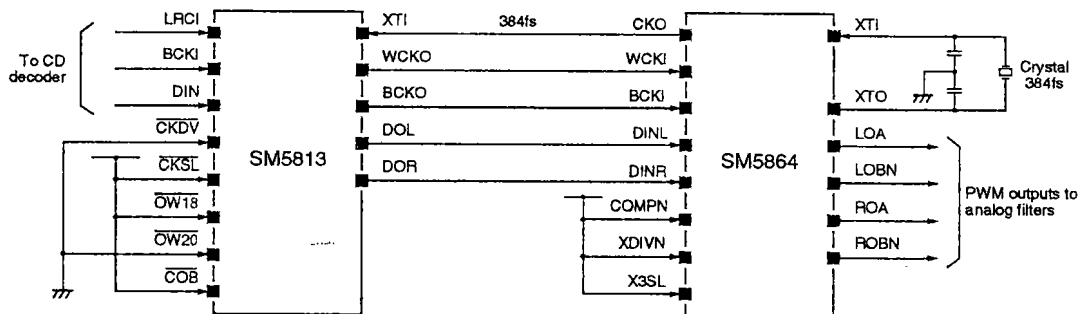


Figure 12. SM5813 interface 3

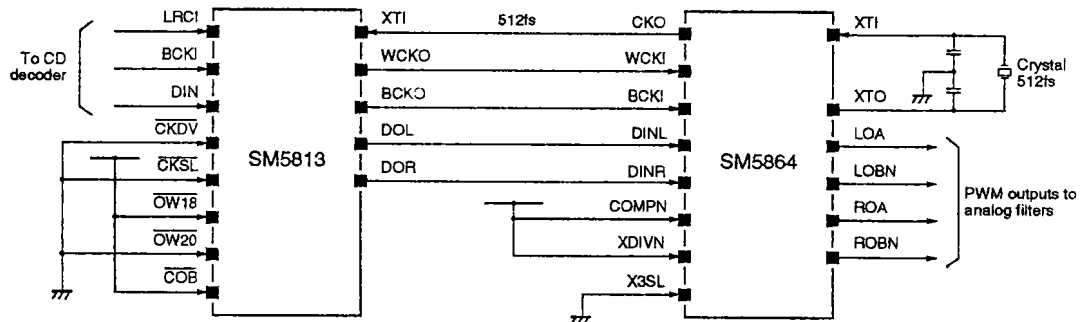


Figure 13. SM5813 interface 4

Interface to SM5840A digital eight-times oversampling filter

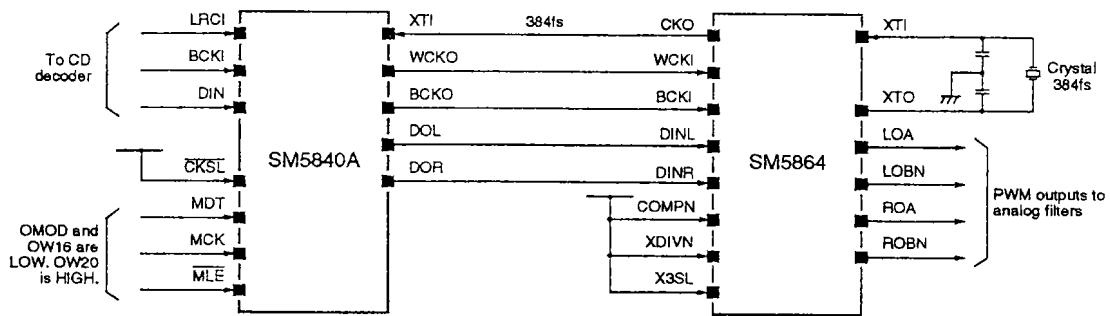


Figure 14. SM5840A interface

Interface to SM5840C digital eight-times oversampling filter

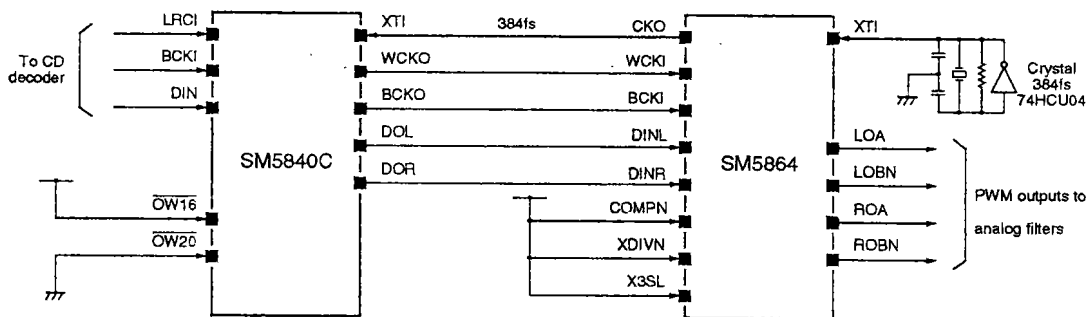


Figure 15. SM5840C interface 1

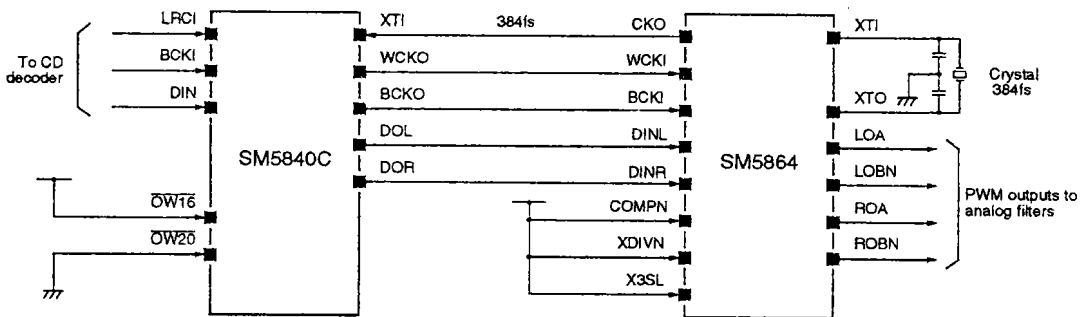


Figure 16. SM5840C interface 2

## Output Interfaces

To avoid duplication, only the left channel has been shown in the following figures.

### Normal output mode

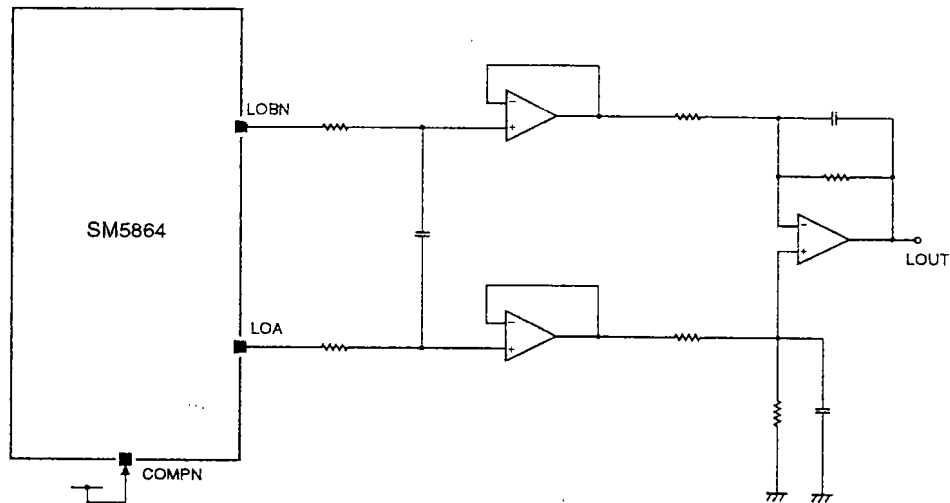


Figure 17. Normal output mode circuit 1

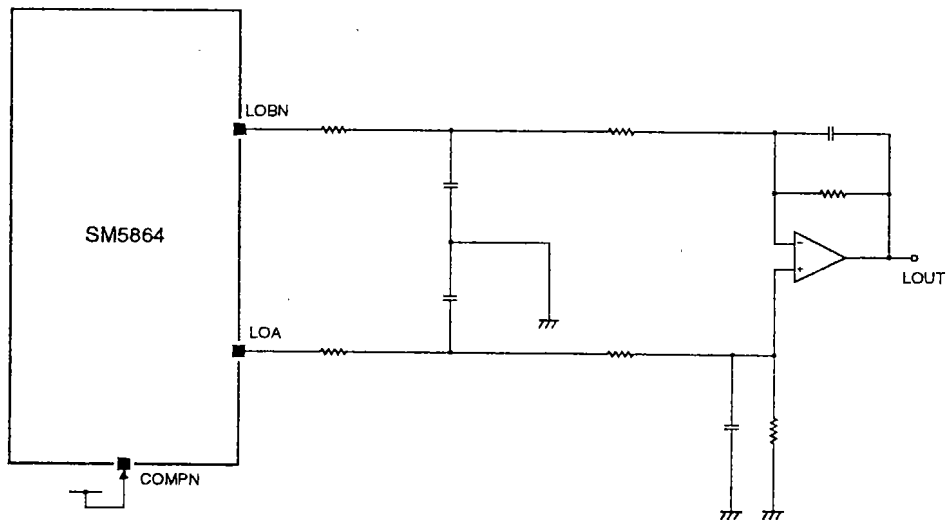


Figure 18. Normal output mode circuit 2

## Complementary output mode

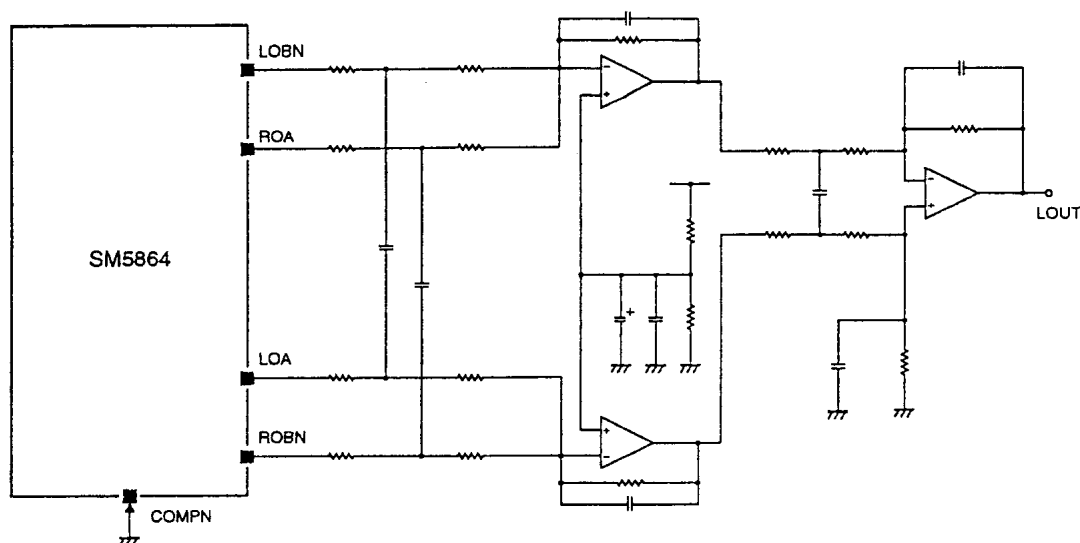


Figure 19. Complementary output mode circuit 1

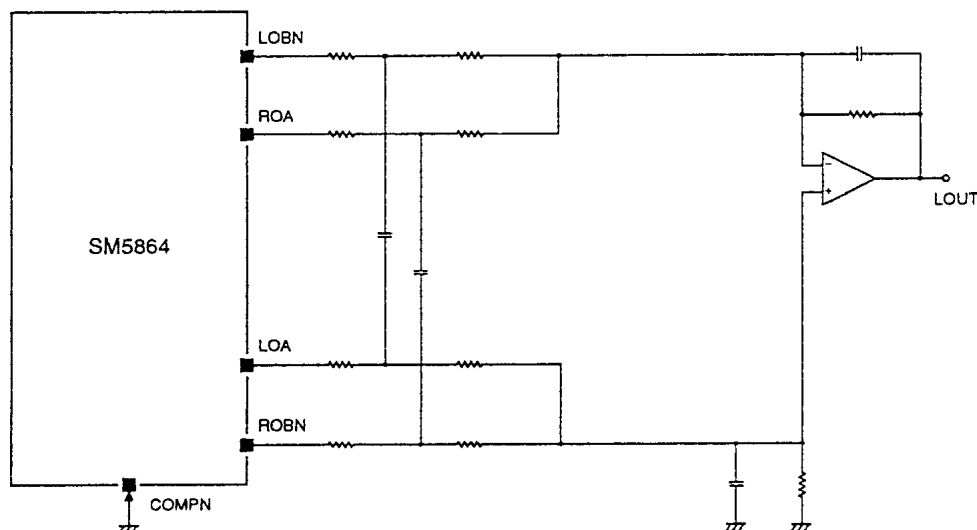


Figure 20. Complementary output mode circuit 2

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