Application Note

AP60x Circuit Design Techniques and Proper Precautions During Tuning

Introduction

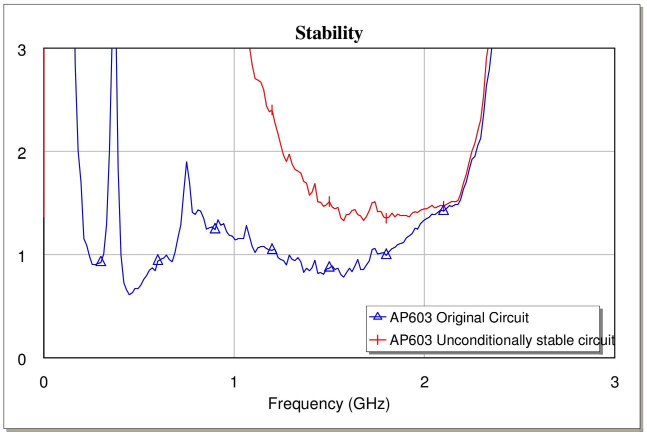
WJ Communications' 28V InGaP HBT line of power products – the AP60x series – offer significant performance advantages over other technologies currently available in the market today. Key advantages are with 'backoff' linearity, while still maintaining above average efficiencies. This key feature allows WJ's AP601 (2W), AP602 (4W) and AP603 (7W) devices to be ideal as pre-driver and driver amplifiers targeted at both linearized and unlinearized high power amplifier (HPA) applications. The good linearity performance also makes the devices ideal for use in systems employing a modulated signal with high peak–to-average ratios (PAR). Long-term reliability studies have been performed and documented with accelerated temperature and other stresses on the high voltage HBT process, so there is a high level of confidence of the component's longevity once they are designed into a system in production. During the design process though, engineers need to be aware of various precautions during the tuning, design, and testing of the devices to avoid potential issues. This application note focuses on methodologies for design engineers and technicians to avoid potential cases for device destruction.

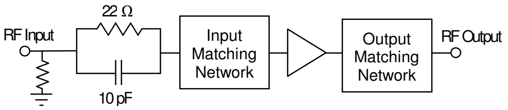
Amplifier Design and Stability Networks

The amplifier design starts with the optimum load impedance for an objective performance: to maximum gain, efficiency, output power, or linearity. The optimal load impedances for those specific characteristics can be determined through measurements on a load pull system. The input matching network is optimized through the conjugate match at the particular frequency of interest using the de-embedded s-parameters of the device. WJ has already done the work to determine the optimal external matching networks to achieve very good ACLR (adjacent channel leakage ratio) performance with a WCDMA single-carrier signal on the AP60x products for various frequency bands. Details of the various matching networks for frequency bands targeting mobile infrastructure are given on the component datasheets. The tuning was done through data from load-pull techniques and simulations as well as with optimization through empirical techniques in the laboratory.

The circuit configurations on the datasheets show the optimal performance of the devices with respect to gain and with the right balance with ACLR performance and the device efficiency. WJ's 28V devices offer unique characteristics for Class AB devices where a high level of efficiency is obtained without a big tradeoff in terms of linearity performance. With that being said though, the circuit configurations shown on the datasheets are also not unconditionally stable. The majority of driver and power amplifiers targeted at HPA applications are only conditionally stable to maximize for gain and linearity performance. Oftentimes, design techniques employed to create an unconditionally stable amplifier may also degrade certain performance parameters. A conditionally stable amplifier should not be an issue for designers as long as the source or load impedance that the device interfaces does not fall into the loci of impedances for instability. This can be determined through a small-signal analysis of the matched amplifier's input and output stability circles.

RC Stabilization Circuits - WJ has moved forward into looking at the circuit designs around the AP60x amplifiers for various frequencies to ensure configurations that allow for unconditional stability. This will assist designers into not having to worry about the source and load impedances into the amplifier as well as mitigate against possibilities of oscillation when looking into highly reflective loads, such as an antenna for repeater applications. For the stabilization of the amplifier circuit, a parallel R-C (resistor / capacitor) trap, typically 10pF and 22 ohms, is placed at the input of the matched amplifier to terminate the amplifier with a fixed load at low frequencies. At frequencies below 1 GHz, the amplifier will see a minimum of 22 ohms which brings the stability factor above 1 for the lower frequency bands. With this type of network, the impedance of the trap is dominated by the low impedance of the capacitor above 1.5 GHz and thus the trap has no effect on the performance (above 1.5 GHz). By analyzing the resulting stability circles for the amplifier circuit with the R-C trap, we see that high impedances need to be avoided. This can be achieved by placing another resistive shunt element at the input of the amplifier circuit to bring the stability factor above 1 for all frequencies and creating an unconditionally stable amplifier. The input shunt resistance value varies with the device type and will slightly lower the amplifier gain. An example of the stability network is shown below along with the stability factor improvements on the figures on this page.





RF Overdrive Conditions

Common occurrences of device failures in the laboratory are a result of RF overdrive conditions. The devices have been confirmed to be able to survive a minimum of CW input power to cause the amplifier to go into 6 dB of compression. This is stated on the datasheets with a maximum RF input power rating or Input P6dB. With regards to modulated signals, the peak power levels of the input signal can cause catastrophic failures. Similar to CW type measurements, the peak power levels – defined by P_{AVG} + PAR_{MAX} – need to be less than the value that causes the device to be 6 dB into compression. Since the amplifiers have different gain levels at different frequencies, a simple equation can be calculated to determine the maximum input power of a modulated signal into the device:

$$\text{Maximum RF Input Power} = P1dB - Gain + 5\ dB - PAR_{MAX}$$

Device type	Frequency (MHz)	P1dB (dBm)	Gain (dB)	Max CW Input Power (dBm)	Max P_{IN} (dBm) With PAR=10dB
AP601	900	32.5	15.8	**21.7**	**11.7**
	1960	32.7	15	**22.7**	**12.7**
	2140	32.5	13.5	**24.0**	**14.0**
AP602	900	35.7	15.5	**25.2**	**15.2**
	1960	35.7	14.2	**26.5**	**16.5**
	2140	35.7	13	**27.7**	**17.7**
AP603	900	38.5	17	**26.5**	**16.5**
	1960	38.5	13	**30.5**	**20.5**
	2140	38.2	11.8	**31.4**	**21.4**

Laboratory Preparations

The preferred measurement set-up for tuning purposes with CW or two-tone signals are the use of two sweeper generators and a spectrum analyzer. A power meter can be used to analyze CW signals. Attenuator pads, isolators, a directional bridge, and high power laboratory amplifier will allow for clean IMD (intermodulation distortion) measurements on the DUT (device under test) without any IMD contributions coming from the test equipment. A network analyzer will help understand how the tuning affects the gain and return loss of the amplifier. The evaluation of system amplifier parameters, such as ACLR/ACPR performance, requires additional equipment such as an Agilent E443x series that is loaded with the complex modulation signal of choice and a transmitter tester or spectrum analyzer. When preparing the measurement set-up, long coaxial cables and the impedances from the test equipment can present unknown loads to the amplifier. Adding some attenuation padding before and after the amplifier will ensure a good match into the DUT. The output of the DUT usually consists of a high power attenuator and a power meter or coupler included for sampling a signal into the spectrum analyzer. The AP60x devices will operate safely in the laboratory environment if they are properly terminated. However (assuming that the circuits do not have the stabilization networks mentioned earlier in this application note), high reflective impedances presented to the evaluation board terminals may result in an amplifier oscillation and cause catastrophic destruction to the amplifier.

DC Sequencing - From a biasing standpoint, the sequencing of the 5V and 28V DC supplies into the amplifier is not specifically required in the final application. Generally in laboratory environments though, it is good practice that the amplifier be turned on and off in the laboratory in the following method to prevent transients from potentially damaging the device. If the supplies are known to be “dirty” and have transients on them during turn on/off, it is recommended to add electrolytic capacitors on the power supply terminals. This will help smoothen the transients on the supply line. In addition, it is recommended to use the current limit feature on power supplies to turn on/off the bias, rather than using the power switch or ramping up the voltages.

Turn-on Sequence:

1. Attach input & output loads onto the evaluation board.
2. Turn on power supply +28V power supply for V_{CC}.
3. Turn on the +5V power supply for V_{BIAS} and V_{PD}. The V_{CC} power supply V_{CC} should now be drawing typical I_{CQ} stated on the amplifier datasheet.
4. Turn on RF power.

Turn-off Sequence:

1. Turn off RF power.
2. Turn off the +5V power supply for V_{BIAS} and V_{PD}.
3. Turn off the +28V power supply for V_{CC}.
4. Remove input & output loads from the evaluation board.

The quiescent current for the amplifier can be optimized in the laboratory by adjusting the R2 resistor through the use of a potentiometer. It can also be adjusted by modifying the V_{PD} voltage, if this is sourced through a separate +5V supply than the V_{BIAS}. The final value for R2 can be calculated by measuring the current though the resistor and measuring the voltage at pin 14. In the laboratory environment, both V_{PD} and V_{BIAS} can be used to turn on and off the amplifier, although it is preferred in actual applications that the switching is applied only to V_{PD}. In simplistic terms, the AP60x series of devices utilize a version of a current mirror, where V_{PD} represents the pin into the base of the transistors in the current mirror while the V_{BIAS} line supply the current into the collector.

Empirical Tuning of Amplifiers in the Laboratory

It is understandable that designers will have to make slight tweaks to the matching networks designing the components into their own systems due to differences in PCB materials, thickness, etc. This may be in addition to retuning the devices into the specific frequency bands of operation. Initially the power level of your sweeper generator should be set at low levels to start the tuning process. After bias is applied, avoid disconnecting the cables without turning off bias. As stated in the previous section, removing the loads into the amplifier can create impedances seen by the device in the unstable regions, resulting in catastrophic destruction.

Active Tuning - When it is time to put hands on work, it is recommended to follow the following approach: attach the output tuning capacitor at the output transmission line. Initially use a capacitor value lower than the value determined by the load pull. Insert at the input transmission line the input capacitor and slide it from the device towards the generator, looking for best input match and gain flatness. Next drive the amplifier near the P1dB power level and tune the output capacitor for best power and efficiency within the frequency band. The RF input power and DC bias should always be turned down or off when moving the output capacitor to avoid creating undesirable loads and RF spikes resulting consequent device destruction. Tuning with the DC and RF on is also known as “active tuning” and should be avoided. For the same reason, avoid touching the input and output traces of the amplifier with bare hands. This can also create an undesirable load.

Tuning the output load impedance will slightly mismatch the input circuit, which will have to be retuned at small signal level. Repeat iteratively this procedure until device provides the desired performance. At this point, it is good practice to take the amplifier to the network analyzer and determine input and output return loss to check if the resulting impedances within the band are greater than 10 dB for the input match and 6 dB for the output match.

Summary

General “good” laboratory practices are essential in tuning and operating WJ Communications’ line of 28V InGaP HBT devices. The AP60x product family has been well received in the market with a lot of positive feedback on the performance from RF power design engineers at various OEM wireless infrastructure equipment makers. The AP60x products have been shipping to customers in production volumes and the devices are very reliable and robust in field applications. The issues and catastrophic failures seen with the devices have come in laboratory environments when designers may not be as familiar with the characteristics of high voltage HBT products. WJ application engineers are also readily available for assistance in terms of evaluating laboratory setups, reviewing schematic and PCB layout designs, or providing other reference designs to assist designers with implementing these devices in their platforms.

A summary of the items discussed in this appnote and things to heed during tuning or laboratory measurements are:

- Always attach input and output loads prior to turning on DC and RF.
- Turn off the RF input power and DC into the amplifier prior to tuning the matching networks.
- Avoid touching with bare hands the input and output traces while the DC or RF is turned on.
- Prevent from injecting a CW tone that can have the device to go into greater than 6 dB of compression.
- For modulated signals, be aware of the PAR of the signal to prevent peaks being heavily compressed in the amplifier.
- Have proper attenuation pads around the amplifier to ensure a good match into the amplifier.
- Utilize stabilization networks as part of the amplifier design allow for unconditional stability.
- Analyze the amplifier stability circles to understand the impedance regions of potential instability.
- Ensure “clean” supplies are used where transients are minimized and voltage overshooting is avoided.