THERMAL CONTROL OF SPACEBORNE SYSTEMS USING FIBRE OPTIC WAVE GUIDES—A NOVEL APPROACH

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ABSTRACT

A new concept of thermal control of spaceborne systems such as communication payload transponders, and reaction control thrusters, etc using infrared fibre optic waveguides is presented. It appears that such an approach can offer better thermal design flexibility, simplicity and reliability.

INTRODUCTION

THERMAL control is one of the vital elements in any space programme for an efficient functioning of the spaceborne systems under the adverse environs of space and its importance need not be emphasised. The thermal control is achieved essentially by concentration and transmission of electro-magnetic radiation from or into the subsystems in order to keep them within the operational temperature limits, normally employing passive and active techniques. In general passive systems, employing heat sinks, thermal blankets, paints and solar optical reflectors are less complex and more reliable compared to the active systems that use heaters and electro-modules and hence, are given preference[1]. However, the efficiency of these passive systems depends on the choice of the method, availability of suitable materials and new advancements made in allied fields.

The tremendous progress made in science and technology of fibre optics, in recent years has resulted in new burst of activity of exploring their potential applications in different disciplines[2]. Already strides are made in the areas of communications, inertial navigation and medicine. In space technology, optical fibres are used in multispectral scanning systems and possible other applications are being explored[3].

In this note, we discuss the possibility of using flexible infrared fibre optic wave guides in thermal control systems. In the first part, the basics of fibre optics systems and in the second part fibre optic based concepts for thermal control of the specific systems *viz* communication payload systems like travelling wave tube amplifiers or solid state power amplifiers and reaction control thrusters are presented.

BASICS OF INFRARED FIBRE OPTIC WAVE GUIDES

The conduction of light among transparent cylinders by multiple total internal reflections is fairly old and well known phenomenon. But the concept of 'Fibre Optics' and conduction of light through flexible fibre optic bundles was introduced by Kapany in 1956[4], and since then, the tremendous advancements made in material science and technology have resulted in a variety of fibre optic bundles useful for different applications[5].

The transportation of electro-magnetic radiation through the optical fibre is illustrated in figure 1. Whereas the fundamental principles governing the conduction of the radiation

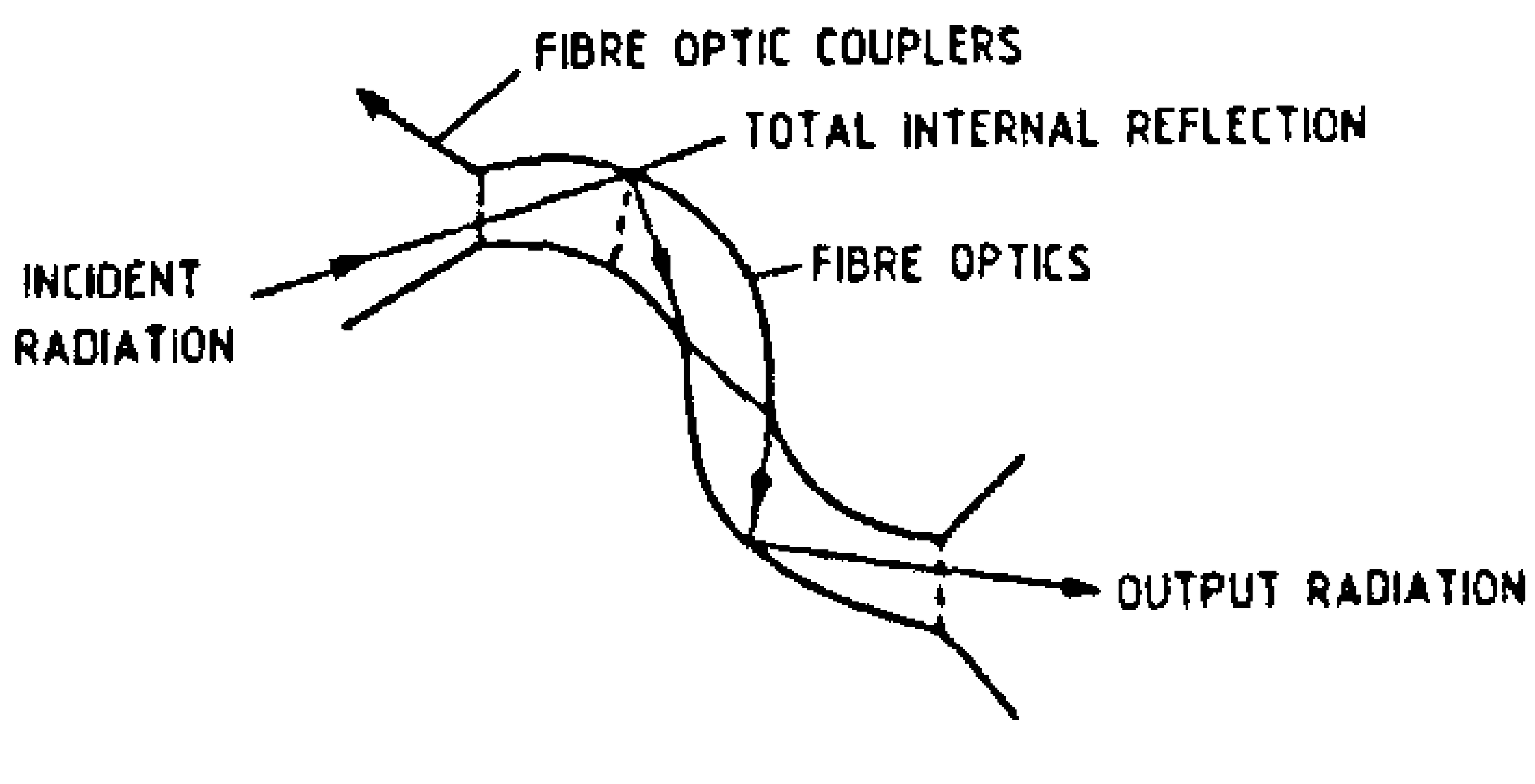

Figure 1. Illustration of conduction of electro-magnetic radiation through fibre optics.

remain unchanged for any fibres, the nature of the materials used imposes the restriction for usage of the fibres for different wavelengths. The critical survey shows that the suitable materials for fibre optics fall into two well defined categories. The first consists of oxide glasses with transmission between 4000 A and 5 μ and the second consists of non-oxide glasses with highly limited transmission in the visible region of the spectrum but having wider infrared transmission upto 14 microns. For visible and near IR regions, optical fibre technology is well established and fibres with losses as small as 1 db/km are available for different applications[6]. For the middle IR region, corresponding to the heat radiations, fibre bundles are developed but with losses shooting upto 15 to 20 db/km[7-10]. Nevertheless, these fibres should be suffice to transport the heat radiation from one end to other end over short lengths[11] (less than few metres). The specific features common to all these optical fibres are that physically they are small, flexible, strong and light weight, optically they have a large bandwidth for optical information carrying, with low loss/attenuations over large lengths, and are able to withstand large extreme temperature range and resist electromagnetic radiation interference. These attractive features distinguish them from other conventional systems and in the succeeding pages the possibility of using these fibres for the thermal control of spaceborne systems is discussed.

THERMAL CONTROL OF COMMUNICATION PAYLOAD SYSTEMS (TWTA/SSPA)

The communication payload systems such as S-band Travelling wave tube amplifiers (TWTA) or C-band Solid state power amplifiers (SSPA) are the systems that generates heat energy during their operation and if this radiation is not dissipated out, it can raise the payload temperature upto 150°C. But most of the payloads can operate only between −20° to 50°C beyond which the mission can be jeopardised. In order to maintain these temperature ranges, the payload is coupled through the heat sinks (or doublers)/heat pipes to the outer space so as to dissipate the heat. But the disadvantage of these are: if the thermal control approach is through solid radiators (heat sinks), the weight and volume to power dissipation ratio is extremely large. This is shown in figure 2. On the other hand, the heat pipes though are attractive from weight point of view at higher ranges[14], they suffer from the serious efficiency losses due to bending. Typically for a 90° bending, the attenuation losses could be as high as 50%[12]. In addition, heat pipes suffer from the other disadvantages in that they should be designed so as not to carry the cool radiations from space to payload. If proper design care is not taken, the payload can go to the other lower extreme temperature and can result in mission failure. Apart from these, solid radiator/heat pipe should be properly insulated, otherwise, it can act as secondary source of radiation within the satellite causing serious interference to other subsystems. These factors make the conventional approach of thermal design more complex and less flexible.

As an alternate, we propose, infrared optical fibre waveguides as coupling system between the payload heat generating points and space. The system operation is more or less same as heat pipes but having greater flexibility and ease of operation. Unlike the conventional heatpipes, in fibre optics, the nature of energy loss due to the

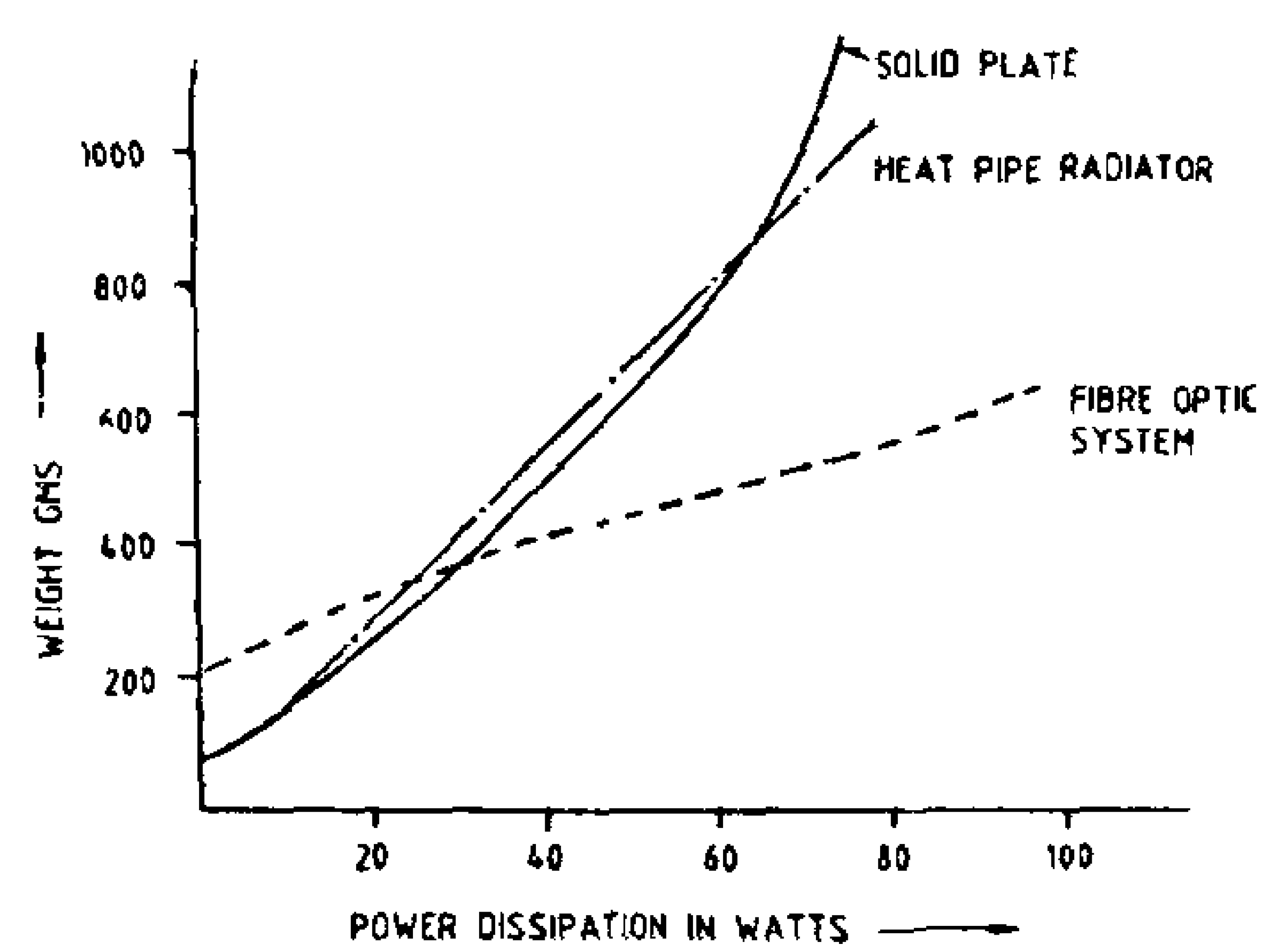

Figure 2. Comparison of radiator panel weight versus average thermal dissipation for the conventional aluminium heat spreader, heat pipes and infra-red fibre optic wave guides.

bending is insignificant. Since the radiation emanating from space corresponds to far-infrared region for which the infrared fibre optic waveguides are blind, this waveguide system acts as unidirectional system, in the sense that it allows radiation to pass only from the payload to space and not vice versa. To achieve the same result in conventional designs variable conductance heat pipes are used which are complex. The other advantage that can be seen in case of Fibre Optics Systems is that the heat generated from the payload, instead of being pumped to outer space (which entails in wastage of energy), can be coupled to other parts of satellite subsystem that needs to be heated. This way, to an extent, the thermal energy can be properly channelled and optimally used. In figure 3, are shown the conventional systems using solid radiators, and heat pipes along with the new concepts using infrared fibre optic waveguides.

But, the specific requirement of these fibre bundles should be that, they should be able to operate in the wavelength range of 5 to 15 microns since the heat radiation, emanating from the payload corresponds to this range. As has been already pointed out, flexible infrared fibre optic waveguides are already available with attenuation losses of less than 15 db/km.

THERMAL CONTROL OF REACTION CONTROL THRUSTERS

Reaction control elements and chemical battery are two critical subsystems from space mission point of view and they cannot be allowed to experience temperature below certain limits. Typically RCS fuel hydrazene starts freezing below 2°C and chemical battery starts chattering below 0°C. In order to maintain these systems above the critical temperatures, normally electrical heaters are used with necessary control electronics. The disadvantage, one can see from a first glance is that if proper shielding design is not done, electro-magnetic interference from these heaters to other subsystem can create problems. Secondly, the energy for these heaters is derived through the silicon solar cells from the main solar energy. In this process, the steps involved are that (a) conversion of solar energy to electrical energy *via* solar cells and (b) electrical energy to heat energy *via* heaters. Since the conversion efficiency in both the steps is less than 20%, the ultimate efficiency reduces to less than 4%. Here is one more area where fibre optics could play a vital role. The concept of directing heat radiation directly from sun to the subsystem is shown in figure 4. A first order calculations show that a square metre area collection of solar energy *via* fibre optics can generate 1 kw power which can be branched off to various subsystems, on the other hand, for the same power, a solar panel of the order of 20 m^2 may be needed in the conventional system. This way efficiency of the systems can be improved manifold compared to the conventional system since the major losses in fibre optics system are mainly due to attenuation losses and these are normally less than 5 db/km. Terrestrial solar energy collection using beam waveguides has already been demonstrated and these fibre optics energy collecting system con-

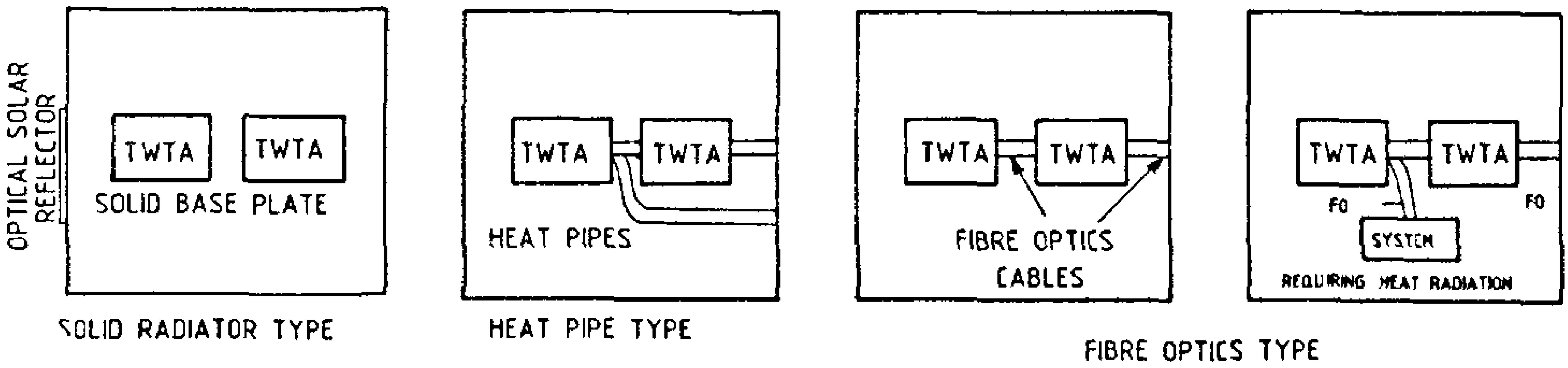

Figure 3. Schematic of the thermal control systems using solid radiator, heat pipes and proposed fibre optic systems.

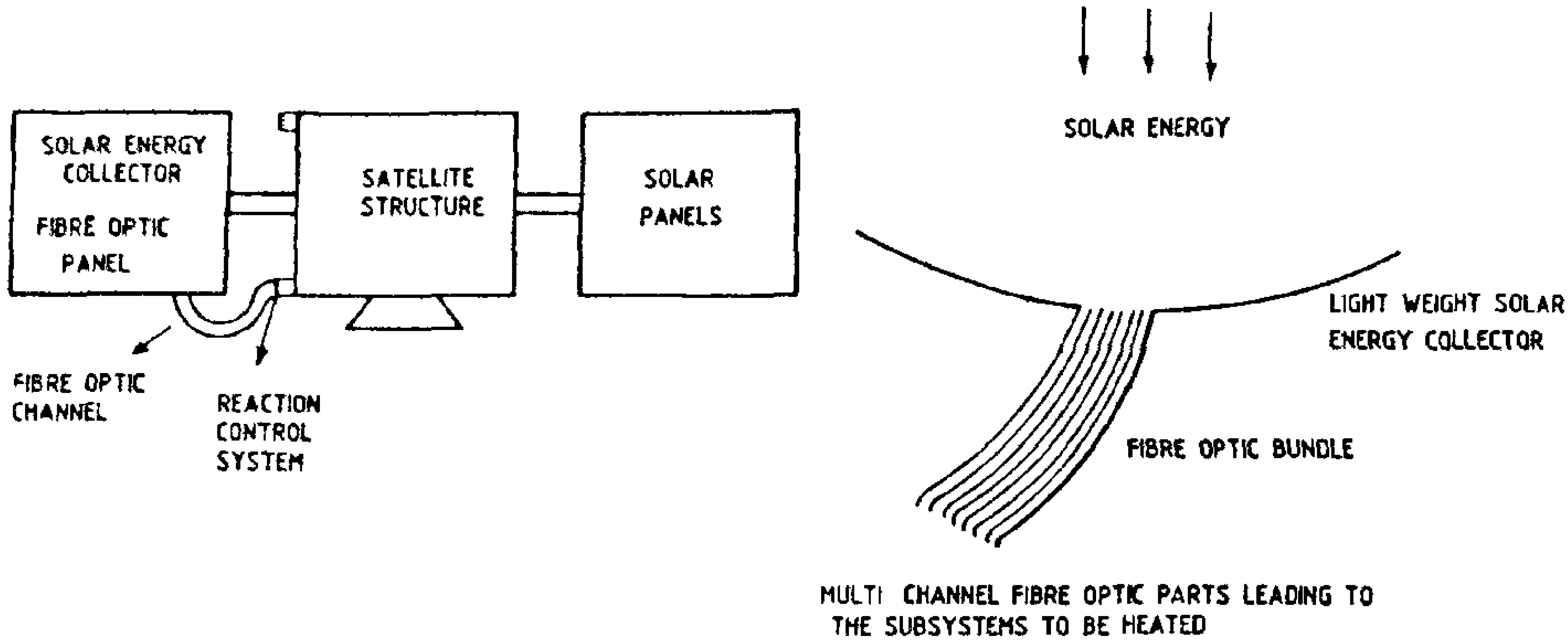

Figure 4. Proposed fibre optic layout for collection of solar energy/heat radiation for reaction control system thrusters etc, for heating.

cepts extended to space can offer new channels in space technology.

CONCLUSIONS

The conventional techniques for transporting heat from the highly dissipating sources like TWTA's require cooling baseplates or heat pipe radiators, demanding 5–8 kg weight in communication satellites having C band and high power S band payloads. Such provisions are also required for high power (200–230 W) TWTA's operating at high frequencies (11–12 GHz) even though a significant portion of the power dissipated by them is directly radiated into space by having suitable designs of the collector portion of the TWTAs. The use of infrared fibre optic waveguides can offer significant advantages in terms of minimizing the weight (by a factor of 3) and improving the reliability (as compared to systems like heat pipe radiators) besides providing the flexibility in terms of layout and operation for thermal control.

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ANNOUNCEMENT

LEAD DEVELOPMENT ASSOCIATION, LONDON—LEAD AND CADMIUM BATTERY COMPETITIONS

Two lead battery and one cadmium battery competition each with major awards are a feature of Battery '85. The international lead and cadmium industries are sponsoring these competitions to promote and highlight new uses and technical innovation in rechargeable batteries. Countries represented by the sponsoring organisations are: Australia, Belgium, Brazil, France, Germany, India, Japan, Mexico, Spain, Sweden, United Kingdom, USA.

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Entries from students for any of the three competitions, may relate more to promising new ideas in the area of technical development, research techniques or application engineering than to actual commercial achievement.

Three prizes will be awarded for each competition of which one will be for the best student entry.

The prizes for each competition will be: First cash and/or award to the value of $1400 plus a certificate; Second cash and/or award to the value of $700 plus a certificate. Student cash and/or award to the value of $500 plus a certificate.

The last date for the entries to be submitted is *25th February* 1985.

Further particulars may be had from the Organisers: Lead Development Association, 34 Berkeley Square, London W1X 6AJ UK.; The address of the sponsoring organisation in India: Indian Lead Zinc Information Centre, B-6/7 Shopping Centre, Safdarjung Enclave, New Delhi 110 029. India.

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