Application Note #47
Application Guide to the A3 Series
10 kHz to 3 MHz Impedance Matching Amplifiers

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Due to a compromise in coaxial power handling capability and efficiency of power transfer, most RF coaxial cables have a characteristic impedance of 50 Ω. To avoid impedance discontinuities and the resultant power reflections, most RF sources are specified with an internal resistance of 50 Ω. There is an electrical engineering theorem that states that maximum power is transferred from a source of fixed internal resistance only when the load resistance matches that of the source. Any variance will result in power reflections in the coaxial transmission line leading to standing waves and energy loss. To preclude this undesirable condition, the vast majority of RF applications attempt to keep the load at or near 50 Ω. To accommodate the majority of these applications, most RF amplifiers on the market have a nominal internal impedance of 50 Ω. Regrettably, many low to mid-frequency RF applications are characterized by impedances other than 50 Ω. It is not uncommon to encounter loads varying from 10 Ω to well over 200 Ω in this region. This is especially true in general purpose lab applications where a circuit detail such as load impedance is often unpredictable. AR RF/Microwave has addressed this dilemma with the introduction of the A3 series of amplifiers that can incorporate a variable output impedance to better match those applications with load impedance other than 50 Ω.

The A3 series amplifiers (10kHz to 3MHz)

800A3	800 Watts; Features an internal impedance transformer with selectable output impedance values of 12.5, 25, 50, 100, 150, 200, and 400 Ω. Optional external impedance transformers are available for applications requiring an extended range from 8 Ω to 2k Ω.
1500A3	1500 Watts; Optional external impedance transformers are available for applications requiring an extended range from 8 Ω to 2k Ω.
5000A3	5000 Watts

Impedance Matching

One might ask why so much attention is paid to matching impedance. In a word, efficiency. If the load impedance is matched to the source, maximum power is transferred. Any variation will result in forward power reflected back from the load to the source. The degree of mismatch is often characterized by the Voltage Standing Wave Ratio (VSWR). The greater the mismatch the greater the standing waves produced and the greater the VSWR. The following equations relate VSWR to the load and source impedance (Z_L and Z_0), and indicate the amount of power reflected back toward the source as a function of VSWR.

$$vswr = \frac{1+\sqrt{\frac{P_{Rev}}{P_{Fwd}}}}{1-\sqrt{\frac{P_{Rev}}{P_{Fwd}}}}, \qquad vswr = \frac{1+\rho}{1-\rho}, \quad vswr = \frac{Z_L}{Z_O}, \quad vswr = \frac{Z_O}{Z_L}$$

$$\rho = \left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right|, \quad \rho = \sqrt{\frac{P_{Rev}}{P_{Fwd}}}$$

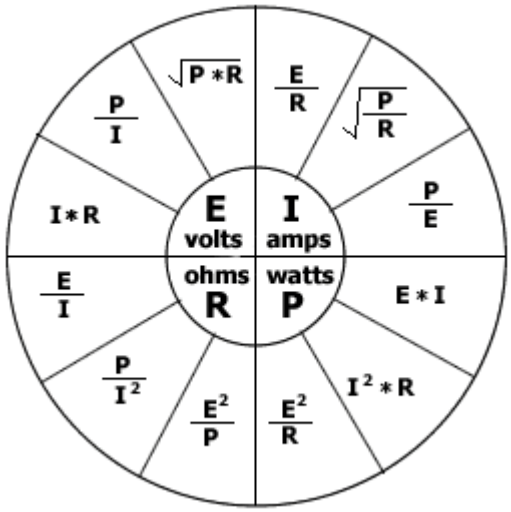
Where, $vswr$ = Voltage Standing Wave Ratio, P=Power (watts), Z=Impedance (ohms), and ρ = Reflection Coefficient

From these relationships one can determine that a VSWR of 2.0:1 results in approximately 11% forward power reflected back to the source. Since this is power wasted and not delivered to the load, it is best to minimize this mismatch by attempting to match the load impedance to the source. See Application Note # 27A for background information on the adverse effects of load mismatch.

Matching Transformers

Matching transformers have proven to be ideal devices when impedance matching is required. The high power and broad frequency range involved are a technical challenge but not insurmountable. For example, AR RF/Microwave Instrumentation has developed an internal matching transformer with multiple switching taps that can cover a broad frequency range of 10 kHz to 3 MHz at the considerable output power of 800 watts. The internal impedance selections of 12.5, 25, 50, 100, 200, and 400 Ω address systems with load impedance ranging from 9.5 Ω to 600 Ω while maintaining a VSWR of no greater than 1.5 resulting in a tolerable maximum reflected power of 4%. If the generous selection of output impedances available via the internal matching transformer is not sufficient, the IT1000 and IT2000 series of external impedance matching transformers have been developed to add more choices and the ability to meet a larger variety of applications. The IT1000 series of external matching transformers provide a very simple manual method of controlling output impedance via a simple rotary switch. The IT2000 series of external matching transformers offer additional simplicity and productivity. When physically connected to either the 800A3 or 1500A3 amplifiers, the output impedance can be *remotely* controlled by the amplifier. Output impedance can be selected from 8 to 2000 Ω, depending on the specific impedance transformer model used. Impedance selection is transparent and in effect functions just as if the matching transformer were internal to the amplifier. In addition, the IT2000 series provides an isolated output and the added benefit of having a balanced output facilitating direct connections to balanced loads.

Ohms Law: How Current and/or Voltage may supersede the need for maximum power transferred to the load



The above discussion focused on delivering maximum power to the load. But in many cases it is not maximum power that is needed or known but either voltage or current. In this case, 50 Ω may not be the best choice. To illustrate this point, consider that the 800A3 is rated at 800 watts and with the standard 50 Ω output impedance will deliver 200 V_{RMS} and 4 amps. What if 400 V_{RMS} was needed? This would normally require 3200 watts of power from a conventional RF amplifier with a 50 Ω source impedance. This is 4 times the power of an 800A3 and could possibly cost 4 times as much. Given the selectable output impedance of the 800A3, one merely needs to select 200 Ω output impedance and now 400 V_{RMS} is readily achievable. With the versatile output impedance selections available, high voltage or high current are now possible, thus increasing the versatility and usefulness of the A3 series for varied applications.

Max voltage with external impedance transformer set to 2000 Ω:

800 watts = 1265 V_{RMS} = 1789 V_P

1500 watts = 1732 V_{RMS} = 2450 V_P

Max current with external impedance transformer set to 8 Ω:

800 watts = 10 A_{RMS} = 14 A_P

1500 watts = 13.7 A_{RMS} = 19.4 A_P

Given that "real life" loads are not static but dynamic complex impedances that may vary as a function of time due to temperature fluctuation or drive current and/or voltage, AR has implemented fast switching (<10msec) vacuum relays so output impedance can be switched on the fly while the load is powered up. Optimum impedance matching is achieved by observing the forward and reverse power on the A3 amplifier front panel display while dynamically adjusting the output impedance of the amplifier.

Applications

The unique impedance matching capabilities and mismatch tolerance of the A3 series of amplifiers lends itself well to the ever changing requirements of basic research and development applications as well as general purpose lab use. There are a myriad of applications in these disciplines that standard 50 Ω RF amplifiers are not well suited for but can be addressed by the A3 series. The applications listed below are but a few of the areas where the A3 is currently in use. As new technologies emerge that require the versatile features of the A3, it is comforting to know that the A3 is up to the challenge.

Florescent Lighting

New research in florescent lighting has demonstrated that RF can be used to excite plasma with a marked increase in efficiency. In the research phase the optimum operating frequency for each type of bulb is unknown, thus the need for a broadband amplifier such as the A3. The A3 has also been found suitable for use in production testing once products exit the research phase. This application requires high voltage / low current to energize the plasma, followed by high current to insure efficient light conversion. The ability of the 800A3 to change impedance on the fly makes it an ideal choice for this type of experimentation. The AR Model 800A3 uses high voltage and high current vacuum relays to allow "hot" switching between different output impedances. This impedance change can be selected from the front panel or directed via the remote computer interface. The forward and reflected power can be monitored on the front panel display and/or via the remote interface. Since the extent of impedance mismatch is directly proportional to the amount of reflected power, knowledge of reflected power is vital in achieving a proper impedance match between the amplifier output and the load.

Ultrasound

These applications employ sound at frequencies slightly higher than can be heard by humans. Applications employing ultrasound transducers vary from biomedical (diagnostics, surgical, and, therapeutic) to industrial cleaning applications. The transducers are nominally 50 Ω but both the resonant frequency and impedance are influenced to some degree by temperature. The variable output impedance of the A3 series can accommodate this impedance shift and allow researches the flexibility to develop the most efficient transducers regardless of their impedance variation.

Plasma generation and testing

Plasma research is similar to the elements that were covered in the florescent lighting application. High voltage to ignite the plasma, followed by a steady current to sustain it. This is easily handled with the impedance switching feature of the A3 series of amplifiers.

Mass Spectrometers

This application requires high voltages but not high power. This is not a good fit for a standard 50 Ω RF amplifier. Amplifiers in the A3 series have the ability to increase their internal impedance and are better suited for high voltage applications.

Piezoelectric Crystals

Crystal impedance is usually much greater that 50 Ω and high voltage rather than high power is desirable. Again the A3 series with their adjustable output impedance offer flexibility not available with standard 50 Ω RF amplifiers.

Electromagnetic Compatibility-EMC

Bulk Current Injection testing can require high power with impedance that varies across the frequency range. The mismatch tolerance and favorable power to size ratio of the 800A3 amplifier makes it an excellent candidate for this application, especially when mobility is a consideration.

In summary, the A3 series unique impedance matching capability, ability to tolerate a great deal of impedance mismatch (see application note #27A for details on load tolerance), and outstanding price performance ratio result in an extremely flexible, feature rich general purpose RF amplifier line that can address a myriad of laboratory applications.

For more information, contact AR RF/Microwave Instrumentation, 160 School House Rd. Souderton, PA 18964 USA at 215-723-8181 or at www.ar-worldwide.com. For an applications engineer, call 800-933-8181.