APPLICATION NOTE # 37
WIRELESS TELECOMMUNICATIONS TESTING WITH "S" SERIES MICROWAVE POWER AMPLIFIERS

AR RF/Microwave Instrumentation offers a broad range of power amplifiers covering DC to 45 GHz with output power ranging from 1 to 10,000 watts. While applications include Electromagnetic Compatibility testing (EMC), RF component testing, physics (plasma generation) and chemistry (mass spectroscopy) applications, military (jammers, radar), material testing (ultrasound), medical diagnostic testing (NMR, MRI) and general lab use, this applications note focuses on a line of amplifiers that has been optimized for wireless telecommunications test use.[1]

The last two decades have seen an explosion in the use of wireless telecommunication. From the first cellular telephone system, the Advanced Mobile Phone Service (AMPS) introduced by AT&T in 1983 to the personal communications services (PCS) that are currently in vogue, telecommunications test system demands for ultra-linear test amplifiers have never been greater. An additional requirement of a test amplifier is broadband frequency coverage. Table 1 lists the frequency ranges for both cellular and PCS wireless telecommunications systems, Bluetooth, and the latest 50MHz block of frequency spectrum allocated for commercial wireless services by the Federal Communications Commission (FCC).[2] This table clearly shows a significant frequency spread from 825MHz to 3.7GHz. AR RF/Microwave Instrumentation has answered the need for wide-band linear test amplifiers by developing the "S" series of Class-A linear microwave amplifiers optimized for telecommunications testing. With maximum bandwidths from 800 MHz to 4.2 GHz, the "S" series provides testing margin on either side of the wireless frequency allocation spectrum.

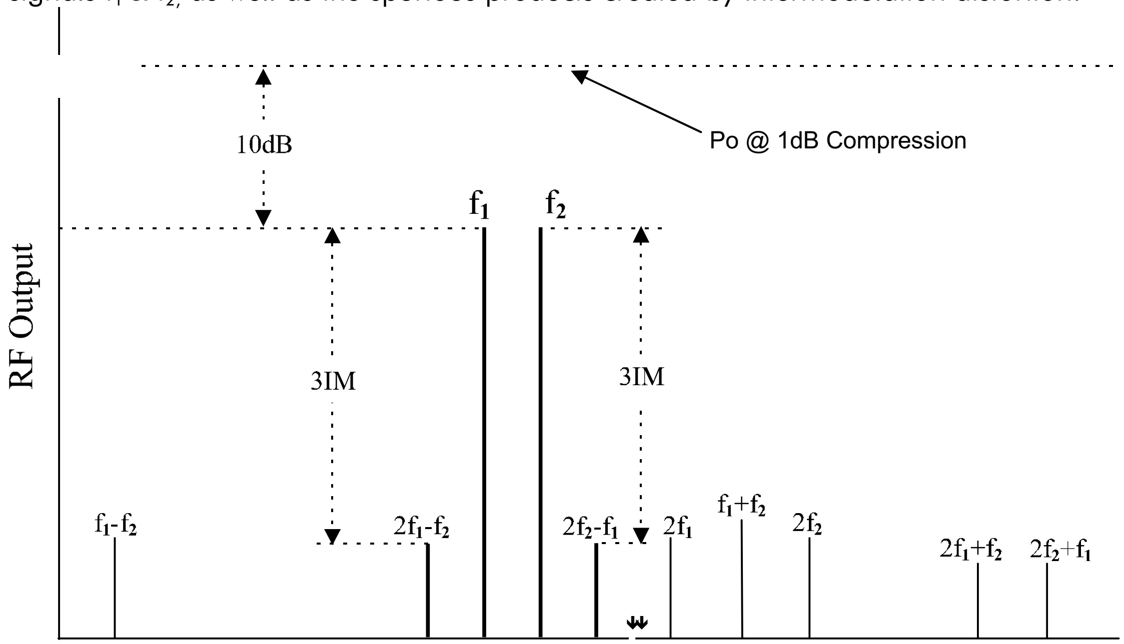
Wireless System	Frequency Allocation
Analog Cellular Telephones (AMPS)	824-894 MHz
Digital Cellular Telephones	824-894 MHz Low Band
Digital Cellular Telephones	1710-1880 MHz High Band
Personal Communications Systems (PCS)	1850-1990 MHz
Bluetooth	2400-2497 MHz
Future Systems [2]	3650-3700 MHz

Table 1

In addition to covering a broad frequency spectrum, wireless applications require amplifiers that are very linear. An ideal amplifier would faithfully reproduce the applied input signal without adding additional frequencies (spurious) to the output signal. Unfortunately, real amplifiers are characterized by some degree of nonlinearity. While design engineers strive to develop linear amplifiers, they are limited by, at the very least, the inherent non-linearierites of the diode junctions that comprise many of the active devices found in most amplifiers. This would not be a serious problem for a single frequency application, but the very nature of telecommunications suggests more than one signal, or tone, be applied to the amplifier. The result of applying two or more tones to "real" amplifiers that exhibit a degree of non-linearity is intermodulation distortion (IMD). IMD is nonlinear distortion characterized by the appearance of signals at the output of the device that are linear combinations of the fundamental frequencies and all harmonics present at the input of the amplifier. The signals produced are often referred to as the sum and difference products, and are defined by a power series expansion of the output device collector current. The unwanted frequencies are given by the expression

$f_s = \pm Mf_1 \pm Nf_2$, where f_s = the spurious response frequency, (Eq. 1)
M & N = positive integers ≥ 1, f_1 = the frequency of tone 1,
f_2 = the frequency of tone 2. The order of the product is M+N.

Figure 1 graphically shows the output of a typical amplifier that includes the desired fundamental signals f_1 & f_2, as well as the spurious products created by intermodulation distortion.



Fundamental Tones and Intermodulation Products

Figure 1

It is apparent from Figure 1 that the third order intermodulation products ($2f_1$-f_2) and ($2f_2$-f_1) are the most significant contributor to distortion in that they are very near the fundamental tones and thus, are not readily filtered out as is the case of the third order intermodulation products ($2f_1+f_2$ and $2f_2+f_1$) and the second order intermodulation products (f_1-f_2, $2f_1$, f_1+f_2 and $2f_2$).

Figure 1 also describes a relatively straightforward and widely accepted method of testing amplifier linearity. With this so-called "two-tone" method, two closely spaced fundamental signals (tones) are applied to the test amplifier. While the levels are often set at 6dB below the 1dB compression point, AR RF/Microwave Instrumentation prefers to reduce the level of the two fundamental tones by 10dB to preclude any possibility of gain saturation during the brief periods when the tones are in phase and the peak envelope power (PEP) is 6dB above the level of either tone. By operating 10dB down from the 1dB compression point, 4dB of compression margin is assured. The amount of intermodulation distortion is given as 3IM and is by definition the level of the two "close-in" third order intermodulation products relative to the two fundamental tones f_1 & f_2.

A more convenient method of defining amplifier linearity is the so-called third order intercept point (IP_3). This method relies on a figure of merit that is determined by graphical extrapolation of amplifier data taken well below saturation.

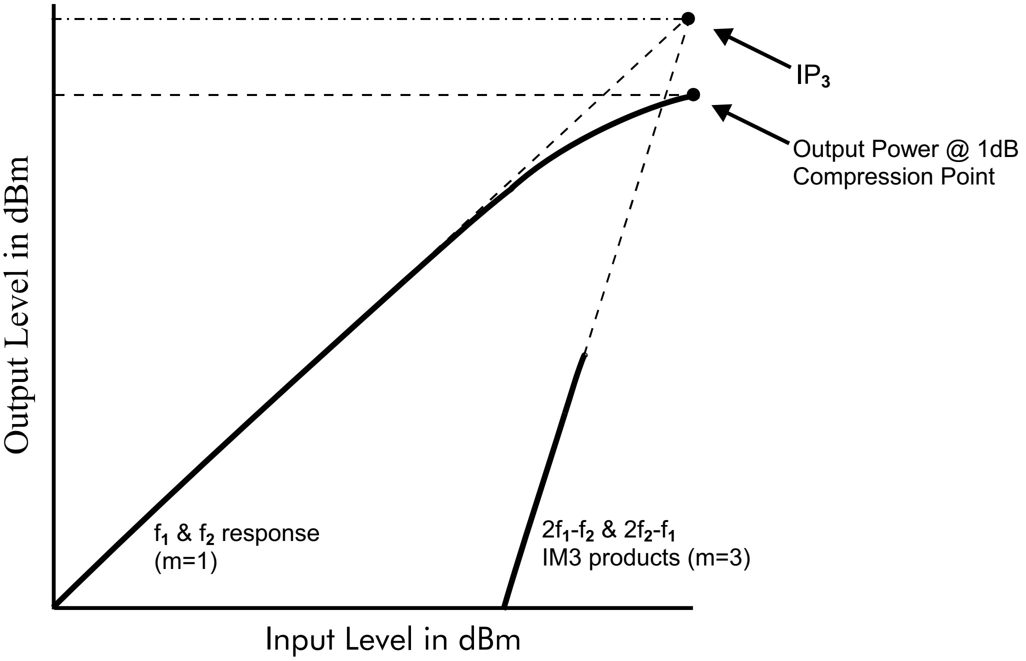


Figure 2

Figure 2 is a plot of the output Vs input transfer function of the hypothetical amplifier whose spurious response is shown in the frequency plot of Figure 1. Note that the desired fu outputs (f_1 & f_2) describe a function with a slope of one ($m = 1$). The output level continues to increase with an increase of input power until a point is reached where output device current limiting results in a gradual roll-off of output power. The point at which the fundamental output differs from the ideal level by 1dB is defined as the 1dB compression point. The third order intermodulation products are also plotted in Figure 2. They are much smaller than the fundamental tones, but have a slope of three ($m = 3$). The IP_3 is a theoretical point obtained by extending the two functions until they intersect. At this point the spurious third order intermodulation products have reached the level of the fundamental output tones. It must be noted that IP_3 is not a measured value, but derived graphically. Amplifier test data is taken well below the 1dB compression point to establish the two curves (fundamental and the third order intermodulation curve) and the curves are extended until they intersect. The intersection point is by definition the third order intercept point (IP_3). In practice, amplifiers reach total saturation long before the two curves converge. Nevertheless, IP_3 is a useful figure of merit. What is particularly interesting is its relationship with actual power levels as seen in the following equation:

$$IP_3 = Power_{(f1\ \&\ f2)} + \frac{3IM}{2}, \qquad \text{(Eq. 2)}$$

where $Power_{(f1\ \&\ f2)}$ = the power in each fundamental signal, $f_1\ \&\ f_2$. (Note that $f_1 = f_2$)

In actual practice, to measure 3IM, the two fundamental tones are set at a level of 10dB below the 1dB compression point of the amplifier. Thus,

$$Power_{(f1\ \&\ f2)} = P_{o\ (@\ 1dB\ compression)} - 10dB,$$

where P_o is the output power at the 1dB compression point the amplifier.

Solving Eq. 2 for the third order intermodulation distortion,

$$3IM = 2(IP_3 - Power_{(f1\ \&\ f2)}) \qquad \text{(Eq. 3)}$$

The above equations allow for the practical application of IP_3 to "real life" system requirements. Data sheets generally provide IP_3 values for linear amplifiers. Given an IP_3, test operators can predict the third order intermodulation products (IM3) for a given output power, or conversely, can specify a required IP_3 for a required output power and allowable distortion (3IM). Lacking manufactures IP_3 data, a rule of thumb for a Class A linear amplifier is that IP_3 is approximately 10dB greater than the 1dB compression point.

Table 2 summarizes the output power specs and actual IP_3 for the "S" series microwave amplifiers, as well as the predicted IP_3 for a typical Class A linear amplifier. Note that the actual IP_3 figures are on average 4dB better than expected. AR RF/Microwave Instrumentation has worked closely with telecommunications providers to develop this line of microwave amplifiers that have been optimized for wireless test applications. Proprietary techniques have been developed to improve noise and linearity to decrease adjacent channel interference or what is commonly referred to as adjacent channel power (ACP). The end result is more efficient use of the small slices of frequency spectrum used in the analog FDMA, the digital TDMA and GSM multiple access technologies and less spectrum regrowth when applied to spread spectrum technologies used in CDMA and W-CDMA. Spectrum utilization is of paramount importance in wireless applications and spurious signals that reduce the available spectrum must be minimized. Irrespective of the multiple-access encoding scheme used, IP_3 is a good predictor of linearity as well as spectrum regrowth (3), and thus, it can be used to determine the applicability of a particular amplifier for use in a wireless test application.

Model	Bandwidth	Power Out (1dB Compression)	Power Out (3dB Compression)	Predicted IP_3 *	Actual IP_3
1S1G4A	0.8 – 4.2 GHz	0.7 watts	1 watt	38	39
5S1G4	0.8 – 4.2 GHz	5 watts	6.5 watts	47	49
10S1G4A	0.8 – 4.2 GHz	10 watts	13 watts	50	52
15S1G3	0.8 – 3 GHz	12 watts	15 watts	51	53
25S1G4A	0.8 – 4.2 GHz	20 watts	25 watts	53	57
30S1G3	0.8 – 3 GHz	25 watts	30 watts	54	58
50S1G4A	0.8 – 4.2 GHz	40 watts	50 watts	56	60
60S1G3	0.8 – 3 GHz	50 watts	60 watts	57	60
100S1G4	0.8 – 4.2 GHz	70 watts	90 watts	58	64
120S1G3	0.8 – 3 GHz	100 watts	120 watts	60	64
200S1G4	0.8 – 4.2 GHz	160 watts	180 watts	62	65
240S1G3	0.8 – 3 GHz	180 watts	200 watts	62	65
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
600S1G3	0.8 – 3 GHz	460 watts	500 watts	67	67
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
800S1G3	0.8 – 3 GHz	600 watts	675 watts	68	68

Table 2

** Predicted IP_3 is the figure one would expect given a typical Class A linear amplifier. Based on an industry "rule-of-thumb", it is arrived at by adding 10dB to the 1dB compression point of the amplifier.*

In summary, the "S" series microwave amplifiers exhibit low noise and distortion characteristics required of wireless test amplifiers. The very broad frequency band address all the higher frequency wireless applications from cellular telephone to the emerging Bluetooth technology to the latest 50MHz slice of spectrum that has extended wireless to 3700MHz. In addition to an average IP_3 improvement of 4dB designed into these amplifiers, the unique circuit design of the "S" series has been shown to yield an additional 3dB improvement in IP_3 when a very simple operational technique is applied. This technique in effect results in a degree of predistortion of the input signal. Contact Application Engineering at 800-933-8181 for details.

(1) *The term wireless communications encompasses a number of applications. In addition to analog and digital cellular telephone service, wireless includes the new personal communications services (PCS), analog and digital cordless telephones, pagers, Global Positioning Systems (GPS), wireless local area networks (LANs), Satellite television, garage door openers, remote controllers and the new Bluetooth technology used to interconnect a wide range of computing and telecommunications devices via a low power short-range rf link.*

(2) *From the Federal Communications Commission News Release: FCC ALLOCATES ADDITIONAL SPECTRUM FOR WIRELESS SERVICES, dated October 24, 2000.*

(3) *Q. Wu, H. Xiao and F. Li, "Linear RF Power Amplifier Design for CDMA Signals: A Spectrum Analysis Approach," Microwave Journal, December 1998, pp. 22-40.*