IMPROVEMENT OF RECEIVER SENSITIVITY AT 806-821 MHz WITH A TOWER MOUNTED PREAMP

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Prediction of "a specific system improvement" requires considerable knowledge of "specific equipment/component specifications", along with the details of their interconnection. Additionally, the ambient RF noise level will also limit the effectiveness of a tower mounted preamp, if all that is accomplished is the amplifying of a "noisy environment".

A particularly "noisy site" is usually already known by reputation, and if suspect, can be evaluated for tower mount preamp location by determining the noise floor of the site with a spectrum analyzer, preceeded by a preselector of the design used in the tower mount preamp. This test requires a high performance spectrum analyzer, and the test procedure is beyond the scope of this article. Practically, more sites suffer from intermodulation due to high level input from nearby mobiles, and sometimes, peculiar interaction with UHF site frequencies, where system antenna isolations may be too low.

A system with an improved sensitivity will also allow you to hear IM products you may not have been aware of before, and transmitter sideband noise may need to be suppressed to a greater degree in the transmit multicoupler.

Assuming we have a "clean environment" to work in, we will make a projection of system sensitivity under two different multicoupler configurations, one using a tower mounted preamp.

System "reference points" must be established for making a meaningful comparison. We will assume the same antenna is used for both systems, so the input to each system will be the transmission line immediately below the antenna. The end point of each system will be the receiver.

The first thing we must do is calculate the "system noise figure" for each configuration. Exhibit 1 is a calculation of system noise figure using a base receiver multicoupler and preselector only. Exhibit 2 is a noise figure calculation, using the same components of Exhibit 1, but with the addition of a tower mounted preamp assembly, now stage 1 in the calculation. The lower preselector and transmission line remains unchanged to more clearly show the system improvement due to the tower mounted preamp. It becomes evident that without tower top gain, tower transmission line loss is a critical factor in system performance.

Total system sensitivity is then calculated by inserting each system noise figure into the expression derived in Exhibit 3.

Three additional attachments used in support of this article are:

1. Typical test data for 421-86-01-TMP and 421-86-02-TMP Tower Mount Preamps.
2. DB-NUMERIC CONVERSION TABLE.
3. EXCERPTS FROM TECHNICAL ARTICLES USED TO ARRIVE AT AN EXPRESSION FOR RECEIVER SENSITIVITY.

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EXHIBIT 1
CALCULATION OF SYSTEM NOISE FIGURE WITH BASE RECEIVER MULTICOUPLER ONLY
806-821 MHz

This system is broken down into five discrete "stages" for insertion into the standard expression for total noise figure for multi-stage systems.
The input of the system is the antenna input to the tower cable. The total loss or gain of each "stage" is indicated in numeric form, which is necessary for this calculation. It is then converted back to NF in dB.

Stage 1 3.77 dB transmission line loss + 0.7 dB preselector loss + 0.2 dB cable to preamp = 4.67 dB. In numeric form:
NF1 = 2.93 , G1 = .357

Stage 2 23 dB preamp gain, 3.5 dB preamp noise figure. In numeric:
NF2 = 2.26 , G2 = 199.5

Stage 3 0.2 dB cable to preamp loss + 16.2 dB power divider loss + 0.2 dB cable to receiver loss = 16.6 dB loss. In numeric:
NF3 = 45.7 , G3 = .0218

Stage 4 Receiver noise figure = 9.2 dB. In numeric:
NF4 = 8.336

NF total

$$= NF1 + \frac{NF2 - 1}{G1} + \frac{NF3 - 1}{G1 \times G2} + \frac{NF4 - 1}{G1 \times G2 \times G3}$$

$$= 2.93 + \frac{2.26 - 1}{.357} + \frac{45.7 - 1}{.357 \times 199.5} + \frac{8.336 - 1}{.357 \times 199.5 \times .0218}$$

NF total = 2.93 + 3.53 + .627 + 4.73 = 11.82 numeric

NF (dB) = 10 LOG NF numeric = 10 LOG 11.82 = 10 x 1.072

NF (dB) = 10.72 dB. This is an overall system degradation of 1.52 dB when compared to the 9.2 dB receiver NF.

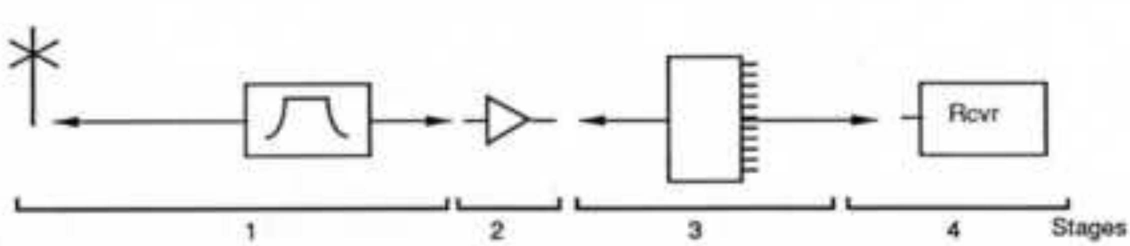


EXHIBIT 2
CALCULATION OF SYSTEM NOISE FIGURE WITH TOWER MOUNT PREAMP & BASE RECEIVER MULTICOUPLER, 806-821 MHz

This system is broken down into six discrete "stages", similar to that shown in exhibit 1, but with the addition of a tower mounted preamp/preselector at the base of the antenna. The balance of the system remains unchanged. Stage 1 is now the Tower Mounted Preamp and its associated lower control panel. The gain and noise figure values are taken from actual measurements made on the total tower preamp/control panel assembly. This Test Data Sheet is attached. The input of the system is the tower mount preamp, with stages 1 - 5 defined below.

Stage 1 — 22 dB gain, 3.5 dB noise figure, tower preamp/preselector ass'y.
NF1 = 2.24 , G1 = 158 numeric

Stage 2 — 3.77 dB transmission line loss + 0.7 dB base preselector loss + 0.2 dB loss, cable to base preamp = 4.67 dB loss.
NF2 = 2.93 , G2 = .357 numeric

Stage 3 — 23 dB gain base preamp, 3.5 dB noise figure.
NF3 = 2.26 , G3 = 199.5 numeric

Stage 4 — 0.2 dB cable to preamp loss + 16.2 dB power divider loss + 0.2 dB cable to receiver loss = 16.60 dB total loss.
NF4 = 45.7 , G4 = .0218 numeric

Stage 5 — Receiver noise figure = 9.2 dB.
NF5 = 8.336 numeric

$$\text{NF total} = NF1 + \frac{NF2 - 1}{G1} + \frac{NF3 - 1}{G1 \times G2} + \frac{NF4 - 1}{G1 \times G2 \times G3} + \frac{NF5 - 1}{G1 \times G2 \times G3 \times G4}$$

$$= 2.24 + \frac{2.93 - 1}{158} + \frac{2.26 - 1}{158 \times .357} + \frac{45.7 - 1}{158 \times .357 \times 199.5} + \frac{8.336 - 1}{158 \times .357 \times 199.5 \times .0218}$$

NF total = 2.24 + .0122 + .0223 + .0039 + .023
= 2.30 numeric

NF (dB) = 10 LOG NF numeric = 10 LOG 2.30 = 10 x .3610

NF (dB) = 3.61 dB total for system. This is a 5.59 dB improvement over the receiver alone, and 7.11 dB better than with the base receiver multicoupler system.

The improvement (or degradation) of the receiver sensitivity can now be calculated using the two system noise figures in exhibits 1 & 2.

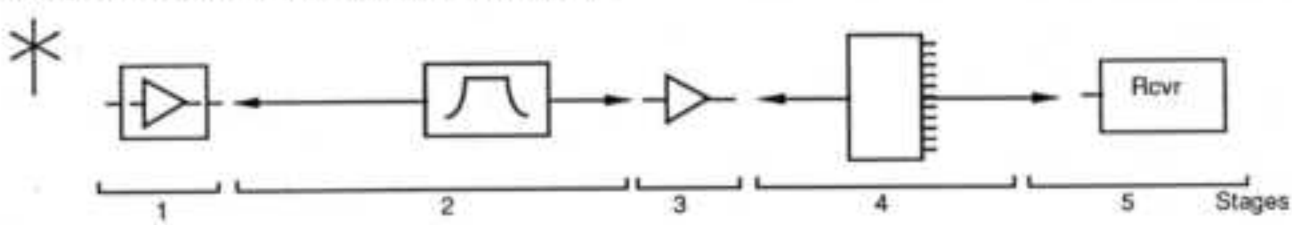


EXHIBIT 3
DERIVING AN EXPRESSION FOR THE CALCULATION OF SYSTEM SENSITIVITY FOR 800 MHz RECEIVE SYSTEMS

Drawing from the information found in various reference materials found at the end of this article, an expression is developed for the calculation of total system sensitivity.

Assumptions made may result in small differences between actual and calculated sensitivity values, but in relative terms, the improvement in sensitivity will agree well with actual performance, assuming that there are no other degrading factors.

The equation for receiver sensitivity is as follows:

$S = F\,B\,k\,T_o\,S_o/N_o$ .... where

- S = sensitivity in watts
- F = numeric system noise figure
- B = Rcvr bandwidth in Hz
- k = Boltzman's constant = 1.38×10^{-23} joule/deg K
- T_o = 290 deg k (room temp.)
- S_o/N_o = Rcvr output signal-to-noise ratio (numeric)

For a typical 800 MHz Receiver, the following assumptions are made:

1. The receiver bandwidth is estimated at 15,000 Hz.
2. S_o/N_o = 4 dB, (2.51 num.) which is the input signal-to-noise ratio presented to the FM detector for a 12 dB SINAD, assuming a 3:1 detector output-to-input ratio in the linear region.
   Comparing 20 dB quieting levels is almost impossible due to widely varying manufacturing characteristics.

Since these comparisons are being made with the same receiver, the only variable is the system noise figure.

$B\,k\,T_o\,S_o/N_o$ can be reduced to a constant = 15.067×10^{-11} microwatts

Therefore,

$S = F \times 15.067 \times 10^{-11}$ microwatts

For the receiver alone, F = 9.2 dB or 8.336 numeric

$S = 8.336 \times 15.067 \times 10^{-11} = 1.256 \times 10^{-9}$ microwatts,

or, S = -119 dBm = .25 microvolts at a 12 dB SINAD sensitivity.

This compares favorably with the performance of present commercial 800 MHz receivers.

EXHIBIT 3
IMPROVEMENT OF RECEIVER SENSITIVITY (con't)

The 12 dB SINAD sensitivity of the system using the base receiver multicoupler system only, can now be computed.

From EXHIBIT 1, NF total = 11.82 numeric.

$$S = F\,B\,k\,T_o\,S_o/N_o$$
$$= F \times 15.067 \times 10^{-11} \text{ microwatts}$$

$$S = 11.82 \times 15.067 \times 10^{-11} \text{ microwatts}$$

$$= 1.780 \times 10^{-9} \text{ microwatts} \quad , \quad (10^{-9} \text{ microwatts} = -120 \text{ dBm})$$

$$= -117.5 \text{ dBm}$$

$$= .30 \text{ microvolts} \quad \text{(1.6 dB less than the receiver alone)}$$

The 12 dB SINAD sensitivity of the system using the tower mount preamp and base receiver multicoupler is obtained using the system noise figure from EXHIBIT 2.

$$S = F\,B\,k\,T_o\,S_o/N_o$$
$$= F \times 15.067 \times 10^{-11}$$

$$S = 2.30 \times 15.067 \times 10^{-11} \text{ microwatts}$$

$$= .3465 \times 10^{-9} \text{ microwatts}$$

$$= -124.6 \text{ dBm}$$

$$= .135 \text{ microvolts}$$

This is a 7.2 dB improvement over the receiver multicoupler system without the tower mount preamp. If your transmission line loss is greater than 3.77 dB, you will still be able to maintain almost the same system improvement, up to about 10 dB line loss, since your signal-to-noise ratio has been established, and there is still 10 dB net gain at the bottom of the line. Compute it using EXHIBIT 2 and prove it yourself.

TEST DATA
421-86-01-TMP & 421-86-02-TMP
800 MHz TOWER MOUNT PREAMPS

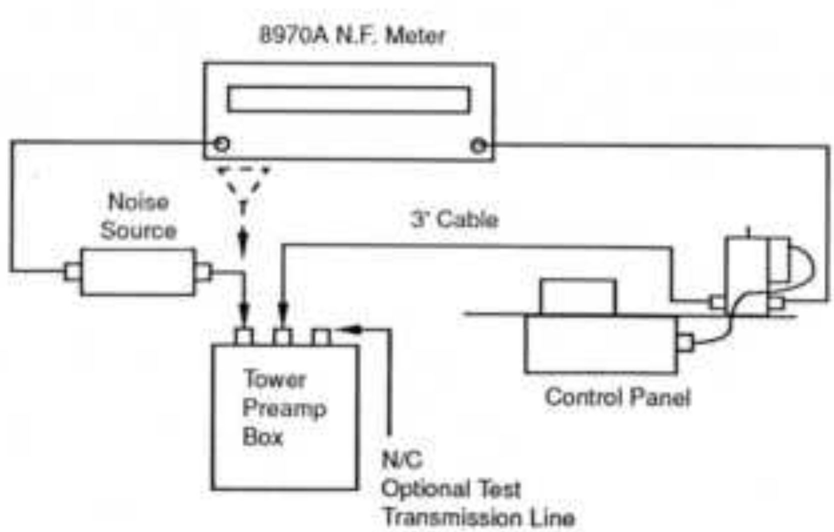
The following data is representative of the performance of our 800 MHz Tower Mount Preamps. The -02 series is provided with a self-test feature which adds about 0.5 dB to the system noise figure, and also reduces net tower top gain by 0.5 dB.

The tower box is connected to the lower control panel with a 3 foot length of RG-213/u cable. Since the net gain of the tower box is 20+ dB, the loss of the cable connecting the tower box to the control panel (simulating the tower transmission line) will have no practical effect on the noise figure measurement for cable loss factors up to 10 dB. This still results in a net gain of 10 dB, which is sufficient to prevent any appreciable degradation of signal-to-noise ratio.

The table of gain and noise figure readings are shown below for units with and without the self-test feature. Readings are taken with the primary preamp in operation. There is no appreciable difference in readings using the back-up preamp.

These readings were taken using a Hewlett Packard Automatic Noise Figure Meter, model 8970A.

	421-86-01-TMP		421-86-02-TMP	
FREQ. MHz	GAIN	NOISE FIGURE	GAIN	NOISE FIGURE
806	23.58 dB	3.19 dB	22.75 dB	3.67 dB
808	23.20 dB	3.31 dB	22.80 dB	3.77 dB
810	22.63 dB	3.48 dB	22.71 dB	3.70 dB
812	22.50 dB	3.40 dB	21.90 dB	3.79 dB
814	22.20 dB	3.42 dB	21.03 dB	4.24 dB
816	22.14 dB	3.38 dB	21.37 dB	4.21 dB
818	22.20 dB	3.41 dB	22.08 dB	3.78 dB
820	22.31 dB	3.37 dB	21.93 dB	3.71 dB
821	22.46 dB	3.37 dB	21.79 dB	3.90 dB



EXCERPTS FROM TECHNICAL ARTICLES USED IN ARRIVING AT THE EXPRESSION FOR CALCULATING SYSTEM SENSITIVITY AT 800 Mhz

From Electronic Design, Dec. '73. "Measuring VHF-FM Receiver Sensitivity", by John Slechta, U.S. Army Electronics Command, Fort Monmouth, N.J.

Noise figure defines ratio of ratios

Noise figure, F, is defined as a ratio of ratios. The ratios are the signal-to-noise at the input and output of a four-terminal network. In our case, the network represents the receiver.

Noise figure, a nondimensional quantity, can be stated mathematically as follows:

$$F = \frac{S_i/N_i}{S_o/N_o} = \frac{N_o}{N_i G_a}, \qquad (1)$$

where S_i = input signal power, $S_o = S_i G_a$ = output signal power, N_i = input noise power, N_o = output noise power and G_a = receiver power gain.

Since noise power, N_i, results from the source impedance, $N_i = kT_oB$ for the following simplification:

$$F = \frac{N_o}{kT_o BG_a}, \qquad (2)$$

where N_o = output noise power in watts, k = Boltzmann's constant, T_o = standard noise temperature—absolute room temperature in our case—and B = effective noise bandwidth in Hz.

The total output noise power, N_o, has two components: the amplified reference noise power due to the source impedance and the noise power generated in the receiver. Calling the receiver noise component N_r, we can write:

$$F = \frac{G_a N_i + N_r}{G_a N_i} = 1 + \frac{N_r}{G_a N_i} = 1 + F_r, \qquad (3)$$

where F_r is the contribution caused by receiver noise. If we have a noiseless receiver, F_r would be zero and F = 1. Thus F = 1 represents the lowest possible noise figure.

Noise figures are most often expressed in dB:

$$F_{dB} = 10 \log_{10} F. \qquad (4)$$

Thus a receiver having F = 1 has a 0-dB noise figure. In vhf receivers, noise figures are commonly in the range of 5 to 10 dB.

Often it's useful to calculate a receiver's sensitivity when its noise figure is known, or vice versa. From Eq. 2, we rewrite noise figure as follows:

$$F = \frac{N_o}{S_o} \frac{S_i}{kT_o B}. \qquad (6)$$

Note that S_o/N_o refers to signal-to-noise ratio, whereas receiver sensitivity is usually specified in terms of signal plus noise to noise ratio. The graph in Fig. 8 provides a means of converting from one to the other. Actually, if the (S + N)/N ratio is 10 dB or greater, the two ratios are almost equal and can be interchanged with only small error.

The bandwidth, B, used in the calculations is the noise bandwidth, defined as

$$B_n = \int_0^\infty \frac{G}{G_o}\, df, \qquad (7)$$

where G = relative power gain of the receiver and G_o = the maximum value of G. Obviously the noise bandwidth is difficult to calculate or measure in a receiver. Fortunately most vhf-FM receivers have either a crystal fi'ter or enough cascaded double-tuned circuits in the i-f so that the passband frequency response shape is essentially reftangular. For this case, we can assume the noise bandwidth to be equal to the receiver's 3-dB bandwidth without much error.

From Mobile Radio Technology. "GaAs FET Preamps Boost System Performance", by Louis N. Anciaux, Lunar Electronics.

Sensitivity

The sensitivity of most present day receiving systems is usually denoted in microvolts (μV) for some output level expressed in dB. This value can be readily obtained, using nothing more than a signal generator and some sort of indicator on the output of the receiver. To equate sensitivity to noise figure or noise temperature the system must be examined. A typical land mobile system might be specified as having a sensitivity of 0.25 microvolts for 12 dB SINAD. In order to equate sensitivity to noise figure, one other number must be known about the receiver: *the detection bandwidth.*

Most FM systems in use today feature 15-kHz bandwidths. A perfectly noiseless receiver with a 15-kHz bandwidth has an equivalent sensitivity of −132.24 dBm. That is approximately equivalent to 0.055 microvolt (μV) for 0 dB output. In this example, a 12 dB SINAD is a handy value because it is almost always equivalent to a 4 dB signal-to-noise input. Most FM detectors on the linear portion of their curve, have a 3:1 ratio of output to input. Therefore, a 12 dB SINAD output is equivalent to a 4 dB input signal versus noise level. It should be noted that 20 dB quieting is very much a function of the particular detector system being utilized and can vary dramatically from one manufacturer to another. Therefore, it is not a very practical number to utilize in evaluating differences between systems, at least insofar as their noise sensitivity is concerned.

Working backwards, taking the 0.25 μV for 12 dB SINAD specification, we find that it is equivalent to −119.02 dBm. However, since the 12 dB SINAD is equivalent to a 4 dB input signal level, 4 dB is subtracted, yielding a −123.03 dBm equivalent sensitivity at zero input signal level. Comparing this to the perfectly noiseless receiver, the difference is 9.21 dB. Therefore, the noise figure of 0.25 μVfor 12 dB SINAD receiver is 9.21 dB.

DB-NUMERIC CONVERSION TABLE

The following is a ready reference for converting dB to numeric values, necessary for insertion into common formulas for Noise Figure and Intercept Point, to name a few.

The numeric values for loss (-dB's) are always less than 1.
The numeric values for gain (+dB's) are always greater than 1.

Noise Figure, by definition, is a positive number, the numeric value being Input signal-to-noise ratio divided by Output signal-to-noise ratio. Noise Figure, in dB, is 10 x LOG of this numeric value.

GAIN (dB)	Numeric Ratio
1	1.259
2	1.584
3	1.995
4	2.512
5	3.162
6	3.981
7	5.012
8	6.309
9	7.943
10	10.00
11	12.59
12	15.84
13	19.95
14	25.12
15	31.62
16	39.81
17	50.12
18	63.09
19	79.43
20	100.0

LOSS (dB)	Numeric Ratio
-1	.794
-2	.631
-3	.501
-4	.398
-5	.316
-6	.251
-7	.199
-8	.158
-9	.126
-10	.100
-11	.0794
-12	.0631
-13	.0501
-14	.0398
-15	.0316
-16	.0251
-17	.0199
-18	.0158
-19	.0126
-20	.0100

For Gain values greater than 20 dB, various dB increments may be added, which means their numeric counterparts are multiplied to obtain the desired conversion.

EXAMPLE: 35 dB = 20 dB + 10 dB + 5 dB
= 100 x 10 x 3.162 = 3162 numeric

Loss values are computed similarly . . . . . .

EXAMPLE: -35 dB = (-20 dB) + (-10 dB) + (-5 dB)
= .01 x .10 x .316 = .000316 numeric