

# ***Electromagnetic Emission From Logic Circuits***

*Application  
Report*

***November 1999***

***Logic Products***

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# ***Electromagnetic Emission From Logic Circuits***

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## **Abstract**

As a result of new legal requirements covering the electromagnetic compatibility of electronic equipment, users must now address this issue at system conception and when choosing components. This application report is intended to give the development engineer insight into a method of making the measurements that establish those properties of integrated circuits that primarily determine their electromagnetic compatibility. The report concludes with an examination of the results obtained with a variety of logic circuits.

## **1 Introduction**

The electromagnetic compatibility of equipment and systems has taken on additional significance now that economic community (EC) regulations require the manufacturers of equipment to declare their compliance with electromagnetic compatibility requirements. One aspect of compatibility covers the interference immunity of the equipment, that is, the extent to which electromagnetic fields generated by external sources may influence the operation of the equipment. In this area, there has been intensive research over many years, and comprehensive literature is available to the design engineer that should answer any questions. The situation is very different with regard to the radiation of electromagnetic fields. Even though the obligation to label equipment as compliant specifically addresses this point, the legal situation basically has not changed, because the appropriate regulations covering radiation have been in force for several decades.

Manufacturers of semiconductors increasingly are being asked about the electromagnetic compatibility of components. Corresponding regulations basically concern only equipment and installations, but not the components they contain. Therefore, the engineer developing a piece of equipment is required to take appropriate measures to ensure compatibility. The manufacturer of semiconductors often can provide only limited help. Measures can, for example, be implemented by protective circuitry integrated into components, which should ensure that the components are not destroyed by an electrostatic discharge. Additional measures can reduce high-frequency interference generated by the components. Two parameters, in this case, are of considerable significance:

- Rise and fall times of signals at the output of the integrated circuit. The steepness of these edges determines, to a large extent, the energy radiated from the signal lines.
- High-frequency current flowing in the supply voltage of the integrated circuits that is the result of load changes inside the circuits

After a discussion of some general aspects of this problem, the measurement results obtained with a variety of logic circuits is shown. Generally, logic circuits cannot be considered to be model examples of low-interference components. Because of their applications in computers and similar equipment, particular care is taken during the development of such integrated circuits to achieve short propagation delay times, which produce rapidly rising and falling signal edges. Interference generated by these components is considered important only to the extent that, in a large system, they should not interfere with each other.

## 2 Propagation of Interference Generated by Integrated Circuits

Electrical energy is radiated by antennas that effectively are created by the conductors within and outside the integrated circuit.

The field strength,  $E$ , at a particular distance,  $r$ , from an antenna,  $A$  (see Figure 1), can be calculated:

$$E = k \times I \times A \times \frac{1}{r} \times \sin \vartheta \quad (1)$$

Where:

$E$  = Field strength

$I$  = Current

$A$  = Area of the antenna

$r$  = Distance to the antenna

$\vartheta$  = Angle to the plane of antenna

$k$  = Antenna constant

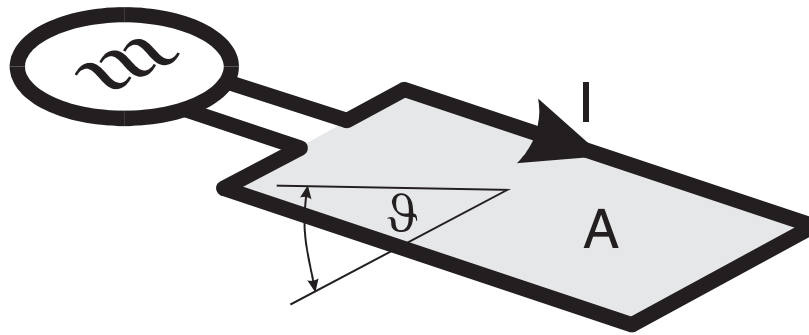


Figure 1. Radiation From an Antenna

In addition to the current that flows, the area of the antenna plays a major role in the field strength generated. In an integrated circuit, this area is bounded by the signal lines within and outside the component, as well as the associated return lines. In this context, connections to the supply voltage should not be overlooked because they conduct significant charging and discharging currents at every switching cycle. The area of the antenna that is formed by the conductors within the integrated circuit can, because of its small size, be disregarded in the frequency range below 1 GHz. The current loops, which are critical for the significant radiation, are shown in Figure 2.

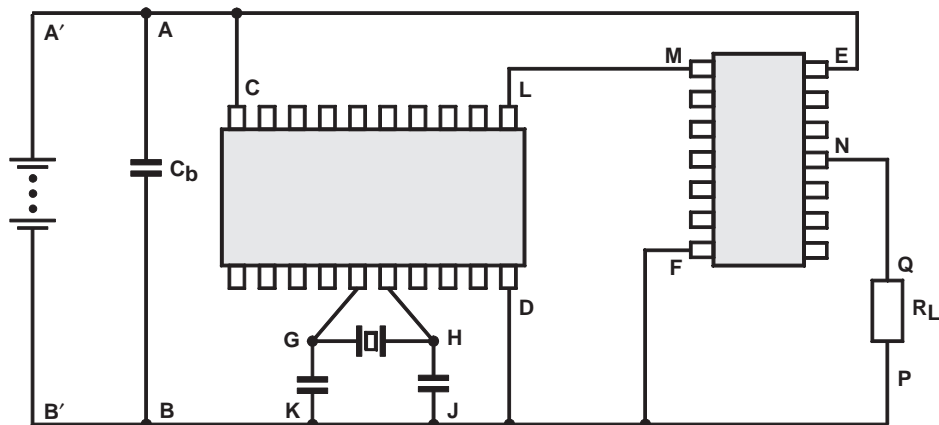


Figure 2. Current Loops on a Circuit Board

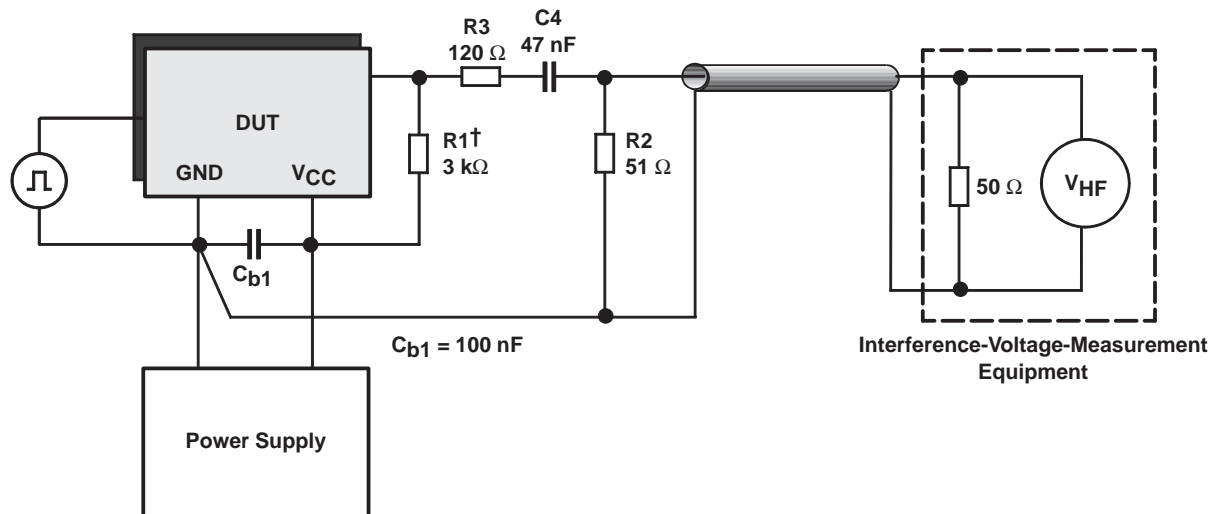
The signal line L-M, together with the associated return path F-D, forms one of the more important loops. The area that is enclosed by this loop operates as an antenna, and radiates high-frequency energy. An additional loop is formed by the positive supply lines A-C and A'-C, and the associated ground lines B-D and B'-D. Because blocking capacitors have only limited ability to equalize current changes in the circuit<sup>1</sup>, the design engineer must consider all supply lines as far as the power supply and, possibly, beyond to the mains transformer and mains power lines. In most cases, the power lines are the longest and, therefore, enclose the largest areas. The currents flowing there have a major influence on the electromagnetic compatibility of a system.

### 3 Measurement of Interference Generated by Integrated Circuits

The design engineer needs components that, as far as possible, generate little electromagnetic interference. Therefore, a measurement procedure that provides results with which the user can compare components from different manufacturers is necessary. As previously mentioned, the connections in a system behave as an antenna that radiates high-frequency interference. For this reason, the measurement procedure<sup>2</sup> developed by a working group from the Deutsche Elektrotechnische Kommission, or German Electrotechnical Commission (DKE), proposes measuring two parameters:

- Spectrum of the output signals of the integrated circuit. These signals are conducted into (and, to some extent, out of) the system over lines that may be long. Therefore, they make a significant contribution to the interference generated by the circuit.
- Spectrum of the supply current of the integrated circuit. Alternating currents of significant magnitude that result from load changes at the output of the circuit, and also from switching processes within the component, flow along the supply-voltage connections. The supply lines also are taken out of the system. The length, i.e., large antenna area, of these lines makes the interference generated from the supply lines increasingly evident.

Figure 3 shows the setup for measuring the spectrum of the output signal of the circuit under examination. In this arrangement, the circuit is driven in a manner typical of its normal operation. The measurement results were obtained by examining bus-interface circuits. These components do not have their own clock generator; therefore, a generator having a frequency of  $f = 1$  MHz controls the device under test (DUT). The integrated circuit is loaded at its output with an equivalent approximate  $150\text{-}\Omega$  resistance. This value is in accordance with the characteristic impedance of lines in the cable harnesses in vehicles. In many cases, this load does not represent the situation in the user's circuit. However, the arrangement chosen does allow for a comparative measurement of various circuits, for example, different logic families. The load resistance consists of a voltage divider, R2 and R3, and the input resistance of the interference-voltage-measuring equipment connected by a coaxial cable. To avoid excessive direct currents at the output of the DUT, an additional capacitor, C4, is provided in the output circuit. With circuits that have an open-collector output, an additional pullup resistor, R1, must be included.

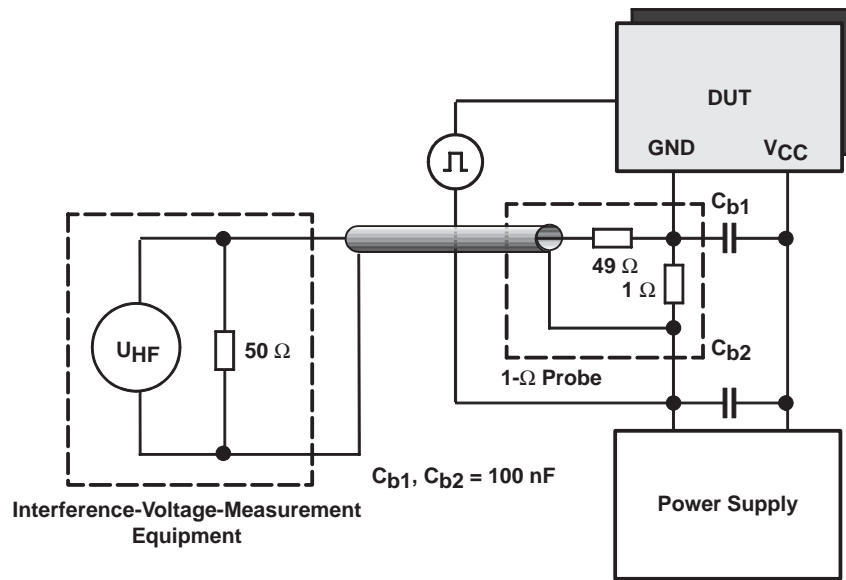


† For devices with open-collector (open-drain) outputs only

**Figure 3. Measurement of the Frequency Spectrum Generated at the Output of a Circuit**

As mentioned previously, the supply-voltage connections of an integrated circuit are a supreme source of high-frequency interference voltages and currents. Because of the switching processes that occur inside the devices, these currents often are greater than currents in the load to which they are connected.

Supply currents can be measured in various ways. One method is to use one of the well-known clamp-on current probes, which must have sufficient bandwidth. Apart from the high cost of such current probes, their mechanical dimensions are a disadvantage. At very high frequencies that must be measured precisely, the comparatively long connection lines and, hence, high inductances that result, make it almost impossible to obtain meaningful measurements. With fast digital circuits, large inductances in the connection lines put into question the function of the device under test or, at least, affect it negatively. Therefore, when the measurement specification was developed, the decision was made to measure the supply current by means of the voltage drop across a  $1\text{-}\Omega$  resistor inserted in the ground connection to the device being tested. For this purpose, a special test probe with an input resistance of  $1\text{ }\Omega$  was developed (see Figure 4). The measured voltage drop is then taken via a  $49\text{-}\Omega$  resistor and a coaxial cable to the interference-voltage-measuring equipment. Tests have shown that an arrangement such as this can be used successfully at frequencies above  $1\text{ GHz}$ .



**Figure 4. Measurement of the Supply Current**

The measurement procedure described herein preferably should measure currents and voltages delivered by the integrated circuit to the lines that follow it and, thus, radiated from the antennas that the lines form. All currents that flow only between the integrated circuit and the closely adjacent blocking capacitor can, therefore, be ignored. If the antenna area remains sufficiently small, significant radiation is not expected. For this reason, when developing the measurement setup, steps should be taken to reduce the interference caused by the device that is being tested. Of particular importance are the blocking capacitors, which must be used with logic circuits to ensure reliable operation of the circuit. As shown in Figure 4, the current of interest is measured only after the capacitor  $C_{b1}$ .

## 4 Measurement of Digital Signals and Current Spikes

### 4.1 Equipment

The equipment listed below was used to obtain the results discussed in the following sections:

- Spectrum Analyzer (Rhode & Schwarz Type FSEA), with the following settings:
  - Frequency range = 1–500 MHz
  - Resolution bandwidth = 10 kHz
  - Video bandwidth = 10 kHz
- Oscilloscope (Tektronix Type TDS744)
- AC Performance Test Board<sup>3</sup>
- 1- $\Omega$  Test Probe (Elditest Electronic Type GE4010)

### 4.2 Spectrum of Digital Signals

When measuring the frequency spectrum of the output signals of the integrated circuits, together with the spectrum of the supply current, the basic waveforms shown in Figure 5 are found. The frequency  $f_1$  is determined by the repetition frequency of the signal that is being measured. For these measurements, the bus-interface circuits were controlled at their inputs with a frequency of 1 MHz. This frequency was chosen at random. In contrast with microprocessors, which are usually driven at a specific clock frequency, the operating frequency used for logic circuits depends mainly on their particular application. The clock frequency of the processor higher up in the hierarchy of the system obviously also plays a part in such cases. The location of the component in the application is equally important. Thus, high frequencies are found on the system bus with backplane wiring. In the peripheral applications of a system, the operating frequencies usually are one or two orders of magnitude lower.

Above the frequency  $f_1$ , the amplitude of the harmonics reduces at 20 dB/decade up to a frequency  $f_2$ , which is determined by the rise and fall time,  $t_r$ , of the measured signal. The following relationship then applies:

$$f_2 = \frac{1}{\pi \times t_r} \quad (2)$$

Above the frequency  $f_2$ , the amplitude of the harmonics reduces at 40 dB/decade and produces the waveform shown in Figure 5.

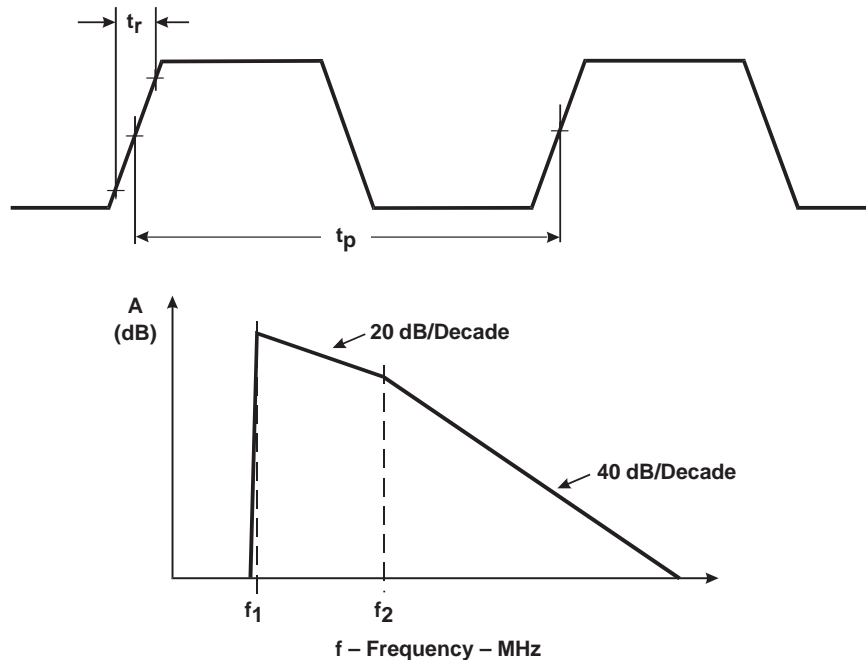


Figure 5. Spectrum of a Digital Signal

During the development of a circuit intended to generate the lowest possible level of electromagnetic interference, and when choosing the integrated circuits to be used, attention must be paid to the following parameters:

- Amplitude of the output signal. A 30% reduction in the amplitude of the signal also reduces by 3 dB the amplitude of the harmonics that are generated. A logical and sensible step is, where possible, to change the circuit supply voltage from 5 V to 3 V.
- Rise time of the signal. With circuits having slow edges, the frequency  $f_2$  also is correspondingly reduced. This also results in a reduction of the harmonic interference that is generated. However, the design engineer is usually under certain constraints. A circuit that generates an output signal with slow edges also has a longer delay time. That is, 50% of the rise/fall time of the output signal is manifested as additional delay time. However, this situation gives rise to the general requirement that only those circuits should be used that are fast enough for the application in question, and not to use any components that are too fast. Apart from the higher cost of the latter, the extra expense for the screening is an additional factor to consider.
- Current spikes generated when switching push-pull (totem pole) outputs are an additional potential source of interference. For this reason, the frequency spectrum of the supply current is discussed. With the logic circuits under consideration, the result must be correctly interpreted relative to the application. At low loading levels, such as those presented by connections with a length of only a few centimeters, the contribution resulting from the current spikes predominates. With low-resistance loads, such as the  $150\ \Omega$  used in the measurement setup or actual bus lines, this part can, to a large extent, be neglected. In such cases, the currents in supply lines that result from the charging and discharging of capacitive reactances instead become significant.

### 4.3 Spectrum of the Output Signal

The waveform in Figure 5 indicates the measurement results that can be expected.

The output of a CMOS circuit can, with some simplification, be represented as an ideal voltage source,  $V_{CC}$ , and an internal resistance,  $R_O$  (see Figure 6). This output resistor is then connected either to the supply voltage  $V_{CC}$  (output high) or to ground (output low). An output voltage,  $V_{out}$ , results, which depends on the load. The voltage is measured according to Figure 3 at the output of the voltage divider  $R_3/R_2$ ; this being connected (via a coaxial cable) to the interference-voltage-measuring equipment having an input resistance of  $R_m$ . The following expression applies for the voltage,  $V_m$ , which subsequently appears at the measuring equipment:

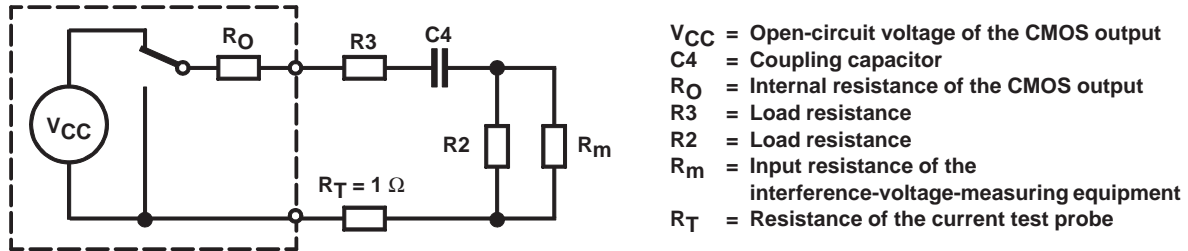


Figure 6. Equivalent Circuit of a CMOS Output Stage When Loaded by a Test Circuit

$$V_m = V_{CC} \times \frac{\frac{R_2 \times R_m}{R_2 + R_m}}{R_O + R_3 + \frac{R_2 \times R_m}{R_2 + R_m}} \quad (3)$$

In this case, the resistance of the probe ( $R_T$ ) is  $1\ \Omega$ , and the impedance of coupling capacitor  $C_4$  can be disregarded. Assuming  $R_m = R_2 = 50\ \Omega$ , the expression is simplified to:

$$V_m = V_{CC} \times \frac{R_2}{2 \times (R_O + R_3) + R_2} \quad (4)$$

The voltage  $V_m$ , which is to be measured, has a square waveform that is made up of an infinite number of sine-wave voltages with the following relationship:

$$V_m = V_{mpp} \left( \sin \omega t + \frac{\sin 3\omega t}{3} + \frac{\sin 5\omega t}{5} + \frac{\sin 7\omega t}{7} \Lambda \right) \quad (5)$$

Where:

$V_{mpp}$  = peak-to-peak voltage of the signal (with CMOS circuits, is the same as  $V_{CC}$ )

Because the interference-voltage-measuring equipment, for example, a spectrum analyzer, measures effective values, the above result must be corrected appropriately. The result is that the value of the voltage of the fundamental of the signal,  $V_{meff}$ , read from the interference-voltage-measuring equipment, is:

$$V_{meff} = 5 \text{ V} \times \frac{50 \Omega}{[2 \times (10 \Omega + 120 \Omega) + 50 \Omega] \times 2 \times \sqrt{2}} = 0.285 \text{ V} \quad (6)$$

The interference voltage is measured over a frequency range of several hundred megahertz; in this case, from 1 MHz to 500 MHz. The range of values of the measured voltages is also correspondingly large. To improve the readability of the curves, a logarithmic representation is used. The unit of measurement commonly used here is dB $\mu$ V. The value of  $V_{meff}$  must be converted using:

$$A = 20 \times \log \frac{V_{meff}}{1 \mu V} \quad (7)$$

For this example, the following value applies for the amplitude of the fundamental ( $f = 1 \text{ MHz}$ ):

$$A_{(1 \text{ MHz})} = 20 \times \log \frac{V_{meff(1 \text{ MHz})}}{1 \mu V} = 20 \times \log \frac{0.285 \text{ V}}{1 \mu V} = 109 \text{ dB}\mu V \quad (8)$$

The cutoff frequency,  $f_2$ , must be determined. The waveform at the output of an AC circuit is shown in Figure 7. The spectrum of the output signal of an AC circuit is shown in Figure 8.

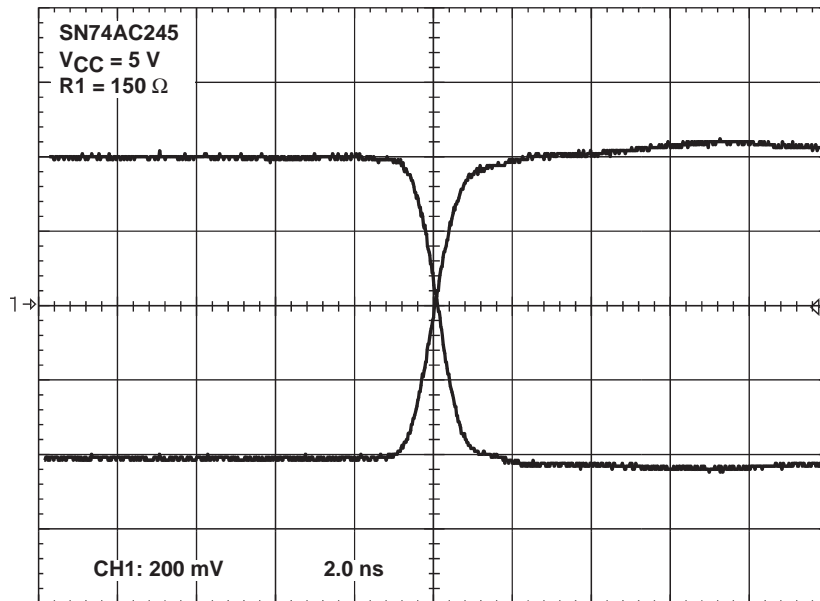
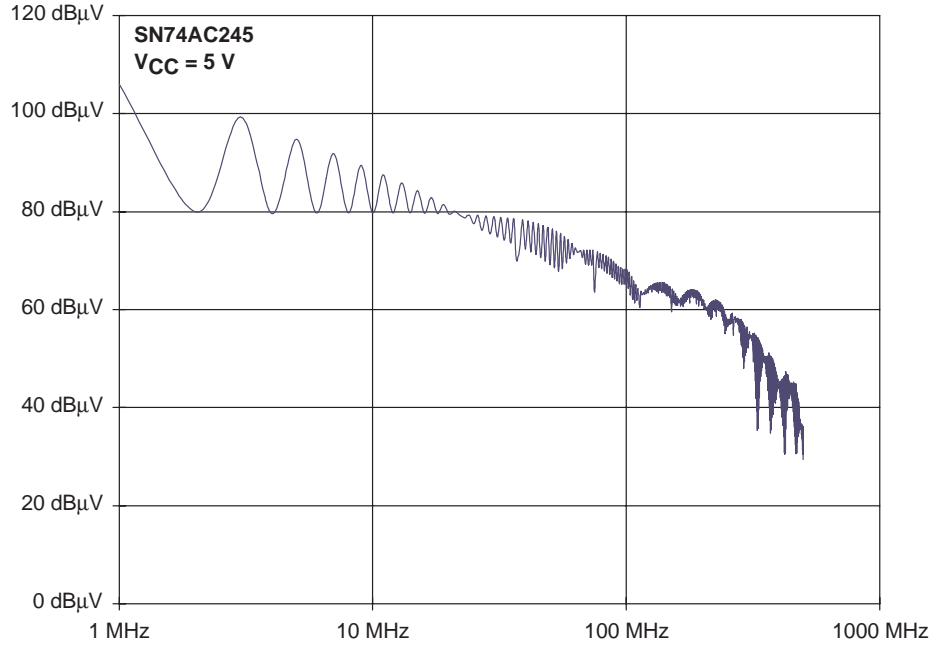


Figure 7. SN74AC245 Waveform at the Output of the Circuit ( $R1 = 150 \Omega$ )



**Figure 8. Spectrum of the Output Signal of an AC Circuit**

The rise and fall times of the signals at the outputs are about 1.5 ns:

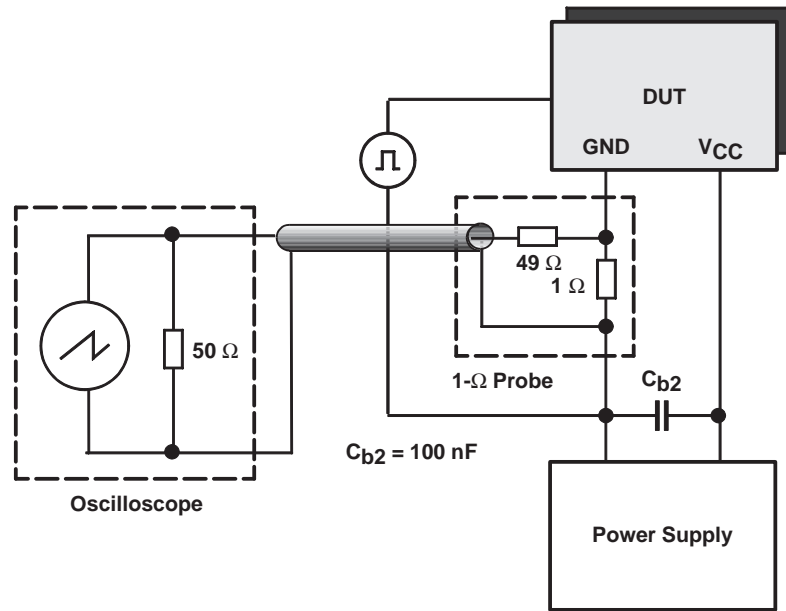
$$f_2 = \frac{1}{t_{r/f} \times \pi} = \frac{1}{1.5 \text{ ns} \times \pi} = 200 \text{ MHz} \quad (9)$$

Up to  $f_2 = 200 \text{ MHz}$ , the amplitudes of the harmonics decrease at 20 dB/decade. Above this frequency, the attenuation is as expected, 40 dB/decade.

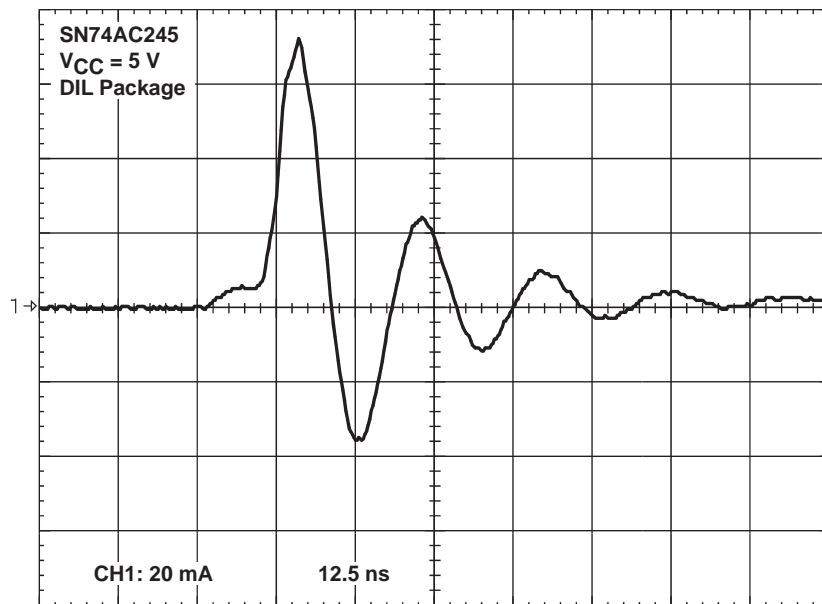
#### 4.4 Measurement of the Spectrum of the Supply Current

The frequency spectrum of the supply current can be determined in a similar way. The current in the ground connection depends on the switching processes occurring inside the integrated circuit and it depends on the load connected to the output of the circuit. The former contribution cannot be predicted without a detailed knowledge of the inside of the circuit, and must, therefore, be determined by measurements. The major contribution is from the so-called current spikes that result when switching the output from one state to the other. During the transition from one state to the other, both output transistors of the push-pull stage simultaneously are conducting for several nanoseconds. This results in an increased supply current. The amplitude of the current spikes can be determined by a setup as shown in Figure 9, very similar to that shown in Figure 4. However, the blocking capacitor  $C_{b1}$  shown in Figure 4, which would be parallel to the device being tested, is not included. As shown in Figures 10, 11, and 12, this capacitor greatly affects the amplitude and the waveform of these current spikes.





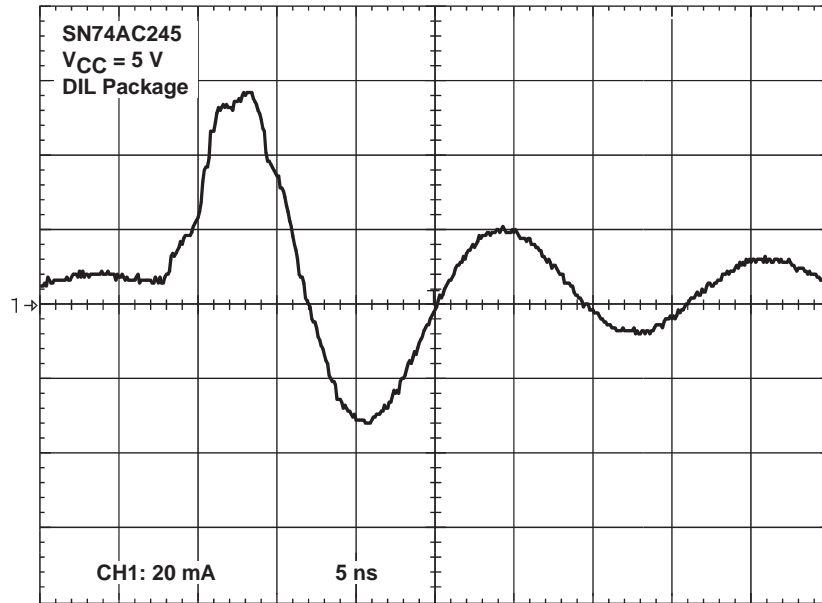
**Figure 9. Test Circuit for Determination of Current Spikes**



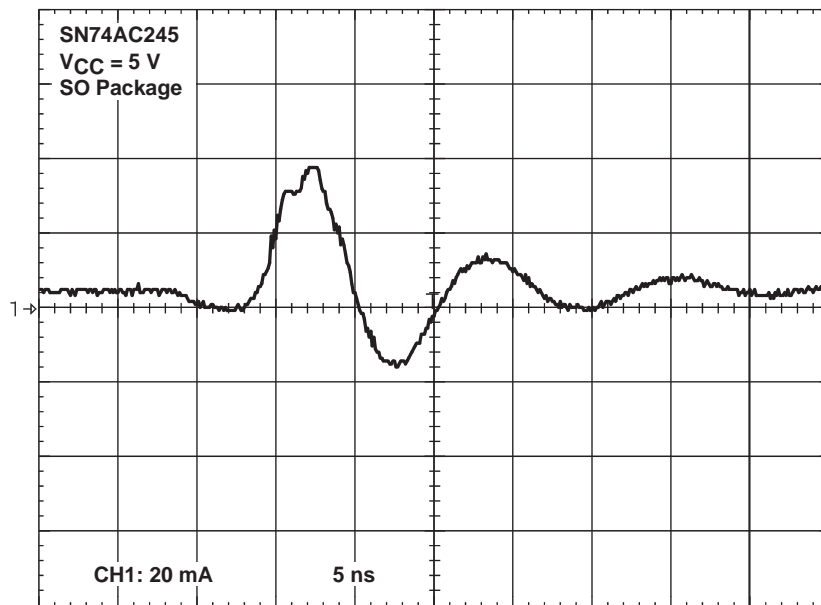
**Figure 10. SN74AC245 Current Spikes With Unloaded Output (DIL package)**

With the AC circuits being measured, the amplitude of the peak current is 70 mA (see Figure 10). Measurements have shown that the waveform and its amplitude are largely independent of the package type (DIL or SO) in which the semiconductor chip is encapsulated.

In practical applications, a blocking capacitor (C<sub>b1</sub> in Figure 4) is found very close to the integrated circuit. One of its main jobs is to provide the energy required when switching over the load at the output. It also has a considerable influence on the amplitude of the high-frequency interference generated by the integrated circuit. The package construction of the integrated circuit plays an important part. With the smaller SO packages having correspondingly lower inductances, a current amplitude can be measured, which is about 30% lower than with the same chip in a DIL package. The lower inductances result naturally in a higher resonant frequency of the damped oscillations, as shown in Figures 11 and 12.

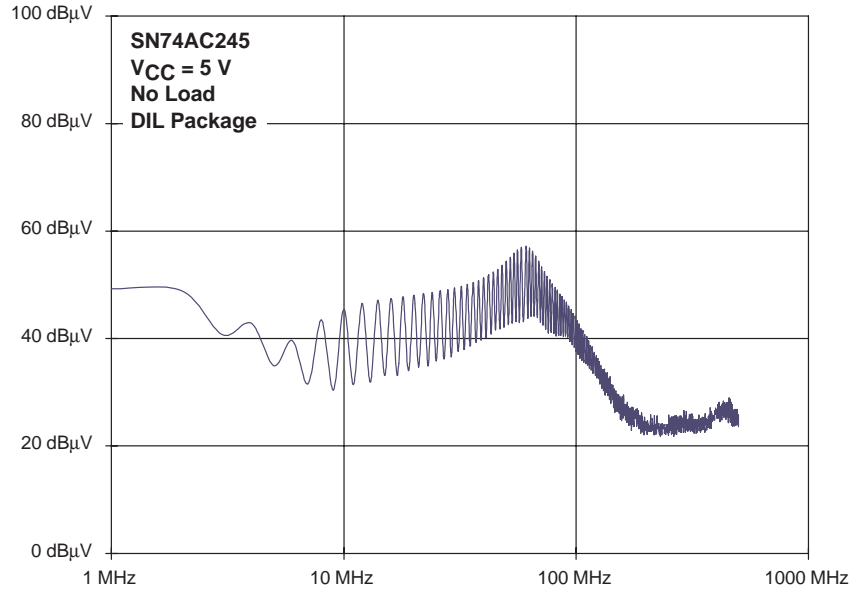


**Figure 11. Supply Current Spikes of an Unloaded AC Circuit (DIL package)**

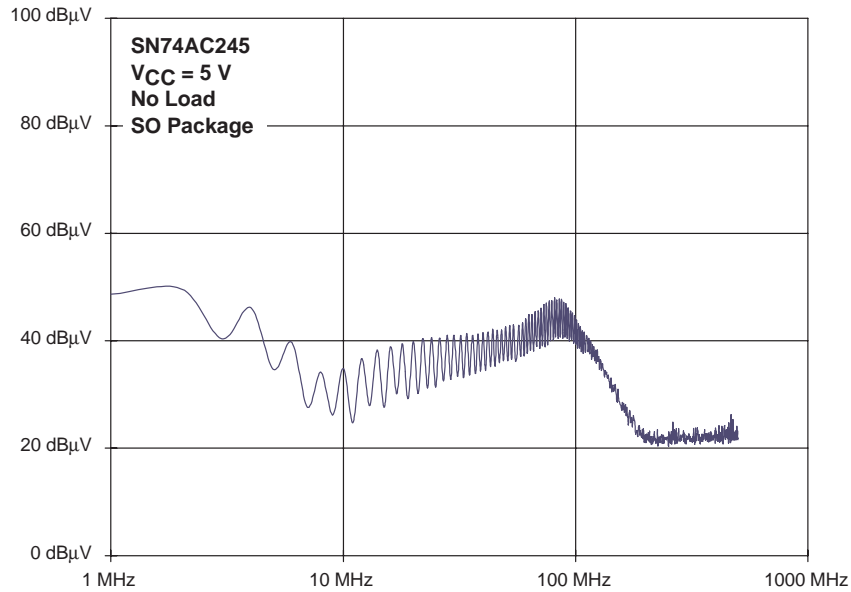


**Figure 12. Supply Current Spikes of an Unloaded AC Circuit (SO package)**

The differences in the behavior of packages become evident when measurements are made of the frequency spectrum of the currents, as previously discussed. With the chip in an SO package, the maximum value of the amplitude of the harmonics is at a frequency about 20 MHz higher than that in a DIL package. At the same time, the amplitude measured with SO packages is about 10 dB lower (see Figures 13 and 14).

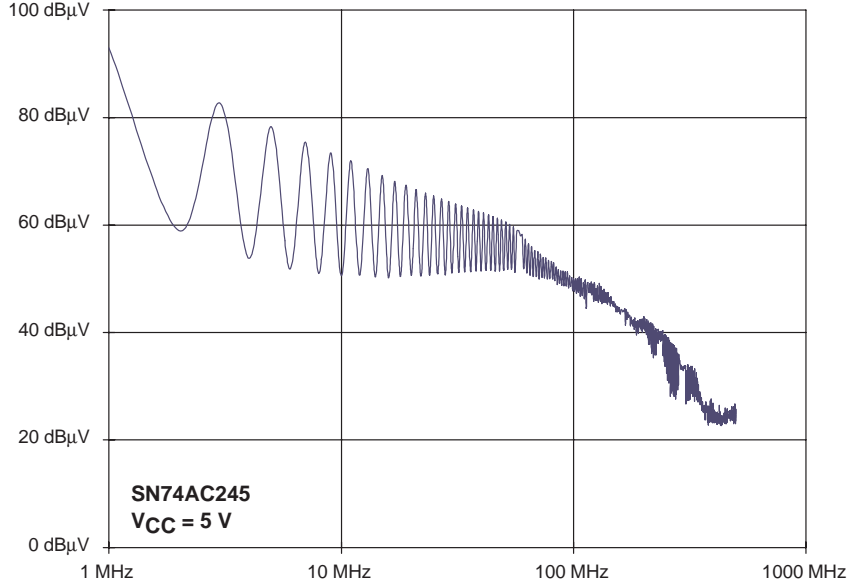


**Figure 13. Frequency Spectrum of the Supply Current of an Unloaded AC Circuit (DIL package)**



**Figure 14. Frequency Spectrum of the Supply Current of an Unloaded AC Circuit (SO package)**

In practical applications, the currents resulting from the load connected to the outputs outweigh the effects just described. Figure 15 shows the spectrum of the sum of the currents flowing in the ground line of an AC circuit. This, and all subsequent measurements, were made with integrated circuits in the DIL package. In this case, all eight outputs of the component switch simultaneously. A load consisting of  $R = 150 \, \Omega$  and  $C = 0.047 \, \mu\text{F}$  in series was connected to the outputs.



**Figure 15. Frequency Spectrum of the Supply Current of a Loaded AC Circuit**

The measurement results can be checked mathematically. The spectrum of the output signal was measured across a load resistance  $R_3 // R_m = 25 \Omega$ . For this measurement, the same load current also flows through the  $1\text{-}\Omega$  test probe. The resulting voltage drop,  $V_{\text{meff(GND)}}$ , is proportional to the ratio of the values of the resistors and must be multiplied by the number of simultaneously switching outputs. In addition, the voltage divider in the  $1\text{-}\Omega$  probe divides the measured voltage by a factor of 2. The result is:

$$V_{\text{meff(GND)}} = V_{\text{meff}} \times \frac{1}{25} \frac{\Omega}{\Omega} \times \frac{n}{2} \quad (10)$$

If the voltage ratio  $(1/25) \times (n/2)$  is now calculated in dB as a unit of measurement, the required ratio  $A_{\text{(GND)}}$  is:

$$A_{\text{(GND)}} = 20 \times \log\left(\frac{1}{25} \times \frac{8}{2}\right) = -15.9 \text{ dB} \quad (11)$$

For low frequencies, the spectrum of the supply current can be determined directly from the frequency spectrum of the output signal. The current spikes become evident only at higher frequencies. The frequency spectrum of the supply current with loaded and unloaded outputs is shown in Section 5.

## 5 Measurement Results

### 5.1 SN74ABT245 Measurement Results

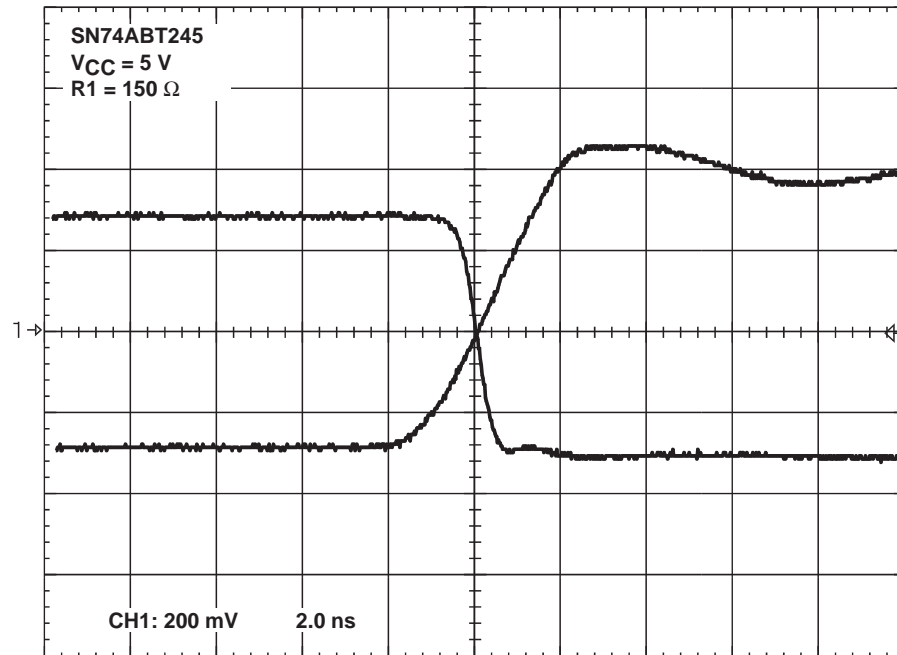


Figure 16. SN74ABT245 Waveform at the Output

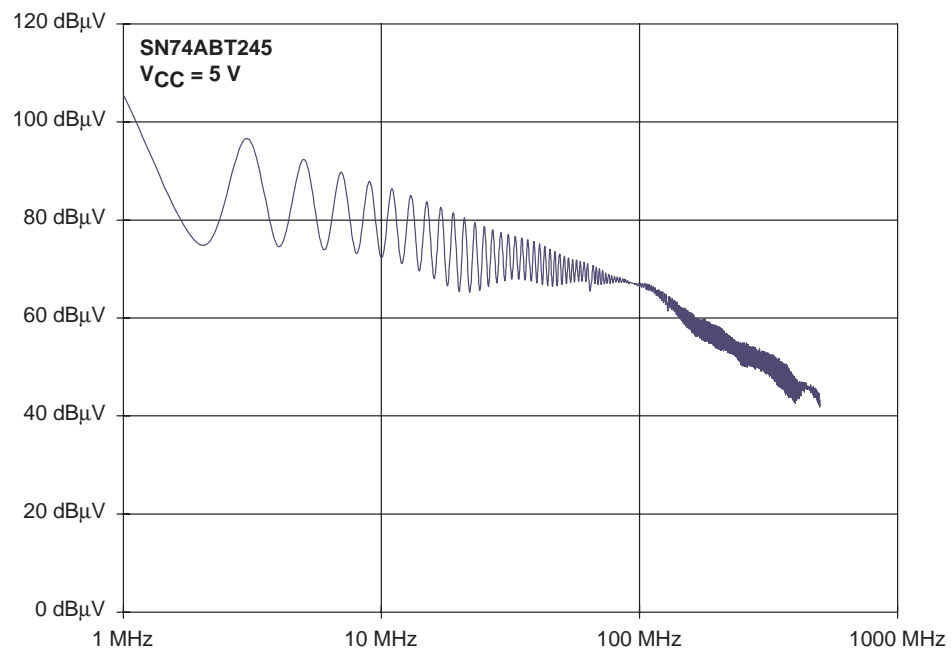
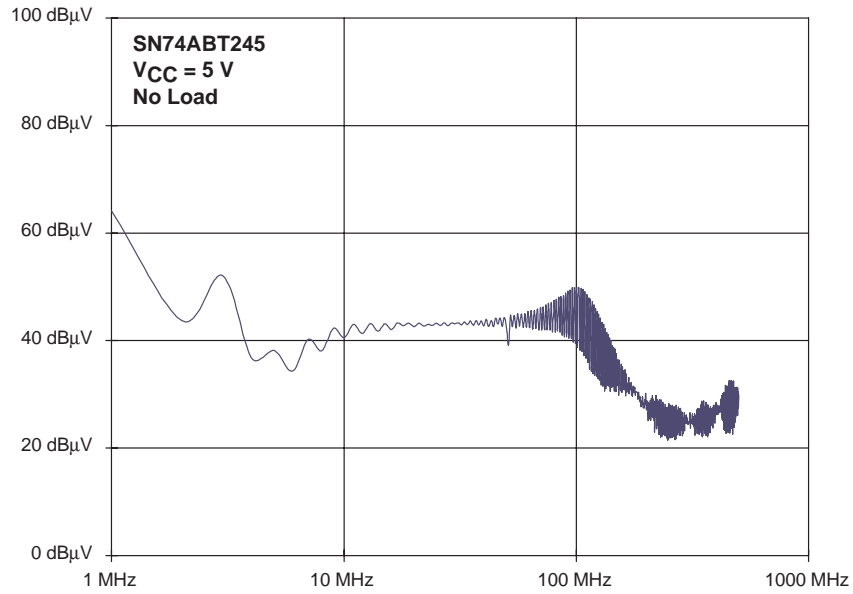
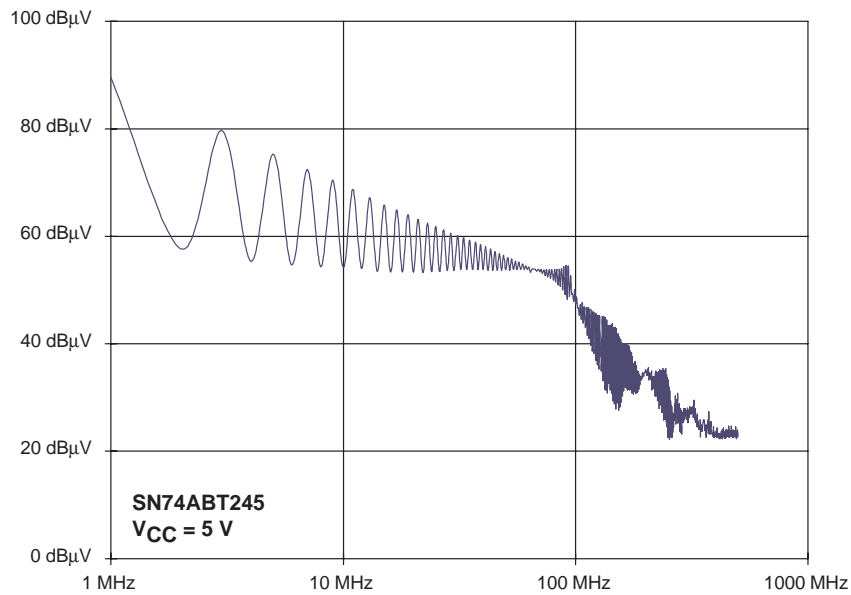


Figure 17. SN74ABT245 Spectrum of the Output Signal



**Figure 18. SN74ABT245 Spectrum of the Supply Current (output unloaded)**



**Figure 19. SN74ABT245 Spectrum of the Supply Current (output loaded)**

## 5.2 SN74ABT2245 Measurement Results

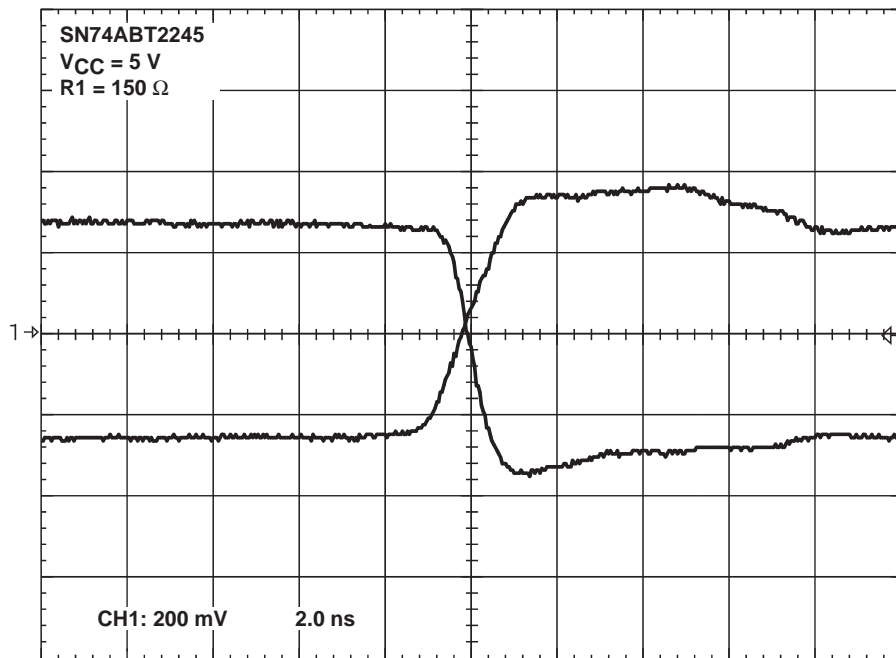


Figure 20. SN74ABT2245 Waveform at the Output

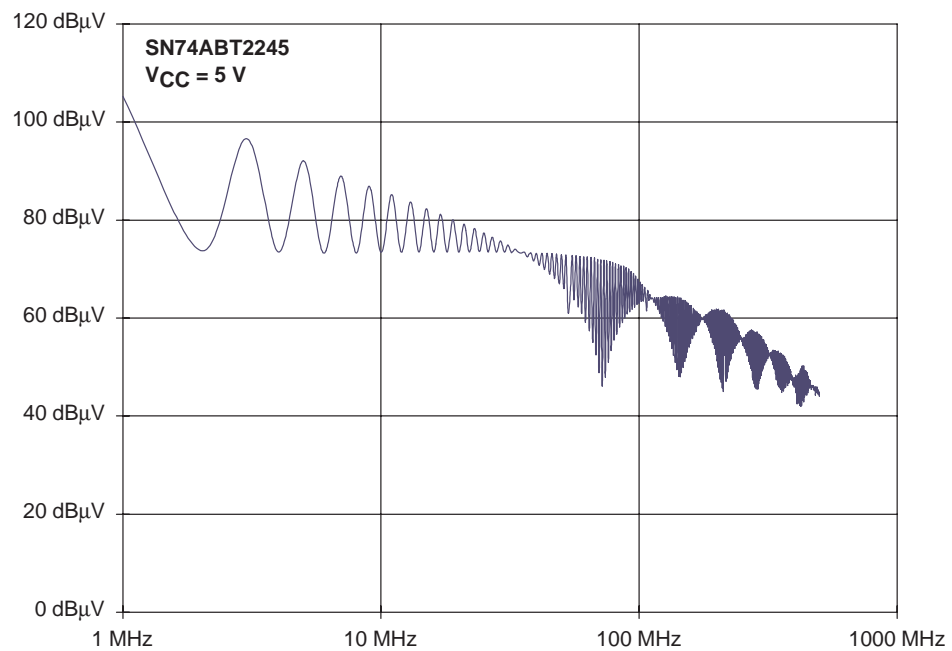
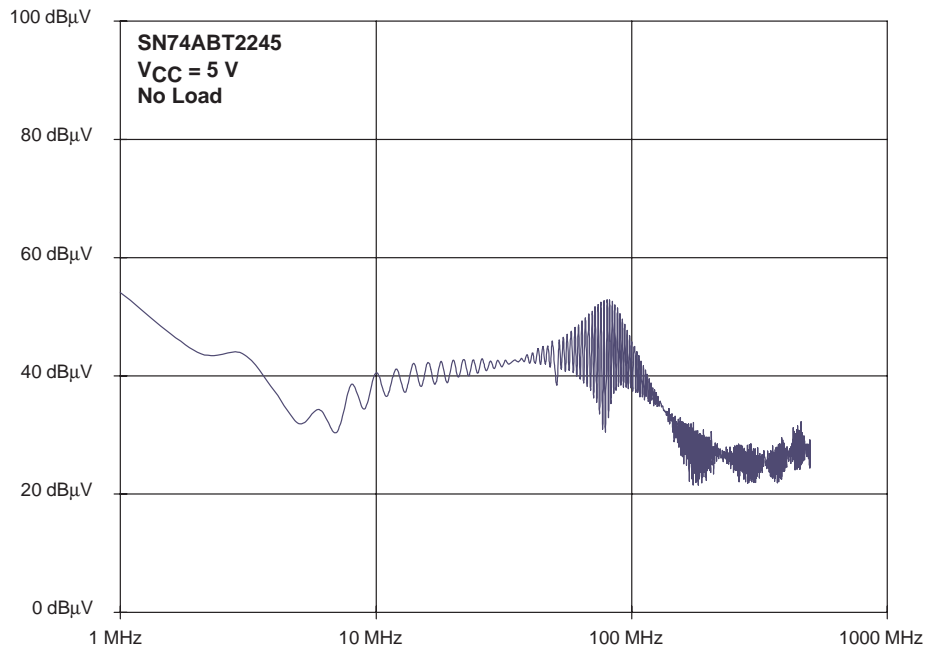
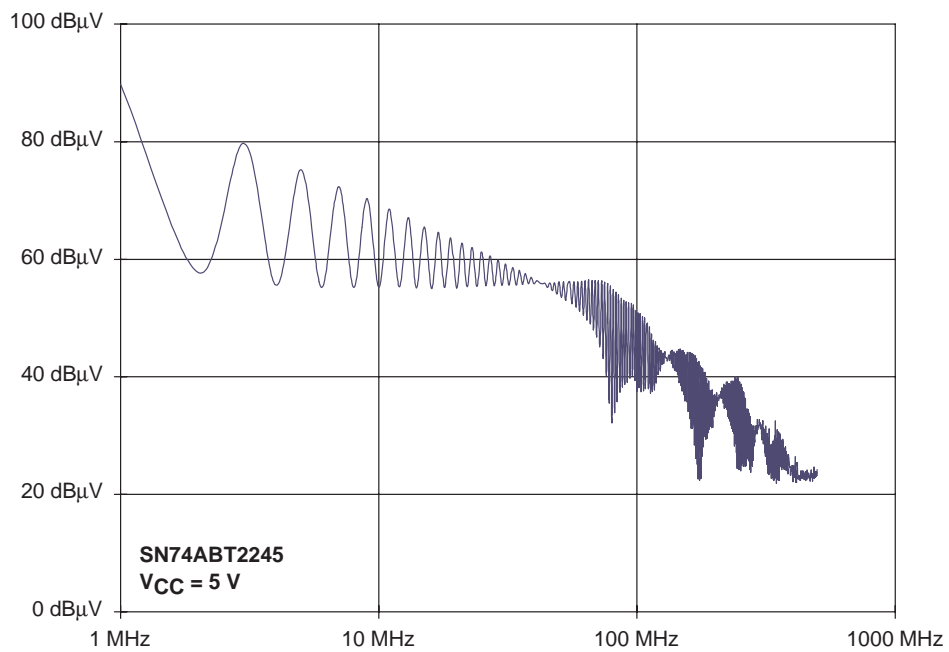


Figure 21. SN74ABT2245 Spectrum of the Output Signal



**Figure 22. SN74ABT2245 Spectrum of the Supply Current (output unloaded)**



**Figure 23. SN74ABT2245 Spectrum of the Supply Current (output loaded)**



### 5.3 SN74AC245 Measurement Results ( $V_{CC} = 5\text{ V}$ )

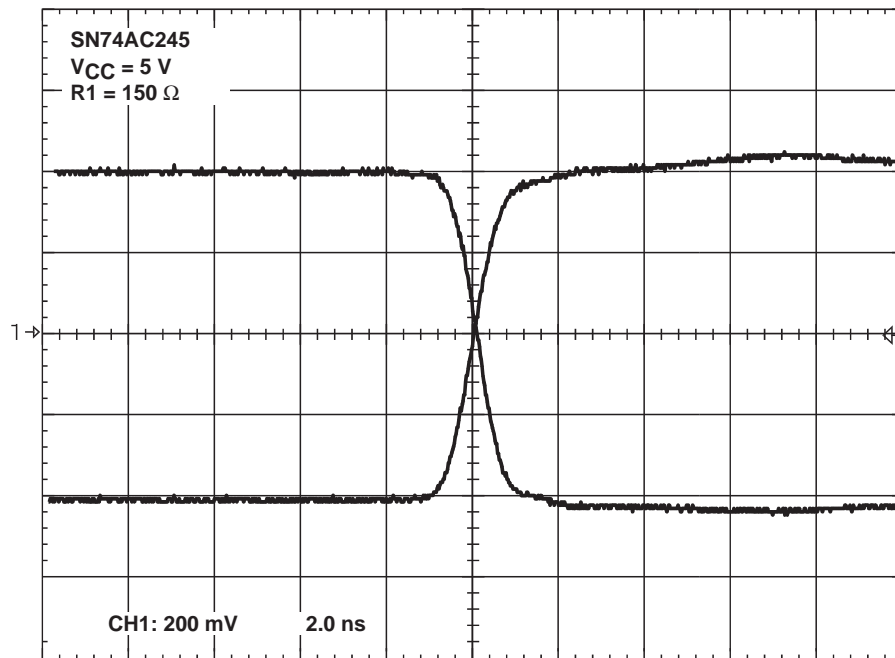


Figure 24. SN74AC245 Waveform at the Output

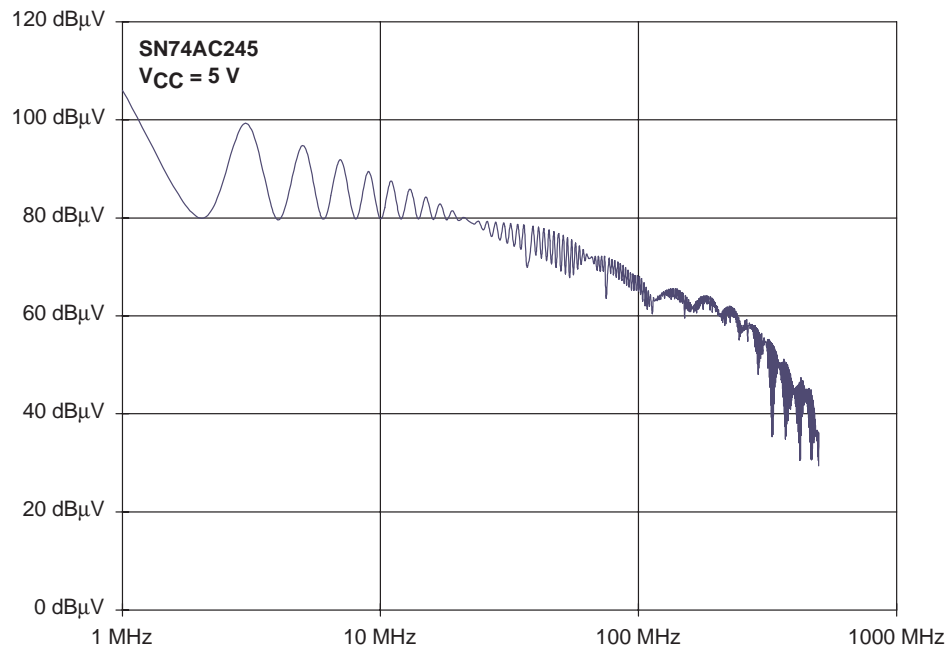
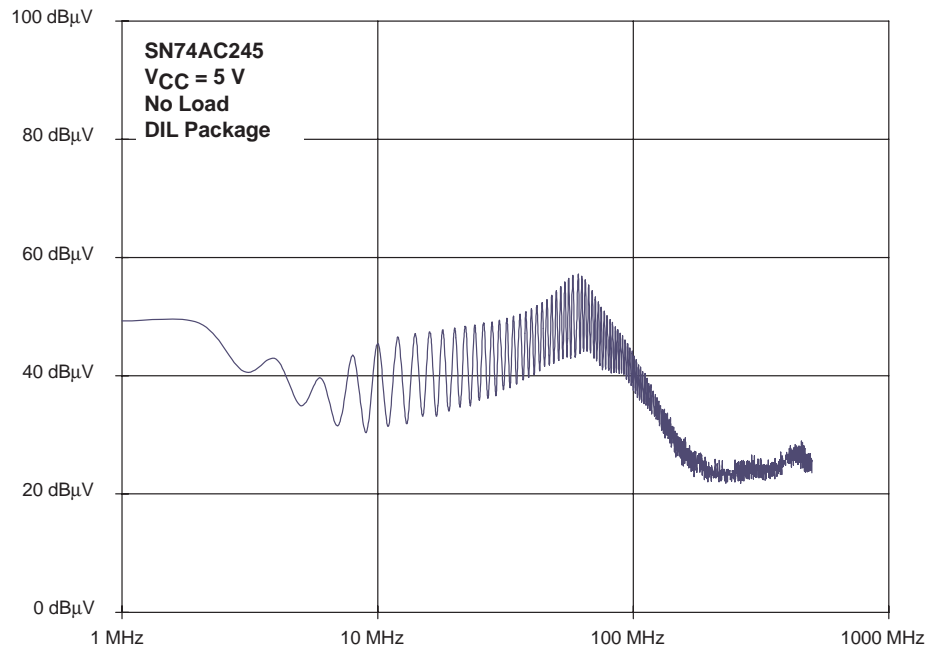
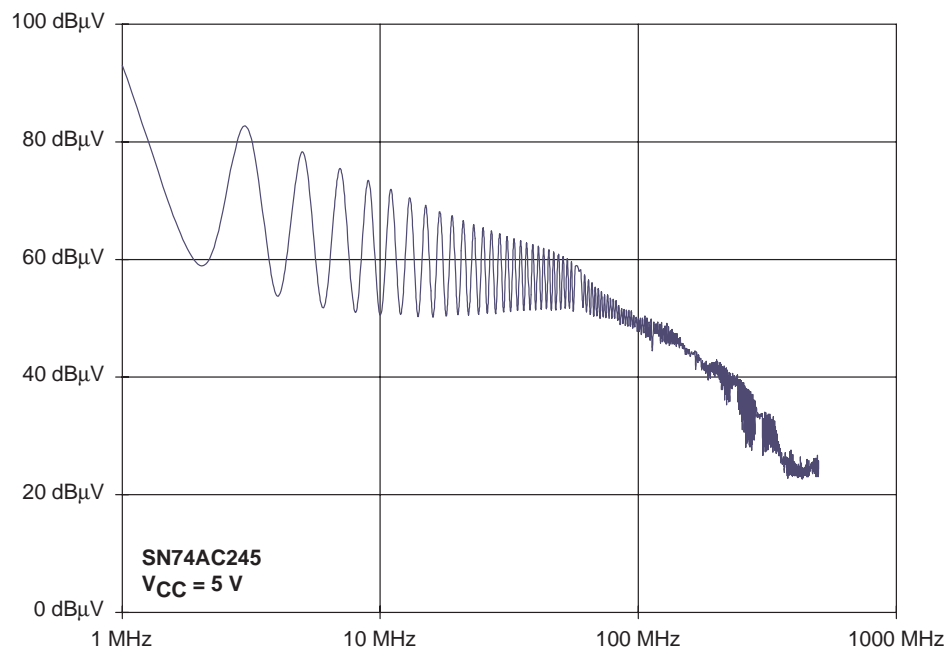


Figure 25. SN74AC245 Spectrum of the Output Signal



**Figure 26. SN74AC245 Spectrum of the Supply Current (output unloaded)**



**Figure 27. SN74AC245 Spectrum of the Supply Current (output loaded)**

#### 5.4 SN74AC245 Measurement Results ( $V_{CC} = 3.3\text{ V}$ )

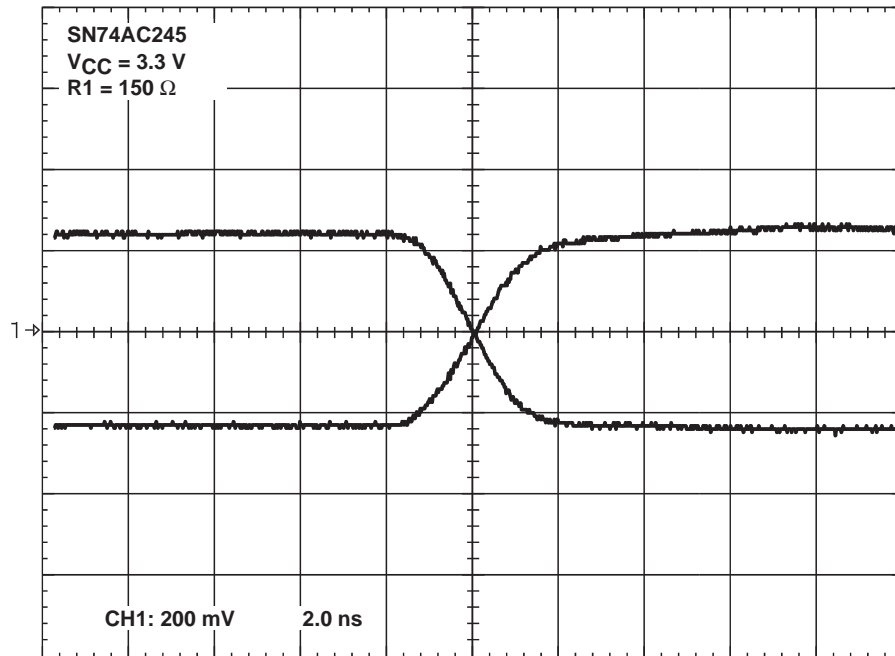


Figure 28. SN74AC245 Waveform at the Output

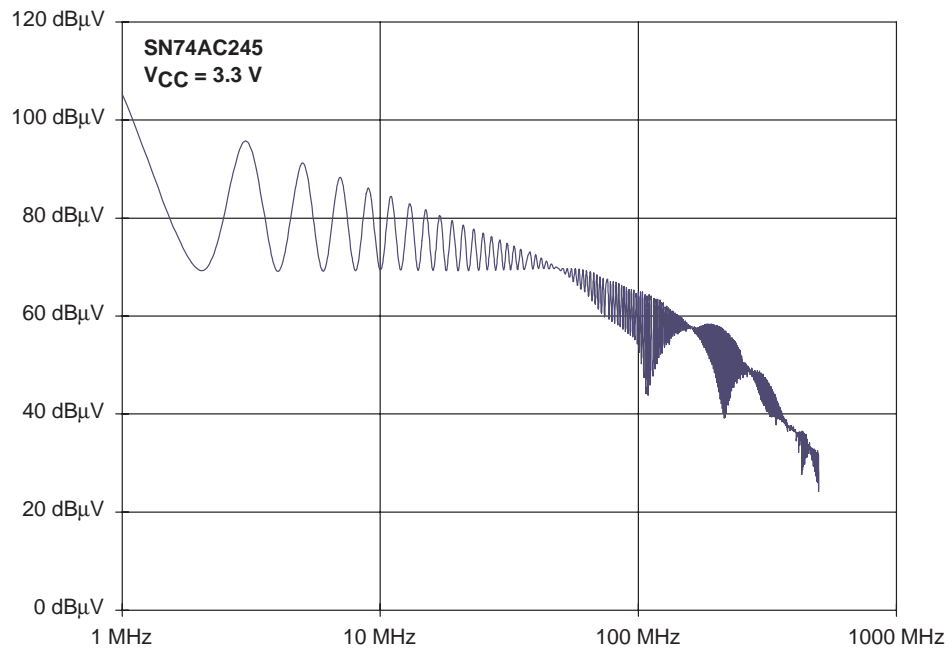
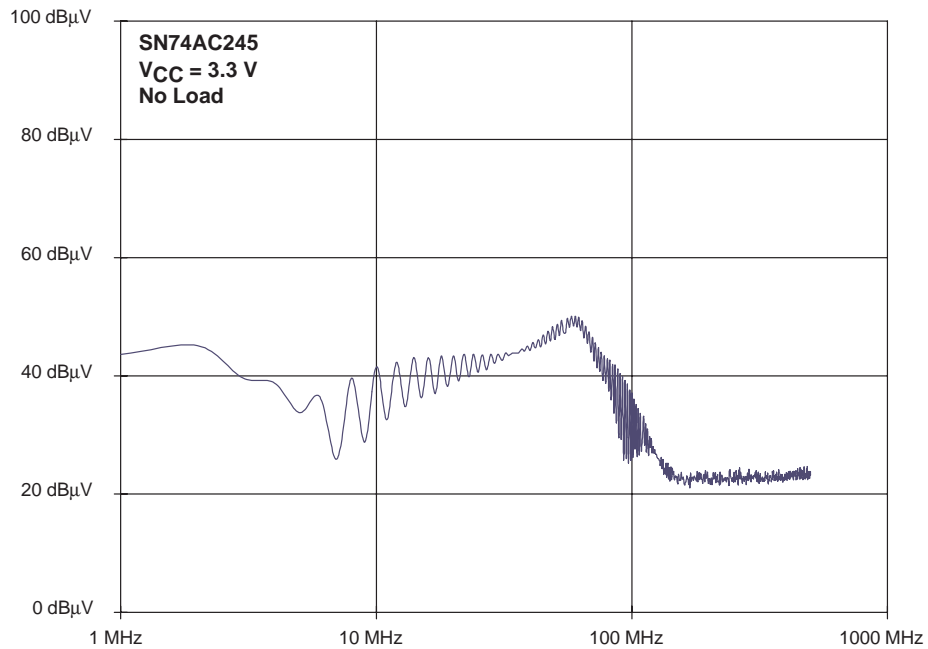
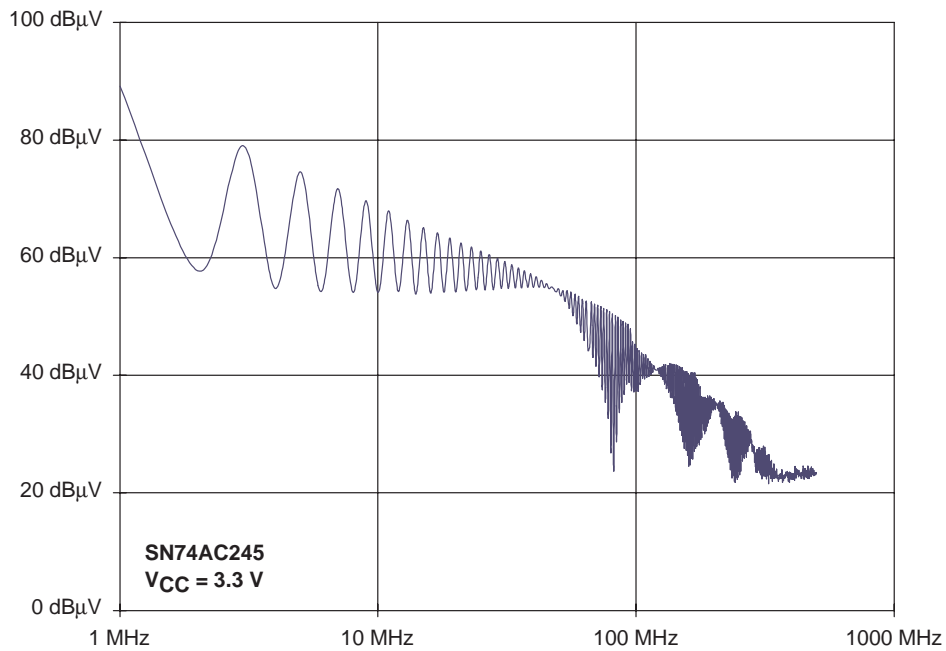


Figure 29. SN74AC245 Spectrum of the Output Signal



**Figure 30. SN74AC245 Spectrum of the Supply Current (output unloaded)**



**Figure 31. SN74AC245 Spectrum of the Supply Current (output loaded)**

### 5.5 SN74AHC245 Measurement Results ( $V_{CC} = 5\text{ V}$ )

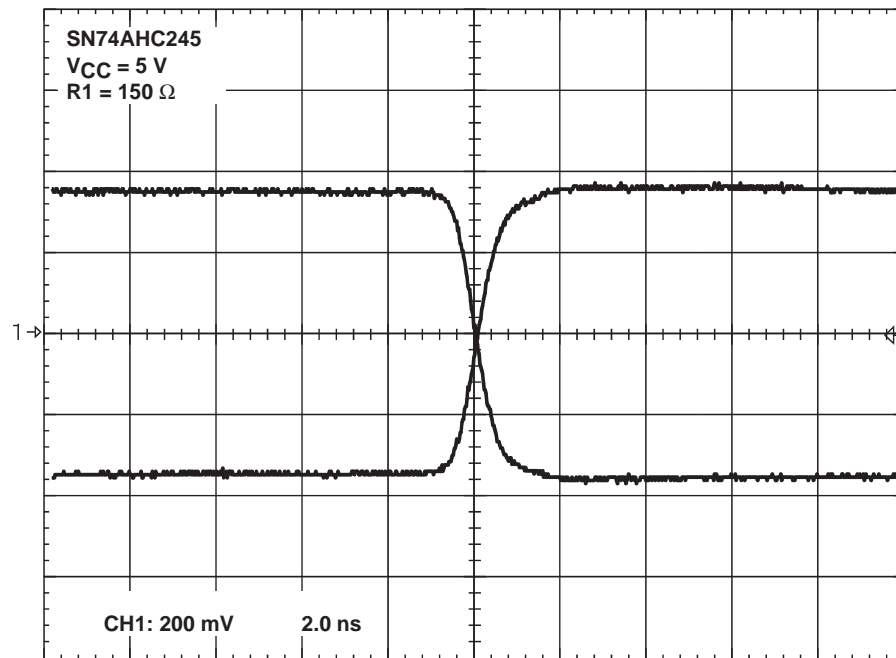


Figure 32. SN74AHC245 Waveform at the Output

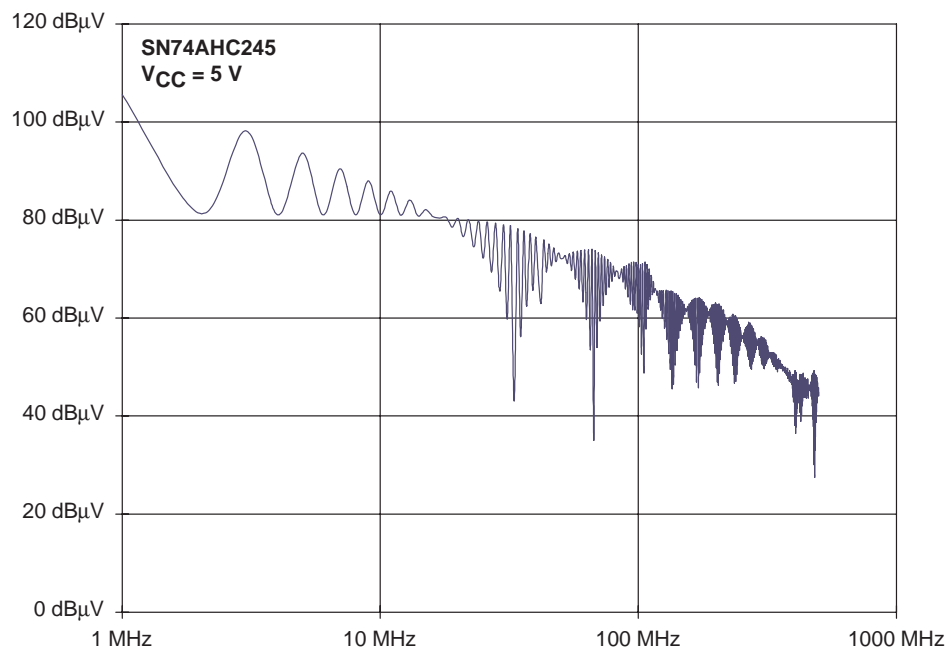
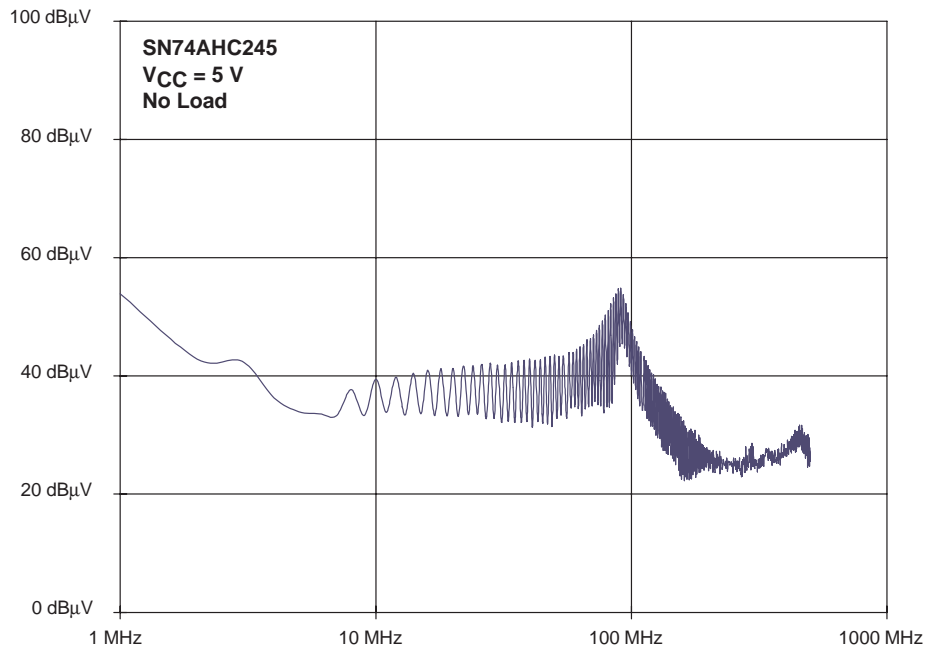
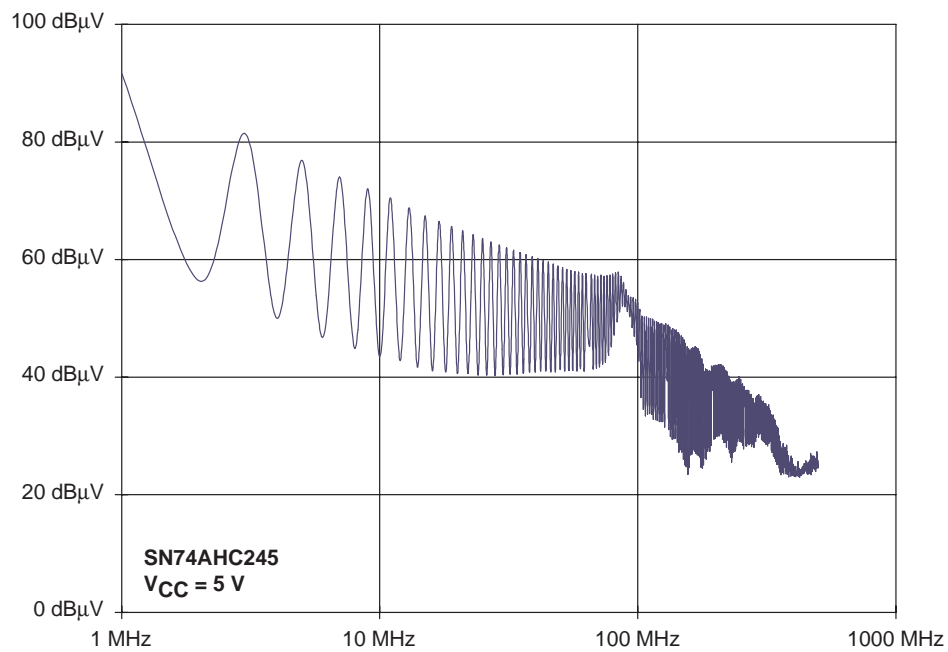


Figure 33. SN74AHC245 Spectrum of the Output Signal



**Figure 34. SN74AHC245 Spectrum of the Supply Current (output unloaded)**



**Figure 35. SN74AHC245 Spectrum of the Supply Current (output loaded)**

## 5.6 SN74AHC245 Measurement Results ( $V_{CC} = 3.3\text{ V}$ )

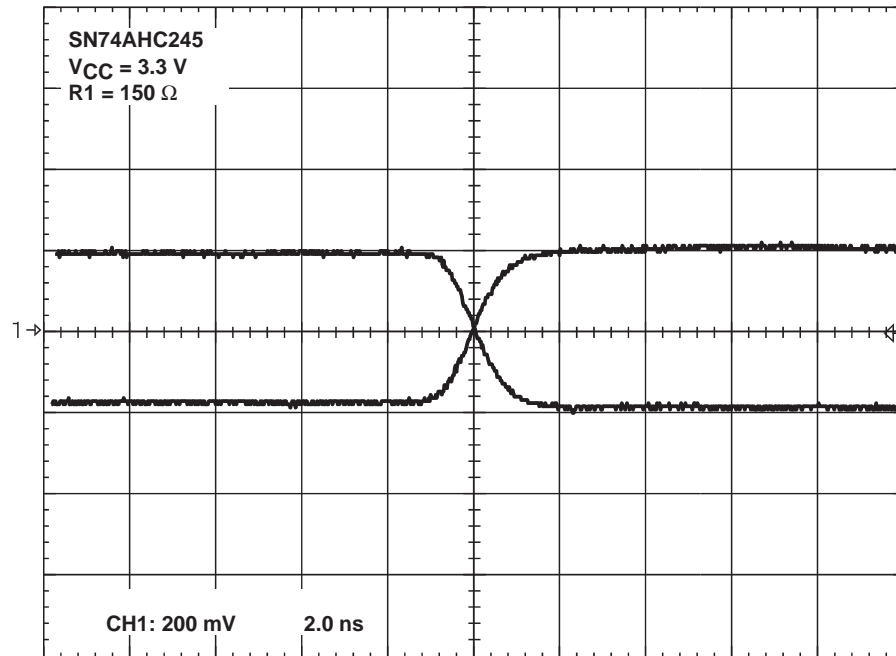


Figure 36. SN74AHC245 Waveform at the Output

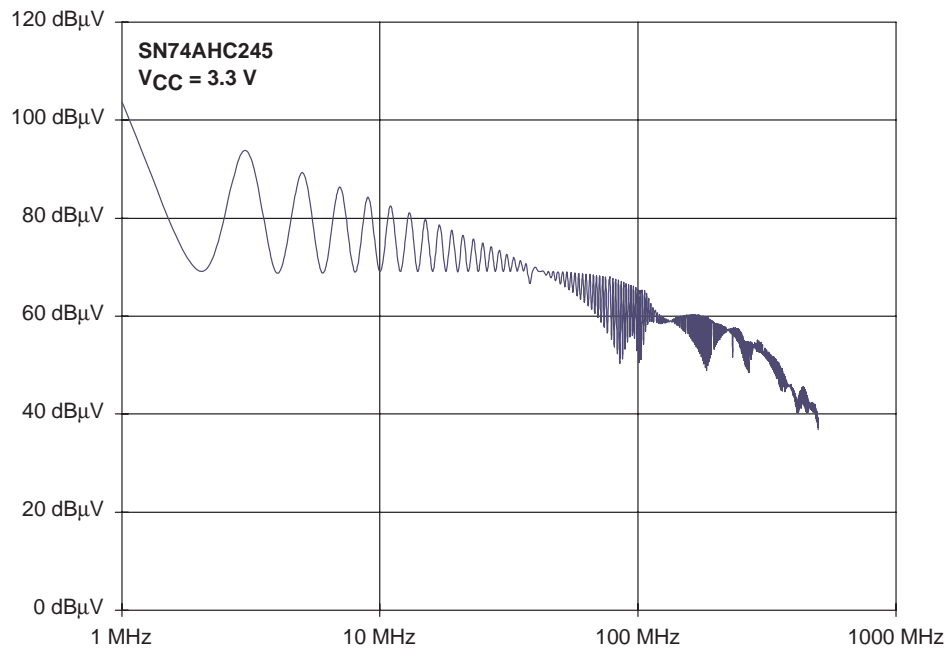
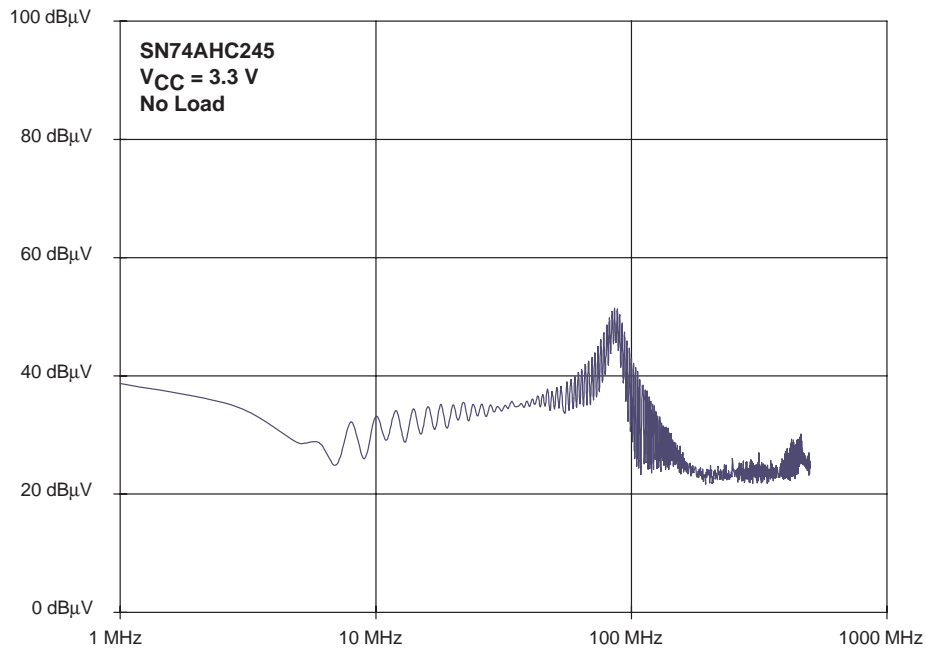
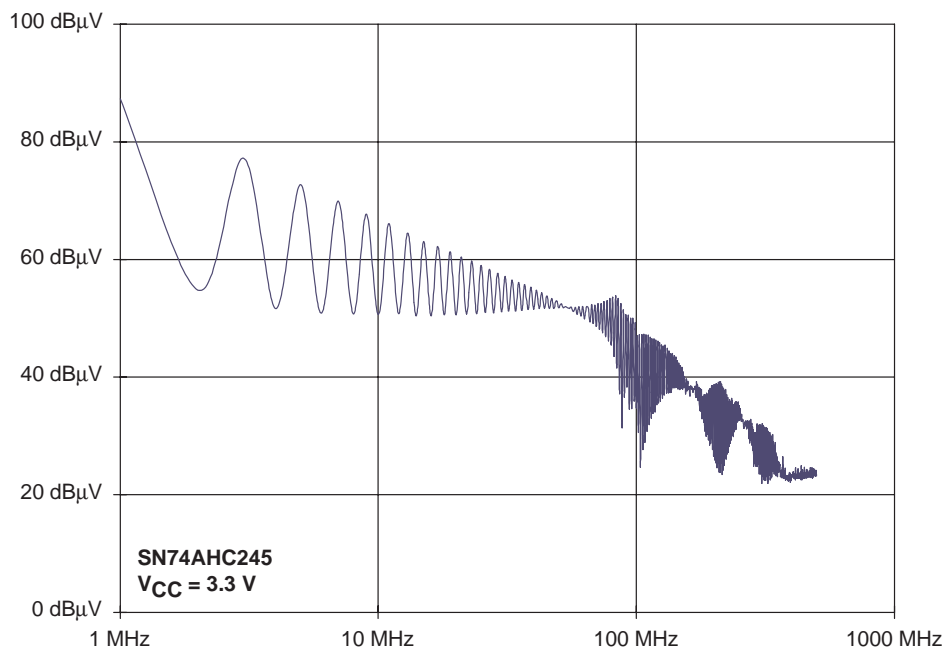


Figure 37. SN74AHC245 Spectrum of the Output Signal



**Figure 38. SN74AHC245 Spectrum of the Supply Current (output unloaded)**



**Figure 39. SN74AHC245 Spectrum of the Supply Current (output loaded)**



## 5.7 SN74ALS245 Measurement Results

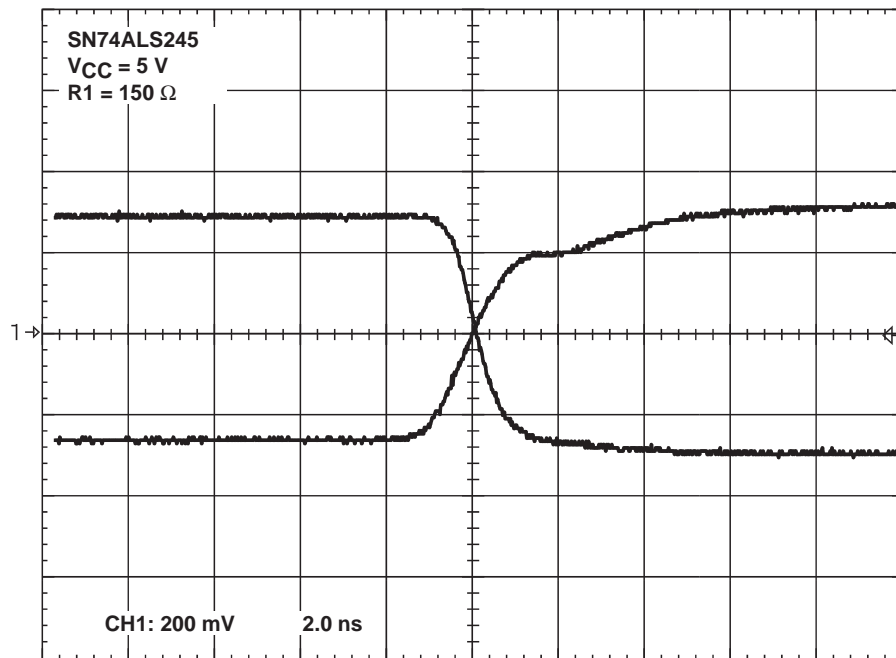


Figure 40. SN74ALS245 Waveform at the Output

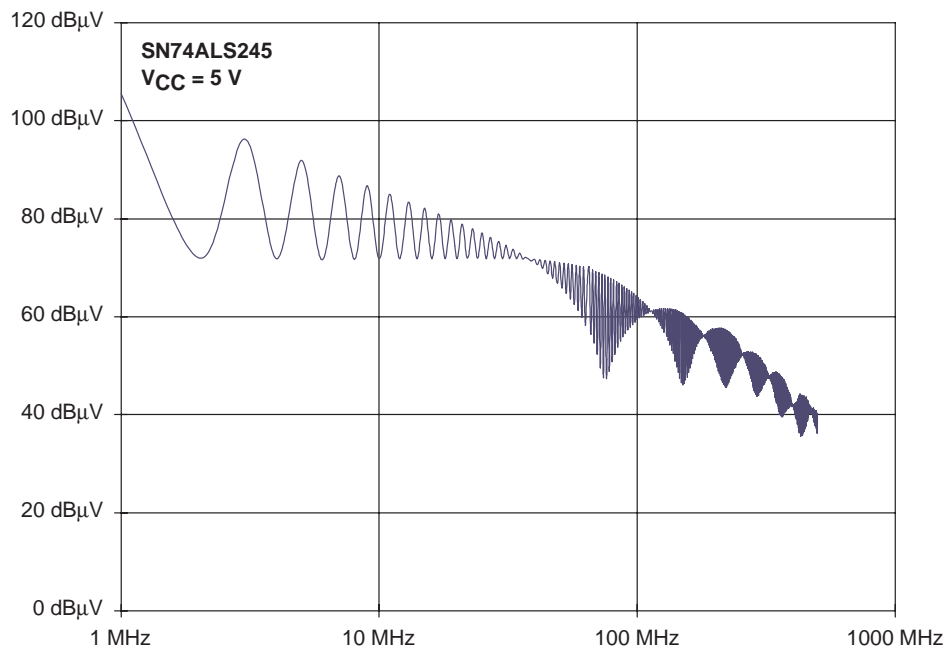
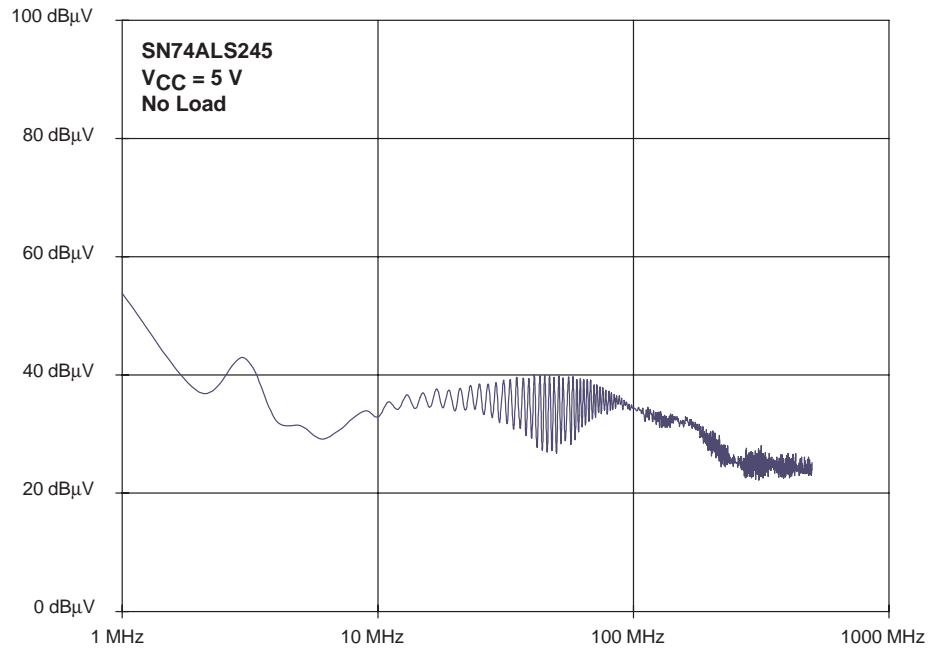
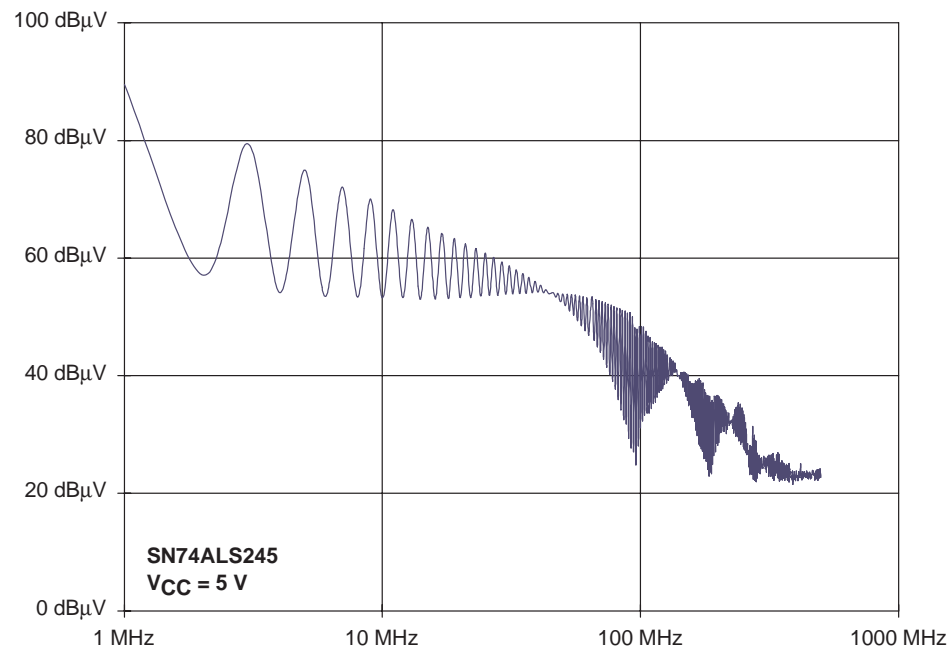


Figure 41. SN74ALS245 Spectrum of the Output Signal



**Figure 42. SN74ALS245 Spectrum of the Supply Current (output unloaded)**



**Figure 43. SN74ALS245 Spectrum of the Supply Current (output loaded)**

## 5.8 SN74AS245 Measurement Results

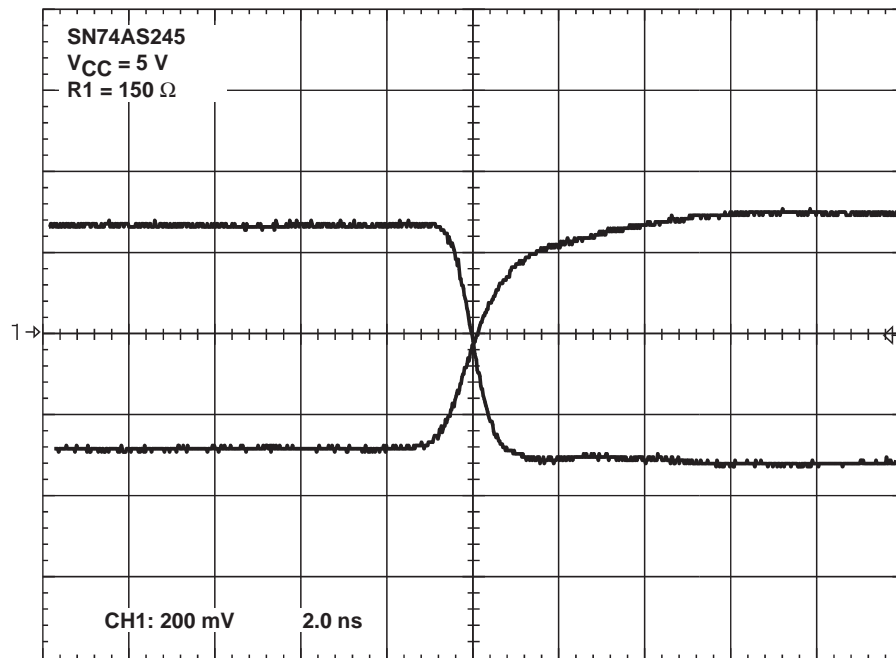


Figure 44. SN74AS245 Waveform at the Output

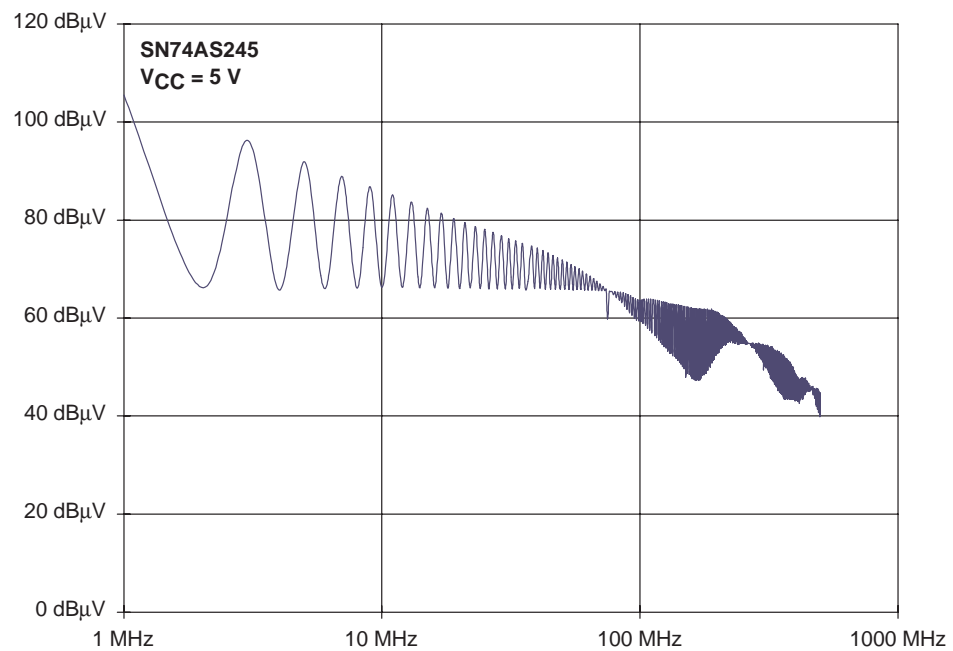
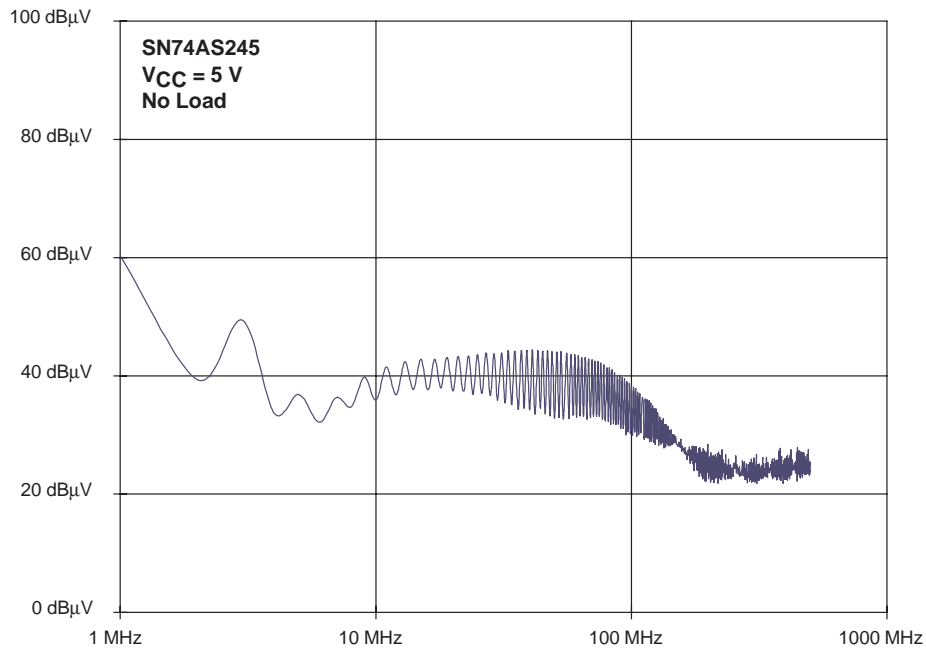
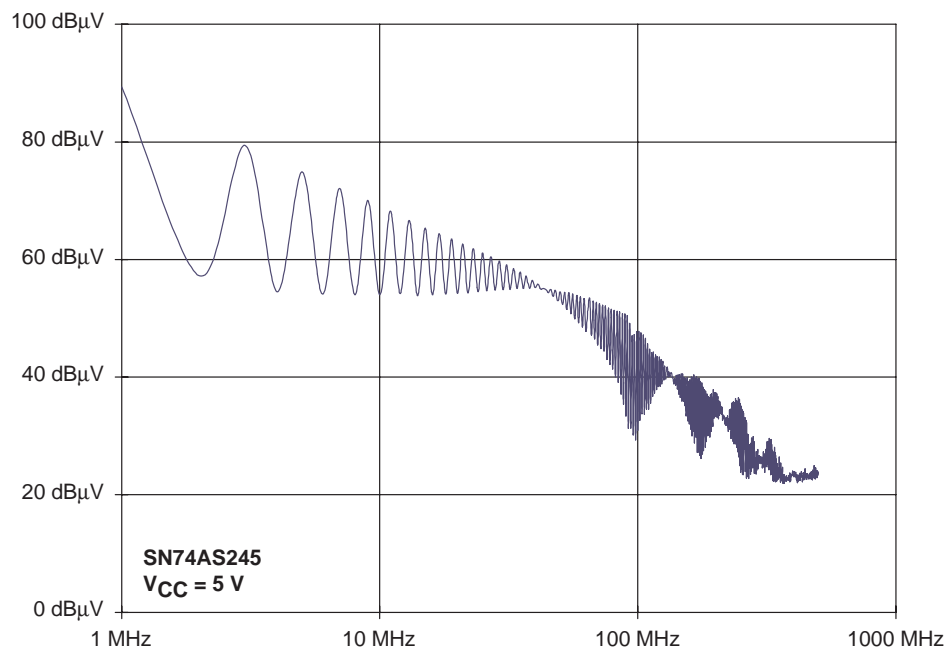


Figure 45. SN74AS245 Spectrum of the Output Signal



**Figure 46. SN74AS245 Spectrum of the Supply Current (output unloaded)**



**Figure 47. SN74AS245 Spectrum of the Supply Current (output loaded)**

## 5.9 SN74BCT245 Measurement Results

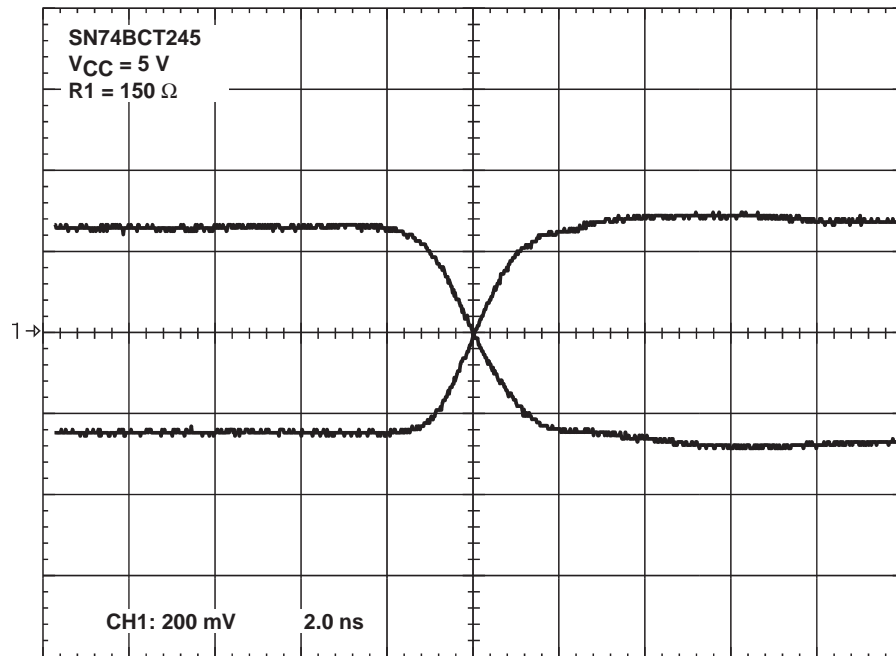


Figure 48. SN74BCT245 Waveform at the Output

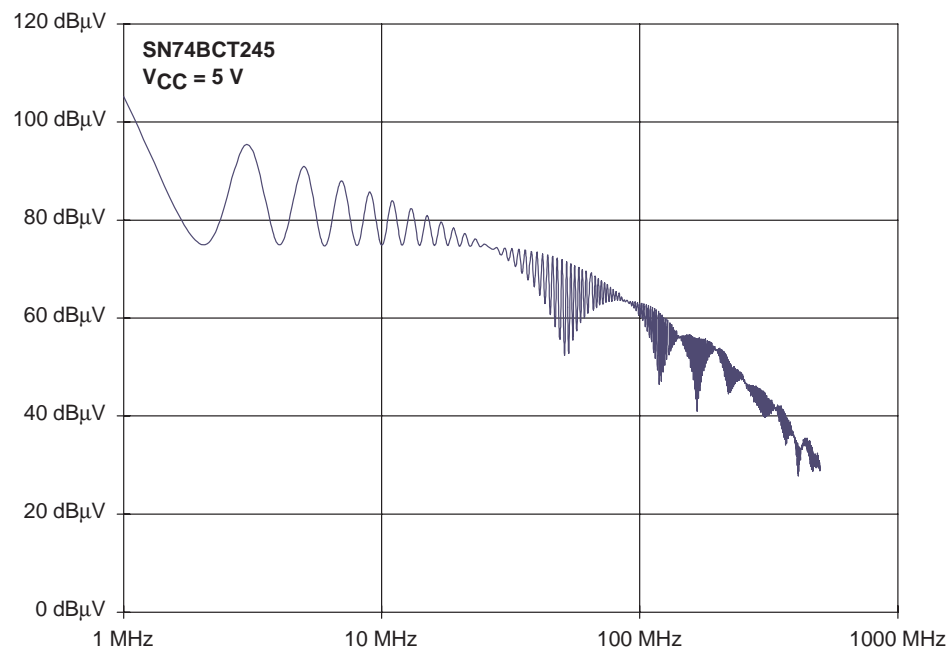
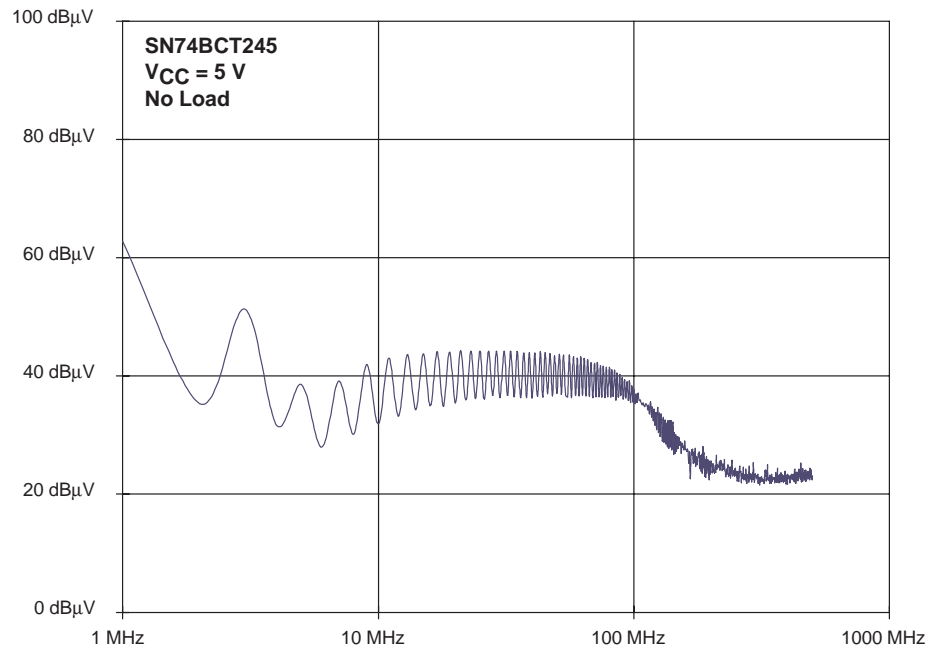
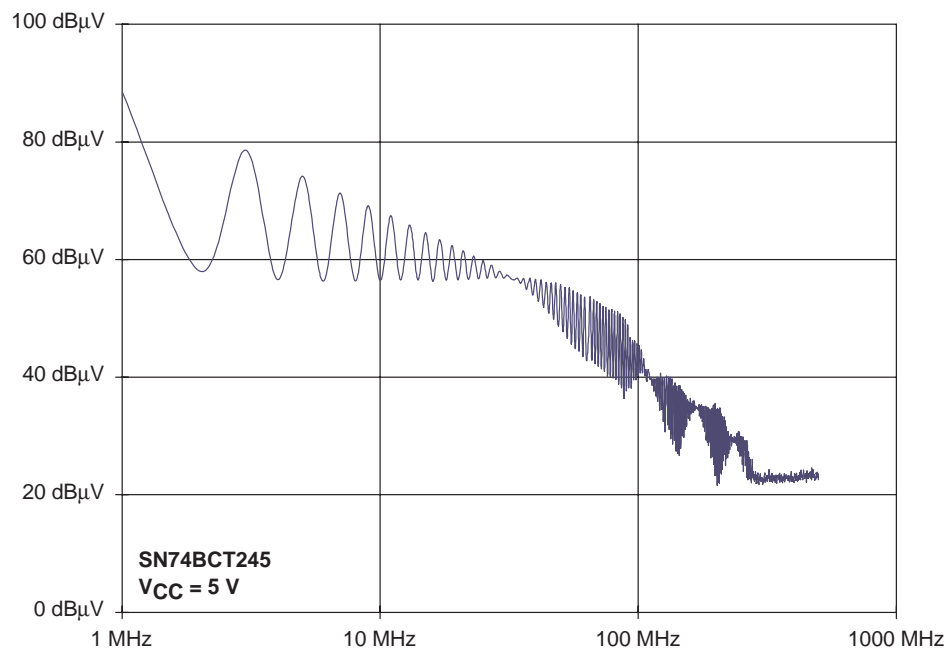


Figure 49. SN74BCT245 Spectrum of the Output Signal



**Figure 50. SN74BCT245 Spectrum of the Supply Current (output unloaded)**



**Figure 51. SN74BCT245 Spectrum of the Supply Current (output loaded)**

## 5.10 SN74F245 Measurement Results

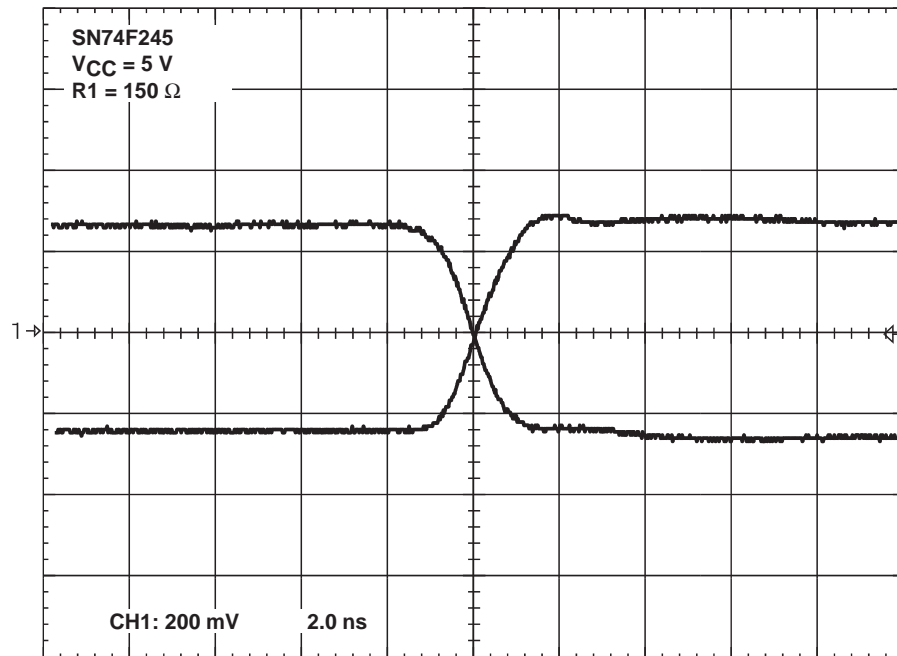


Figure 52. SN74F245 Waveform at the Output

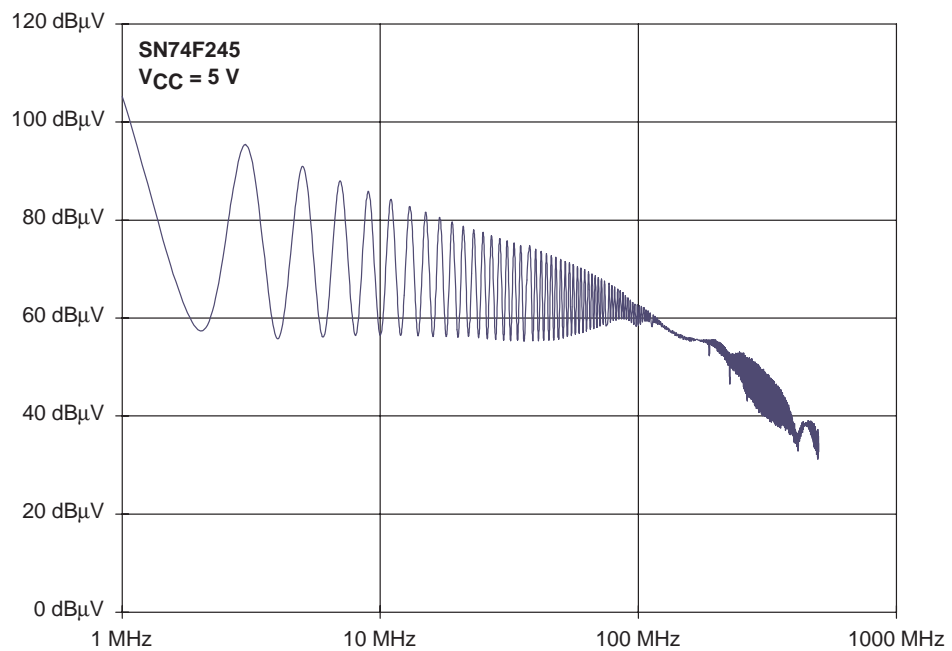
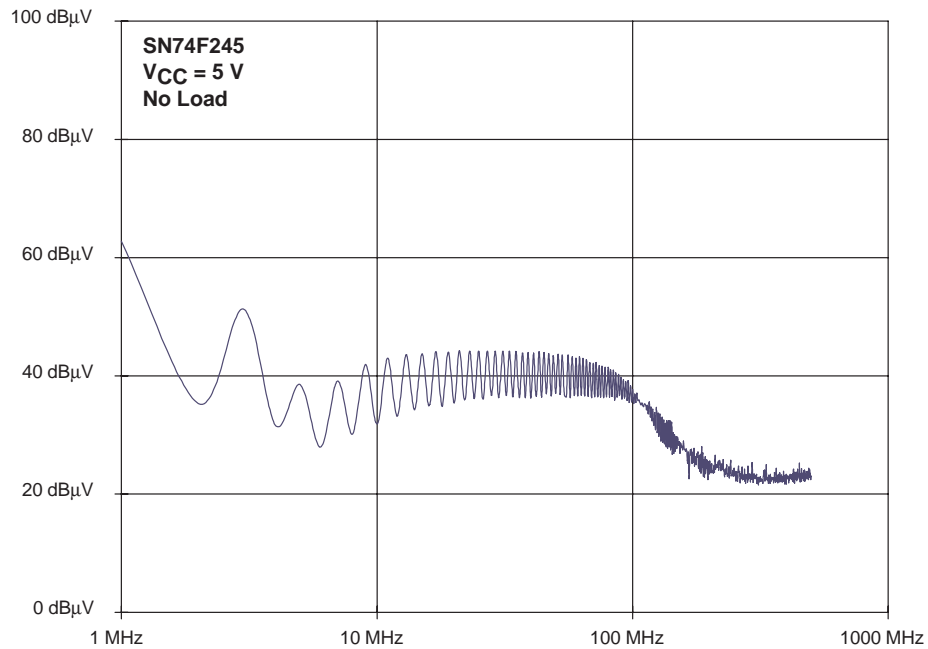
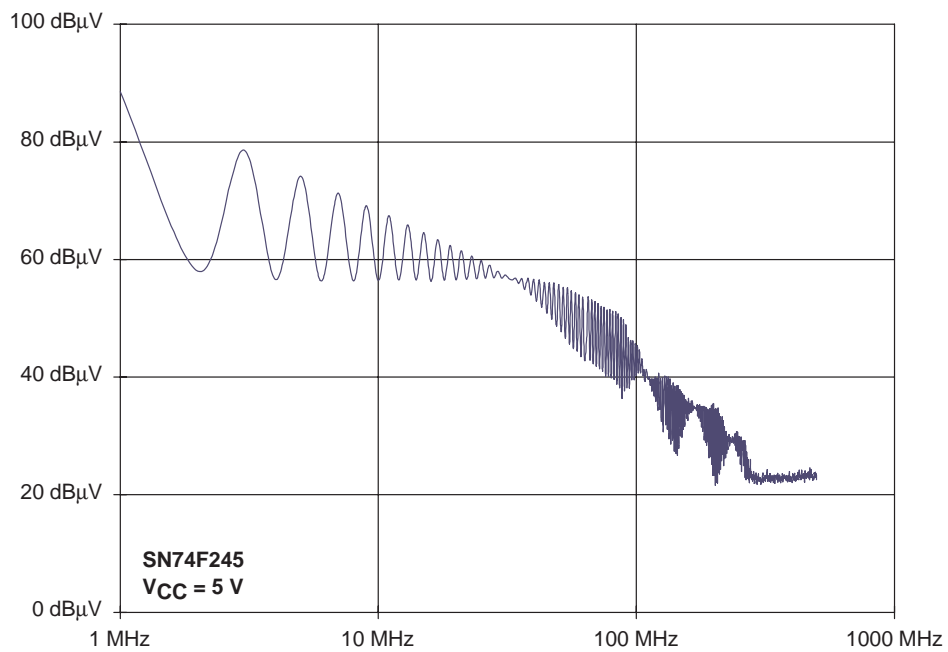


Figure 53. SN74F245 Spectrum of the Output Signal



**Figure 54. SN74F245 Spectrum of the Supply Current (output unloaded)**



**Figure 55. SN74F245 Spectrum of the Supply Current (output loaded)**



### 5.11 SN74HC245 Measurement Results

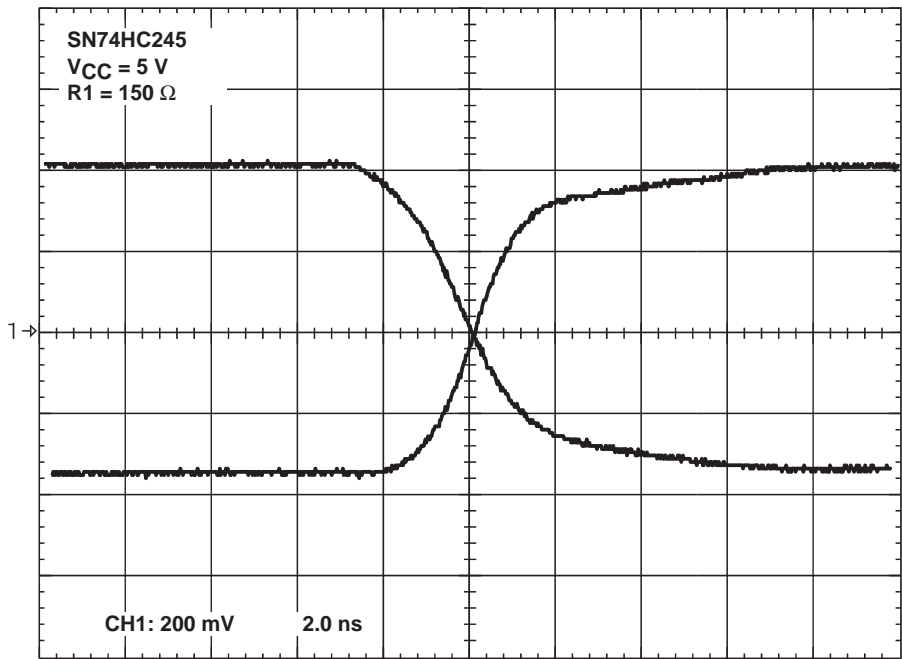


Figure 56. SN74HC245 Waveform at the Output

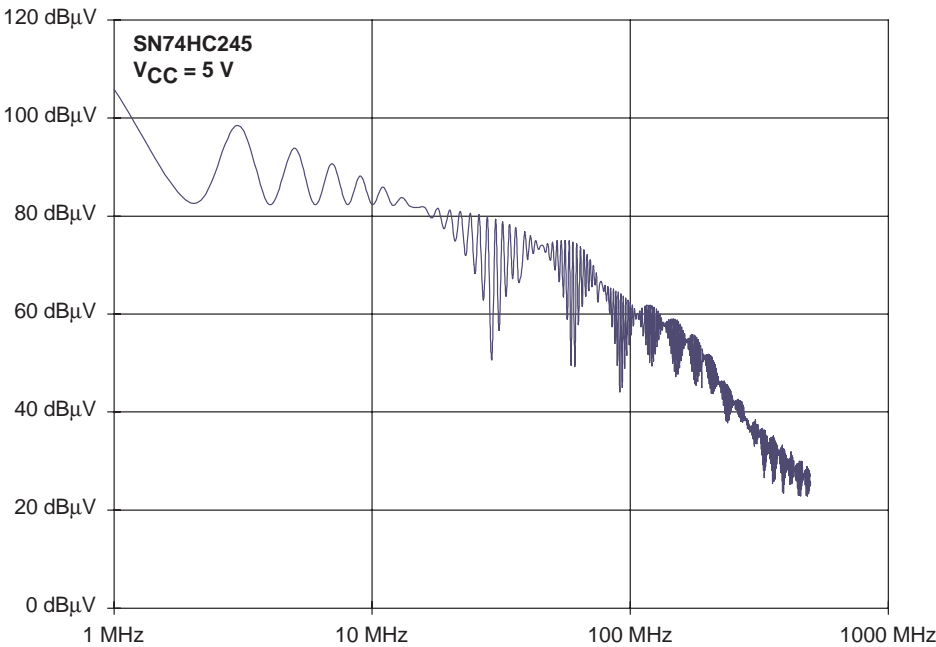
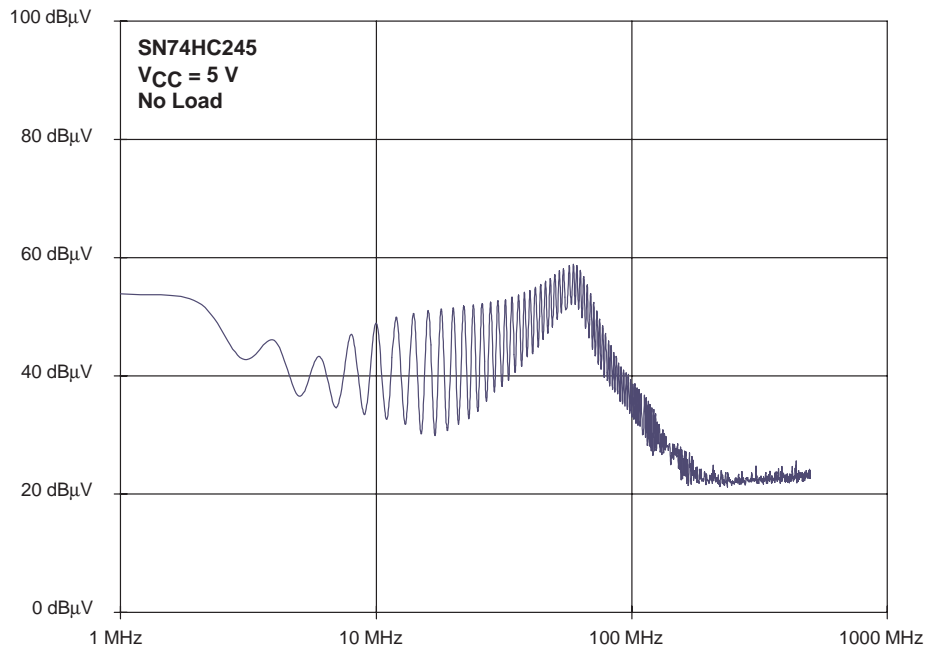
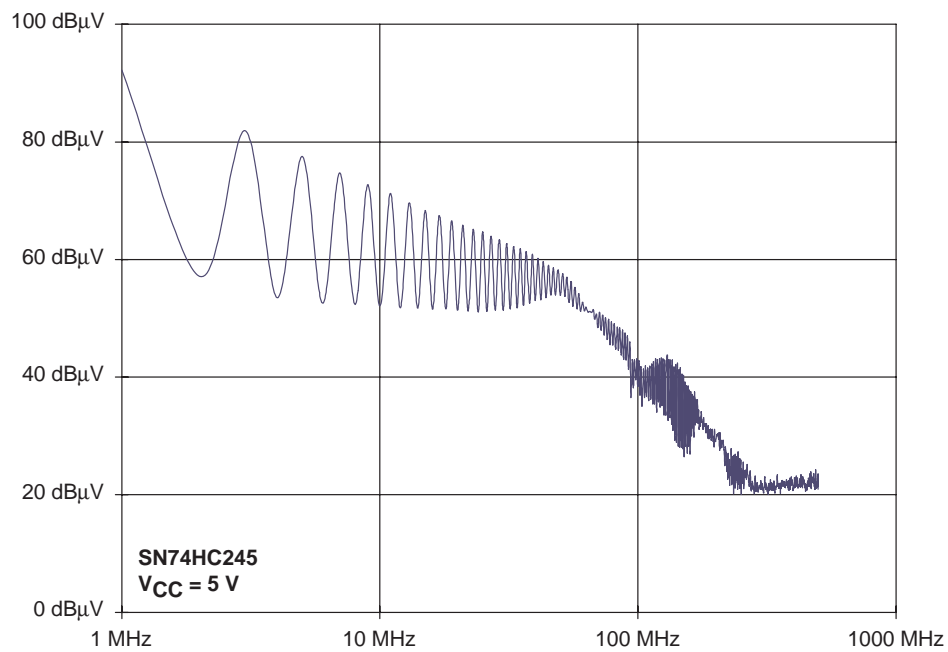


Figure 57. SN74HC245 Spectrum of the Output Signal



**Figure 58. SN74HC245 Spectrum of the Supply Current (output unloaded)**



**Figure 59. SN74HC245 Spectrum of the Supply Current (output loaded)**

## 5.12 SN74LS245 Measurement Results

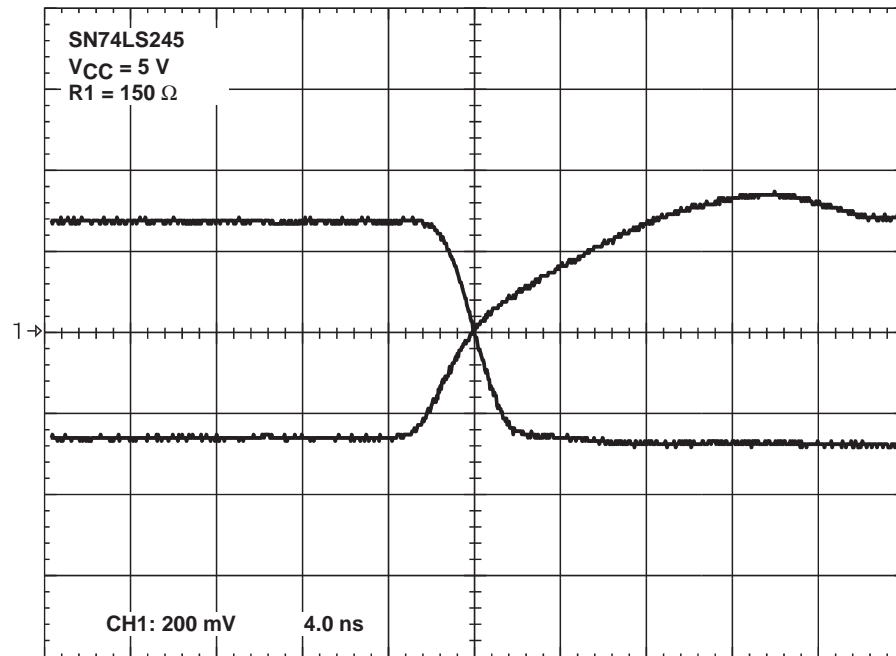


Figure 60. SN74LS245 Waveform at the Output

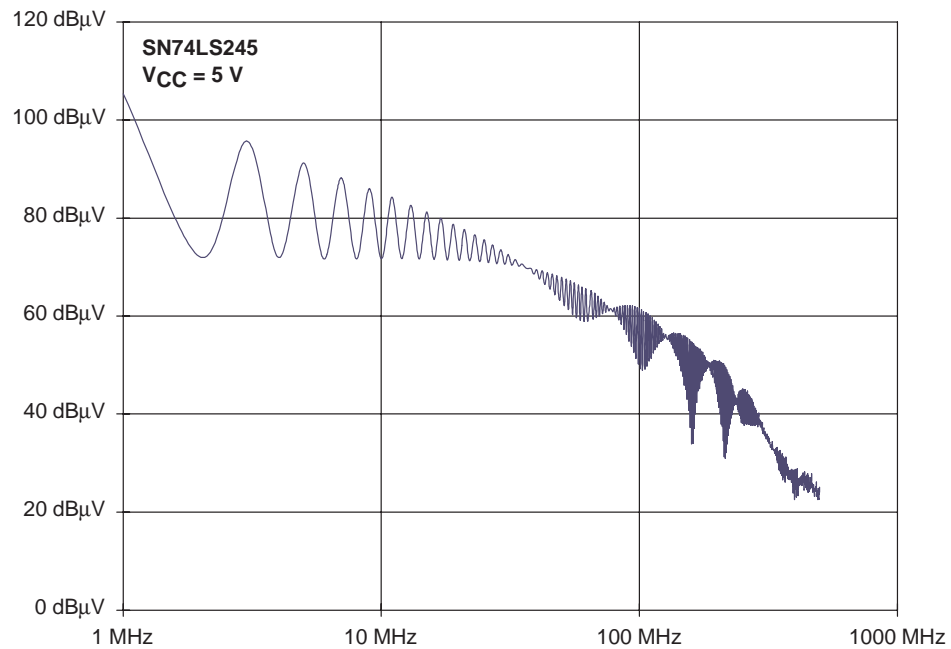
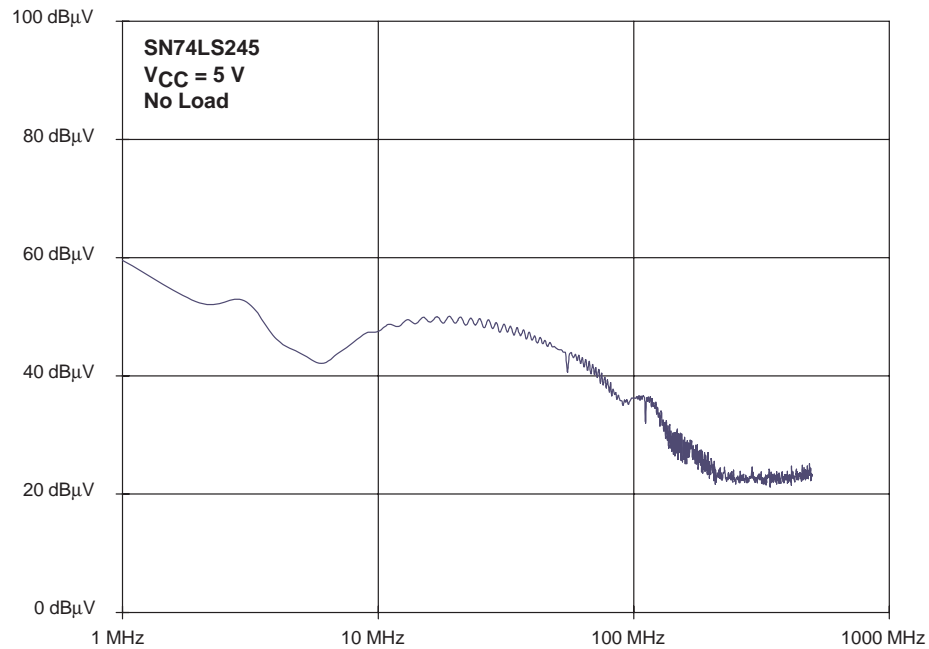
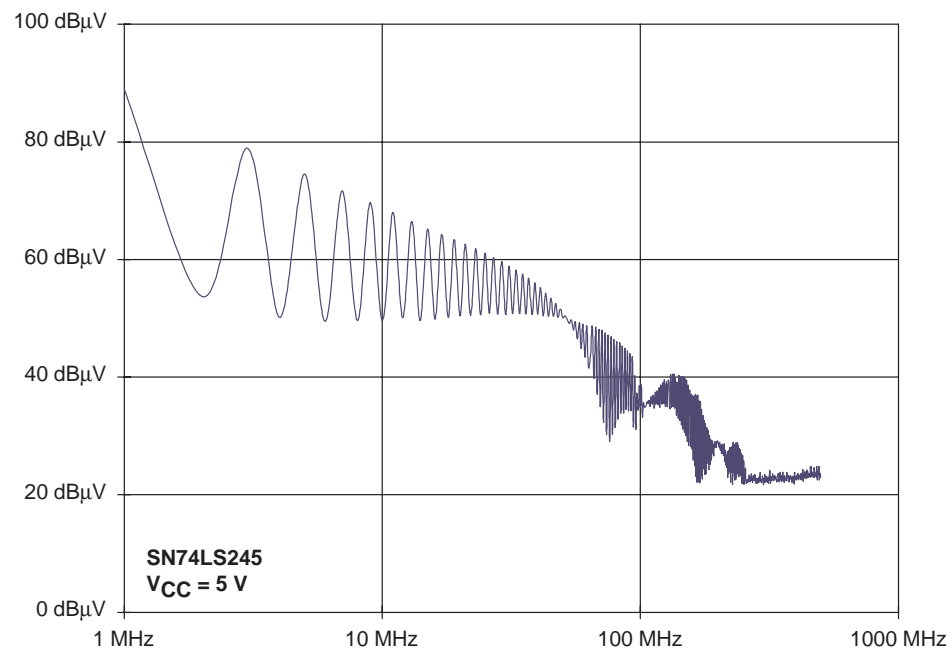


Figure 61. SN74LS245 Spectrum of the Output Signal



**Figure 62. SN74LS245 Spectrum of the Supply Current (output unloaded)**



**Figure 63. SN74LS245 Spectrum of the Supply Current (output loaded)**

## 6 Conclusion

This application report shows the extent to which the measurement method proposed by a working group in the DKE can determine the electromagnetic interference generated by integrated circuits. As previously demonstrated, there is good agreement between the results of measurements and the calculated theoretical values. However, because of the relatively simple structures of logic circuits, a realistic prediction of their electromagnetic compatibility can be made using only a few known parameters, such as signal amplitude and rise time. The situation is very different with highly integrated circuits, such as microprocessors or other VLSI semiconductors. Without a detailed examination of their behavior, the complex structures of these components make it impossible to reliably predict their electromagnetic compatibility. However, the measurement procedure used provides useful assistance in predicting the electromagnetic emission of the module or equipment, which can be done during the planning phase of a new development.

The logic circuits that have been examined are not good examples of components having outstanding electromagnetic compatibility. They have been conceived for applications where short delay times in the signal paths are of importance and, in most cases, have high drive capability at the outputs. Therefore, when developing these components, the intention usually is to achieve steep switching edges because these directly determine signal delay times. With modern logic circuits, the rise and fall times are about 1 ns to 2 ns. Shorter times no longer can be tolerated with the signal swings of 3 V to 5 V, which are common today, because the interference generated by the circuit itself would be of the same order as that which would no longer permit reliable operation of the system. The steep edges inevitably give rise to high interference amplitude in the upper frequency range, and correspondingly high currents in the integrated-circuit connections, which function as antennas.

Nevertheless, equipment with adequate electromagnetic compatibility can be designed using such components. The design engineer must observe certain basic rules when choosing the components to avoid problems later. From the many families of integrated circuits available, those with speeds (maximum clock frequency, required delay time) that are just able to achieve system requirements should be chosen. Every increase in performance often must be at the expense of costly changes to suppress interference. From this point of view, the older (and, thus, slower) bipolar logic families, such as advanced low-power Schottky TTL, and MOS families such as high-speed CMOS, have advantages. Also, bipolar circuits offer advantages because of their approximately 30% smaller signal-level swing. Another way to improve electromagnetic compatibility is to lower supply voltages. For this purpose, the new CMOS families are ideal because they feature excellent performance, even at a reduced supply voltage. The smaller currents, which result from the lower voltage swing, reduce the undesired radiation of high frequencies. Finally, careful layout of printed circuit boards<sup>1</sup> and, possibly, the use of filters in critical parts of the circuit are proven methods of achieving electromagnetic compatibility of a system.

## 7 References

### 7.1 Documents

1. *PCB Design Guidelines for Reduced EMI*, literature number SZZA009.
2. *Fachverband Bauelemente der Elektrotechnik im Zentralverband der Elektrotechnik und Elektronikindustrie: Messung der EME von integrierten Schaltungen* (Expert Association for Electrotechnical Components in the Central Association of the Electrotechnical and Electronic Industry: The Measurement of the Electromagnetic Sensitivity of Integrated Circuits).
3. *Timing Measurement With Fast Logic Circuits*, literature number SDYA015; also obtainable at [http://www.ti.sc.docs.psheets/app\\_digital\\_logic.htm](http://www.ti.sc.docs.psheets/app_digital_logic.htm)
4. *Logic Selection Guide and Data Book*, CD-ROM, literature number SCBC001.
5. *Digital Design Seminar*, literature number SDYDE01A.

### 7.2 Internet

Texas Instruments web page at <http://www.ti.com>

## 8 Acknowledgments

The author of this application report is Eilhard Haseloff.