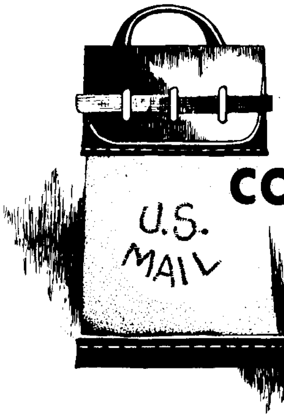


comments

microwave amplifier design

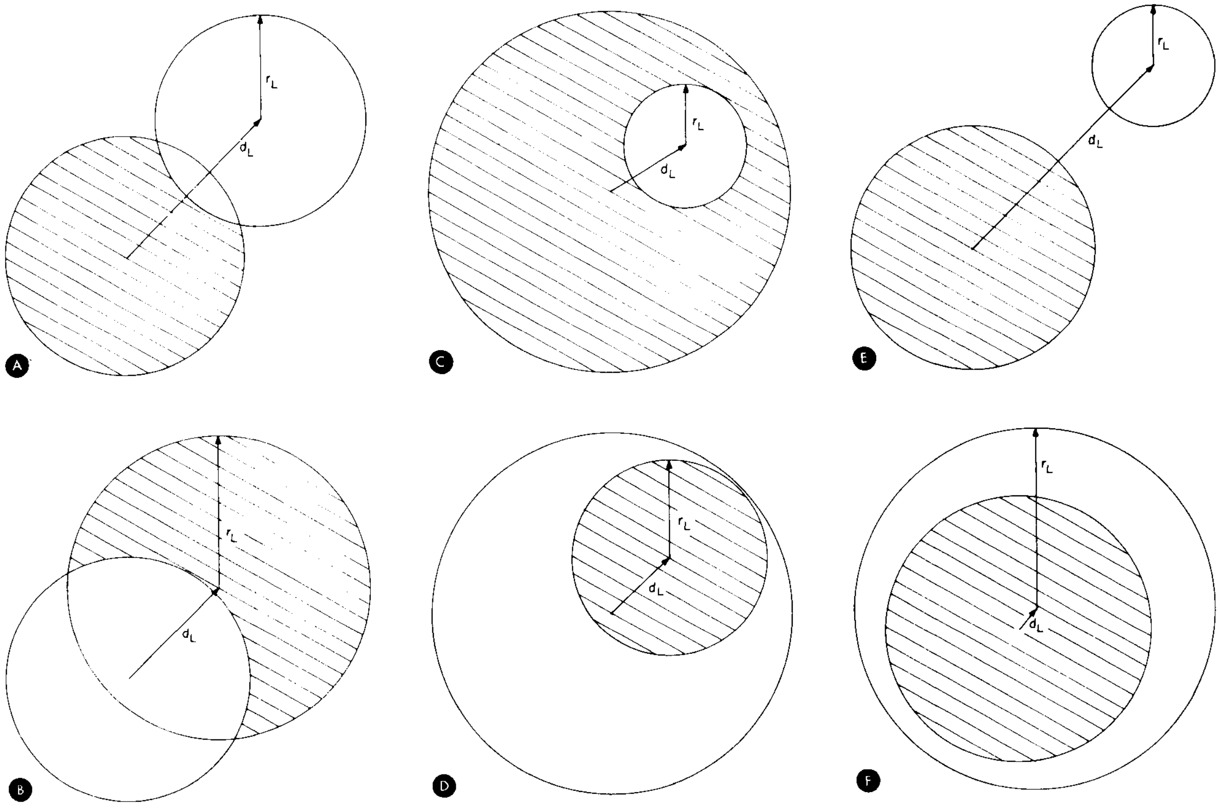
Dear HR:

I feel compelled to correct what I consider to be a serious error in Paul Shuch's otherwise well written article on "Solid State Microwave Amplifier Design" in the October, 1976, issue of *ham radio.*

Under the heading "Gain and Stability Analysis," Paul states that "If K (Rollet's stability factor) is greater than 1, the amplifier will be stable under any combination of input and output impedances or phase angles." This statement is incorrect, although it is understood how it is easy to make such a sweeping statement from a reading of HP Application Note AN-154 (Paul's reference 5) alone.

This fundamental error could be the reason why many amplifiers exist today which are only marginally stable, depending on antenna or load connections, despite their designer's belief that the amplifier is "unconditionally stable." The crux of the matter is that K greater than unity is a *necessary* condition for unconditional system stability, but not a *sufficient* one. Stability analysis of uhf amplifiers is far from as simple as Paul suggests.

First, it must be noted that the expression for the *device* stability factor, as I prefer to call it, is *independent* of either source or load impedance. To ensure a stable design, it



CONDITIONALLY STABLE K < 1

CONDITIONALLY STABLE K > 1

UNCONDITIONALLY STABLE K > 1

fig. 1. Stability circle analysis contributed by VK3TK.

is necessary to know the frequency range over which the system is potentially stable and the load and source impedances which can be used to give stable operation over this frequency range. This information requires that the device stability factor K be known over the frequency range of interest and the reflection coefficients S_{11} and S_{22} for the terminated network (these are not the device s-parameters).*

$$S_{11} = S_{11} + \frac{S_{12} \cdot S_{21}\Gamma_L}{1 - s_{22}\,\Gamma_L} = \frac{S_{11} - \Delta\Gamma_L}{1 - s_{22}\,\Gamma_L}$$

$$S_{22} = s_{22} + \frac{s_{12} \cdot s_{21}\,\Gamma_S}{1 - s_{11}\,\Gamma_S} = \frac{s_{22} - \Delta\Gamma_S}{1 - s_{11}\Gamma_S}$$

for Δ = determinant of device scattering matrix, *i.e.* $s_{11} \bullet s_{22} - s_{12} \bullet s_{21}$.

Since the source and load terminations being considered are passive networks, their reflection coefficients Γ_S and Γ_L will be less than unity. For a two-port network to be unconditionally stable, it is necessary that $|S_{11}| < 1$ for all Γ_L as Γ_L is changed arbitrarily, but kept so that $|\Gamma_L| < 1$. Similarly, it is necessary that $|s_{22}| < 1$ for all Γ_s as Γ_s is changed arbitrarily, with $|\Gamma_S| < 1$.

Consideration of the S_{11} and S_{22} equations shows that if $|s_{11}| > 1$, then any Γ_L will cause $|s_{11}| > 1$ and the network is potentially unstable for all Γ_L and the given Γ_S. Stability with respect to the input port will only then be obtained by ensuring that the positive real part of Z_s is greater than the negative real part of the input immitance. For the condition $|s_{11}| < 1$, the magnitude of s_{11} is less than unity for any passive Γ_L. Further consideration of the two equations shows that the whole Γ_L plane can be separated into two regions, one for which the input immitance is positive real — the stable region, and the other for which the input immitance is negative real — the unstable region. The boundary between these two regions can be defined by solving the relationship

$$|s_{11}| = 1.$$

Using

$$|S_{11}|^2 = S_{11} \cdot s_{11}{}^* = \frac{s_{11} - \Delta\Gamma_L}{1 - s_{22}\Gamma_L} \cdot$$

$$\frac{s_{11}{}^* - \Delta^*\Gamma_L{}^*}{1 - s_{22}{}^*\Gamma_L{}^*} = 1$$

it can be shown, with some algebraic difficulty, that the stable and unstable regions of operation are defined by a circle in the Γ_L plane (unit circle) where:

$$\text{center } d_L = \frac{C_2{}^*}{|s_{22}|^2 - |\Delta|^2}$$

$$\text{radius } r_L = \frac{|S_{21}S_{12}|}{|S_{22}|^2 - |\Delta|^2}$$

where d_L is located on a line through $S_{22}{}^*$ and the origin of the unit circle, and C_2 is as previously defined in WA6UAM's article.

Typical examples of stability circles are shown in the diagrams to the left. The region of the Γ_L plane which provides a positive real input impedance (*i.e.* $|s_{11}| < 1$) is indicated as follows:

1. If the stability circle *includes* the origin of the unit circle, the *inside* of the stability circle (within the unit circle) defines the area in which a selected Γ_L will result in a positive real input immitance.

2. If the stability circle *excludes* the origin, then the area of the unit circle *outside* the stability circle is the area of positive real input immitance.

The stability of the output port can be investigated wiith respect to Γ_S plane being given by:

$$\text{center } d_s = \frac{C_1{}^*}{|s_{11}|^2 - |\Delta|^2}$$

$$\text{radius } r_s = \frac{|S_{12} \cdot S_{21}|}{|S_{11}|^2 - |\Delta|^2}$$

The necessary conditions for a two port to be absolutely stable can now be stated: A two-port network is absolutely stable if there exists no passive source or load termination which will cause the system to oscillate. This is equivalent to requiring the unstable regions to lie outside the unit circles in the Γ_S and the Γ_L planes. This is satisfied if

$$|d_s| - |r_s| > 1$$

$$|d_L| - |r_L| > 1$$

$$|s_{11}| < 1\,|s_{22}| > 1.$$

The establishment of the possible regions of unstable operation inside the unit circle is a necessary prelude to the application of any design technique. Without knowing the constraints imposed on the system by stability requirements, it is pointless to proceed to determine the source and load reflection coefficients to meet some particular gain specification.

I hope this very brief resume has helped in some way to clear the air on this subject.

Graham J. Clements, VK3TK
Technical Director
Relcom Engineering
Melbourne, Australia

Graham Clement's letter is as fine an exposition on stability-circle analysis as I've read since William Froehner's article in the October 16, 1967 issue of Electronics. *And Mr. Clements goes further than that article by correctly pointing out that $K > 1$ is a necessary, but not a sufficient condition, for absolute stability.*

Although the stability circle analysis approach outlined by Mr. Clements appears entirely correct, I regard it as frosting on the cake. It is my belief, and confirmed by others, that the only conditions for absolute stability are $K > 1$, $S_{11} < 1$, and $S_{22} < 1$. In other words, an amplifier with $K > 1$ can oscillate only at the design frequency *if either the input or output impedance is negative. Since the rest of my design equations fall apart if S_{11} or S_2* are greater than 1, there is little danger of inadvertently designing an oscillator using the formula in my article.

The key here, of course, is the term "at the design frequency." Any transistor having $S_{11} < 1$, $S_{22} < 1$, and $K > 1$ at a design frequency may well

---

*A capital S is used to denote external network S-parameters; a lower-case s is used to describe device parameters.

exhibit $K < 1$, $S_{11} > 1$, *or* $S_{22} > 1$ *at some far removed frequency. Thus an amplifier which is unconditionally stable over a particular passband may indeed oscillate at some other frequency! This is another reason to use interstage isolators as described in the February, 1977, issue of* ham radio *(page 26), even for "unconditionally stable" amplifiers.*

Although I have not performed a rigorous analysis to prove that the three conditions for absolute stability are always $K > 1$, $S_{11} < 1$, *and* $S_{22} < 1$, *it has been proven empirically in countless amplifier designs by myself and others. I would be very interested in any careful analysis of this question which* ham radio *readers may care to undertake.*

H. Paul Shuch, WA6UAM
San Jose, California

antenna noise bridge

Dear HR:

The article on the improved RX noise bridge in the February, 1977, issue of *ham radio* was very well done; authors Hubbs and Doting have come up with an excellent solution to the accuracy problem of the original design by YA1GJM (*ham radio*, January, 1973). When designing and building antennas, RX measurements are a must and, considering the simplicity and accuracy of this improved noise bridge, my advice is, "Don't leave home without it!"

The range-extender idea is a very nice way to get added coverage for this instrument, especially for 80- and 160-meter work. For those using 300- or 600-ohm line the thought occurred to me that another version of the range extender assembly might be made except in this case the resistor would be placed in parallel with the *unknown* impedance instead of in series. For best accuracy the resistor should be nearly equal to the resistance of the pot, say 220 to 240 ohms, and the assembly should be constructed using as physically small a resistor as possible to keep down added stray capacitance.

One word of caution: (especially to hand-held calculator wielders) don't impute any greater accuracy to the computations than that of your original readings. If your reading accuracy was good to within 5%, the computed result isn't going to be any better just because you have it out to eight decimal places. This comment applies to either range-extension computation.

Forrest E. Gehrke K2BT
Mountain Lakes, New Jersey

Mr. Gehrke's suggestion for using a 220-ohm shunt range extender with the RX noise bridge is an excellent idea. The 100-ohm series resistor is

measured impedance of adapters

series adapter (output shorted)			**shunt adapter (output open)**		
frequency (MHz)	R_p	C_p	**frequency (MHz)**	R_p	C_p
3.5	101	0	3.5	165	5
7.0	100	0	7.0	165	5
14.0	100	0	14.0	165	4
21.0	100	− 1	21.0	165	3
28.0	100	− 2	28.0	165	3

Note: The small C_p offsets shown above are used to correct the C_p readings to have a 220-ohm resistor available, I used a 170-ohm resistor in the shunt adapter.

frequency (MHz)	R_p	C_p	**shunt adapter?**	**series adapter?**	**measured series impedance** R_s	**measured series impedance** X_s	**actual impedance** R_s	**actual impedance** X_s
test load 1 (350-pF capacitor)								
3.5	203	107	yes	yes	2	− 131	0	− 130
7.0	140	102	no	yes	− 1	− 63	0	− 65
14.0	109	33	no	yes	− 1	− 31	0	− 32
21.0	103	15	no	yes	− 2	− 21	0	− 22
28.0	102	6	no	yes	0	− 14	0	− 16
test load 2 (14-pF capacitor)								
3.5	165	20	yes	no	0	− 3000	0	− 3200
7.0	165	20	yes	no	0	− 1500	0	− 1600
14.0	165	19	yes	no	0	− 750	0	− 800
21.0	165	18	yes	no	0	− 500	0	− 540
28.0	165	18	yes	no	0	− 380	0	− 400
test load 3 (11.6 feet of RG-58/U, open circuited)								
3.5	237	230	no	yes	− 3	− 116	4	− 121
3.5	163	396	yes	no	1	− 115	4	− 121
7.0	152	433	yes	no	1	− 53	2	− 50
7.0	122	86	no	yes	1	− 47	2	− 50
14.0	101	0	no	yes	1	0	1	0
21.0	130	− 27	no	yes	8	− 48	3	50
21.0	150	− 125	yes	no	2	− 59	3	50
28.0	148	3	yes	no	~ 1400	0	~ 1500	0
test load 4 (1000-ohm carbon resistor)								
3.5	142	5	yes	no	~ 1000	0	~ 1000	0
7.0	142	5	yes	no	~ 1000	0	~ 1000	0
14.0	142	4	yes	no	~ 1000	0	~ 1000	0
21.0	142	3	yes	no	~ 1000	0	~ 1000	0
28.0	142	3	yes	no	~ 1000	0	~ 1000	0