Application Note #50
Application and Use of the 350AH1 Low Frequency Amplifier

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Most RF amplifiers have what has come to be known as"*standard*" 50Ω output impedance. The AR RF/Microwave Instrumentation model 350AH1 RF amplifier is unique in that its output impedance is typically less than 1Ω. With such low output impedance and a broad frequency range of 10Hz to 1MHz one might mistakenly make the assumption that the 350AH1 is merely a high-end audio amplifier. This amplifier however was not designed to be used in any stereo system. It was specifically designed as a very versatile and rugged bench-top instrument for lab use in R&D applications, product quality testing, magnetic research, and Electromagnetic compatibility (EMC) testing per MIL-STD-461F: CS101, CS109, CS114, RS109, DO160F sections 18 & 19, as well as many automotive EMC standards. The extreme rugged design ensures that the 350AH1 will deliver required voltage and/or current to any load without fear of amplifier shut-down or failure. This Application Note will explore the characteristics of this unique amplifier, cover methods of interconnecting amplifiers for enhanced performance, and discuss some of the applications addressed by this robust, versatile amplifier.

350AH1 Basic Specifications (Please refer to the data sheet for full and updated specifications).

Frequency Response:	10Hz – 1MHz
Output:	14 Amps & 25 Volts, 10Hz - 300 kHz De-rated at higher frequencies with a gradual sloping down to 5.5 Amps & 10 Volts at 1 MHz
Input Impedance:	600Ω typical
Output Impedance:	<1Ω typical
Mismatch tolerance:	100% rated voltage or current available into any load without amplifier shutdown or failure
Display:	Color with both voltage & current or VA displayed
Interface:	GPIB, serial RS232, Ethernet, and USB

Voltage and Current Limiting

The 350AH1 amplifier differs from all other AR amplifiers in that it guarantees a minimum value of voltage and/or current delivered to the load rather than output power. The load impedance determines whether the output will be voltage or current limited in a manner similar to that of a conventional DC power supply.

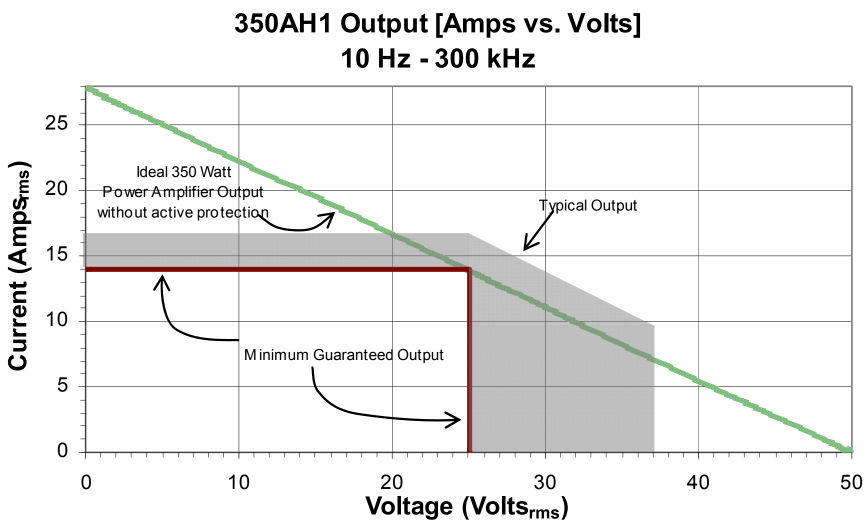

Figure 1: Current vs. Voltage

In particular, for a load impedance exceeding 1.8Ω the output voltage is limited. Typically one could expect a minimum of 25 volts, but no more than 37 volts. Conversely, an output impedance of less than 1.8Ω results in output current limiting. In this situation one can expect an output current of at least 14A but no more than 16.5A. Figure 1 clearly shows the minimum guaranteed voltage and current values as well as the typical levels. Note that the "gray" area containing typical values of voltage and current assume minimal transmission loss in the output lead wires.

Output power is generally considered the major criteria when specifying a power amplifier. However, some applications call for either a fixed voltage or current and in this situation, the power delivered to the load can be determined by applying Ohm's law. The Ohm's law pie chart shown in Fig. 2 shows the various combinations of the four variables, I, V, Ω and W. As shown in Fig.3, an ideal output impedance of 1.8Ω will deliver a minimum output power of 350Watts. Above this impedance the amplifier will voltage limit and below this impedance the amplifier will current limit. More information is available in *Application Note # 49 RF Amplifier Output Voltage, Current, Power, and Impedance relationship*.

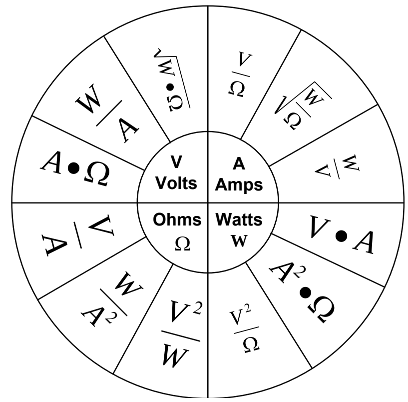

Figure 2: Ohm's Law

Wire Inductance

When operating at frequencies up to about 100 kHz the amplifier's output is very predicable. Unfortunately, as frequency increases, the inductive reactance of the output cables begin to adversely affect delivered power. While insertion loss from 100 kHz to 300 kHz is noticeable, it is not excessive. However, beyond 300 kHz losses can be significant and one must pay particular attention to output cabling to insure adequate power is delivered to the load.

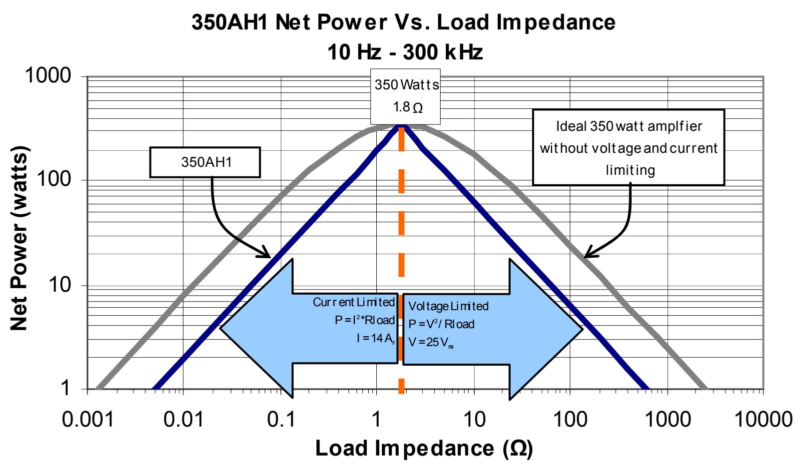

Figure 3: Power vs. Load Impedance

To minimize reactive losses when the load is in close proximity to the amplifier, insure that the wired output is as short as possible and physically large. Bus bars are particularly well suited for this application. By keeping the inductance low, the losses are tolerable. Often the application involves some degree of separation between the amplifier and the load. In this case, matched coaxial cables are recommended to minimize VSWR and maximize delivered power. Since the output impedance of the amplifier is approximately 1.8Ω, the matched cable will need to be <2Ω. Unfortunately 2Ω cable is not readily available. However, with a little ingenuity, one can fashion a serviceable low impedance cable from standard cables. For example, a 2Ω coaxial cable can be formed by combining ten 20Ω coaxial cables in parallel.

A less attractive method is to use a wide copper strap or thick wire braid. The more surface area the strap has the better. This approach works well at lower frequencies but may be limited at 1MHz.

Standard wire is only viable at the lower frequencies or for short distances. Much of the power will be lost as a result of the inductive reactance at the higher frequencies.

Subampability

For applications that require voltage or current levels beyond the capabilities of a single 350AH1, the outputs from two or more 350AH1 amplifiers can be combined. Depending on the physical configuration, one can double either the voltage or current, quadruple the current, or double both the voltage and the current.

Examples of the "Subampability" of the 350AH1:
To double the output current, tie both outputs together in a parallel configuration.

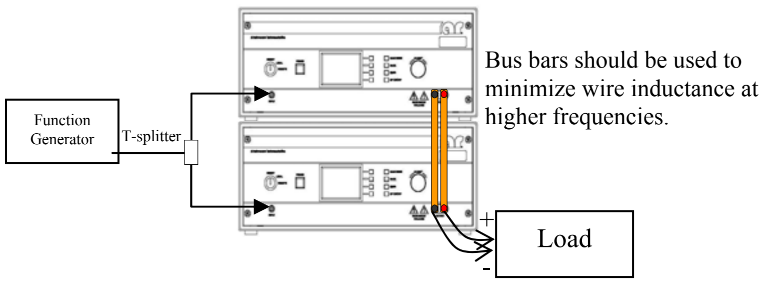

Figure 4: 2x 350AH1 in a Parallel Configuration

If the application requires more voltage than a single 350AH1 can provide, two amplifiers can be combined in a bridged configuration. The second amplifier is set to invert the output signal and the load is placed between the two outputs. The effect is a doubling of the output voltage. This technique is analogous to a residential 220VAC line (commonly used in the United States) where two 110VAC lines 180° out of phase are combined to provide 220VAC.

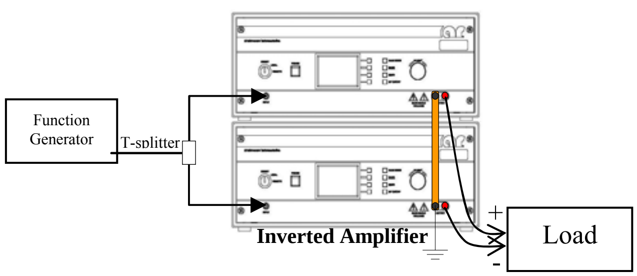

Figure 5: 2x 350AH1 in a Bridged Configuration

By combining four amplifiers, one can quadruple the output current via a parallel configuration or double both the voltage and current via a bridged & parallel configuration.
Note: In parallel configuration 2, 3, 4, 5 … amplifiers can be combined; it is not limited to just 2 and 4.

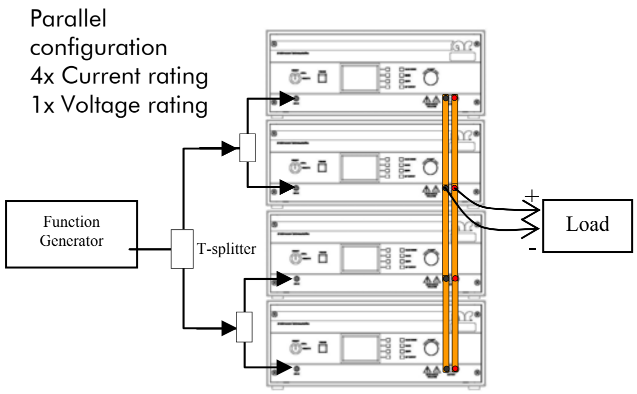

Figure 6: 4x 350AH1 in Parallel Configuration

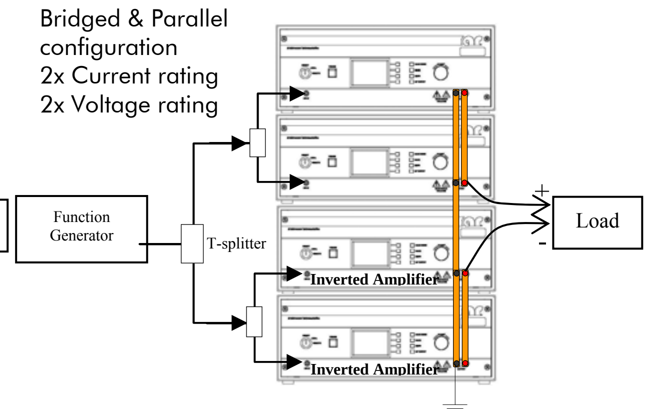

Figure 7: 4x 350AH1 in Bridged and Parallel Configuration

Expected Output Summary

The parameters listed in the table below are useful when operating at frequencies <300 kHz. At higher frequencies, inductive losses become significant and as noted in the spec sheet, current and voltage are gradually de-rated from 300 kHz to 1 MHz

	Voltage	Current	Effective Output Impedance (EOI)	Power at (EOI)*
	Volts	Amps	Ohms V / A = Ω	VA V * A = VA
A single 350AH1	25	14	1.8	350
2X 350AH1 in Parallel	25	28	0.89	700
2X 350AH1 Bridged	50	14	3.57	700
4X 350AH1 in Parallel	25	56	0.45	1400
4X 350AH1 Bridged & in Parallel	50	28	1.8	1400

* Some insertion loss can be expected in the connections, especially at frequencies above 300 kHz where power will de-rate significantly.

Applications

Due to the versatility of the 350AH1's rugged design, it lends itself for use in a myriad of applications. One of the most promising application is EMC testing. Prior to the introduction of the 350AH1, there were no instrument amplifiers available for these demanding tests. Test engineers were forced to compromise with audio amplifiers and sacrifice some of the following desirable features: broad frequency response, durable design, full mismatch tolerance into opens and shorts, and voltage and current output display.

- EMC testing
    - MIL-STD-461D/E/F
    - CS101 – Audio frequency conducted RF [30 Hz - 150 kHz]
    - CS109 – Audio Frequency Conducted RF on housing [60 Hz - 100 kHz]
    - CS114 – New requirement in MIL-STD-461F extending testing down to 4kHz from 10kHz. There is a whole new setup just for this new frequency range *(See Application Note #51)*
    - RS101 – Magnetic field testing [30 Hz - 100 kHz]
    - DO160D/E/F
    - Section 18 Audio frequency conducted RF [10 Hz - 150 kHz]
    - Section 19 Magnetic field susceptibility [350 Hz - 32 kHz]
    - Automotive
    - SAE J1113-2 Audio frequency conducted RF
    - SAE J1113-22 Magnetic field testing
    - ISO 11452-8 Audio frequency conducted RF
    - Chrysler
    - PF-9326, PF-10540 section 3.8.2: Audio frequency conducted RF [15 Hz – 250 kHz]
    - PF-9326, PF-10540 section 3.8.3: Audio frequency conducted RF [125 Hz – 20 kHz]
    - PF-9326, PF-10540 section 3.8.7: Magnetic field testing [15 Hz – 30 kHz]
    - DC-10614 (RS101) Magnetic field testing [15 Hz – 100 kHz]
    - GM
    - GMW3097 Section 3.4.4 MS [16 2/3 Hz – 180 Hz]
    - GMW3100 Section 3.2.1.2.5 MS [16 2/3 Hz – 180 Hz]
    - Ford
    - RI140 (RS101) Magnetic field testing [50 Hz – 10 kHz]
    - RI150 Radiated Susceptibility [0.6 kHz – 10 kHz]
    - CI210 Audio frequency conducted RF [50 Hz – 10 kHz]
    - CI250 Voltage offset [50 Hz – 1 kHz]
- Magnetic Field Research
- Magnetic Field Disinfecting
- Low frequency transient testing
- AC Voltage or current supply