

N9LYA TECHNICAL GUIDES

Amateur Radio Digital Modes

Packet, PACTOR, ARDOP, VARA

Jerome M. Kutche

N9LYA

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About This Book

There is no shortage of amateur radio digital mode information. There is a shortage of it in one place, organized, current, and written by someone who runs the equipment daily rather than someone summarizing a manual.

What exists tends to be one of three things: a wiki page listing modes with a sentence each, a manufacturer's manual for one product, or a forum thread from 2009 describing software that no longer exists. Meanwhile the field has moved considerably — sound card modems displaced hardware TNCs for most purposes, HF data rates went from hundreds of bits per second to thousands, an entire regulatory framework changed, and a genuinely capable open-source alternative to the proprietary modems finally appeared.

This book covers all of it. Packet radio from the TAPR era through today's software modems. Robust Packet. PACTOR I through IV. ARDOP. VARA HF and VARA FM. The open modems that arrived recently. APRS, Winlink, keyboard modes, and the networking layer that ties them together.

The Perspective

I've been licensed since 1991. I run LinBPQ nodes carrying real traffic, operate a store-and-forward system that has been running long enough to teach me most of the ways these things break, and serve as Indiana's 44Net/AMPRNet coordinator — administering the state's allocation within the amateur radio IPv4 space, which is a genuine routed network that most operators don't know exists.

That shapes what's emphasized here.

Networking gets serious treatment. Most digital mode material covers how to make a connection. Much less covers what happens when you want twenty stations to reach each other through four hops, or what a node actually does, or why your forwarding stopped working. Part V is written for people building infrastructure rather than making contacts.

LinBPQ gets its own chapter because it's the software underneath a large share of the packet infrastructure in use, and its documentation assumes you already understand it.

The old modes are covered properly, not as historical curiosities. 1200 baud AFSK is thirty-five years old and still carries traffic every day, for reasons that are entirely rational.

Troubleshooting gets a methodology. Diagnosing a link that worked yesterday is the actual job.

And there's honest assessment throughout. Some of these modes are better than others. Some are proprietary in ways that matter. Some are marketed beyond their capability. I say which.

A Note on Currency

Digital modes move faster than books do. Version numbers, software availability, and the state of development will change.

The physics doesn't move. Modulation, bandwidth, error correction, propagation, and the interfacing problem are the same as they were and will be. Parts I and II should age slowly. Parts III and VI reference specific software and will need checking.

Where I cite a version or a capability, treat it as a snapshot from 2026 and verify before relying on it.

Who This Is For

New digital operators — start at Chapter 1 and read Part I completely. It's the part most guides skip and the part that makes everything else make sense.

Packet operators wanting the modern HF modes, or **HF operators** wanting to understand packet networking.

Anyone building infrastructure — nodes, gateways, BBS systems, or emergency communications capability. Parts II, V, and VI.

Emergency communications volunteers who need to understand what these modes actually deliver under real conditions rather than what the brochure says.

Technically curious operators who want to know how it works, not just which buttons to press.

How to Use It

Each chapter ends with an **On-Air Check** — things to verify, measure, or try. Do them. Digital modes reward hands-on verification more than almost anything in the hobby, because the failure modes are rarely what you predicted and the diagnostic information is usually available if you know where to look.

About the Author

Jerome M. Kutche, N9LYA, was first licensed in 1991 and upgraded to General class in 2003. His interest in radio was sparked in the early 1970s by a mentor named Frank Kime, and his understanding of interference and grounding owes a great deal to the late Mike Baugh, W8AKF.

He serves as Indiana's 44Net/AMPRNet coordinator, is trustee for two amateur radio clubs, and moderates an active group for Raspberry Pi-based amateur radio work. He operates LinBPQ nodes and a store-and-forward system carrying live traffic.

From 1990 to 1996 he built RF test and measurement equipment for the telecommunications and cable television industries. He then spent over three decades in industrial electrical and controls work, holding NFPA 70E and thirty-nine other professional certifications.

He has worked contacts through the Space Shuttle SAREX program, the Mir space station, and the International Space Station, using a two-watt handheld.

Part I — Foundations

Chapter 1: Why Digital Modes

What sending data over radio actually buys you, and what it costs.

The Case

Digital modes exist because some things are better done as data than as voice.

Accuracy. A message passed by voice through three relays acquires errors. A message passed as data either arrives intact or is retransmitted until it does. **For anything containing names, addresses, medication dosages, or serial numbers, this difference is the whole point.**

Unattended operation. A digital station receives messages while nobody is present. Store-and-forward means the sender and receiver never need to be on the air simultaneously — a property no voice mode has.

Efficiency. A formal message that takes four minutes to pass by voice, with repeats and fills, transfers in seconds.

Weak signal performance. Several modes decode reliably at signal-to-noise ratios where voice is unintelligible. Not all digital modes — the fast ones need good signals — and the robust ones work where nothing else does.

Attachments. Forms, images, spreadsheets, position data. Things voice cannot carry at all.

Automation. Position reporting, telemetry, weather data, and status monitoring, without an operator.

And the cost: complexity. A digital station has more to configure, more to go wrong, and more to understand. **A voice contact requires a radio and a microphone. A digital contact requires a radio, a computer, an interface, correct audio levels, correct software configuration, and both ends agreeing on a protocol.**

The Tradeoff That Governs Everything

You cannot have speed, robustness, and narrow bandwidth simultaneously. Pick two.

Fast modes need good signal-to-noise ratio and usually more bandwidth.

Robust modes work in poor conditions by sending less information more redundantly — which means slow.

Narrow modes fit more stations in a band segment and are limited in how much data they can move.

Every mode in this book is a specific point on that surface, and understanding where each sits is what lets you choose correctly. A mode that's wrong for the conditions performs worse than one you'd think was inferior.

The corollary that surprises people: the fastest mode is frequently the wrong choice. On a marginal path, a mode negotiating down to a slow speed and completing beats a fast mode that fails and retries forever.

The Landscape

Roughly organized:

Packet radio and its descendants — connection-oriented data networking. AX.25 on VHF and UHF, at 1200 or 9600 baud, still the backbone of terrestrial digital networking. Chapter 6 onward.

HF ARQ modes — moving data reliably over a hostile channel. PACTOR, ARDOP, VARA, Robust Packet, and the newer open modems. Part III.

Keyboard and weak-signal modes — PSK31, RTTY, Olivia, FT8, JS8Call. Conversation and contacts rather than file transfer. Chapter 21.

Position and telemetry — APRS. Chapter 20.

Digital voice — DMR, D-STAR, System Fusion, M17. Related and mostly outside this book's scope, though the networking concepts overlap.

What You Need to Start

A radio. Almost any FM transceiver for VHF packet; an SSB HF transceiver for HF modes.

A computer. A Raspberry Pi is entirely adequate for most of this, and runs a node or gateway continuously on a few watts.

An interface. Chapter 4. Getting audio between radio and computer, plus a way to key the transmitter.

Software. Chapters 8 and 11.

And an understanding of what you're trying to accomplish, which determines everything else. Making occasional contacts, building infrastructure, and supporting emergency communications lead to different stations.

On Old Technology

Some of what's in this book is decades old and still in daily use. That is not inertia.

1200 baud AFSK packet is slow, inefficient by modern standards, and it works with any FM radio ever made, through the microphone jack, with a five-dollar interface, over a path that barely supports voice. **It has an enormous installed base and near-universal interoperability.**

Newer is not automatically better. A mode that nobody else in your area runs is a mode you can't use. Chapter 30 returns to this.

On-Air Check

1. Identify what digital activity exists within your reach — packet nodes, APRS digipeaters, Winlink gateways, HF activity.
2. Determine what your existing radios can support.
3. Decide what you actually want to do. Write it down.

Chapter 2: Getting Data Onto Radio

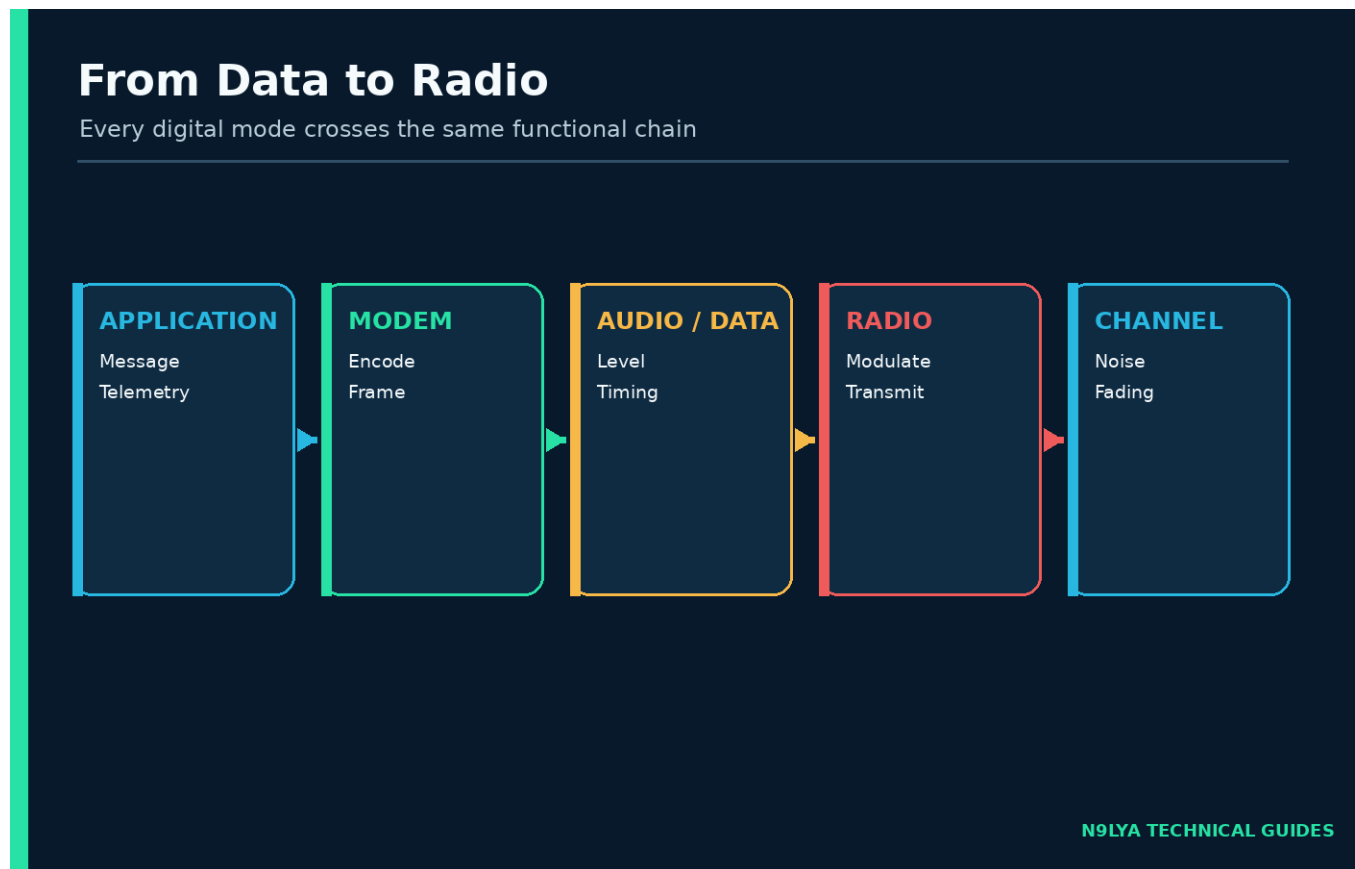


Figure 1: The data-to-radio functional chain

The mechanics, without the mathematics. Understanding this makes every mode comparison meaningful.

Symbols and Bits

A modem converts bits into something transmittable and back.

The transmitted thing is a **symbol** — a defined state of the carrier lasting a defined time. The receiver identifies which symbol was sent and recovers the bits it represents.

Symbol rate (baud) is symbols per second. **Bit rate** is bits per second. **They are not the same**, and conflating them is the most common confusion in this subject.

If each symbol carries one bit, they're equal. If each symbol carries four bits, the bit rate is four times the symbol rate at the same bandwidth.

This is how modern modes achieve high data rates in narrow bandwidth — not by signaling faster, but by packing more bits into each symbol.

The cost: more bits per symbol means the receiver must distinguish more states, which requires a better signal-to-noise ratio. **This is the fundamental reason fast modes need good conditions.**

Modulation

How the carrier is varied to convey symbols.

FSK (Frequency Shift Keying) — the carrier shifts between frequencies. Simple, robust, tolerant of amplitude variation. RTTY, 9600 baud packet, PACTOR I.

AFSK (Audio Frequency Shift Keying) — audio tones shifted, fed into an SSB or FM transmitter. **The distinction matters practically:** AFSK goes through the audio path, so any radio with a microphone jack works. Direct FSK requires access to the modulator.

PSK (Phase Shift Keying) — the carrier's phase shifts. More efficient than FSK for a given bandwidth. BPSK (two phases, one bit per symbol), QPSK (four phases, two bits), 8PSK, and onward.

QAM (Quadrature Amplitude Modulation) — both amplitude and phase vary, packing many bits per symbol. Used in the highest-rate modes and requiring the best signal quality.

OFDM (Orthogonal Frequency Division Multiplexing) — **the technique behind most modern high-performance HF modes.**

Rather than one fast carrier, OFDM uses many slow subcarriers in parallel across the available bandwidth. **The advantage is decisive on HF:** each subcarrier is narrow enough that multipath — the same signal arriving via several paths at slightly different times — affects it far less. A single fast carrier smears; many slow ones don't.

This is why VARA, Robust Packet, FreeDATA, and Mercury all use OFDM, and why they dramatically outperform earlier single-carrier approaches on disturbed paths.

Bandwidth

Bandwidth is the spectrum the signal occupies, and it's the resource everyone shares.

Roughly, **more bandwidth permits more data,** all else equal. A 2400 Hz signal can carry far more than a 500 Hz one.

But the relationship isn't free. Wider bandwidth admits more noise, so a wide signal needs more power for the same signal-to-noise ratio per unit of information.

Practical bandwidths:

Type	Typical bandwidth
CW	~100 Hz
PSK31	~60 Hz
RTTY	~300 Hz
300 baud HF packet	~500 Hz
Robust Packet	~500 Hz
PACTOR I / II	500 Hz
ARDOP	200 / 500 / 1000 / 2000 Hz
PACTOR III	~2200 Hz
VARA HF	~500 Hz narrow, ~2400 Hz wide
PACTOR IV	~2400 Hz
1200 baud AFSK	~15 kHz (in an FM channel)
9600 baud FSK	~20 kHz (in an FM channel)

Note the last two are different in kind — they occupy an FM channel, and the FM channel's bandwidth is what matters, not the baseband data.

Error Handling

The radio channel corrupts data. Every practical mode addresses this, in one of two ways or both.

FEC (Forward Error Correction) — send redundant information so the receiver can correct errors without asking for a repeat.

Advantages: works one-way, no return path needed, no delay for retransmission. **Cost:** the redundancy consumes capacity even when conditions are perfect.

Used by: broadcast-style modes, APRS beacons in some implementations, FT8, and as a layer inside most ARQ modes.

ARQ (Automatic Repeat reQuest) — the receiver checks each block and requests retransmission of anything corrupt.

Advantages: guaranteed delivery, and no capacity wasted on redundancy when conditions are good. **Cost:** requires a two-way link, adds latency, and on a bad path can retry indefinitely.

Used by: AX.25 connected mode, PACTOR, ARDOP, VARA — essentially every mode that transfers files.

Hybrid — FEC inside ARQ. Most modern modes do this: enough FEC to correct typical errors, with ARQ as backstop. **The best of both**, and it's why modern ARQ modes complete transfers on paths where earlier ones stalled.

Memory ARQ — a refinement worth knowing. Rather than discarding a corrupt block, the receiver combines successive corrupt copies, since the errors fall in different places each time. **PACTOR introduced this to amateur radio** and it substantially improves throughput on marginal paths.

Adaptive Rate

Modern HF modes measure the channel and change speed continuously.

Good conditions: a high-order modulation with many bits per symbol, minimal redundancy, high throughput.

Poor conditions: fall back to a robust modulation, more redundancy, low throughput but reliable.

The negotiation happens automatically, per block, and it's why a mode's headline speed is a maximum rather than an expectation. **VARA's advertised thousands of bits per second is what you get on an excellent path** — a marginal path might deliver a fraction of it and still complete, which is the important property.

Compression

Most file-transfer modes compress before transmitting. **Text compresses substantially**; already-compressed data (JPEG, ZIP, PDF) does not.

This is why “user data rate” and “raw data rate” differ, and why sending a compressed attachment through a mode that compresses gains nothing. **Send text as text.**

On-Air Check

1. For a mode you use, find its symbol rate, bits per symbol, and bandwidth.
2. Listen to several digital modes on HF and learn to identify them by sound.
3. Watch a transfer's negotiated speed change as conditions vary.
4. Send the same file as plain text and as a ZIP. Compare transfer times.

Chapter 3: The Channel

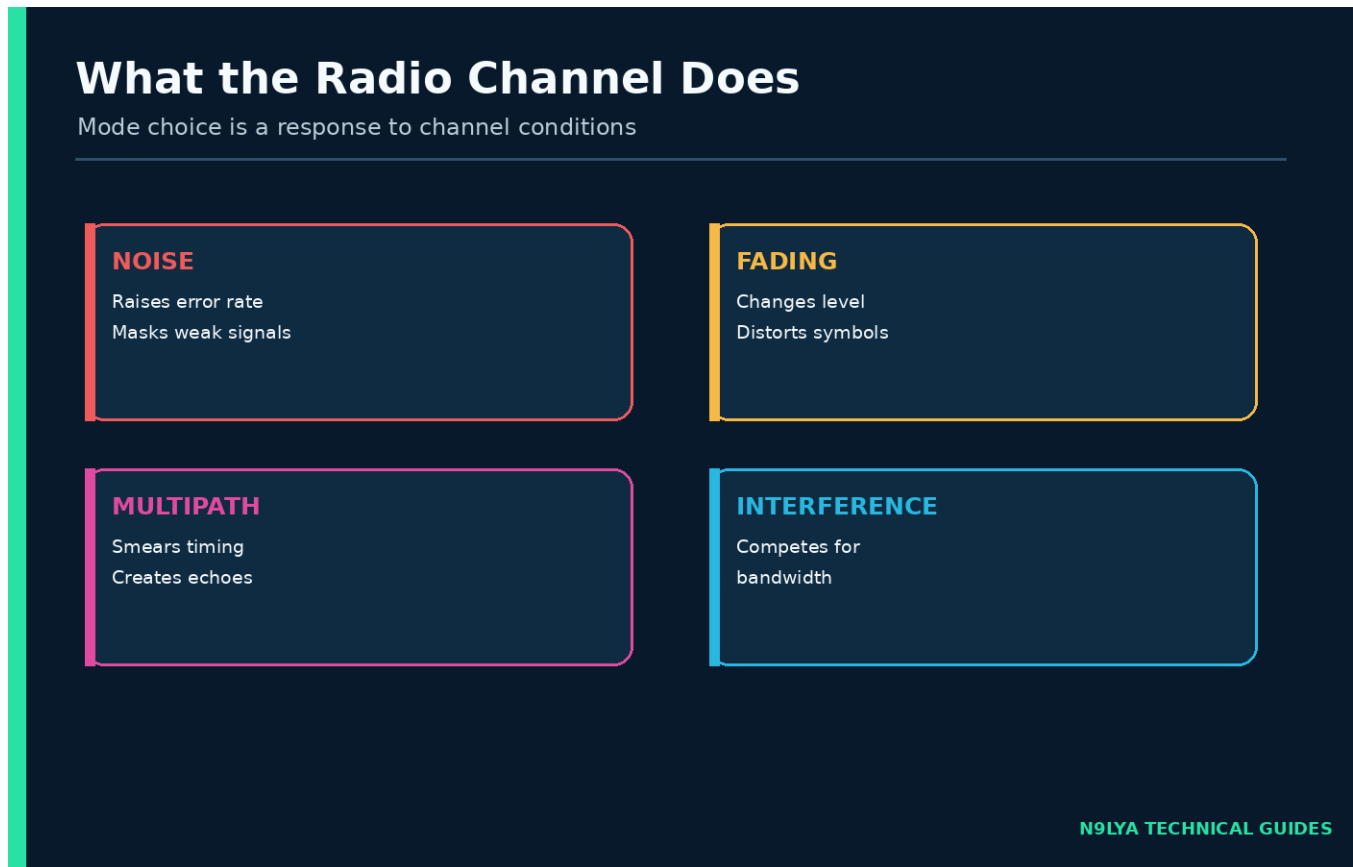


Figure 2: Common radio-channel impairments

What radio does to your data, and why HF and VHF need entirely different approaches.

VHF and UHF

Line of sight, mostly. Signals travel to the radio horizon, somewhat beyond due to atmospheric refraction, and are blocked by terrain and structures.

The channel is comparatively benign:

- Signal strength is stable over minutes and hours
- Multipath exists and is usually mild
- Noise is dominated by receiver noise and local interference
- Either you have a path or you don't

Which is why VHF packet uses simple modulation without heavy error correction. The channel is either good enough or it isn't, and adaptive rate buys little.

What does affect VHF digital:

Mobile flutter — a moving station's signal varies rapidly as the multipath environment changes. This is why mobile packet has higher error rates than fixed.

Picket fencing — rapid amplitude variation from reflections. It destroys 9600 baud far more than 1200.

Deviation and audio response — Chapter 9. The radio's audio processing matters enormously at higher speeds.

Local noise — switching supplies, LED lighting, solar inverters, and everything else in Chapter 27.

HF

A fundamentally hostile channel, and everything in Part III exists to cope with it.

Ionospheric propagation returns signals over long distances, and the ionosphere is not a mirror. It's a moving, layered, variable medium.

What it does to data:

Multipath — the same signal arrives by several paths with different delays, typically differing by a few milliseconds. **Symbols overlap and smear into each other.**

This is the dominant impairment, and it directly limits symbol rate: if symbols are shorter than the delay spread, they interfere with their neighbors. **This is precisely the problem OFDM solves** by using many slow subcarriers, each long enough that a few milliseconds of spread doesn't matter.

Fading — signal strength varies over seconds to minutes. **Selective fading** affects some frequencies within your signal and not others, which is why a wide signal can have part of its bandwidth wiped out while the rest is fine. OFDM handles this too, since only some subcarriers are affected and error correction recovers them.

Doppler shift and spread — the reflecting layer moves, shifting and smearing frequency. Significant on paths through the auroral zone.

Noise — atmospheric noise dominates on lower frequencies, especially in summer. Man-made noise dominates in most locations now.

Interference — the bands are shared, and you will be QRMed.

Propagation windows — a path exists only when the ionosphere supports it, which varies by frequency, time of day, season, and solar activity.

What This Means Practically

HF data requires modes designed for the channel. A mode that works fine on a wire fails on HF.

Speed is conditions-dependent, always. Any HF mode's throughput on a given day is what the path allows.

Choose the band for the path and time. A daytime regional path wants 40 or 60 meters; a nighttime long path wants 40 or 80; a long daytime path wants 20 or higher. **Trying to force a link on the wrong band wastes time no mode can recover.**

Robustness beats speed on marginal paths. Chapter 1's tradeoff.

And propagation prediction tools are worth using. Knowing whether the path is open before you spend twenty minutes retrying is genuinely valuable.

Signal Quality Metrics

What the software tells you, and what it means:

SNR (signal to noise ratio) in dB. **The single most useful number.** Different modes reference it to different bandwidths, so values aren't directly comparable between modes.

Constellation display — where received symbols land relative to their ideal positions. Tight clusters mean a clean signal; smeared clusters mean trouble. **The shape tells you the impairment** — rotation suggests frequency offset, radial smear suggests noise, circular smear suggests phase noise or Doppler.

Waterfall — spectrum against time. **Learn to read it.** You'll see your signal's shape, interfering signals, and the characteristic appearance of each mode.

Error and retry counts — rising retries mean the path is degrading. Chapter 29.

On-Air Check

1. Watch a waterfall on 40 meters across a full day. Note how the band changes.
2. Observe an HF ARQ transfer's SNR and negotiated speed together.
3. Compare the same path on two bands at the same time.
4. Look at a constellation display on a good signal and a marginal one.

Chapter 4: Interfacing Radio and Computer

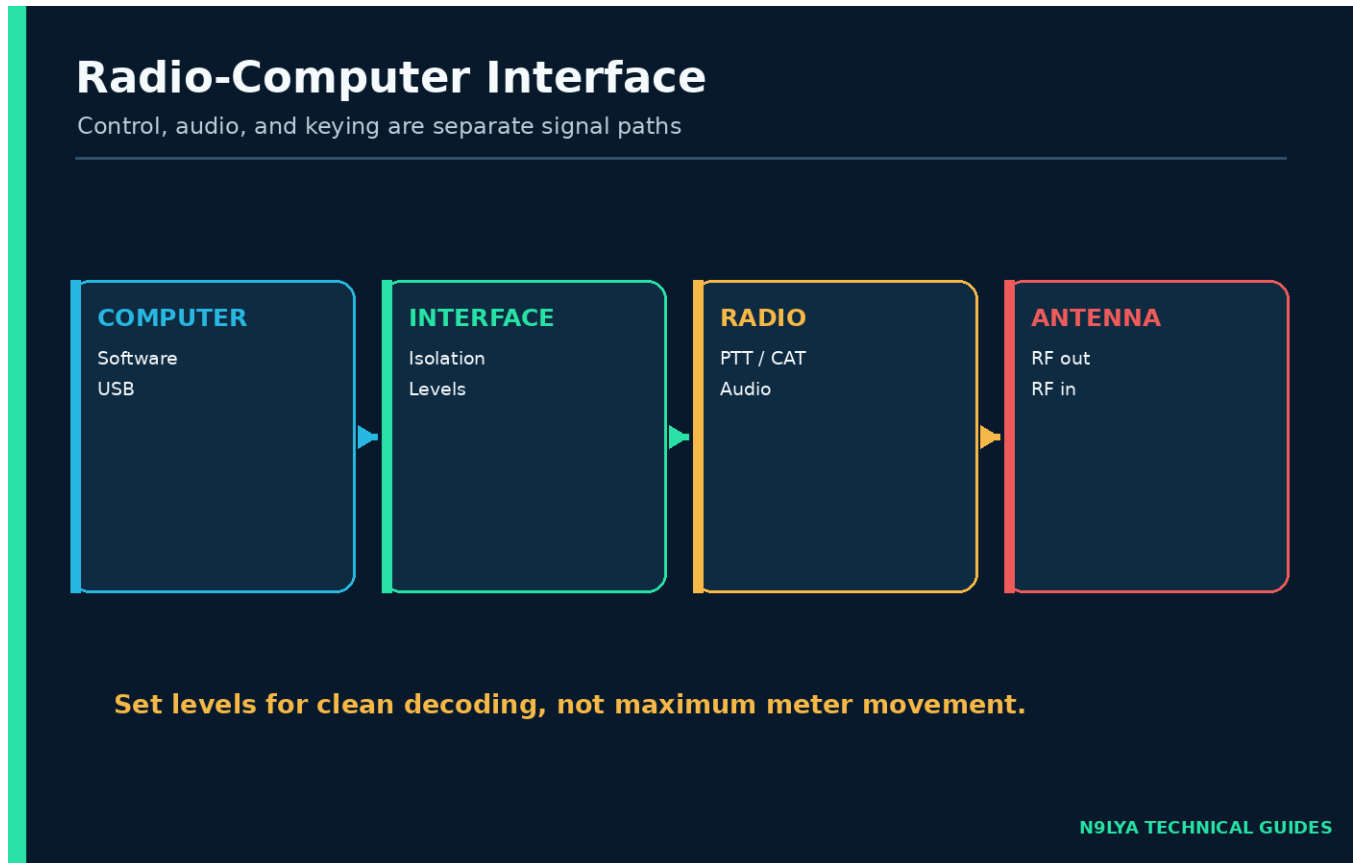


Figure 3: Radio-computer interface signal paths

Three connections: audio in, audio out, and transmit control. Getting them right is most of what separates a working digital station from a frustrating one.

The Three Connections

Receive audio — from the radio to the computer's input.

Transmit audio — from the computer's output to the radio.

PTT (push to talk) — something must key the transmitter.

Everything else is refinement.

Interface Types

Built-in USB audio and CAT — many recent radios expose a sound device and one or more serial interfaces over USB. This reduces cabling and often avoids analog ground-loop problems, but transmit and receive audio levels still require adjustment, USB isolation varies by radio, and operating-system

device assignments can change. Follow the radio manual rather than assuming the interface is automatically correct.

Commercial interface boxes — a sound device, PTT, and usually isolation, in one unit. Well-supported, several standard products, and the right answer for older radios.

Homebrew — audio transformers for isolation, a resistive divider to drop line-level audio to microphone level, and an optocoupler or transistor for PTT.

Absolutely workable, and the two things that must be right are **isolation** — transformers or optocouplers, which prevent ground loops and RF paths — and **attenuation**, since a computer's line output is far hotter than a microphone input and will badly overdrive it.

Direct sound card connection with no isolation works sometimes and produces ground loop hum, RF feedback, and occasionally damage. **Isolate.**

PTT Methods

VOX — audio triggers the transmitter. **No control connection needed**, and it introduces delay, may clip the start of transmissions, and can be triggered by computer sounds. **Disable system sounds on any machine doing this**, and prefer a real PTT method.

Serial port RTS or DTR — the traditional method. Reliable and simple.

CAT command — the software tells the radio to transmit over the control interface. Clean, and note the latency: CAT PTT can be slower to key than a hardware line, which matters for modes with tight timing.

GPIO — on a Raspberry Pi, a pin driving an optocoupler. **Excellent for a dedicated node** — no serial port, no USB device to enumerate incorrectly, and it works from boot.

Hardware PTT is generally more reliable than CAT PTT for timing-critical modes, and the difference matters most on packet, where the TXDELAY parameter is compensating for whatever your keying latency is.

Audio Levels

The most common cause of poor digital performance, by a wide margin.

Transmit level — too high is worse than too low.

An overdriven SSB transmitter produces splatter: intermodulation products spreading across the band, interfering with others, and — critically — **distorting your own signal so the far end decodes it poorly**. You will be loud and unreadable.

Setting it correctly:

Watch ALC. On SSB, adjust audio so ALC shows **zero to barely moving**. Any significant ALC action means compression, which destroys the linearity these modes require.

Watch power output, duty cycle, and temperature. There is no universal safe percentage for every radio or mode. Start low, use the minimum power needed for the path, keep the transmitted signal linear, and follow the manufacturer's continuous-duty or digital-mode rating. A radio advertised as 100 watts PEP on voice may require substantial reduction for long high-duty-cycle transmissions.

Turn off speech processing, compression, and EQ. Every one of them distorts a digital signal.

Use the data or ACC input rather than the microphone input where the radio has one — it typically bypasses processing and has a fixed, appropriate level.

Receive level — the software's indicator should sit in its recommended range, typically well below clipping. **Too low buries the signal in quantization noise; too high clips and generates distortion products the decoder reads as errors.**

Set the radio's AF gain and the computer's input level separately. On many systems the computer's input has both a level control and a microphone boost that must be off.

Disable AGC on the computer input. Automatic gain control in the sound device fights the decoder.

Levels drift. Operating system updates reset mixer settings, and this is a recurring cause of "it stopped working." **Note your settings.**

FM Deviation

For packet on FM, the transmitted deviation matters:

Typical target: about 3 kHz deviation for 1200 baud AFSK on a 5 kHz-deviation system. Too little and the far end's decoder is working with a weak signal; too much and the audio distorts and splatters into adjacent channels.

Setting it properly requires a deviation meter or a service monitor. In practice most people set it by having a well-equipped station listen and report, or by comparing against a known-good station.

9600 baud is far more critical. Chapter 9.

Sound Devices

A dedicated USB sound device per radio is the practical approach for multi-radio stations — one device, one radio, no ambiguity.

Device enumeration changes. On Linux, identify devices by their persistent path rather than by card number, or a reboot renames them and nothing works.

Sample rate accuracy matters for some modes. Cheap sound devices have real clock error, and modes with tight timing can be affected. Most modern software measures and compensates; some lets you enter a correction.

Avoid the motherboard's built-in audio where you can — it's electrically noisy and shares ground with everything.

CAT Control

Not required, and it makes life much easier: the software knows and sets the frequency and mode, logs correctly, and can scan.

Serial port identification on Linux should use the persistent device path rather than a device number, for the same reason as sound devices.

On-Air Check

1. Verify your interface provides isolation on audio and PTT.
2. Set transmit audio for a clean, linear signal with no compression or overdrive. Confirm power and duty-cycle limits with the radio manual and a wattmeter.
3. Disable speech processing, compression, and EQ.
4. Verify the computer's input level is in the software's recommended range with AGC and boost off.
5. Have another station report on your signal quality and deviation.
6. Write down every level setting.

Chapter 5: Regulations and Bandwidth

The rules that constrain what you may transmit. They changed significantly and recently.

End of the free sample

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That was the first 12 of 70 pages. The full book continues with the practical detail, worked examples and recovery steps that don't fit in a sample.

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