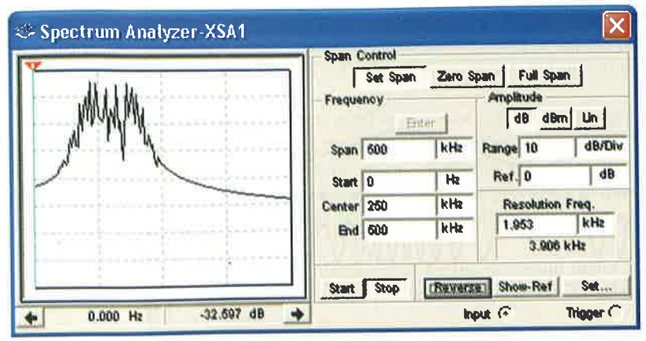

FIGURE 5-35 The output of the voltage-controlled oscillator as viewed with a spectrum analyzer.

Electronics Workbench™ Exercises

1. Open the file **FigE5-2** on your EWB CD. Use Carson's rule to estimate the bandwidth of the FM signal and then compare your result with the measurement obtained with the spectrum analyzer. You will need to double-click on the FM source to view the settings. (~120 kHz)
2. Open the file **FigE5-3** on your EWB CD. Use Carson's rule to estimate the bandwidth of the FM signal and then compare your result with the measurement obtained with the spectrum analyzer. You will need to double-click on the FM source to view the settings. (~53.4 kHz)

Summary

In Chapter 5 we studied the concept of frequency modulation (FM) and learned the basics of FM transmitters. The major topics you should now understand include:

- the definitions of *angle, frequency,* and *phase modulation*
- the generation of FM by using a capacitor microphone and the effects of changes in voice amplitude and frequency on the FM signal
- the analysis of FM using modulation index and Bessel functions
- the determination of FM deviation using the zero-carrier condition
- the analysis of noise suppression by limiter circuits and by using phasors and the signal-to-noise ratio (*S/N*)
- the analysis of direct generation FM circuits, including varactor diodes, the reactance modulator, the LIC VCO, and the Crosby modulator
- the operation of an indirect FM system using the Armstrong modulator
- the generation of FM using a phase-locked loop (PLL)
- the changes made to a standard FM transmitter to enable broadcast stereo operation
- the advantage of FM versus SSB or AM

Questions and Problems

Section 5-1

1. Define *angle modulation* and list its subcategories.
*2. What is the difference between frequency and phase modulation?
3. Even though PM is not actually transmitted, provide two reasons that make it important in the study of FM.
4. A radio transmission is classified as $3A1_i$. Describe this signal as fully as possible.

Section 5-2

5. Explain how a condenser microphone can be used very easily to generate FM.
6. Define *deviation constant.*
7. A 50-mV sinusoid, at a frequency of 1 kHz, is applied to a capacitor microphone FM generator. If the deviation constant for the capacitor microphone FM generator is 500 Hz/20 mV, determine:
   (a) The total frequency deviation. (±1.25 kHz)
   (b) The rate at which the carrier frequency is being deviated. (1 kHz)
8. Explain how the intelligence signal modulates the carrier.
9. In an FM transmitter, the output is changing between 90.001 and 89.999 MHz 1000 times a second. The intelligence signal amplitude is 3 V. Determine the carrier frequency and intelligence signal frequency. If the output deviation changes to between 90.0015 and 89.9985 MHz, calculate the intelligence signal amplitude. (90 MHz, 1 kHz, 4.5 V)
*10. What determines the rate of frequency swing for an FM broadcast transmitter?
11. Without knowledge of Section 5-3 and using Figure 5-1, write an equation that expresses the output frequency, f, of the FM generator. *Hint:* If there is no input into the microphone, then $f = f_c$, where f_c is the oscillator's output frequency.

Section 5-3

12. Define *modulation index* (m_f) as applied to an FM system.
*13. What characteristic(s) of an audio tone determines the percentage of modulation of an FM broadcast transmitter?
14. Explain what happens to the carrier in FM as m_f goes from 0 up to 15.
15. Calculate the bandwidth of an FM system (using Table 5-2) when the maximum deviation (δ) is 15 kHz and f_i = 3 kHz. Repeat for f_i = 2.5 and 5 kHz. (48 kHz, 45 kHz, 60 kHz)
16. Explain the purpose of the *guard bands* for broadcast FM. How wide is an FM broadcast channel?
*17. What frequency swing is defined as 100 percent modulation for an FM broadcast station?

*An asterisk preceding a number indicates a question that has been provided by the FCC as a study aid for licensing examinations.

*18. What is the meaning of the term *center frequency* in reference to FM broadcasting?
*19. What is the meaning of the term *frequency swing* in reference to FM broadcast stations?
*20. What is the frequency swing of an FM broadcast transmitter when modulated 60 percent? (±45 kHz)
*21. An FM broadcast transmitter is modulated 40 percent by a 5-kHz test tone. When the percentage of modulation is doubled, what is the frequency swing of the transmitter?
*22. An FM broadcast transmitter is modulated 50 percent by a 7-kHz test tone. When the frequency of the test tone is changed to 5 kHz and the percentage of modulation is unchanged, what is the transmitter frequency swing?
*23. If the output current of an FM broadcast transmitter is 8.5 A without modulation, what is the output current when the modulation is 90 percent?
24. An FM transmitter delivers, to a 75-Ω antenna, a signal of $v = 1000 \sin(10^9 t + 4 \sin 10^4 t)$. Calculate the carrier and intelligence frequencies, power, modulation index, deviation, and bandwidth. (159 MHz, 1.59 kHz, 6.67 kW, 4, 6.37 kHz, ~ 16 kHz)
25. Assuming that the 9.892-kW result of Example 5-7 is exactly correct, determine the total power in the J_2 sidebands and higher. (171 W)
26. Determine the deviation ratio for an FM system that has a maximum possible deviation of 5 kHz and the maximum input frequency is 3 kHz. Is this narrow- or wideband FM? (1.67, wideband)

Section 5-4

*27. What types of radio receivers do not respond to static interference?
*28. What is the purpose of a limiter stage in an FM broadcast receiver?
29. Explain why the limiter does *not* eliminate all noise effects in an FM system.
30. Calculate the amount of frequency deviation caused by a limited noise spike that still causes an undesired phase shift of 35° when f_i is 5 kHz. (3.05 kHz)
31. In a broadcast FM system, the input $S/N = 4$. Calculate the worst-case S/N at the output if the receiver's internal noise effect is negligible. (19.8 : 1)
32. Explain why narrowband FM systems have poorer noise performance than wideband systems.
33. Explain the *capture effect* in FM, and include the link between it and FM's inherent noise reduction capability.
*34. Why is narrowband FM rather than wideband FM used in radio communications systems?
*35. What is the purpose of preemphasis in an FM broadcast transmitter? Of deemphasis in an FM receiver? Draw a circuit diagram of a method of obtaining preemphasis.
*36. Discuss the following for frequency modulation systems:
(a) The production of sidebands.
(b) The relationship between the number of sidebands and the modulating frequency.
(c) The relationship between the number of sidebands and the amplitude of the modulating voltage.
(d) The relationship between percentage modulation and the number of sidebands.
(e) The relationship between modulation index or deviation ratio and the number of sidebands.
(f) The relationship between the spacing of the sidebands and the modulating frequency.
(g) The relationship between the number of sidebands and the bandwidth of emissions.
(h) The criteria for determining the bandwidth of emission.
(i) Reasons for preemphasis.

Section 5-5

37. Draw a schematic diagram of a varactor diode FM generator and explain its operation.
*38. Draw a schematic diagram of a frequency-modulated oscillator using a reactance modulator. Explain its principle of operation.
39. Using the specifications in Figure 5-14, draw a schematic of an FM generator using the SE/NE 566 LIC function generator VCO. The center frequency is to be 500 kHz, and the output is to be a sine wave. Show all component values. How much center frequency drift can be expected from a temperature rise of 50°C?
40. Explain the principles of a Crosby-type modulator.
*41. How is good stability of a reactance modulator achieved?
*42. If an FM transmitter employs one doubler, one tripler, and one quadrupler, what is the carrier frequency swing when the oscillator frequency swing is 2 kHz? (48 kHz)
43. Draw a block diagram of a broadcast-band Crosby-type FM transmitter operating at 100 MHz, and label all frequencies in the diagram.
44. Explain the function of a discriminator.

Section 5-6

*45. Draw a block diagram of an Armstrong-type FM broadcast transmitter complete from the microphone input to the antenna output. State the purpose of each stage, and explain briefly the overall operation of the transmitter.
46. Explain the difference in the amount of deviation when passing an FM signal through a mixer as compared to a multiplier.
47. What type of circuits are used to increase a narrowband to a wideband?

Section 5-7

48. Explain the operation of the PLL FM transmitter shown in Figure 5-20.

Section 5-8

49. Draw a block diagram of a stereo multiplex FM broadcast transmitter complete from the microphone inputs to the antenna output. State the purpose of each stage, and explain briefly the overall operation of the transmitter.
50. Explain how stereo FM can effectively transmit twice the information of a standard FM broadcast while still using the same bandwidth. How is the S/N at the receiver affected by a stereo transmission as opposed to monophonic?

51. Define *frequency-division multiplexing.*
52. Describe the type of modulation used in the L − R signal of Figure 5-23.
53. Explain the function of a matrix network as it relates to the generation of an FM stereo signal.
54. What difference in noise performance exists between FM stereo and mono broadcasts? Explain what might be done if an FM stereo signal is experiencing noise problems at the receiver.

Section 5-9

*55. What are the merits of an FM communications system compared to an AM system?
*56. Why is FM undesirable in the standard AM broadcast band?
57. What advantage does FM have over AM and SSB?

Section 5-10

58. What is the function of a multiplier stage in an FM transmission system? Explain how to troubleshoot a multiplier stage.
59. Briefly explain the function/operation of the reactance modulator in Figure 5-27.
60. Resistor R5 in Figure 5-27 has changed value. Describe the effect on this circuit and how to troubleshoot this situation.
61. What is the SCA signal? Give a technique to troubleshoot a transmitter that is not properly transmitting the SCA signal.
62. Describe the procedure to check an FM transmitter carrier frequency.
63. Describe the FM output if R5 was shorted in Figure 5-27.
64. Explain what happens if R1 was shorted in Figure 5-27.
65. In Figure 5-29, explain what the output would be if the 38-kHz subcarrier were gone.
66. If the balanced modulator in Figure 5-29 failed, describe the output.

Questions for Critical Thinking

67. Analyze the effect of an intelligence signal's amplitude and frequency when it frequency-modulates a carrier.
68. Contrast the modulation indexes for PM verses FM. Given this difference, could you modify a modulating signal so that allowing it to phase-modulate a carrier would result in FM? Explain your answer.
69. Does the maximum deviation directly determine the bandwidth of an FM system? If not, explain how bandwidth and deviation are related.
70. An FM transmitter puts out 1 kW of power. When $m_f = 2$, analyze the distribution of power in the carrier and all significant sidebands. Use Bessel functions to verify that the sum of these powers is 1 kW.
71. Why is the FCC concerned if an FM broadcast station overmodulates (deviation exceeds ± 75 kHz)?