By Dr. H. Paul Shuch,* N6TX

# DR. SETI'S STARSHIP

## Searching For The Ultimate DX

# The Strange Case of the Oscillating Amplifier

I had an interesting technical query recently from James Brown, W6KYP, an amateur radio astronomer and active SETI League member. Jim has been engaged in the microwave search for possible extraterrestrial signals since 1977, an ongoing effort which garnered him the Giordano Bruno Memorial Award, the SETI League's highest technical honor, back in 2005. He was having problems with his low-noise preamplifier, as he explained in an e-mail:

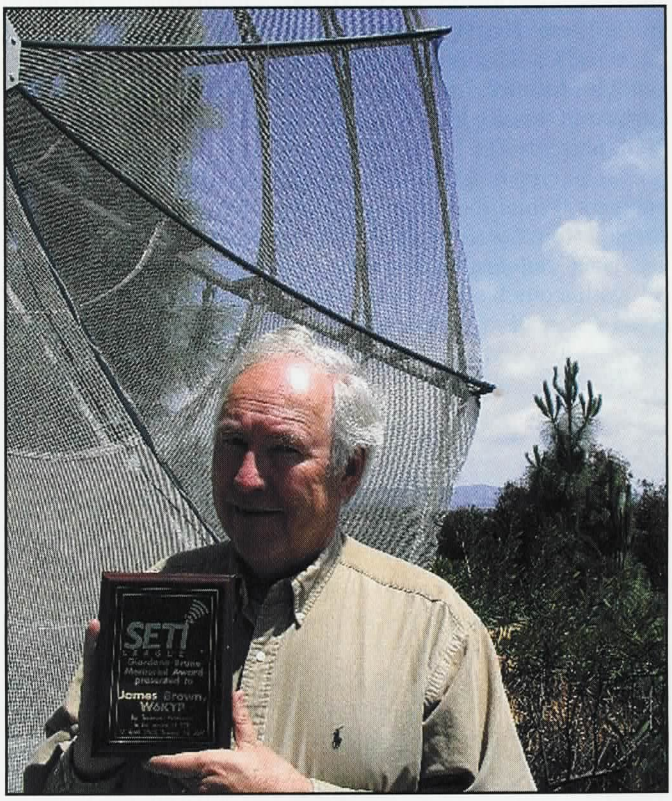
> My system has been acting strangely for a while, so I took the Head End electronics down, pulled out the LNA (Radio Astronomy Supplies, 28 dB gain), and set it up on my bench. When I have the LNA input terminated in a good 50 ohm terminator, I get –36 dBm out of the LNA as measured on my HP Power Meter and 8484 sensor. I don't see anything on my spectrum analyzer, but it only goes to 1.5 GHz so it may be oscillating at a higher frequency. The power supply is solid and quiet. Question: What should I see on a terminated LNA that is working right?

The problem of oscillating amplifiers (call them oscifiers, if you wish) has been with us since first hams discovered the concept of regeneration, so it's not surprising that Jim suspected amplifier instability for causing his problems. An oscillator is, after all, just an amplifier with infinite gain. Let me explain:

We define gain as the ratio between output-signal and input-signal levels. Now whenever there is an output signal, we should be able to reduce the input signal level and watch that output decrease accordingly. This response would indicate a stable, linear amplifier. Sometimes that doesn't happen; we reduce the input and the output signal doesn't go down. Such a response would represent an instable (or extremely nonlinear) amplifier. As the input signal approaches zero, for a constant output, we can say that the gain of the amplifier is approaching infinity.

Of course, dividing by zero is mathematically prohibited. Therefore, we can never really achieve infinite gain, but we can get the same effect by feeding some of the output signal back into the input circuit, in the proper phase relationship. This is how we build oscillators—make an amplifier and introduce regenerative (in-phase) feedback.

Often, feedback occurs when we don't want it to. It's easy to see why. In a simple vacuum-tube triode amplifier, for example, the grid may be the input and the plate circuit the output. Both grid and plate are pieces of metal separated by an insulator (vacuum), so a capacitor exists between output and input, which can facilitate feedback. For this reason, we often have to neutralize triode amplifiers (modify the feedback path so as to prevent oscillation). A similar situation exists in solid-state amplifiers, of course, because a reverse-biased semiconductor junction is also a capacitor.


*Jim Brown, W6KYP, with his radio telescope and Bruno Award plaque. (W6KYP photo)*

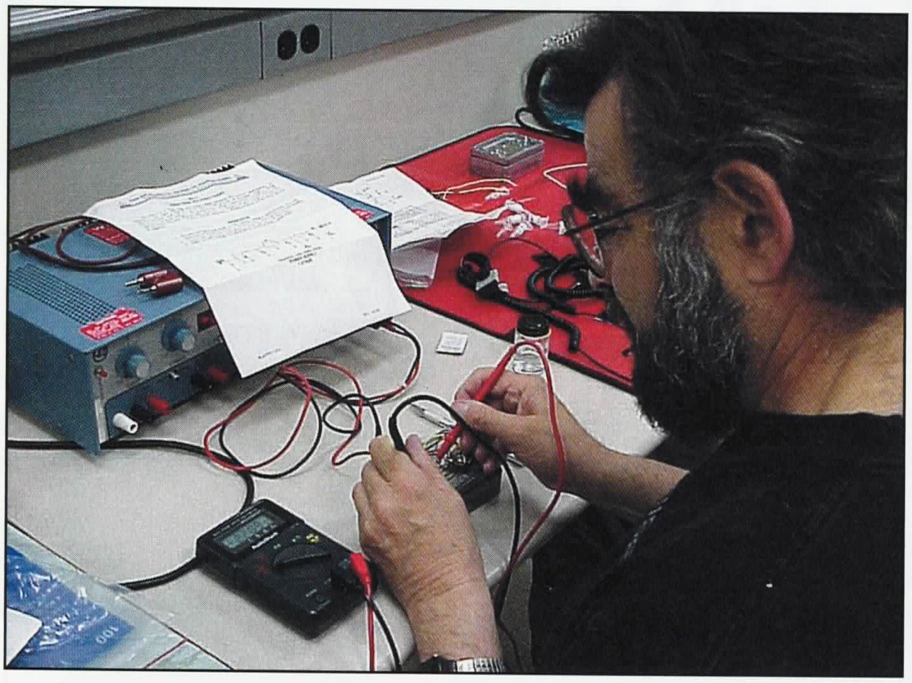
Early in my engineering career, I worked for an aerospace company designing microwave amplifiers. Mine got a reputation for being oscillation-prone (OK, so were everybody else's; the state of the art was not very mature back then). When one of my colleagues needed an oscillator for a particular application, a coworker once told him, "Just ask Paul to design you an amplifier."

When you terminate the input port of an amplifier in its characteristic impedance (say, with a properly matched dummy load), you would think that there could be no input signal. Thus, any signal present at the output would be caused by feedback, and an indication of oscillation. Jim Brown was thinking along these lines when he ran the power-meter test described in his e-mail. But in fact, there is *always* an input signal generated within the dummy load, unless it is chilled to absolute zero. This signal is thermal noise, which varies with temperature. If present, it will be amplified by the gain circuit and result in a possibly measurable output signal. Jim's question, in effect, was: "How much thermal power should I see at the output of my amplifier?"

As a first order approximation, let's consider the amplifier's noise figure to be near zero. That is, its internally generated noise is negligible—it is a *low noise* amplifier, after all. Thus, all we have to do now is calculate the thermal noise generated by the dummy-load resistor.

---

**Executive Director Emeritus, The SETI League, Inc., <www.setileague.org>*
*e-mail: <n6tx@setileague.org>*



*Astrophysicist Malcolm I. Raff, WA2UNP (SK), assembling and testing a low-noise preamplifier at The SETI League's 2003 technical symposium. Mal's amplifier did not oscillate! (N6TX photo)*

Let's consider that load resistor to be a perfect thermal black body. Boltzmann's Law says its noise power (in watts) equals kTB. In this equation, k is Boltzmann's Constant ($1.38 \times 10^{-23}$ Joules/Kelvin). T is the physical temperature of the black body, in Kelvins (for lab temperature, you can assume 300K). And B is the bandwidth in which the noise power is being measured, in Hz (that is, cycles per second).

Invoking unit analysis, we can prove that the Boltzmann equation is dimensionally consistent:

$$\begin{aligned} kTB &= (\text{Joules/Kelvin}) \times (\text{Kelvins}) \\ &\quad \times (\text{Cycles/Sec}) \\ &= (\text{Joules/Sec}) = \text{Watts} \end{aligned}$$

Now since Jim was measuring noise with an HP 8484 power sensor, whose passband is 10 MHz to 18 GHz, one might assume the bandwidth B to use in this calculation to be about 18 GHz. However, remember that the power sensor is going to be placed at the *output* of an amplifier with a much more modest bandwidth. Thus, the only part of the load resistor's noise power that counts is that part within the LNA's passband. Let's say the SETI LNA passes frequencies from 1.3 to 1.7 GHz. That's a 400-MHz bandwidth, which is what we'll use for B in Boltzmann's Equation.

OK, let's calculate. Noise power Pn (coming out of the load resistor, in the amplifier's passband) is kTB:

$$\begin{aligned} Pn &= kTB \\ Pn &= (1.38 \times 10^{-23}\ \text{J/K}) \times (300\ \text{K}) \times (400 \times 10^{6}\ \text{Hz})\ Pn \\ &= (1.66 \times 10^{-12})\ \text{watts} \\ &= 1.66 \times 10^{-9}\ \text{mW} \end{aligned}$$

Converting to logarithmic measure, that's a power level of –88 dBm.

This is the noise power that gets amplified by the LNA. Jim's LNA has 28 dB of gain, so the –88 dBm of noise, after being amplified, comes out of the amplifier at a level of –60 dBm.

OK, now the noise Jim was seeing on the power meter is –36 dBm, which is a whopping 24 dB stronger than the noise he should be seeing. That's a power level about 250 times higher than it should be. From this I conclude that yes, W6KYP's amplifier is probably oscillating.

How's that for a long answer to a simple question? My main point is, the noise power coming out of a properly operating amplifier is entirely calculable (and now you know how to calculate it).

73, Paul, N6TX

## Author's Note:

Dr. SETI thanks Kevin Murphy, ZL1UJG, for pointing out a glaring mathematical error in an early draft of this column.