Introduction

The M2A module is a compact water-cooled 1kW, 2.45GHz modular source designed to demonstrate the performance of Ampleon’s LDMOS devices and pallets applied to industrial applications. It integrates water cooling, power monitoring, synchronization, and MCU control and monitoring with the RF electronics, serving as a complete reference design for a 1kW industrial microwave building block.

The M2A is built around four 250W PA pallets. The two-stage pallets and output combiner are mounted directly on a copper-tubing cold plate which also provides the base for the source package. The combiner includes an isolator for each channel to allow the use of a simple in-phase microstrip combiner.

The module includes a 2.4-2.5 GHz synthesizer, which drives the four pallets through a simple in-phase splitter with per-pallet gain and phase alignment circuits. The M2A includes a microcontroller responsible for front-panel and USB control, calibration, temperature and current monitoring, and real-time measurement and display of forward and reflected power.

In comparison to magnetron generators, a solid-state source has many advantages including higher reliability and safety, reduced maintenance, and a lower lifetime cost. It also allows precise control of power and pulse modulation, and is powered by low-cost switching DC power supplies.

Because of the per-channel isolators and the ability to phase-lock the sources from a common frequency reference, the M2A source can be easily combined into larger systems without giving up the control and protection provided by distributed microcontrollers.

Features

- 1kW CW/pulsed source
- Internal PWM generator
- External gate/trigger input/output
- Frequency reference input/output
- USB and RS-485 Modbus interfaces
- MCU monitoring, control, front-panel GUI
- Forward/reflectd power monitoring
- Compact 22 x 25 x 4.4cm (1U half-rack)
- Integrated water cooling
- Windows RF Energy Testbench GUI

Applications

- Industrial 1kW reference design
- Building block for high-power systems
- Materials processing
- Plasma generation
- Heating and drying
- Microwave chemistry
- Study of biological phenomena
Hardware description

The M2A is based on standard PC24250 250W PA pallets. The PC24250 pallet is intended as a reference design for a 250W PA based on the BLC2425M9XS250 LDMOS transistor, but is available for customer prototyping.

The PC24250 pallet is a compact (8 x 4cm) drop-in amplifier with P1dB output power ≥ 250W across the 2.4-2.5GHz band at a typical efficiency ≥ 60%. It has a high gain (≥ 34dB), so it can be driven by an inexpensive low-power driver. It includes high-isolation shielding and decoupling to simplify system design.

Each pallet is supplied with DC power through a paddle board, which keeps high currents off the main board. The paddle board includes current and voltage monitoring and overcurrent protection.

Each pallet is driven by a small power amplifier IC designed for WiFi and Bluetooth applications. Since production phase and gain variations from pallet to pallet are inevitable at this frequency (and pallet matching is expensive and undesirable), each channel includes electronic phase and gain trimmers backed by nonvolatile DACs.

These four channels are driven by an on-board source, which includes a 1MHz TCXO frequency reference, an integer/fractional-N frequency synthesiser, I/Q modulator, and RF switch. The 1MHz reference can be provided to or sourced from another M2 to allow coherent multi-module applications (e.g. multiple channels or combining modules for higher power). This source is an independent module plugged onto the main board so that it can be replaced with a customer circuit or external exciter.

The outputs of the pallets are combined in a simple in-phase microstrip combiner, which includes per-channel circulators to isolate the power amplifiers from each other and from mismatched loads. The combiner includes a buried directional coupler with diode detectors for forward and reflected power monitoring.

Control and monitoring is provided by an MCU, which supports USB and RS-485 Modbus interfaces for remote control. All operating parameters can also be controlled and monitored via the front-panel LCD interface. The Windows-based RF Energy Testbench software can be used to control and calibrate both single-module and multi-module configurations.
### Specifications

#### RF characteristics
- **maximum output power**: ≥ 1kW CW at $P_{2dB}$ (40°C cooling water)
- **output power range**: 10W to $P_{2dB}$, resolution 0.1dB
- **output power accuracy**: 0.25dB typical open-loop
- **frequency range**: 2.4 to 2.5GHz, resolution 1MHz (coherent mode), 10kHz (high-resolution mode)
- **frequency accuracy**: ±2.5ppm
- **phase**: 360° range, resolution 1°
- **rise/fall time**: 100ns typical
- **reference input**: 1MHz ± 50ppm, -3 to 16dBm, SMA
- **reference output**: 1MHz square, 10dBm typical
- **coherent reference output**: 2.4 to 2.5GHz output frequency, unmodulated, 3dBm typical
- **harmonics**: TBD
- **spurious signals**: TBD
- **safe load mismatch**: VSWR ≥ 35:1, all phases
- **RF/DC efficiency**: 50% typical at $P_{2dB}$

#### Pulse modulation
- **modulation modes**: CW, internal PWM, external PWM, external gate
- **internal PWM**: 1 to 100% duty cycle, resolution 1%, 1Hz to 100kHz frequency range
- **external gate**: internal PWM cycle starts on rising edge, ends last complete PWM pulse after falling edge
- **pulse width**: ≥ 200ns
- **trigger input**: PWM or gate input, active-high TTL, BNC
- **trigger output**: follows RF output, active-high TTL, BNC

#### Control & monitor
- **internal monitors**: forward and reflected power, per-PA current, voltage, temperature
- **USB**: control/monitor, USB-B
- **aux/serial**: selectable RS-232 console or RS-485 Modbus control/monitor, active-low interlock, DB9P
- **Zmon**: external Zmon module for system calibration, HDMI-C

#### Power & physical
- **supply voltage**: 32VDC, ≤ 80A, 6 AWG terminal block
- **size**: 22 x 25 x 4.4cm (1U half-rack), excluding connectors and fluid fittings
- **mass**: 4kg
- **operating temperature**: 0 to 55°C ambient
For ease of application development, the M2A module can be provided in a rack-mount enclosure which provides DC power and cooling. This configuration is designated M2A-R.

**Supplementary specifications**

- **cooling**: internal closed-loop liquid cooling and air/liquid heat exchanger, rear-panel connectors allow operation with external chiller
- **supply voltage**: 90 to 264VAC, ≤ 2.7kVA
- **size**: 40 x 36 x 8.9cm (2U rack), excluding connectors and fluid fittings
- **mass**: 16kg
- **operating temperature**: 0 to 55°C ambient
- **agency certification**: power supplies: UL/EN/IEC60950-1 safety, EN55022/55024 EMC