Amateur Extra License Class

1

Amateur Extra Class

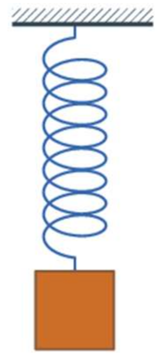
Chapter 7
Radio Signals and Measurements

2

Types of Waveforms

Sine Waves

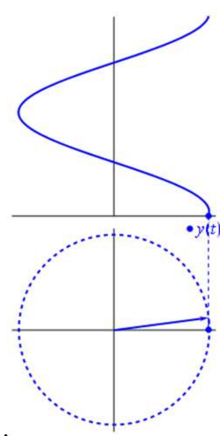
- Most basic type of waveform.
- Occur often in nature.
  - Pendulum.
  - Weight on spring.
  - Point on rim of wheel.



Types of Waveforms

Sine waves

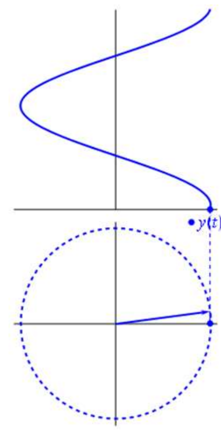
- Contains only one frequency.
- Cycle = One complete set of values before they repeat.
- Cycle = One complete rotation of vector (360°).
  - Phase = Angular position of vector
- Frequency = Number of cycles per second.
- Period = Time to complete one cycle.



Types of Waveforms

Sine waves

- Angle measurements.
  - Degrees: 1 cycle = 360°.
  - Radians: 1 cycle = 2π radians.



Types of Waveforms

Complex Waveforms

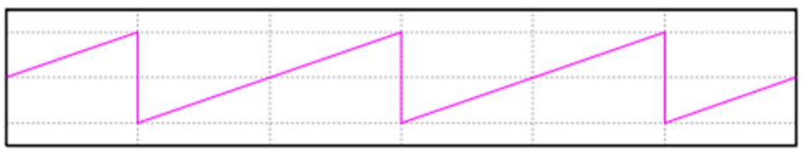
- Waveforms that contain more than one frequency.
- Regular waves.
  - More properly called "periodic" waves.
    - Repeat at a regular interval.
  - Made up of a fundamental & its harmonics.
- Irregular waves.
  - Non-periodic.
    - Human speech.
- Easily visualized in frequency domain.

Types of Waveforms

Sawtooth Wave

- Fundamental and all harmonics.
- Amplitude of harmonics decrease with increasing frequency.

$$f_1 + f_2/2 + f_3/3 + f_4/4 + f_5/5 + \ldots\ldots\ldots.$$



7

Types of Waveforms

Square Wave

- Fundamental and all odd harmonics.
- Amplitude of harmonics decrease with increasing frequency.

$$f_1 + f_3/3 + f_5/5 + f_7/7 + f_9/9 + \ldots\ldots\ldots.$$

8

Types of Waveforms

Rectangular Wave

- Square wave where on & off times are not equal.

Pulse Wave

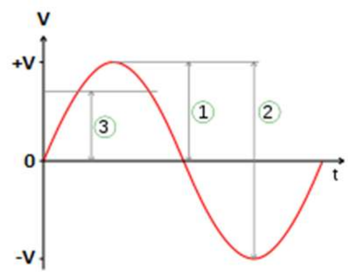
- Rectangular wave where position, width, and/or amplitude of pulses varies.
  - In radio communications, often narrow pulses with wide gaps between pulses.

9

AC Waveforms and Measurements

AC Measurements

- A DC voltmeter/ammeter will read the average voltage/current, which is zero.
- With an oscilloscope, it is easy to read the maximum voltage/current.



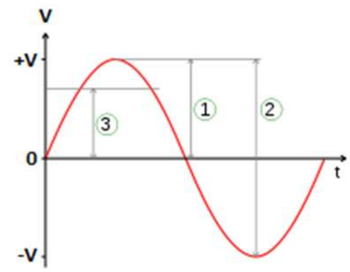
1 = Peak
2 = Peak-to-Peak
3 = Root-Mean-Square (RMS)

10

AC Waveforms and Measurements

AC Measurements

- An AC current will heat up a resistor.
- The amount of DC current that causes the same amount of heating is the root-mean-square (RMS) value.
- For pure sine waves **ONLY**:
  - $I_{RMS} = 0.707 \times I_{Peak}$
  - $V_{RMS} = 0.707 \times V_{Peak}$



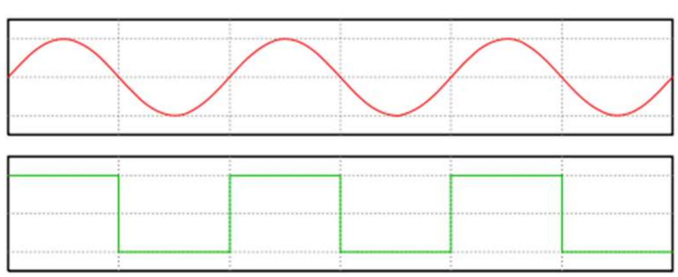
1 = Peak
2 = Peak-to-Peak
3 = Root-Mean-Square (RMS)

11

AC Waveforms and Measurements

AC Measurements

To Calculate	Sine Wave	Square Wave
RMS	0.707 x Peak	Peak
Peak	1.414 x RMS	RMS

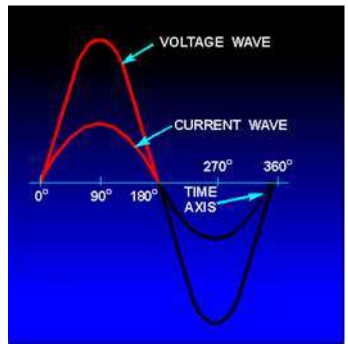


12

AC Waveforms and Measurements

AC Power

- Voltage & Current In-Phase
  - $P_{AVG} = P_{RMS} = V_{RMS} \times I_{RMS}$
  - $P_{Peak} = V_{Peak} \times I_{Peak} = 2 \times P_{RMS}$



13

AC Waveforms and Measurements

Power of Modulated RF Signals

- In an unmodulated RF signal, the average power can be calculated from:
  - $P_{AVG} = V_{RMS}^2 / Z$

14

AC Waveforms and Measurements

Power of Modulated RF Signals

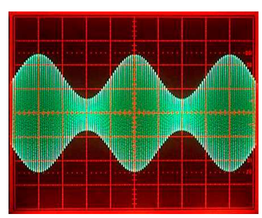
- If the signal is modulated, the situation is more complex.
  - CW, FM, & some digital modes have a constant amplitude & the average power is the same as if the carrier was not modulated.
  - For other modes, it is more useful to use the peak envelope power (PEP) of the signal.

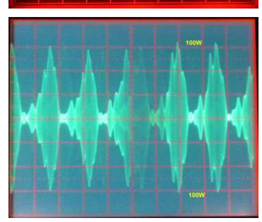
15

AC Waveforms and Measurements

Power of Modulated RF Signals

- Modulated RF signals.
  - Peak-Envelope-Power (PEP).
    - Measure peak voltage.
    - $P_{PEP} = V_{RMS}^2 / R_L = (0.707 \times V_{Peak})^2 / R_L$
  - Average Power.
    - Long term average of power output.
  - Crest Factor.
    - Ratio of PEP to average power.
      - Depends on characteristics of modulating signal.
    - SSB typically 2.5:1 (40%).





16

Test Equipment

Instruments and Accuracy

- Multimeters.
  - a.k.a. – VOM, DVM, VTVM.
  - Accuracy expressed in % of full scale.
    - If accuracy is 2% of full scale on 100 mA scale, then accuracy is ±2 mA.
  - Resolution expressed in digits.
    - Typically 3 ½ digits (0.000 to 1.999)
    - 3 ½ digit → 0.05% resolution.
  - **DO NOT CONFUSE RESOLUTION WITH ACCURACY!**

17

Test Equipment

Instruments and Accuracy

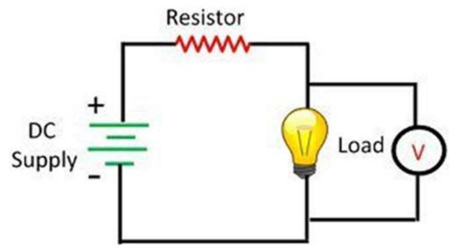
- A meter can only measure current flow.

18

Test Equipment

Instruments and Accuracy

- A voltmeter measures the current flowing through a known resistance and calculates the voltage.

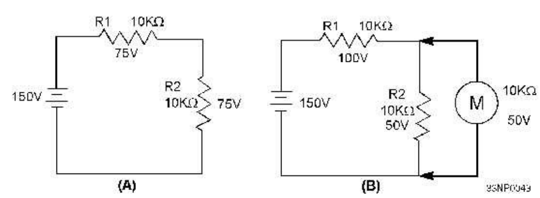


19

Test Equipment

Instruments and Accuracy

- Voltmeter Sensitivity ⟺ Measurement Accuracy.
  - If the series resistance of the voltmeter is not much greater than the resistance of the circuit being measured, the accuracy of the measurement will be reduced.



20

Test Equipment

Instruments and Accuracy

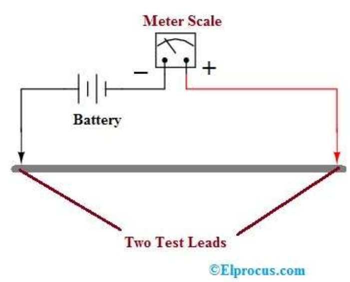
- Voltmeter Sensitivity ⟺ Measurement Accuracy.
  - The magnitude of the accuracy reduction is related to the sensitivity of the voltmeter, which is expressed in ohms/volt.
    - If the full-scale reading of the meter used is 1 mA then a series resistance of 10kΩ is needed for a full-scale reading of 10 volts,
      - The sensitivity of the voltmeter would be 10kΩ/10v, or 1,000 ohms/volt.
      - The input impedance of the voltmeter equals the sensitivity multiplied by the full-scale reading.

21

Test Equipment

Instruments and Accuracy

- An ohmmeter measures the current that flows when a known voltage is applied and calculates the resistance.



22

Test Equipment

Instruments and Accuracy

- Analog Multimeters.
  - D'Arsonval movement.
    - Rotating coil suspended between permanent magnets.
    - When current flows in coil, coil rotates moving needle across scale.
    - Coil impedance affects accuracy.
  - Sensitivity expressed in Ohms/Volt.
    - 20,000 Ω/V → very good analog meter.

23

Test Equipment

Instruments and Accuracy

- Vacuum Tube Voltmeters (VTVM).
  - D'Arsonval movement.
  - Used vacuum tube amplifier to improve sensitivity.
    - Typically 10 megΩ/V or greater.

24

Test Equipment

Instruments and Accuracy

- Digital Multimeters (DVM).
  - Digital display.
  - Uses FET amplifier to improve sensitivity.
    - Typically 10 megΩ/V or greater.

25

Test Equipment

Instruments and Accuracy

RMS Measurements.

- When measuring AC voltage or current, most AC meters assume the voltage or current is a sine wave and will not be accurate when measuring other waveforms.
- Some meters are specified to measure the "true RMS" voltage or current.
  - Sample the voltage or current at a large number of points & calculate the RMS value mathematically.

26

E4B02 -- What is the significance of voltmeter sensitivity expressed in ohms per volt?

A. The full scale reading of the voltmeter multiplied by its ohms per volt rating is the input impedance of the voltmeter
B. The reading in volts multiplied by the ohms per volt rating will determine the power drawn by the device under test
C. The reading in ohms divided by the ohms per volt rating will determine the voltage applied to the circuit
D. The full scale reading in amps divided by ohms per volt rating will determine the size of shunt needed

27

E8A05 -- What is the benefit of making voltage measurements with a true-RMS calculating meter?

A. An inverse Fourier transform can be used
B. The signal s RMS noise factor is also calculated
C. The calculated RMS value can be converted directly into phasor form
D. RMS is measured for both sinusoidal and non-sinusoidal signals

28

Test Equipment

Instruments and Accuracy

- RF Wattmeters.
  - Most modern HF transceivers have the ability built-in to measure & display both the RF power out & the reflected power (SWR).
  - Sometimes an external RF power meter is useful, especially when using an external device such as an amplifier.

29

Test Equipment

Instruments and Accuracy

- RF Wattmeters.
  - Most RF wattmeters measure the average RF power, but amateurs are concerned with the peak power (PEP).
  - Peak power is the same as the average power **ONLY** if the amplitude of the signal does not vary.
    - FM, some digital modes, etc.

30

Test Equipment

Instruments and Accuracy

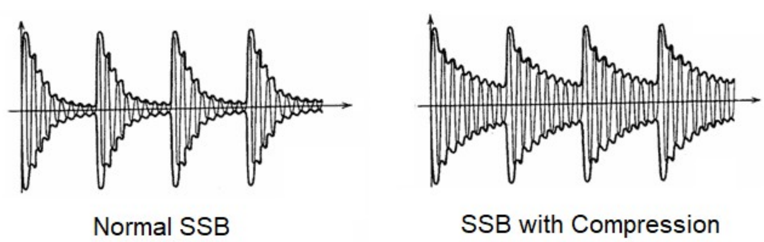
- RF Wattmeters.
  - In an SSB signal, the peak power is much greater than the average power.
  - The amount of difference is dependent on the characteristics of the modulating signal (speech)
  - If the SSB signal is not compressed, the ratio is usually about 2.5:1.
  - Adding compression will increase the average power while maintaining the same peak power.

31

Test Equipment

Instruments and Accuracy

- RF Wattmeters.



32

E8A06 -- What is the approximate ratio of PEP-to-average power in an unprocessed single-sideband phone signal?

➡ A. 2.5 to 1

B. 25 to 1

C. 1 to 1

D. 13 to 1

33

E8A07 -- hat determines the PEP-to-average power ratio of an unprocessed single-sideband phone signal?

A. The frequency of the modulating signal

➡ B. Speech characteristics

C. The degree of carrier suppression

D. Amplifier gain

34

Test Equipment

Instruments and Accuracy

- Frequency Counters and References.
  - Frequency counters measure the frequency of a signal by counting the number of cycles during a specified period of time.

35

Test Equipment

Instruments and Accuracy

- Frequency counter.
  - Direct-count frequency counter
    - Converts a signal into a series of pulses.
    - A time base is used to generate pulses of precise duration.
      - a.k.a. – Gate pulses
    - Counts the number of input signal pulses arriving during each gate pulse.
    - The frequency is calculated from the number of pulses & the length of the gate pulse.

36

Test Equipment

Instruments and Accuracy

- Frequency counter.
  - Period-measuring frequency counter
    - The input signal pulses are used as the gate pulses.
    - Counts the number of time base pulses during one input signal pulse.
    - The period is calculated from the number of time-base pulses during one input signal pulse.
    - The frequency is calculated from the period.
    - Results in improved accuracy for very low frequency signals.

37

Test Equipment

Instruments and Accuracy

- Frequency Counters and References.
  - If the frequency being measured is too high for an accurate measurement, the counter may include a prescaler.
    - A prescaler divides the incoming frequency by a pre-determined amount so that the resulting frequency is within the range of the counter.
      - Usually, the incoming frequency is divided by 10 or 100.

38

Test Equipment

Instruments and Accuracy

- Frequency Counters and References.
  - The accuracy of a counter is dependent on the accuracy of the time base
  - Frequency counter accuracy is expressed in parts per million (ppm).
    - For example: If the time base of a counter has an accuracy of 10ppm, then the error in measuring a 146 MHz signal could be ±1460 Hz.

39

E4A05 -- What is the purpose of using a prescaler with a frequency counter?

A. Amplify low-level signals for more accurate counting

B. Multiply a higher frequency signal so a low-frequency counter can display the operating frequency

C. Prevent oscillation in a low-frequency counter circuit

D. Reduce the signal frequency to within the counter's operating range

40

E4B01 -- Which of the following factors most affects the accuracy of a frequency counter?

A. Input attenuator accuracy

➡ B. Time base accuracy

C. Decade divider accuracy

D. Temperature coefficient of the logic

41

Test Equipment

Displaying Signals

- Time Domain and Frequency Domain
  - Time Domain -- Display the strength of a signal over a period of time.
    - Contains information not available in the frequency domain.
  - Frequency Domain -- Display the strength of a signal over a range of frequencies.
    - Contains information not available in the time domain.

42

E8A03 -- Which of the following describes a signal in the time domain?

A. Power at intervals of phase
B. Amplitude at different times
C. Frequency at different times
D. Discrete impulses in time order

43

Test Equipment

The Oscilloscope

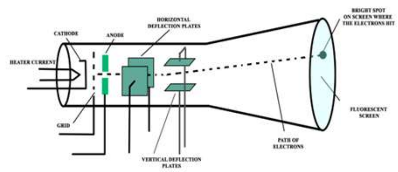
- An oscilloscope allows the visual observation of high-speed signals & waveforms in the time domain.

44

Test Equipment

The Oscilloscope

- Displays voltage versus time.
  - In older oscilloscopes:
    - The signal is applied to the vertical deflection plates.
    - A sawtooth waveform from a time base is applied to the horizontal deflection plates.



45

Test Equipment

The Oscilloscope

- Displays voltage versus time.
  - In modern oscilloscopes, the display is generated by digitally processing the input signal and displaying the result on an LED or LCD display.

46

Test Equipment

The Oscilloscope

- An oscilloscope may have 2 or more vertical amplifiers.
  - Allows displaying multiple signals simultaneously.

47

Test Equipment

The Oscilloscope

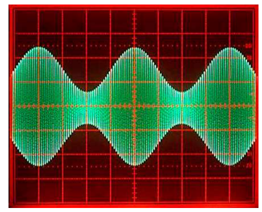
- The bandwidth of the vertical amplifier determines the highest frequency signal that can be displayed.

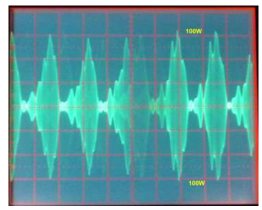
48

Test Equipment

The Oscilloscope

- The easiest value to read using an oscilloscope is the peak-to-peak voltage.
- An oscilloscope can also read:
  - Peak voltage.
  - Period.

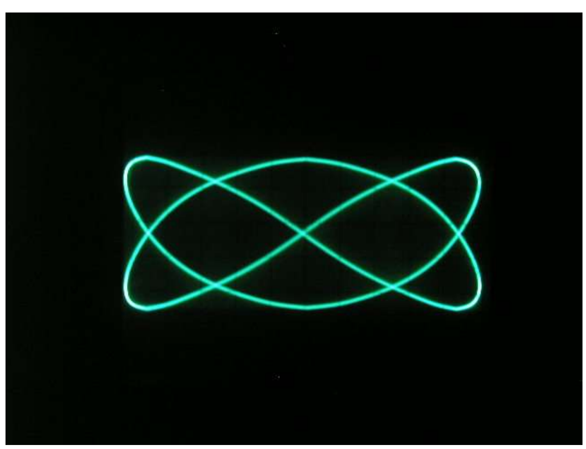




49

Test Equipment

Lissajous Pattern



50

Test Equipment

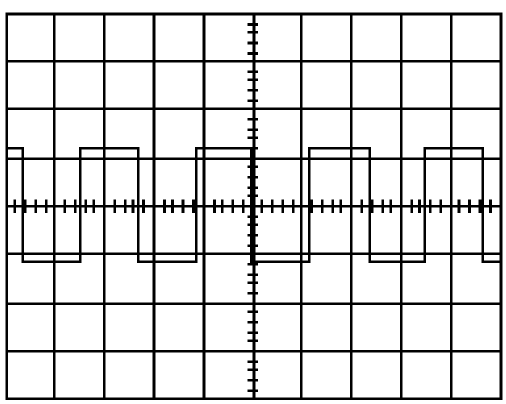
The Oscilloscope

- Oscilloscope probes.
  - A probe is used to connect the signal to the vertical amplifier.
    - Each probe has its own ground lead.
      - Keep ground leads as short as possible.
    - Probes are "compensated" to display high frequency waveforms accurately.

51

Test Equipment

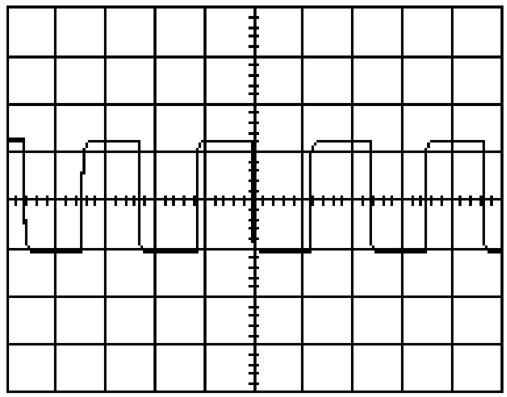
Probe Compensated Correctly



52

Test Equipment

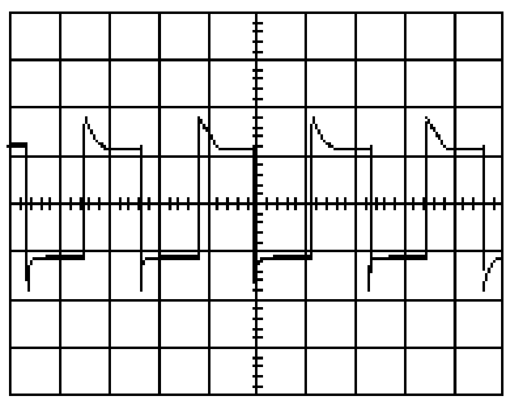
Probe Undercompensated



53

Test Equipment

Probe Overcompensated



54

E4A04 -- How is compensation of an oscilloscope probe performed?

A. A square wave is displayed, and the probe is adjusted until the horizontal portions of the displayed wave are as nearly flat as possible

B. A high frequency sine wave is displayed, and the probe is adjusted for maximum amplitude

C. A frequency standard is displayed, and the probe is adjusted until the deflection time is accurate

D. A DC voltage standard is displayed, and the probe is adjusted until the displayed voltage is accurate

55

E4A09 -- Which of the following is good practice when using an oscilloscope probe?

A. Minimize the length of the probe's ground connection

B. Never use a high-impedance probe to measure a low-impedance circuit

C. Never use a DC-coupled probe to measure an AC circuit

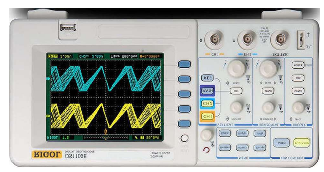
D. All these choices are correct

56

Test Equipment

The Oscilloscope

- Digital Oscilloscopes.
  - Digital oscilloscopes sample the input signal & convert it to digital data.
  - Digital oscilloscopes have the same limitations and restrictions as SDR receivers.
    - Bandwidth.
    - Aliasing.



57

Test Equipment

The Oscilloscope

- Digital Oscilloscopes.
  - Digital oscilloscopes can automate functions that must be done manually (or cannot be done at all) with an analog oscilloscope.
    - Automatic display of signal amplitude & frequency.
    - Storage of signals for future display.
    - Zoom display in or out after signal is captured.
    - Labeling signals.
    - etc.

58

Test Equipment

The Oscilloscope

- Digital Oscilloscopes.
  - Bandwidth.
    - The bandwidth is determined by the sampling rate of the A/D convertor used.
      - $F_{max} < 0.5 \times$ Sampling Rate

59

Test Equipment

The Oscilloscope

- Digital Oscilloscopes.
  - Aliasing.
    - If the frequency being measured is greater than one-half of the sampling rate, or if the time base rate is too low, aliasing can occur.
      - Aliasing results in a false, low frequency, jittery alias of the signal being measured.
    - Low-pass filters are used to ensure that the frequency of the input signal is less than one-half of the sampling rate.

60

Test Equipment

The Oscilloscope

- Digital Oscilloscopes.
  - Instead of traces occurring continuously, an oscilloscope can be set to trigger a trace only when a specified event occurs.
    - External– A trace triggered by an external signal.
    - Edge – A trace is triggered when there is a rapid increase or decrease in input signal level.
      - Leading or trailing edge of a pulse.
    - Line – A trace is triggered when the AC power line voltage reaches 50% of its maximum value.
      - Useful for looking for power supply ripple.

61

Test Equipment

The Oscilloscope

- The Logic Analyzer
  - A special type of oscilloscope used for displaying digital signals.
  - Can display 16 or more signals at a time.

62

E4A01 -- Which of the following limits the highest frequency signal that can be accurately displayed on a digital oscilloscope?

➡ A. Sampling rate of the analog-to-digital converter

B. Analog-to-digital converter reference frequency

C. Q of the circuit

D. All these choices are correct

63

E4A06 -- What is the effect of aliasing on a digital oscilloscope when displaying a waveform?

➡ A. A false, jittery low-frequency version of the waveform is displayed

B. The waveform DC offset will be inaccurate

C. Calibration of the vertical scale is no longer valid

D. Excessive blanking occurs, which prevents display of the waveform

64

E4A10 -- Which trigger mode is most effective when using an oscilloscope to measure a linear power supply s output ripple?

A. Single-shot

B. Edge

C. Level

D. Line

65

Test Equipment

The Spectrum Analyzer

- Waveform Spectra.
  - Fourier analysis is a mathematical tool to analyze AC signals by breaking a signal into the individual frequency components that comprise the signal.
    - Can convert from one domain to the other using an algorithm called a Fourier transform.
  - A spectrum analyzer performs a Fourier analysis on a signal & displays its various components.

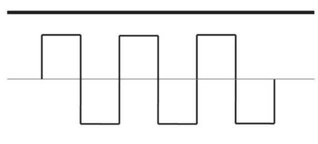
66

Test Equipment

The Spectrum Analyzer

- Waveform Spectra.
  - Square waves – a square wave consists of a fundamental frequency plus all of its odd harmonics with decreasing amplitude.
    - cos(f) + cos(3*f)/3 + cos(5f*)/5 +…cos(n*f)/n

SQUARE WAVE



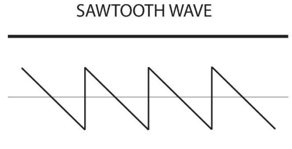
67

Test Equipment

The Spectrum Analyzer

- Waveform Spectra.
  - Sawtooth waves – a sawtooth wave consists of a fundamental frequency plus all of its harmonics with decreasing amplitude.
    - cos(f) - cos(2*f)/2 + cos(3f*)/3 - cos(4f*)/4 +…cos(n*f)/n

SAWTOOTH WAVE



68

E8A01 -- What technique shows that a square wave is made up of a sine wave and its odd harmonics?

A. Fourier analysis

B. Vector analysis

C. Numerical analysis

D. Differential analysis

69

Test Equipment

The Spectrum Analyzer

- A spectrum analyzer displays signals in the frequency domain.

70

Test Equipment

The Spectrum Analyzer

- Displays signal amplitude versus frequency.
  - An oscilloscope displays signals in the time domain.
    - Horizontal axis displays time.
  - A spectrum analyzer displays signals in the frequency domain.
    - Horizontal axis displays frequency.
- A spectrum analyzer is equivalent to an oscilloscope showing the output of a narrow filter swept across a range of frequencies.

71

Test Equipment

The Spectrum Analyzer

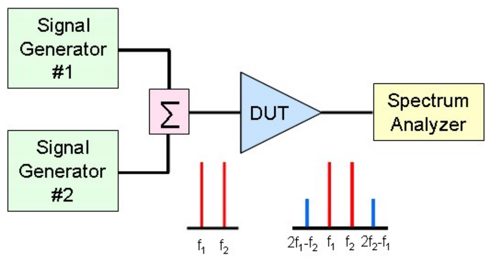
- Ideal for checking output of transmitter or amplifier for spurs.
- Ideal for checking transmitter intermodulation distortion (IMD).
  - Use power attenuator or sampler to protect the analyzer from damage.

72

Test Equipment

Two-tone Intermodulation Distortion (IMD) Test

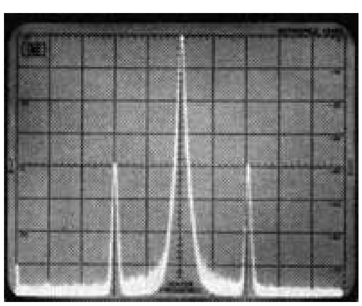
- 2 non-harmonically related audio tones.
  - ARRL Labs uses 700 Hz & 1900 Hz.

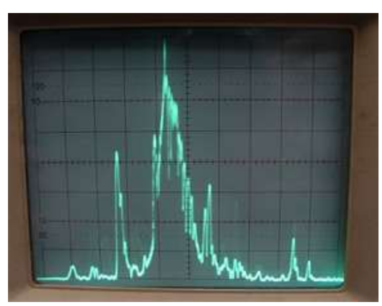


73

Test Equipment

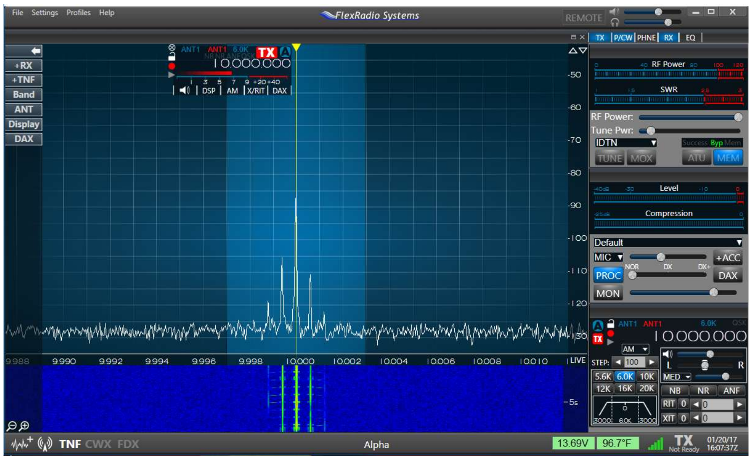
- The Spectrum Analyzer





74

Test Equipment

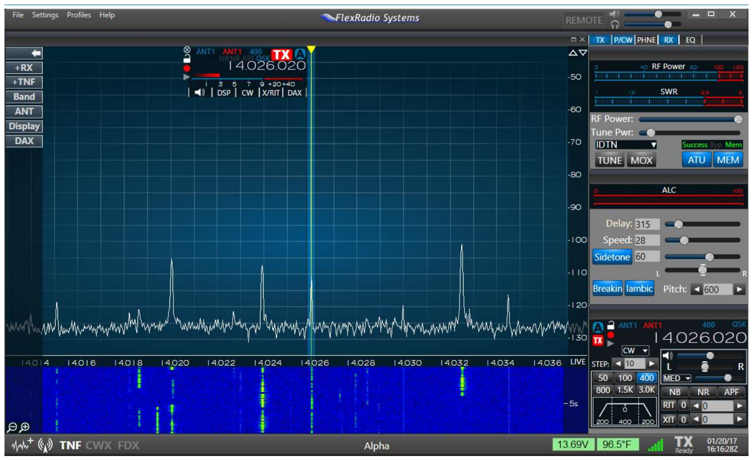


75

Test Equipment

76

Test Equipment



77

E4A02 -- Which of the following parameters does a spectrum analyzer display on the vertical and horizontal axes?

A. Signal amplitude and time

➡ B. Signal amplitude and frequency

C. SWR and frequency

D. SWR and time

78

E4A03 -- Which of the following test instruments is used to display spurious signals and/or intermodulation distortion products generated by an SSB transmitter?

A. Differential resolver
B. Spectrum analyzer
C. Logic analyzer
D. Network analyzer

79

E4B10 -- Which of the following methods measures intermodulation distortion in an SSB transmitter?

A. Modulate the transmitter using two RF signals having non-harmonically related frequencies and observe the RF output with a spectrum analyzer
B. Modulate the transmitter using two AF signals having non-harmonically related frequencies and observe the RF output with a spectrum analyzer
C. Modulate the transmitter using two AF signals having harmonically related frequencies and observe the RF output with a peak reading wattmeter
D. Modulate the transmitter using two RF signals having harmonically related frequencies and observe the RF output with a logic analyzer

80

Break

81

Receiver Performance

Good receiver performance is essential to successful amateur radio communications.

- “If you can’t hear ‘em, you can’t work ‘em!”
- The topics we will cover in this section will allow you to intelligently compare receivers based on published specifications and test results.

82

Receiver Performance

Sensitivity and Noise

- Receiver sensitivity is a measure of how weak a signal that a receiver can receive.
  - a.k.a. – Minimum discernible signal (MDS).
  - a.k.a. – Noise floor.
  - Determined by the noise figure and the bandwidth of the receiver.
    - For SDR, also the minimum level that the ADC can encode.
      - Determined by reference voltage & number of bits.

83

Receiver Performance

Sensitivity and Noise

- Minimum discernible signal (MDS).
  - Expressed in dBm or µV.
    - 0 dBm = 1 mW into 50Ω load (≈0.224V).
  - Theoretical minimum = -174 dBm/Hz.
    - Noise power at the input of an ideal receiver with a bandwidth of 1 Hz at room temperature.
    - -174 dBm ≈ 4 x 10^{-9} mW (4 billionths of a mW).

84

Receiver Performance

Sensitivity and Noise

- Minimum discernible signal (MDS).
  - The noise floor increases as the bandwidth of the receiver increases.
    - If you double the bandwidth, the noise floor is increased by a factor of 2 (3dB).

85

Receiver Performance

Sensitivity and Noise

- Minimum discernible signal (MDS).
  - Calculating MDS.
    - MDS = 10 x log(f_{BW}) – 174.
    - Example: What is the MDS of a 400 Hz bandwidth receiver with a noise floor of -174dB/Hz?
      - 10 x log(400) = 26.
      - MDS = 26 – 174 = -148 dB.

86

Receiver Performance

Sensitivity and Noise

- Noise figure.
  - The noise figure of a receiver is the difference in dB between the noise output of the receiver with no antenna connected and that of an ideal receiver with the same gain & bandwidth.
    - NF = (Internal Noise) / (Theoretical MDS).
  - “Figure of merit” of a receiver.
    - Typically a “good” VHF or UHF preamplifier has a NF ≈ 2dB.
  - Actual noise floor = (Theoretical MDS) + NF.

87

Receiver Performance

Sensitivity and Noise

- Signal-to-noise ratio (SNR).
  - SNR = (Input Signal Power) / (Noise Power).
- Signal-to-noise and distortion (SINAD).
  - Distortion is added to the noise.
    - SINAD = (Input Signal Power) / (Noise Power + Distortion Power).

88

Receiver Performance

Sensitivity and Noise

- Minimum discernible signal (MDS).
  - At MF & HF frequencies with an antenna attached, the MDS is determined by the atmospheric noise.
    - On the MF and lower HF bands, turning on an attenuator or turning off the pre-amp can help reduce overload, but will have little impact on the signal-to-noise ratio.
  - At VHF frequencies & up, the MDS is determined by the noise generated inside the front end of the receiver.
    - Brownian noise.

89

E4C04 -- What is the noise figure of a receiver?

A. The ratio of atmospheric noise to phase noise

B. The ratio of the noise bandwidth in hertz to the theoretical bandwidth of a resistive network

C. The ratio in dB of the noise generated in the receiver to atmospheric noise

➡ D. The ratio in dB of the noise generated by the receiver to the theoretical minimum noise

90

E4C05 -- What does a receiver noise floor of -174 dBm represent?

A. The receiver noise is 6 dB above the theoretical minimum
B. The theoretical noise in a 1 Hz bandwidth at the input of a perfect receiver at room temperature
C. The noise figure of a 1 Hz bandwidth receiver
D. 12`The receiver noise is 3 dB above theoretical minimum

E4C06 -- How much does increasing a receiver's bandwidth from 50 Hz to 1,000 Hz increase the receiver's noise floor?

A. 3 dB
B. 5 dB
C. 10 dB
D. 13 dB

E4C07 -- What does the MDS of a receiver represent?

A. The meter display sensitivity
B. The minimum discernible signal
C. The modulation distortion specification
D. The maximum detectable spectrum

93

E4C11 -- Why does input attenuation reduce receiver overload on the lower frequency HF bands with little or no impact on signal-to-noise ratio?

A. The attenuator has a low-pass filter to increase the strength of lower frequency signals
B. The attenuator has a noise filter to suppress interference
C. Signals are attenuated separately from the noise
D. Atmospheric noise is generally greater than internally generated noise even after attenuation

94

E4D14 -- What power level does a receiver minimum discernible signal of -100 dBm represent?

A. 100 microwatts

B. 0.1 microwatt

C. 0.001 microwatts

➡ D. 0.1 picowatts

95

Receiver Performance

Selectivity

- The ability of a receiver to receive the desired signal & reject all others is called selectivity.
- The selectivity is determined by receiver's **ENTIRE** filter chain.
  - Filters at RF frequency.
  - Filters at IF frequency.
  - Filters at AF frequency.

96

Receiver Performance

Selectivity

- Band-pass front-end filter.
  - At input to RF pre-amp.
  - Provide front-end selectivity.
  - Reduces interference from strong out-of-band signals.
  - Reduces interference from image response.
  - Prevents overload in an SDR receiver.
- Pre-selector.
  - Same as a band-pass front-end filter but tunable.

97

E4C02 -- Which of the following receiver circuits can be effective in eliminating interference from strong out-of-band signals?

A. A front-end filter or pre-selector

B. A narrow IF filter

C. A notch filter

D. A properly adjusted product detector

98

E4D09 -- What is the purpose of the preselector in a communications receiver?

A. To store frequencies that are often used

B. To provide broadband attenuation before the first RF stage to prevent intermodulation

C. To increase the rejection of signals outside the band being received

D. To allow selection of the optimum RF amplifier device

99

Receiver Performance

Selectivity

- Analog Receiver IF Filters.
  - A major issue with heterodyne receivers is the reception of unwanted signals called images.
  - There are 2 different RF frequencies that, when mixed with the local oscillator, produce an output on the desired IF frequency.
    - $f_{IF} = f_{RF} - f_{LO}$ **OR** $f_{IF} = f_{RF} + f_{LO}$
  - The unwanted frequency is called the "image".

100

Receiver Performance

Selectivity

- Analog Receiver IF Filters.
  - The primary way to remove the image is by filtering before the mixer.
    - Band-pass front-end filter.
    - Pre-selector.
  - However, choice of IF frequency is also important.
    - The higher the IF frequency, the farther apart the image is from the desired signal.
      - Easier for the front-end filtering to remove the image.

101

Receiver Performance

Selectivity

- Analog Receiver IF Filters.
  - Soon after the invention of the heterodyne receiver, it was determined that using a local oscillator frequency greater than the receive frequency would result in the image being farther away from the desired frequency, making it easier to filter out.
    - Thus was born the superheterodyne receiver.

102

Receiver Performance

Selectivity

- Analog Receiver IF Filters.
  - Most modern HF superheterodyne receiver designs use an IF frequency in the VHF range.
  - Recent advances in technology allow the construction of extremely sharp filters at VHF frequencies.
    - Roofing filters.

103

Receiver Performance

Selectivity

- Analog Receiver IF Filters.
  - Roofing filter.
    - Normally located at the input of the 1st IF amplifier, right after the 1st mixer.
      - Typically VHF (70 MHz is common).
    - A sharp crystal filter wider than the bandwidth of the widest signal to be received.
    - Reduces IMD from strong signals outside of the filter passband.
      - Improves dynamic range.

104

Receiver Performance

Selectivity

- Analog Receiver IF filters.
  - Narrow filters in the final IF stage provide the selectivity needed to filter out signals on nearby frequencies.
    - Crystal filters or mechanical resonators.
    - Being replaced by DSP filters.

105

Receiver Performance

Selectivity

- Analog Receiver IF filters.
  - Different width filters are provided for different operating modes.
    - Matching the filter width to the bandwidth of the signal being received results in the best signal-to-noise ratio.
    - 2.4 kHz to 3.0 kHz for SSB & most digital modes.
    - 500 Hz or less for CW & RTTY.

106

Receiver Performance

Selectivity

- Analog Receiver IF filters.
  - Some receivers provide an “IF Shift” control.
    - Shifts the IF filter frequency slightly up or down to help minimize interference from a station on an adjacent frequency.

107

Receiver Performance

Selectivity

- Analog Receiver AF filters.
  - Primarily external DSP filters.
  - Can be narrower than IF filters.
  - Adaptive filters can reduce noise, add notches, etc.

108

E4C09 -- Which of the following choices is a good reason for selecting a high IF for a superheterodyne HF or VHF communications receiver?

A. Fewer components in the receiver
B. Reduced drift
C. Easier for front-end circuitry to eliminate image responses
D. Improved receiver noise figure

109

E4C10 -- What is an advantage of having a variety of receiver bandwidths from which to select?

A. The noise figure of the RF amplifier can be adjusted to match the modulation type, thus increasing receiver sensitivity
B. Receiver power consumption can be reduced when wider bandwidth is not required
C. Receive bandwidth can be set to match the modulation bandwidth, maximizing signal-to-noise ratio and minimizing interference
D. Multiple frequencies can be received simultaneously if desired

110

E4C12 -- How does a narrow-band roofing filter affect receiver performance?

A. It improves sensitivity by reducing front end noise
B. It improves intelligibility by using low Q circuitry to reduce ringing
➡ C. It improves dynamic range by attenuating strong signals near the receive frequency
D. All of these choices are correct

111

E4C14 -- What is the purpose of the receiver IF Shift control?

A. To permit listening on a different frequency from the transmitting frequency
B. To change frequency rapidly
➡ C. To reduce interference from stations transmitting on adjacent frequencies
D. To tune in stations slightly off frequency without changing the transmit frequency

112

Receiver Performance

Receiver Dynamic Range

- The dynamic range of a receiver is the range of signal strengths that the receiver can handle.
- The dynamic range is the range of signal levels from the minimum discernable signal (MDS) up to the level where audible distortion of the received signal occurs.
- Dynamic range is normally based on signal levels expressed in dBm.
  - 0 dBm = 1 mw into a 50Ω load (~0.224V).

113

Receiver Performance

Receiver Dynamic Range

- SDR Dynamic Range
  - The dynamic range of an SDR receiver is primarily determined by the sample width (number of bits) of the A/D converter.
    - More bits ➔ Larger dynamic range.
    - Can never exceed maximum "count" of A/D.
      - Larger count (more bits) allows larger voltage to be counted which increases dynamic range.
    - The maximum signal level is equal to the reference voltage of the A/D convertor.

114

E4C08 -- An SDR receiver is overloaded when input signals exceed what level?

A. One-half the maximum sample rate

B. One-half the maximum sampling buffer size

C. The maximum count value of the analog-to-digital converter

➡ D. The reference voltage of the analog-to-digital converter

115

Receiver Performance

Receiver Dynamic Range

- Blocking Dynamic Range
  - A signal can be so strong that an analog receiver can no longer respond, & its apparent gain decreases.
    - Known as:
      - Blocking.
      - Compression.
      - De-sensitization (de-sense).

116

Receiver Performance

Receiver Dynamic Range

- Blocking Dynamic Range
  - A signal may appear weaker than it actually is due to the presence of a strong adjacent signal.
  - A near-by stronger signal may appear to “modulate” a weaker signal.
    - Cross-modulation.

117

Receiver Performance

Receiver Dynamic Range

- Blocking Dynamic Range
  - A receiver’s “blocking level” is the strength of a signal that results in a 1 dB reduction in apparent gain.
  - The “blocking dynamic range” is the difference between the MDS & the blocking level.
  - If signal is far enough away in frequency, the blocking dynamic range may be improved by IF filters.

118

E4D01 -- What is meant by the blocking dynamic range of a receiver?

A. The difference in dB between the noise floor and the level of an incoming signal that will cause 1 dB of gain compression
B. The minimum difference in dB between the levels of two FM signals that will cause one signal to block the other
C. The difference in dB between the noise floor and the third-order intercept point
D. The minimum difference in dB between two signals which produce third-order intermodulation products greater than the noise floor

119

E4D06 -- What is the term for the reduction in receiver sensitivity caused by a strong signal near the received frequency?

A. Reciprocal mixing
B. Quieting
C. Desensitization
D. Cross modulation interference

120

E4D07 -- Which of the following reduces the likelihood of receiver desensitization?

A. Insert attenuation before the first RF stage
B. Raise the receiver s IF frequency
C. Increase the receiver s front-end gain
D. Switch from fast AGC to slow AGC

121

Receiver Performance

Intermodulation (IMD)

- In a non-SDR receiver, as the signal strength increases, the receiver response becomes non-linear.
- Non-linearity produces intermodulation distortion (IMD) products.
  - $f_{IMD} = nf_1 \pm mf_2$
    - If n+m is even, then products are even-order products.
      - n+m=2 → 2nd-order products
    - If n+m is odd, then products are odd-order products.
      - n+m=3 → 3rd-order products
      - Odd-order products may be close to desired frequency.

122

Receiver Performance

Intermodulation (IMD)

- There are four 3rd-order products associated with the 2nd harmonic of the signals:
  - $f_{IMD} = 2f_1 + f_2$
  - $f_{IMD} = 2f_1 - f_2$
  - $f_{IMD} = 2f_2 + f_1$
  - $f_{IMD} = 2f_2 - f_1$

  - The subtractive products are the ones that can cause interference.

123

Receiver Performance

Intermodulation (IMD)

- Example of 3rd-order IMD interference:
  - Your receiver is tuned to 146.70 MHz.
  - There are strong signals on 146.52 MHZ & 146.34 MHz.
    - 2 x 146.52 MHz – 146.34 MHz = 146.70 MHz.
  - There are strong signals on 146.52 MHZ & 146.61 MHz.
    - 2 x 146.61 MHz – 146.52 MHz = 146.70 MHz.
  - Cannot filter out interfering signals because they are within the band.
    - You need a receiver with good linearity.

124

E4D05 -- What transmitter frequencies would cause an intermodulation-product signal in a receiver tuned to 146.70 MHz when a nearby station transmits on 146.52 MHz?

A. 146.34 MHz and 146.61 MHz
B. 146.88 MHz and 146.34 MHz
C. 146.10 MHz and 147.30 MHz
D. 146.30 MHz and 146.90 MHz

125

E4D11 -- Why are odd-order intermodulation products, created within a receiver, of particular interest compared to other products?

A. Odd-order products of two signals in the band being received are also likely to be within the band
B. Odd-order products are more likely to overload the IF filters
C. Odd-order products are an indication of poor image rejection
D. Odd-order intermodulation produces three products for every input signal within the band of interest

126

Receiver Performance

Intermodulation (IMD)

- Intercept points.
  - The strength of 2nd-order IMD products increases 2dB for every 1dB of increase in input signal strength.
  - The strength of 3rd-order IMD products increases 3dB for every 1dB of increase in input signal strength.
  - At some point the strength of the IMD products will equal the strength of the input signal.
    - This is called the ”intercept point”.
    - There are separate intercept point for each order of IMD products.

127

Receiver Performance

Intermodulation (IMD)

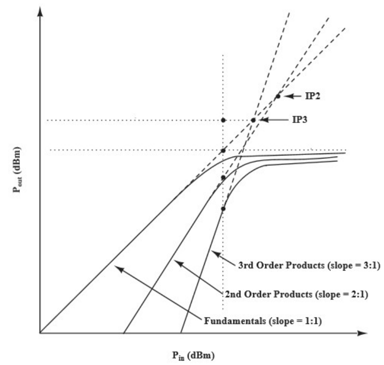
- Intercept points.
  - For example:
    - A 40 dBm 3rd-order intercept point means that an input signal of 40 dBm would produce 3rd-order IMD products with a total power of 40 dBm.
  - The intercept point is only an indication of the linearity of the receiver. It is **NOT** an indication of how strong a signal it is capable of receiving.
    - 40 dBm = 10 W.

128

Receiver Performance

Intermodulation (IMD)

- Intercept points.



129

Receiver Performance

Intermodulation (IMD)

- Intercept points.
  - IMD performance normally gets worse as frequencies get closer together.
    - Usually specified at several different frequency spacings.
  - IMD dynamic range indicates the ability of a receiver to avoid producing IMD products.
    - $DR_3 = (2/3)(IP_3 - MDS)$.

130

E4D02 -- Which of the following describes problems caused by poor dynamic range in a receiver?

A. ➡ Spurious signals caused by cross modulation and desensitization from strong adjacent signals
B. Oscillator instability requiring frequent retuning and loss of ability to recover the opposite sideband
C. Poor weak signal reception caused by insufficient local oscillator injection
D. Oscillator instability and severe audio distortion of all but the strongest received signals

131

E4D10 -- What does a third-order intercept level of 40 dBm mean with respect to receiver performance?

A. Signals less than 40 dBm will not generate audible third-order intermodulation products
B. The receiver can tolerate signals up to 40 dB above the noise floor without producing third-order intermodulation products
C. ➡ A pair of 40 dBm input signals will theoretically generate a third-order intermodulation product that has the same output amplitude as either of the input signals
D. A pair of 1 mW input signals will produce a third-order intermodulation product that is 40 dB stronger than the input signal

132

Receiver Performance

Phase Noise

- Small variations in the local oscillator frequency cause random phase shifts in the received signal.
- Sidebands resulting from these phase shifts are called “phase noise”.

133

Receiver Performance

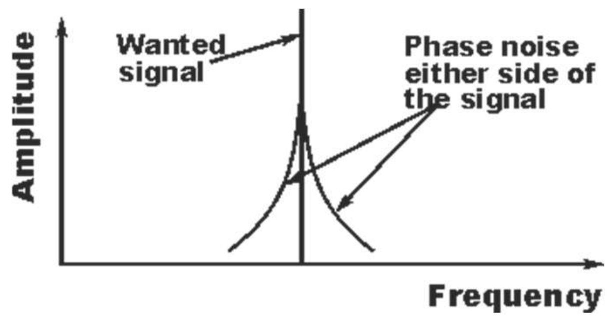
Phase Noise

- Phase noise from a strong nearby signal can raise the apparent receiver noise floor and mask a weaker, desired signal.
- The phase noise sidebands will mix with the local oscillator signal the same as the desired signal does.
  - This is called “reciprocal mixing”.
  - As you tune towards a strong signal, the apparent noise level increases.

134

Receiver Performance

Phase Noise



135

E4C01 -- What is an effect of excessive phase noise in an SDR receiver's master clock oscillator?

A. It limits the receiver's ability to receive strong signals
B. It can affect the receiver's frequency calibration
C. It decreases receiver third-order intercept point
D. It can combine with strong signals on nearby frequencies to generate interference

136

E4C15 -- What is reciprocal mixing?

A. Two out-of-band signals mixing to generate an in-band spurious signal

B. In-phase signals cancelling in a mixer resulting in loss of receiver sensitivity

C. Two digital signals combining from alternate time slots

➡ D. Local oscillator phase noise mixing with adjacent strong signals to create interference to desired signals

137

Receiver Performance

Capture Effect

- FM receivers react differently to the presence of QRM than AM receivers do.
  - Only the strongest signal will be demodulated.
  - Weaker signal(s) are totally hidden.
  - Only a few dB difference in signal strength is required.
  - This is called the "capture effect".

138

E4C03 -- What is the term for the suppression in an FM receiver of one signal by another stronger signal on the same frequency?

A. Desensitization

B. Cross-modulation interference

➡ C. Capture effect

D. Frequency discrimination

139

Interference and Noise

Transmitter Intermodulation

- Non-linear circuits or components can act as mixers to generate signals at the sums & differences of the signals being mixed.
  - An unwanted signal can be heard along with the wanted signal.
  - Signals can also mix in corroded metal junctions or junctions of dissimilar metals.

140

Interference and Noise

Transmitter Intermodulation

- Signals can mix in the output stage of a transmitter.
  - The IMD products can be transmitted along with the desired signal.
  - Common problem in repeater systems.
    - Low-pass or high-pass filters are NOT effective.
    - Circulators & isolators are used.
      - Ferrite devices that act like "one-way valves" for RF.
    - Cavity resonators.

141

E4D03 -- What creates intermodulation interference between two repeaters in close proximity?

A. The output signals cause feedback in the final amplifier of one or both transmitters

B. The output signals mix in the final amplifier of one or both transmitters

C. The input frequencies are harmonically related

D. The output frequencies are harmonically related

142

E4D04 -- Which of the following is used to reduce or eliminate intermodulation interference in a repeater caused by a nearby transmitter?

A. A band-pass filter in the feed line between the transmitter and receiver

➡ B. A properly terminated circulator at the output of the repeater's transmitter

C. Utilizing a Class C final amplifier

D. Utilizing a Class D final amplifier

143

E4D08 -- What causes intermodulation in an electronic circuit?

A. Negative feedback

B. Lack of neutralization

➡ C. Nonlinear circuits or devices

D. Positive feedback

144

E4E11 -- What could be the cause of local AM broadcast band signals combining to generate spurious signals on the MF or HF bands?

A. One or more of the broadcast stations is transmitting an over-modulated signal
B. Nearby corroded metal connections are mixing and reradiating the broadcast signals
C. You are receiving skywave signals from a distant station
D. Your station receiver IF amplifier stage is overloaded

145

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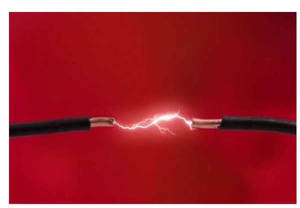
Interference and Noise

Power Line Noise

- Man-made noise caused by electric arc.
  - Electric motors.
  - Light dimmers.
  - Neon signs.
  - Defective doorbell or doorbell transformer.
  - Thermostats.



146

Interference and Noise

Power Line Noise

- Electric motors.
  - Install a “brute force” AC line filter in series with the motor power leads.

147

Interference and Noise

Power Line Noise

- To prevent AC line noise or transient voltage spikes from getting into your equipment, install a capacitor across the power supply transformer secondary winding.
  - Called a “snubber” capacitor.

148

E4E05 -- What is used to suppress radio frequency interference from a line-driven AC motor?

A. A high-pass filter in series with the motor's power leads

➡ B. A brute-force AC-line filter in series with the motor's power leads

C. A bypass capacitor in series with the motor's field winding

D. A bypass choke in parallel with the motor's field winding

149

E4E10 -- Which of the following can create intermittent loud roaring or buzzing AC line interference

A. Arcing contacts in a thermostatically controlled device

B. A defective doorbell or doorbell transformer inside a nearby residence

C. A malfunctioning illuminated advertising display

➡ D. All these choices are correct

150

Interference and Noise

Locating Noise and Interference Sources

- Interference originating inside a building is usually conducted through the AC power wiring.
  - Inside your house.
  - Outside your house.

151

Interference and Noise

Locating Noise and Interference Sources

- To determine if noise is generated within your own house, turn off the main breaker & listen on a battery-operated receiver.
  - Not an FM receiver.
- Restore power & make certain that the noise returns.
  - The offending device may need to be powered on for a while before generating noise.
- Remove power one circuit at a time until the noise disappears.

152

Interference and Noise

Locating Noise and Interference Sources

- Interference originating outside a building is usually picked up by the antenna or transmission line.
  - Use "fox hunting" techniques to locate the source.

153

Interference and Noise

Interference from Strong Signals

- Strong signals can cause interference to most types of electronic devices:
  - TVs.
  - Radios.
  - Stereos.
  - Telephones.
  - Electronic doorbells.
  - etc.

154

Interference and Noise

Interference from Strong Signals

- Your transmitter can couple RF into AC and/or telephone wiring & cause interference to other devices.
  - Common mode signals.
    - In a transmission line, the RF flows in opposite directions on the two conductors.
    - With common mode current, the RF flows equally in the same direction on all conductors of a multi-conductor cable.

155

Interference and Noise

Interference from Strong Signals

- To reduce common mode current:
  - Install a common mode choke.
    - Several turns of wire around a ferrite toroid core.
    - A snap-on ferrite choke.

156

E4E07 -- Which of the following can cause shielded cables to radiate or receive interference?

A. Low inductance ground connections at both ends of the shield

➡ B. Common-mode currents on the shield and conductors

C. Use of braided shielding material

D. Tying all ground connections to a common point resulting in differential-mode currents in the shield

157

E4E08 -- What current flows equally on all conductors of an unshielded multi-conductor cable?

A. Differential-mode current

➡ B. Common-mode current

C. Reactive current only

D. Magnetically-coupled current only

158

Interference and Noise

Computer Interference

- Computer and network equipment generate RF signals that can interfere with radio reception.
  - Typically unstable modulated or unmodulated signals at specific frequencies.
  - Signals can change as the device performs different tasks.

159

E4E06 -- What type of electrical interference can be caused by computer network equipment?

A. A loud AC hum in the audio output of your station s receiver

B. A clicking noise at intervals of a few seconds

C. The appearance of unstable modulated or unmodulated signals at specific frequencies

D. A whining-type noise that continually pulses off and on

160

Interference and Noise

Vehicle Noise

- When installing a mobile radio in a vehicle, check to see if the vehicle manufacturer has specific instructions on the best way to do it.
- Always connect the radio power leads directly to the battery terminals.
  - Connect **both** the hot and ground wires to the battery terminals.
  - Install fuses in **both** the hot and ground wires.

161

Interference and Noise

Vehicle Noise

- One of the most common sources of noise in a mobile environment is the pulse-type noise generated by the vehicle's ignition system.

162

Interference and Noise

Vehicle Noise

- Suppressing ignition system noise.
  - Pre-1975 vehicles.
    - Use resistance spark plugs.
    - Use high-resistance spark plug cables.
    - Use shielded cables.
  - 1975 & later vehicles.
    - Use shielded cables.
      - High resistance plugs & cables can degrade engine performance.

163

Interference and Noise

Vehicle Noise

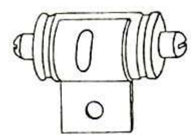
- Vehicular System Noise
  - Another common type of interference is charging system noise.
    - A high-pitched whine or buzz.
    - Changes frequency with engine speed.
    - Noise can be:
      - Radiated & picked up by antenna.
      - Conducted through power wiring.

164

Interference and Noise

Vehicle Noise

- Vehicular System Noise
  - To suppress charging system noise, you can:
    - Connect radio power leads directly to battery.
      - Fuse EACH lead.
    - Add ferrite chokes or beads to alternator leads.
    - Add coaxial capacitors in alternator leads.
      - a.k.a. – Feed-through capacitors.



165

Interference and Noise

Vehicle Noise

- Vehicular System Noise
  - Instrument noise.
    - Some instruments can generate RF noise.
      - Install 0.5 µF coaxial capacitor at the sender element.
    - Wiper, fuel pump, & other motors can generate RF noise.
      - Install 0.25 µF capacitor across the motor winding.

166

E4E04 -- How can conducted noise from an automobile battery charging system be suppressed?

A. By installing filter capacitors in series with the alternator leads
B. By installing a noise suppression resistor and a blocking capacitor at the battery
C. By installing a high-pass filter in series with the radio s power lead and a low-pass filter in parallel with the antenna feed line
D. By installing ferrite chokes on the charging system leads

167

Interference and Noise

Noise Reduction

- Once inside a receiver, noise is difficult to eliminate.
- Two common techniques are used to reduce received noise:
  - Noise blanking.
  - Noise reduction.

168

Interference and Noise

Noise Reduction

- Noise Blankers
  - Noise blankers are used to eliminate pulse-type noise, such as ignition noise.
  - A noise blanker detects a noise pulse & interrupts the signal during the duration of the pulse.
    - a.k.a. – Gating.
    - Particularly effective for power line or ignition noise.
    - Triggered by a rapid increase in signal level.
      - Signal appears across a wide bandwidth.
    - Strong nearby signals may appear excessively wide.

169

Interference and Noise

Noise Reduction

- DSP Noise Reduction.
  - DSP noise filters use adaptive filter techniques.
    - Look for signals that have characteristics of the desired signals & remove everything else.
  - Works well with **all** types of noise & interference, especially broadband (or "white") noise.

170

Interference and Noise

Noise Reduction

- DSP Noise Reduction.
  - Automatic Notch Filters (ANF).
    - Very effective in eliminating interference from a strong steady signal (carrier) in the receive passband.
    - Not recommended for copying CW or low data rate digital signals.
      - A good ANF will ”notch out” the desired signal.

171

E4E01 -- What problem can occur when using an automatic notch filter (ANF) to remove interfering carriers while receiving CW signals?

A. Removal of the CW signal as well as the interfering carrier

B. Any nearby signal passing through the DSP system will overwhelm the desired signal

C. Excessive ringing

D. All these choices are correct

172

E4E02 -- Which of the following types of noise can often be reduced by a digital noise reduction?

A. Broadband white noise
B. Ignition noise
C. Power line noise
➡ D. All these choices are correct

173

E4E03 -- Which of the following types of noise are removed by a noise blanker?

A. Broadband white noise
➡ B. Impulse noise
C. Hum and buzz
D. All these choices are correct

174

E4E09 -- What undesirable effect can occur when using an IF noise blanker?

A. Received audio in the speech range might have an echo effect

B. The audio frequency bandwidth of the received signal might be compressed

→ C. Strong signals may be distorted and appear to cause spurious emissions

D. FM signals can no longer be demodulated

175

Questions?

176

Amateur Extra Class

Next Week

Chapter 8

Radio Modes and Equipment

177