



Amateur Extra License Class

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Amateur Extra Class

Chapter 7 Radio Signals and Measurements

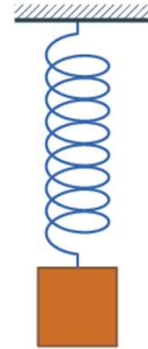
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Types of Waveforms

Sine Waves

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



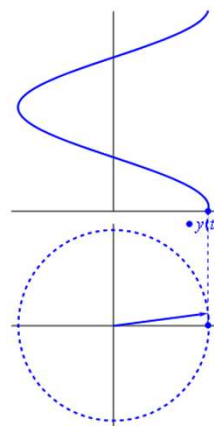
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Types of Waveforms

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.



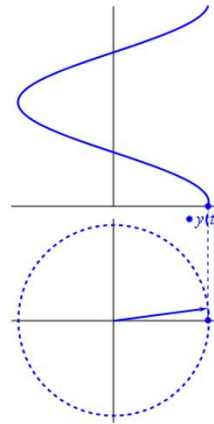
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Types of Waveforms

Sine waves

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



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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.

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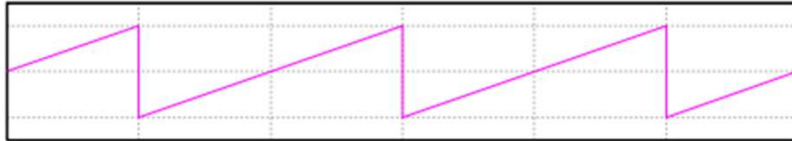


Types of Waveforms

Sawtooth Wave

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

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



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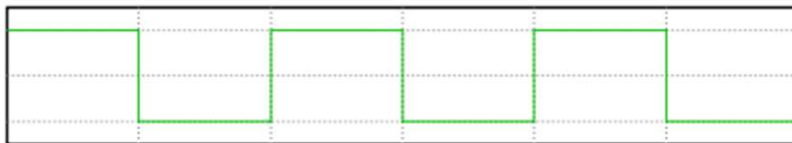


Types of Waveforms

Square Wave

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

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



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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.

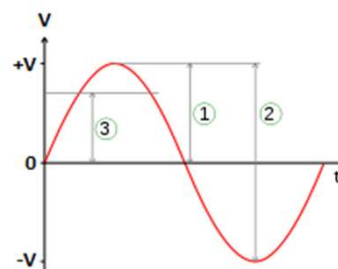
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AC Waveforms and Measurements

AC Measurements

- 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)

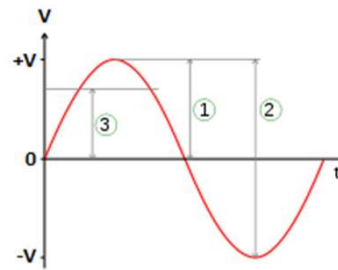
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AC Waveforms and Measurements

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.
- $I_{RMS} = 0.707 \times I_{Peak}$
- $V_{RMS} = 0.707 \times V_{Peak}$



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

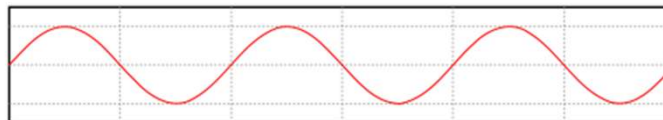
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AC Waveforms and Measurements

AC Measurements

To Calculate	Sine Wave	Square Wave
RMS	$0.707 \times Peak$	Peak
Peak	$1.414 \times RMS$	RMS



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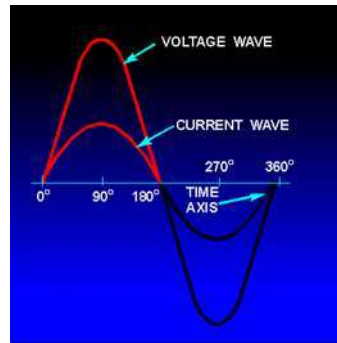
AC Waveforms and Measurements

AC Power

- Voltage & Current In-Phase

- $P_{AVG} = P_{RMS} = V_{RMS} \times I_{RMS}$

- $P_{Peak} = V_{Peak} \times I_{Peak} = 2 \times P_{RMS}$



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AC Waveforms and Measurements

Power of Modulated RF Signals

- In an unmodulated RF signal, the average power can be calculated from:

- $P_{AVG} = V_{RMS}^2 / Z$

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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.

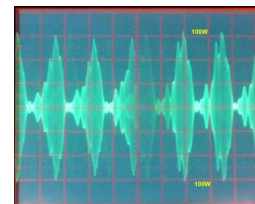
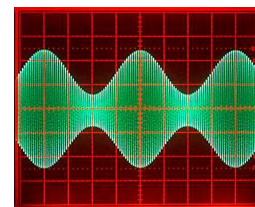
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AC Waveforms and Measurements

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%).



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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 \rightarrow 0.05% resolution.
 - **DO NOT CONFUSE RESOLUTION WITH ACCURACY!**



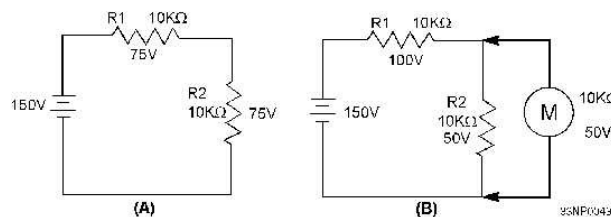
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Test Equipment

Instruments and Accuracy

- Voltmeter Sensitivity \leftrightarrow Measurement Accuracy.
 - Dependent on how much current is drawn from the circuit under test.



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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 \rightarrow very good analog meter.



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Test Equipment

Instruments and Accuracy

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



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Test Equipment

Instruments and Accuracy

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



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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.

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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 will indicate the input impedance of the voltmeter
- B. When used as a galvanometer, the reading in volts multiplied by the ohms per volt rating will determine the power drawn by the device under test
- C. When used as an ohmmeter, the reading in ohms divided by the ohms per volt rating will determine the voltage applied to the circuit
- D. When used as an ammeter, the full scale reading in amps divided by ohms per volt rating will determine the size of shunt needed

23

E8A05 -- What of the following instruments would be the most accurate for measuring the RMS voltage of a complex waveform?

- A. A grid dip meter
- B. A D'Arsonval meter
- C. An absorption wave meter
- D. A true-RMS calculating meter

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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.



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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.

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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.

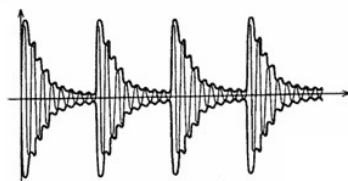
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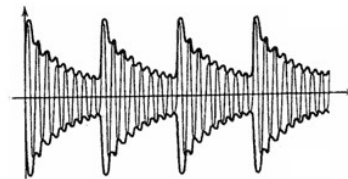
Test Equipment

Instruments and Accuracy

- RF Wattmeters.



Normal SSB



SSB with Compression

28

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

- A. 2.5 to 1
- B. 25 to 1
- C. 1 to 1
- D. 100 to 1

29

E8A07 -- What determines the PEP-to-average power ratio of a single-sideband phone signal?

- A. The frequency of the modulating signal
- B. Speech characteristics
- C. The degree of carrier suppression
- D. Amplifier gain

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Test Equipment

Instruments and Accuracy

- Frequency Counters and References.
 - Accuracy dependent on time base
 - Accuracy expressed in parts per million (ppm).
 - May use a prescaler.



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Test Equipment

Instruments and Accuracy

- Frequency counter.
 - Converts the input signal into a series of pulses.
 - Sometimes a prescaler is used to divide the frequency of the input signal down to a frequency that the counter can handle.
 - An internal oscillator, called the “time base”, determines the accuracy of the counter.
 - Accuracy is normally expressed as “parts per million” (ppm).

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Test Equipment

Instruments and Accuracy

- Frequency counter.
 - Direct-count frequency counter
 - 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.

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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.


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E4A05 -- What is the purpose of the prescaler function on a frequency counter?

- A. It amplifies low level signals for more accurate counting
- B. It multiplies a higher frequency signal so a low-frequency counter can display the operating frequency
- C. It prevents oscillation in a low-frequency counter circuit
-  D. It divides a higher frequency signal so a low-frequency counter can display the input frequency

35

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

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Test Equipment

The Oscilloscope

- An oscilloscope allows the direct observation of high-speed signals & waveforms.



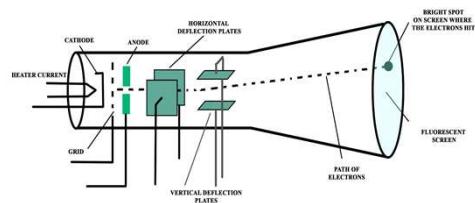
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Test Equipment

The Oscilloscope

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



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Test Equipment

The Oscilloscope

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



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Test Equipment

The Oscilloscope

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

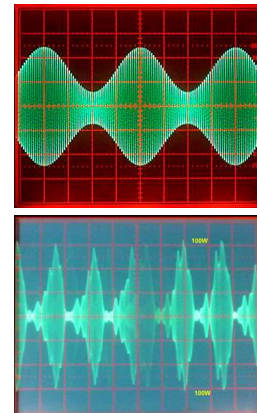
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Test Equipment

The Oscilloscope

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

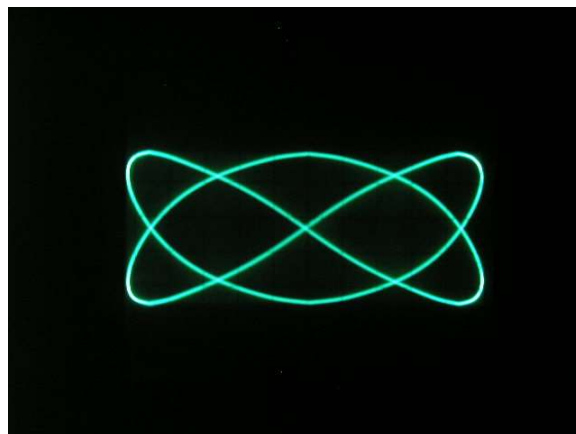


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Test Equipment

Lissajous Pattern



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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.

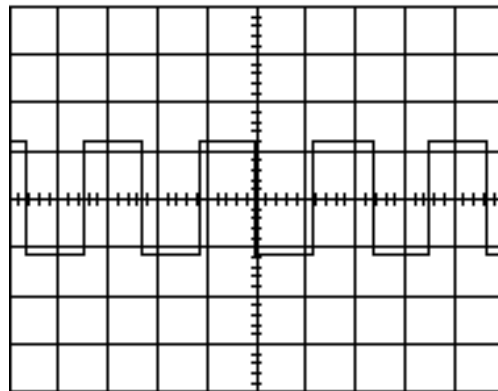


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Test Equipment

Probe Compensated Correctly

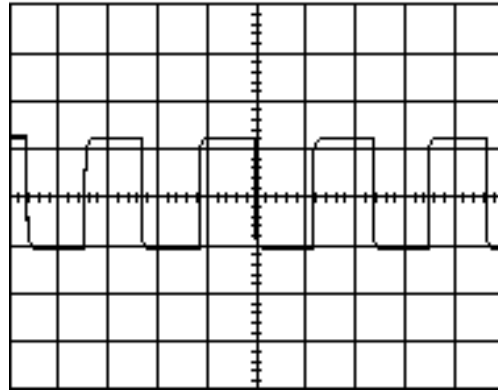


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Test Equipment

Probe Undercompensated

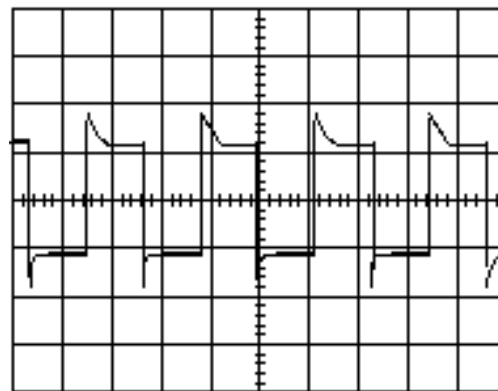


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Test Equipment

Probe Overcompensated



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E4A04 -- How is the compensation of an oscilloscope probe typically adjusted?

- 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

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

- A. Keep the signal ground connection of the probe as short as possible
- 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 of these choices are correct

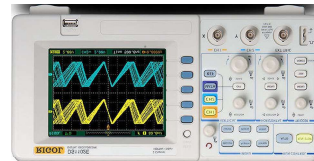
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Test Equipment

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.



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Test Equipment

The Oscilloscope

- Digital Oscilloscopes.
 - Digital oscilloscopes can automate functions that must be done manually 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.

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Test Equipment

The Oscilloscope

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

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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.

52

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. Amount of memory
- C. Q of the circuit
- D. All these choices are correct

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E4A06 -- What is the effect of aliasing on a digital oscilloscope caused by setting the time base too slow?

- A. A false, jittery low-frequency version of the signal is displayed
- B. All signals will have a DC offset
- C. Calibration of the vertical scale is no longer valid
- D. Excessive blanking occurs, which prevents display of the signal

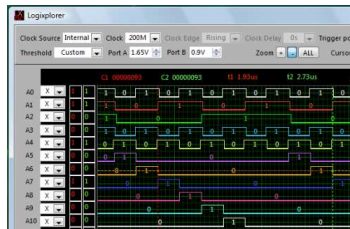
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Test Equipment

The Oscilloscope

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



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E4A10 -- Which of the following displays multiple digital signal states simultaneously?

- A. Network analyzer
- B. Bit error rate tester
- C. Modulation monitor
- D. Logic analyzer

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Test Equipment

The Spectrum Analyzer



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Test Equipment

The Spectrum Analyzer

- Time Domain and Frequency Domain.
 - An oscilloscope displays signals in the time domain
 - A spectrum analyzer displays signals in the frequency domain.



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Test Equipment

The Spectrum Analyzer

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

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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.

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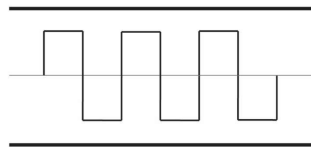


Test Equipment

The Spectrum Analyzer

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

SQUARE WAVE



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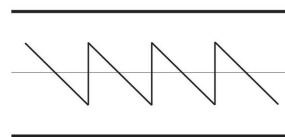


Test Equipment

The Spectrum Analyzer

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

SAWTOOTH WAVE



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E8A01 -- What is the name of the process that shows that a square wave is made up of a sine wave plus all its odd harmonics?

- A. Fourier analysis
- B. Vector analysis
- C. Numerical analysis
- D. Differential analysis

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E8A03 -- What type of wave does a Fourier analysis show to be made up of sine waves of a given fundamental frequency plus all its harmonics?

- A. A sawtooth wave
- B. A square wave
- C. A sine wave
- D. A cosine wave

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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.
- Narrow filter swept across a range of frequencies.

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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 analyzer from damage.



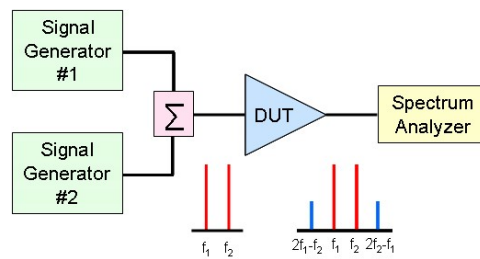
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Test Equipment

Two-tone Intermodulation Distortion (IMD) Test

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

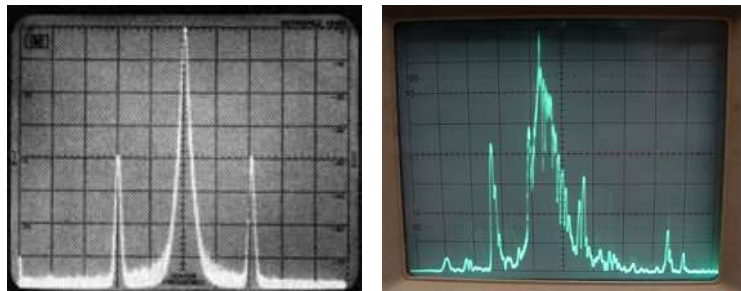


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Test Equipment

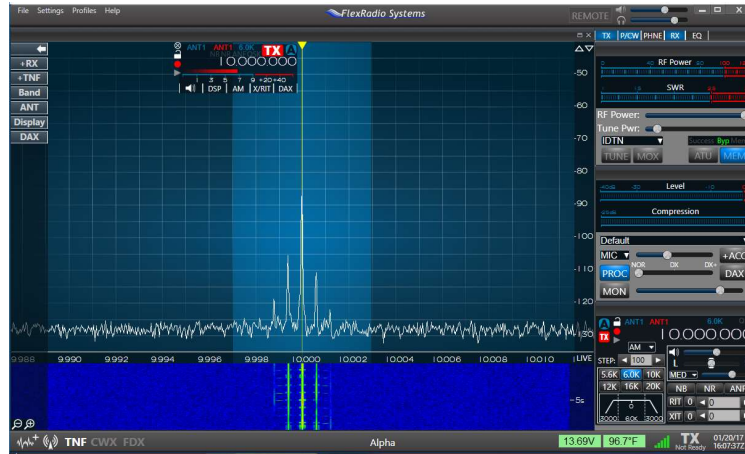
- The Spectrum Analyzer



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Test Equipment



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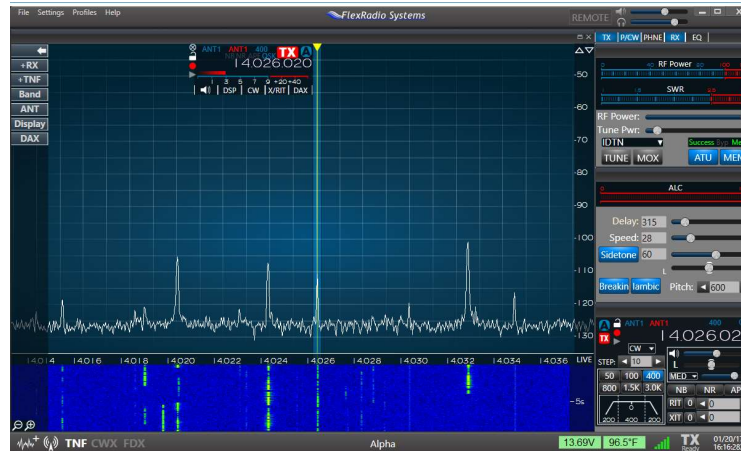
Test Equipment



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Test Equipment




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

- A. RF amplitude and time
- ➔ B. RF amplitude and frequency
- C. SWR and frequency
- D. SWR and time


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

- A. A wattmeter
-  B. A spectrum analyzer
- C. A logic analyzer
- D. A time-domain reflectometer

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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

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Break



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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.

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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.
 - Number of bits.

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Receiver Performance

Sensitivity and Noise

- Minimum discernible signal (MDS).
 - Expressed in dBm or μV .
 - 0 dBm = 1 mW into 50 Ω load ($\approx 224\text{mV}$).
 - 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 $\approx 4 \times 10^{-9}$ mW (4 billionths of a mW).

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Receiver Performance

Sensitivity and Noise

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

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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.
 - $NF = (\text{Internal Noise}) / (\text{Theoretical MDS})$.
 - “Figure of merit” of a receiver.
 - Typically a “good” VHF or UHF preamplifier has a $NF \approx 2\text{dB}$.
- Actual noise floor = (Theoretical MDS) + NF.

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Receiver Performance

Sensitivity and Noise

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

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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.


82

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

- A. The minimum detectable signal as a function of receive frequency
-  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. The galactic noise contribution to minimum detectable signal

83

E4C06 -- A CW receiver with the AGC off has an equivalent input noise power density of -174 dBm/Hz. What would be the level of an unmodulated carrier input to this receiver that would yield an audio output SNR of 0 dB in a 400 Hz noise bandwidth?

- A. -174 dBm
- B. -164 dBm
- C. -155 dBm
-  D. -148 dBm

84

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

- A. The meter display sensitivity
- B. The minimum discernible signal
- C. The multiplex distortion stability
- D. The maximum detectable spectrum

85

E4C11 -- Why can an attenuator be used to 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

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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.
 - $NF = (\text{Internal Noise}) / (\text{Theoretical MDS})$.
 - “Figure of merit” of a receiver.
 - Typically a “good” VHF or UHF preamplifier has a $NF \approx 2\text{dB}$.
 - Actual noise floor = (Theoretical MDS) + NF.

87

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 of thermal noise to atmospheric noise
- D. The ratio in dB of the noise generated by the receiver to the theoretical minimum noise

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Receiver Performance

Selectivity

- The ability to select the desired signal & reject all others.
- Determined by receiver's **ENTIRE** filter chain.
 - Filters at RF frequency.
 - Filters at IF frequency.
 - Filters at AF frequency.

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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.

90

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

91

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

- A. To store often-used frequencies
- B. To provide a range of AGC time constants
- C. To increase rejection of signals outside the desired band
- D. To allow selection of the optimum RF amplifier device

92



Receiver Performance

Selectivity

- Analog Receiver IF Filters.
 - A major issue with heterodyne receivers is image response.
 - 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 response.
 - The image is removed by filtering before the mixer.

93



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.

94



Receiver Performance

Selectivity

- Analog Receiver IF Filters.
 - Using an IF frequency greater than the frequency being received also increases the separation between the receive frequency and the image.
 - 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.

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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.

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Receiver Performance

Selectivity

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

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Receiver Performance

Selectivity

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


98

E4C09 -- Which of the following choices is a good reason for selecting a high frequency for the design of the IF in 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


99

E4C10 -- What is an advantage of having a variety of receiver IF 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


100

E4C13 -- 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

101

E4C14 -- What transmit frequency might generate an image response signal in a receiver tuned to 14.300 MHz and which uses a 455 kHz IF frequency?

- A. 13.845 MHz
- B. 14.755 MHz
- C. 14.445 MHz
-  D. 15.210 MHz

102



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 (~224 mV).

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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.

104

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

105

E4C12 -- Which of the following is caused by missing codes in an SDR receiver's analog-to-digital converter?

- A. CPU register width in bits
- B. Anti-aliasing input filter bandwidth
- C. RAM speed used for data storage
- D. Analog-to-digital converter sample width in bits

106



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).

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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.

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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.

109

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

110

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

- A. Decrease the RF bandwidth of the receiver
- B. Raise the receiver IF frequency
- C. Increase the receiver front end gain
- D. Switch from fast AGC to slow AGC

111

E4D12 -- What is the term for the reduction in receiver sensitivity caused by a strong signal near the received frequency?

- A. Desensitization
- B. Quieting
- C. Cross-modulation interference
- D. Squelch gain rollback

112



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.
 - $f_{\text{IMD}} = nf_1 \pm mf_2$
 - If $n+m$ is even, then products are even-order products.
 - $n+m=2 \rightarrow 2^{\text{nd}}$ -order products
 - If $n+m$ is odd, then products are odd-order products.
 - $n+m=3 \rightarrow 3^{\text{rd}}$ -order products
 - Odd-order products may be close to desired frequency.

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Receiver Performance

Intermodulation (IMD)

- There are four 3rd-order products:
 - $f_{\text{IMD}} = 2f_1 + f_2$
 - $f_{\text{IMD}} = 2f_1 - f_2$
 - $f_{\text{IMD}} = 2f_2 + f_1$
 - $f_{\text{IMD}} = 2f_2 - f_1$
- The subtractive products are the ones that can cause interference.

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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.
 - $2 \times 146.52 \text{ MHz} - 146.34 \text{ MHz} = 146.70 \text{ MHz}$.
 - There are strong signals on 146.52 MHz & 146.61 MHz.
 - $2 \times 146.61 \text{ MHz} - 146.52 \text{ MHz} = 146.70 \text{ MHz}$.
 - Cannot filter out interfering signals because they are within the band.
 - You need a receiver with good linearity.

115

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. 173.35 MHz and 139.40 MHz

116

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

- A. Odd-order products of two signals in the band of interest are also likely to be within the band
- B. Odd-order products 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

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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.

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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.

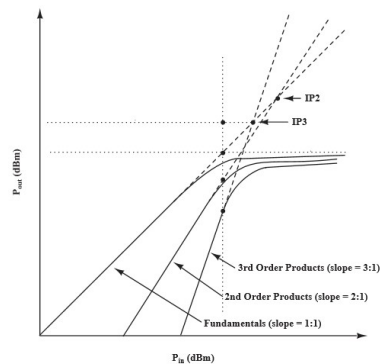
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Receiver Performance

Intermodulation (IMD)

- Intercept points.



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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.
 - $DR_3 = (2/3) (IP_3 - MDS)$.

121

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. Cross-modulation of the desired signal and insufficient audio power to operate the speaker
- D. Oscillator instability and severe audio distortion of all but the strongest received signals

122

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

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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”.

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Receiver Performance

Phase Noise

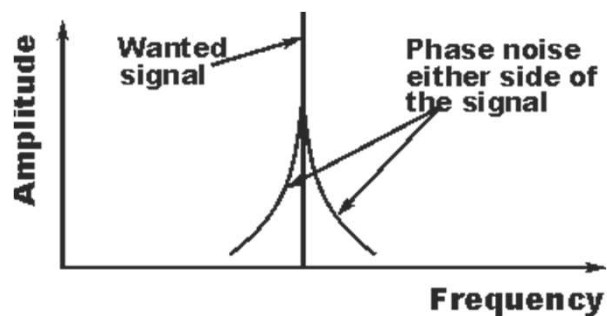
- Phase noise from a strong nearby signal can raise the apparent receiver noise floor and mask a weaker, desired signal.
- The phase noise sidebands will mix with the local oscillator signal the same as the desired signal does.
 - This is called “reciprocal mixing”.
 - As you tune towards a strong signal,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

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Receiver Performance

Phase Noise



126

E4C01 -- What is an effect of excessive phase noise in a receiver's local 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

127

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

128



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”.

129

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

130



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.
 - Unwanted signal can be heard along with wanted signal.
 - Signals can also mix in corroded metal junctions or junctions of dissimilar metals.

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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.

132

E4D03 -- How can intermodulation interference between two repeaters occur?

- A. When the repeaters are in close proximity and the signals cause feedback in the final amplifier of one or both transmitters
- B. When the repeaters are in close proximity and the signals mix in the final amplifier of one or both transmitters
- C. When the signals from the transmitters are reflected out of phase from airplanes passing overhead
- D. When the signals from the transmitters are reflected in phase from airplanes passing overhead

133

E4D04 -- Which of the following may reduce or eliminate intermodulation interference in a repeater caused by another transmitter operating in close proximity?

- 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

134

E4D06 -- What is the term for spurious signals generated by the combination of two or more signals in a non-linear device or circuit?

- A. Amplifier desensitization
- B. Neutralization
- C. Adjacent channel interference
- D. Intermodulation

135

E4D08 -- What causes intermodulation in an electronic circuit?

- A. Too little gain
- B. Lack of neutralization
- C. Nonlinear circuits or devices
- D. Positive feedback

136

E4E11 -- What could cause local AM broadcast band signals to combine to generate spurious signals in the MF or HF bands?

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

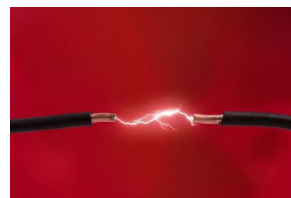
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Interference and Noise

Power Line Noise

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



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Interference and Noise

Power Line Noise

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



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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.

140

E4E05 -- How can radio frequency interference from an AC motor be suppressed?

- A. By installing a high-pass filter in series with the motor's power leads
- B. By installing a brute-force AC-line filter in series with the motor leads
- C. By installing a bypass capacitor in series with the motor leads
- D. By using a ground-fault current interrupter in the circuit used to power the motor

141

E4E10 -- What might be the cause of a loud roaring or buzzing AC line interference that comes and goes at intervals?

- 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

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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.

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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.

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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.

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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.

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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.

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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.




148

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

149

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. Return current

150



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.

151

E4E06 -- What is one type of electrical interference that might be caused by a nearby personal computer?

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

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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.

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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.

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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.

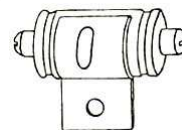
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Interference and Noise

Vehicle Noise

- Vehicular System Noise
 - Charging system noise.
 - High-pitched whine or buzz.
 - Changes frequency with engine speed.
 - Radiated & picked up by antenna.
 - Conducted through power wiring.
 - Connect radio power leads directly to battery.
 - Fuse EACH lead.
 - Add coaxial capacitors in alternator leads.
 - a.k.a. – Feed-through capacitors.



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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.

157

E4E04 -- How can conducted and radiated noise caused by an automobile alternator be suppressed?

- A. By installing filter capacitors in series with the DC power lead and a blocking capacitor in the field lead
- B. By installing a noise suppression resistor and a blocking capacitor in both leads
- C. By installing a high-pass filter in series with the radio's power lead and a low-pass filter in parallel with the field lead
- ➔ D. By connecting the radio's power leads directly to the battery and by installing coaxial capacitors in line with the alternator leads

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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.

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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.
 - Must see signals that appear across a wide bandwidth.
 - Strong nearby signals may appear excessively wide.

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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.

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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.

162

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. Received CW signals will appear to be modulated at the DSP clock frequency
- D. Ringing in the DSP filter will completely remove the spaces between the CW characters

163

E4E02 -- Which of the following types of noise can often be reduced with a digital signal processing noise filter?

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

164

E4E03 -- Which of the following signals might a receiver noise blanker be able to remove from desired signals?

- A. Signals that are constant at all IF levels
- B. Signals that appear across a wide bandwidth
- C. Signals that appear at one IF but not another
- D. Signals that have a sharply peaked frequency distribution

165

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. Nearby signals may appear to be excessively wide even if they meet emission standards
- D. FM signals can no longer be demodulated

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Questions?



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Amateur Extra Class

Next Week

Chapter 8

Radio Modes and Equipment

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