

# CS8416 Delivers Performance Gains Over CS8413/14

by  
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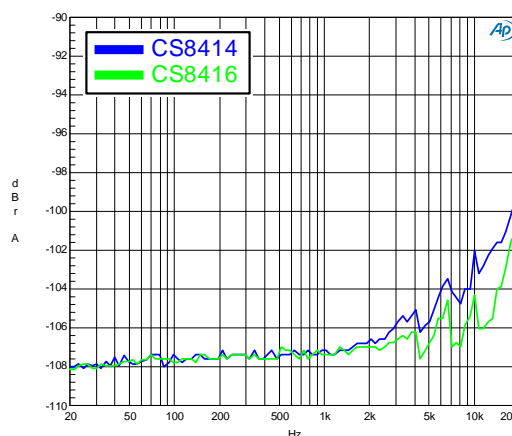
## 1. INTRODUCTION

The CS8413/14 S/PDIF receivers have long held a position of respect as the industry-favored receivers for recovered clock quality. As of early 2009, an upcoming end-of-life of these products has many system designers wondering what their next move will be, and where they'll go to get the level of performance they've become accustomed to. Others simply need 192 kHz support, which the CS8413/14 does not provide.

Satisfying both of these requirements, Cirrus Logic offers the CS8416 S/PDIF receiver with new features and lower recovered clock jitter than the CS8413/14.

When the CS8416 was first released in 2002, it used a phase detector scheme that resulted in higher recovered clock jitter compared to the CS8413/14. To improve on its performance and follow in the tradition of the CS8413/14, a new phase detector option was added to the CS8416 in 2004. This new option offers even lower recovered clock jitter than the CS8413/14 and results in measurably improved audio performance as shown in [Figure 1](#).

This application note details how the CS8416 improves upon the performance of the CS8413/14. A summary of important functional differences and detailed jitter and audio performance measurements are included to clearly demonstrate the improvements that can be expected when transitioning to the CS8416.



**Figure 1. DAC THD+N**

## 2. SUMMARY OF IMPROVEMENTS

Many improvements were made in the generational leap from the CS8413/14 to the CS8416. For reference, some of the high-level improvements are summarized in the table below. For more information, please refer to each device's datasheet.

Parameter	CS8413/14	CS8416	Unit
Maximum Sample Rate	96	192	kHz
Baseband Jitter ( <a href="#">Note 1</a> )	158.5	122.6 ( <a href="#">Note 2</a> )	ps
Logic Supply Voltage Range	5	3.3 - 5	V
Power Supply Consumption	175	47.5	mW
Back-up System Clock During Receiver Error	None	OMCK pin	-
Receiver Input Pins	1	8 in SW Mode, 4 in HW Mode	-
Dedicated Reset Pin	None	Yes	-
Control Port Protocol	Parallel Port, CS8413 Only	I <sup>2</sup> C and SPI	-

**Table 1. Summary of CS8416 Improvements**

**Notes:** 1. Values listed are from experiment results. See [Section 5](#)  
2. PDUR=1. See [Section 3](#)

Beyond those listed in the table, several other notable enhancements are available in the CS8416:

### General Enhancements

- Optional automatic enable of de-emphasis filter based on channel status bits.
- Dedicated S/PDIF receiver pass-through pin.
- Selectable recovered master clock frequency of  $256 \times F_s$  or  $128 \times F_s$ .
- SOIC, TSSOP, and QFN package options.
- Available in automotive grade.

### Software Mode Enhancements

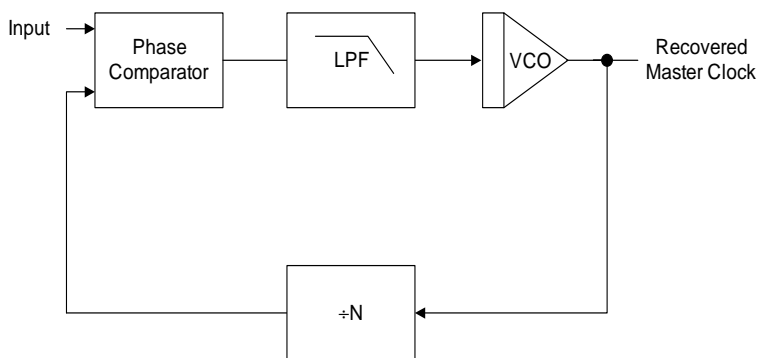
- Three configurable GPO pins.
- Data output muting capability.
- Data format detection and reporting.
- Channel status register update inhibit function.
- User data Q-channel subcode decoding into registers.
- IEC61937 Pc/Pd burst preamble registers.

There are a number of other differences between the CS8413/14 and the CS8416 that a designer considering a transition from the CS8413/14 to the CS8416 should be aware of. For reference, a list of some of the more significant differences is included in [Section 9.1 on page 10](#).

## 3. BASICS OF CLOCK RECOVERY

The purpose of a S/PDIF receiver is to convert a 1-wire S/PDIF input signal containing both clock and data information into discrete serial audio clock and data signals. A phase-locked loop (PLL) is used to derive a system clock signal synchronous to the S/PDIF stream, and digital logic is used to decode the data.

In some limited applications, a S/PDIF receiver is used to source data into a purely digital system where clock jitter needs to be only good enough to operate the internal digital components. However, the vast majority of systems with a S/PDIF receiver also contain a D/A converter, an A/D converter, or a combination of the two, all being clocked by the PLL recovered system clock generated by the S/PDIF receiver. In these systems, the jitter performance of the S/PDIF recovered clock is of extreme importance because it has a direct impact on the system's analog audio performance.



**Figure 2. PLL Block Diagram**

As a result, an important qualifying factor for a S/PDIF receiver is the performance of its recovered clock. If the S/PDIF receiver does not provide a low-jitter recovered clock, then any converters that use the clock for sampling can be expected to exhibit reduced performance as a result.

The basic block diagram of the PLL is shown in [Figure 2](#). The PLL uses a negative feedback loop to compare the phase of the input clock to that of the output clock. The resulting error voltage signal is low pass filtered and sent to an internal voltage-controlled oscillator (VCO). The VCO output

clock frequency is adjusted by the error signal voltage until the output clock frequency matches the input. The feedback loop contains a frequency divider so that the output clock frequency can be a multiple of the input frequency.

The amount of jitter present on the recovered clock is dependent on the characteristics of the PLL that generates the clock. Since the CS8413/14 and CS8416 have different PLLs, the jitter on their recovered clocks is expected to be different as discussed in the following section.

## 4. CS8413/14 AND CS8416 CLOCK RECOVERY COMPARED

The primary difference between the CS8413/14 and CS8416 PLLs is found in the input source to each PLL's phase detector block. In each of these devices, digital logic analyzes the incoming biphas encoded S/PDIF stream to generate pulses that serve as the input to the phase comparator. The frequency of these pulses is referred to as the phase detector update rate.

The more often the phase detector is updated, the more often the VCO output frequency is corrected to match the frequency of the input S/PDIF signal. A slower update rate allows the VCO frequency a greater degree of wander, leading to increased low frequency (audio-band) recovered clock jitter. See [Figure 3](#) and [Figure 4](#).

In practice, the CS8413/14 detector is updated once per bit of the input S/PDIF signal; thus the update rate is data dependent 64 times the input sample rate. With an update rate of this frequency, the CS8413/14 has good audio-band output jitter.

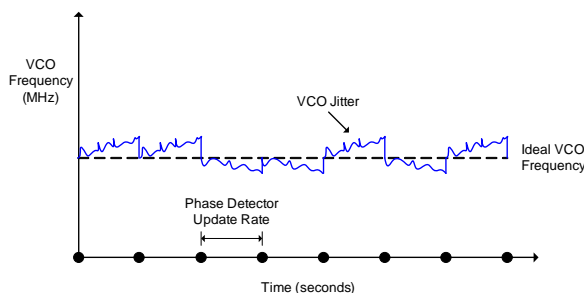
When the CS8416 was first released in 2002, its digital logic was designed to update its phase detector only once per subframe of the S/PDIF input signal, or at 2 times the input sample rate. This was done as a measure designed to support 192 kHz sample rates and to reduce data dependency. The unfortunate result of this slower update rate was higher audio-band jitter present on the recovered master clock.

To address this issue and improve upon the CS8416 and CS8413/14, in 2004 a new phase detector update rate option was added to the CS8416.

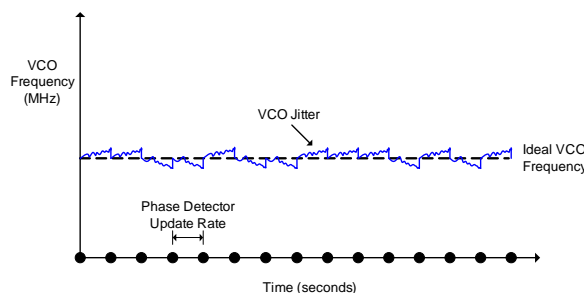
When enabled, the newer update rate option causes the phase detector to be updated on every edge of the biphas S/PDIF input signal; thus the update rate is data dependent from 64 to 128 times the input sample rate. This new detector lowers the audio-band recovered clock jitter and results in improved converter performance.

It's important to note that the maximum sample rate is limited to 108 kHz in this newer mode. The different detector modes in the CS8416 are selected by the Phase Detector Update Rate (PDUR) control. PDUR set low ('0') selects the original and slower update rate, while PDUR set high ('1') selects the new fast update rate. The PDUR setting can be accessed at start-up through the TX pin in hardware mode, or in register 00h in software mode.

Since the CS8416 with PDUR = 1 has the same update rate or faster than the CS8413/14, the CS8416 is expected to have lower audio-band recovered clock jitter. [Section 5](#) below details the results of jitter measurement tests that empirically support this conclusion.



**Figure 3. Slow Phase Detector Update Rate**



**Figure 4. Fast Phase Detector Update Rate**

## 5. MEASURED JITTER COMPARISON

Although there are several different jitter specifications used to quantify the jitter present on a clock signal (period, cycle-to-cycle, etc.), they are not all useful for correlating measured jitter to the THD+N performance of an audio converter that uses the measured clock signal to drive its sampling circuits.

The best jitter specification for this correlation is 'baseband jitter' as defined in section 3.4.2 of AES-12id-2006. A baseband jitter measurement band-passes the measured jitter signal, calculating the jitter amplitude over a frequency band from 100 Hz to 40 kHz. Jitter outside of this frequency band is said to have no effect on the THD+N performance of an audio converter because the resulting modulation tones will either be psycho-acoustically masked (jitter less than 100 Hz) or higher than the upper limit of the 20 kHz audio band (jitter greater than 40 kHz).

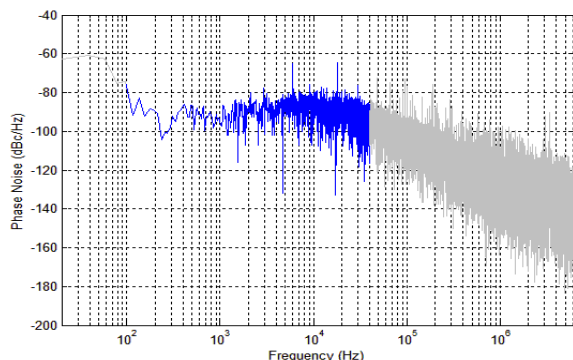
Each receiver, including both of the CS8416 phase detector update modes, was tested with input S/PDIF sample rates at common values of 48 kHz and 96 kHz. Additionally, the CS8416 was tested at 192 kHz with PDUR = 0.

The resulting baseband jitter measurement data is presented in [Table 2](#). Phase noise plots showing the measured jitter signal on the receivers' recovered clocks are displayed in [Figures 5 through 11](#). Refer to [Section 9.2](#) for detailed test set-up information and diagrams.

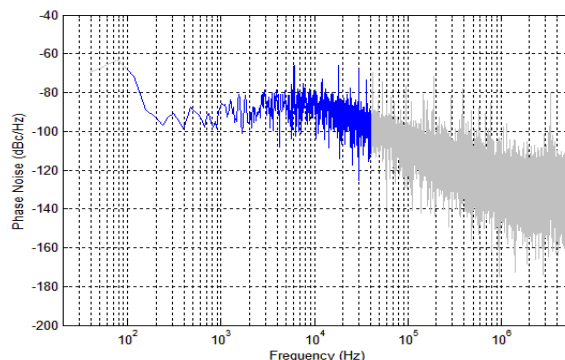
Sample Rate	CS8414 -	CS8416 PDUR=1	CS8416 PDUR=0	Unit
48 kHz	158.5 ( <a href="#">Figure 5</a> )	122.57 ( <a href="#">Figure 7</a> )	531.41 ( <a href="#">Figure 9</a> )	ps
96 kHz	111.01 ( <a href="#">Figure 6</a> )	45.278 ( <a href="#">Figure 8</a> )	212.35 ( <a href="#">Figure 10</a> )	ps
192 kHz	-	-	215.43 ( <a href="#">Figure 11</a> )	ps

**Table 2. Baseband Jitter - Summary**

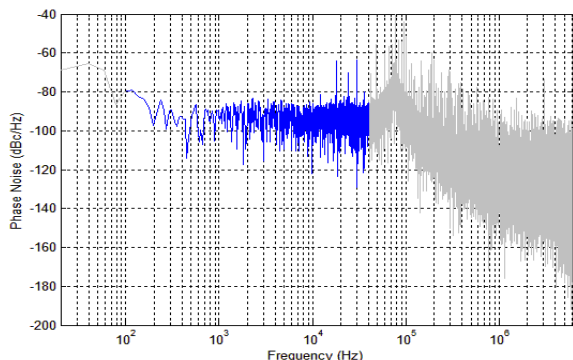
The highlighted portions of each plot denote the 100 Hz to 40 kHz bandwidth specified by the AES-12id-2006 baseband jitter definition. As the definition suggests, the magnitude of the highlighted portion of the plots correlate to audio-band converter THD+N performance. Thus, the lower the magnitude, the better the converter performance.



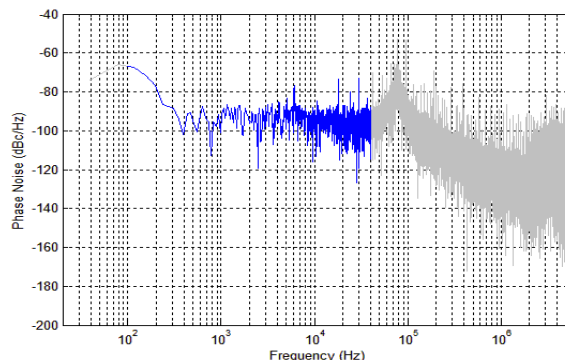
**Figure 5. CS8414 MCK Phase Noise**  
Fs = 48 kHz



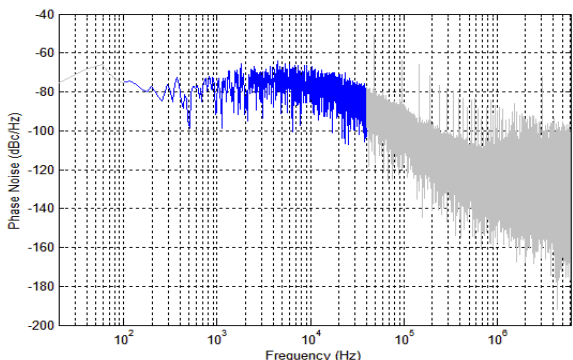
**Figure 6. CS8414 MCK Phase Noise**  
Fs = 96 kHz



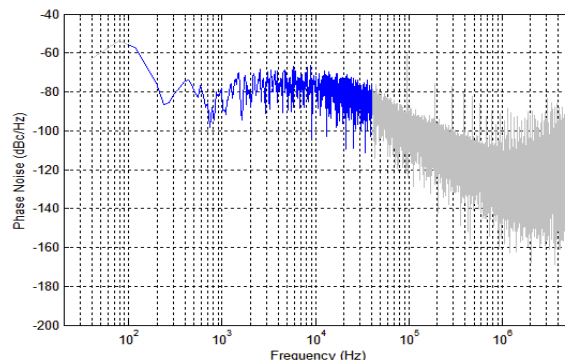
**Figure 7. CS8416 RMCK Phase Noise**  
Fs = 48 kHz, PDUR = 1



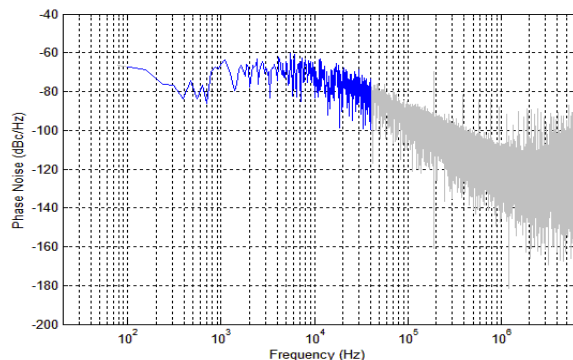
**Figure 8. CS8416 RMCK Phase Noise**  
Fs = 96 kHz, PDUR = 1



**Figure 9. CS8416 RMCK Phase Noise**  
Fs = 48 kHz, PDUR = 0



**Figure 10. CS8416 RMCK Phase Noise**  
Fs = 96 kHz, PDUR = 0



**Figure 11. CS8416 RMCK Phase Noise**  
Fs = 192 kHz, PDUR = 0

The measurements show the CS8416 has less baseband jitter than the CS8414 when PDUR = 1. While the plots also indicate that the CS8416 has more jitter at higher frequencies, as suggested by AES-12id-2006 and confirmed by the measurements to be shown in [Section 6](#), this high frequency jitter does not affect audio converter THD+N performance.

It can also be seen that the CS8416 has higher baseband jitter when PDUR = 0; this is due to its slower phase detector update rate in this mode. As an alternate illustration of this point, notice that the baseband jitter is reduced for all three receiver cases when the sample rate is increased. This is an indication that a faster phase detector

update rate results in reduced low frequency VCO noise on the recovered clock.

## 6. MEASURED CONVERTER PERFORMANCE COMPARISON

An alternate, and arguably more tangible way to evaluate the impact of the recovered clock jitter improvement provided by the CS8416 would be to simply measure the analog performance of a D/A converter clocked by the receiver's recovered clock. The results from a few of these tests have been included to provide an example of how the improvements made in the CS8416 will benefit a real-world audio application.

From a high-level, it's easy to see that the improved jitter performance results in better THD+N performance of the converter; see [Table 3](#). Detailed plots and summary data can be found in the next few sections. These represent the most common and critical analog performance metrics that can be expected to be affected by clock jitter.

The CS4398 high-performance D/A converter was used as the audio source for each measurement. Three common sample rates were tested for each measurement: 48 kHz, 96 kHz, and 192 kHz. Since the CS8414 cannot accept a sample rate of 192 kHz, performance data for the CS8414 operation at 48 kHz is used as a comparison baseline for the plots demonstrating the CS8416 operation at 192 kHz.

Refer to [Section 9.2](#) for detailed test set-up information and diagrams.

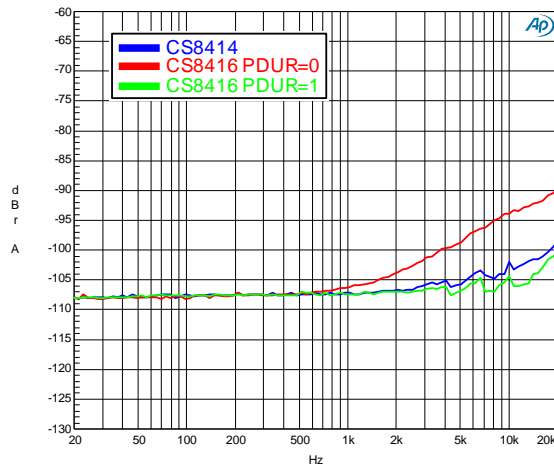
### 6.1 THD+N Measurements

[Table 3](#) summarizes the performance differences, which are clearly most notable at 18 kHz. The plots that follow show that the THD+N performance degrades as the signal amplitude and frequency are increased.

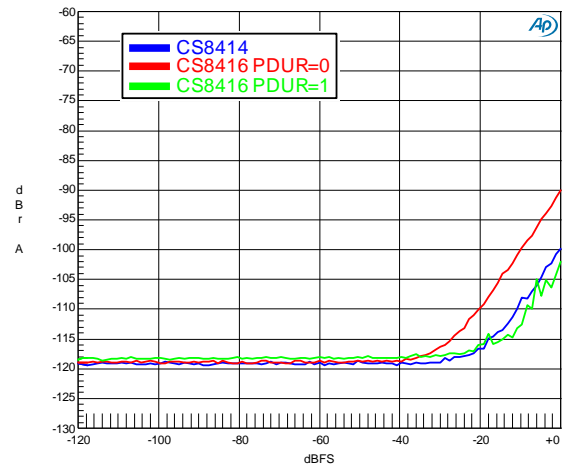
As predicted by the baseband jitter values in [Section 5](#), the converter's performance improves as the sample rate is increased from 48 kHz to 96 kHz when sourced by either receiver. It's also noteworthy that the performance with the CS8416 and PDUR = 0 at a sample rate of 192 kHz is comparable to the performance with the CS8414 at a sample rate of 48 kHz. This shows that using the extended sample rate range of the CS8416 doesn't come at the expense of performance relative to the benchmark set by the CS8414.

Fundamental Frequency	Sample Rate	CS8414 THD+N	CS8416 THD+N PDUR=1	CS8416 THD+N PDUR=0	Unit	Figure
997 Hz	48 kHz	-106.97	-106.97	-105.53	dBr	<a href="#">12</a>
997 Hz	96 kHz	-106.96	-106.96	-106.77	dBr	<a href="#">14</a>
997 Hz	192 kHz	-	-	-107.57	dBr	<a href="#">16</a>
18 kHz	48 kHz	-99.21	-101.17	-90.06	dBr	<a href="#">12</a>
18 kHz	96 kHz	-103.33	-110.27	-97.59	dBr	<a href="#">14</a>
18 kHz	192 kHz	-	-	-98.50	dBr	<a href="#">16</a>

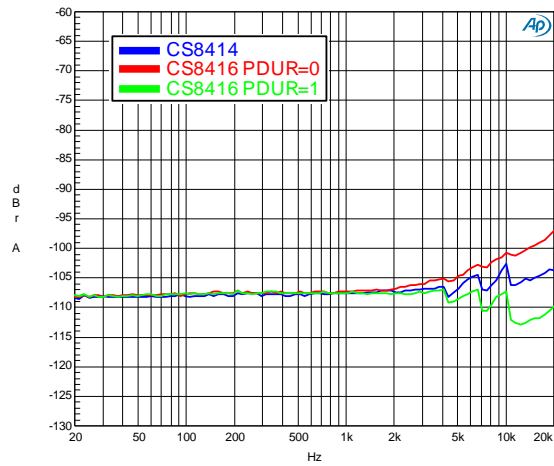
**Table 3. THD+N Summary**



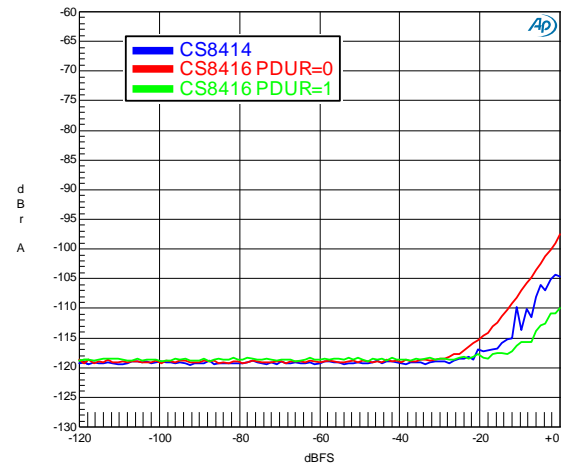
**Figure 12. THD+N vs Frequency - 0 dBFS  
Fs = 48 kHz**



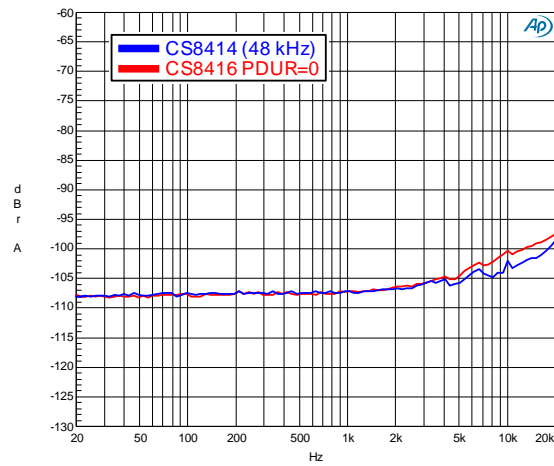
**Figure 13. THD+N vs Amplitude - 18 kHz  
Fs = 48 kHz**



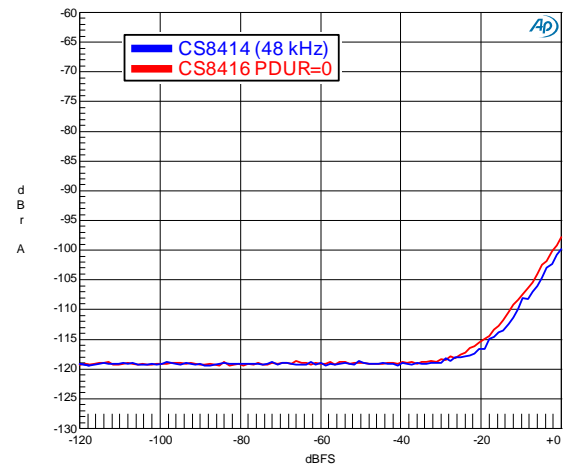
**Figure 14. THD+N vs Frequency - 0 dBFS  
Fs = 96 kHz**



**Figure 15. THD+N vs Amplitude - 18 kHz  
Fs = 96 kHz**



**Figure 16. THD+N vs Frequency - 0 dBFS  
Fs = 192 kHz**

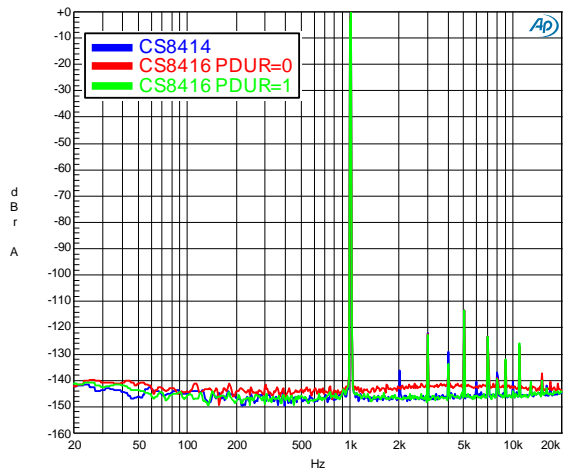


**Figure 17. THD+N vs Amplitude - 18 kHz  
Fs = 192 kHz**

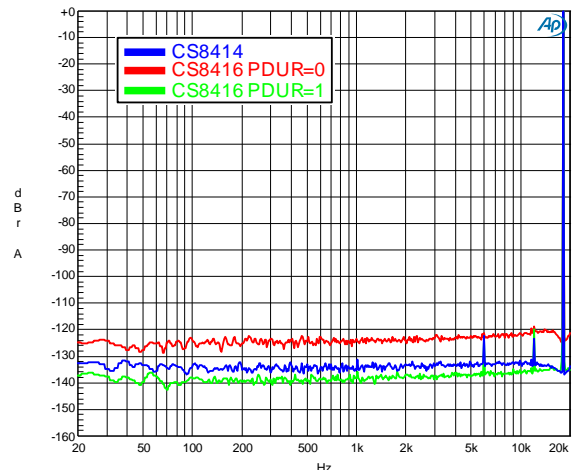


## 6.2 Full-Scale FFTs

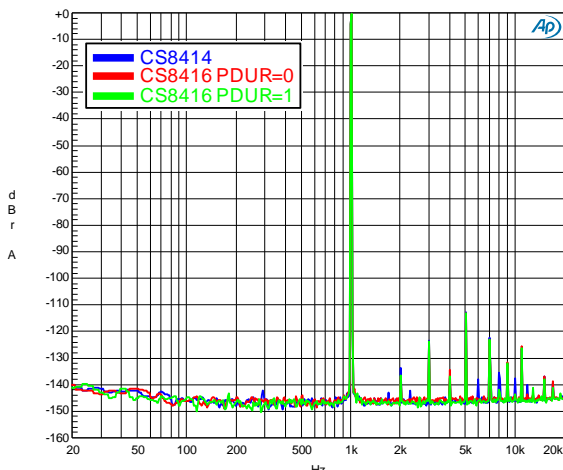
FFT's of the 997 Hz and 18 kHz test cases are provided below. These show the differences in the tonal and noise signatures of the converters when clocked from the CS8413/14 and the CS8416 in each PDUR mode.



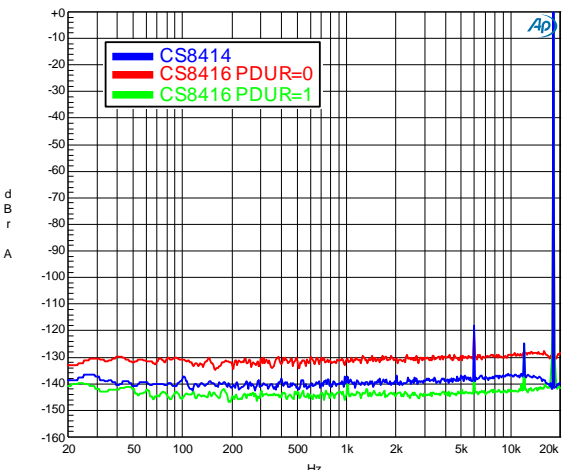
**Figure 18. FFT - 0 dBFS, 997 Hz  
Fs = 48 kHz**



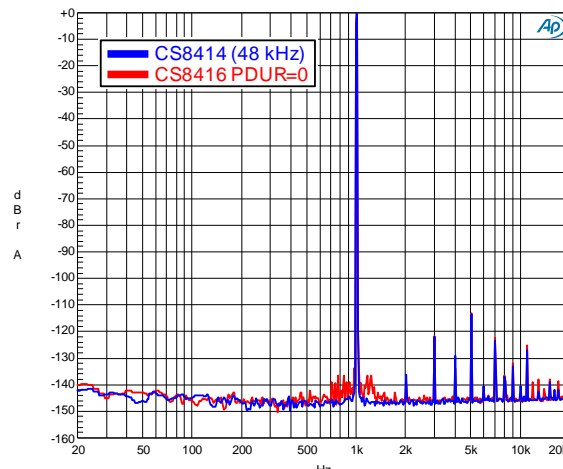
**Figure 19. FFT - 0 dBFS, 18 kHz  
Fs = 48 kHz**



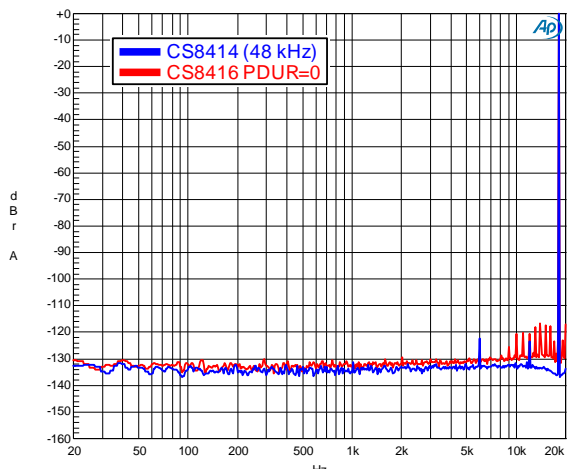
**Figure 20. FFT - 0 dBFS, 997 Hz  
Fs = 96 kHz**



**Figure 21. FFT - 0 dBFS, 18 kHz  
Fs = 96 kHz**



**Figure 22. FFT - 0 dBFS, 997 Hz  
Fs = 192 kHz**



**Figure 23. FFT - 0 dBFS, 18 kHz  
Fs = 192 kHz**

## 6.3 Dynamic Range Measurements

As discussed in section 5.2 of AES-12id-2006, jitter outside of the baseband frequency range can interact with the shaped quantization noise of an audio converter and result in decreased dynamic range regardless of the level or frequency of the audio input signal. The level of dynamic range reduction is dependent upon the out of band energy of the converter and the out of band jitter signal on its sample clock. Since the predominant multi-bit converter architectures of today produce less out of band energy than earlier converters using a single-bit architecture, they can be expected to be less sensitive to out of band jitter.

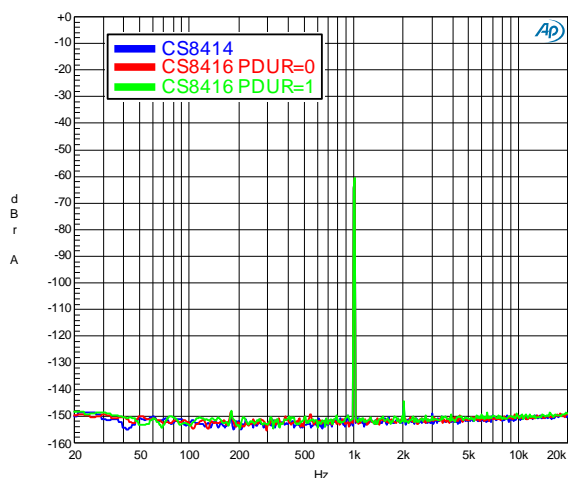
The measurements reveal that there is little difference between the converter's dynamic range when sourced by each recovered clock source. There is a small reduction in dynamic range for the CS8416 and PDUR = 1 case that can be attributed to the RMCK jitter in the ~100 kHz range as shown in Figure 7.

Table 4 summarizes the measurement results.

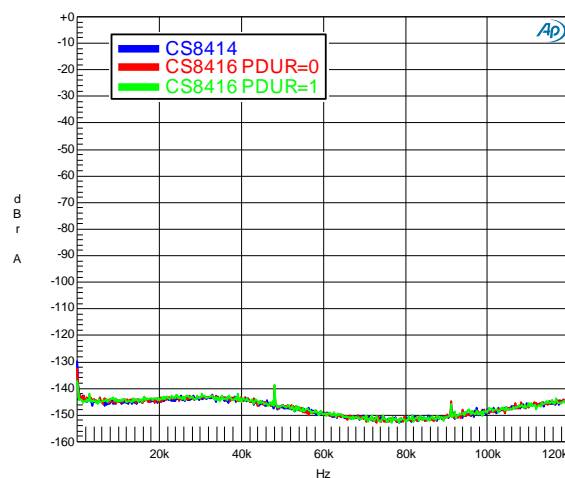
The plots that follow show the converter's output spectrum for each sample rate, both across the audio band with a -60 dB input stimulus, and out of the audio band with no input stimulus.

Sample Rate	CS8414 -	CS8416 PDUR=1	CS8416 PDUR=0	Unit	Figure
48 kHz	-119.29	-118.64	-119.02	dBr	24
96 kHz	-119.36	-119.18	-119.23	dBr	26
192 kHz	-	-	-119.11	dBr	28

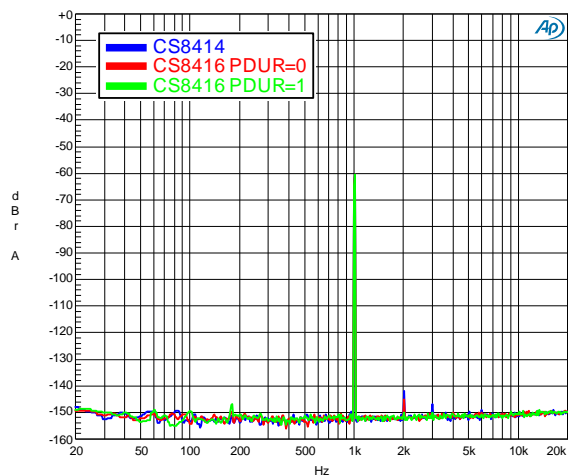
**Table 4. A-Weighted Dynamic Range Summary**



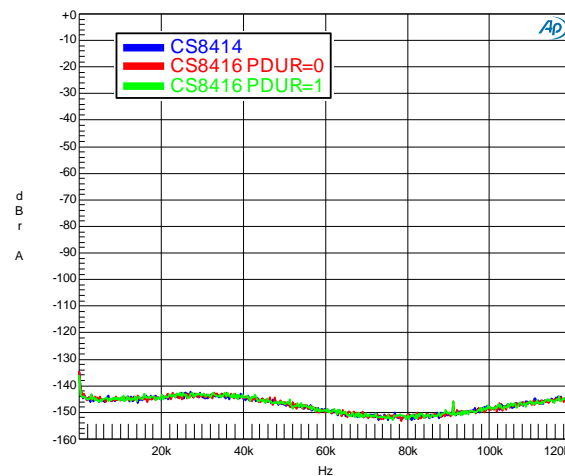
**Figure 24. FFT - -60 dBFS, 997 Hz  
Fs = 48 kHz**



**Figure 25. FFT - No Input (w/ Dither)  
Out of Band, Fs = 48 kHz**

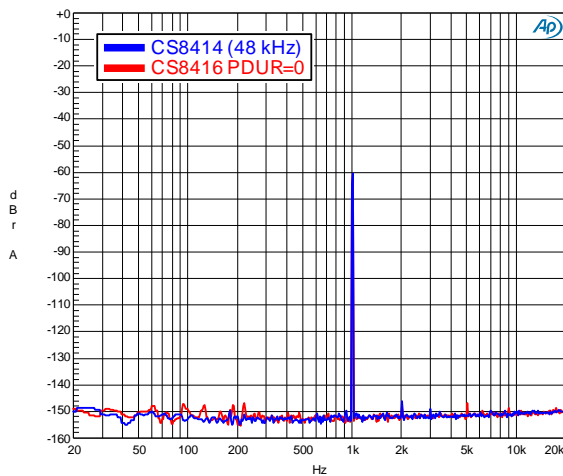


**Figure 26. FFT - -60 dBFS, 997 Hz  
Fs = 96 kHz**

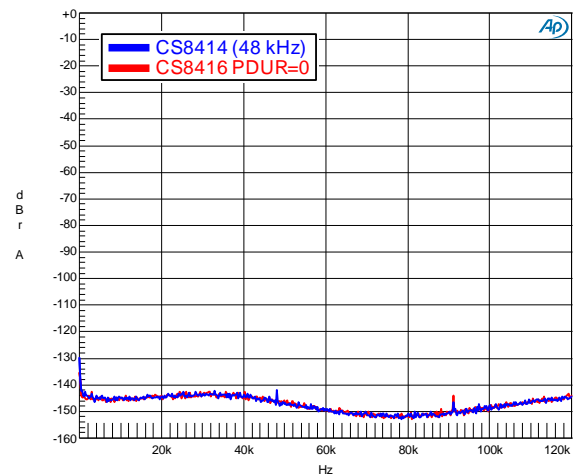


**Figure 27. FFT - No Input (w/ Dither)  
Out of Band, Fs = 96 kHz**





**Figure 28. FFT - -60 dBFS, 997 Hz**  
Fs = 192 kHz



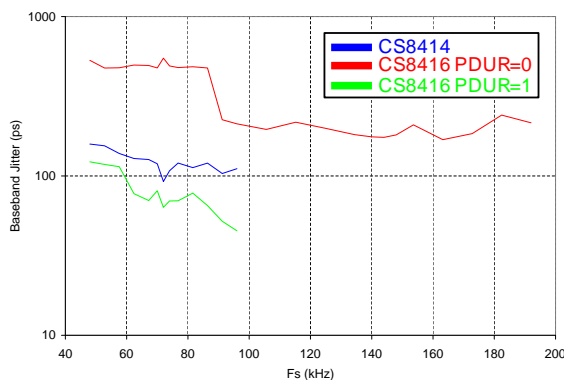
**Figure 29. FFT - No Input (w/ Dither)**  
Out of Band, Fs = 192 kHz

## 7. JITTER MEASUREMENT TO DAC THD+N CORRELATION

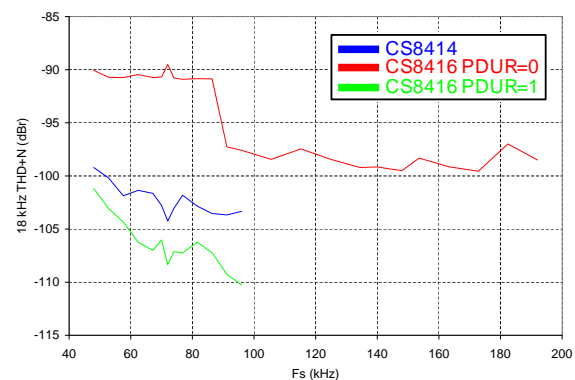
The results presented in [Section 5](#) show that the amount of baseband jitter present on the recovered master clock of each receiver is reduced as the sample rate of the input S/PDIF signal is increased. This relationship is a direct result of the increased phase detector update rate, which is proportional to the incoming sample rate.

Also, the results of [Section 6](#) show that baseband jitter present on the recovered master clock has the most significant affect on the converter's THD+N performance when its audio input signal level and frequency are both high.

Using this information, a simple test was devised to help correlate the level of baseband jitter to the DAC's THD+N. To do this, a S/PDIF signal with a fixed 0 dBFS, 18 kHz audio tone was transmitted into both receivers. The sample rate of the S/PDIF signal was then varied, and both the recovered clock baseband jitter and the THD+N of the CS4398 were measured at each sample rate step. The results are shown in [Figure 30](#) and [Figure 31](#) below.



**Figure 30. Baseband Jitter vs Sample Rate**



**Figure 31. THD+N vs Sample Rate**

The plots confirm the relationship between recovered clock baseband jitter and DAC THD+N. It can again be seen that the baseband jitter and THD+N for the CS8416 when PDUR = 1 is better than that with the CS8414. For sample rates greater than 96 kHz (up to 192 kHz), the jitter and THD+N for the CS8416 with PDUR = 0 is comparable to the performance of the CS8414 with a sample rate of 48 kHz.

## 8. CONCLUSION

The CS8416 offers many improvements and features beyond those of the CS8413/14. One of the CS8416's primary improvements is the reduction of baseband jitter on its recovered master clock.

As shown through experiment, this jitter reduction improves the THD+N performance of a converter sourced by the CS8416 when compared to the same converter sourced by the CS8413/14. This demonstration supports the CS8416 as a performance-enhanced replacement for existing CS8413/14 designs.

## 9. APPENDIX

### 9.1 Other Differences Between CS8413/14 and CS8416

Aside from those listed in [Section 2 on page 1](#), there are a number of other differences between the CS8413/14 and the CS8416 that a designer considering a transition from the CS8413/14 to the CS8416 should be aware of. For reference, a list of some of the more significant differences is included below. For complete details on any of these, please refer to each device's datasheet.

- The CS8416 is not pin compatible with the CS8413/14.
- The CS8416 receiver input pins are not RS-422 compliant; the receiver input absolute maximum voltage range is  $\pm 12$  V for the CS8413/14 and  $-0.3$  V to  $V_L + 0.3$  V for the CS8416.
- The typical  $V_A$  and  $V_D$  supply voltages are 5 V for the CS8413/14 and 3.3 V for the CS8416.
- The external PLL filter component values are different between the CS8416 and CS8413/14.
- The recovered clock frequency provided when the PLL is unlocked is approximately 3 MHz for the CS8413/14 and approximately 375 kHz or 750 kHz for the CS8416, depending upon the selected RMCK ratio.
- The CS8416 recovered clock output pin is not active during reset.
- There are various differences between the devices' C and U data framing implementations.
- The devices indicate their input sample rate differently.
- Although typical I<sup>2</sup>S, Left-Justified, and Right-Justified formats are supported by the devices, there are various differences in other supported serial audio output formats.
- The available controls over the state of the serial data output during a receiver error condition are different.
- There are various differences in the operation of the devices' error indication pins.
- Certain pins dedicated to the reporting of the C data bits on the CS8414 are not available in the CS8416's hardware mode.
- The CS8413 is not directly register-compatible with the CS8416 in software mode.
- The first five bytes of both channels' C data are register accessible in the CS8416's software mode, while the CS8413 allows sequential 1-byte access to all 24-bits of a single channel's C data.
- There are various differences in the behavior of the CS8413 and CS8416's interrupt functions.

### 9.2 System Set-Up

The data presented in this document is derived from measurements collected using one randomly selected sample of each device. Measurements were taken at each device's nominal voltage and at room temperature. Specifically, the CS8414 Revision A and the CS8416 Revision E were used.

To collect the audio performance data, the CS4398 high-performance DAC was chosen to demonstrate the effect of each receiver's output jitter. A single CDB4398 customer evaluation board was used to conduct each test. The CS4398 FILT+ capacitor on the CDB4398 was increased from 100  $\mu$ F to 1000  $\mu$ F to ensure a flat low-frequency THD+N response. The CS8414 located on the CDB4398 was used for all measurements sourced by the CS8414, and a CDB8416 customer evaluation board was used to drive the CS4398

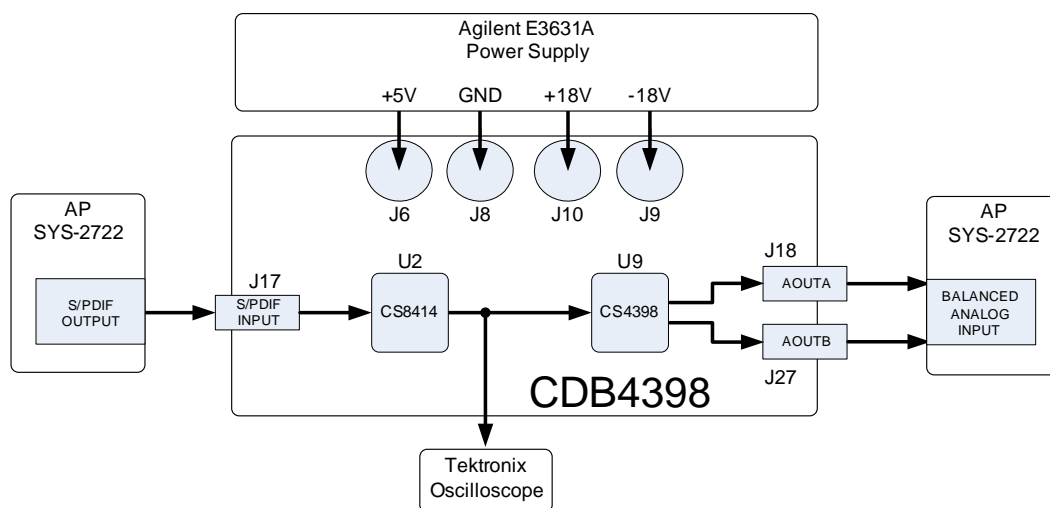
on the CDB4398 for all measurements sourced by the CS8416. Refer to the CDB4398 and CDB8416 data sheets for more information on each evaluation board.

Block diagrams of each test set-up are shown in [Figure 32](#) and [Figure 33](#).

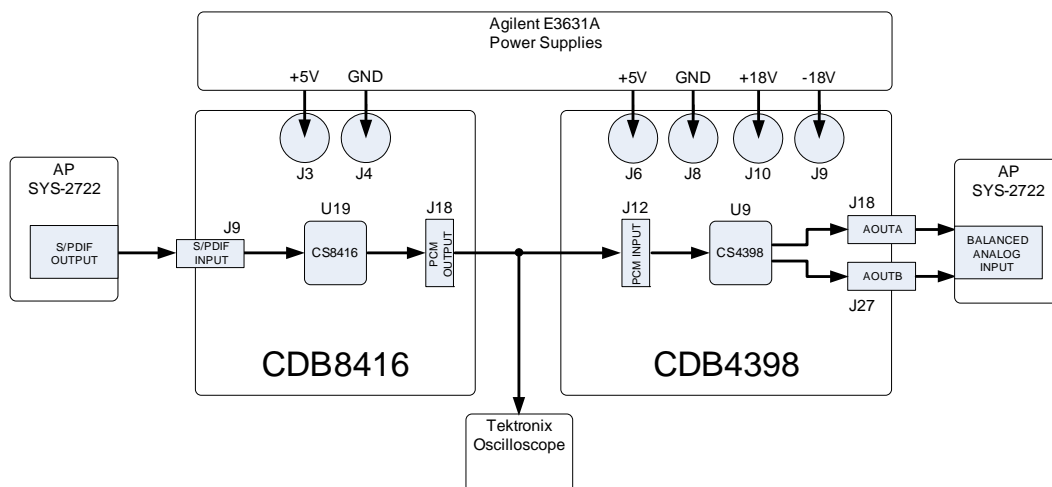
An Audio Precision® (AP) SYS-2722 high-performance audio analyzer was used to generate the digital input signals for the receivers and to measure the analog output signals from the CS4398. Agilent® E3631A power supplies were used to power the evaluation boards.

A Tektronix® DPO7054 oscilloscope with JIT3 software was used to measure the jitter signal of the CS8414 and CS8416's recovered master clocks. The software was configured to generate phase noise plots with no averaging applied to produce the figures shown in [Section 5](#). The phase noise integration function was used to calculate the baseband jitter values shown in [Table 2](#).

For each plot shown, the blue traces represent data taken using the CS8414 as the clock and data source, the green traces with the CS8416 and PDUR=1 as the clock and data source, and the red traces with the CS8416 and PDUR=0 as the clock and data source. For clarity, only AOUTA is shown in the plots; no notable differences were seen between the CS4398 output channels.



**Figure 32. CS8414 Test Setup**



**Figure 33. CS8416 Test Setup**

## 9.2.1 Test Conditions

For all tests, unless otherwise stated: CS4398 VA = VREF = VD = VLS = VLC = 5 V; PCM data is 24 bit I<sup>2</sup>S format; 22 Hz to 20 kHz measurement bandwidth for THD+N and dynamic range values. The unit “dBr” is dB referenced to the measured 997 Hz full scale output voltage of the CDB4398, which was measured at 2.41 V<sub>RMS</sub>. The S/PDIF input signal amplitude is 0.5 Vpp with 24-bit resolution. CS8414 VA = VD = 5 V. CS8416 VA = VD = 3.3 V; VL = 5 V. The bin width is 2 Hz for all of the FFT plots, with the exception of [Figures 25, 27 and 29](#), which have a bin width of 8 Hz.

## 10. REFERENCES

1. Audio Engineering Society AES-12id-2006: “AES Information Document for digital audio measurements - Jitter performance specifications,” May 2007.

## 11. REVISION HISTORY

Revision	Date	Changes
REV1	JUL 2009	Initial Release

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### Contacting Cirrus Logic Support

For all product questions and inquiries contact a Cirrus Logic Sales Representative.

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