Common base connection may be best choice in low noise, RF transistor amplifiers

On the surface a great disparity

According to two circuit designers at General Electric's Communication Products Department in Lynchburg, Va., the common emitter connection, which is usually recommended in the application of transistors to low noise RF amplifiers, may not be as good a choice as the common base connection for this purpose. They back their claim with some recent work that they've done to determine simple formulas for the Noise Figure and optimum source impedance—which they substantiated with actual measurements in this configuration.

Hall

Peppiatt

Results obtained by GE's J. A. Hall and H. J. Peppiatt indicate that a previous Noise Figure comparison between the common emitter and common base connections—to the apparent detriment of the latter—is not pertinent to many high frequency transistors which give very nearly the same noise performance in either connection. In addition, they say that the common base (CB) connection offers such features as wide dynamic range, and predictable linear input and output impedances. So, they decided to take a closer look at this design problem.

CB performance. On the surface, the great disparity between the normally encountered source impedance Z_g and the input impedance $Z_B = R_B + jX_B$ of the grounded base connection might be considered a deterrent to the use of this configuration. However, you need a severe mismatch for optimum Noise Figure and, if the available power gain of the stage is sufficiently greater than the power loss due to the mismatch at the input, the overall Noise Figure can be excellent. Furthermore, input circuit Q in the CB connection is relatively low so that you can achieve optimum performance over the complete flat portion of the device's Noise Figure response without input tuning.

Mismatched filter synthesis originally described by E. Green ("Amplitude Frequency Characteristics of Ladder Networks", Marconi Wireless Telegraph Co., Essex, England, 1954) is useful in designing selectivity into the input circuit if it is needed or unavoidable. An important application of this occurs in the IF amplifier used with low noise mixers where the RF bypass capacitor normally places a limitation on the bandwidth for a common emitter stage. In the CB situation, filters including the bypass capacitor may be synthesized with much larger bandwidths.

In further making the case for the CB connections, GE's Hall and Peppiatt point out that the CB input and output parameters are relatively insensitive to changes in transistors in a given circuit, and many different types can be used with only minor circuit adjustments. For most high frequency small signal transistors the CB input impedance is a series combination of the normal diode resistance $r_d \simeq 26/I_e$ and a small inductive reactance which is very nearly a linear function of frequency.

As for the dynamic range of the CB connection, the GE circuit designers say that it is superior to—and more predictable than—the common emitter connection. Linear signal current swung over nearly twice the dc bias current

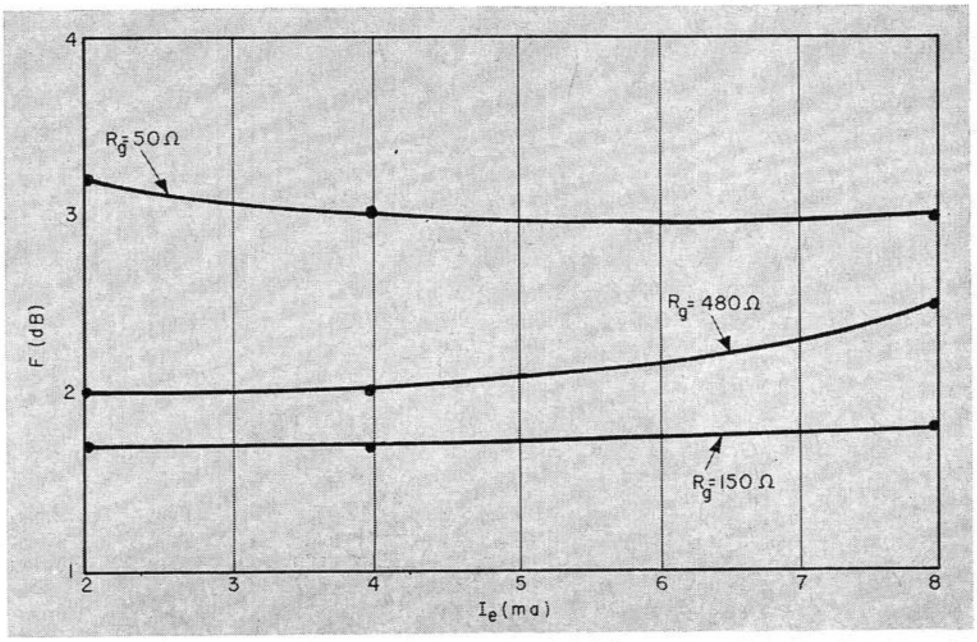

Fig. 1—Noise Figure at 70 MHz of a low noise, grounded base, germanium transistor stage for various source impedances.

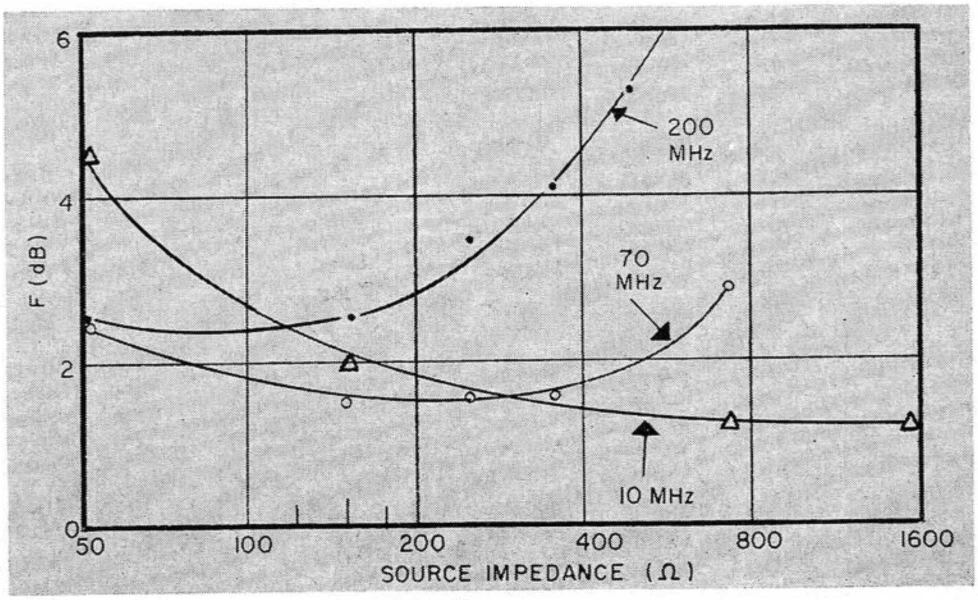

Fig. 2—Noise Figure for transistor with I_e = 2 ma.

is easily realized, they say. Maximum excursions in the emitter current cause large changes in the input resistance but the source resistance is usually sufficiently large so that the current into the emitter remains sinusoidal. In Fig. 1 measurements of the Noise Figure for a typical high frequency germanium transistor show a very mild variation with the dc emitter current, indicating that relatively high bias currents can be used for good dynamic range without sacrificing sensitivity.

Measured variations of noise figure with source impedance and frequency for a typical low noise germanium transistor appear in Figs. 2 and 3 while Fig. 4 gives you a feel for the source impedance-frequency interplay. In these measurements the collector current is 2 ma and the transistor is the same as that used to obtain the results of Fig. 1.

An approximate expression for the noise figure due to shot noise is

$$F \simeq 1 + \frac{R_{bb'} + R_e/2}{R_g} + \frac{qI_e}{2kT}\frac{f^2}{f_\alpha^2}R_g\left[1 + \frac{R_{bb'} + R_e}{R_g}\right]^2, \quad (1)$$

where $R_{bb'}$ is the base resistance, R_e is the resistance of the emitter-base diode, I_e is the emitter current, f is the frequency, f_α is the α cut-off frequency, R_g is the source resistance, q is the electronic charge, k is Boltzmann's constant and T is the temperature. This equation is based on the assumption that the dc common emitter current gain is large (> 200), that reactive impedances are low, that certain correlation impedances can be neglected, and that I_{eBO} is small. You can approximate the corresponding optimum source impedance for a given emitter current I_e by the relation

$$R_{go} \simeq \frac{f_\alpha}{f}\sqrt{\frac{R_{bb'} + R_e/2}{qI_e/2kT}} \quad (2)$$

for $f < f_{\alpha/2}$. In Fig. 4 you can see fair agreement between measured frequency variation of R_{go} and that predicted by Eq. (2). For this transistor ($R_{bb'} = 33\Omega$, $R_e = 20\Omega$, $I_e = 2$ ma) the f_α computed from Eq. (2) and the measurement of R_{go} is 460 MHz, corresponding to an f_T of about 300 MHz. The increase in optimum source impedance at the lower frequencies presents a difficult problem in the common emitter configuration which requires a lower source impedance for good stability at these frequencies. Conversely, the stability of the common base connection is improved as the impedance increases at these low frequencies.

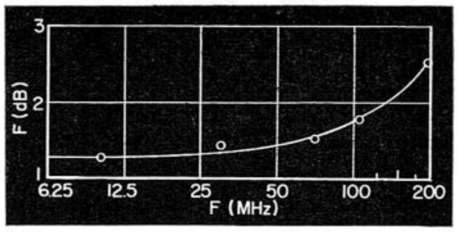

Fig. 3—Measured Noise Figure for transistor with I_e = 2 ma. Source impedance optimized at each frequency according to Fig. 4.

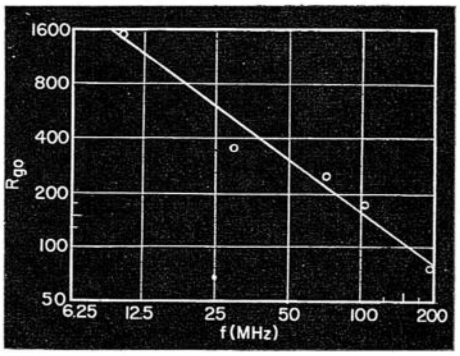

Fig. 4—Optimum source impedance.

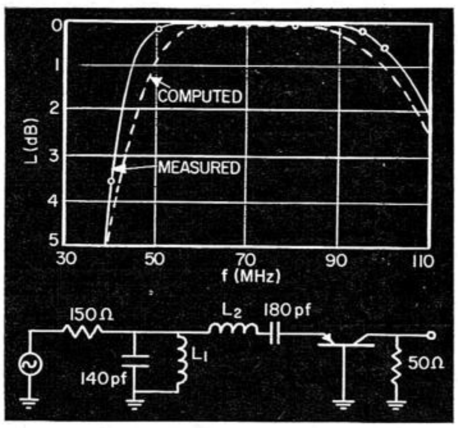

Fig. 5—Butterworth mismatched filter response and RF measuring circuit.

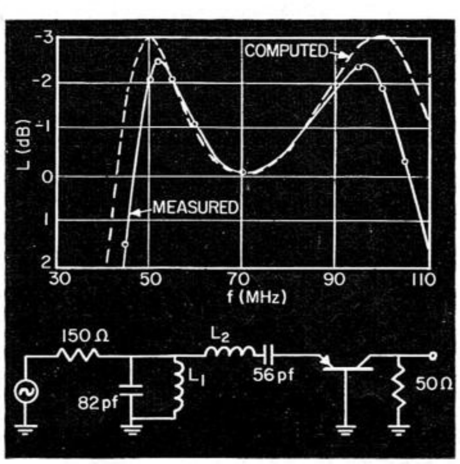

Fig. 6—3-dB Tschebycheff filter response and RF measuring circuit.

In some applications the CB configuration can be used without any input tuning. For example, the measured results of Fig. 3 were obtained with purely resistive source impedances even at the high RF frequencies.

To provide for selectivity which may be necessary at the input circuit of a grounded base stage, without deterioriating the Noise Figure, a filter section with mismatched terminations must be used. In addition to the filters synthesized by Green, which are quite useful for this purpose, symmetrical matched filters can also be connected to mismatched filters by bisecting and changing the impedance levels of one-half of the filter. Figs. 5 and 6 compare the measured and computed relative response of two different designs which use 150Ω as the source impedance with the emitter as the load.

L_1 and L_2 tune with the shunt and series capacitors respectively at a center frequency of 70 MHz. The Noise Figure using these circuits at about 70 MHz (Fig. 7) is good over a rather narrow region in the center of the loss-response curve because of the rapid off-band decrease in the source impedance presented by the filter. However, the extremely flat group delay response of these filter circuits would outweigh this slight disadvantage in many applications, Hall and Peppiatt emphasize. Other types of mismatched filters could be used, they say, to provide optimum noise performance over the full filter bandwidth. They further point out that in cases of extreme selectivity requirements, mismatched cavity filters can be used to advantage without incurring excessive losses. For more on this refer to a book by G. L. Matthaei *et al*, "Microwave Filters, Impedance-Matching Networks and Coupling Structures", published by McGraw-Hill in 1964. •

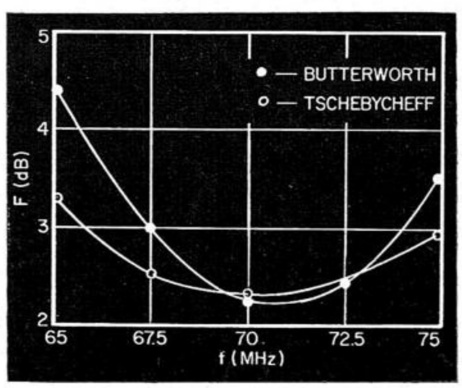

Fig. 7—Noise Figure of grounded base stage.