The ARRL General Class License Course

All You Need to Pass Your General Class Exam
LEVEL 2: General

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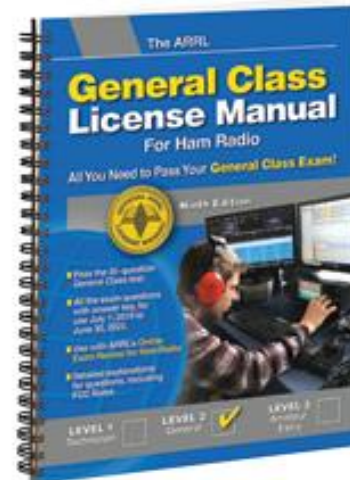
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Module 6

ARRL General Class
Chapter 6 – Digital Modes
(6.1, 6.2, 6.3, 6.4)

Basics of Digital Modes, Character-Based Modes, Packet-Based Modes & Systems, Receiving & Transmitting Digital Modes

Basics of Digital Modes: Where to Find Digital Activity

- Communications are digital modes if info is exchanged as individual characters encoded as digital bits ... Morse Code (CW), radioteletype, PSK31, FT8, D-STAR, DMR, slow-scan TV, etc.
- Digital modes restricted to CW/data segments of each HF band
  - Found near top of CW segment
  - Example: On 20 meters, most PSK signals are near 14.070 MHz. RTTY and other digital modes are found above that between 14.070 and 14.112 MHz. Also see Table 6.1.

Digital Modes Overview

- Data rates and bandwidths specified by FCC rules

- Digital codes not specified by the FCC *must be public*

- Radioteletype (RTTY) – originally used mechanical teleprinters but migrated to computer sound cards

- PSK31 – good weak signal mode using low transmitter power and very narrow bandwidth (computer sound card)

- PACTOR – stands for PACket Teletype Over Radio

- WINMOR – stands for WINdows Messaging Over Radio

- Packet Radio – common on the VHF and UHF bands (1200 & 9600 baud)

Table 6.1: Digital Signal Band Plan (HF Bands)

Band (meters)	Frequency Range (MHz)	Notes
160	1.800 – 1.810	FT8 is on 1.840 MHz
80	3.570 – 3.600	
60	5332, 5348, 5358.5, 5373, 5405 kHz	Channel center frequencies
40	7.070 – 7.125	RTTY DX calling frequency 7.040
30	10.130 – 10.150	
20	14.070 – 14.0995 and 14.1005 – 14.112	PSK31 calling frequency 14.070
17	18.100 – 18.110	
15	21.070 – 21.110	
12	24.920 – 24.930	
10	28.070 – 28.189	

Definitions

- Air link: the part of the comm system that involves radio transmission and reception of signals
- Bit: the fundamental unit of data; a 0 or 1 representing all or part of a binary number
- Bit rate: number of digital bits/second sent from one system to another
- Baud(s): number of symbols/second sent from one system to another
- Duty cycle: ratio of time that transmitter is on to total time plus off time
- Protocol: rules that control the method used to exchange data between systems
- Mode: combination of a protocol with a modulation method

Frequency Shift Keying (FSK)

VFO = variable frequency oscillator

- Individual bits of data encoded as tones

  – As data are transmitted, different tone frequencies are used

- The frequencies in a two-tone FSK signal are called *mark* and *space*

  – Space represents 0, mark represents 1

- In "direct" FSK, the frequency of the transmitter's VFO is controlled by a digital data signal from the computer

- Audio FSK (AFSK) – audio tones modulate an SSB or FM transmitter through the mic input

- Multiple FSK – more than 2 tones are used to create more codes

Phase Shift Keying (PSK)

- Most common type of phase shift is to invert one of the tone waveforms (shifting phase 180°)
- Rapid changes in phase can be heard from human ear as a raspy noise of buzz – the signature of PSK signals on the air received by a CW or SSB receivers (sort of like the sound on an old computer modem)

PRACTICE QUESTIONS

What segment of the 20-meter band is most often used for digital transmissions (avoiding the DX propagation beacons)?

A. 14.000 - 14.050 MHz

B. 14.070 - 14.112 MHz

C. 14.150 - 14.225 MHz

D. 14.275 - 14.350 MHz

What segment of the 80-meter band is most commonly used for digital transmissions?

A. 3570 — 3600 kHz

B. 3500 — 3525 kHz

C. 3700 — 3750 kHz

D. 3775 — 3825 kHz

In what segment of the 20-meter band are most PSK31 operations commonly found?

A. At the bottom of the slow-scan TV segment, near 14.230 MHz

B. At the top of the SSB phone segment, near 14.325 MHz

C. In the middle of the CW segment, near 14.100 MHz

D. Below the RTTY segment, near 14.070 MHz

How is an FSK signal generated?

A. By keying an FM transmitter with a sub-audible tone

B. By changing an oscillator's frequency directly with a digital control signal

C. By using a transceiver's computer data interface protocol to change frequencies

D. By reconfiguring the CW keying input to act as a tone generator

How are the two separate frequencies of a Frequency Shift Keyed (FSK) signal identified?

A. Dot and dash

B. On and off
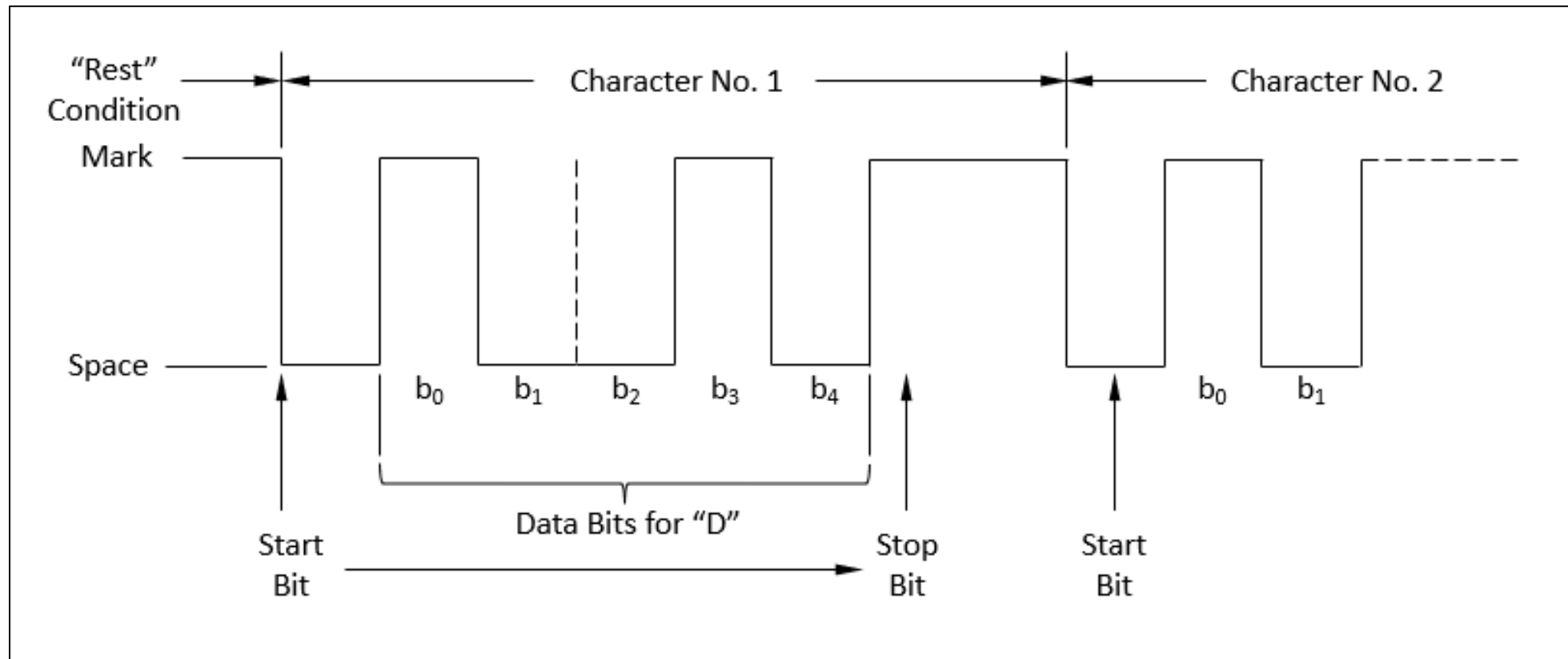
C. High and low

D. Mark and space

Character-Based Modes

- Simplest use of digital communications is a mode in which individual characters are entered by an operator, then transmitted to another station where they are read by another operator (CW, for example)

- Speeds are low, but convenient to use and require little additional equipment other than sound card or modem

- Sometimes referred to as *keyboard-to-keyboard* or *chat*

- Transmit a stream of characters without additional data

RTTY: Oldest form of ham radio digital communications

Fig 6.1: The Baudot timing sequence for the bit pattern that encodes the letter "D". The start bit is sent first. Start and stop bits are required to allow the receiving and transmitting systems to synchronize. Mark and space are represented as audio tones in the transmitted signal. Baudot is origin of term *baud*.

Radioteletype (RTTY)

- RTTY uses Baudot code which represents each text character as a sequence of 5 bits
  - 5 bits only allow for 32 different characters … not enough for entire English alphabet, numerals, and punctuation
  - 2 special codes (LTRS & FIGS) are use to switch between 2 character sets (doubling number of available characters)
- The difference between the mark and space tones (see Fig 6.1) is called the signal's shift
- You should always answer an RTTY station at same speed and shift it's using

PSK31 (Phase Key Shifting)

- Most popular PSK mode (also called 31 Baud)
- Uses a sound card to generate RTTY signals
- "31" is the symbol rate of the protocol (actually 31.25 baud)
- Designed for keyboard-to-keyboard communication (typing rates up to 50 wpm)
- QPSK31 (quadrature PSK31) sends TWO audio tones, so there are now four possible phase shift combinations

PSK31 (cont.)

- Since PSK has two tones, you have to select the right sideband (USB or LSB) to decode the data … *sideband sensitive*

- QPSK31 / PSK31 have about the same bandwidth (2.5 kHz)

- PSK uses a variable length character code called *Varicode* that assigns shorter codes to common characters and longer codes for uncommon characters (like Morse code)

  – Capital letters & punctuation take longer to send

  – If you're used to RTTY (no lower case), turn off CAPS LOCK!
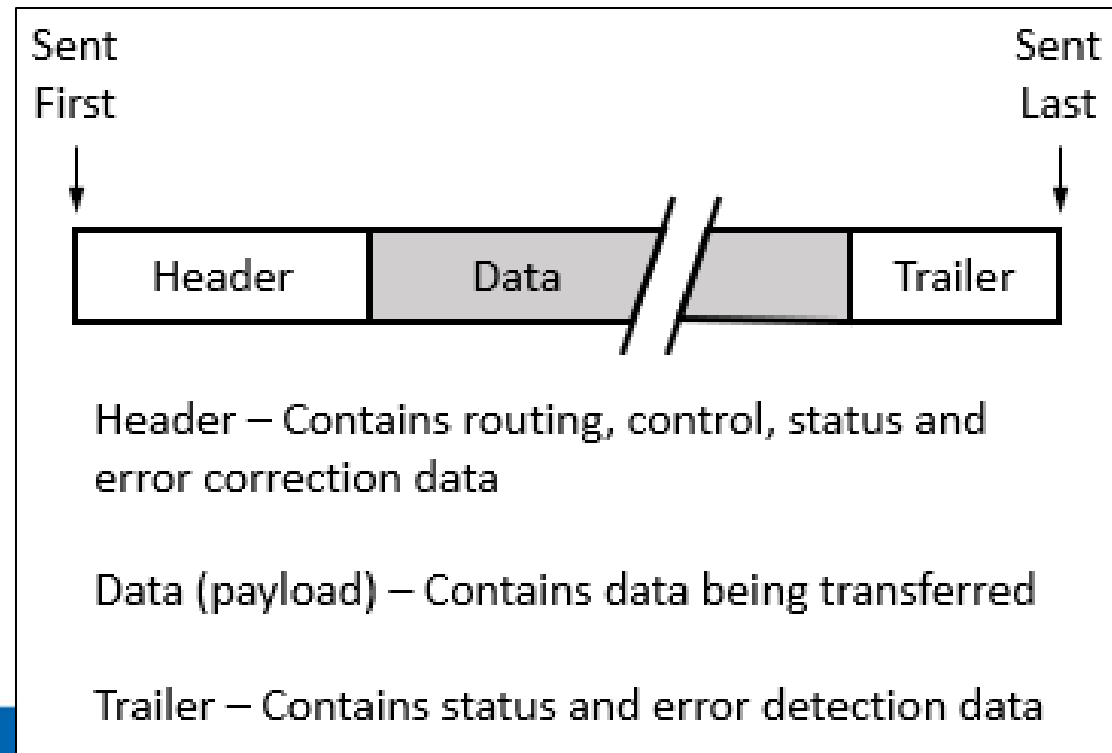
Packet-Based Modes & Systems

- Packet-based or structured modes are derived from early teletype-over-radio modes and computer-to-computer network protocols

- Hams have adapted these protocols, creating packet radio, PACTOR, WINMOR, and other communication systems

- Some packet modes (JT65 & FT8) require precisely-defined transmission periods … utility software is available to keep your computer synchronized to within 1 second of standard time

Packet Basics

- Packet refers to the transmission of data in structured groups (called *frames*)

Figure 6.2: Packet communication systems package data with control and routing information and add error detection information. Each package of header, data, and trailer is called a frame. Different packet protocols use different sets of information and methods of creating the frame.

Sent First

Sent Last

| Header | Data | | Trailer |

Header – Contains routing, control, status and error correction data

Data (payload) – Contains data being transferred

Trailer – Contains status and error detection data

Packet Basics (cont.) ... see Fig 6.2

- Header – Contains bit patterns that allow receiver to synch with the packet's structure, control, and routing information, and for some protocols, error detection/correction information.

- Data – Data to be exchanged between the systems. Usually ASCII characters. Usually compressed for efficiency.

- Trailer – Additional info used for error detection.

  - *Forward error correction* (FEC) goes beyond simply detecting errors. By including redundant encoded info with the data, it's possible for receiver to CORRECT certain types of data errors.

Automatic Repeat reQuest (ARQ) Systems

- If mismatch is detected, receiving system responds with *NAK* (not acknowledged) and protocol requests retransmission.

- Transmitting system will continue to send packet until received without errors or retransmission limit is exceeded.

- ARQ used in modes: PACTOR, packet radio, WINMOR, etc.

- ARQ protocols were designed for <u>wired</u> network connections, and the transmission can only be received from one receiving station during the connection. This means you can't break in to an ongoing contact between two stations using an ARQ mode.

ARQ (cont.)

- So that a station can advertise its presence, ARQ protocols provide a broadcast mode to transmit without another station having established a contact

- A *MON* mode is also provided so that other stations can listen to the conversation without error correction

- Using the MON (monitoring) mode allows you to determine if a frequency is occupied by 2 stations having an ARQ mode contact

Packet Radio

- Used almost exclusively on VHF and UF bands
- Based on computer network protocol X.25
  - One of the oldest packet-switching communication protocols
  - X.25 protocol popular during the late 1970s and 1980s in the computer industry
- Packets are exchanged using VHF FM voice transceivers at 1200 or 9600 baud
- Does not work well with HF because data are easily disrupted by noise and fading (even at 300 baud allowed on HF)

PACTOR and WINMOR

- RTTY protocol was not designed to manage transmission errors
- Teletype Over Radio (TOR) systems were developed to address this (AMTOR, G-TOR, etc.)
- These original TOR protocols are reliable, but slow
- PACTOR (Packet-based TOR) and WINMOR (Windows TOR) addresses reliability AND speed ... and extends TOR capability
- PACTOR 1 uses FSK modulation; PACTOR 1 thru 4 use advanced PSK modulation (PACTOR 4 not yet legal for US amateurs)

WINLINK

- Enables transferring of email messages & digital files on HF bands
- Winlink isn't a *mode* … it's a communication system
- Uses the internet to connect its email servers with gateway and mailbox stations around the world on HF, VHF and UHF
  - Winlink stations do not connect directly with the internet, but provide an effective means for stations out of local internet connection range
  - Even without internet connectivity, *Winlink Express* can act as standalone mailbox stations or communicate directly with each other

FT8 & WSPR (WS = Weak Signal)

- Supported by the WSJT software suite (and JT65, MSK144, etc.)

  - https://physics.princeton.edu/pulsar/k1jt/

- Uses precisely-timed sequences of transmit/receive, 8-tone FSK modulation and error decoding/correction to enable successful decoding at very low signal-to-noise ratios (*SNR*)

- FT8 exchanges 75-bit messages … there is a limited amount of info that can be exchanged with this size limit (call signs, grid locators, signal reports)

- WSPR uses HF propagation paths at very low SNR … does not support 2-way QSOs

- Low power WSPR transmitters generate coded packets; stations that receive these report success on www.wsprnet.org

PRACTICE QUESTIONS

How can a PACTOR modem or controller be used to determine if the channel is in use by other PACTOR stations?

A. Unplug the data connector temporarily and see if the channel-busy indication is turned off

B. Put the modem or controller in a mode which allows monitoring communications without a connection

C. Transmit UI packets several times and wait to see if there is a response from another PACTOR station

D. Send the message, "Is this frequency in use?"

How do you join a contact between two stations using the PACTOR protocol?

A. Send broadcast packets containing your call sign while in MONITOR mode

B. Transmit a steady carrier until the PACTOR protocol times out and disconnects

C. Joining an existing contact is not possible, PACTOR connections are limited to two stations

D. Send a NAK response continuously so that the sending station must stand by

Which of the following is characteristic of the FT8 mode of the WSJT-X family?

A. It is a keyboard-to-keyboard chat mode

B. Each transmission takes exactly 60 seconds

C. It is limited to use on VHF

D. Typical exchanges are limited to call signs, grid locators, and signal reports

Which communication system sometimes uses the internet to transfer messages?

A. Winlink

B. RTTY

C. ARES

D. SKYWARN

Which of the following is a requirement when using the FT8 digital mode?

A. A special hardware modem

B. Computer time accurate within approximately 1 second

C. Receiver attenuator set to -12 dB

D. A vertically polarized antenna

What type of modulation is used by the FT8 digital mode?

A. 8-tone frequency shift keying

B. Vestigial sideband

C. Amplitude compressed AM

D. Direct sequence spread spectrum

Which of the following narrow-band digital modes can receive signals with very low signal-to-noise ratios?

A. MSK144

B. FT8

C. AMTOR

D. MFSK32

Which digital mode is used as a low-power beacon for assessing HF propagation?

A. WSPR

B. Olivia

C. PSK31

D. SSB-SC

What part of a packet radio frame contains the routing and handling information?

A. Directory

B. Preamble

C. Header

D. Footer

In the PACTOR protocol, what is meant by a NAK response to a transmitted packet?

A. The receiver is requesting the packet be retransmitted

B. The receiver is reporting the packet was received without error

C. The receiver is busy decoding the packet

D. The entire file has been received correctly

How does the receiving station respond to an ARQ data mode packet containing errors?

A. It terminates the contact

B. It requests the packet be retransmitted

C. It sends the packet back to the transmitting station

D. It requests a change in transmitting protocol

How does forward error correction (FEC) allow the receiver to correct errors in received data packets?

A. By controlling transmitter output power for optimum signal strength

B. By using the Varicode character set

C. By transmitting redundant information with the data

D. By using a parity bit with each character

Bandwidth of Digital Modes

- Like other amateur signals, digital mode bandwidth is defined by the FCC … §97.3(a)(8)
  - Bandwidth of signal changes with the symbol rate
  - As symbol rate increases, so does the bandwidth needed for the signal needed to transmit them … see Table 6.2 for details
- Most common method of generating / transmitting these modes is to connect to audio output from computer sound card to microphone of an SSB transceiver

Table 6.2
Bandwidth Comparison of Digital Modes

Bandwidths are approximate for the highest commonly used symbol rate and are not specifications

MODE	BANDWIDTH (Hz)
PSK31	50
FT8	50
RTTY	200
MFSK16	300
JT65	350
DominoEX	524
Olivia	1000
WINMOR	1600
MT63	2000
PACTOR-III	2300
PACTOR-4	2300

Be careful when operating near the edge of a data signal band. Using LSB for an FSK mode, the sidebands will be *below* the displayed carrier frequency of you radio.

Transmitter Duty Cycle

- Most amateur transmitters are not designed to operate at full power for an extended period of time
    - CW only operates at full power 40-50% of the time
    - SSB only operates at full power 20-25% of the time
    - *FM modes operate at full power the entire transmission time!*
- Extended transmissions may be enough to exceed a transmitter's average power rating
    - Reduce transmit power to prevent overheating

Digital Mode Signal Quality

- Digital modes are just as capable of generating interference as phone and CW

- For digital modes that use an SSB transmitter to transmit *audio frequency shift keying* (AFSK), the most common problem is supplying too much or too little audio from the computer to the radio's microphone input

- On waterfall displays, the vertical lines represent spurious emissions ... cause by overmodulation of the transmitter

ALC and Digital Modes (automatic level control)

- Used for preventing excessive drive to amplifier inputs
- ALC circuits reduce gain when power levels get too high
  - However, it comes at a price. The signal compression can result in distortion.
- For digital signals, distortion caused by ALC makes the signal harder to decode and creates spurious emissions, similar to overmodulation
- So, when in digital mode, disable your ALC!

PRACTICE QUESTIONS

Which mode is normally used when sending RTTY signals via AFSK with an SSB transmitter?

A. USB

B. DSB

C. CW

D. LSB

What is the standard sideband used to generate a JT65, JT9, or FT8 digital signal when using AFSK in any amateur band?

A. LSB

B. USB

C. DSB

D. SSB

What could be wrong if you cannot decode an RTTY or other FSK signal even though it is apparently tuned in properly?

A. The mark and space frequencies may be reversed

B. You may have selected the wrong baud rate

C. You may be listening on the wrong sideband

D. All these choices are correct

What is likely to happen if a transceiver's ALC system is not set properly when transmitting AFSK signals with the radio using single sideband mode?

A. ALC will invert the modulation of the AFSK mode

B. Improper action of ALC distorts the signal and can cause spurious emissions

C. When using digital modes, too much ALC activity can cause the transmitter to overheat

D. All these choices are correct

What is the approximate bandwidth of a PACTOR-III signal at maximum data rate?

A. 31.5 Hz

B. 500 Hz

C. 1800 Hz

D. 2300 Hz

Why is it important to know the duty cycle of the mode you are using when transmitting?

A. To aid in tuning your transmitter

B. Some modes have high duty cycles that could exceed the transmitter's average power rating

C. To allow time for the other station to break in during a transmission

D. The attenuator will have to be adjusted accordingly

What is the relationship between transmitted symbol rate and bandwidth?

A.   Symbol rate and bandwidth are not related

B.   Higher symbol rates require wider bandwidth

C.   Lower symbol rates require wider bandwidth

D.   Bandwidth is always half the symbol rate

What is indicated on a waterfall display by one or more vertical lines on either side of a digital signal?

A. Long path propagation

B. Backscatter propagation

C. Insufficient modulation

D. Overmodulation

Digital Operating Procedures
Initiating & Terminating Digital Contacts

- Sample CQ from a digital mode (RTTY, PSK31, etc.) …
  - CQ CQ CQ DE KØILP KØILP KØILP K

- Sample/typical response …
  - KØILP KØILP KØILP DE KX4IU KX4IU KX4IU K

- Modes such as PACTOR and WINMOR … the software or modem will have a specific disconnect message … **BYE** or **D**

Connecting to Gateway and Mailbox Stations

- The exact connection method depends upon equipment and mode, but begin by sending a **CONNECT** message

- If signal is received without errors, a *training sequence* of packets may be exchanged to determine protocol to use

- Because these stations respond without a human control operator present, FCC classifies them as automatically-controlled digital stations … restricted to certain band segments (Table 6.3)

- Stations under FCC rules must operate under local or remote control (with control operator in charge of all transmissions)
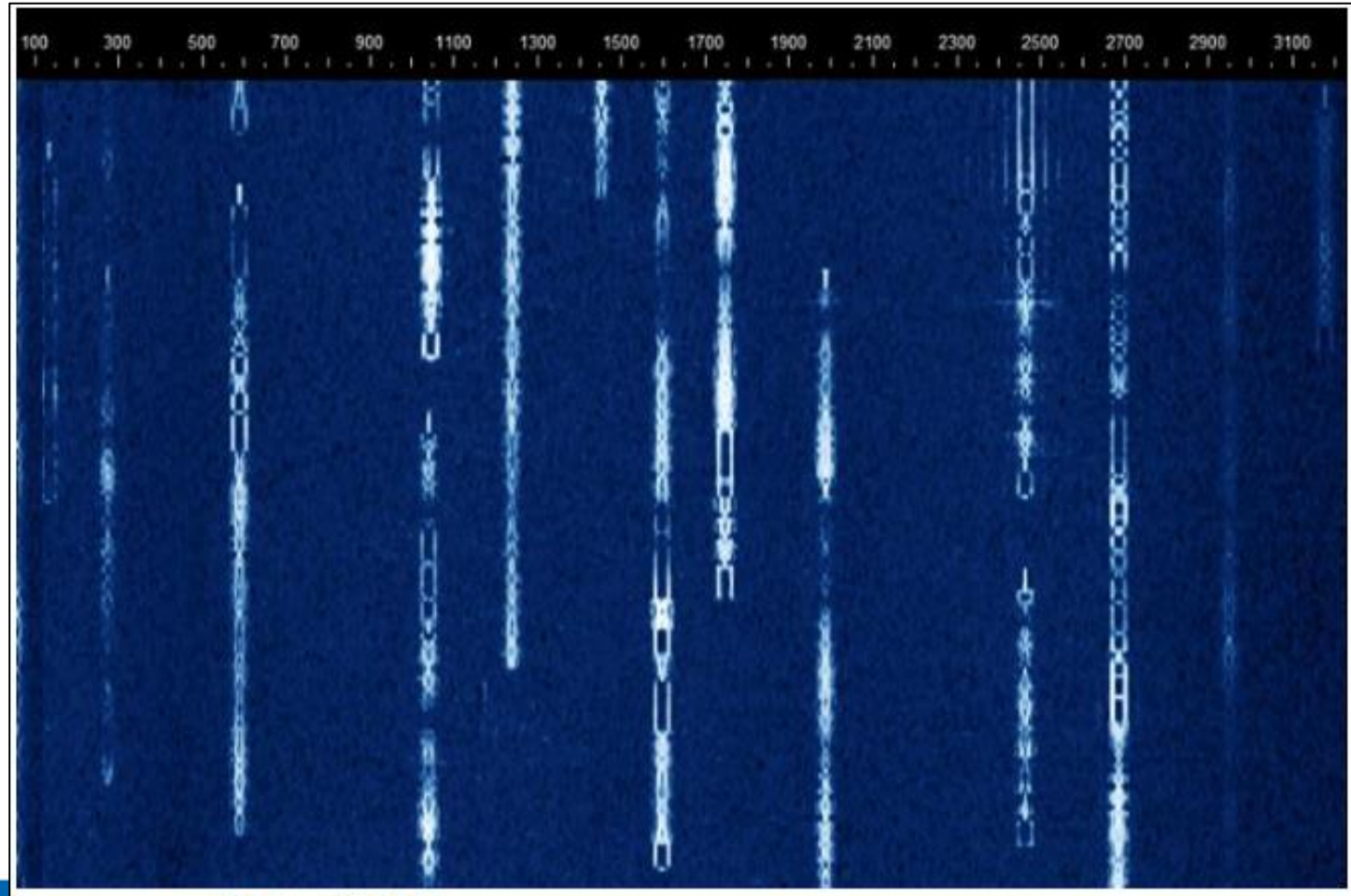
Table 6.3
Automatic Control Band Segments for RTTY & Data

BAND (Meters)	FREQUENCY RANGE (MHz)
160	Not permitted
80	3.585 – 3.600
60	Not permitted
40	7.100 – 7.105
30	10.140 – 10.150
20	14.095 – 14.0995 & 14.1005 – 14.112
17	18.105 – 18.110
15	21.090 – 21.100
12	24.925 – 24.930
10	28.120 – 28.189
6	50.1 – 54.0

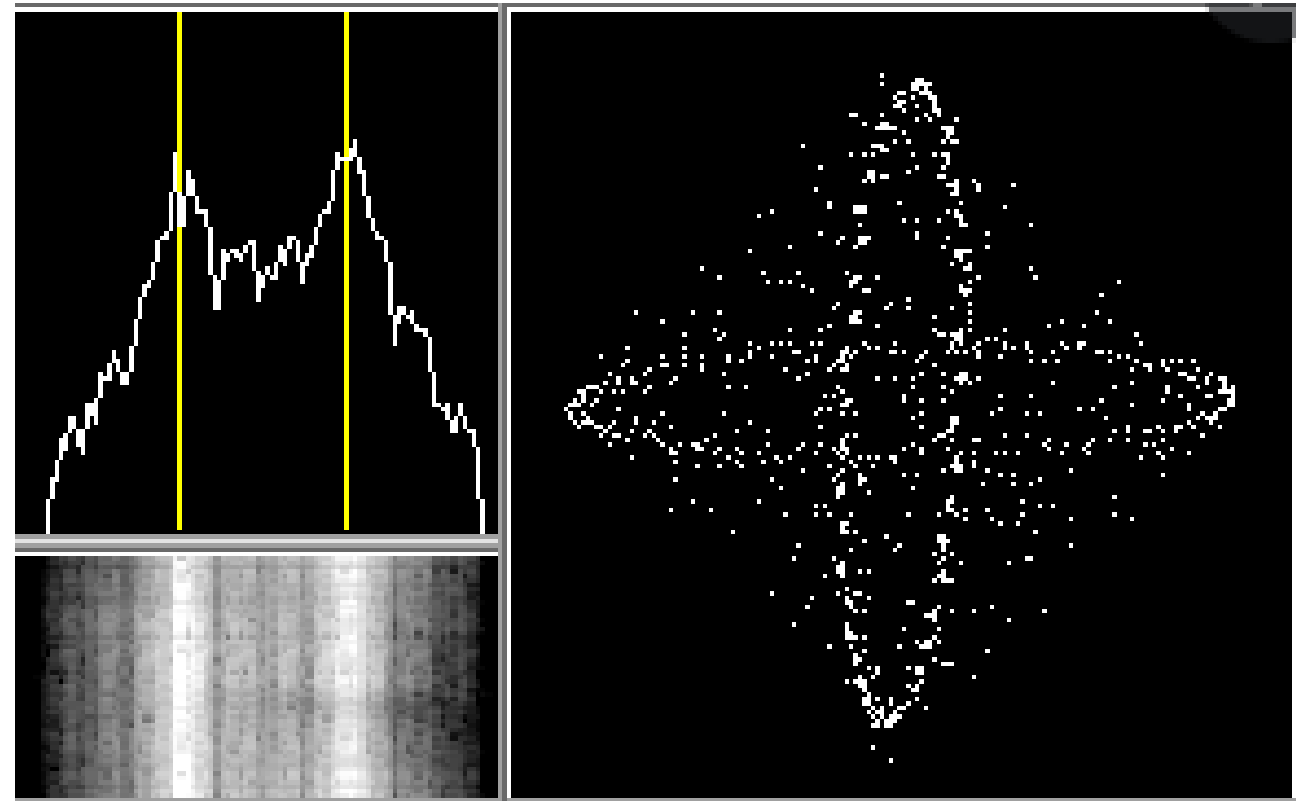# During the Contact (*Operating Displays*) – See Fig 6.3 in text

- A waterfall display displays the presence of signals as a series of lines representing a scan across the frequency range.

- Signal strength is represented as brightness, intensity, or color.

- As new lines are captured, older lines are moved down or to one side, giving the impression of a waterfall.

Waterfall Display – tuning aids for RTTY signals

- The left side is a spectrum of the filtered received audio. The vertical lines are at the mark and space frequencies, and help tune in the signal so the peaks are on the lines (indicating the right tone frequencies.

- The crossed-ellipses on the right are used for fine tuning … ellipses at right angles and the same size indicate correct tuning.

Third-Party Traffic in Digital Modes

- All FCC rules about 3rd party messages apply to digital transmissions
  - Includes info in email, digital images, or web pages transmitted via amateur radio
- Commercial messages may not be transmitted via amateur radio
  - Includes advertisements and info pertaining to your business

Interfering Signals in Digital Modes

- "Hidden transmitter" problems occur in all modes
  - If you're in a skip zone for one of the stations involved in a contact or that is trying to connect to the same digital station, you won't hear the hidden transmitter, but the receiving station might hear both of you (it's hidden to YOU)
  - The resulting interference is unintentional but prevents both you and the hidden transmitter from completing a contact
- Packet modes (PACTOR, WINMOR) don't recover from reception difficulties as well as keyboard-to-keyboard modes (RTTY, PSK31), resulting in … failure to connect, frequent retries, transmission delays, timeouts, and dropped connections

PRACTICE QUESTIONS

Which of the following is a way to establish contact with a digital messaging system gateway station?

A. Send an email to the system control operator

B. Send QRL in Morse code

C. Respond when the station broadcasts its SSID

D. Transmit a connect message on the station's published frequency

Under what circumstances are messages that are sent via digital modes exempt from Part 97 third-party rules that apply to other modes of communication?

A. Under no circumstances

B. When messages are encrypted

C. When messages are not encrypted

D. When under automatic control

What symptoms may result from other signals interfering with a PACTOR or WINMOR transmission?

A. Frequent retries or timeouts

B. Long pauses in message transmission

C. Failure to establish a connection between stations

D. All these choices are correct

Which of the following is a way to establish contact with a digital messaging system gateway station?

A. Send an email to the system control operator

B. Send QRL in Morse code

C. Respond when the station broadcasts its SSID

D. Transmit a connect message on the station's published frequency

What action results from a failure to exchange information due to excessive transmission attempts when using PACTOR or WINMOR?

A. The checksum overflows

B. The connection is dropped

C. Packets will be routed incorrectly

D. Encoding reverts to the default character set

Which of the following describes a waterfall display?

A.   Frequency is horizontal, signal strength is vertical, time is intensity

B.   Frequency is vertical, signal strength is intensity, time is horizontal

C.   Frequency is horizontal, signal strength is intensity, time is vertical

D.   D. Frequency is vertical, signal strength is horizontal, time is intensity

END OF MODULE 6

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Feel free to contact me if you find errors or have

suggestions for improvement.