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Line-Plant Considerations for the Optical Local Network [and Discussion]

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Line-plant considerations for the optical local network

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Recent proposals for future local networks have focused on all-optical solutions that use single-mode fibre. Increasingly, these networks attempt to become cost-effective against copper-based solutions by sharing a single fibre among several subscribers, using either electronic or optical multiplexing. The line plant for such systems must be able to carry wide-bandwidth transmission over a large range of wavelengths.

Attempts to keep all of the line plant passive (for example, splitter-based networks) typically result in a need for low-loss components, and bidirectional working and coherent transmission place constraints on reflection levels from line-plant components.

Throughout all this, component solutions must remain low cost and be easily installed, maintained and tested by personnel currently installing copper pairs.

In addition, the fibre-sharing aspect typically means that line-plant systems must be tested while 'live', without disturbing the transmission links on them.

This paper discusses the line plant for future local networks within these constraints, and presents various technical solutions to the challenge ahead.

1. Introduction

Proposals have recently been made for passive optical networks for the local loop that could be deployed initially for telephony, and yet have the capacity for future wideband use (Stern *et al.* 1987; Bergen 1988).

A key feature leading to a reduction in cost of such networks is the sharing of fibre and other plant amongst a number of customers, thus reducing the plant cost per customer and the overall amount of plant in the ground. In addition these networks share exchange equipment to further reduce cost and have the desirable feature of no street-sited electronics.

However, the result is a radical departure from the existing copper pair network, raising many questions of plant design, network installation and maintenance.

This paper discusses the line-plant issues arising from one particular approach to passive optical networks studied at BTRL (the splitter-based network or star-bus architecture) and the results of an on-site demonstrator are presented. This approach has been called telephony on a passive optical network (TPON).

2. System outline

In the TPON network a single fibre is fed from the exchange and fanned out via passive splitters to feed a number of individual customers. A time division multiplexed (TDM) signal is broadcast to all terminals from the exchange on a single wavelength, with the customer time-accessing the particular bits meant for him. In the return direction data from the customer is inserted at a predetermined time to arrive at the exchange in synchronism with that from other customers. Inclusion of an optical filter in the customer's terminal that passes only the TPON wavelength allows the later provision of new services on other wavelengths without disturbing the telephony transmission. A target of a 128-way split operating at 20 Mb s^{-1} would allow the provision of basic rate integrated service digital network (ISDN) to all customers.

In line-plant terms the cable count near to the exchange is considerably reduced, with fibre and cable costs shared between many customers. Table 1 shows a comparison of component numbers for various levels of split against a point-to-point system having one fibre to each customer. It is apparent that the passive splitter network typically has 10% of the fibre and half the number of splices and connectors.

Table 1. Plant per customer for the network of figure 1

plant per customer	fibre/m	splices	connectors	splitters
point-to-point duplex	2050	6.00	4.00	2
TPON 128-way split	93	4.15	2.02	2
TPON 64-way split	105	4.17	2.03	2
TPON 32-way split	159	4.34	2.06	2
TPON 16-way split	206	4.44	2.13	2
TPON 8-way split	300	4.63	2.25	2

3. Overall plant issues

In the BT network the majority of cable is housed in underground ducts, with the exception of the last drop to the customer, where a considerable amount of overhead dropwire exists in the residential part of the network. The existing copper network is based around a topology having two flexibility points, at streetside cabinets serving up to 600 lines and at distribution points (DPs) serving around 10–15 lines. The duct network tends to reflect this geography.

The difficulty of relocating duct work in practice means that future optical schemes must use the existing geography and thus the network described here is based on the existing duct and cabinet/DP layout. This results in two splitter points, at cabinet and DP positions respectively, with up to an 8-way split at the cabinet and 16 ways at the DP.

The basic system is shown in figure 1, with typical system lengths.

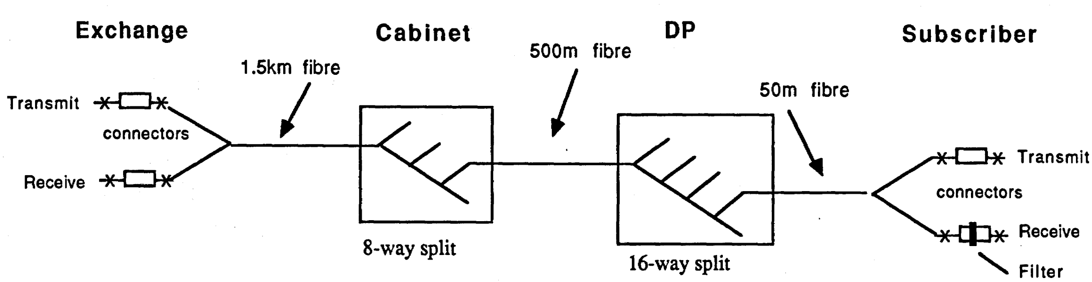

Figure 1. Basic passive splitter network with average lengths.

It is likely that initial operation for telephony will be in the 1300 nm window, with wideband services being carried on additional wavelengths in the same window or in the 1550 nm window. This leads directly to the need for a blocking filter in the telephony customers equipment designed to pass only the telephony wavelength, thus avoiding interference from later wideband wavelengths. In addition all of the installed plant must be wavelength ‘flat’, i.e. have a low loss across a range of wavelengths. In the case of the splitter arrays this includes the need for constant coupling ratios across the required wavelength band, to avoid wavelength 'steering' by the network.

It is almost certain that the network will need to be tested and monitored while 'live', it being impractical to shut down service to 100 customers merely to test a fault in one.

Finally, if bidirectional working is used, (as in figure 1) or reflection-sensitive systems (microwave subcarrier or coherent systems for example) are contemplated for future use, then attention will need to be paid to reflection levels from splices, connectors and unused fibre outlets on splitter arrays. This paper explores these aspects.

Not specific to the particular architecture is the need for a cable and housing infrastructure that can effectively route fibre through cabinet and DP positions and into and around business and residential premises while providing adequate fibre management and testing facilities. Included here is a need to house and power the customer's equipment.

Overlaid on the above factors is a general need to keep component costs low and installation practices rapid and simple if cost targets are to be met and existing local network staff used effectively.

In summary the factors important to the passive splitter-based network are

wavelength flat splitter arrays of up to 16 ways;

blocking filters to exclude later wavelengths from the customer's receiver;

low fibre-count cables for cabinet and DP interconnect and customer's drop (overhead and underground) and internal applications;

housings for splitter arrays and customer's equipment with adequate fibre management and testing facilities;

testing and monitoring facilities that can be used with the network 'live';

consideration of reflection levels from splices, connectors and unused splitter outlets;

low-cost components easily used by local network staff.

To study each of these aspects a system demonstrator has been built at BTRL, and an overall system model produced by consideration of individual component losses. In the following part of the paper the critical components and issues are examined in more detail to produce an overall expected power budget for the system from the system model. This is then compared with results from the demonstrator.

4. Component design

4.1. *Splitter arrays*

At the present time the technology most suitable for making passive splitter arrays is that of the fused splitter, with planar ion-diffused glass and integrated optics (e.g. $LiNbO_3$) likely to be contenders in the future. The work at BTRL has concentrated on the fused-splitter approach. In this approach a 2×2 splitter is made by fusing and tapering two fibres together. The wavelength dependence of the splitter can be reduced by altering one fibre slightly to ensure that the maximum available coupling between the two is at the 50% point. The splitter is then tapered to this point to produce a fairly flat wavelength response. Figure 2 shows the wavelength response for a single splitter, giving a deviation from the 3 dB or 50% split of up to 0.8 dB over the system wavelength range of 1270–1580 nm. Each curve corresponds to the output from one of the splitter legs.

Clearly any particular path through an array of splitters will exhibit a loss due to the summation of effects from each split. These may add or cancel, producing a variation in wavelength response from path to path (Mortimore 1986). Nevertheless, it is always the case that one path will exhibit the worst case response, leading to a loss given by multiplying the response of figure 2 by the number of split levels. This loss is used in the system model.

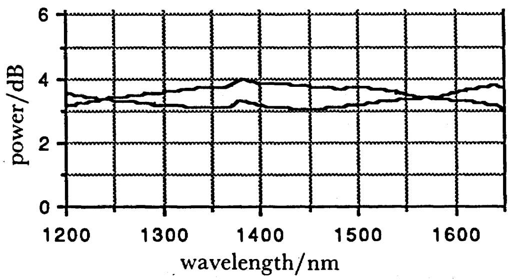

FIGURE 2. Wavelength response for a single splitter.

In addition to the 'loss' effect of coupling ratio, losses due to polarization effects on coupling and splitter excess loss due to imperfections must be taken into account. Measured values for these effects across a typical batch of 20 splitters made at BTRL are shown in table 2 and later used in the system model.

TABLE 2. TYPICAL RESULTS FOR WAVELENGTH FLATTENED SPLITTERS

(Polarization changes shown are changes in coupling ratio for all input polarization states.)

	mean and standard deviation
flatness (dB)	0.48 ± 0.04
excess loss @ 1300 nm (dB)	0.05 ± 0.01
excess loss @ 1550 nm (dB)	0.10 ± 0.02
coupling ratio @ 1300 nm (%)	49.48 ± 4.18
coupling ratio @ 1550 nm (%)	49.18 ± 4.03
polarization @ 1300 nm (%)	0.94 ± 0.56
polarization @ 1550 nm (%)	0.38 ± 0.19

The results shown are for individual 2×2 splitters spliced into arrays. Although this approach can give adequate performance it is unlikely to lead to low cost, and tends to produce large package sizes. A method of producing the splitter arrays by direct 'knitting' of the fibres without splicing is required, either by sequential or simultaneous manufacture of a number of splitters in one operation. Thus far prototype 4×4 arrays have been made at BTRL by simultaneous pulling of four splitters, although much work remains to be done to refine the process.

4.2. *Customer's blocking filter*

As previously explained a blocking filter is needed in the customer's telephony equipment to exclude later wavelengths from the receiver. To reduce the amount of optical spectrum used for telephony it is planned to use a well-controlled distributed feedback (DFB) laser in the exchange. The result is a target for the blocking filter of 15 nm full width at half maximum (FWHM), 1.5 dB loss and essentially 'top-hat' spectral shape.

Figure 3 shows a prototype device produced at BTRL. In this approach a multilayer dielectric filter is mounted in a slot in a conventional connector ferrule, with the connector ferrule providing fibre alignment to yield a low-cost fibre-tailed device that can be spliced into the network. Figure 4 shows the response of the filters produced so far, with a performance of 23 nm FWHM and 3 dB loss. AR coating of the filter and tapering the fibre core should reduce this loss to the required value (Harper *et al.* 1988), while improved filters require tuning of the multilayer process.

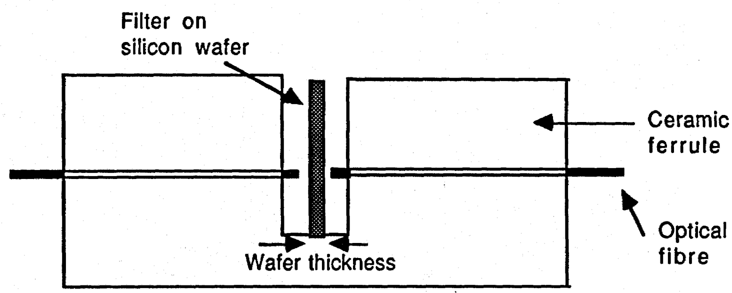

FIGURE 3. Prototype optical blocking filter.

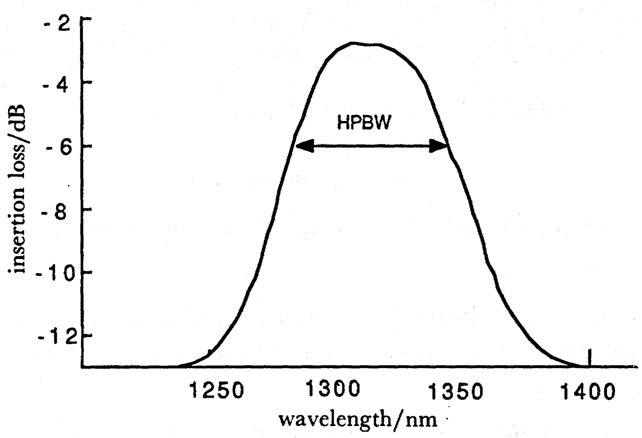

FIGURE 4. Wavelength response of the blocking filter. HPBW is 23 nm, IP is 1320 nm and the peak insertion loss is 3.1 dB.

4.3. *Cabling*

Interconnection of exchange to cabinet and cabinet to DP can be effected with cables containing a relatively small number of single-mode fibres (either conventional or blown fibre) already in use in the network without significant development effort, with the existing specification of less than 0.5 dB km^{-1} in both windows.

For the cable from the distribution point to the subscriber (the subscriber drop cable), and the subscriber's internal cables, little is commercially available. With as much as 70% of subscriber drops on overhead cable in some areas it is likely that both overhead and underground solutions will be required. In the case of an overhead drop the cable termination methods are vitally important and often dictate cable design. Cables must be built to withstand ice and wind loadings of 5 mm radial thickness and 80 km h^{-1} repectively, while still maintaining fibre strains below 0.15%. With internal cables it is likely that installation conditions will dictate a need to withstand bends of small radius. Overall the subscriber cable problem is one that is technically challenging to the designer of optical cables.

Figure 5 shows prototype ruggedized blown-fibre tubes suitable for direct burial in underground drops and a prototype overhead drop cable in which the support member can be separated from the blowing tube and held using existing methods.

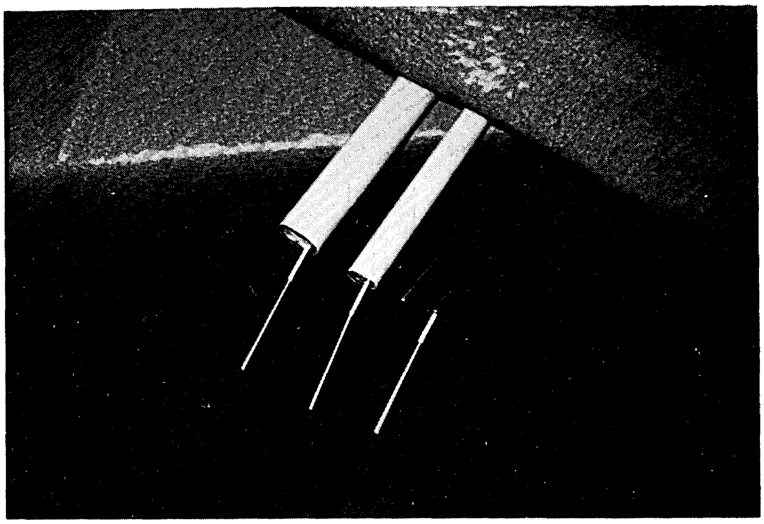

FIGURE 5. Prototype subscriber drop cables.

4.4. *Cabinet and DP housings*

Housings are required at cabinet and DP points for the passive splitter arrays and associated splices. Important factors are

maintenance of minimum bend criteria (35 mm) to avoid loss increases at 1550 nm;

fibre management. Housings must allow rapid reentry for addition of new subscribers without damage to existing fibres;

test access. Provision must be made for clip-on or end-on access to each fibre;

termination of spare fibre ends to prevent stray reflections.

Experience from the demonstrator has shown that fibre management is critical, with conventional approaches – in which splice trays hold a number of fibres and splices – being totally inadequate. An approach has been developed in which each splice and the associated fibre loops for splicing and clip-on are held in a novel single-splice holder having moveable components to release and contain the fibre loops. A prototype DP made in this way is shown in figure 6.

4.5. *Reflection levels*

The use of bidirectional working (as shown in figure 1) has advantages in reducing the amount of plant in the ground, of easing the fibre management problem at cabinet and DP points, and of reducing the possibility of error in record keeping (there is no chance of confusing go and return fibres). However, the network immediately becomes sensitive to reflections appearing at the near end receiver in the form of crosstalk.

The analysis of Rosher (1987) indicates that a signal-to-crosstalk ratio of at least 5 dB is required for correct system operation. If we assume a launch level of 0 dBm and a receiver sensitivity of −50 dBm for a bidirectional system, then reflection levels close to the system ends

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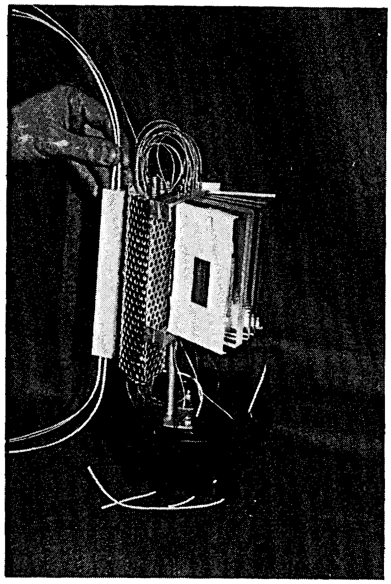

FIGURE 6. Prototype subscriber DP.

must be kept at least 50 dB down on the incident signal (i.e. a return loss of 50 dB). This applies to both splices and unterminated ends on splitter arrays. As most mechanical splicing systems currently have return losses in the 30–40 dB range it is difficult to see how they can be used, and fusion splicing seems to be essential.

5. SYSTEM MODEL

The average local route length in the BT network is about 2 km, with 90% less than 5 km. To assess likely overall losses of the TPON network a model was built of a 5 km system having a 128-way split and full duplex operation. This gives nine levels of splitting (seven for 128 ways and two duplex). Measured data for splitter arrays and other components such as splices, connectors and cables was gathered as shown in table 3.

TABLE 3. MEASURED DATA FOR PASSIVE NETWORK COMPONENTS

device	mean loss	standard deviation of loss	number or length used
coupler splitting ratio	3.18	0.29	9
coupler excess loss	0.1 dB	0.04 dB	9
connector loss	0.17 dB	0.07 dB	2
splice loss	0.2 dB	0.1 dB	19
fibre loss	0.4 dB km^{-1}	0.05 dB km^{-1}	5.6 km
filter loss	1.5 dB	—	1
system	37.4 dB	1.0 dB	—

Summation of the statistical loss data for each component to produce an overall loss for the system gives the curve of figure 7 at the wavelength of 1300 nm. Since the operation of the splitter arrays is to produce a loss variation from path to path a worst case path has been chosen for this plot. The resulting spectral loss is shown in figure 8.

Losses up to 42 dB are expected for the worst-case components and wavelengths.

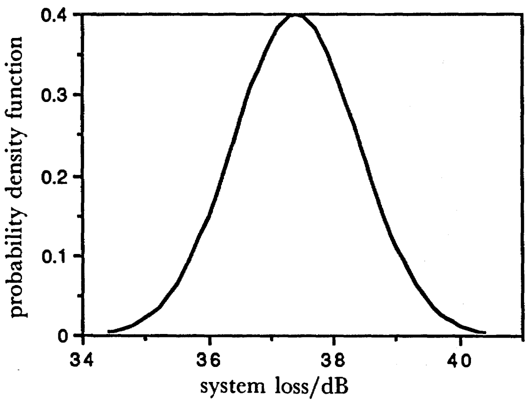

FIGURE 7. Overall system loss distribution.

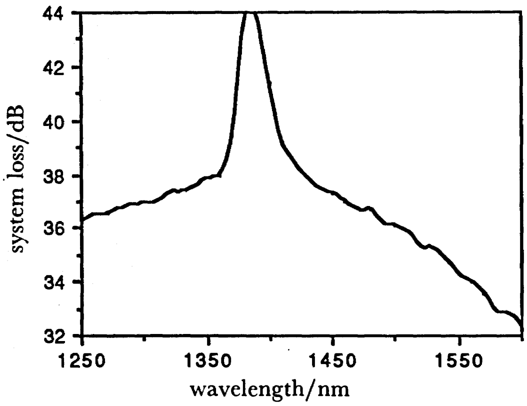

FIGURE 8. Overall system loss spectrum.

6. TESTING

The TPON network will be designed to have some in-built continuous monitoring of both laser power levels and errors in the data. However, it is still considered necessary to have some means of testing for, and locating, faults that might include fibre breaks, loss caused by temperature effects, bending, etc.

Two approaches have been taken to testing the passive splitter network while live. The first involves conventional optical time domain reflectometry (OTDR) equipment used at a test wavelength, with the blocking filters screening the test wavelength from the system receivers. Commercially available OTDR equipment currently has a dynamic range of about 23 dB, with the result that fibre can only be monitored over half of the split levels in a 128-way (nine split levels) network before losses become too great. This was overcome by monitoring from a mid-point in both directions through a demountable optical tap. The test wavelength was 1550 nm, with the system running at 1300 nm. The tap was made from a polished coupler (Digonnet & Shaw 1982) designed to preferentially couple at 1550 nm. In this way the loss to the system due to the tap was 0.7 dB when coupled and 0.02 dB uncoupled, while the loss seen by the test equipment was 3 dB. In this way a conventional OTDR trace could be obtained while the system was running without the need to terminate the fibre ends.

Clearly, in a splitter network light will be returned to the OTDR from several branches simultaneously, leading to problems of interpretation in determining in which branch a fault lies. A partial solution is to make use of customer's laser power monitoring normally used by the system to determine which leg has developed a fault by looking for increased laser current to that subscriber.

In addition to the test-wavelength approach a second test method was produced by using optical 'clip-on' to produce a low-cost power meter, somewhat equivalent to the AVOmeter in use for copper pair. In this way a piece of test equipment was produced that would allow basic fault finding by each linesman.

The clip-on idea is to use a small bend in the fibre to tap out a small amount of light. This light is collected and guided to a detector by a short waveguide to the power meter. Careful choice of the bend radius can give an indication of power in the fibre to around 3 dB while adding less than a 3 dB loss to the system with even the most bend-sensitive fibre allowed by the fibre specification at the highest wavelength. A prototype instrument sensitive to −30 dBm fibre core power is shown in figure 9.

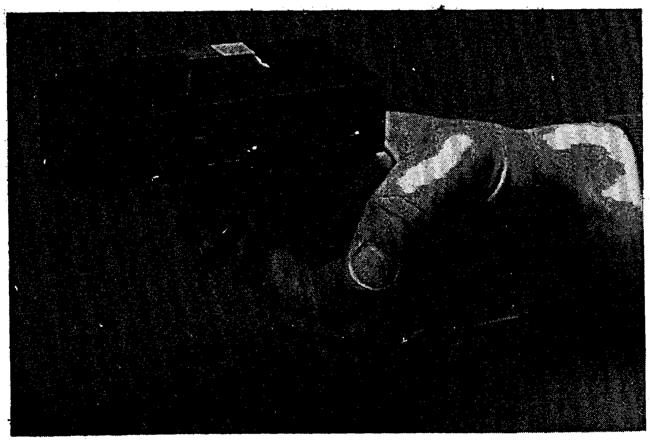

FIGURE 9. Clip-on optical power meter.

7. DEMONSTRATION SYSTEM

To test the various trade-offs inherent in the passive splitter network a demonstrator system was built at BTRL, as shown in figure 10. Two exchange points and two DPS were interconnected via a passive splitter array mounted in a standard BT external cabinet to simulate a 128-way split. The total system length was 1.5 km, with blown-fibre cable throughout. The measured loss of the system at 1300 nm was 35 dB, compared with a loss of 34 dB predicted by the system model.

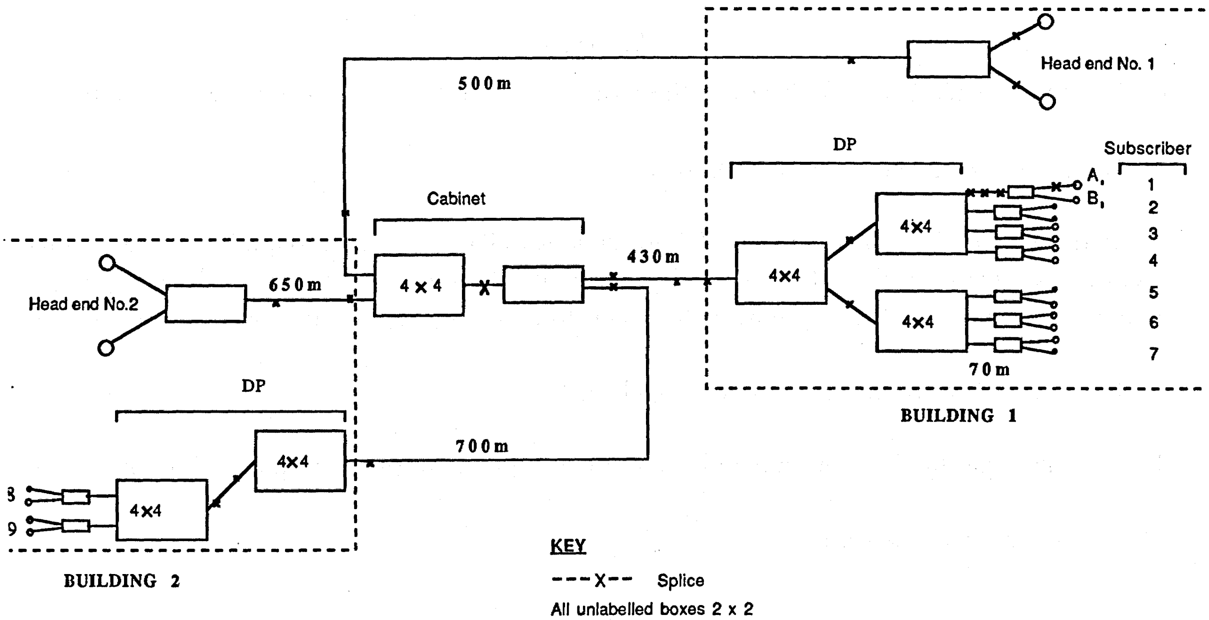

FIGURE 10. Schematic of the passive network demonstrator.

Unused legs on the splitter arrays were terminated by a mandrel-wrap technique of introducing several turns at 3.4 mm radius to prevent reflections back into the network. Although effective it is unlikely to prove reliable in the long term and further work is necessary to produce a field termination for unused fibre ends.

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As previously described, the system could be tested with clip-on testers or by means of OTDR equipment launched by means of a demountable tap in the external cabinet.

Conclusions

Passive splitters in the local network can enable initial deployment for telephony by means of fibre sharing among a number of customers. The result is a considerable reduction in the installed plant in the ground.

This paper has considered the problems of design, installation and testing presented to the optical plant by such a radical approach and has described the successful exploitation of prototype solutions in an on-site demonstrator at BTRL.

The author thanks his many colleagues who have contributed to the work presented in this paper and the Director of Research and Technology for permission to publish the paper.

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Discussion

B. Catania (*CSELT*, *Torino*, *Italy*). Is the cost per subscriber going to be around £300?

M. H. Reeve. Yes, that is the target cost.

T. Ikegami (*NTI Optoelectronics Labs*, *Japan*). TPON is well designed, although it could be limited to 20 Mb s^{-1} transmission. If the capacity needs to be increased, how is Mr Reeve going to change the structure of his system? Is he going to increase the output power of laser diodes?

M. H. Reeve. We would use another wavelength.

T. Ikegami. Does he therefore have plans to use an optical amplifier in the cabinet or the DP?

M. H. Reeve. It is one option.

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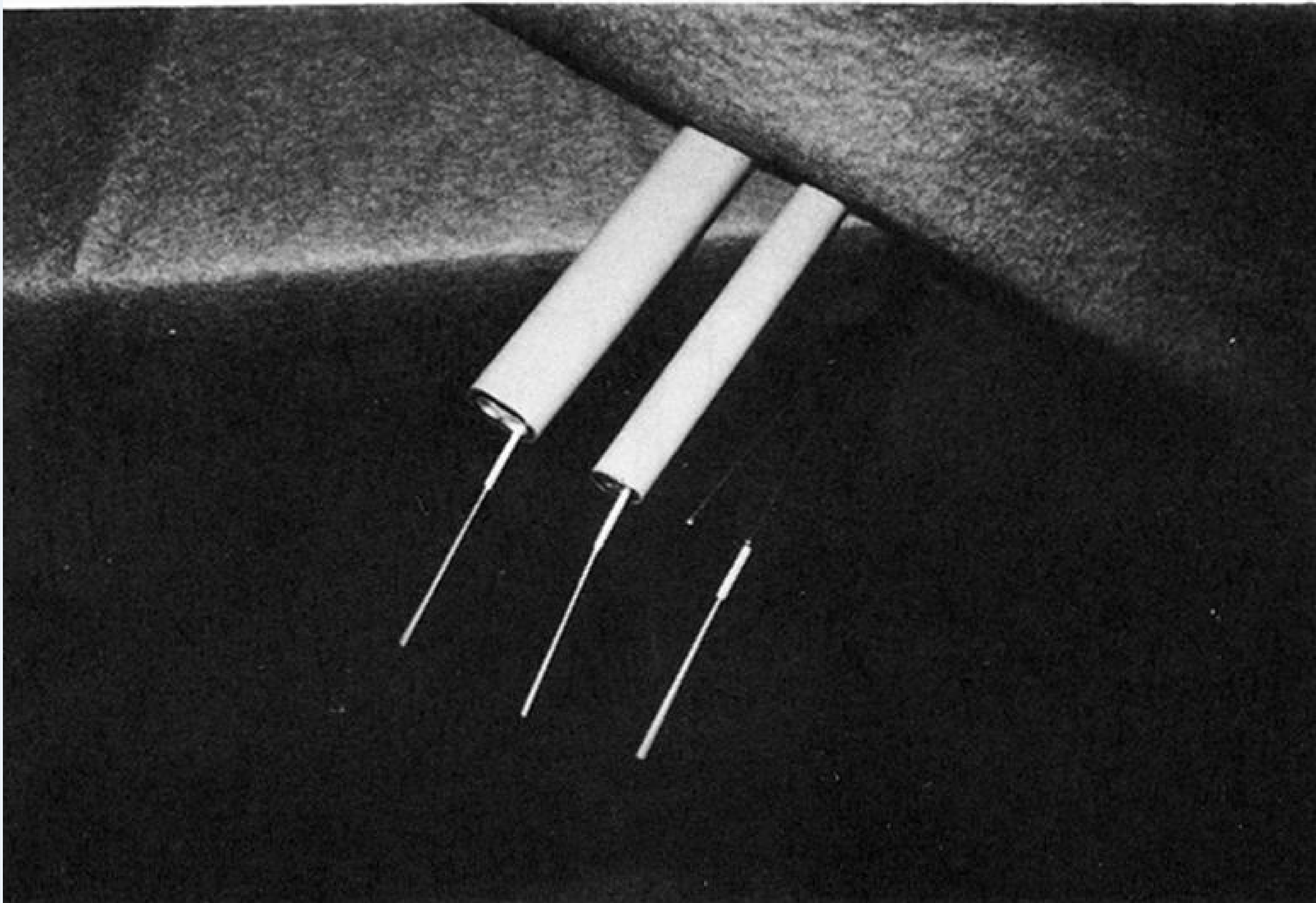

FIGURE 5. Prototype subscriber drop cables.

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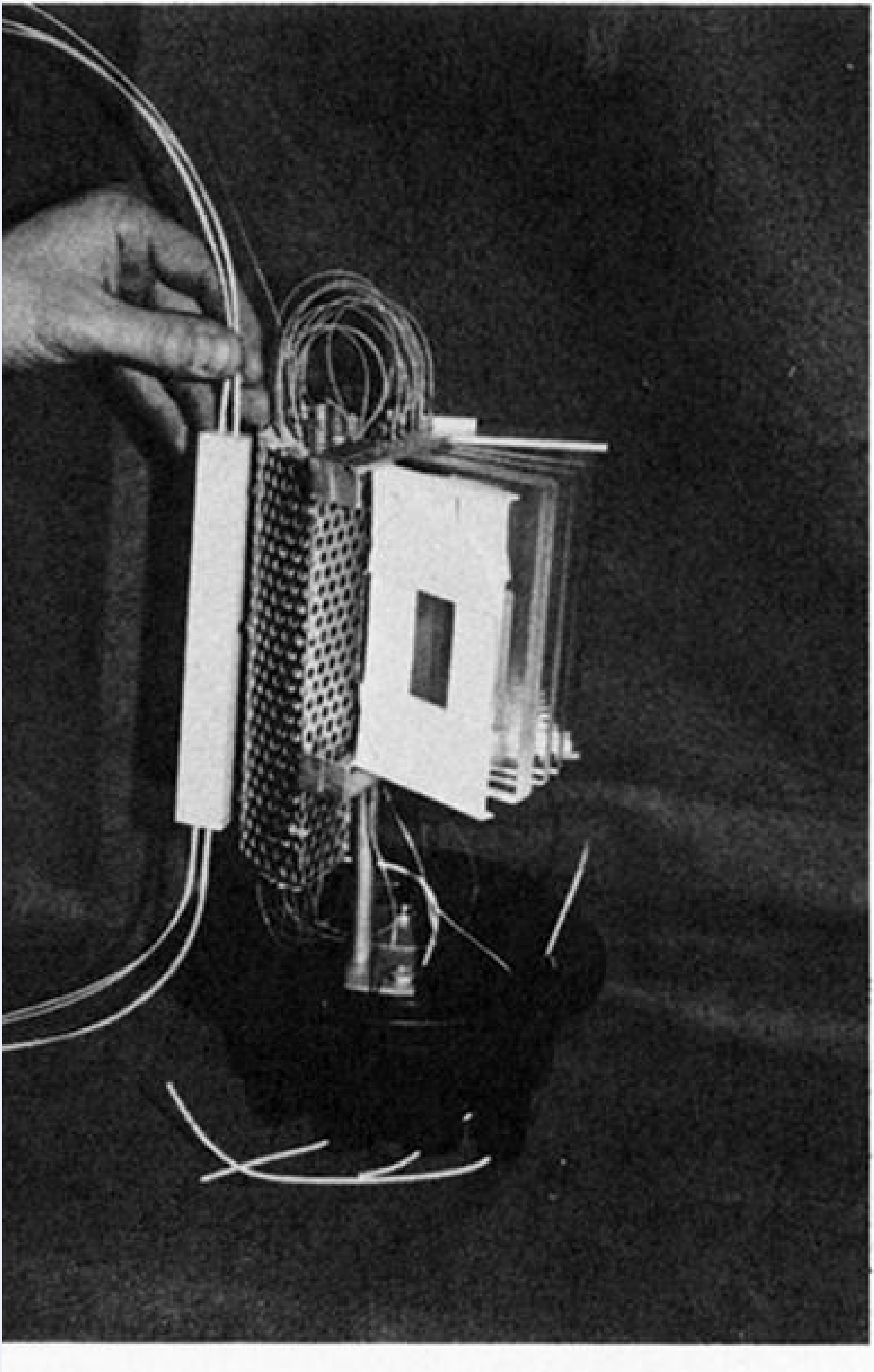

FIGURE 6. Prototype subscriber DP.

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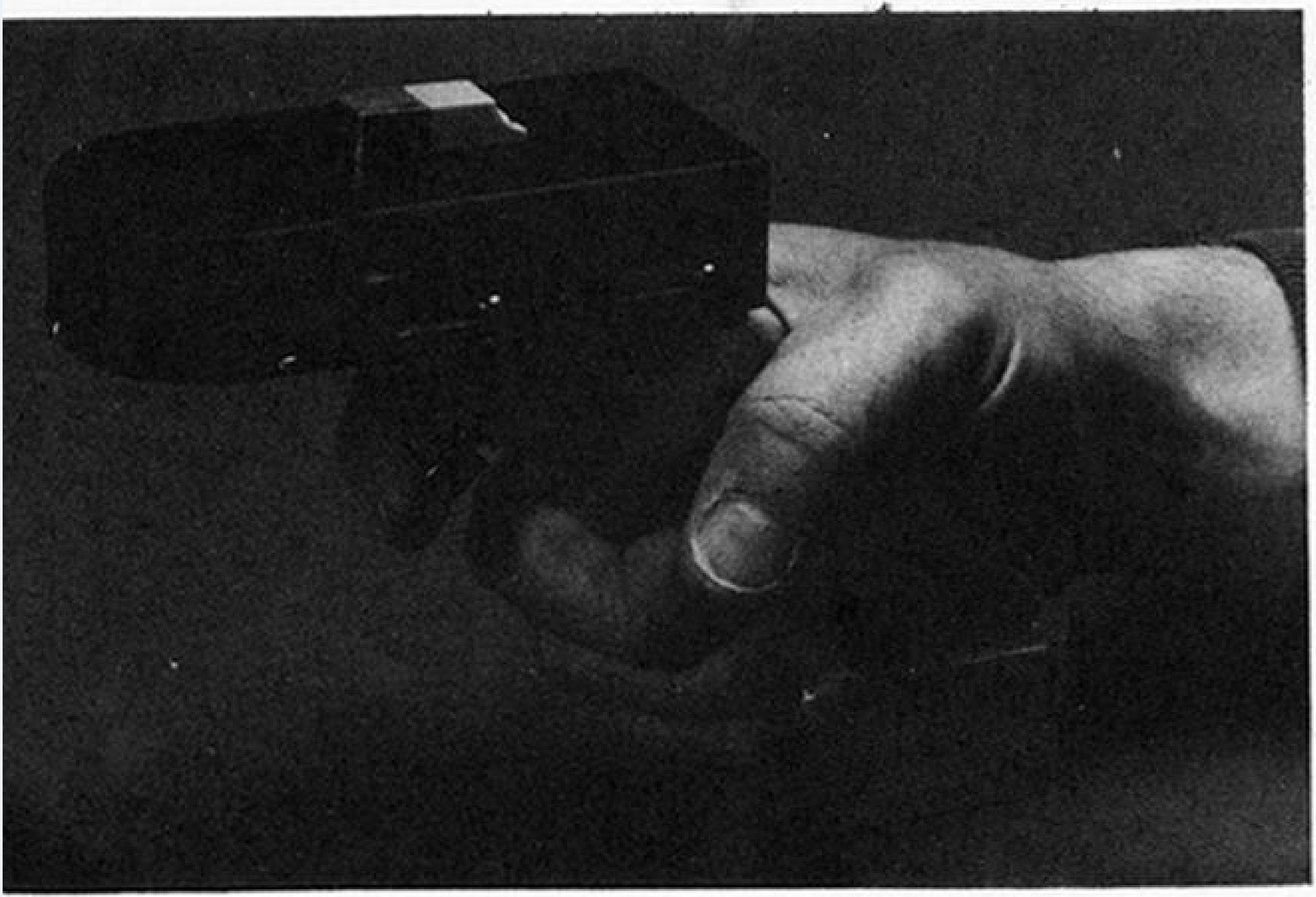

FIGURE 9. Clip-on optical power meter.