MIT Innovation Center

Invention Evaluation

POWER CONVERSION OF ENERGY FLUCTUATIONS

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Abstract

A preliminary evaluation of an invention by JOSEPH C. YATER for power conversion of energy fluctuations has been conducted. It is claimed by the inventor that the device can transfer thermal energy into useable electrical power with high efficiency. The basic concept is that the thermal shot noise generated in an electrical circuit can be rectified and used for power by cascading large numbers of such circuits.

It was concluded that the concept is theoretically plausible, but considerable research will be necessary before it can be physically demonstrated and exploited as a product. The efficiency claimed for the device is overly optomistic. The original estimate of the efficiency neglected heat loss by conduction which can be appreciable. It is recommended that an attempt be made to build and test a research prototype of the device to better understand what might be achievable.

Concept

The concept of the invention under evaluation is that the thermal noise generated in an electrical circuit can be rectified and used for power by cascading large numbers of such circuits. The approach taken by the inventor is to use a vacuum as a thermal barrier and couple the electrical circuits across the vacuum with capacitors. Diodes are selected as circuit elements and the basic configuration for a single circuit is shown schematically in Figure 1.

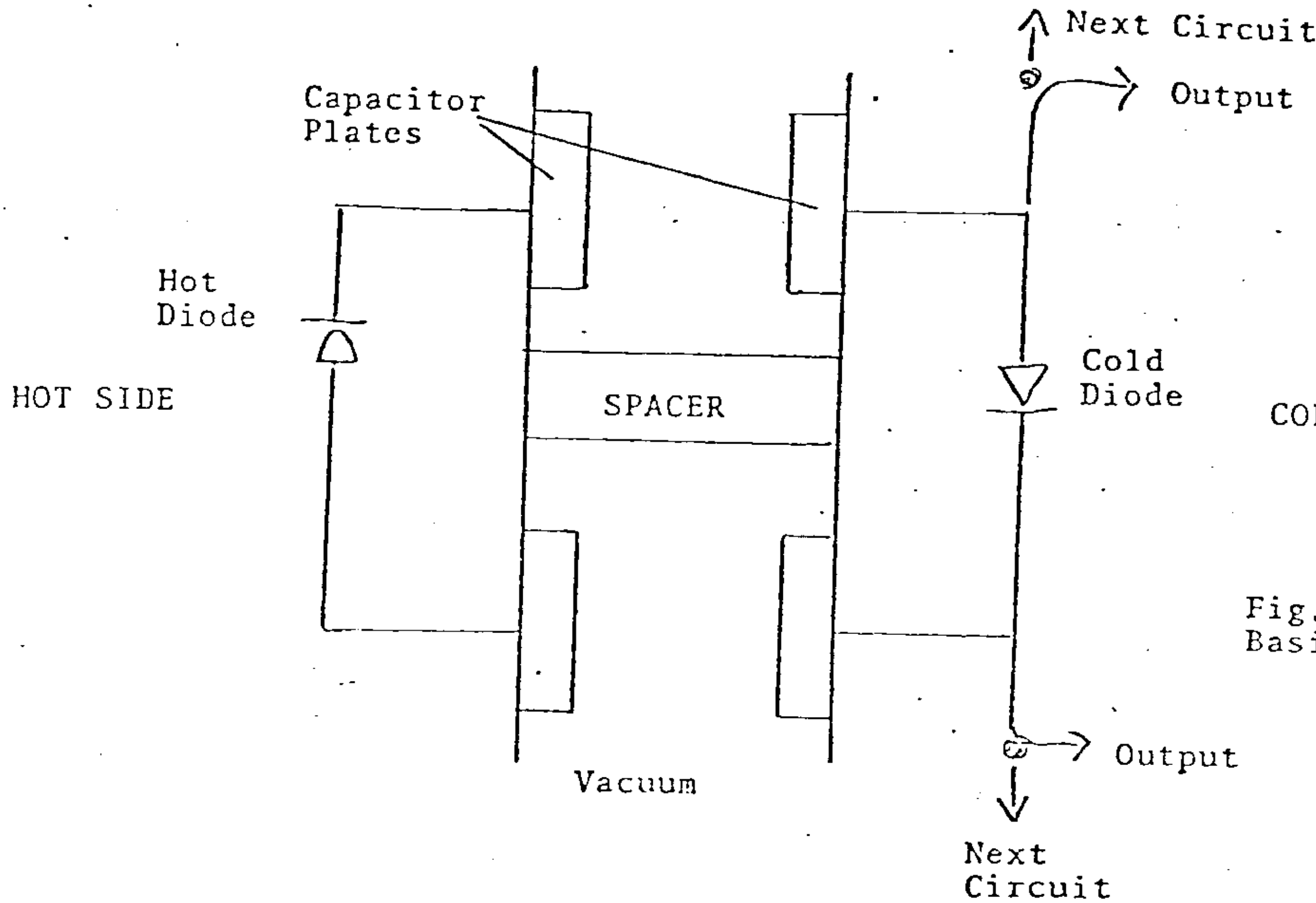

Fig. 1
Basic Design

Typical power output from a single circuit is about 10^{-6} watts. Consequently to achieve reasonable power output the circuits need to be tightly spaced. The inventor states that the density needs to be between 10^6 and 10^{10} devices/cm^2. Below 10^6 devices/cm^2 the efficiency is unreasonable. Above 10^{10} devices/cm^2 the linear dimensions approach the mean free path of an electron. Table 1 shows the consequences of the circuit density.

The inventor proposes to have the device built using modern microcircuit technology. It would be comprised of a layer of microcircuit modules for con-

Circuit Density	Linear Spacing	Capacitor Gap	Power Output
$10^6/cm^2$	10^{-3} cm	10^{-4} cm	10^4 watts/m^2
$10^8/cm^2$	10^{-4} cm	10^{-5} cm	10^6 watts/m^2
$10^{10}/cm^2$	10^{-5} cm	10^{-6} cm	10^8 watts/m^2

TABLE 1. Circuit Density

verting thermal energy into electric voltage fluctuations, a second layer of modules for coupling the voltage fluctuations across the vacuum thermal barrier, and a third layer of modules for converting the elastic voltage fluctuations to direct current power. Some sort of spacer is required to separate the substrates which form the vacuum barrier. The inventor originally proposed a low loss dielectric such as sapphire.

The theory which supports the physical process is contained in Ref. 1. It is based on quantum physics and may be difficult for the engineering reader to follow. Electrical engineers, at least, are probably more familiar with thermal shot noise whose power is given by

$$P = KT\,\Delta f$$

where K = Boltzman's constant

T = Absolute temperature

Δf = Bandwidth

In order to obtain power of the order of 10^{-6} watts per circuit the diodes have to be able to rectify the noise fluctuations over a bandwidth of 10^{14} Hz. It has been shown experimentally that certain diode junctions do retain their nonlinear current-voltage characteristics over such a frequency range (Ref. 2)

Parameter Analysis

The ultimate utility of the proposed device will be determined primarily by the efficiency with which it converts thermal energy to electrical power. The efficiency of the conversion process itself was the main consideration in Ref. 1, where it was concluded that there was no theoretical limit to approaching Carnot efficiency. However, as a practical device, the major factor which will determine the percentage of Carnot efficiency which can be achieved is the heat loss across the vacuum barrier. The three ways in which the heat energy can be lost are radiation, convection and conduction. Radiation was considered by the inventor to be the most significant and he calculated it to be negligible (2×10^{-12} watts/cm^2). Convection was not considered by the inventor. It is difficult to estimate because it is not known what level of vacuum can be obtained in the gap. Convection could be a problem if there is any out gassing from the components. The mean-free-path length for the molecules will probably be large with respect to the size of the gap. Conduction across the spacer was also not considered by the inventor. It is straightforward to estimate under simplifying assumptions. The heat loss per unit area, $\frac{Q}{A}$, is given by

$$\frac{Q}{A} = \frac{K\,\Delta T}{L}$$

where

K = thermal conductivity of material

ΔT = temperature difference

L = length of thermal path

The value of K for carborundum which is one of the best insulating materials that could be used for a spacer and which approximates the material proposed by the inventor is .002 watts/cm/°C. Using 500°C as the temperature difference, as-

5X

suming the smallest gap of 10^{-6} cm; and allowing 1% of the area for spacer; the heat loss through conduction is the same order of magnitude as the energy output. This is equivalent to an efficiency of only 50% of Carnot. With a larger gap the heat loss through conduction reduces inversely with the gap size, but the electrical energy output reduces inversely as the square of the gap size which makes the efficiency worse. In order to get 50% of Carnot in the case of the 10^{-4} cm gap the spacer cross section would have to be less than .01% of the area. These calculations indicate that for the device as proposed major losses will occur as heat conduction across the spacers in the thermal gap.

The inventor has responded to this criticism by observing that there may be engineering techniques which will allow the gap to be maintained with as little as .001% of the area used for support. He refers to his own work on the preservation of optical flats using thin films for support (Ref. 4). It may also be possible to have the spacer thermal path made larger than the capacitor plate separation. In any event, considerable engineering design will be necessary to minimize heat conduction while maintaining the gap. The figure of merit will be the thermal heat loss per circuit. With present technology even 10^{-6} watts/circuit (50% of Carnot efficiency) appears optimistic.

Expert Opinions

Part of the evaluation procedure was to ask selected MIT faculty to express their personal opinions about the potential of the invention. This included, in addition to the regular Innovation Center faculty, E.P. Gyftopoulous, G.N. Hatsopoulous, C.G. Fonstad, and A. Sanchez-Rulsio.

All those reviewed the invention agreed that an attempt should be made to build and test a demonstration model. There was a unanimous opinion that the power output and efficiency of a working model would be much less than anticipated by the inventor. The most pessimistic opinion was expressed by Gyftopoulous, who felt that the device as described would not work, and if any electrical power output were achieved it would be because the capacitors across the vacuum gap would be acting the same as thermionic diodes whose efficiency has been studied extensively and is far worse than that claimed in the invention statement. Professor Frances Lee felt that it might be necessary to put the electrical load across the output diodes in a bridge circuit as shown in Figure 2.

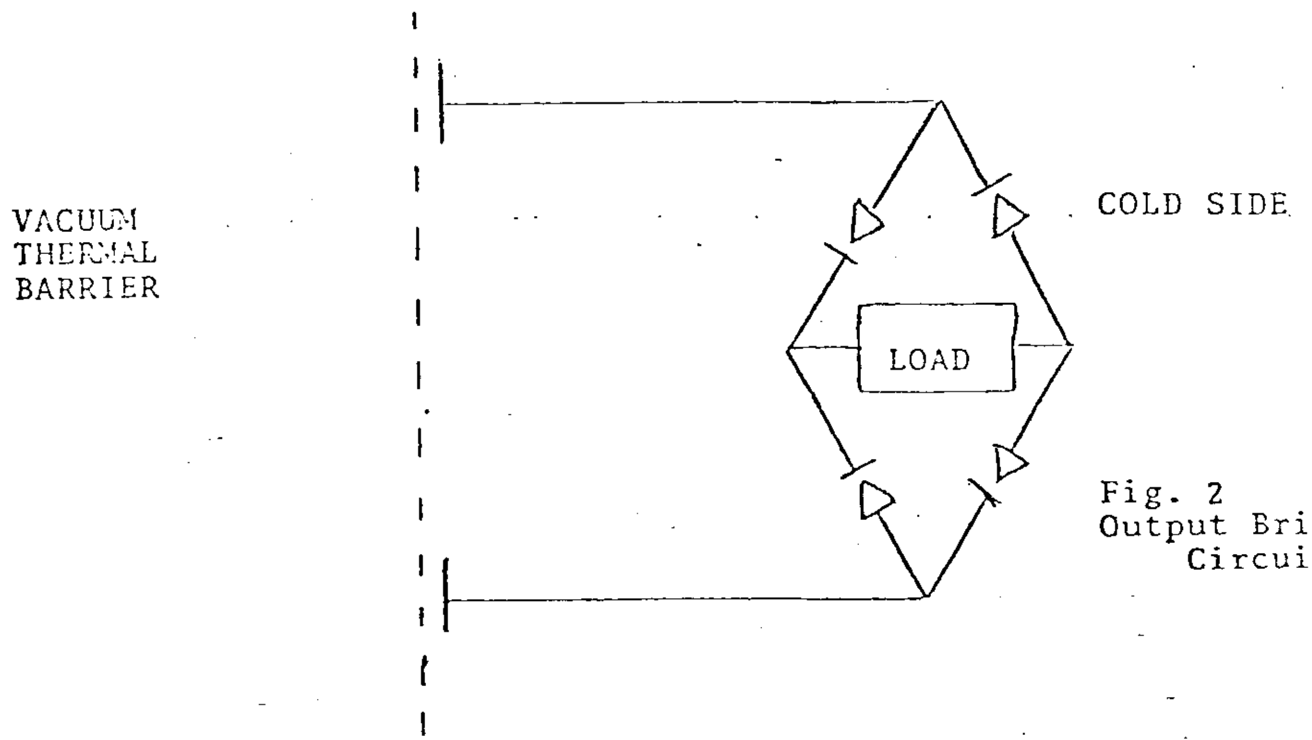

Fig. 2
Output Bridge
Circuit

For electrical engineers who understand diodes as circuit elements better than as quantum mechanical devices, Figure 2 provides a more appealing conceptual explanation of how rectification can occur. With the above exceptions, the majority of experts felt that, in principle, the concept of rectification of thermal noise power was theoretically valid.

Experimental Verification

Experimental verification that thermal noise power can be rectified has been reported in the literature (Ref. 3). The experiment was done with a radiometer and a video detector. The result showed only qualitatively that rectification took place. There were no quantitative measurements that could be extrapolated into an efficiency for the process. The power generated was all at the signal level.

In order to get electrical output at the power level it will be necessary to have large numbers of circuits cascaded together as proposed by the inventor. It appears reasonable to attempt the experiment since it is technically feasible and has not been conducted. Circuit spacing to 10^{-3} cm is state of the art with optical etching. Some manufacturers claim 10^{-4} cm with optical etching. Tighter spacing is probably achievable with electron beam etching. Most of these numbers are based on silicon technology which starts to have problems with its characteristic properties above 400°C. Researchers have made diodes work at elevated temperatures with different materials. There is a problem with cost for some of the more exotic technologies. The size of the thermal gap can be monitored during construction with an electron microscope. Professor Fonstad has stated that it would be very reasonable to attempt to build the device. There is considerable engineering to be done in the choice of materials and detailed design. There will be inevitable tradeoffs that can only be fully appreciated by attempting to build the device for experimental verification.

Evaluation

1. Parameter analysis of the proposed device for power conversion of thermal noise showed that heat loss through conduction across the spacers supporting the vacuum barrier seriously degrades the overall efficiency. Innovative engineering design might make it possible to overcome this deficiency.

2. The theoretical basis for rectification of thermal noise energy is valid. There was a minority opinion that the inventor's device would not work as depicted. The majority opinion was that it could be made to work. There are too many unknowns to predict the efficiency without carrying out a detailed engineering design.

3. The only physical demonstration of the rectification of thermal noise has been for a single isolated circuit at signal power levels.

4. Electric circuits of the small dimensions necessary have been manufactured although not in the configuration proposed. The major technological barrier is to be able to maintain 10^{-4} to 10^{-6} cm spacing across the vacuum gap without conducting excessive heat through the supporting structure.

5. Considerable design work has yet to be done in the choice of the electrical circuit components and the structure of the thermal barrier. Engineering tradeoffs will be necessary in the selection of the materials to be used. A detailed design of the device has yet to be completed.

6. There are many potential problems which can limit the usefulness of the device. There is technical uncertainty in the following areas:

   (a) The tolerances on the dimensions of the vacuum gap may not be maintained in the face of the temperature and pressure gradients. Heat loss by conduction will be increased at any point where the two sides of the gap come into contact.

   (b) Outgassing of the components may degrade the quality of the vacuum with attendant heat loss across the gap through convection.

   (c) The electrical circuit elements may not be able to survive the temperature or pressure environment.

   (d) Leakage capacitance or stray inductance may influence the electrical characteristics of the circuits. Coupling would cause inefficiency.

   (e) The cost of manufacturing the device may make it noncompetitive with other energy converters.

Conclusions and Recommendations

The concept is theoretically plausible. The efficiency will be poorer than claimed. There are many potential technical problems that need to be better understood. Work on the concept should be considered as research as opposed to product development. While there is always the risk of spending research money and not obtaining a practical device further expenditure of research funds is deemed appropriate since there is no conclusive evidence at this stage that the concept cannot be made to work. An attempt should be made to manufacture and test a device of the type proposed.

References

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