ANALOG DEVICES

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Dynamic Performance of CMOS DACs in Modem Applications

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INTRODUCTION

In the new high-speed modems manufactured to meet the V.32 and V.33 standards, it is of prime importance to be able to produce a high-quality carrier signal. The D/A converter used to produce this needs excellent dynamic characteristics; harmonic distortion must be typically less than −70dB. This application note evaluates three Analog Devices CMOS DACs when used in this application. It explains how to get the best performance from each DAC and looks at the requirements for deglitchers. The note is intended to provide the information necessary for modem designers to evaluate these DACs and assess their suitability for particular systems.

TEST CIRCUIT AND CONDITIONS

In both the V.32 and V.33 standards, the carrier signal frequency is 1800Hz. The D/A converter digitally constructs a composite signal with update rates of 9.6kHz in V.32 systems and 14.4kHz in V.33 systems. One of the fall back rates for both standards is 7.2kHz. Figure 1 shows the test circuit used to evaluate the distortion performance of the DACs. The system generates an 1800Hz sine wave using the three DAC update rates already mentioned (14.4kHz, 9.6kHz and 7.2kHz). To do this the HP300 Series computer generates the digital values for the sine wave based upon the output frequency and the update frequency. These are then loaded into RAM. When the timing control logic block is activated, it sequences through the RAM at the predetermined update rate and loads the digital words into the DAC to produce the 1800Hz sine wave.

This is then fed into the spectrum analyzer via the deglitcher which may or may not be used depending on the glitch performance of the DAC under test. The spectrum analyzer shows the spectral content of the output sine wave, and output distortion can be calculated from this.

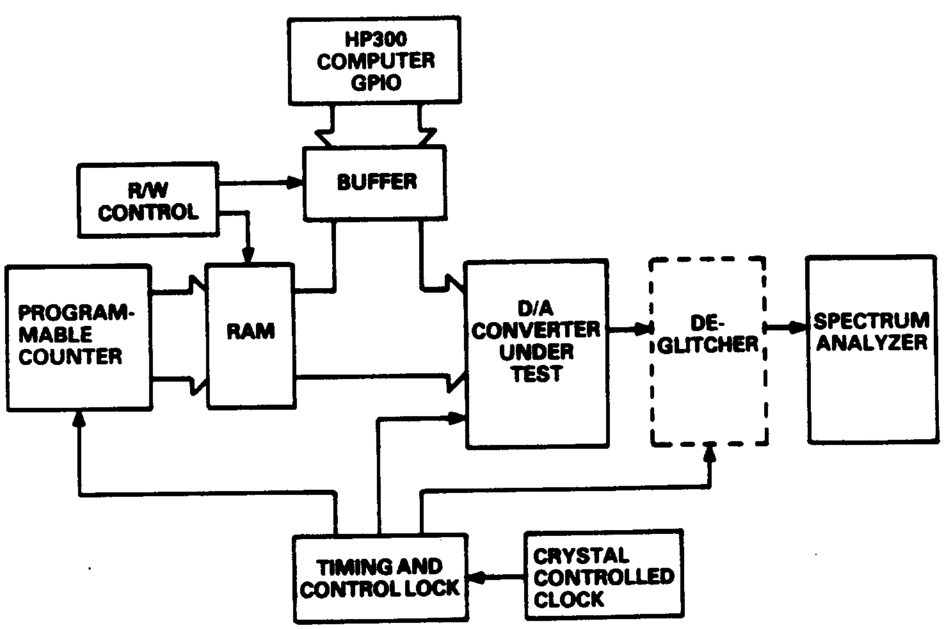

Figure 1. Harmonic Distortion Test Circuit

DEGLITCHER

When the code changes in a current-steering CMOS DAC, there is a capacitive coupling of charge across the switches in the DAC. This causes an injection of charge into the I_{OUT} line which in turn causes a voltage spike or glitch to appear at the output of the current to voltage amplifier. When the DAC is being used in sine wave construction, the presence of these output glitches results in increased harmonic distortion. This harmonic distortion increases as the glitches increase.

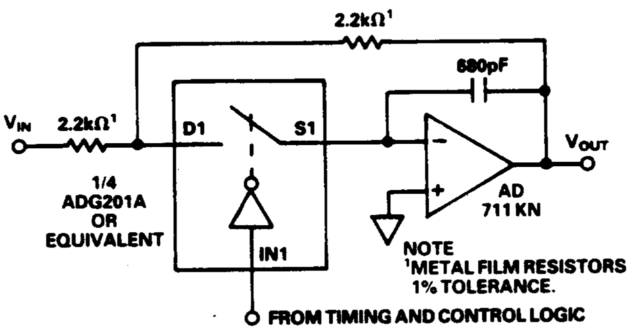

Figure 2. Deglitcher Circuit

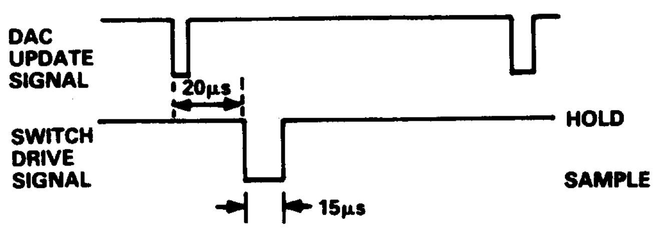

Figure 3. Deglitcher Timing

In order to overcome the problems caused by glitches, it is possible to use a deglitcher. Such a circuit is shown in Figure 2 with its timing in Figure 3. The digital value loaded to the DAC changes when the DAC update signal goes low. The switch in the deglitcher is turned on 20µs after this, causing V_{IN} to be sampled. This delay allows plenty of time for the DAC output to settle. The deglitcher samples for 15µs before going back into hold and waiting for the next DAC update. At the slowest sampling rate of 7.2kHz this means that the signal must be held for up to 125µs. This presents no problems for the circuit. The control signal for the deglitcher can be derived from the DAC update signal with a dual monostable. Alternatively, if a microcomputer with on-chip timer-counter is used to load the DAC, then the deglitcher control signal can be set up as an output from the controller.

The deglitcher of Figure 2 is used in some of the following circuits with excellent results. It is up to the system designer to decide if he can achieve acceptable performance without the deglitcher. The results given in this application note will help in making this decision.

AD7537/AD7547 In Current-Steering Mode

The AD7537/AD7547 are dual 12-bit DACs, packaged in narrow 0.3", 24-pin DIPs or 28-terminal LCCCs and PLCCs. Power consumption is low (100mW typical). The only difference between the two devices is in their loading structures. The AD7547 has a 12-bit parallel structure while the AD7537 has (8+4) loading. Figure 4 shows the AD7537/AD7547 set up in the standard current mode for ±5V output. This circuit is used with the system of Figure 1 to produce an output sine wave with 10V pk-pk amplitude and 1800Hz frequency.

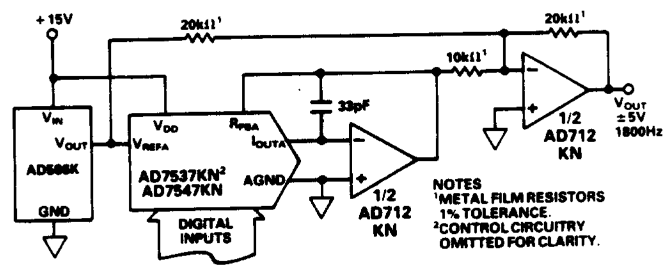

Figure 4. AD7537/AD7547 in Bipolar Current-Steering Mode

The distortion figures for this circuit at the three update rates (14.4kHz, 9.6kHz, 7.2kHz) vary from −69dB to −73dB. This is shown in Table I. To improve on this you can use the deglitcher circuit of Figure 2. This cleans up the output waveform and gives improved distortion performance which is shown in Table II. The improvement gained by using the deglitcher is about 10dB which shows that the glitches in the DAC have a considerable effect on the ac performance. APPENDIX A contains a selection of spectral responses obtained with different circuits. All of those shown are for the 14.4kHz sampling frequency, making comparisons between the circuits more meaningful. Figures A1 and A2 show the spectral responses for Figure 4 with and without the deglitcher. When the deglitcher is used, the level of the 2nd harmonic drops from −70dB to −90dB.

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−73	−73
9.6kHz	−69	−71
14.4kHz	−69	−71

Table I. Distortion Performance of Circuit in Figure 4

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−85	−85
9.6kHz	−78	−86
14.4kHz	−76	−90

Table II. Distortion when Using Deglitcher of Figure 2

AD7537/AD7547 in Voltage-Switching Mode

Another way of getting improved distortion performance from the AD7537/AD7547 is to use it in the voltage-switching mode. Figure 5 shows the circuit diagram. The DAC connections have now been reversed with the reference voltage applied to the I_{OUTA} terminal, AGNDA grounded and the V_{REFA} terminal as the output. R_{FBA} is not used and is tied to I_{OUTA} to prevent stray pickup. The glitches at the output of this circuit are much smaller than in Figure 2. The point where the glitches appear (I_{OUT}) is now connected to a low impedance point (AD580 output) which can absorb the current glitches without producing voltage spikes. The resulting major-carry glitches from Figure 5 are typically 20nV-secs compared to 200nV-secs for Figure 4. When operating in the voltage-switching mode, the DAC linearity degrades as the reference voltage increases. For this reason, the reference input in Figure 5 is limited to +2.5V, giving an output signal of ±2.5V.

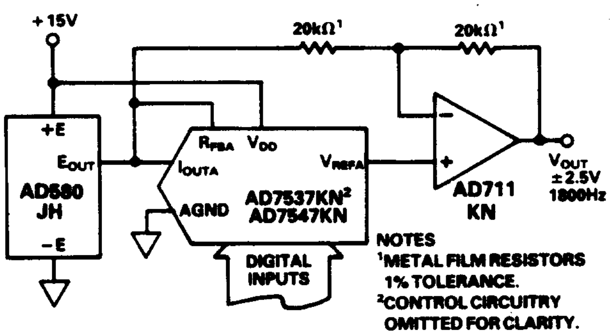

Figure 5. AD7537/AD7547 in the Voltage Switching Mode

Table III shows the distortion figures for the voltage-switching circuit. The results are the same both with and without the deglitcher and Figures A3 and A4 are the spectral responses when sampling at 14.4kHz. The deglitcher makes no difference to the performance of this circuit, verifying the absence of glitches in the outputs. However, if you compare the distortion results directly with those for the standard current-steering circuit plus deglitcher, you can see there is a slight degradation. Though the glitches are much smaller, the linearity performance in the voltage mode is degraded. (See the AD7537/AD7547 data sheets for typical performance.) This degraded linearity will increase distortion in the output signal. The distortion figures for the voltage-mode circuit are still better than −70dB making it suitable for many modem applications.

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−75	−75
9.6kHz	−74	−82
14.4kHz	−72	−79

Table III. Distortion Performance of Figure 5 with and without Deglitcher

AD7245/AD7248

The AD7245 and AD7248 are voltage-switching, 12-bit DACPORTs™. Each contains a reference, 12-bit DAC and output amplifier. They differ only in their loading structure; the AD7245 is a 12-bit parallel load device while the AD7248 has a byte loading structure. When connected as in Figure 6, the AD7245/AD7248 can be programmed for a sine wave output as previously discussed. The output signal range is ±5V.

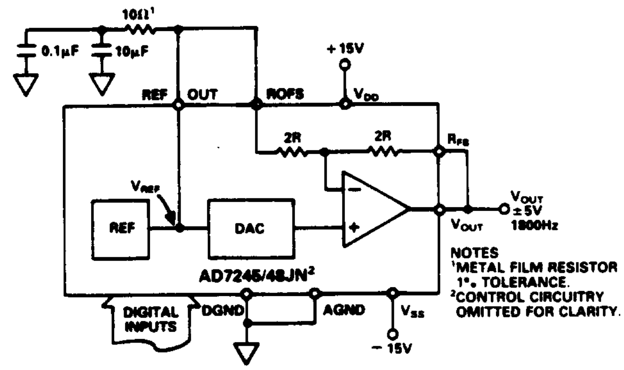

Figure 6. AD7245/AD7248 Connected for Bipolar ±5V Output

Table IV shows the distortion results obtained from this circuit, and Figure A5 is the spectral response. The distortion is caused by slew rate distortion in the AD7245/AD7248 output amplifier. If the deglitching, circuit of Figure 2 is cascaded with Figure 6 and used as a sample/hold amplifier, there is a marked improvement in performance. The output is now sampled at a time when the slew rate effects are over and distortion is determined by the SHA output amplifier (AD711). The distortion results with this setup are shown in Table V, and Figure A6 shows the spectral response for the 14.4kHz – sampled signal.

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−76	−76
9.6kHz	−57	−71
14.4kHz	−61	−69

Table IV. Distortion of AD7245/AD7248 in Figure 6

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−82	−82
9.6kHz	−74	−83
14.4kHz	−75	−82

Table V. AD7245/AD7248 Distortion Performance Using Circuit of Figure 2

DACPORT is a trademark of Analog Devices, Inc.

AD7538 in Current-Steering Mode

The AD7538 is a 14-bit CMOS DAC and is of interest to the designer who needs somewhat better than 12-bit system performance. The device is packaged in the same narrow 24-pin package as the previous DACs.

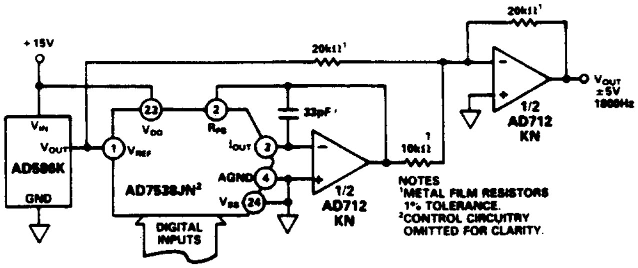

Figure 7. AD7538 in Bipolar Current-Steering Mode

Figure 7 shows the AD7538 in the standard bipolar current-steering configuration. Table VI gives the dynamic performance of Figure 7 when used on its own without a deglitcher. The performance is a reflection of the larger D/A glitch impulse which this part exhibits over the previous 12-bit devices. When the deglitcher of Figure 2 is used there is a major improvement in the performance as can be seen from Table VII. THD is now down to a level of −86dB for the 14.4kHz−sampled signal. Figure A7 and A8 are the spectral responses for Figure 7 with and without the deglitcher.

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−56	−56
9.6kHz	−57	−65
14.4kHz	−54	−57

Table VI. Distortion Performance of Figure 7

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−88	−88
9.6kHz	−84	−89
14.4kHz	−86	−89

Table VII. Distortion Performance Using Deglitcher

AD7538 in Voltage-Switching Mode

When the AD7538 is operated in the voltage mode, the reference driving I_{OUT} must have extremely good dynamic characteristics (i.e., response to a changing load). The nominal impedance which it is driving is 6kΩ and this changes with the DAC code. As well as this, the glitches which the reference must absorb at I_{OUT} as the code changes are large. The AD580 is not capable of delivering this performance and must be buffered by the AD712 shown in Figure 8. The distortion results are in Table VIII. The spectral responses for Figure 8 are shown in Appendix A. Figure A9 is the response without deglitching and Figure A10 is the response with deglitching.

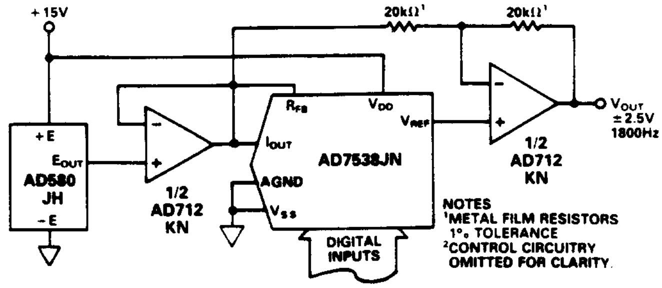

Figure 8. AD7538 in the Voltage Switching Mode

Update Rate	Distortion (dB)	2nd Harmonic (dB)
7.2kHz	−75	−75
9.6kHz	−75	−79
14.4kHz	−72	−78

Table VIII. Distortion Performance of Figure 8

DISCUSSION OF RESULTS

The method used to calculate the distortion figures for the various circuits was to feed the digitally constructed sine wave directly into the spectrum analyzer without any filtering. Then, the distortion was calculated as the rms sum of the distortion components. This may seem to be a somewhat cumbersome approach. However, if a distortion meter was used, there would be very severe output filtering requirements. For example, when sampling at 7.2kHz, even if we wanted to measure only up to the 2nd harmonic (3.6kHz), a filter with cutoff at 3.6kHz and sufficient attenuation at 7.2kHz to eliminate the clock frequency would be necessary. The best way of practically evaluating the circuit distortion is to use the spectrum analyzer. For each of the update rates, components up to half this rate were summed to calculate the circuit distortion. In this way, all harmonics of interest are included.

In practical modem systems, the output signal from the D/A converter will be followed by a filter section. This lowpass filter will nominally have a cutoff frequency of 3.5kHz for V.32 and V.33 systems. It will remove clock components and other unwanted noise from the carrier signal. The output filter will also attenuate all but one of the harmonics at the output. The one that does not get attenuated is the 2nd harmonic (3.6kHz) and so it is of special interest to the modem designer. For this reason the 2nd harmonic in each of the circuits tested has been listed separately in the tables.

In analyzing the performance of the various circuits, the best results were obtained from the AD7537/AD7547 and AD7538 when both were operated in the current-steering mode and the output was deglitched. The 2nd harmonic level was equal for both of these (−89dB), but in terms of THD the AD7538 was superior (−86dB versus −76dB for the 14.4kHz sampled circuit). In practical terms this means that if the system designer is using a 14.4kHz clock-rate, his filter requirements will be less if he uses the AD7538.

Attenuation of the higher harmonics isn't as critical as with the AD7537/AD7547 and so a lower order filter is possible. If the designer wants to eliminate the deglitcher, then the best circuits to use are the AD7537/AD7547 or the AD7538 in the voltage-switching mode. Both of these give good results with a THD of −72dB and 2nd harmonic level of −78dB in the 14.4kHz sampled circuit.

The AD7245/AD7548 achieves good performance when the circuit of Figure 2 is used with it as a sample/hold. It also has the advantage of an on-board reference. THD for this circuit is −75dB and the 2nd harmonic level is −82dB.

CONCLUSIONS

Each of the CMOS DACs discussed in this application note is capable of delivering better than −70dB distortion performance when synthesizing an 1800Hz signal with the stated update frequencies. Some, but not all, of the DAC configurations require deglitching to achieve this. There are varying levels of performance among the devices which deliver better than −70dB THD, ranging from −72dB for the AD7537/AD7547 in the voltage mode without deglitching to −86dB for the AD7538 in the current-steering mode with a deglitcher.

It should be remembered that the results contained in this application note are typical and were obtained from a range of devices taken randomly. Several production/fabrication lots were sampled. However, the results are meant to show typical performance only and do not guarantee that this will be met in all cases.

APPENDIX A

Spectral Responses of Figures 4, 5, 6, 7 and 8. F_{OUT} = 1800Hz. Update Rate = 14.4kHz. Responses are shown both with and without the deglitcher circuit of Figure 2.

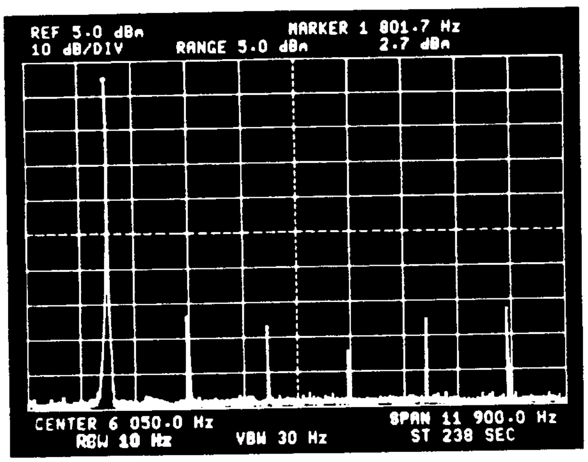

Figure A1. Spectral Response of Figure 4 (AD7537/AD7547 in Current-Steering Mode) without Deglitcher

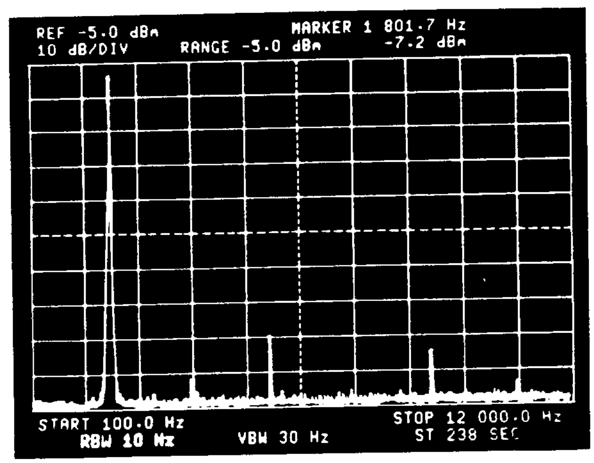

Figure A2. Spectral Response of Figure 4 with Deglitcher

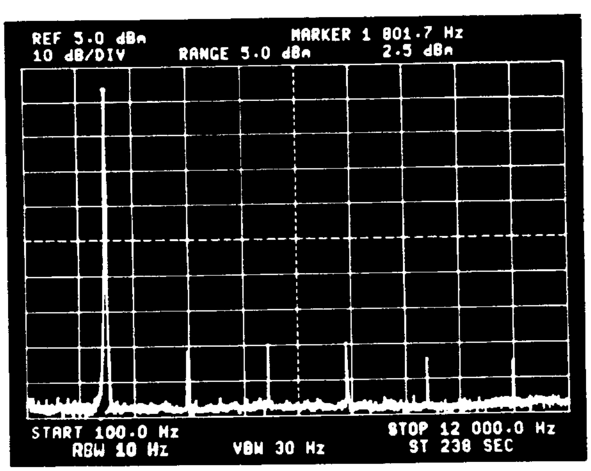

Figure A3. Spectral Response of Figure 5 (AD7537/AD7547 in Voltage-Switching Mode) without Deglitcher

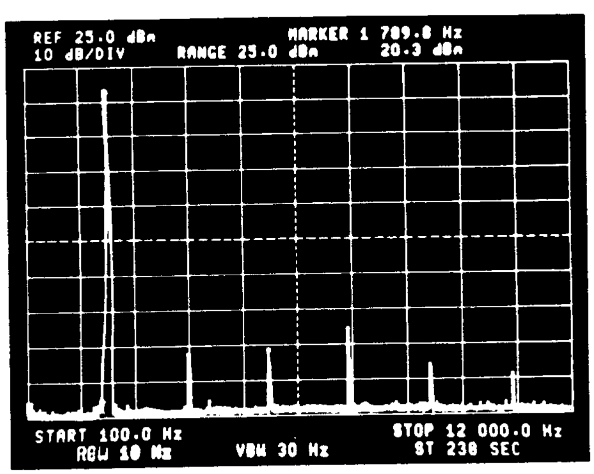

Figure A4. Spectral Response of Figure 5 with Deglitcher

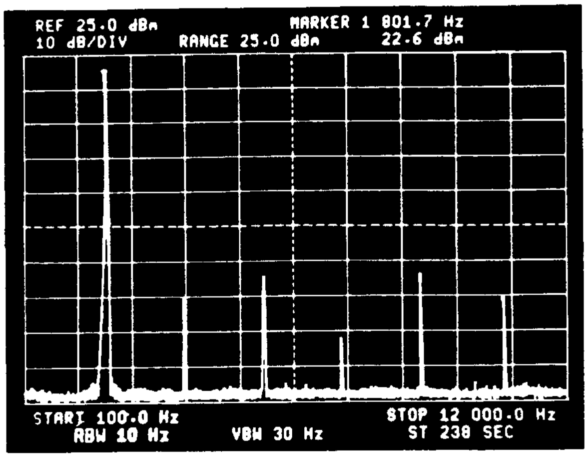

Figure A5. Spectral Response of Figure 6 (AD7245/AD7248 in Bipolar Output Configuration) without Deglitcher

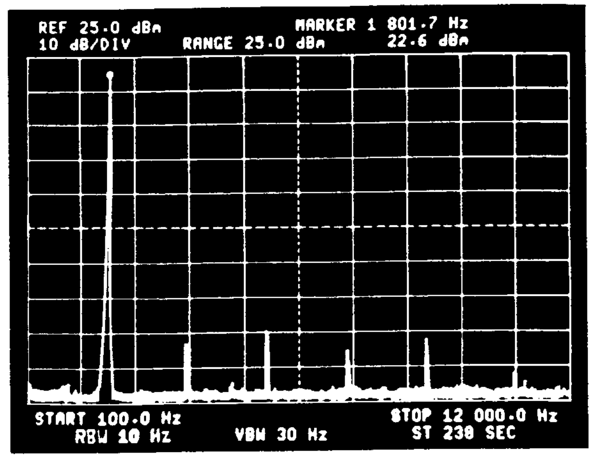

Figure A6. Spectral Response of Figure 6 with Deglitcher

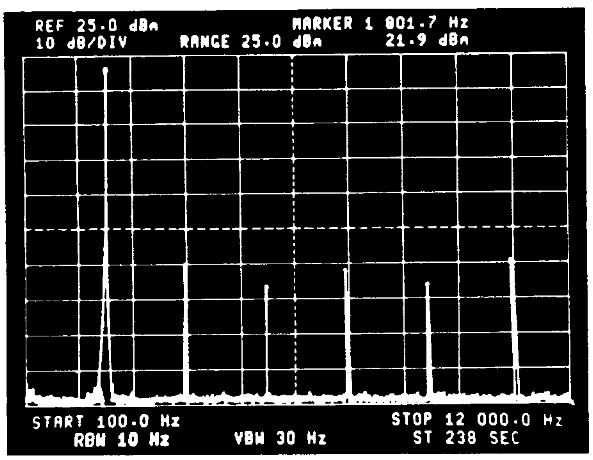

Figure A7. Spectral Response of Figure 7 (AD7538 in Current-Steering Mode) without Deglitcher

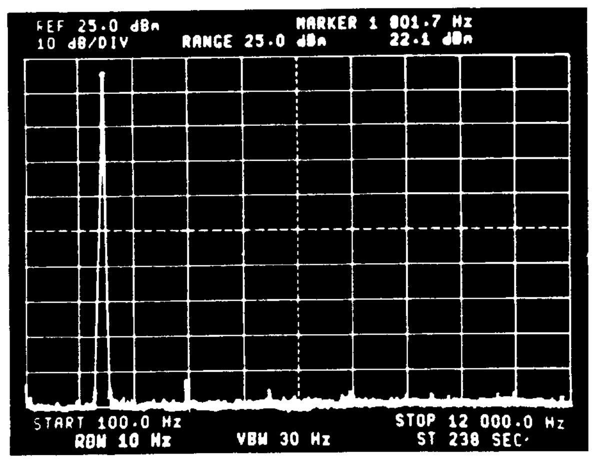

Figure A8. Spectral Response of Figure 7 with Deglitcher

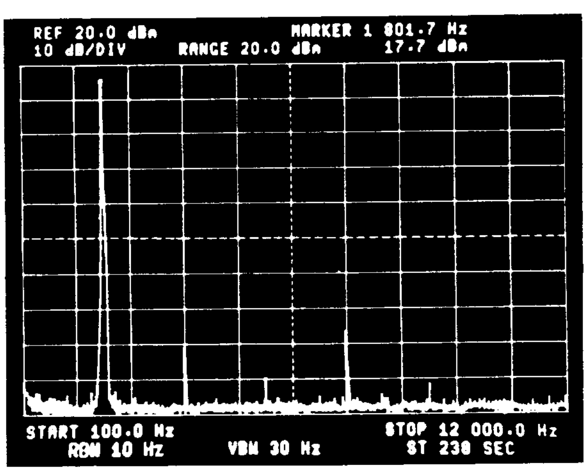

Figure A9. Spectral Response of Figure 8 (AD7538 in Voltage-Switching Mode) without Deglitcher

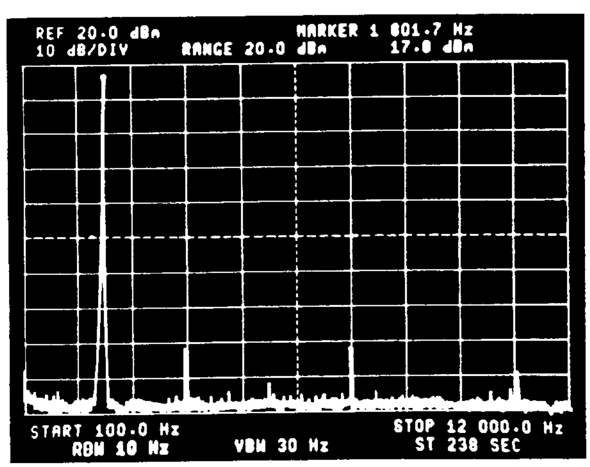

Figure A10. Spectral Response of Figure 8 with Deglitcher