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LIGHTWEIGHT, HIGH-FREQUENCY TRANSFORMERS

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The weight of a power electronic transformer can be reduced in three ways. One way is to increase frequency. As frequency is increased, the cross-sectional area of the core can decrease. The kilovolt-amperage rating of a transformer is proportional to frequency, flux density, and current density. The second way is to use high current density in the windings. When the kilovolt-amperage rating is held constant, increasing the frequency has to decrease the cross-sectional area. Also, increasing current density must decrease the cross-sectional area of a conductor for a given current. This causes a decrease in the window area and reduces the size and weight of the transformer.

The third and perhaps the major way is thermal management or thermal control. Maximum use must be made of good heat transfer techniques. Of course, in the space environment, conduction is the method of thermal management. Another, but minor, method is radiation. You attempt to build as many thermal paths as possible in your device and also to use high-thermal-conductivity materials. That is not just restricted to the insulation systems but applies even to such things as the core material. To dissipate the heat from the core losses, you must also use a high-thermal-conductivity material.

Figure 1 compares space and commercial transformers. The 25-kVA space transformer was developed under contract by Thermal Technology Laboratory, Buffalo, N. Y.

The NASA Lewis transformer technology program attempted to develop the baseline technology. We chose to start at the 25-kVA level. Future projections are for megawatt transformers. For the 25-kVA transformer the input voltage was chosen as 200 V, the output voltage as 1500 V, the input voltage waveform as square wave, the duty cycle as continuous, the frequency range (within certain constraints) as 10 to 40 kHz, the operating temperatures as 85° and 130° C, the baseplate temperature as 50° C, the equivalent leakage inductance as less than 10 μH, the operating environment as space, and the life expectancy as 10 years. Such a transformer can also be used for aircraft, ship, and terrestrial applications.

Figure 2 shows the mechanical structure of the 25-kVA transformer. Basically the mechanical structure consists of three parts: the plates, the clamps, and the baseplate. The plates provide the conduction cooling for the windings. There are eight plates; each plate is approximately 1/10th inch thick. The plates are slit from the top of the core tube to the top of the plate to prevent the plate from acting as a shorted turn. The plates the conduct the heat down to the baseplate. Each plate has a foot that is mechanically fastened to the baseplate. We use a double "C" core arrangement. The material used in this particular application was 80Ni-20Fe, known as Supermalloy. The clamps and supports mechanically are fastened to the baseplate. For good thermal transfer the underside of the core is ground smooth to give good contact.

Figure 3 shows the finished product. Kapton sheets are bonded to the cooling plates, and then the windings are bonded to the Kapton. The windings are pie or pancake type with the primary winding on one side of a plate and the secondary winding on the other side. The primary windings are connected in parallel by the two large bus bars on the top of the transformer. The primary current is fed from both ends of the bus bars. The secondary windings are connected in series, and the output terminals are shown on the right side of the transformer extending at a 45° angle.

The primary and secondary resistances were measured by a four-terminal Kelvin bridge, and the temperature correction was applied. The primary had a resistance of 4.7 mΩ. The equivalent leakage inductance was measured with an impedance bridge. Since we wanted to reflect the leakage inductance to the primary, the secondary was short circuited. As a result the inductance was less than 2 μH. The goal was an inductance of less than 10 μH.

The two components of loss are the primary and secondary I^2R loss and the core loss (table I). The primary loss is 74 W, or approximately 38 percent of the total loss. The secondary loss is somewhat lower, 62 W, or about 32 percent of the total. The total I^2R loss is 36 W, or 69 percent of the total. The core loss is 60 W, or about 31 percent of the total. There is almost an equal division of loss between the primary, secondary, and core losses. Total loss is 196 W. Calculating the transformer efficiency from the total loss results in a value of 99.2 percent.

The weight breakdown (table II) shows the lightweight features of the transformer. The magnetic core weighs 1.53 lb, or 22 pe cent of the total weight. The coils and bus bar assembly are 1.92 lb, or 28 percent. The structural components, which include the mounting plates, the core supports and brackets, and the baseplate, weigh 2.5 lb, or 36 percent of the total. The insulators weigh 0.47 lb, or 6.8 percent. The fasteners weigh 0.53 lb, or 7.6 percent. The magnetic core and the coils and bus bar assembly weights, the active part of the transformer, add up to 50 percent. The structural components, insulator, and fastener weights also add up to 50 percent. However, in parametric studies, many times the last three weights are ignored.

Total weight is 6.95 lb. Specific weight is 0.28 lb/kVA. Specific power is 3.6 kVA/lb.

The lightweight, high-frequency transformer was a space-program development but can be used for aircraft, shipboard, and terrestrial applications in lightweight, high-frequency dc converters or high-frequency ac distribution systems. The technology developed in this program certainly should be transferable to other power-magnetic components.

TABLE I. - 25-kVA TRANSFORMER LOSS AND EFFICIENCY

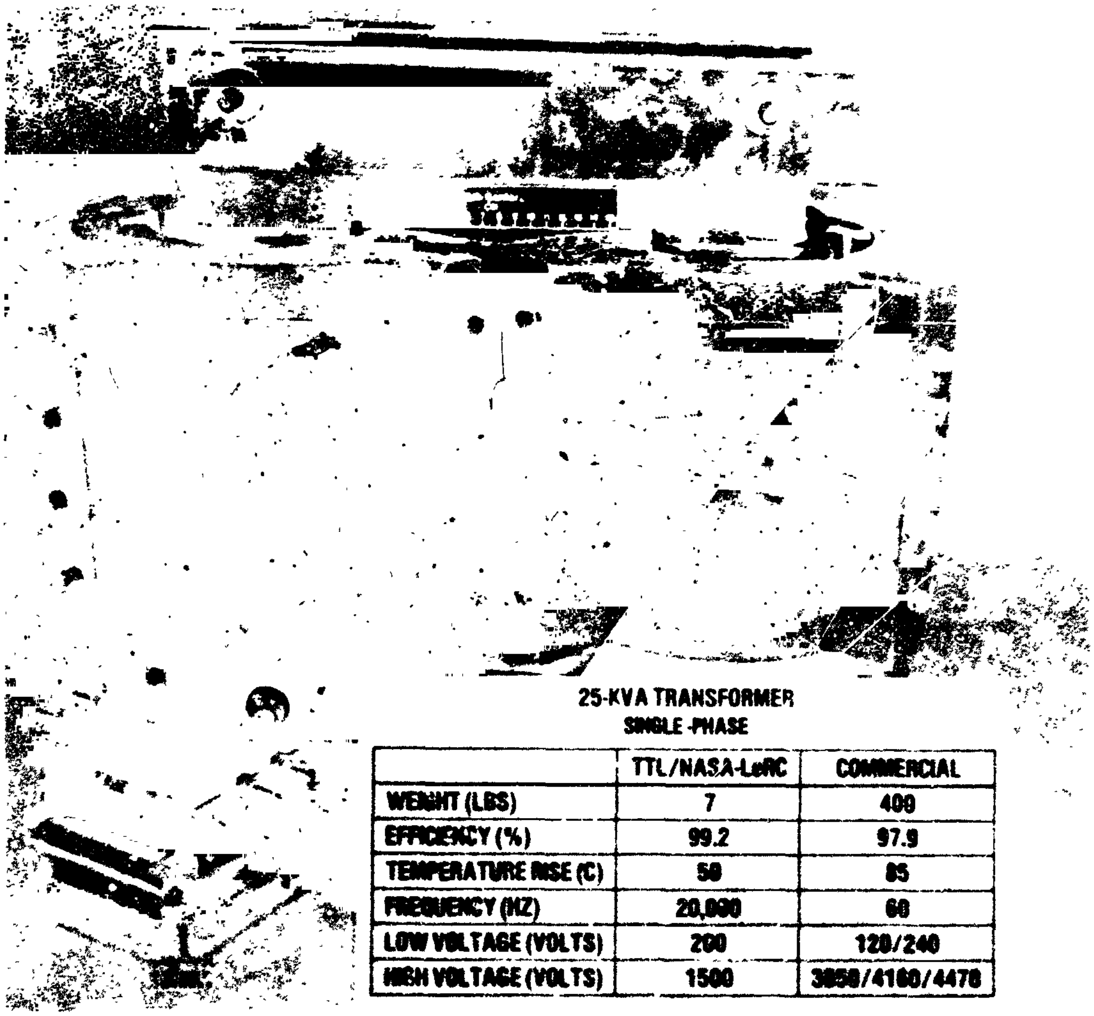
DESCRIPTION	LOSS (WATTS)	% OF TOTAL
PRI. WDG I^2R	74	37.8%
SEC. WDG I^2R	62	31.6%
TOTAL I^2R	136	69.4%
CORE	60	30.6%

- O TOTAL TRANSFORMER LOSS - 196 WATTS
- O TRANSFORMER EFFICIENCY: 99.2%

TABLE II. - 25-kVA TRANSFORMER WEIGHT BREAKDOWN

DESCRIPTION	WEIGHT (LBS)	% TOTAL WEIGHT
MAGNETIC CORE	1.53	22.0%
COILS & BUS BAR ASSY	1.92	27.6%
STRUCTURAL COMPONENTS	2.50	36.0%
INSULATORS	0.47	6.8%
MECHANICAL FASTENERS	0.53	7.6%

- O TOTAL WEIGHT - 6.95 LBS
- O SPECIFIC WEIGHT- 0.28 LB/KVA (0.13 KG/KVA)
- O SPECIFIC POWER - 3.6 KVA/LB (7.92 KVA/KG)



25-KVA TRANSFORMER
SINGLE-PHASE

	TTL/NASA-LeRC	COMMERCIAL
WEIGHT (LBS)	7	400
EFFICIENCY (%)	99.2	97.9
TEMPERATURE RISE (C)	50	85
FREQUENCY (HZ)	20,000	60
LOW VOLTAGE (VOLTS)	200	120/240
HIGH VOLTAGE (VOLTS)	1500	3850/4160/4470

Figure 1. - Comparison of space and commercial 25-kVA single-phase transformers.

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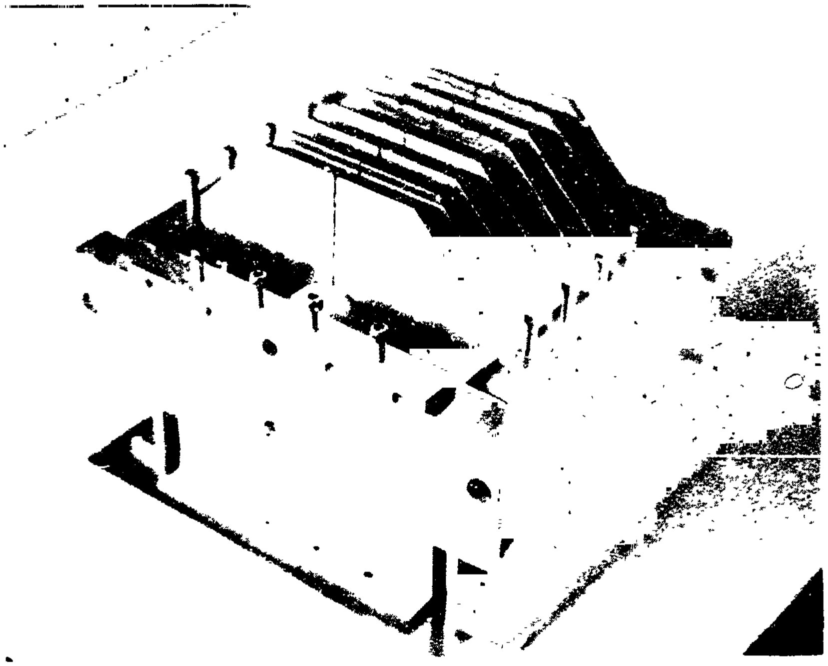

Figure 2. - Mechanical structure of 25-kVA transformer.

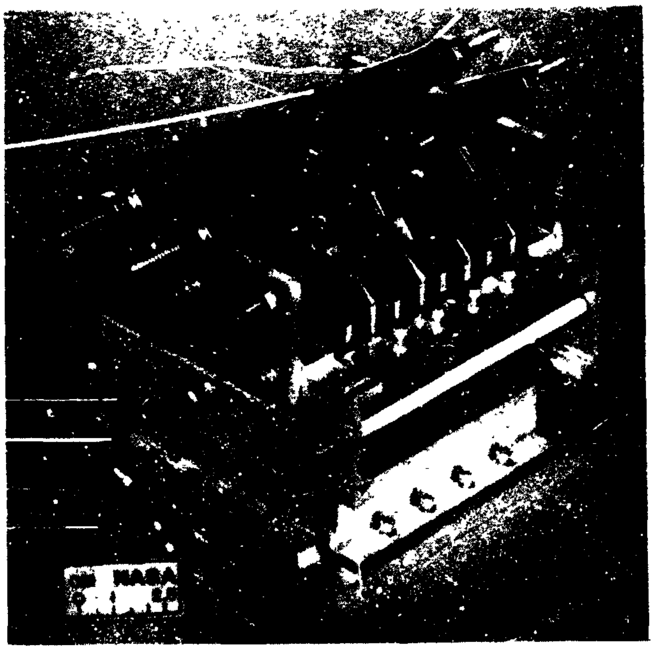

Figure 3. - 25-kVA transformer.