Continental Electronics

Company Background & Experience in RF Systems for Science Applications

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HIGH-POWER RF POWER AMPLIFIERS & INTEGRATED SYSTEMS

Continental Electronics Corporation is a world-class expert in the engineering and manufacture of High-Power RF Transmitters, specializing in Integrated High-Power RF Amplifier Systems that include:

- High-Power RF Amplifiers to from 10 kW to Multi-MegaWatt Levels
- Solid State Crowbar-less High-Voltage (HV) Power Supplies
- Liquid Cooling and Thermal Management Systems
- Fully Automated Controls, Safety Protection, and Integration with Customer Systems
- RF Load Matching Networks with Automated Closed-Loop Systems
- AC Mains Switchgear, Power Management and Protection Subsystems

Known throughout the global broadcasting industry for our line of highly dependable Transmitters, Continental delivers custom systems for scientific, defense, and industrial applications, engineered and built to customer requirements. With an installed base that includes major High-Power RF installations at many US National Laboratories, Continental Electronics has served our customers with the finest in High-Power RF Amplifier and HV Power Supply Systems for more than 60 years.

In broadcast transmitters, both commercial and defense, Continental Electronics' expertise comprehends long wave, medium wave, short wave, and VHF spectra, including AM, FM, PM, and SSB transmission modes. Our High-Power RF systems have encompassed LF and VLF Transmitters, Antenna Matching Systems, and Antennas for shore-to-submarine communications; HF communications transmitters; over-the-horizon (OTH) HF radar transmitters; and large-scale RF amplifiers for many scientific and industrial applications in HF, VHF, microwave and even millimeter wave bands. Continental has experience in essentially every segment of the electromagnetic RF spectrum.

Continental now offers two digital broadcasting formats, HD Radio for VHF FM, and DRM (Digital Radio Mondiale) for HF.

Examples of Continental's equipment supplied for scientific programs are described in the following pages. Continental is pleased to offer total integrated system design, engineering, manufacturing, and field commissioning. Our customers have come to call on Continental for all their High-Power RF needs.

BROOKHAVEN NATIONAL LABORATORY

Continental Electronics designed, manufactured, and delivered to Brookhaven National Laboratory two RF Power Amplifier systems operating at 100.625 MHz, each producing 350 kW peak-power pulses. The Power Amplifiers, designed and built specifically to Brookhaven's specifications and awarded to Continental by competitive contract, are to be employed as part of the Electron-Beam Ion Source (EBIS) program.

The Electron-Beam Ion Source (EBIS) program has been proposed by Brookhaven scientists to provide a replacement for the present Pre-injector in Brookhaven's Relativistic Heavy-Ion Collider (RHIC). The new heavy-ion Pre-injector will be comprised of the high charge-state ion source and a Radio Frequency Quadrupole (RFQ). The new pre-injector will be a reliable, low-maintenance Linear-Accelerator (linac)-based facility. Linac-based pre-injectors are now used in many other accelerator and collider facilities.

Each of the RF Power Amplifier systems supplied by Continental operates at 100.625 MHz, and each produces 350 kW peak-power pulses for the RFQ and the Linac. Pulse duration is 1 millisecond, and pulse repetition rate is 5 pulses per second.

Amplifier Monitor Panel

Single HPA Section

Water Cooling Manifold

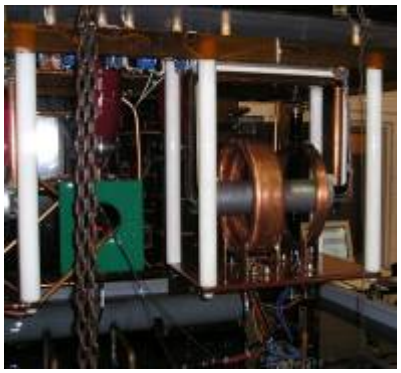
BROOKHAVEN NATIONAL LABORATORY

In 2007 Continental Electronics delivered to Brookhaven National Laboratory (BNL) an Integrated 1 MW Klystron Transmitter and 100 kV High-Voltage Power Supply (HVPS). The system was designed by Continental Electronics and manufactured under a competitive contract from BNL. The Transmitter and HVPS system are integrated with a 1 MW CW klystron operating at 704 MHz. The equipment is part of an ERL (Energy Recovery Linear accelerator) experiment to be conducted at BNL for several years. The ERL will ultimately be installed as an improvement to the Relativistic Heavy Ion Collider (RHIC) facility. The HVPS is based on Continental Electronics' Crowbar-less IGBT High-Voltage Switching supply design and provides up to 100 kV at a full-load current of 21 A for the 1 MW klystron Transmitter. No crowbar circuit is needed because the solid state switching approach leaves little stored energy to be dissipated during a shut-down. In addition to the HVPS, the integrated Transmitter system includes PLC controls and interface, water-cooling and monitoring system, high-voltage oil tank assembly, klystron and magnet supplies, and a custom designed user interface, as well as all safety interlocks, monitoring, and operational features.

Control Panel, A-B PLC Console, AC Distribution, RF Pre-Amp & Monitoring, Magnet Supplies

Transformers and Switch Module Columns (viewed from inside protected area)

Factory testing: Switch Module Columns, HV Oil Tank, Klystron Enclosure (back: Control rack)



Oil Tank Components before immersion

KOREAN ATOMIC ENERGY RESEARCH INSTITUTE

In 2007 Continental Electronics delivered a special purpose cavity amplifier for the 30-60 MHz frequency range, capable of operating at up to 2 MW power output in long pulse mode. The system will be used for the Korean Superconducting Tokamak Reactor (KSTAR) in Daejon, Korea. It is based on a proven design built by Continental Electronics for a number of customers engaged in fusion research. System includes intermediate, driver, and final power amplifiers, all power supplies, water-cooling for all stages, crowbar and switchgear. Transmitter, shown below, has been operated at 2 MW (megawatts) for up to 300 seconds in pulse duration.

Control Panel

IPA & Driver Cabinet during assembly

2 MW Final Power Amplifier

System installed at Daejon

Water-cooling manifold, gages

INTERNATIONAL ISOTOPES, INC.

In 1997 Continental was awarded a contract to design and manufacture two PFN-type pulse modulators for use in the experimental production of medical radio isotopes. Those modulators supplied the beam power to 427 MHz klystrons used in International Isotopes' linear accelerator. Continental also supplied the local and remote controls, interfaces, protection circuits, and ancillary klystron power supplies for the modulator systems.

LOS ALAMOS NATIONAL LABORATORY

In 1996 and 1997 Continental received three consecutive contracts to design and build equipment for the prototype model of the APT (Advanced Production of Tritium) system. The first contract consisted of four (4) 352 MHz klystron transmitters, plus three (3) similar systems designed for 704 MHz as follow-on. The second contract was for two (2) Continental 95 kV, 21 A IGBT Crowbar-less switching power supplies to be used with two of the transmitters for comparison with traditional power supplies on other transmitters. A third contract was for a similar power supply providing 45 kV at 40 A. That supply was intended for use with a transmitter based on a new IOT (Inductive Output Tube). Figures below illustrate some of the principal items delivered.

Control Cabinet and A-B PLC

45kV HV Transformers and Switch Module Column

PRINCETON PLASMA PHYSICS LABORATORY

In 1989 Continental received a contract for four (4) High-Power RF Amplifier systems from Princeton Plasma Physics Laboratory (PPPL), similar to two modified RF Amplifiers previously designed and delivered to the same customer. Those amplifiers were pulsed at 1.5 MW peak power in the 40 - 80 MHz range. The previous contract included the manufacture and testing of FPA and Driver cavity amplifiers and the capacitor/crowbar units for protecting the FPA and driver.

ATOMIC ENERGY OF CANADA LIMITED

Continental was awarded a contract by AECL in 1989 for two (2) 250 kW CW, Klystrode amplifiers operating at 267 MHz for AECL/CRNL's proton beam accelerator experiments. An amplitude control loop was employed for level stability and reduction of sidebands related to the SCR controlled variable power supply. Closed-loop and open-loop pulse/amplitude modulation were also accommodated. The system was delivered to the customer in 1992.

GENERAL ATOMICS

In 1986 Continental received a contract for a High-Power RF Amplifier system to deliver 2.25 MW pulsed power over the frequency range of 30 - 60 MHz. The system continues in use today by General Atomics for Ion Cyclotron Resonance Heating (ICRH) of plasma. Figures below show the 2.25 MW, 30 - 60 MHz final power amplifier and IPA/ Driver.

2.25 MW Final Cavity Amplifier

Intermediate and Driver Cavity Amplifiers

OAK RIDGE NATIONAL LABORATORY

In 1985 Continental received a contract from Martin Marietta Energy Systems, Inc. for one high High-Power RF Amplifier system to be used for Ion Cyclotron Resonance Heating (ICRH) of plasma at Oak Ridge National Laboratory. The amplifier was modified from FMIT (see below) equipment to deliver 1.5 MW pulsed power over the frequency range of 40 to 80 MHz. Figures below show the 1.5 MW FPA and the IPA/ Driver.

1.5 MW Pulsed Final Cavity Amplifier

Intermediate and Driver Cavity Amplifiers

FUSION MATERIALS IRRADIATION FACILITY

In 1980 Continental received a contract from Los Alamos National Laboratory (formerly Los Alamos Scientific Laboratory) for 17 power amplifiers in support of the Fusion Materials Irradiation Facility (FMIT) Program. Each amplifier provided 600 kW at 80 MHz and was to have been used to power linear accelerators at both the prototype facility in Los Alamos and at Hanford Engineering Development Laboratory in Richland, Washington. (The research effort for the program was subsequently discontinued and the equipment diverted to other programs.) Figures below show the final power amplifier and IPA/Driver.

FMIT 600kW Final Cavity Amplifier

FMIT Driver & Intermediate Cavities

PRINCETON PLASMA PHYSICS LABORATORY

In 1980 Continental was awarded a study contract by Princeton Plasma Physics Laboratory (PPPL) for the preliminary design of 16 each 50 - 100 MHz High-Power RF Amplifier systems for Ion Cyclotron Resonance Frequency (ICRF) heating of the Princeton Tokamak Fusion Test Reactor (TFTR) plasma. The output power of each amplifier was 1.5 MW, so that a total of 24MW was produced. Linear operation was required over the domain of 30 to 90 percent of full power. Normal operation required one 1.0-second pulse per 5.0-minute interval. Fast pulse operation required 120 pulses per second maximum with variable pulse width. The amplifiers were required to be grouped in sets of four; each set being fed from a single power supply. Both local and remote control and monitoring systems were provided with the system.

OAK RIDGE NATIONAL LABORATORY

In 1979 Continental designed a High-Power RF Amplifier system to be used for Ion Cyclotron Resonance Heating (ICRH) of the plasma in the Elmo Bumpy Torus Proof of Principle Experiment (EBT-P) for Oak Ridge National Laboratory. The RF system included a signal generator and four (4) 600 kW CW, 50 - 70 MHz RF Amplifiers. The output power was variable up to 600 kW for each amplifier (2500 kW total). The system included a remote control and monitoring capability for each amplifier, and individual phase and amplitude controls.

TOKAMAK FUSION TEST REACTOR BREAKDOWN OSCILLATOR

Under a subcontract originating from U.S. Department of Energy, Princeton Plasma Physics Laboratory awarded Continental a contract for a Tokamak Fusion Test Reactor (TFTR) Breakdown Oscillator (BDO). This BDO is a pulsed, High-Power Oscillator-Amplifier combination operating in the LF/VLF region, generating pulses of carrier frequency between 15 and 45 kHz which are delivered via shielded transmission lines to inductors inside the test cells. The pulses produce preliminary ionization of the gas contained in the vacuum vessel of the TFTR. Included in the contract were the BDO and Control Systems, Tuning/Matching Network, Transmission Line (from BDO to Tuning/Matching Network), Transmission Line - DC Break (from Tuning/Matching Network to Test Cell), and Dummy Load.

NEW ENGLAND NUCLEAR

When New England Nuclear (NEN) decided to expand its production capabilities in the medical electronics field, they turned to Continental for high-power amplifier systems. In 1979 NEN awarded Continental a contract for three (3) 201 MHz, 5 MW peak, 200 kW average power amplifiers for use with NEN's new 45 MeV, 5 mA Proton Linear Accelerator. The RCA 7835 triode was used in what had become a standard cavity amplifier for Continental.

In addition to the cavity amplifier chain, Continental provided the Power Supplies, HV Modulator, AC distribution system, control and monitor systems, prime power switchgear and Crowbar protective systems. Continental also provided two low power systems for the bunchers. Each low power system provided 0.6 kW average and 5 kW peak; one at 201 MHz and the other at 402 MHz. The systems were delivered in 1980. Continental equipment installed at NEN is shown below.

NEN: 5 MW Peak Final Cavity Amplifier (7835)

Filament P.S., Pressurization & Driver (4616)

WSMR S-BAND TRANSMITTERS

During 1973, Continental Electronics delivered two klystron S-Band Transmitters to the U.S. Army Nuclear Effects Laboratory at the White Sands Missile Range. The transmitters, which operate at 2855 MHz, have a 10 microsecond pulse width and each provide 15 MW of peak power for combining inside the customer's linear accelerator.

ATOMIC ENERGY OF CANADA LIMITED

Continental provided Atomic Energy of Canada Limited with a 100 kW RF Amplifier and accompanying Dummy Load. The operating frequency was continuously tunable from 31 to 62 MHz and output power was adjustable with drive power from 100 kW down to the noise floor. The amplifier provided RF excitation for the resonators in the Chalk River Nuclear Laboratories superconducting heavy-ion cyclotron.

MCGILL UNIVERSITY

In 1975 Continental Electronics was contracted to upgrade the RF source for McGill University's cyclotron facility at Montreal that was originally built in 1948. The RF source, comprised of a single oscillator stage was replaced. In addition, Continental provided a new D.C. anode supply, plus a control facility which was integrated with the McGill supervisory control system. Continental's new oscillator provided for additional power and expansion of the frequency range in order to expand the range of particle weights usable in the system.

RF AMPLIFIERS FOR CNEN

Continental provided 100 kW linear amplifiers to the Italian Economic Corporation on behalf of Comitato Nazioale per L'Energia Nucleare (CNEN). The 100 kW amplifiers were installed at the Frascati Laboratories and used as an RF system to drive a cavity resonator for the ADONE Storage Ring. The cavity type amplifiers were supplied complete with power supplies, remote control, dummy load and spares.

PROJECT TRIUMF

Continental designed, fabricated, and installed an RF Amplifier for the Tri-University Meson Facility (TRIUMF) located at Vancouver, BC. TRIUMF was jointly funded by the Atomic Energy Control Board of Canada and three universities: Simon Fraser University, the University of Victoria and the University of British Columbia (later joined by the University of Alberta).

The RF Amplifier provides 1.65 MW at 22.6 MHz, and is comprised of four power amplifiers combined in pairs. The three combiners are of a bridge type, each having a waster load dissipating near zero power under normal operating conditions. Each power amplifier is capable of 450 kW output with a 450 kW plate dissipation capability. The amplifier continues to operate today.

FERMI NATIONAL ACCELERATOR LABORATORY (FNAL)

Shortly after its inception in 1967, the injector group from the Fermi National Accelerator Laboratory (Fermilab), began discussions with Continental concerning the 200 MHz injector RF equipment. One prototype 7835 amplifier cavity was delivered by Continental in 1968. Since Fermilab placed emphasis on maintaining a tight schedule, Continental was also selected to develop a prototype anode modulator and power supply for the 7835, plus a prototype for the RF driver. Following successful prototype testing at FNAL, Continental received production orders for nine (9) each of the amplifier cavities, modulator-power supplies, and RF drivers. Those systems were installed and placed in operation by Continental Electronics in 1970.
Five of the 10 systems installed at Fermilab in 1970 continue to operate at present.

CORNELL UNIVERSITY

In 1966 Cornell University presented Continental with an unusual modulation problem. It required the generation of a shaped pulse for the RF system of Cornell's10 GEV Electron Synchrotron. The desired pulse was 9 milliseconds long at a repetition rate of 60 Hz. The shape desired was a quasi-exponential rise for 7 milliseconds followed by 2 milliseconds of flat-topped pulse, and a decay time of approximately 100 milliseconds. To derive such a shaped pulse using linear amplifier techniques would have resulted in an inherently low efficiency circuit. But Continental's unconventional solution allowed the use of relatively small switch tubes in saturated mode as compared with larger tubes that would have been required for linear mode. The overall efficiency of the system measured 35 percent, compared with an estimated 25 percent for a linear system.

TEXAS A&M UNIVERSITY

In 1965 Continental Electronics was called upon to reconstruct an accelerator from a previous design. Continental produced an exact replica of the RF system of the "Berkeley 88" Cyclotron. The system was built for the Texas A&M Variable Energy Cyclotron and was constructed from University of California drawings created many years before.

LOS ALAMOS NATIONAL LABORATORY (LANL)

In 1966 Continental was awarded a contract from Los Alamos National Laboratory (LANL, formerly Los Alamos Scientific Laboratory) to develop a prototype amplifier cavity for the 200 MHz section of a new tandem 200 MHz to 800 MHz linear accelerator. The high average beam requirements imposed special constraints on cavity cooling. The extremely high average beam currents were necessary to provide a high meson yield.

The initial design included a system for circulating and cooling the pressurized cavity air. But testing under high average power conditions disclosed that irrathene blocking capacitors were incapable of surviving the severe thermal stresses involved. Rising to the technical challenge, Continental, in cooperation with a chemical manufacturer, developed capacitors not only capable of surviving the thermal stresses, but also exhibiting improved RF characteristics. In 1969 LANL ordered three (3) additional 200 MHz amplifier cavities, all of which were delivered by year end. LANL's cavity with pressurized air-to-water heat exchanger connection is shown below at left.

Los Alamos: 200 MHz Hi-Beam Current Cavity

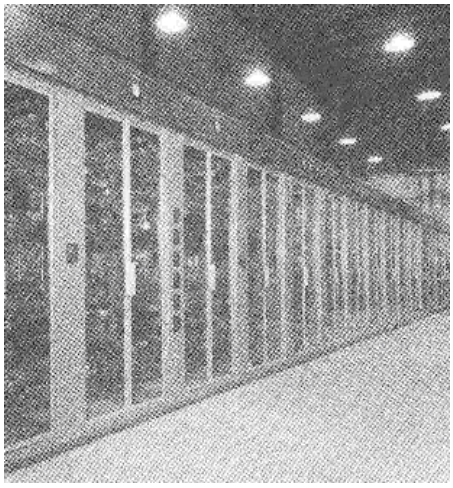
Brookhaven: 200 MHz Cavity Amplifier

BROOKHAVEN NATIONAL LABORATORY

Continental was awarded a contract to develop a prototype amplifier cavity using a RCA (now Burle) 7835 triode in 1964, shortly after Brookhaven's Alternating Gradient Synchrotron (AGS) became operational. The cavity served as an upgrade to Brookhaven's 200 MHz injector. For the Brookhaven design a previous Continental cavity design was modified: 42-inch waveguide was replaced by 9-inch coaxial output, and air pressurization resulting in improved high voltage stability was added. The cavity was delivered in 1965 and tested extensively at Brookhaven in anticipation of the injector upgrading. Following design completion for the new injector, Brookhaven ordered nine (9) cavity amplifiers from Continental in 1968, all of which were delivered by early 1969. Some of those amplifiers continue in operation at Brookhaven to the present time. The amplifier cavity is shown in photo at above right.

ARGONNE NATIONAL LABORATORY

Continental's original entrance into the particle accelerator field began with the development of the RF source for the 200 MHz injector of the Zero Gradient Synchrotron at Argonne National Laboratory. The RF source, which delivers 5 MW peak power, was installed in 1962 and served as the model for all proton linear accelerator exciters built in the United States for some time after. It operates with a 500 microsecond pulse at 10 pulses per second to accelerate the protons to the zero gradient synchrotron injection level of 50 MeV. The RF Amplifier system developed by Continental uses the RCA (Burle)7835 triode and includes all RF components from the Exciter through the Final Amplifier, complete with Power Supplies, Modulators, Cooling equipment, as well as RF and video dummy loads for component testing. The Argonne installation is shown at left below. Figure at right below shows the amplifier cavity with the output waveguide tuner at the bottom.



Argonne Installation

Argonne later awarded Continental a contract to develop the synchrotron RF source regulated power supply, programmable from 14 kV to 17 kV, also delivered in 1962.

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Since our initial entry into science applications more than 45 years ago, Continental has served the accelerator and science community with expertise in High-Power RF Amplifiers, High-Voltage Power Supplies, and Turn-Key Integrated High-Power Systems. As the premier engineering and manufacturing supplier for the broadcast industry, Continental continues to excel in state-of-the-art High-Power RF.

Our continuing leadership in commercial products assures our customers in the science community that Continental Electronics represents the value leader in engineered solutions for High-Power RF Systems.