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DEVELOPMENTS IN
SPACE POWER COMPONENTS
FOR
POWER MANAGEMENT AND DISTRIBUTION

David D. Renz
NASA Lewis Research Center
Cleveland, Ohio

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**Power Electronic Component Development
at Lewis Research Center**

Advanced power electronic component development for space applications has been going on at NASA Lewis for more than a decade (Fig. 1). A wide range of development work has been done, including transformers and inductors, semi-conductor devices such as transistors and diodes, remote power controllers, and supporting electrical materials development. Present power component capability for space applications is about 25 kW. Work in the early and middle 1980's should raise this capability up to 100 kW and begin work toward a megawatt.

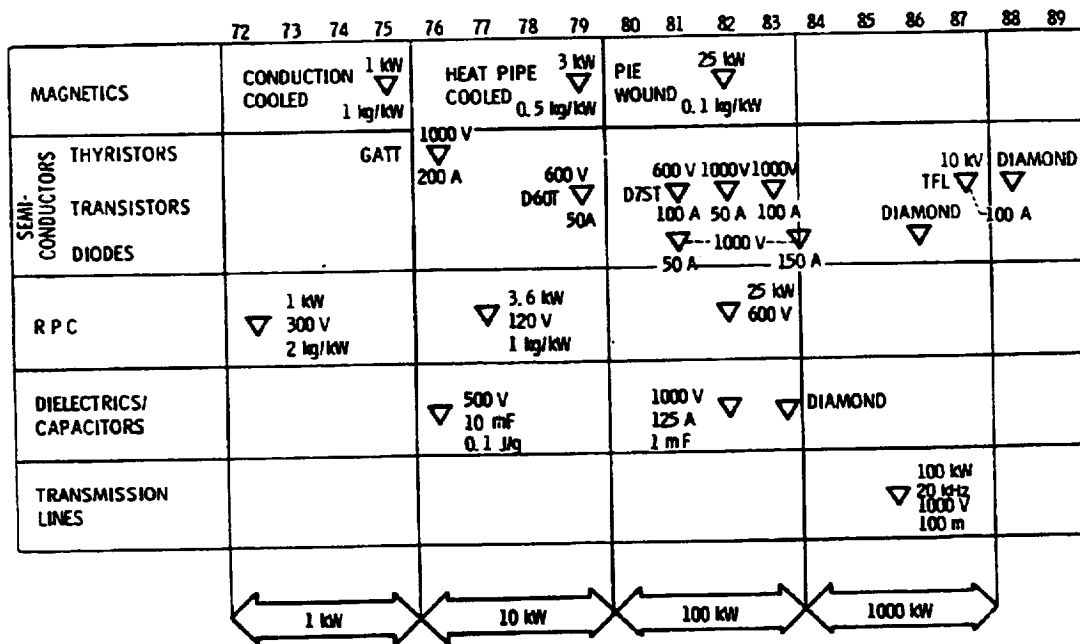


Fig. 1

D60T Transistor

Against the backdrop of a circuit diagram for a solid-state remote power controller a technician holds a D60T (Fig. 2) ready for assembly in a stud package (ref. 1). In her right hand the interdigitated silicon wafer may be seen inside the base. The emitter-base contacts are visible in the ceramic-to-metal top held in her left hand. To the left of the picture are shown three package types. From the top are a special flat base package (a modification of the stud package), a stud package and a disc-type package. This transistor is rated at 400 to 500 volts, 100 amperes continuous (200 A peak) collector currents with switching frequency of 20 to 50 kHz. This device can be used in DC-DC inverters, DC-AC converters, DC motor controllers and remote power controllers.



Fig. 2

RESEARCH AND
DEVELOPMENT
CENTRAL LABORATORY

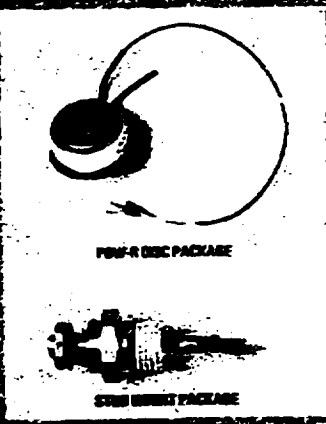
High Current Power Switching Transistor

Figure 3 shows the Westinghouse D7ST (ref. 2), which is now being marketed as a direct transfer of technology from a research contract supported and directed by NASA LaRC. The two package types available are shown in the center photograph. Surrounding the picture are listed the features and applications of the D7ST. The primary benefit of the new transistor to NASA is the extension of the power handling capability to 50 kW without paralleling of transistors. This opens new areas of application and directions for future space power system design.

**WESTINGHOUSE MODEL D7ST
(HIGHER CURRENT VERSION OF D60T)**

FEATURES

- VOLTAGE: 400 TO 500 VOLTS
- CURRENT: 100 TO 120 AMPERES • GAIN OF 30 AND AMPERES PEAK
- POWER HANDLING: 50 KILOWATTS
- POWER DISSIPATION: 2 W @ 25°C
- RISE AND FALL TIMES: 0.25 MICROSECOND
- STORAGE TIME: 4 MICROSECONDS
- LOW SATURATION AND PER CYCLE SWITCHING LOSSES



POWER DISC PACKAGE

STUD MOUNT PACKAGE

APPLICATIONS

- 25-50 MHz HIGH FREQUENCY INVERTERS
- VSCF CONVERTERS IN MILITARY AIRCRAFT
- ELECTRIC VEHICLE MOTOR CONTROLLERS
- DC MOTOR CONTROLLER FOR SPACE SHUTTLE ACTUATOR
- 100 MW VLF TRANSMITTERS
- 50 MHz RF INDUCTION HEATERS
- POWER SUPPLIES FOR CONSUMER AND INDUSTRIAL APPLICATIONS

BENEFITS TO NASA

- DOUBLES CAPABILITY OF PREVIOUS 10-20 KW RATED WINDING CORE TRANSISTOR
- COMMERCIALLY AVAILABLE IN QUANTITY AT REASONABLE COST
- MAKES POSSIBLE 50 MW SPACE POWER SYSTEM CONVERTERS AND POWER CONTROLLERS WITHOUT PARALLELING OF TRANSISTORS
- MOST IMPORTANT USES ALSO IN AIRCRAFT POWER DISTRIBUTION AND CONTROL
- ESTABLISHES TECHNOLOGY FOR LARGER AREA, HIGHER POWER TRANSISTORS

Fig. 3

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Augmented Power Transistor Specifications

Figure 4 shows the ratings and main characteristics of a research contract now underway at Westinghouse (ref. 3). Transistors from this program are now available. The two significant developments of this program were the demonstration of glass passivation of the wafer to provide hermetic sealing of the junctions and a new package that isolates the thermal and electrical interfaces.

VOLTAGE: 800 TO 1000 VOLTS

CURRENT: 70 TO 112 AMPERES (GAIN OF 10)
400 AMPERES PEAK

POWER HANDLING: 75 KILOWATTS

POWER DISSIPATION: 1.25 KILOWATTS AT 75°C

RISE AND FALL TIMES: 0.5 MICROSECOND

STORAGE TIME: 2.5 MICROSECONDS

Fig. 4

Fast Recovery, High Voltage Power Diode

Figure 5 shows the benefits to NASA, the features and general applications of a newly developed 50 ampere, 1200 volt fast recovery power diode (ref. 4). Power Transistor Company developed the new diode on contract to NASA LeRC. Because of the large demand for such a device commercially in motor controllers, Power Transistor Company is already marketing the product as their PTC 900 series Power Rectifier. A 150 ampere device (ref. 5) has also been developed but is not shown.

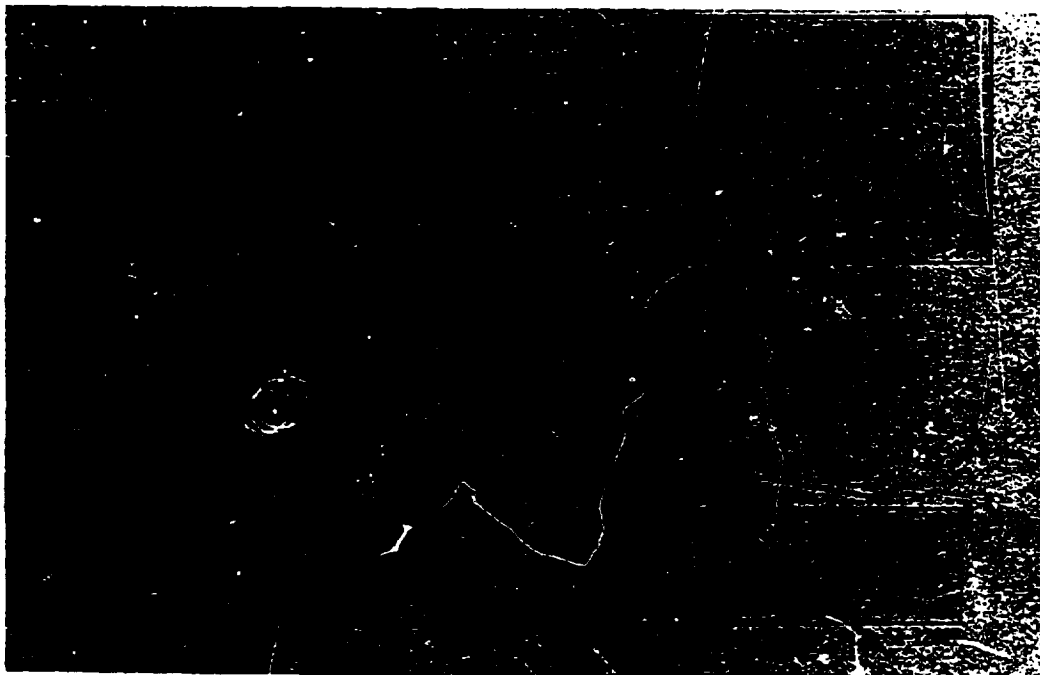


Fig. 5

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120 VDC, 30 Amp, Solid State Remote Power Controller

Figure 6 shows the 30 ampere version of the 120 VDC solid state RPC (ref. 6) developed for NASA LeRC by Westinghouse Aerospace Division. This version incorporates I^2t trip characteristics rather than current limiting. It may be noted that this version has a single layer substance 6 x 7 cm and weighs about 7 ounces.

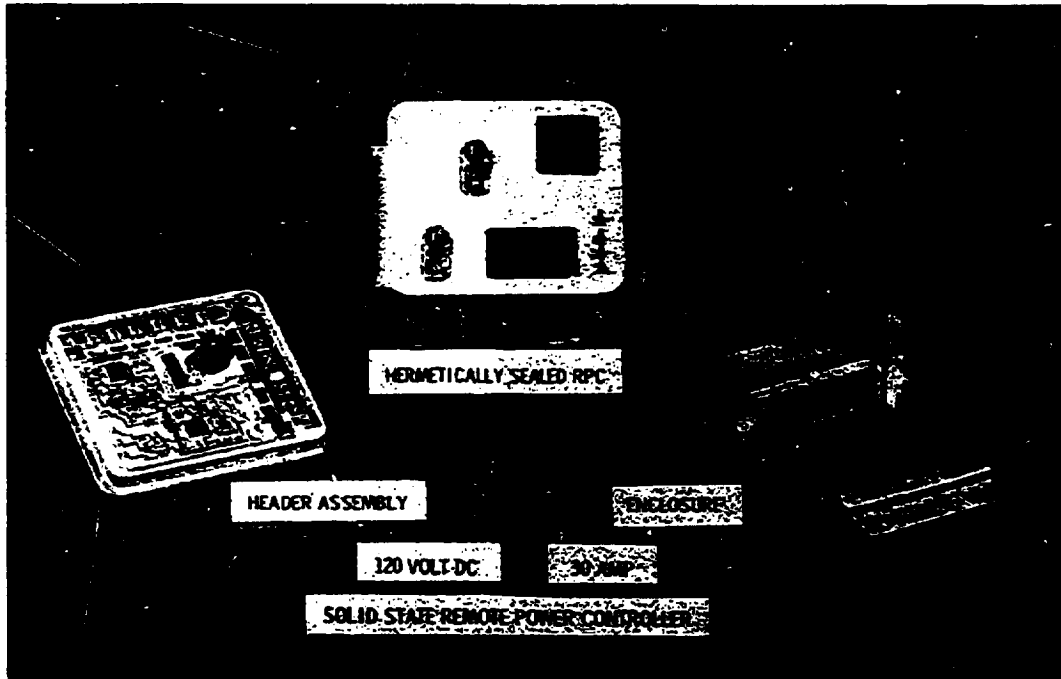


Fig. 6

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NASA High Voltage, High Power Circuits

Figure 7 shows an SCR switched solid state circuit breaker breadboard for 1000 volts DC and 25 amperes (ref. 7). This is an early model developed for use with ion thruster power supplies by John Sturman of Lewis Research Center. With the development of the 1000 volt D7 size transistor, a transistorized version is now available as symbolized by the circuit schematic on the right. Three advantages are listed, also. Solid state circuit breakers at high voltage DC have other significant advantages over conventional electromechanical circuit breakers. These include: arcless circuit interruption, long life (no contact wear), reliability, 99% efficiency, and universal source, load, computer interface compatibility.

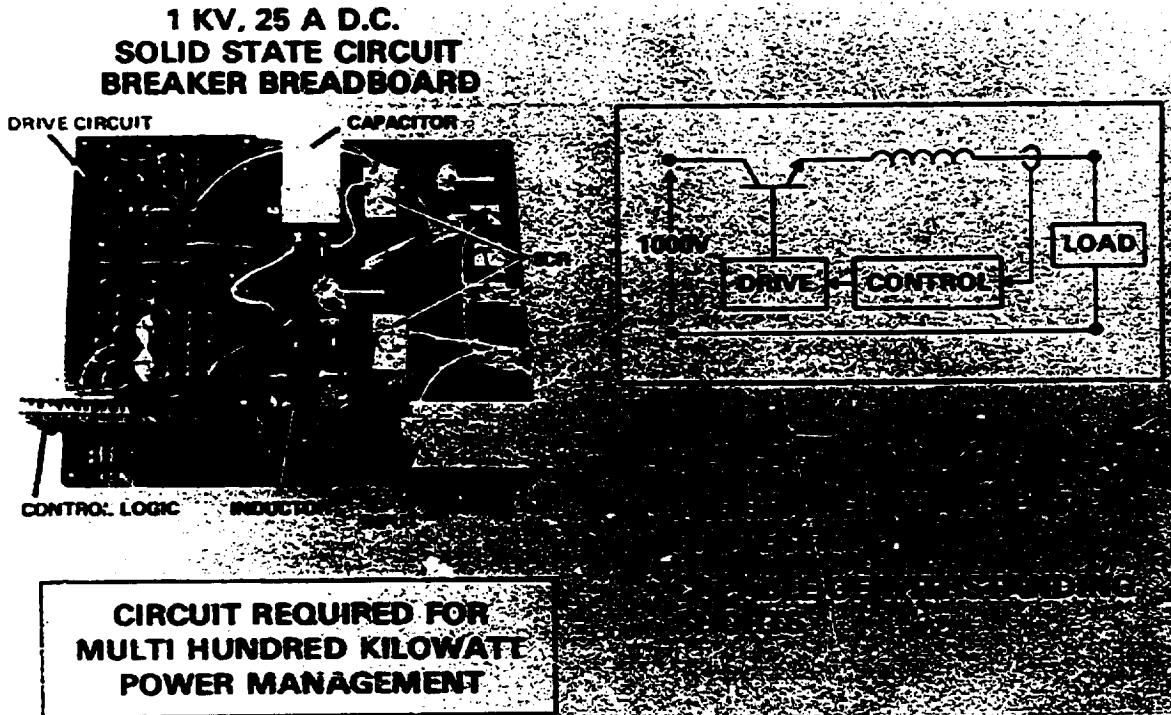


Fig. 7

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Heat Pipe Cooled Transformer

Using heat pipe cooling permits about a 30% reduction in transformer weight in the transformer shown (ref. 8). Lifetime is also probably improved, as the maximum temperature rise above baseplate is only half as much. The transformers shown in Figure 8 have a nominal 2.2 kW power rating and a power density of 0.6 kg/kW at an operating frequency of 10 kHz.

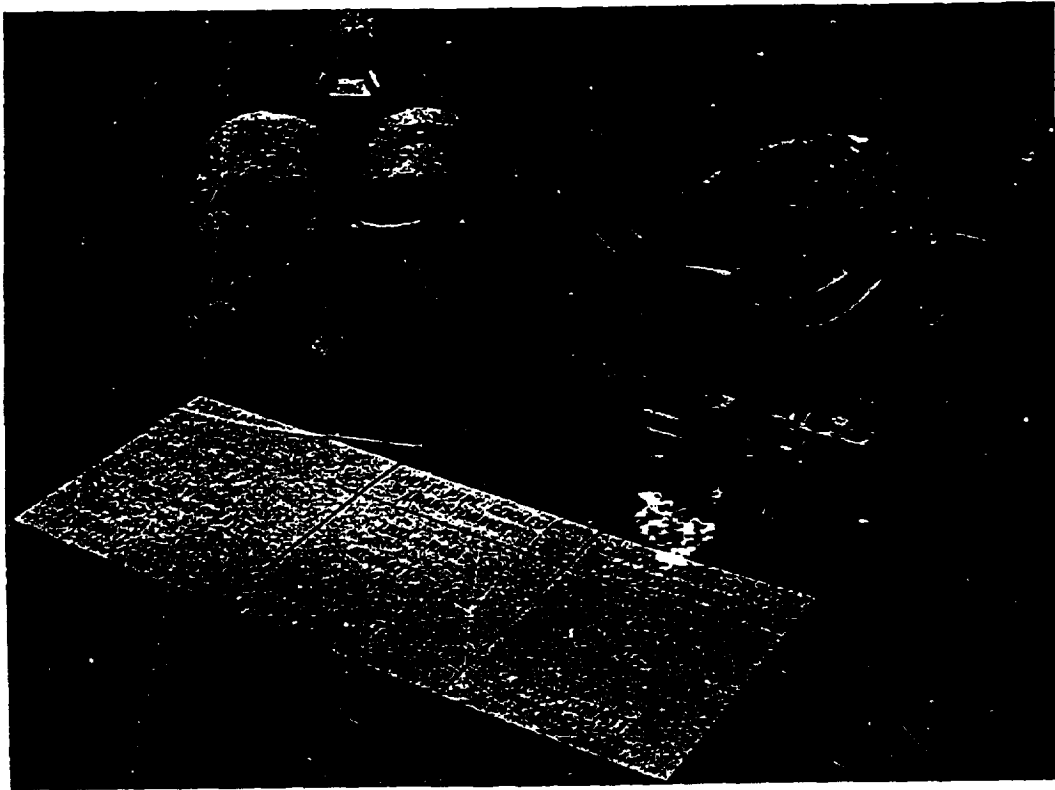


Fig. 8

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Comparison of Space-Type and Commercial Transformers

The significant weight and size reductions which can be realized by going to high frequency operation and unique thermal control techniques are clearly illustrated in Figure 9. Of major importance also is the fact that the 25 kVA space-type transformer (ref. 9) is more than 1% more efficient and has a 35°C lower temperature rise than the commercial transformer. The specific weight of the space-type 25 kVA, 20 kHz transformer is 0.28 lb/kVA, while that of the commercial 25 kVA, 60 Hz transformer is 16 lb/kVA. The very good maintainability and easy serviceability of the space-type transformer are additional outstanding features. The advanced technology which the space-type transformer exemplifies is not limited to power transformers but should be applicable to other power magnetic components. Power systems utilizing this type of magnetic components should show marked improvement in system weight, size, efficiency and reliability.

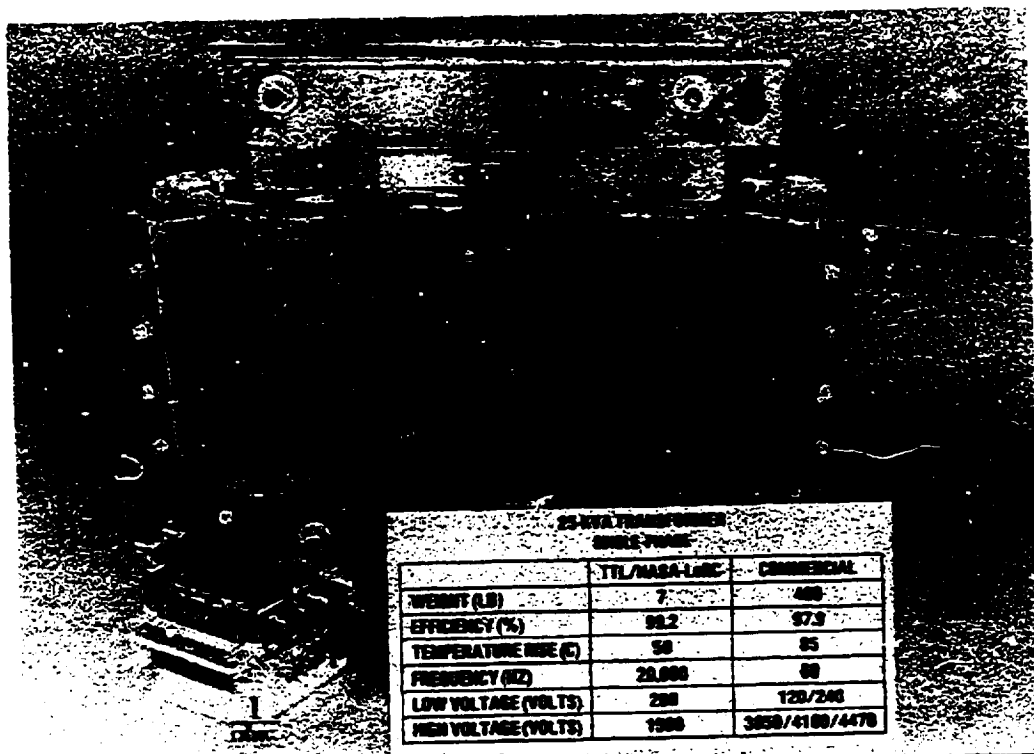


Fig. 9

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25 kVA Space-Type Transformer

Shown in Figure 10 is a close up photograph of the 25 kVA high frequency transformer shown on the previous page. Pie or pancake-type coils bonded to metallic conduction plates are the basic building blocks for constructing the primary and secondary windings. Very low leakage inductance is possible by placing a primary pie coil on one face of the metallic conduction plate and the secondary pie coil on the opposite face. Good thermal control is realized since the coil's I^2R loss is uniformly transmitted directly to the metal coil plates which then conduct the heat directly to the heat sink baseplate. In this transformer, the 8 primary pie coils for a 200 V input are connected in parallel and the ends of each pie-coil terminate on copper tabs which become an integral part of the primary bus bars located on top of the transformer. The 8 secondary pie coils for a 1500 V output are connected in series, and again the ends of each pie-coil terminate on copper tabs which become an integral part of the secondary bus bars located below the primary bus bars.

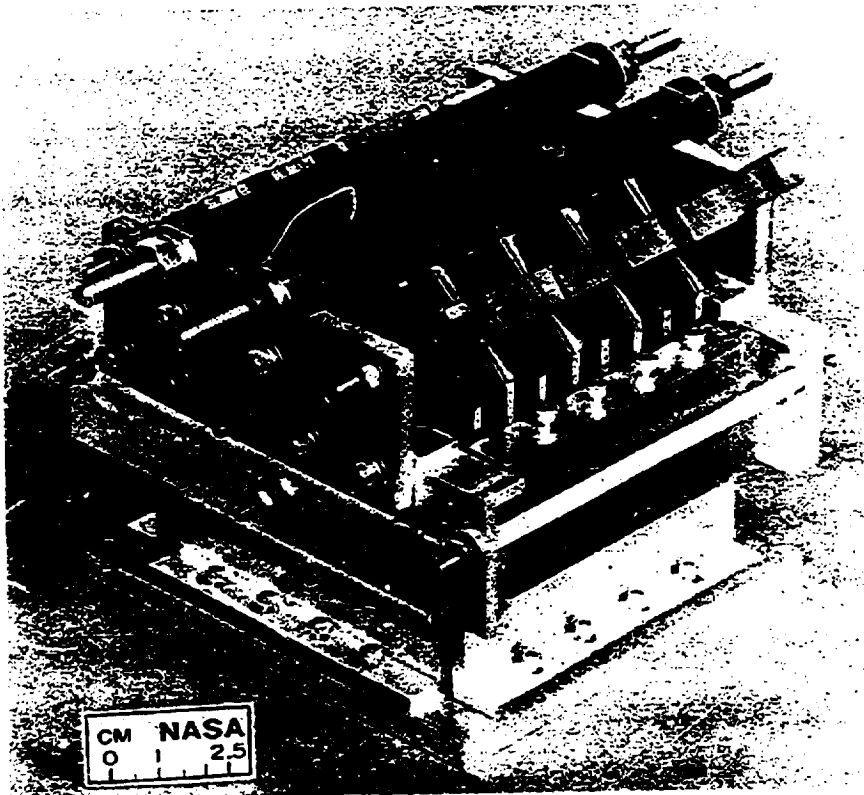


Fig. 10

High Power High Frequency Lightweight Capacitor

The smaller capacitor is a nominal microfarad, 600 volt capacitor with a maximum current capability of 125 A at 40 kHz (ref. 10). The dielectric is polypropylene. The losses at maximum operating conditions are 22 watts, which may be compared to the 75 kVA rating of the capacitor. The small capacitor developed for NASA applications as shown in Figure 11 is compared to a typical commercial 40 kHz capacitor, which has a rating of 1.8 kVAR per pound. The NASA capacitor, as developed by Maxwell Laboratories, Inc., has a power density of 11 kVAR per pound. This represents a decrease in size and weight by a factor of seven.

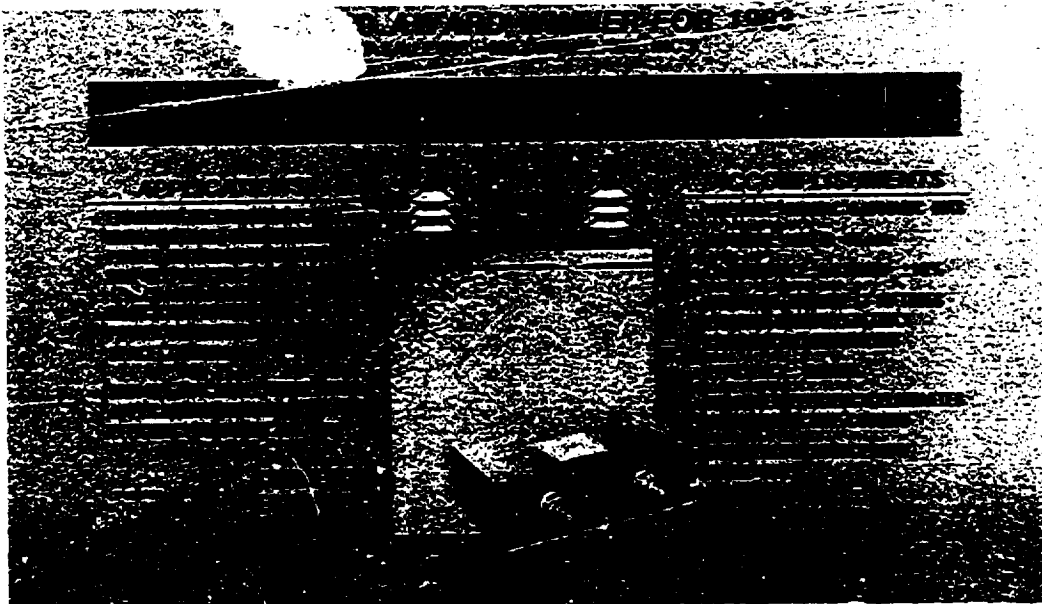


Fig. 11

Lightweight Filter Using Heat Pipe Cooled Inductor

Figure 12 shows a factor of two reduction in weight resulting from the use of heat pipe cooled inductors (ref. 8) in the first stage input filter in a DC-DC converter. Both capacitor and inductor weights are reduced, because the lightweight inductor allows the use of a large inductance value, and therefore a smaller capacitance.

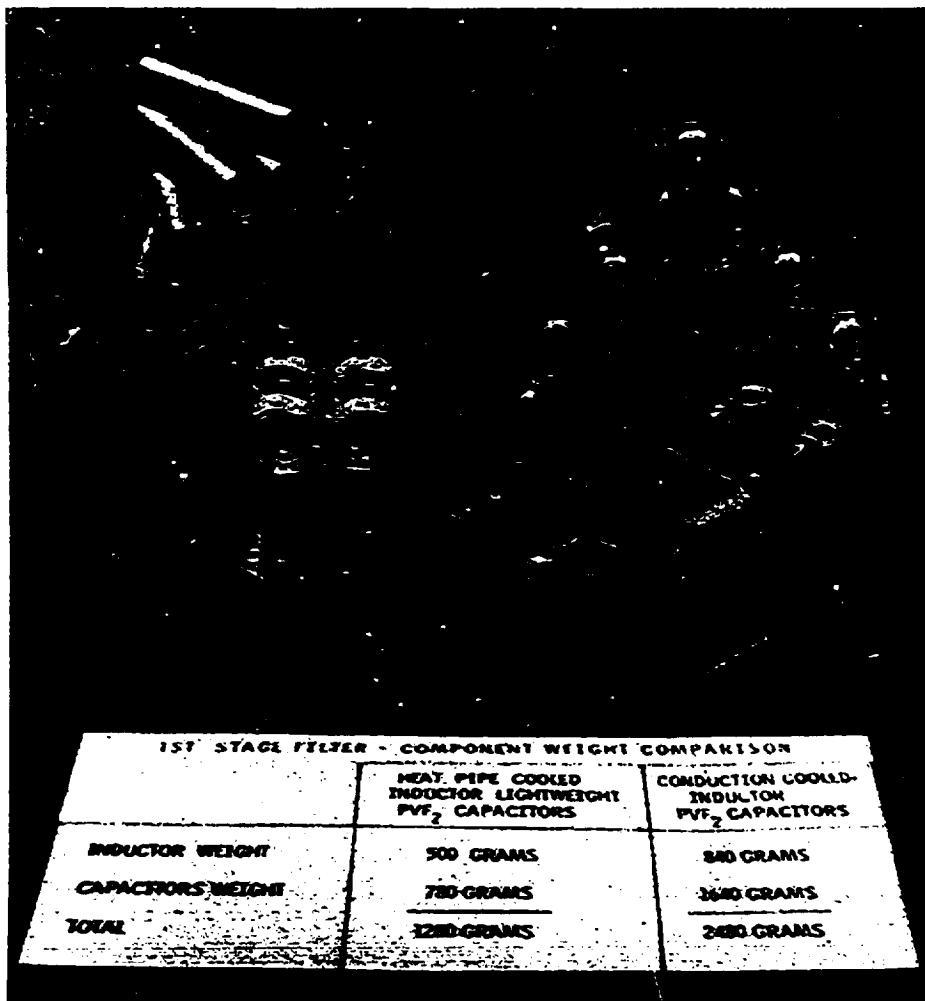


Fig. 12

Power Processor for Ion Rockets, Functional Model

The power processor for a pair of 30 cm ion thrusters (ref. 11) is shown in Figure 13 in its package form. Included in this functional model is Lewis developed new technology in both circuits and electronic components. Circuit development includes the series resonant inverter, which through zero current turn off and turn on of switches allows low stress long-life operation. Components developed at Lewis and incorporated in this model include heat pipe cooled lightweight transformers and inductors, polyvinylidene fluoride capacitors, and gate assisted turn-off thyristors. The power level is about 6 kW.



Fig. 13

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Kotary Power Transformer

Two studies were conducted by General Electric for Lewis Research Center. The first study designed a 100 kW rotary transformer (ref. 11) which had an axial gap (axial symmetric) and utilized four 25-kW modules placed along the shaft axis. The second study (ref. 12) was to investigate a radial gap (vertical gap) rotary transformer and compare its characteristics with those of the axial gap configuration. The conclusion of the study was that the radial gap rotary transformer is the most feasible method for transferring electrical power of 100 kW or more across a rotary joint. The rotary transformer program is shown in Figure 14.

PAST

STUDIES

- A) 100 KW (GENERAL ELECTRIC)
- B) > 100 KW (GENERAL ELECTRIC)

2 KW, 2 KHZ SQUARE-WAVE DEMONSTRATION MODEL

PRESENT

TRANSFORMER CHARACTERIZATION

FUTURE

BUILD PROTOTYPE MODEL

- A) 25 KW
- B) 20 KHZ
- C) 1000 VOLTS

Fig. 14

Roll Ring

The Roll Ring is a device that transfers electrical power across a rotating joint through rotating flexures between concentric conductors (Fig. 15). The advantages of the Roll Ring over the slip ring are the elimination of sliding friction and the low torque needed to rotate the device. The Roll Ring can transfer both AC and DC power and will be more efficient than the rotary transformer. Lewis Research Center is purchasing a multi-kilowatt device from Sperry Flight System, Phoenix, Arizona for in-house component testing. Each power circuit will be capable of conducting 200 amperes at 500 volts DC.

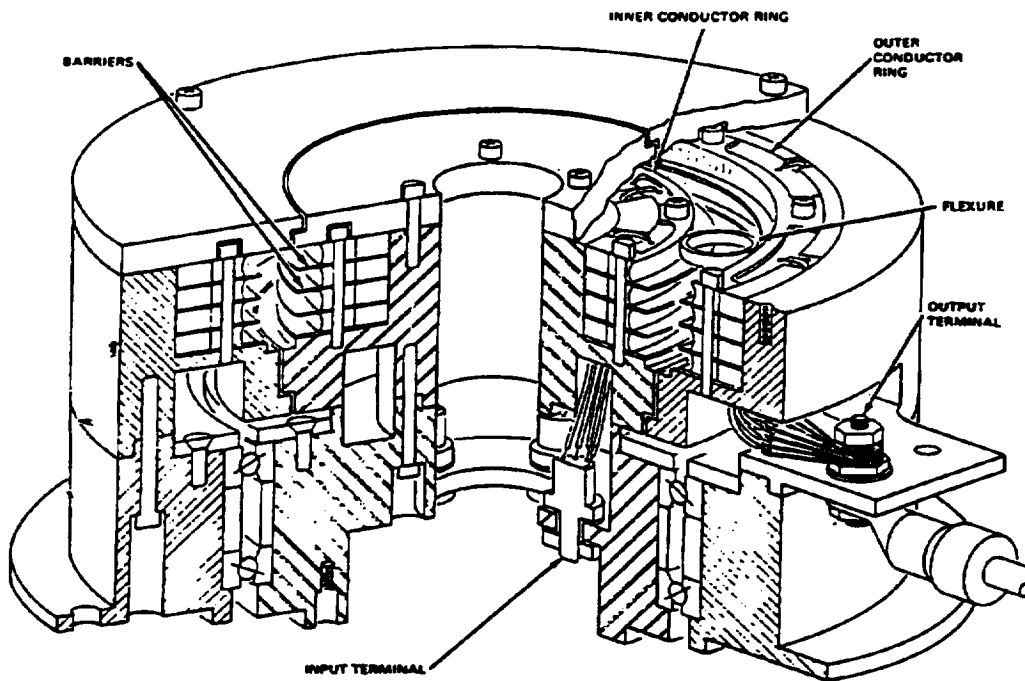


Fig. 15

Transmission Lines

Lewis Research Center is presently preparing an RFP for a high power, high frequency transmission line. The specifications of the line will be 1000 volts, 100 amperes at 20 kHz. The output of the contract will be a 50 meter transmission line that will be tested to determine the line characteristics. Fig. 16 shows two possible configurations of a high frequency transmission line.

HIGH-POWER HIGH-FREQUENCY TRANSMISSION LINE

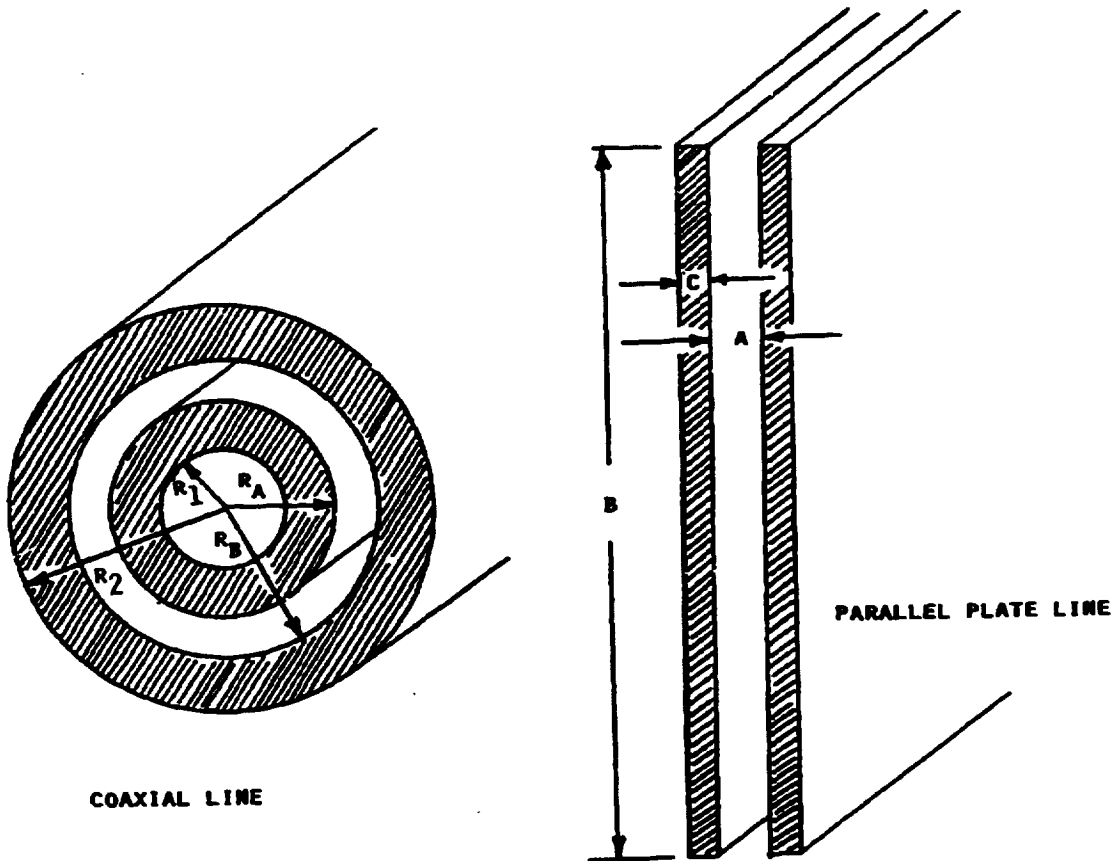


Fig. 16

Power Management

For the last 15 years, Lewis Research Center has been developing power processors for space flights. The current development is a 25 kW series resonant DC/DC converter which is at the prototype level (ref. 13). With today's component technology, the power level of space power processors could reach 50 kW. These 50 kW modules could then be paralleled, which could increase the power system size to 250 kW or larger (Fig. 17).

STATUS: 25 kW DC/DC CONVERTER - PROTOTYPE

TODAY'S TECHNOLOGY: 50 kW POWER PROCESSORS (AC OR DC)
(USING NEW POWER COMPONENTS)

SYSTEM SIZE: BY USING 25 TO 50 kW MODULES IN PARALLEL, SYSTEM
SIZES >250 kW ARE REASONABLE

Fig. 17

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