Chapter 8
Radio Modes and Equipment

Digital Protocols and Modes

- Bits vs. Baud (plural of Baud is Baud NOT Bauds)
- Bits = over the air data rate, bits/sec
- Baud = symbol rate, symbols/sec, transitions/sec, signaling event
- Bit rate = Baud rate when there are only 2 states 1 or 0, on or off, 2295 or 2125 HZ

Digital Protocols and Modes (cont.)

- Data rate (bits) > Baud rate when there are more than 2 states per transition (baud)

Baud	States	Bits/sec
300	2	300
300	4	600
300	8	1200
300	32	4800

Digital Signal Bandwidth

- “No free lunch” applies to bandwidth of digital signals; faster baud rate = more bandwidth
- BW = B X K where BW is the bandwidth needed, B is the Baud rate and K is a constant related to the shape of the keying envelope

Protocols and Codes

- Protocol = rules for encoding, packaging, exchanging & decoding digital data
- Code = method of conversion to/from digital data
  - Varicode (mores & PSK) variable length
  - Baudot – 5 bits, requires shift for numbers/letters
  - ASCII 7 bits allow numbers and letters without shift character

Codes (cont.)

- Start bits, Stop bits, Parity bits
  - Transmissions are Asynchronous (transmitting and receiving clocks are not synchronized) so need bits to signify start and stop of data frames; i.e. start and stop bits
  - A Parity bit can be added to <u>detect</u> single bit errors
    - Even parity = even number of 1's in data frame
    - Odd parity = odd number of 1's in data frame
    - No parity = most common
  - Stop bit; 1.5 for Baudot, 1 for ASCII (2 was used for mechanical teleprinters) always 1 for electronic devices

Digital Modes

- Digital Mode = protocol + method of modulation
- FCC assigns different emission designator for each specific use (3rd symbol of designator)
  - E = voice (J3E)
  - B = text (telegraphy for automatic reception) (F2B)
  - D = data (F1D)
  - F = television/image (C3F)
- Advantage is ability to transmit and copy multiple times without error

CW

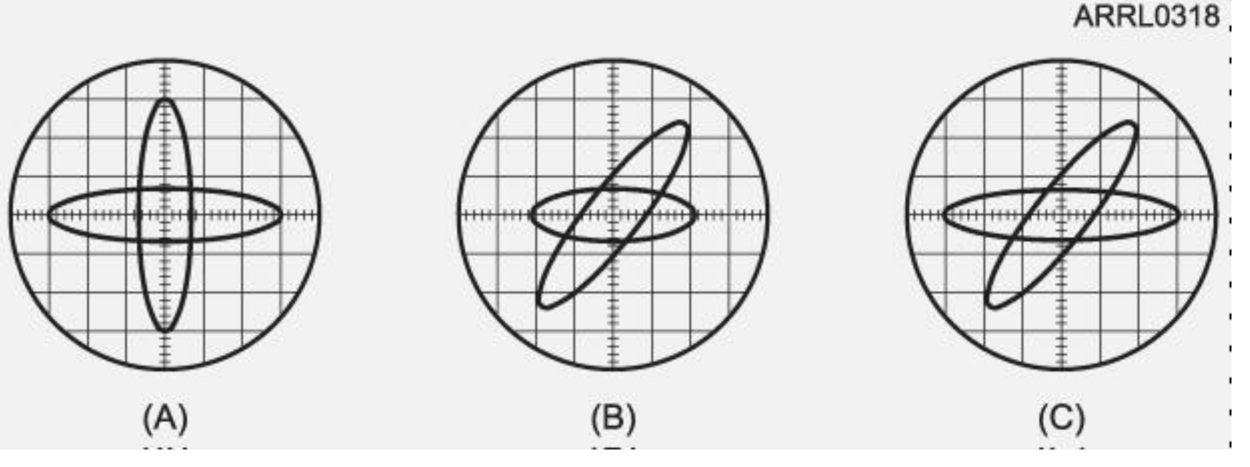
- Simplest form is turning an AM transmitter on and off (A1A)
- Bandwidth determined by speed and keying envelope
- Standard “word” is PARIS
- BW = WPM x 1.2 x K where K is 3 to 5 reflecting abruptness of keying waveform, more abrupt is larger
- 13 WPM BW = 13x1.2x4 = 62.4 Hz

FSK/AFSK

- Most amateur data transmissions (all on HF) use Frequency Shift Keying (FSK)
- RTTY/ASCII use two states/tones (Mark & Space)
- Shift is the difference between Mark & Space tones
- Direct FSK is F1B generated by directly shifting oscillator freq
- AFSK is J2B or J2D generated by injecting audio tones into mic circuit

FSK/AFSK Bandwidth

- BW = (K x shift) + B where K is 1.2 and B is baud
- 170 Hz 300 baud ASCII J2D transmission bandwidth = (1.2x170)+300=504Hz
- VHF Packet example
  (1.2



PSK

- Phase Shift Keying (PSK) PSK31 very popular keyboard to keyboard mode on HF
- J2B emission, full 128 char ASCII 256 char ANSI
- Uses variable length characters (Varicode)
- 00 is the intercharacter gap
- BW minimized by using sinusoidal shaping
- PSK31 BW=31.25x1.2=37.5 Hz narrowest HF digital mode
- Many variations now; PSK125C12 (BW 2100 Hz), PSK1000C2 (BW 2400 Hz), PSK250R6 (BW 2000 Hz)(bits/sec # carriers R includes error correction)

HF Packet

- Uses AX.25 protocol same as VHF packet but limited to 300 baud by FCC; designated J2D
- AX.25 includes error <u>detection</u> so if receiving station does not <u>ACK</u>nowledge good reception transmission is repeated up to max retry limit, typically 5

Pactor I/II/III

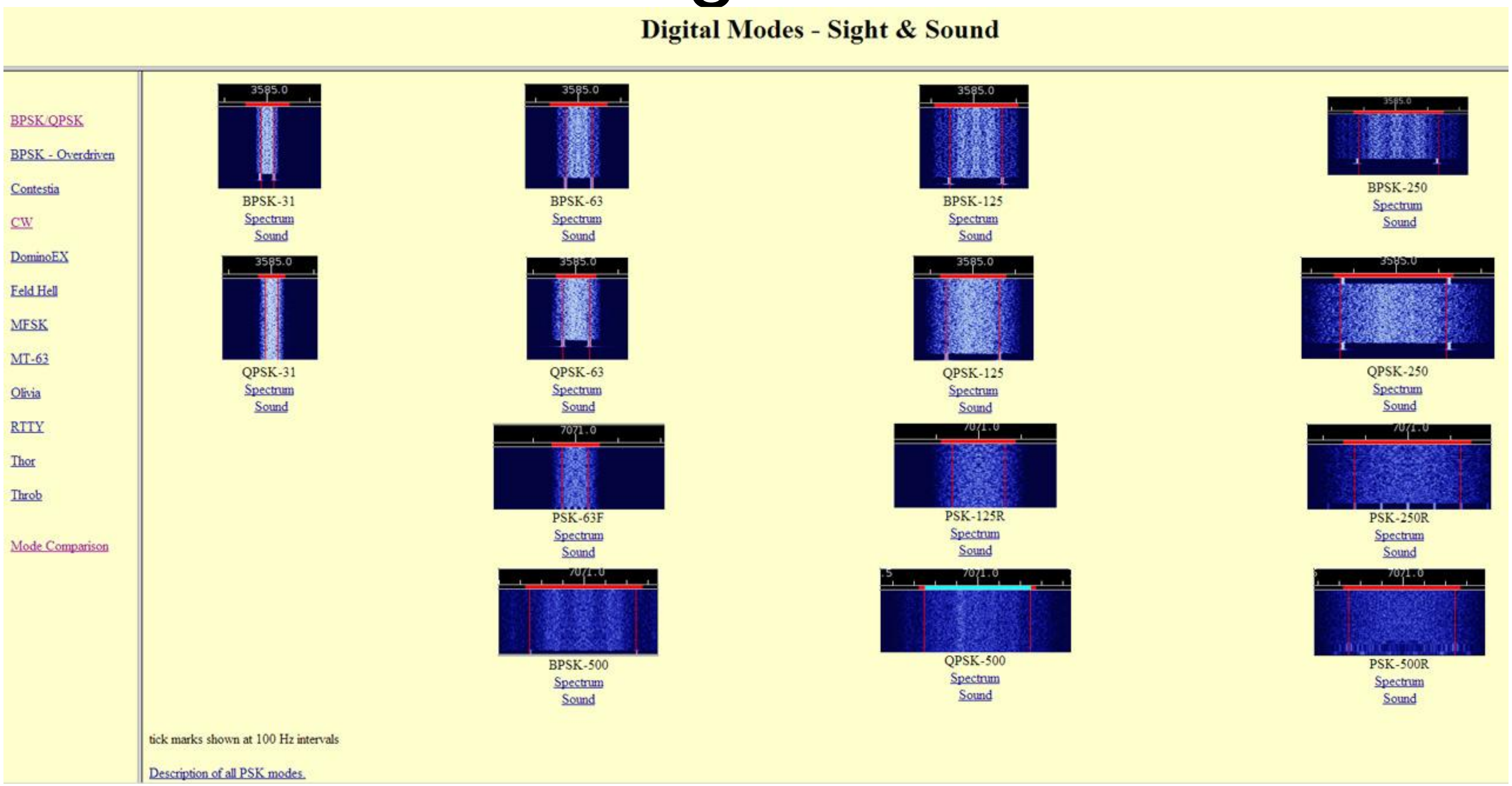
- Performs well under weak signal and high noise conditions
- Supports binary data transfers
- Automatic Repeat reQuset (ARQ) error correction
- Pactor II/III require SCS Pactor modem
- Automatic evaluation of conditions between transmitter/receiver to adjust speed to highest for current conditions
- Pactor III can exceed 5000 bits/sec

MFSK/MT63

- Soundcard modes
- Use multiple tones to increase data rate
- MFSK16 uses 16 tones BW 316 Hz 63 bps
- MFSK can use 4,8,11,16,22,31,32,64 or 128 tones
- MT63 uses 64 tones BW 1000 Hz 70 bps
- MT63 can use 500, 1000 or 2000 Hz bandwidth

www.W1HKJ.com

Sights and Sounds of Digital Signals



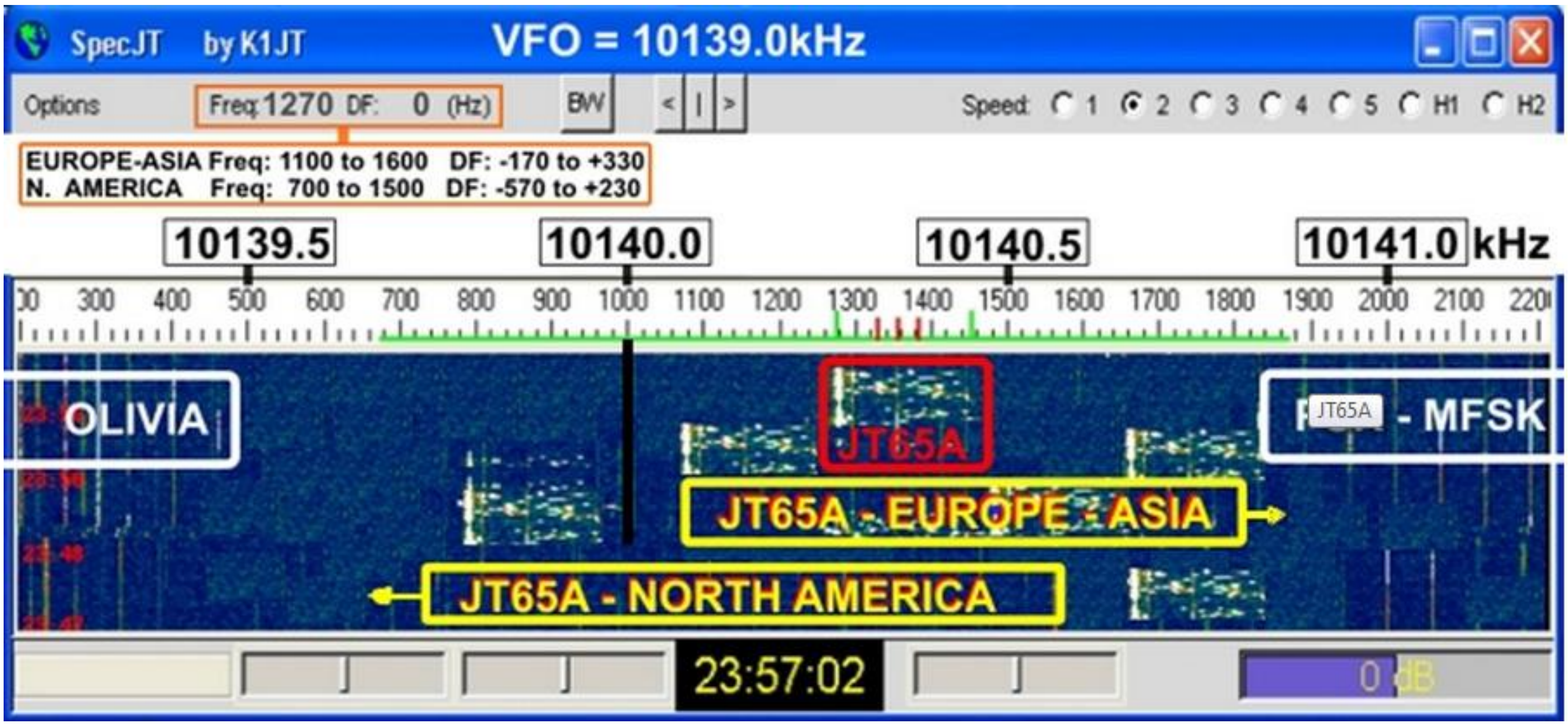
WSJT

- Developed for weak-signal VHF/UHF such as EME
- 5 modes
  - FSK441 meteor scatter
  - JT65 EME
  - JT6M 6 meter meteor scatter
  - EME Echo for measuring your own signal bounced from the moon
  - CW 15 WPM QSOs
- JT65 can decode signals well below noise level

Where to get WSJT/JT65

- Google WSJT or JT65
- WSJT Home Page http://www.physics.princeton.edu/pulsar/K1JT/
- JT65
- http://sourceforge.net/projects/jt65-hf/
- JT65 frequencies 14.076, 10.139, 7.039, 7.076

JT65 Signal



SpecJT by K1JT
VFO = 10139.0kHz
Options
Freq 1270 DF: 0 (Hz)
BW
Speed 1 2 3 4 5 H1 H2
EUROPE-ASIA Freq: 1100 to 1600 DF: -170 to +330
N. AMERICA Freq: 700 to 1500 DF: -570 to +230
10139.5
10140.0
10140.5
10141.0 kHz
300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100
OLIVIA
JT65A
JT65A
- MFSK
JT65A - EUROPE - ASIA
JT65A - NORTH AMERICA
23:57:02
0 dB

Transmitting Digital Modes

- *DO NOT OVERDRIVE THE TRANSMITTER*
- Keep drive level low enough that no ALC is indicated
- Do not use any speech processing
- Check your signal by transmitting into a dummy load and receiving on a second receiver with computer/soundcard with demodulation program for that mode

Spread Spectrum (SS)

- Spreading a signal over a very wide bandwidth by rapidly varying carrier frequency in a predefined sequence (spreading-code)
- Dilution of the signal across many frequencies makes it sound like noise to conventional receiver; may appear to be below noise floor
- Ignores strong non-spread signals because they do not follow the spreading-code

SS (cont.)

- FM, SSB,CW signals as well as other SS with a different spreading-code are ignored
- Many SS systems can share frequencies by using different spreading-code; Code-Division Multiple Access (CDMA)
- CDMA is used by may Cellular service carriers

Error Detection & Correction

- What good is data if it’s corrupted!
- RTTY & PSK31 have no error detection or correction
- Adding a Parity bit can detect single-bit errors
- Cyclic-Redundancy-Check (CRC) can detect multi-bit errors
- Automatic Repeat reQuest (ARQ)
  – ACKnowledged (ACK) or Not AcKnowledged (NAK)

Error Correction (cont.)

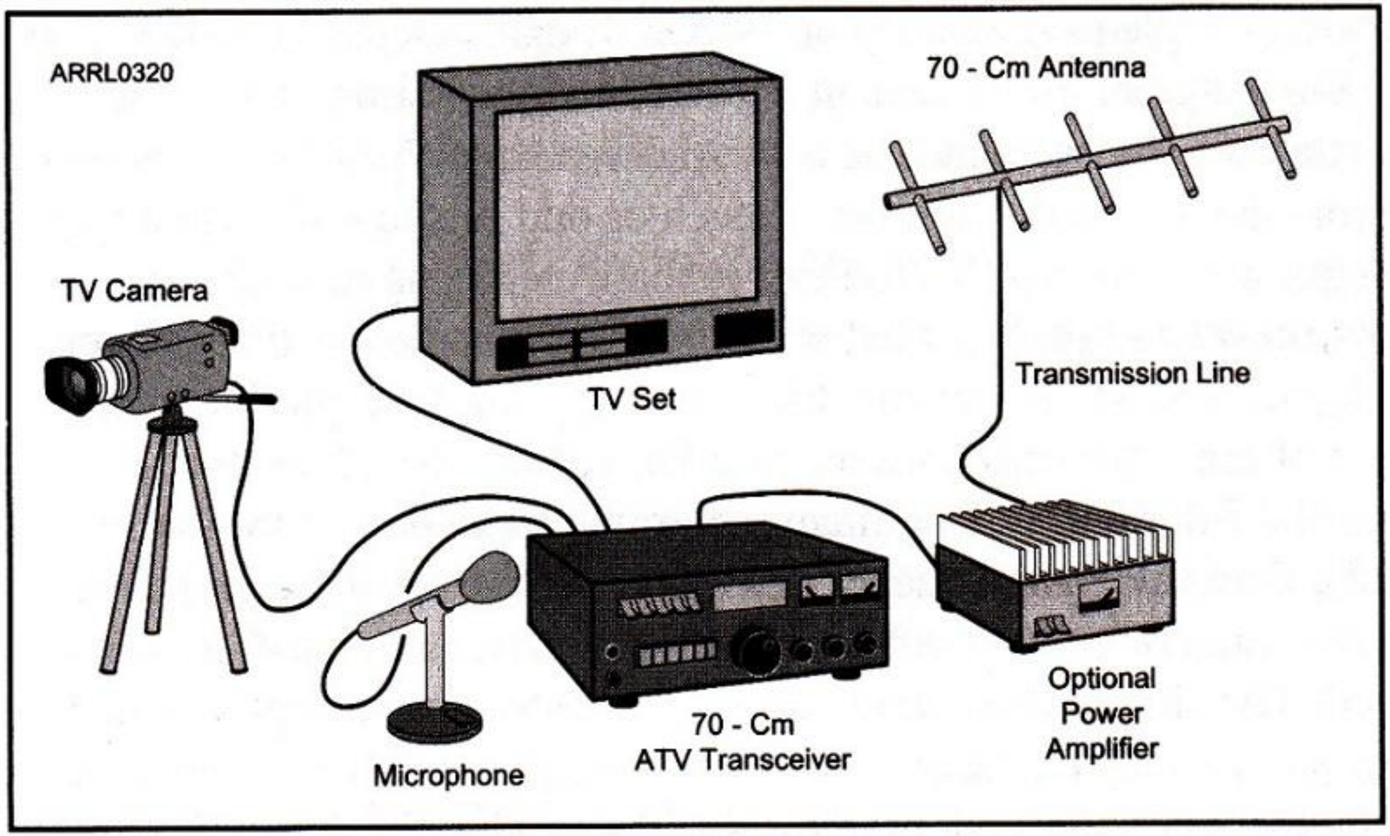
- But can’t we include some additional data up-front to correct errors!
- Forward Error Correction (FEC) does just that
- FEC adds correction data ahead of the “information” data, may be spread over several data packets
- Many types of FEC codes, Reed-Solomon, Hamming, BCH, Golay

Error Correction (cont.)

- Garbage once error rate exceeds correction threshold
- Viterbi encoding restricts the number of symbols sent over the air to a subset of the original data, the Viterbi decoder algorithm then presents the most likely data to been sent to the encoder

Amateur Television (fast Scan)

- Analog TV standards are used, not current HDTV (digital) standards

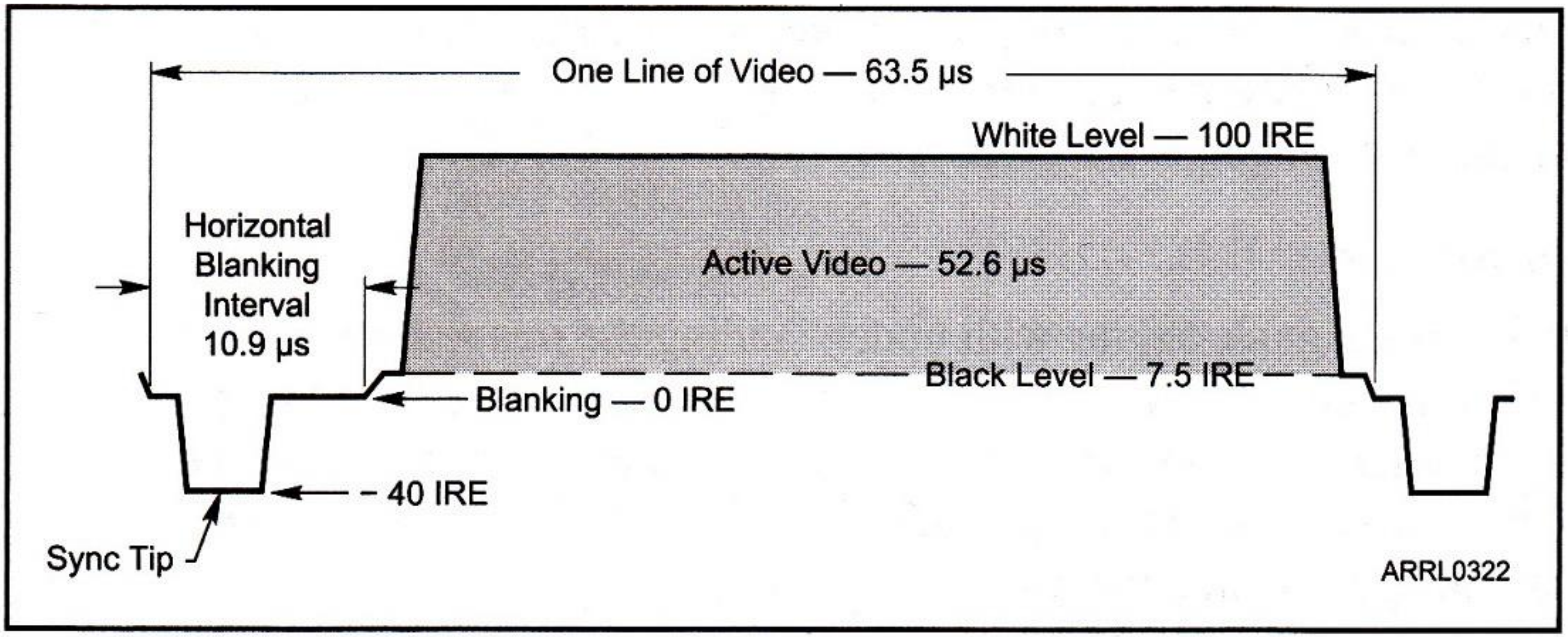


Signal Definitions

- B/W NTSC

Line rate	**15,750 Hz**
Field rate	60 Hz
Frame rate	30 Hz
Horizontal Lines	262.5/field 525/frame
Sound subcarrier	4.5 MHz
Channel bandwidth	6 MHz

RS-170 B/W Signal



IRE Levels

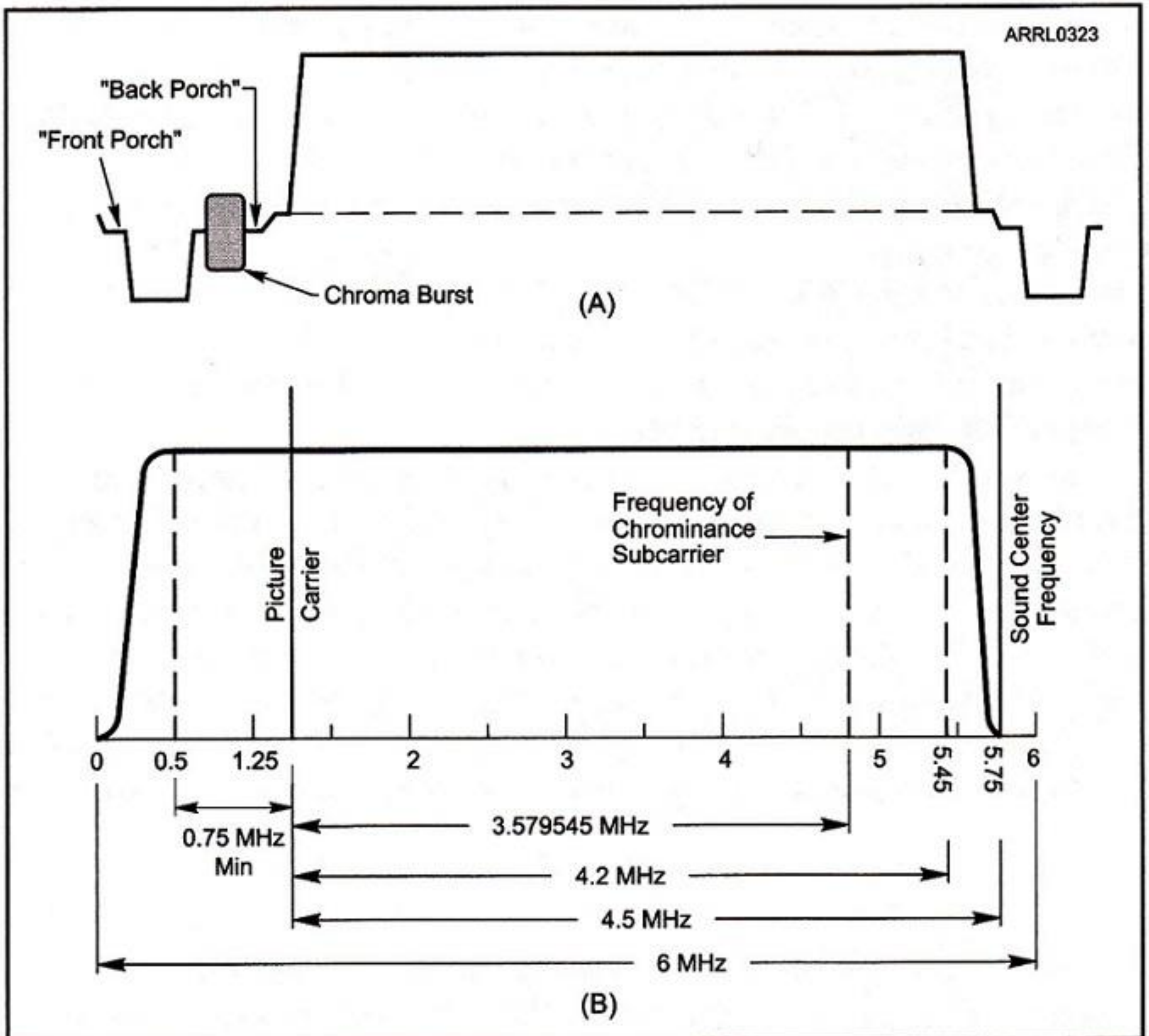
Zero carrier	120 IRE
White	100 IRE
Black	7.5 IRE
Blanking	0 IRE
Sync tip	-40 IRE

- %Peak Envelope Voltage (%PEV) is obsolete, use IRE

Color Video

- NTSC Analog Color not Digital

Line rate	**15,734 Hz**
Field rate	59.94 Hz
Frame rate	29.97 Hz
Horizontal Lines	262.5/field 525/frame
Color subcarrier	3.579545 MHz
Sound subcarrier	4.5 MHz
Channel bandwidth	6 MHz


ARRL0323
"Back Porch"
"Front Porch"
Chroma Burst
(A)
Picture Carrier
Frequency of Chrominance Subcarrier
Sound Center Frequency
0
0.5
1.25
2
3
4
5
5.45
5.75
6
0.75 MHz Min
3.579545 MHz
4.2 MHz
4.5 MHz
6 MHz
(B)

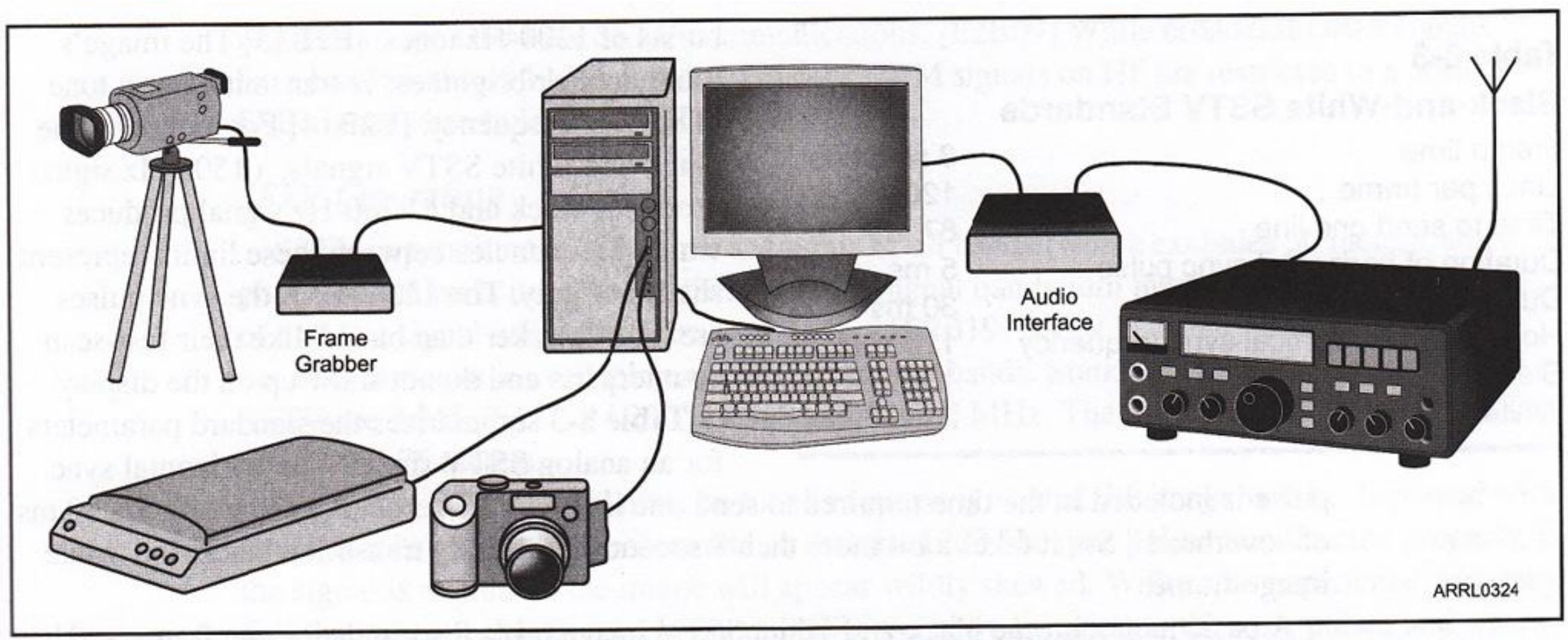
Transmitting ATV

- Need to have a stable picture even with very weak analog signals
- RS-170 video is inverted for transmission
- Peak signal is thus the tip of the sync pulses
- Of the 525 lines only 483 are used for picture, the rest are sync only
- UHF or above only
- FM ATV 1.2, 2.4, 10.25 GHz, 17-21 MHz BW
- AM carrier of video can be FM'd with audio

Slow-Scan Television

- Isn't there some way of transmitting pictures on HF or VHF?
- On HF & VHF we can use facsimile (pretty much obsolete) or Slow-scan television
- Slow-scan using soundcard based software is popular using SSB on HF or FM on VHF
- No interlace, one frame per picture
- NASA used a form of SSTV for the Apollo program

SSTV Station



Analog SSTV

- B/W Standards

Frame time	8 sec
Lines per frame	120
Time to send 1 line	67 ms
Duration Hsync pulse	5 ms
Duration Vsync pulse	30 ms
Hsync & Vsync freq	1200 Hz
Black freq	1500 Hz
White freq	2300 Hz
Bandwidth	2000 Hz

Color Analog SSTV

Format	Name	Time (sec)	Lines
Wraase SC-1	24	24	128
	48	48	256
	96	96	256
Martin	M1	114	256
	M2	58	256
	M3	57	128
	M4	29	129
Scottie	S1	110	256
	S2	71	256
	S3	55	128
	S4	36	128

Digital SSTV

- Based on the Digital Radio Mondale (DRM) protocol
- Bandwidth limited to 3 KHz
- No additional hardware required beyond a receiver required to decode DRM on a PC
- EasyPAL is most common software
- http://www.kc1cs.com/
- 14.233 MHz is where most activity is found

Operating SSTV

- 100% duty cycle, reduce power
- As with other digital modes, no ALC or speech processing
- No noise blanker or DSP on receive
- Phone segment of all bands except 30 Meters
- Analog 14.230 & 7.171 MHz most popular
- Picture ID is ok, voice recommended in case listener is unable to copy picture

Receiver Performance

- It is important to be able to measure and evaluate receiver quality.
  - Successful communications depends on quality reception of signals.
    - Free of noise and distortion
    - Ignore unwanted signals
    - Sensitive to the weakest signals

Receiver Performance
Sensitivity and Noise

- One basic receiver specification is sensitivity or Minimum Discernible Signal (MDS).
  - MDS of a receiver is the strength of the smallest discernible input signal.
  - Depends on noise figure and bandwidth.
  - MDS also called the receiver’s noise floor.
    - Signal that produces same audio level as the receivers noise.
  - The lower the MDS the more sensitive the receiver.

Receiver Performance
Sensitivity and Noise

- MDS often expressed in dBm
  - Decibels with respect to one milliwatt
    - 0 dBm is the same as 1 mw, +10 dBm 10 mw, etc.
- MDS also expressed as μV.
  - An MDS of 0.5 μV equals and MDS of -113 dBm.
    - Practical MDS on the HF bands.
    - The theoretical noise at the input of an ideal receiver, with an input filer bandwidth of 1 Hz, is -174 dBm/Hz at room temperature.
- Atmospheric noise is the primary source of noise in and HF receiver and therefore the limiting factor for sensitivity of receivers on the HF bands.

Receiver Performance
Sensitivity and Noise

- A receiver bandwidth of 1 HZ is impractical but is used as a reference.
  – For the filter width the receiver uses you can calculate the theoretical MDS.
    - MDS for a receiver with a -174 dBm/Hz noise floor if a 400 Hz filter band-width is used.

10 log (400 Hz) = 26 db

-174 dBm + 26 db = -148 dBm

Receiver Performance
Sensitivity and Noise

- Noise Floor and Signal-to-Noise ratio
  - Noise figure is a "figure of merit" for the receiver.
    - Ratio in dB of the noise generated by the receiver itself to the theoretical MDS.
    - The higher the noise figure the more noise generated within the receiver.
    - Higher noise floor.
    - Lower noise figures are more desirable
      - <u>Low-noise UHF preamp might have a noise figure of 2dB.</u>

Receiver Performance
Sensitivity and Noise

- Receiver's internal noise degrades the noise floor, or raises the power that actual signals must have to be heard.
- You can calculate the actual noise floor.
  - Actual Noise Floor = Theoretical MDS + noise figure
- Noise figure of a receiver is related to signal-to-noise ratio (SNR) or the input and output signals.
- <u>Lowering a receiver's noise figure lowers it noise floor and improves weak signal sensitivity</u>.
- Another type of signal to noise ratio is signal-to-noise-and-distortion (SINAD).

Receiver Performance
Selectivity

- The perfect receiver can tune any frequency and reject every signal except the one you want to receive.

- Selectivity
  - The ability to select a specific signal.
  - Selectivity determined by bandwidth the receiver’s entire filter chain from front end to audio output.
  - Superheterodyne receivers have several filters in the signal path.

Receiver Performance
Selectivity

- Band-pass front end filters
  - Provide front end selectivity
  - Reject strong near out of band signals
- Preselector
  - Tunable input filter that passes the desired frequency.
  - Increases rejection of out of band signals.
- Band pass filters and preselectors both are effective in eliminating image signal interference.
- IF amplifier filters.
  - LC, quartz crystal, ceramic resonator.
  - Reject unwanted mixing products and prevent spurious signals from slipping into the signal path.

Receiver Performance
Selectivity

- Increasing a superheterodyne receiver's IF frequency improves selectivity. As the IF is increased the frequency at which image responses occur becomes farther from the desired signal and easier to filter out.

- Example:
  - IF of 455Khz. Signal on 14.300 MHz

    BFO tuned to 14.3 + .455 = 14.755 MHz
  - Image on 15.210 received because 15.210 – 14.755 MHz = 0.455 MHz.
  - If we raise the IF to 9 MHz, BFO is 14.3 + 9 = 23.3 MHz and the image frequency would be 23.3 + 9 MHz. Farther away from the desired signal and easier to filter.

Receiver Performance
Selectivity

- At the input to each IF stage a roofing filter is often used.
  - Usually crystal filters.
  - Bandwidth wider than the widest signal to be received.
  - Attenuates strong signals near the receive frequency.

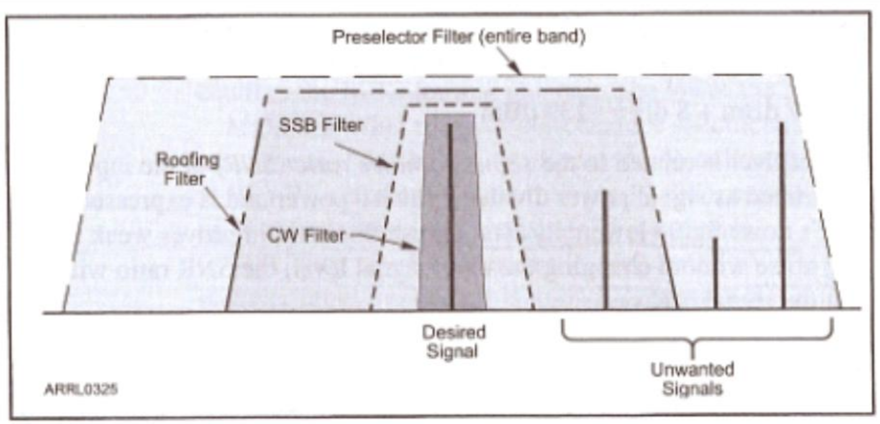


Figure 8-10 — A typical multiple-conversion superheterodyne receiver has several stages of filtering. Preselector filters reject out-of-band signals. Roofing filters at the input to each IF further restrict receiver bandwidth, attenuating strong in-band signals that might overload the IF amplifiers. In the final IF stage, single-signal filters are used to select just the desired signal.

Receiver Performance
Selectivity

- In the final IF, narrow filters used to select on signal from the many that may be present.
  - Crystal (most common)
  - Mechanical
  - Filter must be appropriate for the desired signal.
    - Examples: RTTY 300 Hz, SSB, 2.4 KHz
  - Narrower filters improve selectivity but limit fidelity and the ability to detect nearby signals.
  - Wider filters are more comfortable to listen to but <u>allow undesired signals on nearby frequencies to be heard as well.</u>

Receiver Performance
Dynamic Range and Intermodulation

- Dynamic Range
  - The ability of a receiver to tolerate strong signals outside of the normal passband.
  - The ratio between the MDS and the largest input signal that does not cause audible distortion products.
  - Dynamic range measurements are in dB.
- Blocking Dynamic Range (BDR)
  - A strong input signal can cause the receiver to no longer respond linearly and gain to drop.
  - Causes weaker signals to appear to fade
  - Gain compression or blocking.

Receiver Performance
Dynamic Range and Intermodulation

- Blocking may be observed as desensitization or desense…the reduction in apparent strength of a desired signal caused by a nearby strong interfering signal.
- Blocking Dynamic Range (BDR) is the difference in dB between the noise floor and the level of an incoming signal which will cause 1 dB of gain compression.
- It may be possible to reduce the desensitization by using IF filters to reduce the receiver’s RF bandwidth and reject the strong signals.

Receiver Performance
Dynamic Range and Intermodulation

- Intermodulation (IMD)
  - A perfectly linear receiver will produce an output signal with a strength that changes exactly the same as the input signal. This is called first order response.
  - As the signal strength increases the receiver's response becomes nonlinear and IMD products are created.

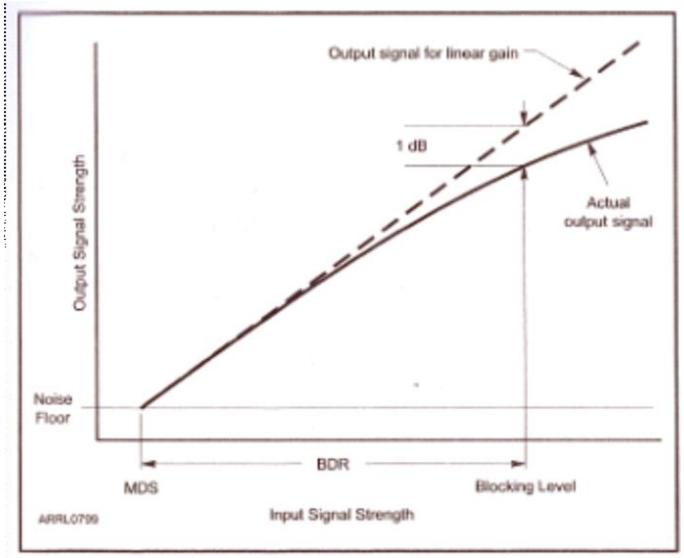


Figure 8-11 — Gain compression occurs when the input signal is too strong for the receiver to develop full gain. Blocking Dynamic Range (BDR) is measured in dB from MDS to a level at which the input signal strength causes a 1 dB drop in receiver gain, called the blocking level.

Receiver Performance

Dynamic Range and Intermodulation

- IMD products are created at frequencies which are the sum and differences of the input signals and their harmonics.
- The frequencies of second-order IMD products caused by signals that are close together are far from the frequency of either input signal and are generally not a problem if caused by signals within an amateur band.

Receiver Performance
Dynamic Range and Intermodulation

– If the signals causing the IMD products are close together, such as in the same amateur band as the desired signal, the subtractive IMD products could be very close to the desired signal.

- Third Order IMD Product Frequencies

$f_{IMD1} = 2f_1 + f_2$

$f_{IMD2} = 2f_1 - f_2$ ⇦

$f_{IMD3} = 2f_2 + f_1$

$f_{IMD4} = 2f_2 - f_1$ ⇦

– Third-Order IMD performance of a receiver is an important specification.

Receiver Performance
Dynamic Range and Intermodulation

– Example
  - What are the likely frequencies for a second strong signal that could combine with the one on 146.52 MHz to produce the IMD product you hear on 147.70 MHz ?

$f_{IMD2} = 2f_1 - f_2$

$f_2 = 2f_1 - f_{IMD2}$

$f_2 = 2 \times 146.52 – 147.70$

$f_2 =$ 146.34 MHz

$f_{IMD4} = 2f_2 - f_1$

$f_1 = (f_{IMD2} + f_2) / 2$

$f_1 = (146.70 + 146.52) / 2$

$f_1 =$ 146.61 MHz

Receiver Performance
Dynamic Range and Intermodulation

- It may not be practical to filter out strong input signals because they are in-band signals.
  - Possible remedies
    - Use a receiver with higher dynamic range.
    - Use an attenuator at the signal input.
    - Reduce RF gain
    - Use a roofing filter.

Receiver Performance
Dynamic Range and Intermodulation

– Intercept Point
  - The input signal power at which the level of the distortion products equals the output level for the desired signal is the receiver's intercept point.
    - – Example
      - » <u>A 40 dBm third-order intercept point means the a pair of 40 dBm signals would produce and IMD product of same 40 dBm level.</u>

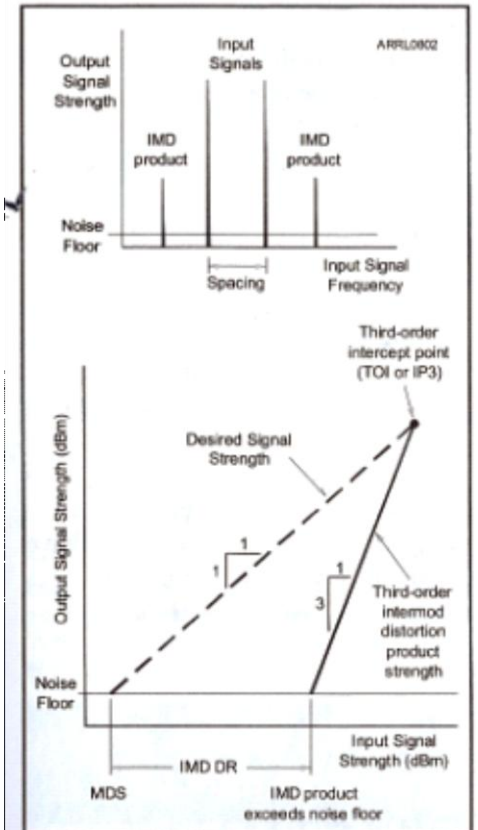


Figure 8-12 — Receiver output power for a desired signal and for third-order distortion products varies with changes of input signal power. The input signal consists of two equal-power sine-wave signals. Higher intercept points represent better receiver IMD performance.

Receiver Performance

Dynamic Range and Intermodulation

- Intermodulation distortion dynamic range measures the ability of the receiver to avoid generating IMD products. When input signal levels exceed the IMD dynamic range, IMD products will begin to appear along with the desired signal.

- If a receiver has poor dynamic range, cross modulation or IMD products will be generated and desensitization (blocking) from strong adjacent signals will occur.

Receiver Performance
Phase Noise

- Phase noise has become more apparent as receiver improvements have reduced the noise floor and increased dynamic range.

- Caused by PLL or DDS synthesizers continually adjusting their frequency as compared to a reference.

- <u>Excessive phase noise in a receiver local oscillator allows strong signals on nearby frequencies to interfere with the reception of a weak desired signal.</u>

Receiver Performance
Capture Effect

- FM receivers exhibit an effect know as capture effect. The loudest signal received even if it is only a few dB stronger than the other signals on the same frequency will be the only signal demodulated, blocking all weaker signals.
  - Can be an advantage if you are trying to receive a strong station and there are weaker stations on the same frequency.