Six Things about Giga-tronics Microwave Power Amplifiers

Application Note

High-Performance Microwave Power Amplifiers

The Giga-tronics Microwave Power Amplifiers offer linear high-power amplification across multi-octave bands. They are ideal for testing in EMC, wireless communications applications and Defense test systems, allowing broadband testing without band switching or swapping narrow band amplifiers resulting in faster and more accurate testing. The amplifiers can be used in wireless communications and component testing wherever a highly linear amplifier is needed. The following six reasons demonstrate why the Giga-tronics Microwave Power Amplifiers are the best solutions for meeting your most demanding amplification needs.

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1 Replacing TWTAs with Solid-State Amplifiers

The replacement of Traveling Wave Tube Amplifiers (TWTA) with solid-state power amplifiers in the test equipment market has significantly impacted electromagnetic interference (EMI), safety, and measurement accuracy. Tubes characteristically have high noise floor and poor intermodulation and harmonic signatures. Since they typically take time to warm up and stabilize, tubes are often left on, making them a potential safety issue, as well as a potential cause of EMI. Solid-state amplifiers require no warm-up, so they can be turned on and off as needed, eliminating concerns about significant short and long term stability, safety, and EMI issues.

Spatial power combining parallel-MMIC amplifiers[1] augment traditional power amplifier architectures and expand the market space of solid state power amplifiers into the domain traditionally dominated by vacuum electron devices (VEDs) such as traveling wave tube amplifiers (TWTAs). Parallel-MMIC amplifiers provide the stability and reliability associated with solid state amplifiers as well as exceptionally broad bandwidth and high power. Spatially-combined amplifier's manufacturability, scalability, linearity, efficiency, and thermal packaging are generally superior to circuit-combined amplifiers. Characteristics of parallel-MMIC amplifiers include excellent linearity relative to VEDs, graceful degradation on failure, low voltage operation, solid state reliability, low intermodulation and harmonic distortion, flat gain without equalization, and good phase noise characteristics. They are fault tolerant, so that the loss or failure of one or even multiple elements does not result in total system failure, and they do not have the warm-up, drift, or aging issues associated with TWTAs.

With spatial power combining parallel-MMIC amplifiers, the combining losses are low and power is not wasted in the combining scheme, the operational efficiencies are maximized, resulting in lower heat dissipation and less prime power for a given power level. Also, because of the high number of combined elements, the root mean square (RMS) phase noise of the amplifier is less than that of a single comparable device and significantly lower than what might be expected from a TWTA.

As GaAs MMIC semiconductor technology and capability improves with even greater power at microwave frequencies, parallel-MMIC solid-state amplifiers using spatially power combining technology will continue to increase their ability to provide an alternative solution to TWTAs. Applications traditionally dominated by TWT or VED solutions, such as test and measurement, electronic warfare, electronic counter measures, and simulators, can now take advantage of all the associated preferable performance attributes of solid-state implementation including: higher reliability, low-voltage operation for safety and reliability, longer life, low thermal noise characteristics for improved signal-to-noise ratios, and improved linearity.

[1] "Finally – The Spatial Frontier," Scott Behan, CAP Wireless, MPDigest, September 2008

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Many TWTAs are used in pulsed applications. While solid-state amplifiers have not reached the same high power levels available in TWTAs, moderate power have been achieved, with superior results. Pulsed TWTAs are limited in pulse width (typically less than a few milliseconds) and duty cycle (typically less than 5%), and have a relatively high noise power density when on. They may also exhibit a substantial delay from the time of the pulse input to the start of the RF pulse.

The Giga-tronics microwave power amplifiers offer outstanding pulse performance, with 3 ns nominal rise and fall times, with minimum overshoot and ringing. Because these are very broadband amplifiers, they do not exhibit the pulse performance limitations common to narrowband amplifiers. The Giga-tronics microwave power amplifiers with excellent pulse fidelity are ideal for many Aerospace and Defense applications.

Additional considerations include linearity and AM-PM conversion. TWTAs have a power rating defined by their peak power output capacity and must be operated substantially (typically 6 dB or more) below their rated saturated output power for linear performance. Solid-state parallel-MMIC amplifiers have a linear range to the P1dB power level typically only 1 or 2 dB below their rated saturated output power. That is, a 10 Watt solid-state amplifier will offer equal or better linear performance compared to a 40 or 50 Watt TWTA. The same applies to AM to PM conversion. While solid-state amplifiers exhibit little AM-PM conversion up to the P1dB power level, TWTAs must be backed off 10 dB or more from their rated saturated power before achieving minimal AM-PM.

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The following table summarizes performance comparison between spatially combined solid-state Parallel-MMIC amplifiers and TWTA's.

Parameter	Solid-State Power Amplifier	TWTA
Frequency Limit	~ 50 GHz	~ 50 GHz
Bandwidth Capability	Decade or more	One to Two Octaves
Noise Figure	< 10 dB	> 25 dB
Gain	Medium	High
Gain Flatness	± 3 dB	± 8 dB
Harmonics at P_{1dB}	< 20 dBc	0 to -6 dBc
Phase Noise and Thermal Noise Power	Low	High
Load Mismatch Tolerance	Good	Poor
Required Warm-up	None	3 to 5 Minutes
Reliability	> 100k Hours	< 10k Hours

Lastly, solid-state amplifiers operate at low voltage compared to the kilovolts required for TWTA operation relating to increasing safety, and lower cost and complexity.

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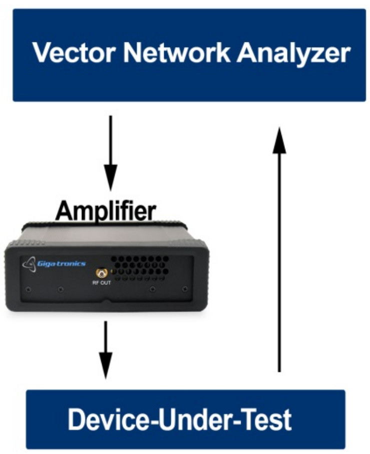
2 Amplifiers in ATE Systems and with VNAs

The Giga-tronics microwave power amplifiers are often used for boosting test signals to overcome cable and connector loss whenever long cable runs are needed in assembly bays, environmental test chambers or field locations. Significant power can be lost in cables and connections at higher frequencies. The best quality low-loss microwave cable is about 0.35 dB per foot at 20 GHz, and 1 dB per foot at 40 GHz.

With an amplifier near the device-under-test, significant power is still lost in the cable, but full power from the amplifier is available at the DUT. The high gain of the amplifier compensates for the loss in the cable, and puts the amplifier power where it is needed.

The Giga-tronics microwave power amplifiers were originally developed for the purpose of boosting available power from test and measurement instruments such as microwave signal generators and vector network analyzers. Microwave signal generators can provide significant power at microwave frequencies, typically up to +20 dBm (100 mW). There are signal generators with expensive high power options up to +30 dBm (1 Watt), but with much higher harmonics.
Microwave power amplifiers are most often the best solution for increasing available power from signal generators.

The Giga-tronics 2520B Microwave Signal Generator combined with the GT-1000B Microwave Power Amplifier (pictured here) can provide +40 dBm (10 Watts) to 8 GHz and +37 dBm (5 Watts) to 18 GHz.



Microwave vector network analyzers (VNAs) often have limited power available from their output ports. VNA maximum output power levels are typically from +5 dBm to +13 dBm up to 20 GHz and even less at higher frequencies.

Adding an external power amplifier to a microwave vector network analyzer is common in some VNA applications, such as load-pull testing, and the broad frequency range of the Giga-tronics microwave power amplifiers well match 20 GHz, 40 GHz and 50 GHz VNAs.

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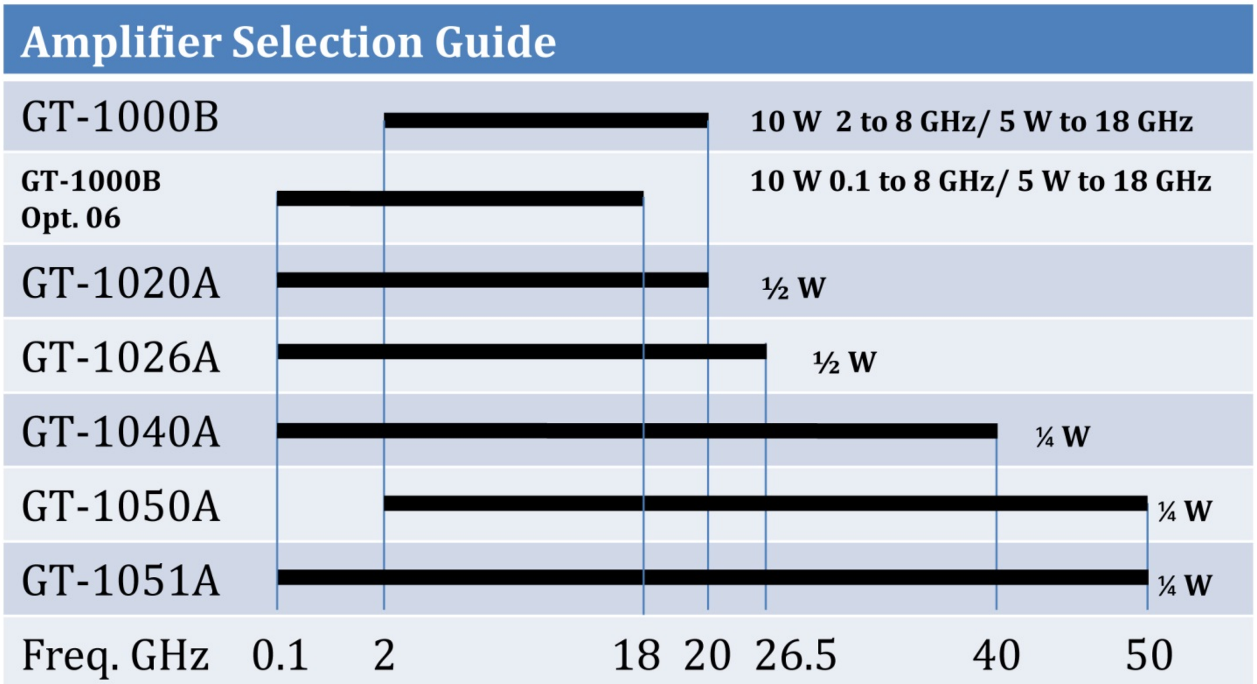

The amplifier selection guide above provides a quick reference to the Giga-tronics family of microwave power amplifiers.

Giga-tronics Microwave Power Amplifiers deliver outstanding performance and exceptional value. These ultra-broadband amplifiers have excellent pulse performance and modulated signal fidelity, ideal for testing in wireless communications, defense EW and radar testing and general purpose microwave laboratory applications. Have the power you need to overcome cable and switching losses, or to drive higher power mixers, detectors and very high power amplifiers.

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Specification Summary

Model	Freq. Range (GHz)	Psat (Minimum)	Gain (Nominal)	Gain Flatness (Maximum)	Noise Figure (Typical)
GT-1000B	2 to 20	2–8 GHz: 38.5 dBm (7W) 8-12 GHz: 37 dBm (5W) 12-18 GHz: 36 dBm (4W)	40 dB	± 3.0 dB	< 10 dB
GT-1020A	0.1 to 20	0.1-10 GHz: 26 dBm (0.4W) 10-20 GHz: 25 dBm (0.3W)	35 dB	± 3.5 dB	< 5 dB
GT-1026A	0.1 to 26.5	0.1-18 GHz: 26 dBm (0.4W) 18-26.5 GHz: 21 dBm (0.1W)	25 dB	± 3.5 dB	< 6 dB
GT-1040A	0.1 to 40	0.1-0.5 GHz: 20 dBm (0.1W) 0.5-26.5 GHz: 23 dBm (0.2W) 26.5-40 GHz: 20 dBm (0.1W)	20	± 3.5 dB	< 8 dB
GT-1050A	2 to 50	2-10 GHz: 26 dBm (0.4W) 10-30 GHz: 25 dBm (0.3W) 30-40 GHz: 23 dBm (0.2W) 40-50 GHz: 20 dBm (0.1W)	25	± 3.5 dB Nominal	< 10 dB
GT-1051A	0.1 to 50	0.1-2 GHz: 27 dBm (0.5W) 2-10 GHz: 26 dBm (0.4W) 10-30 GHz: 25 dBm (0.3W) 30-40 GHz: 23 dBm (0.2W) 40-50 GHz: 20 dBm (0.1W)	25	± 3.5 dB Nominal	< 10 dB

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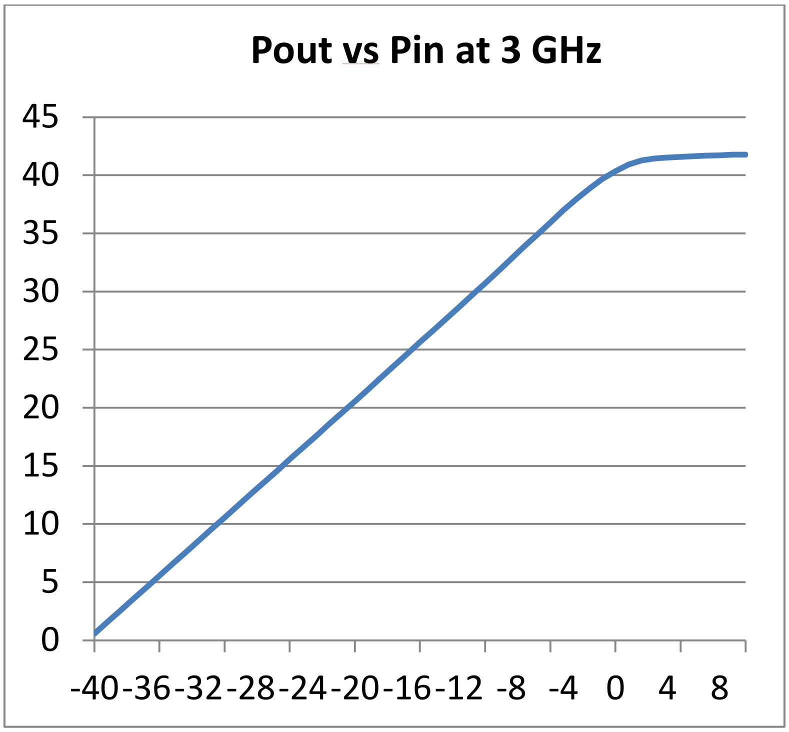
3 Ultra-Broadband versus Narrowband Amplifiers

The Giga-tronics microwave power amplifiers cover ultra-wide frequency range with relatively flat frequency response and wide linear range. They are ideal for testing in EMC labs, Radar and Defense EW systems, allowing broad band testing without band switching or swapping narrow band amplifiers, resulting in faster and more accurate testing.

Because the Giga-tronics microwave power amplifiers are designed using parallel broadband Gallium Arsenide MMIC amplifiers, they exhibit very sharp knees between the linear region of operation and the saturation region.

P1dB, the 1 dB gain compression power level is typically within 2 dB of Psat, the saturated power level.

In this example, measuring a typical GT-1000B 20 GHz amplifier, Psat is 42 dBm or 12 Watts, while the P1dB is 40 dBm, or 2 dB lower than Psat, with a large linear region with about 40 dB of gain.



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Because these are very broadband amplifiers, they do not exhibit the pulse performance limitations common to narrowband amplifiers.

The ultra-broad frequency range of the Giga-tronics microwave power amplifiers can save time, weight and cost over multiple narrow-band amplifiers, as well as increasing reliability due to the elimination of redundant power supplies, cables, and cross-over networks.

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4 Amplifier Power, Voltage and Current Considerations

Power amplifiers for use at microwave frequencies are specified in Watts or the decibel (dB) equivalent of Watts (dBm or dBW), are almost always designed and specified for use with a 50 Ohm[2] load impedance. There are instances where the voltage and/or current associated with a given power level are needed. Calculating the voltage and current for a given power can be easily done using the Ohm's law equations or by using one of the many "Ohm's Law" calculators that can be found on the internet.

Ohm's law relates voltage (V), current (I), resistance (R) and power (P).
The equations states $V = IR$ and $P=IV$.

With substitution, we get $V^2 = RP$ or $V = \sqrt{(RP)}$ and $I^2 = P/R$ or $I = \sqrt{(P/R)}$

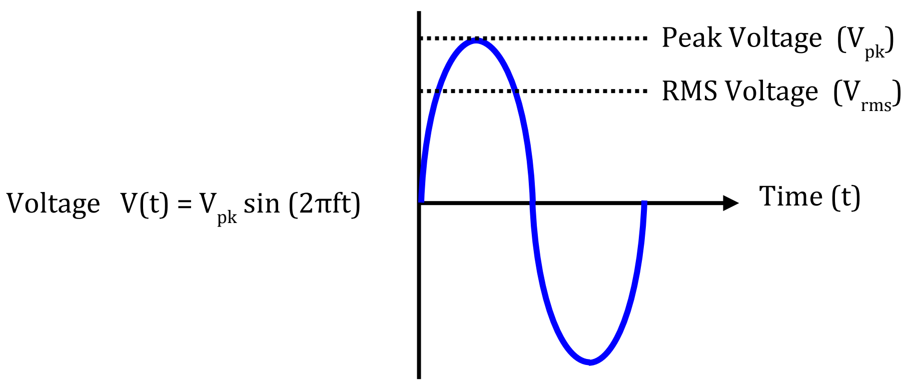
Example: for 10 Watts into 50 ohms, an amplifier has to provide 22.4 Volts and .45 Amps.

For sine waveforms, these values of power, voltage and current are RMS (root mean square) values. The RMS value of a sine wave is the value equivalent to the DC (Direct Current) value that would product the same power as given by Ohm's law.

If a sine wave is given as $V(t) = V_{pk} \sin(2\pi ft)$, the RMS value V_{rms} is $V_{pk}/\sqrt{2} = 0.707V_{pk}$
The peak value (V_{pk}) for a given RMS value V_{rms} is $V_{rms}\sqrt{2} = 1.414V_{rms}$

So in our example above, for 10 Watts into 50 Ohms, $V_{pk} = 32$ Volts and $I_{pk} = 0.63$ Amps.

Pictorially:



If an amplifier designed for driving a 50 Ohm load is presented with a lower impedance load, the current requirement increases and the voltage requirement decreases, and

[2] Side note: Why 50 Ohms? The answer is historical. 50 Ohms was chosen in the early days of RF and microwave systems as a compromise between air-core coax cable minimum insertion loss (around 75 Ohms) and maximum power handling ability (around 30 Ohms).

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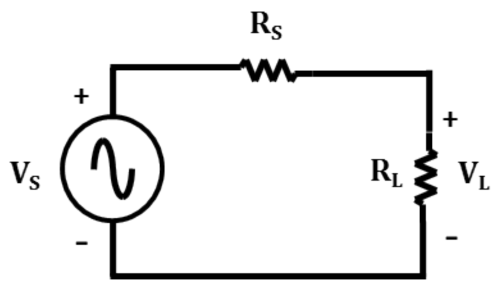
vice-versa for a higher impedance load. The amplifier's voltage and current limitations can easily be exceeded if the load impedance varies significantly from 50 Ohms.

Besides the voltage and current limitations of the amplifier, power delivered to the load is maximum at 50 Ohms for RF/Microwave power amplifiers.[3,4] This is because the amplifier's input and output impedance are carefully designed to be as close to 50 Ohms as is reasonably possible. Consider the following circuit, with the amplifier modeled as a voltage source with source resistance R_S of 50 Ohms, and a load resistance R_L.



R_S represents the output impedance of the amplifier with the amplifier providing voltage V_S and current I. Intuitively, as the load R_L decreases to zero, the voltage across the load decreases to zero, but the current is limited to V_S/R_S so that the power at the load decreases to zero as well. As R_L increases to infinity, the current decreases to zero, but the voltage is limited to V_S so that the power at the load decreases to zero again. The maximum power transfer is at the optimum balance of voltage and current.

3 http://en.wikipedia.org/wiki/Maximum_power_transfer_theorem
4 http://technologyinterface.nmsu.edu/Spring08/30_Cartwright/index.pdf

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Load Mismatch and Reflected Power Considerations

Power delivered to the load is maximized when the load is 50 Ohms, ideally matching the 50 Ohm output impedance of the amplifier. As the load impedance varies away from an ideal 50 Ohms, an impedance mismatch occurs and power is reflected back from the load to the amplifier.

The term "mismatch" refers to the situation where the source impedance and load impedance are not equal, resulting in power being reflected from the load. In the ideal case, all power from the source (amplifier) is transferred to the load. As the load impedance deviates from the source impedance, "mismatch" occurs, and power is reflected back from that discontinuity.

In the worst case condition of short circuit and open circuit, 100% of the power is reflected back to the source (amplifier). While most amplifiers are designed to withstand this condition, damage or degradation and reduced reliability can occur, especially at higher power levels, and should be avoided whenever possible.

The most common measures of mismatch are VSWR (Voltage Standing Wave Ratio) and RL (Return Loss). In addition, the term "reflection coefficient", symbolized by the upper case Greek letter Gamma (Γ), is also used. The parameter VSWR is expressed as a ratio of the value to 1, where a VSWR of 1:1 is the ideal case of perfect match and a value of infinity to 1 is worst case.

Return Loss (RL) is express in dB (a ratio) where RL of infinity is the ideal case of perfect match and a value of zero is worst case. Reflection Coefficient (Γ) varies from zero (ideal) to 1 (worst case).

The relationships, in terms of VSWR:

$$\text{RL (dB)} = -20 \text{ Log} \left(\frac{\text{VSWR} - 1}{\text{VSWR} + 1} \right)$$

$$\Gamma = \left(\frac{\text{VSWR} - 1}{\text{VSWR} + 1} \right)$$

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Typical range of mismatch in tabular form:

Power Loss, Transmitted % and Voltage Refl. Coeff vs VSWR and Return Loss

VSWR	RL (dB)	Loss (dB)	Trans. (%)	Γ
1.1	26.4	0.01	99.8	0.05
1.2	20.8	0.036	99.2	0.09
1.3	17.7	0.075	98.3	0.13
1.4	15.6	0.122	97.2	0.17
1.5	14	0.177	96	0.20
1.6	12.7	0.238	94.7	0.23
1.7	11.7	0.302	93.3	0.26
1.8	10.9	0.37	91.8	0.29
1.9	10.2	0.44	90.4	0.31
2	9.5	0.51	89	0.33
2.5	7.4	0.88	82	0.43
3	6	1.25	75	0.50
4	4.4	1.94	64	0.60
5	3.5	2.55	55	0.67

Giga-tronics microwave power amplifiers are specified to withstand a maximum VSWR of 3:1 (25% of the power reflected back to the amplifier) without any damage or degradation in performance.

As a safety precaution, amplifiers should always be turned off when changing loads, including cables and antennas. The open end of a cable can radiate electromagnetic energy when disconnected from a load as may happen when changing antennas. The practice of “hot-swapping” antennas can cause electronic interference and possibly even radiation burns. A good safety precaution is to never look into the open end of a cable connected to a microwave signal source.

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6 Amplifiers used as Pre-Amps with Spectrum and Signal Analyzers

The low noise figure, high gain and flat frequency response of the Giga-tronics amplifiers allow them to be used as preamplifiers for high noise figure spectrum and signal analyzers. The Giga-tronics amplifiers used as a preamp can help bring low level signals above the noise floor of the analyzer.

The approximate formula[5] for noise figure of cascaded amplifiers is calculated in linear terms of noise factor (F):

$$F_{total} = F_1 + (F_2 - 1)/G_1$$

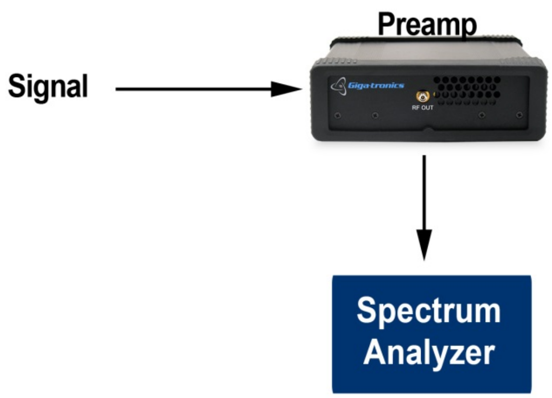
Where F_1 is the noise factor of the first amplifier, G_1 is the gain of the first amplifier, and F_2 is the noise factor of the second or following amplifier. Note that in the exact formula, there may be additional terms for additional amplifiers following the first two, but these terms are negligible if the gains are reasonably high, since the gains multiply in the denominator of additional terms.

This can be written in terms of a preamp and analyzer:

$$F_{system} = F_{amplifier} + (F_{analyzer} - 1)/GAIN_{amplifier}$$

<u>For example:</u>

$NF_{amplifier}$ = 6 dB	$F_{amplifier}$ = 3.98
$NF_{analyzer}$ = 20 dB	$F_{analyzer}$ = 100
$GAIN_{amplifier}$ = 40 dB	$Gain_{amplifier}$ = 10,000
NF_{system} = 6.1 dB	F_{system} = 3.99



[5] http://en.wikipedia.org/wiki/Noise_figure

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Note that the system noise figure is greatly reduced by the preamplifier and for a high gain preamplifier is essentially the noise figure of the preamplifier.

The broad frequency ranges of the Giga-tronics amplifiers, from 100 MHz to 20 GHz, 40 GHz and 50 GHz, well match the frequency range of the majority of spectrum and signal analyzer applications. The Giga-tronics' parallel-MMIC design provides wide linear range and a sharp saturation knee. The result is outstanding performance when used with signals having high peak to average ratios. The broad frequency range provides excellent pulse performance preserving the fast rise and fall times of high speed signals and narrow pulses.

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