VHF Mixer Design Using the RCA-3N128 MOS Transistor

by

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The 3N128 is a vhf MOS field-effect transistor suitable for use throughout the vhf band (30 to 300 MHz) as an amplifier, mixer, or oscillator. This Note discusses some of the design criteria pertinent to the construction of MOS mixers, and presents an example of a complete vhf MOS converter.

Mixer Design Considerations

The conversion gain obtained from a mixer is the ratio of intermediate-frequency (if) power output divided by the radio-frequency (rf) power input. This conversion gain CG is usually expressed in dB, as follows:

$$CG = 10 \log \frac{if\ P_{out}}{rf\ P_{in}}$$

The value of CG approximates the gain of the active device operated as an amplifier (unneutralized) at the intermediate frequency, minus the rf losses at the input of the device. Practical mixers normally have a conversion gain of 3 to 5 dB less than their if-amplifier gain.

The 3N128 transistor has good gain and noise figure throughout the vhf band. Because it also has a nonlinear region of operation, it may be used as a vhf mixer to provide good conversion gain. The transfer function of the 3N128, shown in Fig.1, indicates that the maximum nonlinearities occur at a drain current of about 1.5 milliampere. At drain currents above approximately 5 milliamperes, the transfer function starts to become linear. No mixing action can occur if the transfer function is perfectly linear. Because the ampli-

fier gain of the 3N128 is higher at 5 milliamperes than at 1.5 milliamperes, the best bias point for an MOS mixer is a compromise between the region where best mixing occurs and the region where optimum if power gain occurs. For the 3N128, this point is empirically determined to be between 3.5 and 4.5 milliamperes.
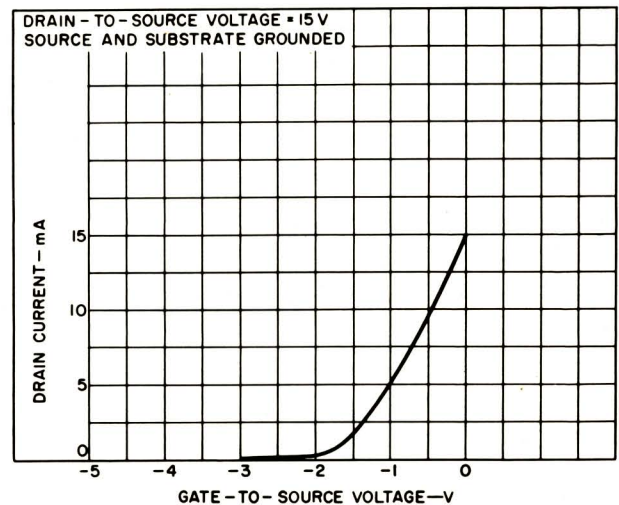

Fig.1 - Drain current as a function of gate-to-source voltage for the 3N128 vhf MOS transistor.

The local-oscillator signal may be introduced into a 3N128 mixer at the insulated gate, the source, or the junction gate (substrate). Application of the oscillator signal to the junction gate can be very effective, but is not recommended because the junction gate of the

3N128 is tied to the case; placing the transistor case at local-oscillator signal potential can pose possible radiation problems.

Injection of the oscillator signal at the source is not desirable because the source should always be at rf/if ground for optimum gain, but could not be at ground at the oscillator frequency. Designing a network to meet these criteria is difficult and adds to the cost of the mixer.

Injection of the oscillator signal at the insulated gate is the least troublesome of the three methods. The local oscillator may be coupled to the insulated gate by means of an inductive loop or a small coupling capacitor.

The input circuit is normally designed for a conjugate match with the input impedance of the MOS transistor at the radio frequency. The output circuit is normally designed for a conjugate match with the output impedance of the 3N128 at the intermediate frequency, unless electrical instabilities (oscillations) occur, in which case the output circuit must be mismatched. Oscillations are not normally a problem in a 3N128 mixer, provided the if and rf signals are relatively far apart in frequency. Under these conditions, the output circuit presents a low impedance to the rf signal, and the input circuit presents a low impedance to the if signal; consequently, oscillations at either frequency are unlikely to occur.

Neutralization is not generally used in mixers because of the different frequencies at the output and the input.

Design Example

A vhf receiver "front end" has been designed and built to demonstrate the preceding design considerations and to illustrate the use of the 3N128 vhf MOS transistor in all four stages: rf, mixer, if, and local oscillator. The complete converter, shown in Fig.2, uses an rf input frequency of 200 MHz and an if output frequency of 30 MHz.

The input stage is a straight-through 200-MHz amplifier* employing a source resistor for gate bias. This configuration permits the gate to be at dc ground, and greatly reduces the possibility of damage to the MOS gate from input transients. The 240-ohm resistor allows a current of approximately 5 milliamperes to flow through the device so that maximum vhf power gain is obtained. A variable inductor resonates with the output capacitance of the 3N128 to provide a bandwidth of approximately 12 MHz for the rf stage alone. (Narrower bandwidth could have been obtained by use of more capacitance in the tuned circuits and different loading on the output circuit; however, no particular effort was made to achieve very narrow bandwidth because a wide bandwidth is desirable in some applications.) Capacitive bridge neutralization is used to achieve the maximum allowable stage gain of 20 dB for the particular 3N128 used.

The input coil of the mixer stage is designed to permit a conjugate match with the transistor input admittance. The input admittance y_{11} of the 3N128 at 200 MHz is approximately $0.45 + j 7.2$ millimhos. Therefore, an admittance of y_{11}* (=0.45 - j 7.2 milli-
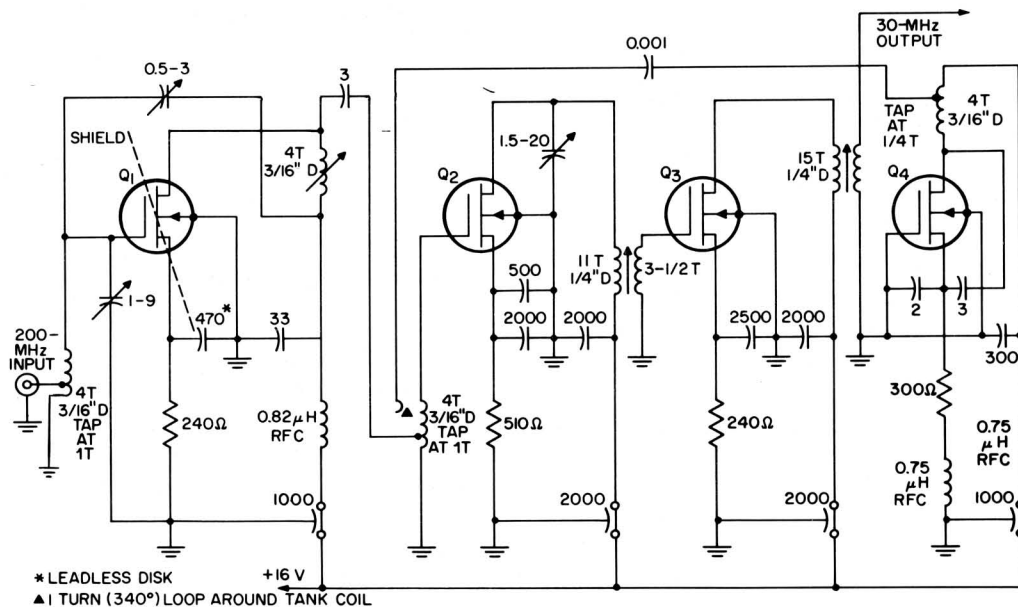

Fig.2 - VHF receiver "front end" using the 3N128 in all stages.

*LEADLESS DISK
▲1 TURN (340°) LOOP AROUND TANK COIL

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mhos) should be presented to the mixer input. A conjugate match is not used at the output because it is desirable to load the input of the following (if) stage for stability. Therefore, a step-down transformer is used. (A conjugate match would require use of a step-up transformer because $g_{11} > g_{22}$ at 30 MHz.)

The local oscillator is coupled into the insulated gate of the mixer by means of an ungrounded 340-degree loop placed around the input tank coil at its high-impedance end. A small coupling capacitor could also be used for this purpose. Local-oscillator amplitude is approximately 1.4 volts rms into the coupling loop. Power gain of the mixer stage is 16 dB. Fig.3 shows the conversion gain of the mixer as a function of local-oscillator amplitude. A lower oscillator level than 1.1 volts would probably be desirable if spurious output frequencies were found to be troublesome.
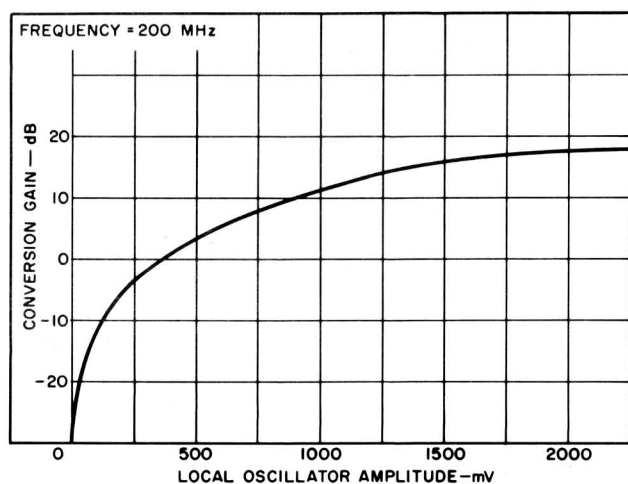

Fig.3 - Conversion gain of the mixer stage in Fig.2 as a function of local-oscillator amplitude.

A 510-ohm source resistor is used in the mixer stage to provide a drain current of 4 milliamperes. (This value is larger than would normally be expected for a drain current of this level because the gate is subjected to large signal excursions by the local oscillator.)

The maximum available gain (MAG) of the 3N128 at 30 MHz in a conjugately matched circuit (with y_{12} assumed to be approximately zero) may be computed from the y-parameters for the device, as follows:

$$MAG = \frac{|y_{21}|^2}{4\,g_{11}\,g_{22}} = \frac{|7.2|^2}{4\,(0.03)\,(0.12)} = 3610 = 35.6 \text{ dB}$$

The maximum usable gain (MUG) of the 3N128 in an unneutralized 30-MHz amplifier is computed as follows:

$$MUG = \frac{0.4\,g_m}{\omega C_{rss}} = \frac{(0.4)(7.2)(10^{-3})}{(2\pi)(30)\,10^6\,(0.13)\,10^{-12}} = 118 = 20.7 \text{ dB}$$

If the 30-MHz stage is operated at a gain significantly above the MUG value, the possibility of circuit oscillation exists. Therefore, the input of the if stage is mismatched to reduce the stage gain from the MAG level to about 20 dB. (In some cases, it may be easier to mismatch at the output than at the input.) The output of the if stage is transformer-coupled to a 50-ohm load.

The local-oscillator stage is a Colpitts circuit in which frequency is adjusted by means of a slug-tuned inductor.

The complete converter has a power gain of 56 dB, a noise figure of 3 dB, and a bandwidth of 1.5 MHz. Spurious responses (referred to a level of 0 dB at the 200-MHz input frequency) are -51 dB at 100 MHz, -36 dB at 215 MHz, and -35 dB at 260 MHz. These spurious responses could be greatly improved by use of a narrower bandwidth in the rf stage; the present bandwidth is 12 MHz at the 3-dB points.

Table I shows measurements of cross-modulation of the converter as a function of frequency.

Interfering Frequency (MHz)	Interfering Signal Voltage Necessary for 1% Cross-Modulation (mV)
50	160
90	115
100	87
110	98
120	97
130	87
140	78
150	77
160	65
170	52
180	39
190	9

Table I - Cross-modulation of MOS mixer.