HIGH-POWER CONVERTERS FOR MILITARY AND SPACE PROGRAMS

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Abstract: Advanced weapons and space systems present new applications for compact, lightweight power converters. The successful deployment of new technologies in military and space systems requires substantial advances in power sources and power converters. New compact power converters are needed to charge pulse-forming networks in pulsed power systems, to convert low voltages to high voltages in radar or beam systems, to convert power for transmission systems, to drive electric motors in propulsion and control systems, and to convert direct current to alternating current in a variety of applications.

Power converters for military and space applications must conform to size, weight, efficiency, thermal management, and reliability specifications determined by mission requirements. Recent advances in high-frequency switching semiconductors and low loss magnetic materials make it possible to significantly improve the power density of power converters. A survey of converter topologies and present component technology shows that power densities exceeding 7 kW/kg and volumes less than 0.5 m^3/MW can be achieved. The key to this performance is new MOSFET technology and use of amorphous alloys in transformers.

Parametric design optimizations of power converters from 20 kW to 2 MW have been made using present state-of-the-art components and are described along with projected performance data and selected test data from an actual 1.2 MW dc/dc converter based on this technology. Mass and performance estimates derived from more detailed point design studies are compared with parametric design study results.

Background

Power converters to charge energy storage banks for pulsed power or high-voltage CW applications in ground-based, airborne, and space-based platforms operate from a variety of power sources. Typical sources are ac alternators with various output voltages and frequencies and dc sources such as batteries, fuel cells, or dc generators. These power sources are generally not suited for powering the load directly because of their output impedance characteristics. Power conditioning is therefore required to step the voltage up to meet the specific load requirements. The power conditioners described in this paper were selected as optimum configurations based on a trade-off study of parallel resonant, series resonant, and pulse width modulation (PWM) converter topologies. The criteria for the selection were efficiency, power density (kW/kg), and volumetric efficiency (m^3/kW). PWM was selected for the low power converters (20 kW and 60 kW) because of the weight and volume penalties associated with the resonating components, with the series resonance topology being a stronger contender at the higher power rated converters (>200 kW). The input/output characteristics of the converters studied are shown in Table 1.

Table 1

Converter Input and Output Characteristics

	20 kW	60 kW	2 MW
Maximum output voltage*	45 kV	45 kV	±70 kV
Output current	0.86 A	2.54 A	34.3 A
Average power out	19.4 kW	57 kW	1.2 MW
Peak power out	38.7 kW air space	114 kW	2.4 MW
Input voltage	120/208 300 Vdc 400 Hz	240/416 400 Hz	480 467 Hz

* A typical application for the converters is to charge a capacitive energy storage bank. In this application the voltage rises linearly from zero to maximum output voltage during a charging cycle.

Critical Component Selection

A survey of switching power semiconductors, rectifiers, magnetic materials, and capacitors suitable for use in high frequency power converters was conducted and was the basis for component selection for the converters. A summary of the most important components selected in this study is shown in Table 2.

Table 2

Critical Component Selection

Component	Function
Power MOSFETs	Converter switching devices
Fast recovery diodes (30–50 ns)	Output rectifier, clamp diodes
Metglas 2714A magnetic material	Power transformer
Supermalloy magnetic material	Power transformer (second choice)
Deltamax magnetic material	Output choke
Metallized polypropylene capacitors	Input filter, res. capacitor

Parametric Design Trade-Offs

In order to determine the optimum operational parameters of the converters, computer models for the functional characteristics of each component were derived from their respective specification sheets. These component models were then combined in a circuit model to study such converter characteristics as efficiency, power density, and component temperature versus operating frequency. Figures 1 through 5 show the results of these trade-offs. The 20 kW PWM converter was selected to operate at 30 kHz, the 60 kW PWM converter was selected to operate at 35 kHz, and the 2 MW converter, which is made up of 200 kW modules, was selected to operate at 30 kHz.

Preliminary Design

The 20 kW, 60 kW, and 2 MW power converters were designed using the components selected. The predicted performance of each converter is given in Table 3.

While the series resonant converter configuration was chosen for the larger converter to avoid potential problems with high-frequency resonance, it should be noted from Fig. 3 that a PWM configuration would yield a power density of approximately 7 kW/kg at a modest sacrifice in efficiency.

Table 3
Preliminary Design Results

Converter Type	kHz	Effective (%)	kW/kg	MW/m^3
20 kW PWM	30	96	1.9	0.81
60 kW PWM	35	98	4.18	1.51
2.4 MW series resonant	30	97	4.97	2.93

Related Development

General Atomics is currently fabricating a 1.2 MW dc/dc converter based on this technology for a major defense contractor. Figures 6 and 7 are photographs of subassemblies of the 1.2 MW converter system. Test results to date indicate very close agreement between the earlier design projections and present performance in terms of efficiency and power density. Large (>7 kg) amorphous alloy cores from Allied Metglas Products have been evaluated. These cores represent a major advancement in state of the art in the size of amorphous cores. Minor problems associated with the fabrication process of these cores are being addressed by the manufacturer. Meanwhile, Supermalloy (1 Mil) is being used as a backup material.

Summary and Conclusions

The feasibility of high-power (megawatt) converters has been demonstrated using high-frequency switching power semiconductors and advanced magnetic materials. Power densities exceeding 7 kW/kg and volumes less than 0.5 m^3/MW can be achieved with present technology components. Amorphous alloy core materials will soon allow a factor of two reduction in magnetic losses over the nearest competing alloy.

Acknowledgment

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Fig. 1. 20 kW PWM versus series resonant converter.

Fig. 2. 60 kW PWM versus series resonant converter.

Fig. 3. 200 kW PWM module versus series resonant module.

Fig. 4. 200 kW series resonant module characteristics.

Fig. 5. 200 kW transformer characteristics.

Fig. 6. 20 kW FET inverter submodule.

Fig. 7. 200 kW inverter module.

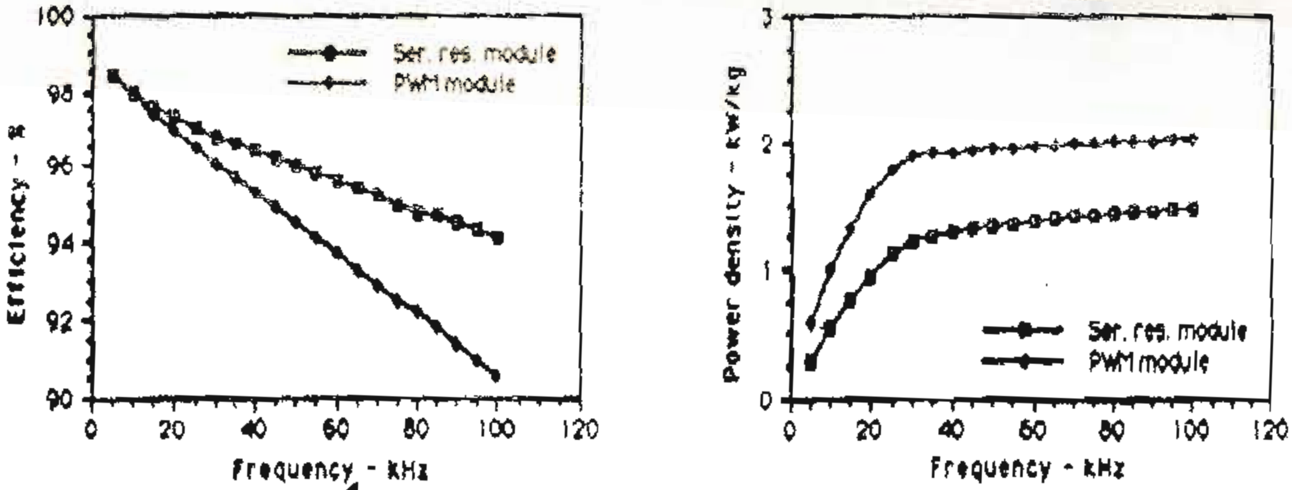

Figure [illegible]. 20 kW PWM versus series resonant converter

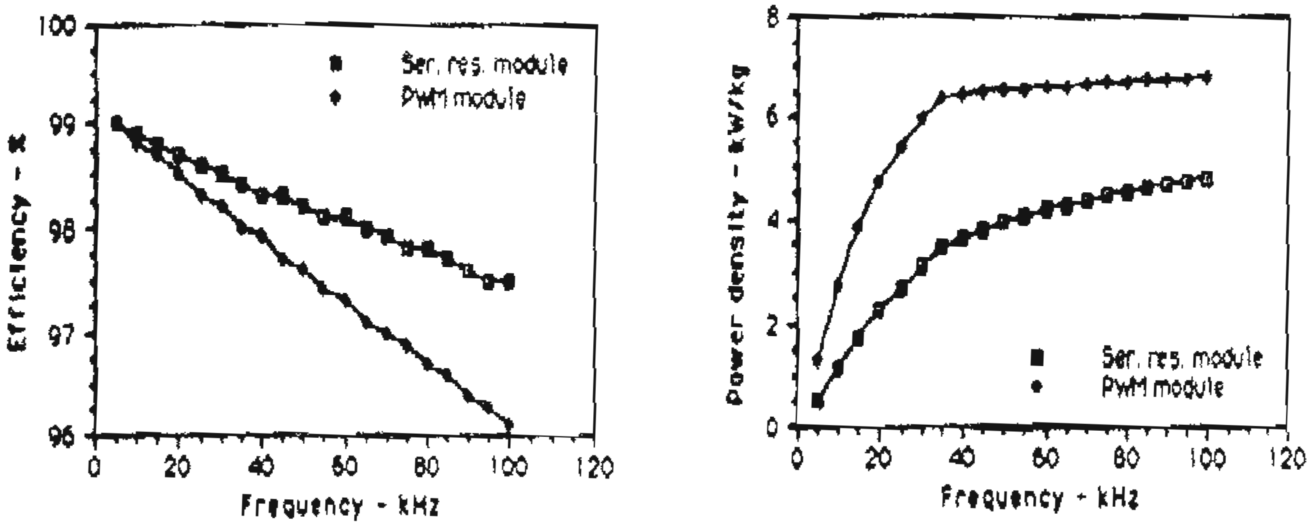

Figure 2. 60 kW PWM versus series resonant converter

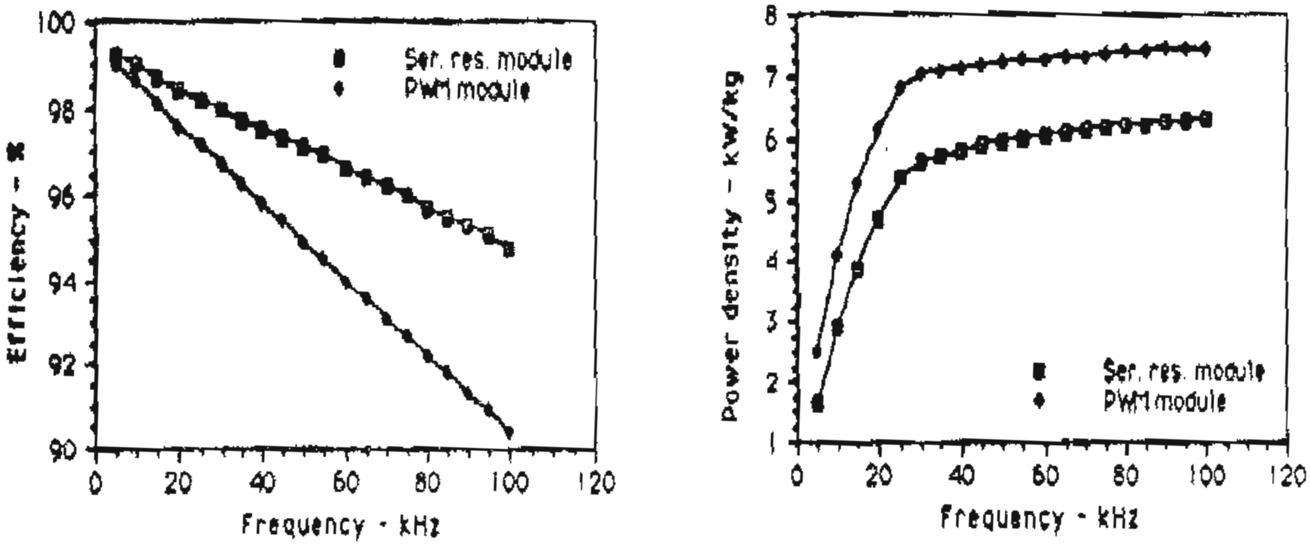

Figure 3. 200 kW PWM module versus series resonant module

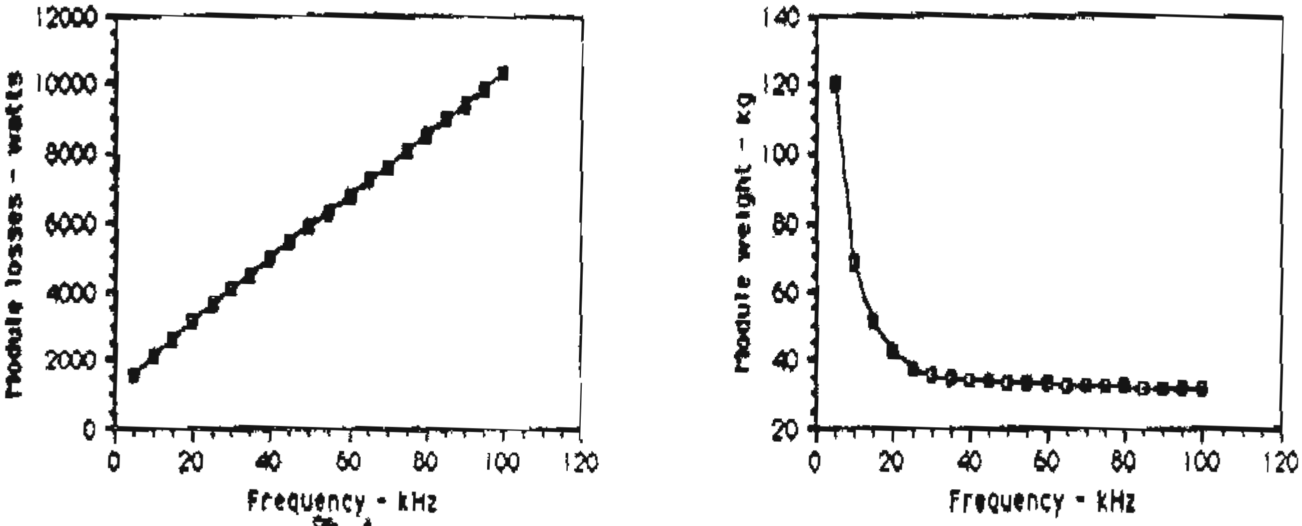

Figure [illegible] 4. 200 kW series resonant module characteristics

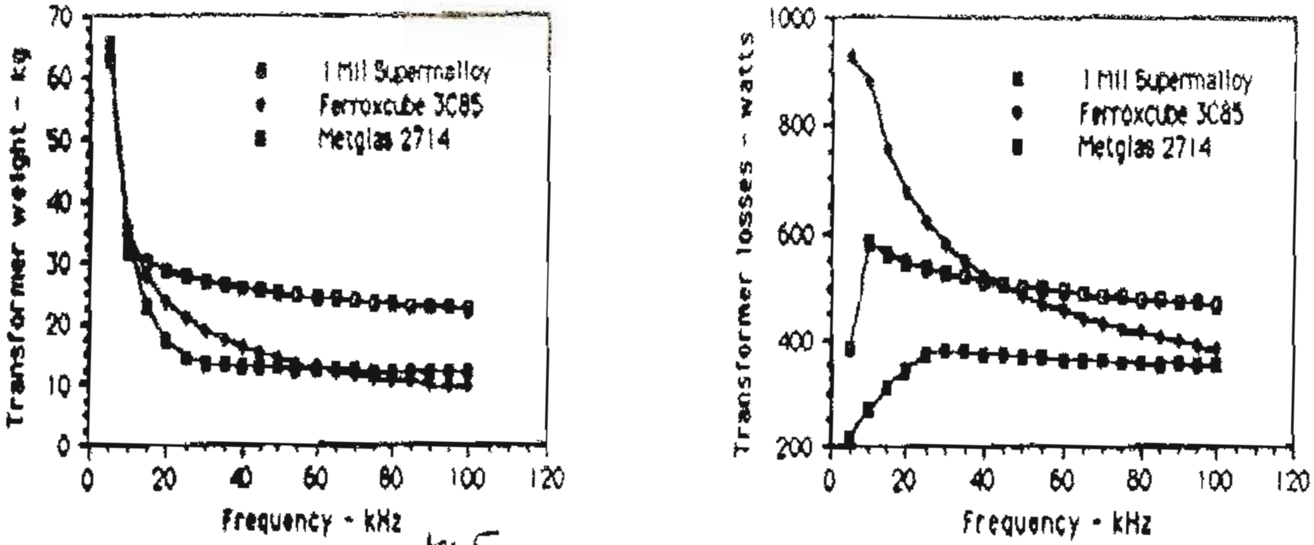

Figure H5. 200 kW transformer characteristics

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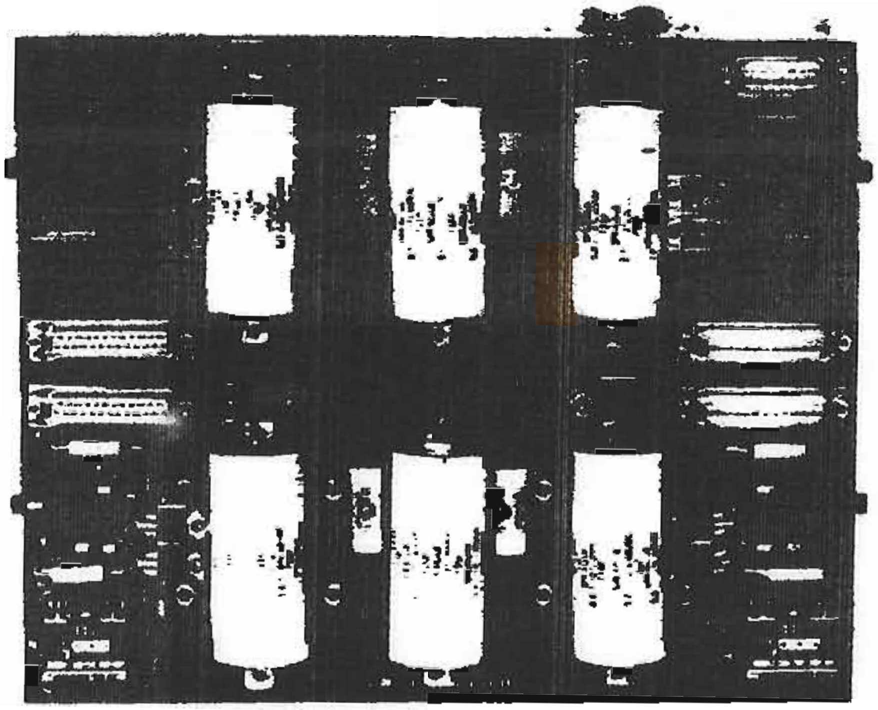

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Figure ~~8~~ 7 [illegible]