A high-performance FM receiver for audio and digital applicatons

This receiver design offers high sensitivity and low distortion for today's demanding high-signal environments.

By Wayne C. Ryder

One of the fundamental parameters governing radio receiver performance is its sensitivity. This article discusses an FM radio receiver design, called SUPRX, which overcomes sensitivity deficiencies. The approach is to optimize carefully the strong signal wideband characteristics of the receiver front end and mixer. The objective is to maintain front-end weak signal sensitivity when the receiver is subjected to adjacent channel high-level signals. For this article this will be referred to as the "apparent sensitivity" of the radio. Another concern is intermediate frequency (IF) harmonic distortion. As this article suggests, careful selection of components can provide acceptably low levels of distortion. A means for simulating the signal environment in a controlled and repeatable way is also shown, as is a way to make use of this method for the stage and integrated receiver-level evaluations.

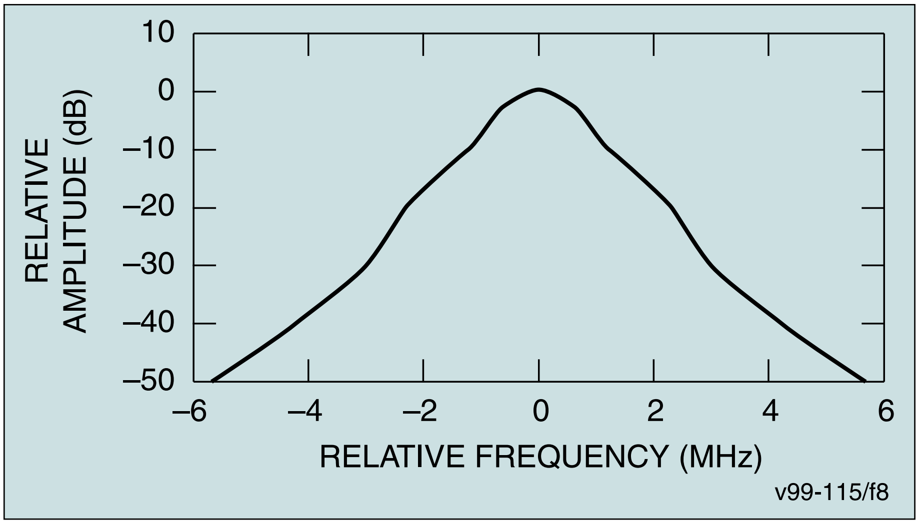

Figure 1. Front-end bandwidth.

The beginning

Modern FM band receivers are specified to have adequate sensitivity for use in far fringe areas of a station's coverage. However, measurements have shown that in a dense, high signal-level environment, the apparent sensitivity of the receivers degrades by several orders of magnitude.

For example, six modern FM tuner/amplifiers had 10 to 30 µV sensitivity for a 30 dB signal-to-noise ratio (SNR) when connected to a signal generator. However, when connected to an antenna in a high signal-level environment, the same receivers required a signal level between 2 and 5 mV at the same unoccupied frequency to achieve the same SNR.

Components used in modern practical receiver front ends have limitations. Mixers are susceptible to intermodulation distortion. RF amplifiers have similar limitations, though not as severe. Again, these limitations are most pronounced when receiving a weak signal in the presence of many strong signals.

Another consideration usually associated with the IF amplifier, limiter, and detector is harmonic distortion. Harmonic distortion can degrade audio performance and put unwanted signals into the FM baseband, where subcarriers are received.

Most harmonic distortion occurs in the IF amplifier, limiter, and detector stages. Ceramic filters with lower group delay provide minimum distortion but have the poorest skirts. In addition, carefully matching the detector and quadrature coil provides minimum harmonic distortion.

Overcoming radio receiver sensitivities and harmonic distortion deficiencies, then, become objectives in radio receiver design. SUPRX is a design that meets these objectives.

Design considerations

In designing SUPRX, the components for evaluation (mixers, RF amplifiers, local oscillator, and IF components) are described in the following subsections.

•*Mixers*: Several mixers were evaluated using the slot noise generator described in detail later in the article. Mixers using high local oscillator drive, up to +27 dBm, performed far better than mixers using +7 dBm local oscillator drive. However, considering mixer cost, local oscillator driver parts cost, and possible local oscillator radiation exceeding FCC limits, the +7 dBm mixer was selected for the design. The slot noise levels for the mixers are shown in Table 1. The lower the slot noise level at the output of the mixer, the better the performance.

•*RF amplifiers*: Since a low local oscillator drive mixer was used, with its poor out-of-band strong signal handling capability, a narrow-band tuned front end was required. The best selection was a front-end with an unloaded Q of about 150 to minimize adjacent channel interference. Also, the front-end tuning had to track the local oscillator.

Overall, units with two to six tuned circuits were evaluated. The chosen unit contained four tuned circuits. This unit provided a front-end loaded Q of > 150 at 88, 98, and 108 MHz (see Figure 1). The local oscillator tracked the front end within ±2 dB. Also evaluated were several dual-gate field-effect transistors (FETs) for use as RF amplifiers. The BF904 provided the highest third-order intercept (IP_3, a measure of strong signal handling ability). Applying voltage to gate 1 provides bias for the BF904.

•*Local oscillator*: A conventional Colpitts circuit was used as the local oscillator. In-band spurs were > 60 dB down, and worst-case harmonics were > 30 dB down. Since the front end provides reasonable selectivity, oscillator harmonics should not affect receiver performance.

•*IF assembly*: The IF assembly was tested with a 6 kHz modulation frequency and ±75 kHz deviation. Several demodulator ICs, resonators, and inductors were evaluated as well. The best matches were found to be the Sanyo LA 1235 limiter-demodulator and the Sumada quad coil (harmonic distortion was 70 dB down). In the evaluation of ceramic filters, it was found that the one with the lowest group delay had the lowest distortion–the Murata SFE10.7MX-A. This combination of components resulted in final distortion being down over 65 dB.

Receiver description

A block diagram and a schematic of the receiver are shown in Figures 2 and 3, respectively. In Figure 3, L_6 and L_7 are spaced 0.6 inch for a loss of about 0.5 dB. Q_4 is the first RF amplifier. L_9 and L_{10} are spaced about 0.8 inch with a partial shield between them. The front-end gain is about 10 dB as measured at the input to the mixer. This gain is sufficient to overcome the loss of the mixer, but not to overload it.

C_{23} and L_{11} provide a match between the output of Q_5 (the second RF amplifier) and the mixer. The local oscillator Q_3 is followed by a two-stage amplifier, Q_1 and Q_2. The components between the mixer output and Q_8 provide termination for the mixer. CF_1, CF_2, and CF_3 provide about 200 kHz receiver bandwidth. U_5 is an IF amplifier, limiter, and detector. U_4 and U_5 provide phase lock for the local oscillator.

The slot noise generator

The purpose of the slot noise generator is to evaluate the front-end performance of an FM receiver that will be operating in a metropolitan area with strong signals. Because of front-end nonlinearities, the locally strong signals may add artifacts to a frequency occupied by a weak station.

A repeatable figure of merit had to be found to measure the front-end nonlinearities. Two-tone intermodulation testing does not adequately measure high-order intermodulation distortion.

One measurement method is the use of over-the-air stations. However, if the antenna is moved in any way, or if atmospheric conditions change, results are no longer valid. Also, it would be difficult to find an empty space in the FM band with sufficient bandwidth to add a test signal.

A second method is the combination of the output of 50 small FM trans-

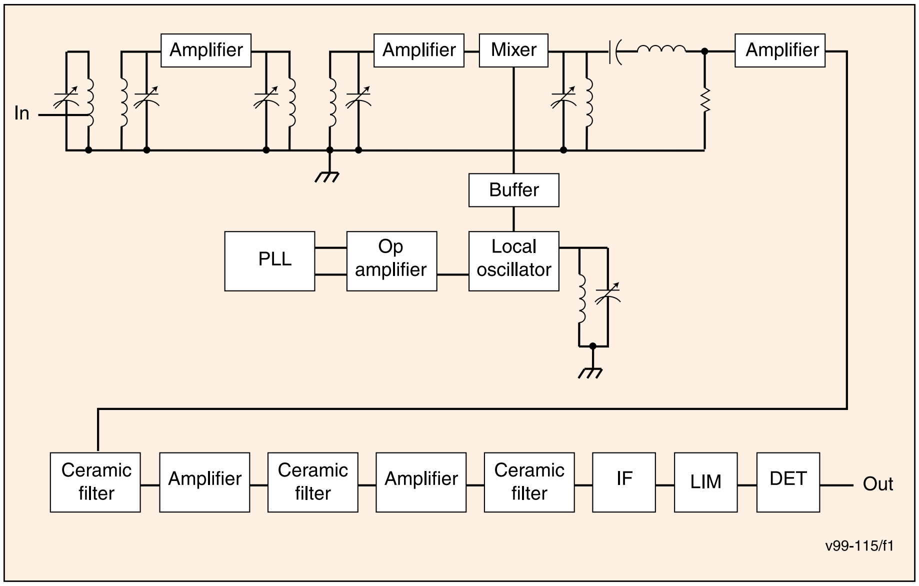

Figure 2. Block diagram of the SUPRX design.

mitters, all modulated with different program material. However, unless this is done with extreme care, the transmitters could intermodulate, filling the test slot with noise. In addition, this is a rather complex measurement method.

A third approach is to generate noise over the entire FM band with a narrow deep slot placed in the noise at the center of the FM band.

The ratio of noise in and out of the slot is defined as the noise power ratio. However, generating a slot in the noise with the required 1% bandwidth with steep skirts would be difficult. One approach might be to generate the noise at baseband, bandpass it from 2 to 10 MHz, and mix it up to the frequency of interest. Mixing and amplifying must be linear so as not to add noise in the slot. A noise power ratio of greater than 50 dB might be achievable. In fact, such a device was successfully constructed, with a measured slot noise depth of –30 to –58 dB, depending on the spectrum analyzer used, and with a spectrum analyzer bandwidth of 300 kHz (random noise is generated from 0 to 15 MHz). A block diagram and a schematic of the slot noise generator are shown in Figure 4.

Next, it is bandpassed from 2 to 10 MHz. The 2 MHz filter edge defines the width of the slot and the 10 MHz filter edge keeps noise out of the image frequency. Two filters were implemented to avoid slot noise depth problems. The signals were mixed up to 98 MHz using +17 dBm LO mixers. The two signals were then amplified and combined. A second combiner allows the addition of a test signal in the slot.

In the frequency plan shown in Figure 5, the baseband noise is down 3 dB at 2 and 10 MHz and down 60 dB at 1.5 and 17 MHz. Noise is mixed up to 97.35 MHz and 98.85 MHz for a center frequency of 98.0 MHz.

Figure 6 shows a slot noise width at about 2 MHz with a depth of about 56 dB using a Tektronix 7L14 or 2712. All slot noise testing was done with a spectrum analyzer bandwidth of 300 kHz.

Testing

Two test methods have proven useful in testing a receiver. When an individual assembly, such as an amplifier or mixer, is tested, it is connected to the output of the slot noise generator. The output of the device being tested is con-

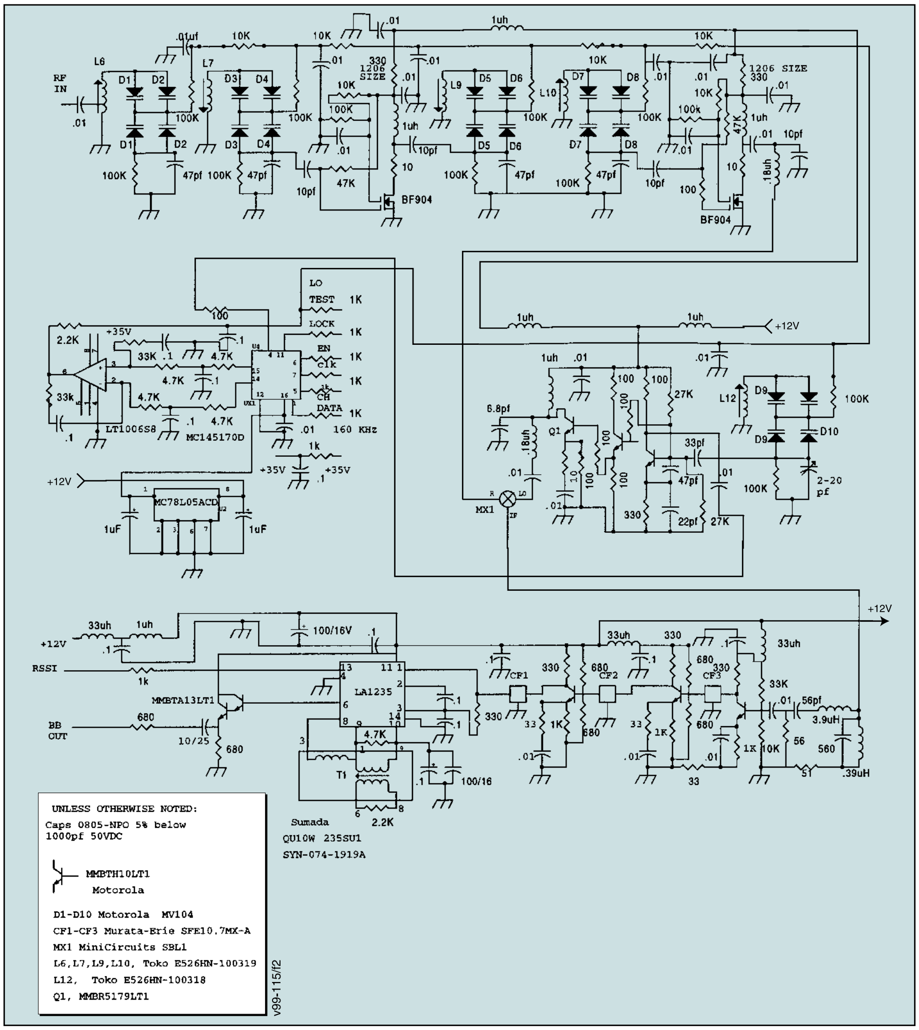

Figure 3.The receiver schematic.

	WJ	Pulsar	WJ	U signal	MCL
Ref level	M9E	CMPA26	M9G	X1111HP	SBL-1
–10 dBm	–46dB	–22dB	–25 dB	–20 dB	10 dB
–20 dBm	–48dB	–46dB	–36 dB	–40 dB	24 dB
LO level	+27dBm	+17dBm	+17 dBm	+17 dBm	+7 dBm

Table 1. Mixer slot noise level.

nected to a spectrum analyzer. Noise from the slot noise generator is increased until the device being tested becomes nonlinear; that is, noise in the slot goes up. An FET probe can be used if care is taken not to overload it.

When looking at overall receiver performance, another useful test is to add a carrier at 98 MHz into the second combiner. Carrier SNR can then be measured as a function of slot noise generator input power level.

For testing of the receiver, a noise level of –10 dBm and an analyzer bandwith of 300 kHz were chosen because they represent the signal levels measured near the Empire State Building and the Sears Tower using a power meter and bandpass filter. The slot noise depth is down about 56 dB for the front end. This level represents a compromise between improving the noise depth and meeting the development time schedule. It is possible that the noise depth could be reduced further. Other analyzers show less noise depth, probably as a result of their own LO sidebands or front-end nonlinearities. A receiver front-end noise depth of 50 dB provided satisfactory receiver performance for our tests.

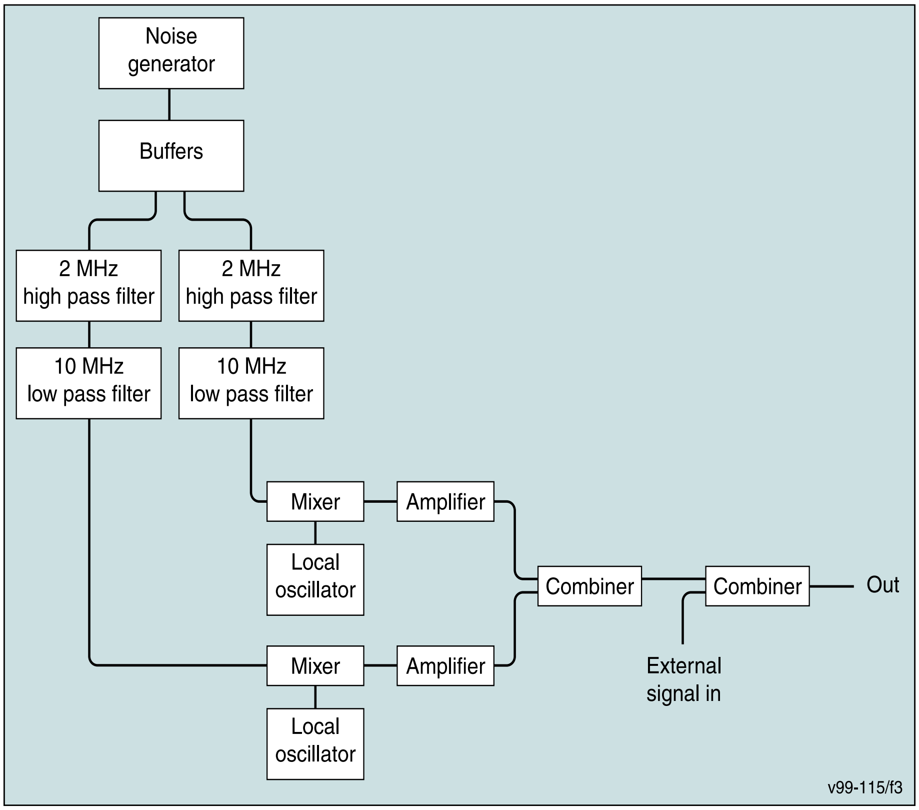

Figure 4. The block diagram of the slot noise generator.

Six receivers were tested using slot noise levels from –10 dBm to –70 dBm (see Figure 7). Receivers 1 and 2 were small, inexpensive and low power; receiver 3 was a tuner amplifier; receiver 4 was a commercial tuner used for FM rebroadcast; receiver 5 was a high-end tuner only; and receiver 6 was SUPRX.

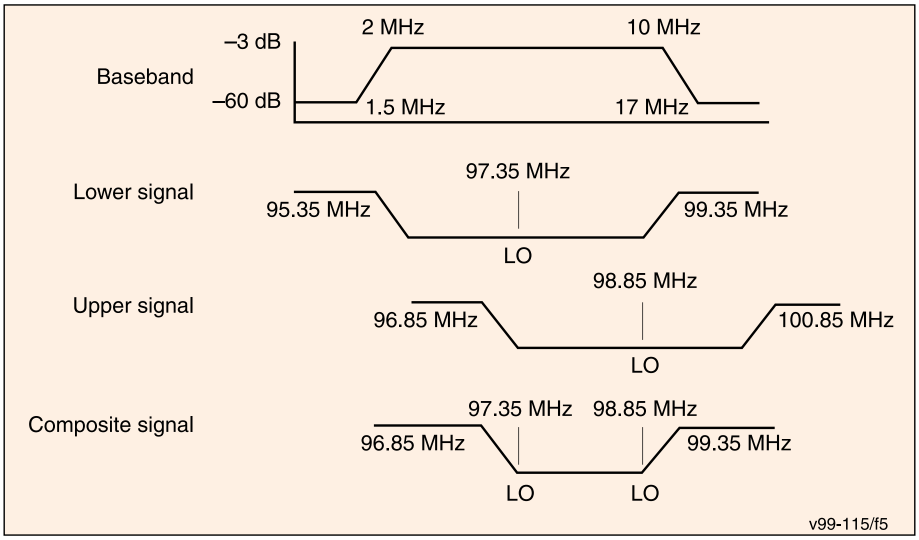

Figure 5. The slot noise generator frequency plan.

These tests were conducted using a digital subcarrier at 70 kHz, 9600 baud, and 7.5 kHz deviation. An arbitrary level of 90% good packets and 10% bad packets was used. As shown in Figure 8, receivers 1 through 5, at –10 dBm noise level, provided sensitivity between 20 and 300 mV (–22 to +3 dBm). SUPRX had a sensitivity of 280 µV (–58 dBm) or about a 45 dB improvement in average sensitivity.

As a final test, a weak station was listened to in the presence of many strong signals. The weak station was 100 µV, and the other stations were 2 to 20 mV. Eight tuner amplifiers, one high-end tuner only, and SUPRX were tested with the following results:

- *Four receivers*: Only noise was heard.
- *Three receivers*: Only sounds from

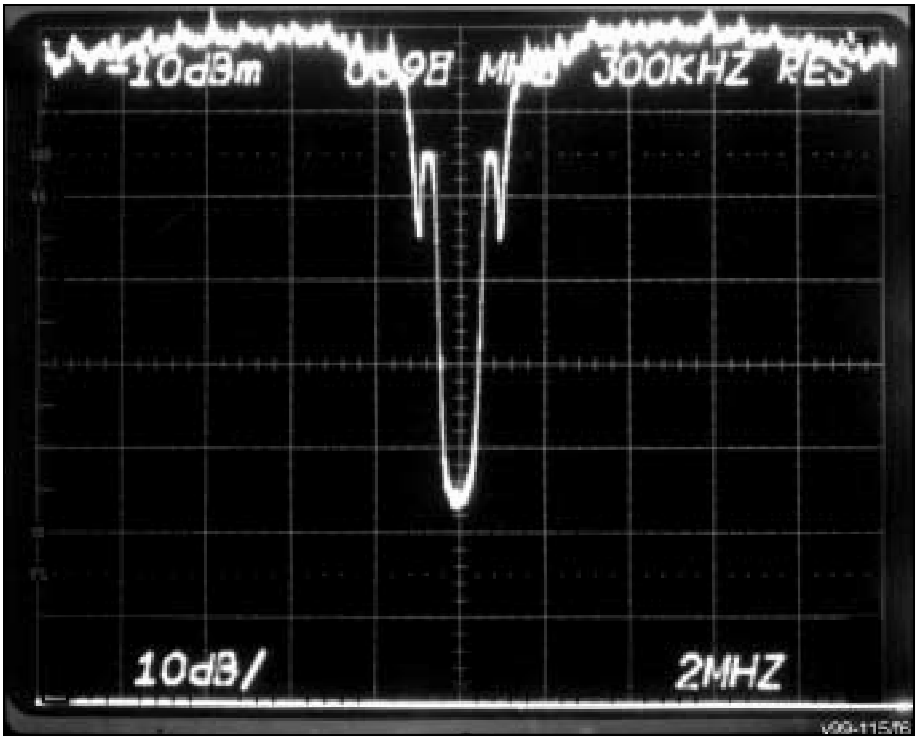

Figure 6. The slot noise generator spectrum.

other stations were heard.

- *Two receivers*: The station was audible in the background.
- *SUPRX receiver*: The station was audibly noise-free and had good stereo separation.

Conclusion

It has been shown that this design is more sensitive and offers lower distortion in demanding high-signal environments than conventional FM receivers. The design principles followed here (for the mixer, RF amplifier, and demodulator) and the evaluation method (using a slot noise generator), can be applied to other receiver implementations at any desired frequency.

RF

APPENDIX

SUPRX specifications

- Tuning range:
88 to 108 MHz in 200 kHz steps
- Input impedance: 75 Ω
- Sensitivity: 5 µv for 30 dB S/N
- Image rejection: 120 dB

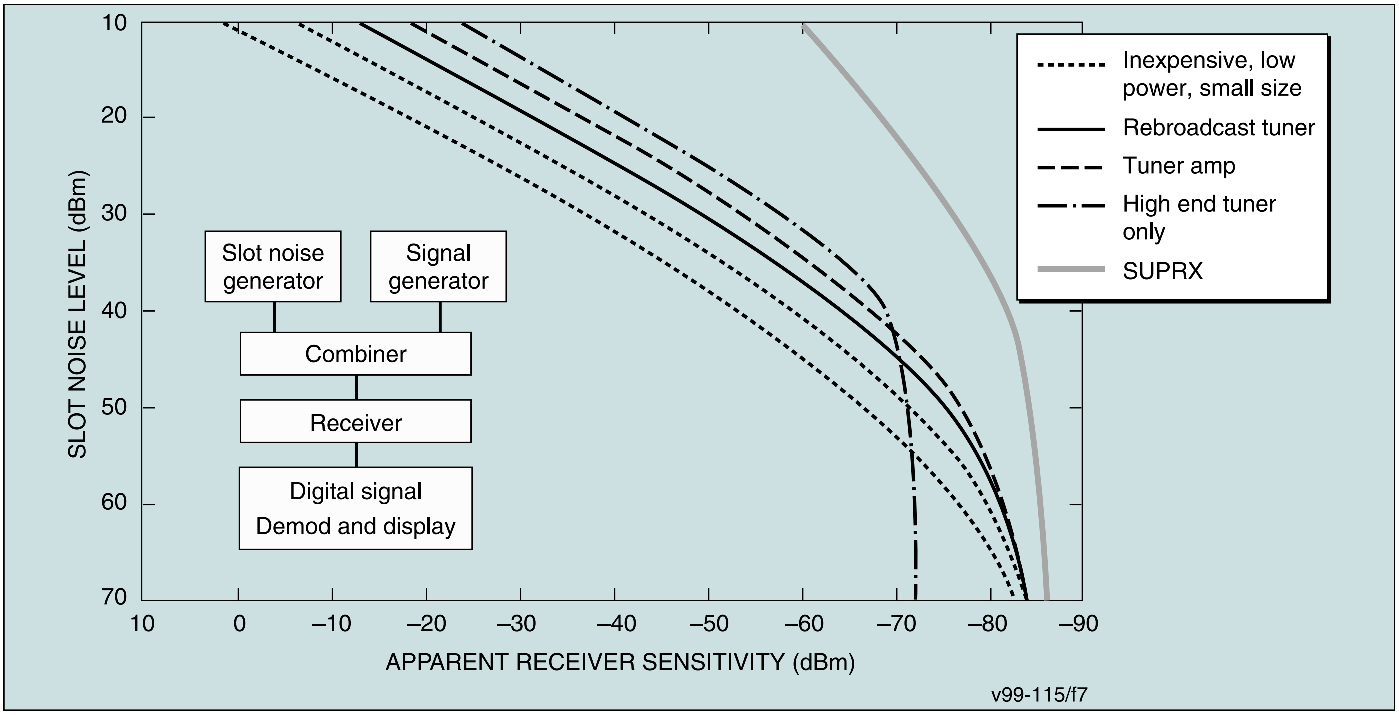

Figure 7. The slot noise level vs. apparent sensitivity.

- Tuning voltage: 7 to 30 V
- IF frequency: 10.7 MHz
- IF bandwidth: 200 kHz
- Capture ratio: 1.9 dB
- Baseband frequency response: 10 Hz to 100 kHz ±1 dB
- Harmonic distortion: –65 dB second and third harmonics using 6 kHz modulation and ±75 kHz deviation
- Dynamic range: 110 dB
- Demodulator output level: 1 V p to p for 100% modulation
- Demodulator output impedance: 1000 Ω

About the author

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