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PREAMPLIFIER NOISE IN VLF RECEIVERS

Rapid methods of estimating antenna preamplifier noise contribution to receiver performance are presented for JFET or CMOS transistors. An improved CMOS preamplifier circuit is suggested.

by

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I. SUMMARY AND CONCLUSIONS

Noise specifications for junction field-effect transistors are presented in different ways depending on the particular semiconductor manufacturer. A review of the arithmetic involved in converting these specifications to equivalent RMS noise in microvolts developed at the preamplifier input terminal is presented. The methods are useful for estimating the noise performance of high input impedance preamplifiers used with E-field antennas operating in the range of 1 KHz to 10 MHz.

Both the JFET MPF-102 transistor and the COS/MOS CA3600 transistor array can provide amplification for VLF receivers where the internally generated noise is well below the atmospheric noise level. The CA3600 transistor array can provide better performance because of the more symmetrical complementary MOS transistor transfer characteristics than a single N-type biased JFET transistor. The CMOS amplifier results in self-compensating gain characterisitics over a very wide temperature range from -55 to +125 °C. Another advantage is the symmetrical limiting characteristics which largely eliminates cross-modulation or harmonic generation caused by very strong out-of-band signals appearing at the antenna terminal.

II. NOISE FIGURE METHODS

Specifications for JFET transistors are frequently given in terms of the noise figure (NF) for a specified frequency range with a given input gate resistance. An example:

$NF_{dB} = 3$ dB at 100 KHz with 1 megohm gate resistance for a typical JFET.[1]

$$NF_{dB} = 10 \log \left(\frac{KT\,\Delta f + NR}{KT\,\Delta f} \right) \quad \text{(Reference [2])}$$

NR = noise power generated at receiver input (watts)

$KT = 4 \times 10^{-21}$ watts/Hertz at 290 °K

Δf = receiver bandwidth in Hertz.

For a simplified analysis, assume $NF_{dB} = 3$ dB

Then: $NR = (KT\ \Delta f)$

$$\frac{KT\,\Delta f + (KT\,\Delta f)}{KT\,\Delta f} = 2$$

$$10 \log 2 = 3 \text{ dB}$$

For a 20 KHz bandwidth receiver:

$$KT \ \Delta f = 4 \times 10^{-21} \times 2 \times 10^{4} = 8 \times 10^{-17}$$

Since NR for the 3 dB case is KT Δf, then total noise power generated is:

$$W = 8 \times 10^{-17} \text{ watts}$$

Convert this to equivalent RMS µv across 1 megohm input resistor:

$$W = \frac{E^2}{R} \quad \text{or} \quad E^2 = 8 \times 10^{-17} \times 1 \times 10^{6} = 8 \times 10^{-11}$$

$$E = \sqrt{8 \times 10^{-11}} = 8.9 \times 10^{-6} \text{ volts or } 8.9 \text{ microvolts.}$$

This 8.9 µ volts in a 20 KHz bandwidth receiver is the contribution of the input antenna preamplifier noise alone without any antenna connected.

III. NOISE CURRENT METHODS

MOS and CMOS transistors are often given a more direct noise specification. [3] An example for a dual complementary pair of the COS/MOS transistor array, RCA CA3600E:

Frequency Range	P +	N junction noise = total noise current	
1 KHz	.10	.20	.30 pA $\sqrt{Hz}$
10 KHz	.09	.11	.20 pA $\sqrt{Hz}$
100 KHz	.01	.03	.04 pA $\sqrt{Hz}$

where pA = picoamperes = $\times 10^{-12}$ amperes, assuming a source resistance of 1 megohm and a drain current I_D = 1 ma.

Convert this to RMS µv noise across a 1 megohm input R:

$$E = IR, \text{ where } I = .04\text{pA} \sqrt{Hz} = 4 \times 10^{-14} \sqrt{20,000} - 5.64 \times 10^{-12} \text{ amperes}$$

$$E = 5.64 \times 10^{-12} \times 1 \times 10^{6} = 5.64 \times 10^{-6} = 5.64 \text{ microvolts.}$$

A 20 KHz bandwidth receiver centered on 100 KHz is assumed.

IV. COMPARISON OF RECEIVER NOISE WITH ANTENNA NOISE

The atmospheric noise level in a 20 KHz bandwidth at 100 KHz is typically greater than 100 µv (40 dB above 1 µv/meter of antenna height). [4] The receiver noise in both these cases, 8.9 μv and 5.6 μv, is thus >20 dB below the atmospheric noise with the antenna connected except for very short antennas (≪1 meter). For Loran-C, when we define the S/N ratio with respect to the atmospheric noise bandwidth of the receiver, a zero dB S/N implies that the signal and noise are each about 100 μv. If the preamp has sufficient gain, then the contribution of the semiconductor noise is very small compared to the atmospheric noise which at times can exceed 60 dB above 1 μv/meter in a 20 KHz bandwidth system. [5]

V. IMPROVED PREAMPLIFIER

A new antenna preamplifier circuit has been devised which eliminates some of the problems of previous designs. The preamp uses one COS/MOS complementary pair from an RCA CA3600E transistor array. The RCA CD4007AE is pin-for-pin compatible with this IC and can also be used in the circuit shown in Figure 1. The amplifier has a gain of 10 dB (x3) which is limited by the output transformer loading. The circuit will drive a coaxial cable of about 20 meters length. The preamp is intended to be mounted directly at the base of a whip or wire antenna with the cable connecting to the receiver. Power for the preamplifier is directed on the same coax cable through a 680 ohm isolating resistor in the receiver. The preamplifier may be used to drive several different VLF receivers over the range of 10 KHz to 150 KHz. The upper frequency limit and output voltage gain are determined by this transformer. There is a compromise between achieving a high gain with a high-resistance primary winding and retaining a low-impedance output for driving the coaxial cable. Subminiature audio transformers with a 1.5k ohms to 500 ohm impedance ratio have been satisfactory over the range desired.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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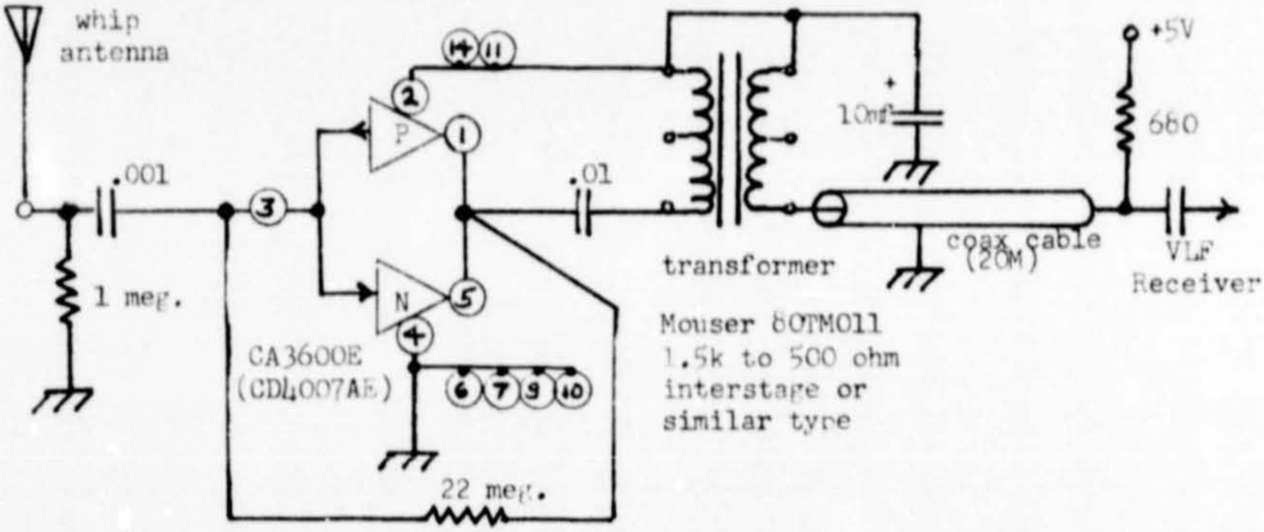

GAIN ≈ 10db, FREQUENCY RESPONSE ≈ 10 kHz to 150 kHz

Figure 1. CMOS VLF Antenna Preamplifier.