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(72) Inventeurs/Inventors:
DRODOFSKY, ULRICH, CH;
ZELLER, MARCEL, CH

(73) Propriétaire/Owner:
VECTRONIX AG, CH

(74) Agent: KIRBY EADES GALE BAKER

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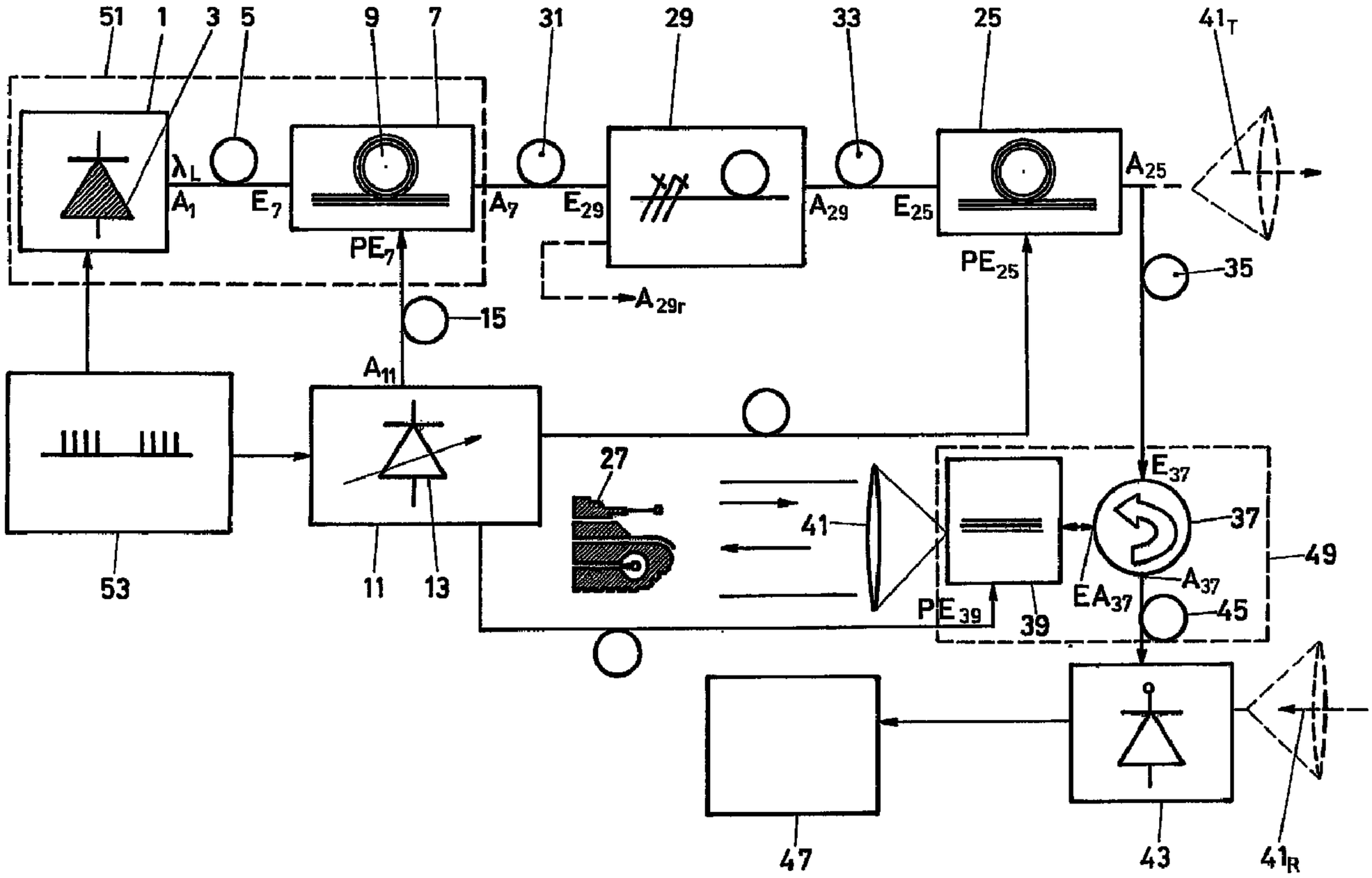

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So as to establish laser light with a desirec characteristic downstream a laser light source (151), the light is amplified by an amplifier (107) which is gain-modulated (E_{107G}).

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(71) Applicant *(for all designated States except US)*: **VECTRONIX AG** [CH/CH]; Max Schmidheiny-Strasse 202, CH-9435 Heerbrugg (CH).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **DRODOFSKY, Ulrich** [DE/CH]; Degenstrasse 5, CH-9442 Berneck (CH). **ZELLER, Marcel** [CH/CH]; Wiesenstrasse 9d, CH-9436 Balgach (CH).

(74) Agent: **TROESCH, J.**; Troesch Scheidegger Werner AG, Schwäntenmos 14, CH-8126 Zumikon (CH).

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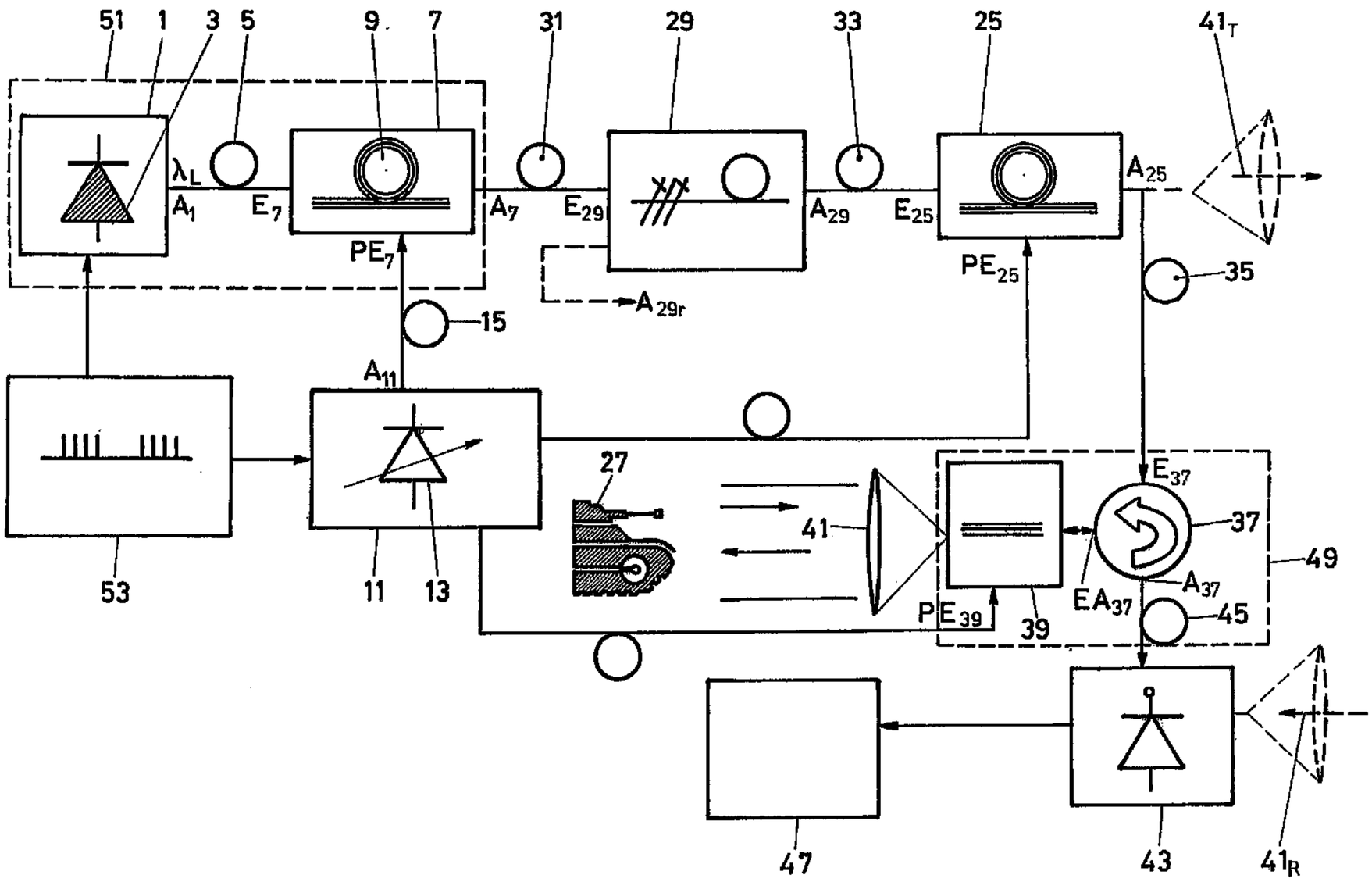
(54) **Title:** NOT TEMPERATURE STABILIZED PULSED LASER DIODE AND ALL FIBRE POWER AMPLIFIER



(57) **Abstract:** So as to establish laser light with a desirec characteristic downstream a laser light source (151), the light is amplified by an amplifier (107) which is gain-modulated (E_{107G}).

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NOT TEMPERATURE STABILIZED PULSED LASER DIODE AND ALL FIBRE POWER AMPLIFIER

The present invention departs from the object to construe a laser system which is highly compact, low power consuming and robust to environmental hazards so as to be applicable for portable or even handheld devices. The invention especially departs from such an object to be resolved for a laser system integrated into a laser range finder device or target designator device e.g. incorporated in an observation instrument. Thereby, in addition to the addressed requirements with respect to compactness, power consumption and robustness such a laser system, as for long distance range findings and target designation, must be of relatively high output power and must allow accurate evaluation of target reflected laser light.

One problem which is especially addressed in the present application is the control of a characteristic of output laser light especially of at least one of intensity, signal-to-noise-ration, wall-plug efficiency, departing from a laser system as addressed above. Nevertheless, the solution of this object may be applied more generically on laser systems where especially constructional compactness and power consumption as well as accurate evaluation are prevailing considerations.

Thus the present invention is directed on a method for producing laser light with a desired characteristic of the output laser light. This is accomplished according to the present invention in that there is generated laser light in

a spectrum range. The laser light is amplified with an active fibre amplifier. The gain of such amplifying is modulated so as to achieve and maintain the addressed desired characteristic.

Instead of providing stabilizing measures within a laser system so as to properly control e.g. keep constant, parameters which do affect the addressed characteristic of output laser light, which measures customarily necessitate significant constructional efforts and do consume additional power as e.g. for cooling, negative feedback-controlling purposes, the desired characteristic is achieved and maintained by appropriately modulating the addressed gain of amplifying.

Further, providing the addressed amplifying with an active fibre amplifier significantly improves constructional compactness on one hand as well as output power of laser light on the other hand.

Certain exemplary embodiments can provide a method for producing laser light in a range finder or in a target designator, said laser light having a desired characteristic, comprising the steps of: (a) generating pulsed laser light in a spectrum range; (b) amplifying said laser light with an active fibre amplifier; (c) modulating the gain of said amplifying so as to achieve and maintain a desired characteristic, namely at least one of intensity of laser light dependent on said laser light generated, signal-to-noise ratio of said dependent laser light and of wall-plug efficiency of said dependent laser light, (d) said modulating being performed by at least one of pumping light intensity for said amplifying, spectrum of pumping light for said amplifying, pulse-width of pulsed pumping light for said amplifying, shift of spectral position of an optical filter characteristic, length of active fibre for said amplifying, and time-synchronized with said pulsed laser light.

Certain exemplary embodiments can provide a laser system in a laser rangefinder or target designator system with a pulsed laser light source, the output thereof being operationally coupled to an input of an active fibre optical amplifier said active fibre optical amplifier having a gain modulation control input whereat at least one of pumping light with modulated intensity for said

amplifier, pumping light with modulated spectrum for said amplifier, pulsed pumping light with modulated pulse-width for said amplifier, a control signal for shift of spectral position of an optical filter characteristic in said amplifier, a control signal for a length of an active fibre of said amplifier is input, said gain being modulated in a time-synchronized manner with pulsed operation of said laser light source.

In one embodiment of the method according to the present invention as a desired characteristic at least one of intensity of laser light which depends on the laser light generated, of signal-to-noise ratio of such dependent laser light and of wall-plug efficiency of the dependent laser light is selected.

In a further embodiment of the method according to the invention modulating is performed within a negative feedback control loop for the addressed desired

characteristic. As perfectly known to the skilled artisan such a negative feedback control loop comprises sensing the addressed characteristic as momentarily prevailing, comparing such momentarily prevailing characteristic with a desired characteristic or with a desired time-course of such characteristic and acting upon the system by adjusting so as to match the momentarily prevailing characteristic as closely as desired with the desired characteristic. Such adjusting in the control loop is performed by acting on the gain modulation of the amplifying.

In one embodiment modulating of the gain of amplifying by means of the active fibre amplifier is performed by at least one of intensity of pumping light for such amplifying, spectrum of such pumping light, pulse-width of pulsed pumping light for such amplifying, shift of a spectral position of an optical filter, length of active fibre for such amplifying.

A significant improvement especially with an eye on signal-to-noise ratio is achieved at output laser light, by generating pulsed laser light and time-synchronizing at least a part of the addressed gain modulating with the laser light as pulsed. Just as an example it thereby becomes possible to increase the gain of amplifying just during time periods in which the laser light pulses are "ON". Thereby the noise during "OFF"-periods of the laser light pulses is reduced.

By providing the addressed amplifying, noise may be generated by amplified spontaneous emission ASE which may significantly contribute to the overall noise in the output laser light. Therefore in one embodiment there is performed optical filtering laser light which has been amplified by the addressed amplifying. Thereby normally such optical filtering will comprise narrow pass-band filtering, on one hand to pass the desired spectral band of laser light and on the other hand to reduce light components which are located spectrally aside the desired laser light spectral band. Clearly such filtering may be performed by transmissive pass-band or by reflective pass-band type filters.

In a further embodiment the just addressed filtering is performed with a filter characteristic which is controllably shiftable with respect to spectral location. This significantly improves the possibility to cope with effects in the laser system which provide for undesired variations of the desired characteristic as e.g. of output laser light intensity, signal-to-noise ratio or wall-plug efficiency. Due to the fact that the addressed filter characteristic is controllably shiftable with respect to its spectral location, in fact additional gain modulation ability is introduced. This ability as being based on spectral shift is especially suited to cope with any spectral shift of the spectral band at which laser light downstream the addressed filtering is generated. As an example if, due to temperature influences, the spectral band at which laser light is generated is shifted and a

narrow pass-band filtering is provided downstream the addressed amplifying, as for noise reduction, and if the filtering characteristic of such filtering is kept spectrally at a constant position, the addressed spectral shift of the laser light spectral band will lead to an overall change of amplification due to mutual shift of such spectral band relative to the stationar filter characteristic. If, as proposed in one embodiment, the spectral location of the addressed filter characteristic is controllably shifted and the control of such shift is performed to match the shift with the shift of the addressed spectral band, then the spectral shift of the laser light spectral band e.g. caused by temperature variation at the laser light source will not cause an undesired change of overall amplification.

With an eye on temperature caused variation of the desired characteristic to be achieved, in one further embodiment the addressed shift of spectral location of the filter characteristic is performed dependent from a temperature.

As one of the main sources for temperature caused variation of a desired characteristic is the temperature variation at the laser source generating the laser light, in a further embodiment the addressed temperature is selected to be dependent on the temperature of the laser source.

By the fact that generating laser light comprises generating laser light by means of a laser diode, on one hand the requirement of constructional compactness is

further dealt with and on the other hand a lasering element is introduced which has a spectral shift of the spectral band of emitted laser light, which depends on temperature. Therefore, combining the use of a laser diode with controlled spectral shift of the filter characteristic as was addressed above is to be closely considered.

A further embodiment of the method according to the present invention comprises stabilizing the laser light by a stabilizing filter and filtering the laser light after amplifying. Thereby there is applied on one hand a stabilizing filter characteristic and on the other hand a downstream filter characteristic. Both filter characteristics are controllably shiftable with respect to spectral position. The addressed shifts of spectral position of the stabilizing filter characteristic and of the downstream filter characteristic are matched.

Stabilizing filtering which is done by narrow pass-band reflective filtering (see definition of stabilizing filter) governs the spectral band of laser light applied to the amplifying and to the downstream filtering. Whenever the filter characteristic of stabilizing filtering is spectrally shifted, this causes the spectral band of laser light to the amplifier to be shifted. Filtering downstream the addressed amplifying which is again normally done by narrow pass-band filtering, reduces, as was addressed, noise thereby improving signal-to-noise ratio. The addressed shift of spectral position of the spectral band of laser light caused before amplifying, will affect the

overall amplification due to the downstream filtering if latter is not spectrally shifted as well. Therefore both, namely stabilizing and downstream filtering are matched with respect to spectral location of their filter characteristics. Again such shifting may be controlled in dependency of temperature.

In a further embodiment all the addressed filtering, be it for stabilizing purposes or for removing spectral components, is performed by means of optical fibre filter. Thereby with an eye on constructional flexibility and compactness an additional improvement is reached.

It has to be noticed that optical filters and especially optical fibre filters which are controllably shiftable with respect to spectral location of their filter characteristic may be conceived by providing the filter characteristics of such filters governed by at least one geometric entity of a respective filter element, be it spatial location of a material interface, be it thickness of dielectric layers, be it width of gratings etc. Shifting of the addressed spectral location is thereby effected in one embodiment by mechanically acting upon such entity which is decisive for the spectral location of the filter characteristic. In the case of making the addressed spectral shift controlled in dependency of a temperature the temperature is sensed remote from such filter element and by temperature to mechanical conversion a respective mechanical signal is applied to the addressed filter element. Alternatively the filter element is exploited itself as a temperature sensing

element in that temperature caused variations of at least one geometric entity and/or of at least one optical parameter of a material which is or are decisive for the addressed spectral location, are exploited so as to vary as a function of temperature as desired.

In a further embodiment the laser light as generated is generated as pulsed laser light.

Still in a further embodiment of the method according to the present invention, laser light which is dependent on the generated laser light is amplified and emitted and laser light which is dependent on the emitted laser light is received at a common laser input/output port. Providing a common input/output port for transmitting as well as for receiving laser light additionally contributes to constructional compactness of an overall laser system performing the method according to the present invention.

By guiding the generated laser light up to a laser output port substantially exclusively in optical fibres utmost flexibility is reached with respect to placing different components of an overall laser system and opens the possibility to construe such system in a highly compact manner.

In one embodiment laser light dependent from laser light as generated is guided by an optical fibre to a transmitter optic. Thereby the divergence of the laser beam output from the transmitter optic is determined by appropriately

conceiving the end of the fibre adjacent to the transmitter optic. Different approaches to do so are addressed in the detailed description part. By doing so a significant saving of lenses is achieved which leads to further advantages with respect to compactness, robustness and price of a respective laser system.

In a further embodiment the transmitter optic is also a receiver optic for laser light and, still in a further embodiment, the addressed optical fibre is an active optical fibre.

Under a further aspect of the present invention there is proposed a method of laser range finding or of laser target designating which comprises generating laser light according to the method for producing such laser light as has been addressed above, whereby such laser light is generated in a pulsed manner. Laser light dependent on the laser light as generated, thus pulsed too, is directed towards a target. In a further embodiment of the just addressed method especially for laser range finding, it further comprises evaluating multiple laser light pulses as received.

Still under a further aspect, the present invention proposes a laser system with a laser light source, the output thereof being operationally coupled to an input of an active fibre optical amplifier. The active fibre optical amplifier has a gain modulation control input.

The inventions under all their aspects and combinations shall now be exemplified by means of figures which show:

Fig. 1 a signal-flow/functional-block diagram of an all-fibre laser system as realized today for portable range finder- or target designator-applications;

Fig. 2 schematically and simplified the occurrence and result of relative laser wavelength shift relative to a downstream optical filter characteristic;

Fig. 3 in a schematic and simplified representation the principle of controlling spectral shift of a

filter characteristic matched to laser wavelength shift;

Fig. 4 in a simplified schematic representation, controlled spectral shifting of the stabilized laser wavelength and of the spectral position of a downstream filter characteristic;

Fig. 5 simplified and schematically, "active" shifting of a filter characteristic;

Fig. 6 in a representation in analogy to that of fig. 5 "passive" spectral shifting of a filter characteristic;

Fig. 7 by means of a simplified signal-flow/functional-block diagram a laser system with matched laser wavelength and filter characteristic both shifting as a function of temperature;

Fig. 8 the matching technique according to fig. 7 applied to a laser system according to fig. 1;

Fig. 9 a controllably spectrally shiftable pass-band optical filter in a simplified and schematic representation as applicable in the embodiment of fig. 8;

Fig. 10 a simplified signal-flow/functional-block representation of a laser system with a transmission filter;

Fig. 11 by means of a part of the laser system as of fig. 1 a possible form of realizing the principle as of fig. 10 at the laser system as of fig. 1;

Fig. 12 by means of a simplified signal-flow/functional-block diagram a laser system with gain modulated optical amplifier;

Fig. 13 purely qualitatively, pulsed laser light (a), modulated gain (b) of an amplifier for the addressed laser light and laser light resulting from gain modulated gain (c);

Fig. 14 pulsed laser light (a) amplified by pulse-width-modulated gain (b) of an optical amplifier and the result laser light (c);

Fig. 15 a part of the laser system as of fig. 1, whereat pulse-width-modulation as of fig. 14 is applied;

Fig. 16 an all-fibre coupling device in a simplified and schematic representation for bi-directional laser emission/reception and as integratable in the system of fig. 1.

Description of the Invention

The present invention will first be described by means of a today's realized embodiment. This under the title of "1. Today's realized embodiment".

As in this embodiment, various features are considered per se inventive and may be realized in different variants, may further be combined with other laser systems different from the today's realized embodiment, subsequent to the description of today's realized embodiment, those specific features possibly with their variants, their applicability to laser systems different from the today's realized will be addressed under separate titles namely under "2. Temperature shift matching", "3. Modulatable Amplifier", "4. Bi-directional coupler".

1. Today's realized embodiment

The today's embodiment as shown in fig. 1 is a laser range finder for cooperative or non-cooperative targets or applied as a laser target designator. The laser system as shown is of a size, construction and power consumption which allows integration into a handheld device and is fully autonome. It may also be applied for other fields of applications where similar requirements are valid with respect to size or compactness, power consumption and robustness.

A master laser unit 1 comprises a single mode DFB (distributed feedback) laser diode 3 emitting light pulses of a wavelength within a predetermined bandwidth. The spectral temperature drift of the wavelength of emitted laser light of such DFB diode is typically of the order of 0.1 nm/K and below. Such a DFB laser diode is e.g. a diode of Series FOL 15DCWD as available from Fitel, Furukawa Inc. The light emitted from the DFB diode 3 is coupled from an output A_1 of the master laser unit 1, possibly via an optical fibre 5, to the input E_7 of a first amplifier stage 7. The length of the optical fibre 5 is primarily selected according to the mutual positioning of the unit 1 and unit 7 and is omitted for optimum packaging density and for minimum optical loss from output A_1 to input E_7.

The first amplifier stage 7 comprises, as an actively amplifying element, an active fibre 9 which is optically pumped by light input at pumping input PE_7. Thus the output laser light of the master laser unit 1 is coupled into and amplified by the active fibre 9.

The active fibre is an Er/Yb co-doped fibre having a gain spectral band between 915 nm and 1500 nm. More generically the active fibre is doped with metallic ions as e.g. ions of Erbium and/or of Ytterbium and/or of Neodymium and/or of Praesodymium and/or of Chromium. The spectral band of light output at A_1 - is within the gain band of amplifier stage 7.

The pumping light energy input to input PE_7 is generated at an output A_{11} of a pumping unit 11 comprising a pumping diode 13. Diode 13 is a Fabry-Pérot Pump-Laser diode having a typical temperature dependency of the emission wavelength of 0.3 nm/K and having its 20°C centre wavelength at about 945 nm. Such a diode is e.g. a diode QOFP-975-3 from QPhotonics, LLC.

Thus by selecting the centre wavelength of the pumping diode 13, at about a centre temperature of a temperature range expected at the pumping diode 13, within the gain spectrum band of the first and, as will be described later, of a second and possibly a third amplifier, and the expected temperature shift of that centre wavelength covered by the gain absorption spectral bands of the amplifier stages, no temperature stabilization of the pump laser diode 13 is necessary. Thereby a first substantial saving of constructional space and of electric power is already achieved.

Depending on intended constructional positioning of pumping unit 11 and first amplifier stage 9 an optical fibre 15 is interconnected between output A_{11} and input PE_7.
Due to the high gain G of the first fibre amplifier stage 7 there is present at its output A_7 optical noise especially due to amplified spontaneous emission ASE, that is emitted in a broad spectral band and which increases with the gain value of the amplifier stage 7. Amplified spontaneous emission ASE results in broadband light emission out of the first high gain amplifier stage 7 independent from and superimposed on the amplified laser light wavelength λ_L. Because the energy of the ASE has to be taken into account for qualification into certain laser safety classes, and, in addition, adds to the noise level of the output light at λ_L and finally at and from an illuminated target, a fibre-optical ASE filter unit 29 with input E_{29} and output A_{29} is coupled, possibly via an optical fibre 31, to the output A_7 of the first amplifier stage 7. The ASE filter unit 29 is a fibre narrow band- pass filter. The central pass wavelength λ_F of ASE filter unit 29 accords with the wavelength λ_L of laser light generated by the master laser 1. To prevent the narrow pass-band of the ASE filter unit 29 and thus λ_F and the wavelength λ_L of laser light to become offset due to temperature variations at the laser source 51 and/or the ASE filter unit 29, a temperature shift matching is established as will be discussed also under a more generic aspect in "2. Temperature shift matching".

By such shift matching it is achieved that λ_F shifts spectrally substantially equally as does λ_L.
Thereby, no cooling or temperature control is to be provided at the laser source 51 which leads to a second substantial saving of constructional space and power consumption.
In fig. 1 the ASE filter unit 29 although represented rather to operate in transmissive band-pass mode may also be conceived to operate in reflective band-pass mode as schematically shown by dash line at the filter output A_{29r}.

The output A_{29} (or A_{29r}) of fibre ASE filter unit 29 is coupled, possibly via an optical fibre 33, to an input E_{25} of a second fibre-optical amplifier stage 25, which is conceived at least similar to the first fibre amplifier stage 7 and which has an output A_{25} and is pumped at an input PE_{25}. The output A_{25} is coupled via an optical fibre 35 to the input E_{37} of a fibre based circulator 37, as e.g. available from JDS Uniphase as polarization-intensive fiber optic circulator.

The circulator 37 has an input/output EA_{37}. According to the arrow direction shown, light input at E_{37} is output at EA_{37} and isolated from an output A_{37}. Light input at EA_{37} is isolated from E_{37} and output at A_{37}. The EA_{37} is coupled via an optical fibre 39 to the transceiver optics 41. Output A_{37} is coupled to a detector unit 43 via optical fibre 45. In the detector unit 43 optical to electrical conversion is performed and the respective electric signals are fed to an evaluation unit 47 which generates the desired result

information as e.g. target distance, target speed, targed trajectory etc.

In spite of the fact, that fibre 39 as shown may be realized as a third fibre amplifier stage pumped at PE_{39}, in the today's realized embodiment it is a "passive" optical fibre.

By the fibre based circulator 37 and the optical fibres 35, 39 and 45 there is realized a fibre output/input coupler unit 49 comprising the circulator device 37 for polarised or unpolarized laser light.
Thereby fibre 45 and 39 are of few- mode type. Fibre 35 is optimized with respect to the laser source up to A_{25} e.g. with respect to laser light intensity.
As fibre 39 is selected short i.e. up to at most 10 cm and is not bended, coupling from the fundamental to higher order modes in that fibre is neglectable. Because manufacturers of commercially available circulating devices as of 37 do impose fibre parameters, fusion splicing of the fibres 35, 39 and 45 to the fibres of the device 37 is performed to minimize losses. For such fusion splicing we refer to Electron.Let.Vol.22 No.6; pp.318, 1986; "Low-loss joints between dissimilar fibres by tapering fusion splices".
The connector at the end of fibre 39 towards the transceiver optics 41 adapts the mode field diameter MFD to the transceiver optics 41 acting as emitter and receiver optics and determines the divergence of the emitted light beam. The coupler unit 49 with transceiver optics 41 is

considered per se inventive and is more generically addressed in "3. Bi-directional-coupler."

If there is provided, separately, a transmitter optic 41_T as shown in dash line and a receiver optic 41_R also shown in dash line,obviously the circulator 37 is omitted. Then the end of that fibre, as of active fibre from amplifier stage 25 adapts the MFD to the optic 49_T and thereby determines the divergence of the emitted laser beam. By determining this divergence by appropriate conceiving the addressed fibre end, significant structural savings at the respective optics 41_I, 41_T as with respect to lenses are achieved.

If the unit with fibre 39 is to be conceived as an amplifier stage, instead of an active fibre a doped body of glass as e.g. a rod of doped glass may be provided.

In spite of the fact that it might be possible to pump all the amplifier stages 7, 25 and possibly 39 with a single pump diode 13, it has to be understood, that the pumping unit 11 which is shown in fig. 1 to pump the first 7, second 25 and possibly further fibre amplifier stages comprises the number of decentralized pumping diodes necessary to provide the pumping power as requested. Thus the "one unit" representation as in fig. 1 has been selected merely for simplifying reasons.

The laser source 51 incorporating master laser unit 1 and at least the first fibre amplifier stage 7 is a fibre

Master-Oscillator-Power-Amplifier laser source, a fibre MOPA laser source.

Definition

We understand under "optical fibre", be it "passive" or active as for amplifying purposes, coaxial- as well as strip- waveguides. As it becomes more and more possible to manufacture low-loss waveguides by strip coating plastic material substrates allowing high waveguide package density and flexible mount, we believe that in the rather near future it will become possible to construe the optical fibres also for the present system by this strip-technique.

In the embodiment of fig. 1, a double stage or possibly triple stage fibre amplifier system is used. Today such systems are limited to single pulse energies of approx. 100 µJ, which is not enough for single pulse laser ranging on non-cooperative targets at distances of several kilometres. Therefore a multi-pulse integrating evaluation method is today used.

Multi-pulse direct range finding or target designating comprises - as known in the art - detection of the time-variant light signal reflected from the target 27 and according to fig. 1 collimated by the transceiver optics 41 or 41_R.

The signal is converted into an electronic signal, digitised and stored e.g. in evaluation unit 47. By

integrating in the evaluation unit the electric digital signals representing reflected light of multiple pulses the signal-to-noise-ratio is increased.

Various known methods of digital signal processing can be applied to identify the time-of-flight of the laser multi-pulses emitted from the laser system, reflected form the target 27, detected and evaluated by the receiver detector and evaluation units 43 and 47 which methods are not described in the frame of the present inventions under all its aspects.

As may be seen schematically in fig. 1 the laser diode 3 of master laser unit 1 is controlled by a pulse control unit 53. The pumping diode or diodes 13 of pumping unit 11 are operated in pulsed mode too, whereby under one aspect considered inventive per se, and addressed under "3. Modulatable Amplifier" pulsing of the pumping diode or diodes 13 is synchronised with pulsing of the laser diode 3. Thus there is established a predetermined or adjustable phasing of pulsating control of the pumping diodes 13 with respect to pulsing control of the laser diode 3. Nevertheless such phasing needs further not be equal for respective pumping diode or diodes pumping different fibre amplifier stages and needs not be constant in time. The synchronisation is phase locked by respective negative feedback phase lock control loops (not shown in fig. 1). Pulsating power applied from the pumping diodes 13 to their respective fibre amplifier stages 7, 25, possibly 39 may be said to be a pulse modulation of the gain G of these

stages. Parameters of such gain modulation as especially gain value, duty cycle, on/or gain ratio may be adjusted or negative feedback controlled to optimize stability and signal-to-noise ratio of the overall system.

As addressed above the ASE fibre filter unit 29 is conceived so that its pass-band with λ_F has substantially the same shift as a function of temperature and in a predetermined temperature range as the wavelength λ_L of the laser light emitted from master laser unit 1. This is achieved by "passive" matching fibre ASE filter unit 29 realized as exemplified in fig. 9 and explained under "2. Temperature shift matching". The master laser unit 1, the fibre ASE filter unit 29 as well as possibly the fibre amplifier stages 7, 25 and possibly 39 are thermally tightly coupled, so that they experience substantially the same temperature variations over time. This simplifies the addressed matching.

In context with fig. 1 there has been described a fibre MOPA Laser System in context with a non-coherent direct multi-pulse detection method for laser-range finding on cooperative or non-cooperative targets or for target designator purposes by portable or even handheld instruments.

Instruments including the system as has been described with the help of fig. 1 are compact, show maximum detecting ranges dependent from installed laser power from 1 km far above 10 km distance on non-cooperative end even small

sized targets, exhibit low power consumption, provide an emitted laser beam of extremely low divergence - due to fibre-end MFD adaptation - even with short focal length collimators and are easy to integrate into optical systems. Due to the all fibre design, this laser system is rugged or robust without the need of stable construction elements to fix discrete optical components that could misalign during vibration, temperature cycling or temperature shocks. An in-fibre output beam has several advantages for place-independent application. The flexibility of packaging of the components of the fibre MOPA laser system within the housing leads to reduced form factors when integrated into optical systems, like portable observation instruments and surveying instruments, handheld distance meters or ship-, sub-marine-, space craft-, aircraft-land vehicles - based systems as tanks, where available space is limited.

2. Temperature shift matching.

With the help of fig. 1 matching of temperature shift of the spectral location of the characteristic of filter unit 29 with temperature shift of laser wavelength λ_L was addressed. More generically, a laser source with a downstream optical filter especially having a narrow pass-band characteristic removing unwanted spectral components from the light emitted from the laser source, shall now be considered.

Without providing in the laser source as of 51 of fig. 1 a temperature stabilization at least for the active laser light generating devices e.g. by high capacity cooling or by negative feedback temperature control, dependent also from the environmental temperature conditions to which the laser source is exposed in operation, the varying temperature leads to a shift of the laser light wavelength λ_L. The signal-to-noise ratio (S/N) downstream a narrow band-pass filter unit, as of 29 in fig. 1, increases with diminishing width of the pass-band of the filter unit at stationar, timeinvariant conditions. On the other hand the smaller than the pass-band width is selected, the more shifting of the laser light wavelength λ_L will lead to reduced S/N. Especially for laser systems whereat compactness, low-power consumption and high S/N are predominant requirements, the necessity of temperature stabilizing the laser source establishes serious problems. This is especially true for substantially all fibre laser sources, especially MOPA laser sources as of 51 of fig. 1 with downstream filter unit 29 whereat the filter unit 29 is especially provided to reduce ASE noise.

Whenever the temperature shift of the laser light wavelength λ_L per se is not of significant harm but the resulting decrease of S/N is, the principal approach according to one aspect of the present invention is not to stabilize the wavelength of the laser light by stabilizing the temperature but to match the temperature dependency of the spectral location of the filter characteristic of the

downstream filter with the temperature dependency of the laser light wavelength.

Thereby in a laser system whereat downstream of a laser source there is provided an optical filter, temperature stabilization of the laser wavelength λ_L is superfluous and thus omitted.

By means of a functional-block/signal-flow diagram according to fig. 2 the generic solution according to the one aspect of the present invention shall be described.

The laser source 51_g emits laser light at a wavelength λ_{Lo} given a temperature ϑ_o of the laser source, with an eye on fig. 1 especially of the laser diode 3. As qualitatively shown within the block representing laser source 51_g the wavelength λ_L shifts as a function of temperature ϑ_{51} according to a wavelength/temperature characteristic (a).

The laser light emitted at the output A_{7g}, as of output A_7 of fig. 1, is operationally connected to the input E_{29g} of filter unit 29_g which has at least one characteristic wavelength λ_F of the filter characteristic. This characteristic may, in the most general case, be a low-pass and/or a high-pass or a band-pass characteristic. The filter unit 29_g may act in transmission or reflection with respect to input and output light at output A_{29g}.

Generically, the addressed characteristic wavelength λ_F of filter unit 29_g characterizes that part of the filter characteristic which is exploited to remove undesired spectral bands from the output light. The filter characteristic may define for more than one characteristic wavelength λ_F. The filter characteristic defined by the one or more than one characteristic wavelengths λ_F may shift as a function of filter temperature ϑ_{29} as qualitatively shown in fig. 2 by characteristic (b).

According to the addressed aspect of the present invention, instead of stabilizing ϑ_{51} e.g. on the working point temperature ϑ_O at the laser source 51_g and either selecting a filter unit 29_g whereat spectral shift of the filter characteristic as a function of temperature is neglectable or stabilizing the temperature ϑ_{29} at the filter unit 29_g as well, as on e.g. ϑ_O as shown in fig. 2, the temperature shift of the characteristic filter wavelengths λ_F is tailored to closely match with the temperature shift of the laser light wavelength λ_L at least in a predetermined temperature range $\Delta\vartheta$. This is facilitated by establishing thermally narrow coupling between the laser source 51_g and the filter unit 29_g as represented schematically by coupling 60.

Assuming the laser light output at A_{7g} has a desired wavelength λ_L and has noise energy in the spectral ranges adjacent to λ_L. As λ_L shifts with temperature, at the output A_{29g} filtered output light is thus present with a shifted

wavelength λ_L and with a substantially unaffected S/N. Thereby, a significant reduction of temperature dependency of S/N is achieved. Due to the fact that no temperature stabilization, in the sense of keeping temperature constant, is necessary as e.g. a negative feedback temperature control, the overall arrangement is significantly simplified which leads to improved compactness as well as to reduced power consumption. Also dependent on the intensity of the laser light emitted by the laser source 51_g and thereby on thermical loading of the optical filter unit 29_g different techniques may be used as known to the skilled artisan to realize an optical filter unit 29_g first considered without additional measures for providing the controlled shift of spectral location shift of its characteristic in dependency of temperature.

Such filters may be e.g.

- interference filters comprising a layer system of thin dielectric layers
- optical surface and/or volume gratings
- Bragg gratings
- spectrally selective mirrors

all in transmissive of reflecting operation mode.

All or at least practically all optical filters which may be used for the addressed purpose reside on the geometry of filter structures e.g. on layer thickness, grating width, which are decisive for the characteristic wavelengths of

such filters as well as on optical parameters as on index of refraction of materials involved.

Such residing on geometry is exploited according to the present aspect of the invention by generating at the respective filter a mechanical loading which may - in one case - be realized directly by loading the respective filter structure thermally and exploiting material inherent geometric variations as a function of temperature or - in another case - by applying externally a mechanical load generated by on appropriate thermal-to-mechanical conversion, Thereby also taking temperature dependent variation of optical material parameters into account. In fact in both cases there is exploited a thermal-to-mechanical conversion be it by respective thermal behaviour of a material or be it by applying externally a mechanical load as a function of a temperature. Thus under a most generic aspect there is exploited a thermal-to-mechanical conversion.

Generically and according to fig. 3 there is provided a temperature to mechanical converter 62 the mechanical output signal A_{62} being operationally connected to a mechanical input E_{29g} of filter unit 29_g which unit acts as a mechanical to optical converter, in that the filter characteristic with λ_F is spectrally shifted by the mechanical loading and, resulting therefrom, geometric variation. Thereby the spectral location of the filter characteristic with λ_F of the filter unit 29_g in dependency

of input temperature ϑ is matched with the temperature dependency of laser wavelength λ_L.

According to the embodiment of fig. 3, the combined temperature to mechanical and mechanical to optical conversion has to be matched with the temperature dependency of the wavelength λ_L of the laser source 62.

If the laser source, as of laser source 51 of fig. 1, comprises an active laser device, as of the laser diode 3, which emits light in a broader spectral band as e.g. a Fabry-Pèrot diode it is customary to stabilize the laser source output by loading the lasering device with an optical resonator. Such a resonator may be optically delimited by an optical filter acting as a narrow-band reflective filter. The center wavenelgth of the filter-structure pass-band substantially defines for the wavelength at which the lasering device operates and is thus stabilized.

Definition:

We call a filter structure as a part of an optical resonator which loads an active laser device, and which filter structure operates as a narrow-pass-band reflective filter, the center wavelength thereof stabilizing the addressed device to operate in a narrow wavelength-band, ideally on a laser -wavelength, a stabilizing filter. In this case one possibility of realizing substantially equal temperature shifts of the emitted laser light wavelength λ_L and of the filter characteristic with wavelength λ_F of the

downstream filter unit is to establish for substantially equal spectral temperature shifts of the stabilizing filter and of the downstream filter. This is shown in fig. 4 schematically.

According to fig. 4 the active lasering device 64, in the specific embodiment of fig. 1 laser diode 3, emits in its operation light in a relatively broad spectral band B_{64}. A stabilizing oscillator 65 with stabilizing filter 66 has a resonance wavelength substantially determined by the central wavelength λ_{F1} of the pass-band of stabilizing filter 66. The stabilizing filter 66 is conceived as a mechanical to optical converter. A mechanical load, as a sharing-, compressing-, pulling-or moving-action, applied thereon, results in a spectral shift of the center wavelength λ_{F1}. Thus in dependency of a mechanical signal m applied to the stabilizing filter 66 the wavelength λ_L on which the device 64 is stabilized is varied.

Especially due to additional optical stages as of amplifier stages according to amplifier stage 7 of fig. 1, at the output of stabilized laser source 51_s the emitted light comprises also energy at wavelength different from $\lambda_L = \lambda_{F1}$ (m)which is considered as noise.

There it is provided, in analogy to fig. 3, a filter unit 29_g simultaneously acting as a mechanical to optical converter. The spectral location of the filter characteristic of unit 29_g, specified by one or more than one characteristic wavelengths λ_F, is controllably shifted

in dependency of an applied mechanical load signal. In the case of a narrow pass-band characteristic of filter unit 29_g, the pass-band central wavelength λ_{F2} is selected equal to λ_{F1} of stabilizing filter 66. The spectral shifts of λ_{F1} and of λ_{F2} respectively in dependency of input mechanical load signals m is tailored to be as equal as possible.

If the stabilizing filter 66 and the filter 29_g are equal and a temperature to mechanical converter 68 provides to both filters 66 and 29_g the same mechanical load signal m, then the temperature shift of λ_{F2} and of λ_{F1} will be substantially equal. As λ_{F1} governs the laser light wavelength λ_L, the temperature ϑ does not affect the gain of laser light in spite of the varying wavelength $\lambda_L(\vartheta)$ as would be caused by a shift of λ_L with respect to the characteristic filter wavelength λ_{F2}.

It is not necessary that the two filters 66 and 29_g have the same mechanical to optical conversion characteristic. If these characteristics are different, and as schematically shown in fig. 4 by respective weighting units 70_{66} and 70_{29g}, the different characteristics are taken into account by applying for the same temperature ϑ different mechanical loadings to the filters 66 and 29_g.

In the embodiment according to fig. 3 the overall conversion characteristic of temperature ϑ to spectral shift of the filter characteristic with λ_F is to be matched with the spectral temperature shift of the laser wavelength

λ_L. In the embodiment according to fig. 4, this is achieved by matching the downstream filter 29_g with the stabilizing filter 66. In both embodiments as of fig. 3 and of fig. 4 we have discussed controlled temperature dependent shift of the spectral location of the filter characteristic of one or more than one optical filters so as to avoid the wavelength of laser light becoming offset from a desired spectral filter band.

As was already addressed, two approaches are to be considered with respect to mechanical control of optical filter characteristics. In a first approach that we call "active" the optical filter is subjected to a mechanical load signal as e.g. to a force which is generated in dependency of temperature by an external converter. A second possibility is to exploit mechanical and/or optical characteristics e.g. index of refraction, which vary in dependency of temperature at the optical filter itself. Such material characteristics may be thermal expansion, compression, bending index of refraction etc. The filter characteristic is then controlled by the geometric and material layout and the thermical/mechanical and thermical/optical characteristics of material which governs the filter characteristic in dependency of temperature. We call this approach the "passive" approach.

The "active" and the "passive" approaches for realizing temperature control of filter units as of unit 29_g and/or stabilizing filter 66 of fig. 3 and 4 and, with an eye on fig. 1, of filter unit 29, are schematically shown

respectively in the figs. 5 and 6. According to fig. 5 a filter unit 72 as has been addressed is realized e.g. by grating 72_a e.g. applied within the volume of material M_O. An external drive unit comprises a temperature to electric converter 74 e.g. a temperature probe. The output of converter 74 acts on an electrical to mechanical converter unit 76 as e.g. on a Piezo-material device. The electrical to mechanical converter unit 76 acts as e.g. by pressure on the filter unit 72 with the grating 72_a. Thereby the grating 72_a is mechanically deformed which results in a spectral shift of the transmitted or reflected spectrum with wavelength $\lambda(m)$.

In the "passive" embodiment as schematically shown in fig. 6 the grating 72_p is realized in the interface between two different materials M_1 and M_2 or possibly within the volume of single material. Due to temperature dependent geometric and optical variation of the one material or of the different materials, the spectral location of the filter characteristic is shifted. Thus in the "passive" embodiment as schematically exemplified in fig. 6 the material structure of the filter element per se acts as a temperature to mechanical converter as of 62, 68 of the figs. 3 or 4 and, additionally, as a mechanical to optical converter and, with respect to optical material characteristics as thermical to optical converter.

In fig. 7 there is schematically shown by means of a signal-flow/functional-block diagram one realization form

of the embodiments as have been principally explained with help of figs. 2 to 6.

The output A_{80} of a laser source 80 is operationally connected to input E_{82} of circulator 82. The input/output EA_{82} of circulator 82 is fed to input/output EA 84 of bi-directional optical amplifier unit 84. The output/input AE_{84} of amplifier unit 84 is operationally connected to input/output EA_{86} of a narrow-band reflecting unit 86. The reflected spectral band of unit 86 is controllably shiftable via mechanical load input signal mE_{86}. A temperature to mechanical converter unit 88 has a mechanical output mA_{88} which is operationally connected to the mechanical input mE_{86} of narrow band reflecting unit 86. As evident to the skilled artisan laser light at A_{80} is led via circulator 82 and amplifier unit 84 onto the narrow band reflecting unit 86 and is there reflected. The reflected light is fed via amplifier unit 84 and EA_{82} of circulator 82 to the output A_{82}. Temperature ϑ_2 of laser source 80 is sensed by temperature to mechanical converter 88, resulting in shifting the spectral position of the narrow-band reflected spectrum of the reflecting unit 86. Thereby the spectral position of the filter characteristic reflecting unit 86 is matched to the temperature shift of laser light wavelength λ_L.

This embodiment described up to now accords with the embodiment as was described with the help of fig. 3, thereby exploiting "active" matching according to fig. 5.

As shown in dash lines in a further embodiment there may be provided a stabilizing filter 89 according to stabilizing filter 66 of fig. 4 so that the filter characteristic of unit 86 is spectrally shifted matched with the spectral shift of laser wavelength λ_L transmitted due to the stabilizing filter 89.

Both embodiments i.e. with or without stabilizing filter 89 may thereby also be realized in "passive" form. This according to fig. 6 and as shown in fig. 7 by temperature ϑ_1, directly affecting unit 86 and its geometric and/or optical parameters decisive for the spectral location of filter characteristic at unit 86. The same "passive" technique may be applied to stabilizing filter 89. In one embodiment the stabilizing filter 89 is conceived at least similar to the narrow band reflecting unit 86 as of same type and material so as to facilitate spectral shift matching. As further schematically shown in fig. 7 by the mechanical signal m e.g. the tilting angle φ of a mirroring surface may controllable be varied, "passively" or "actively", thereby varying controllably the spectral location of the reflected pass-band.

In certain cases and with applying a stabilizing filter 89, mixed type realization may be adequate e.g. "active" operation of stabilizing filter 89 and "passive" operation of filter unit 86 or vice-versa.

As we have already addressed, matching the spectral positions of filter characteristics of filter units

downstream the laser source with the laser wavelength shift, in dependency of temperature, is especially suited for highly compact, low-power laser systems. Such a laser system is especially one which is at least in a substantial part conceived in optical fibre technique. Thereby and as shown in fig. 7 e.g. the amplifier unit 84 may be realized by an "active" optical fibre 84_a whereby in such case the narrow band reflecting unit 86 is advantageously realized in optical fibre technology, too.

Several possibilities for realizing a reflecting unit 84a exist:

- An optical filter unit consisting of thin layers of dielectric materials and operating as an interference reflecting device. The layers are applied e.g. by gluing or coating on the end AE_{84a} of the "active" optical fibre 84_a or are provided in a separate optical element which is butt-coupled or coupled via a separate coupling device to the addressed fibre end. The dielectric coatings are conceived to result in a spectral shift of the reflected narrow-band spectrum when mechanically stressed or when directly thermically loaded.
- A further possibility is to provide surface and/or volume gratings as e.g. spatially periodic structures at the/or adjacent to the end AE_{84a} of the "active" optical fibre 84a. Here too the gratings are conceived e.g. so as to be geometrically varied by mechanical stress applied thereto being "actively" or "passively" as was explained.

- A further possibility is to apply fibre Bragg gratings, uniform apodized or chirped or coated fibre Bragg gratings, fibre Bragg gratings in different fibre compositions or structures such as e.g. on polymer fibres, germanosilicate fibres or photonic crystal fibres. Here too geometric variations and/or variations optical parameters of material provide for spectral shift of the filter characteristics.

Laser systems which are temperature matched as describe and realized in fibre technique - at least in part - are highly suited for handheld or at least portable systems, for systems where space, power consumption and robustness are predominant requirements. Such systems may e.g. be submarines, ships, spacecrafts, aircrafts, landvehicles as tanks. A laser system especially suited for such applications was described in context with fig. 1.

Fig. 8 shows a part of the system of fig. 1 which is realized according to fig. 7 in fibre technique. The same reference numbers are used for elements which have already been described to facilitate understanding. The output of laser diode 1 of fig. 1 is operationally connected to circulator 82 of fig. 7. The amplifier stages 7 and 25 of fig. 1 are realized by the pumped bi-directional fibre amplifier stage 84a as of fig. 7 and the ASE filter unit 29 is realized by a narrow band reflecting fibre unit 86 as has been explained in context with fig. 7. The output of circulator 82, with an eye on fig. 1, may directly operationally be connected to the input E_{37} of circulator

37. Amplifier stage 7, ASE filter 29 and second amplifier stage 25 as of fig. 1 are realized by the fibre bi-directional, pumped amplifier stage 84_a and the fibre narrow band reflecting unit 86. Clearly for temperature matching all the possibilities which have already been addressed as of "passive" control, "active" control, additional provision of a stabilizing filter as of 89 of fig. 7 may be applied also in the embodiment of fig. 8.

The embodiment of fig. 8 is a double-pass MOPA laser system configuration with a narrow band ASE filter which is matched with the master laser as concerns temperature shift of laser wavelength and spectral location of the pass-band of the ASE filter.

The narrow band reflecting unit 86 of fig. 7 and according the ASE filter unit 29 of fig. 8 may e.g. be realized as was addressed in context with fig. 7.

In fig. 9 there is schematically exemplified one realization form of unit 86 especially to be linked to an upstream optical fibre as to the active fibre amplifier 84a of fig. 8. Unit 86 comprises a low-pass grating filter stage 87 followed by a high-pass grating filter stage 88, at a reference temperature ϑ_o, both with corner wavelengths at about λ_L of the laser light. A fibre Bragg grating 90 acts as reflecting element. Mechanical control especially of the corner wavelengths of the stages 87 and 88 is e.g. performed by "active" compression or, "passively", by providing the respective grating in a material which has a

desired volume versus temperature shrinking characteristic. With an eye on fig. 7 it is evident that the stabilizing filter 90 may be provided with grating filter stages similar to the stages 87 and 88 to provide for matched shift of laser wavelength λ_L and filter pass-band.

The laser system as has been exemplified in the figs. 7, 8 and 9 are operating with reflective filter units 86.

In analogy to fig. 7, fig. 10 exemplifies schematically a laser system whereat the narrow pass-band filter unit operates as a transmissive unit.

According to fig. 10 the output A_{92} of laser source 92 is operationally connected to the input E_{94} of an optical amplifier unit 94. The output A_{94} is operationally connected to the input E_{96} of a narrow pass-band filter unit 96. The wavelength λ_L of the laser source 92 shifts with temperature ϑ as shown in block 92. The filter characteristic with the centre wavelength λ_F of the narrow pass-band filter unit 96 is shifted in dependency of temperature ϑ substantially equally as λ_L. Thereby, again "active" or "passive" control of temperature dependent spectral shift of the filter characteristic may be realized.

Both "passive" and "active" control have become clear to the skilled artisan from previous explanations so that in

fig. 10 both possibilities are addressed merely by the mechanical loading signal m_1 (ϑ).

The principle of the system of fig. 10 is e.g. realized in the system of fig. 1 as shown in fig. 11. Thereby the ASE filter unit 29 is conceived with a fibre grating low-pass stage 87 and a fibre grating high-pass stage 88 in analogy to fig. 9. Again, "passive" or "active" control may be applied so as to spectrally shift the pass-band centre frequency in dependency of temperature ϑ matched with the temperature shift of laser wavelength λ_L. Clearly here too, and with an eye on fig. 7 or fig. 4 a stabilizing filter may be provided and temperature shift of that filter matched with temperature shift of ASE filter 29.

We have described in this chapter according to one aspect of the present invention a technique by which the impact of laser light wavelength temperature shift is remedied not by stabilizing the temperature at the laser source but by matching the addressed temperature shift and the temperature shift of the spectral location of downstream filter characteristics. Due to the fact that the addressed matching technique may make cooling or temperature control circuits superfluous it is most apt to be applied for laser systems whereat high compactness, low power consumption and robustness is a predominant requirement. These requirements are especially encountered for laser systems which are at least in part conceived by optical fibre on one hand, to be most flexible in construction leading to increased compactness and which are, due to this advantage, most

suited for handheld or portable equipment which also require low power consumption and high robustness. A high advantage with respect to compactness is thereby achieved by a substantially all optical fibre laser system as has been disclosed in context with fig. 1, specifically but not exclusively suited for portable laser range finders or target designators. Nevertheless the addressed matching technique may also be used more generically and as was described for all kind of laser systems where a relative shift of laser wavelength and spectral position of a downstream filter characteristic is a problem and where the wavelength shift per se is acceptable.

3. Modulated Amplifier

In context with the laser system as realized today and as has been described with a help of fig. 1 we have addressed pulsing operation of the laser diode 3 and pulsing pumping of the optical fibre amplifier stages 7, 25 and possibly 39, whereby pumping of the addressed fibre amplifier stages is synchronized with pulsing of the laser diode 3.

We consider more generically the technique of pulsing operation of a laser source and of pulsing pumping of a downstream optical amplifier thereby synchronizing such pulsing operations. These aspects shall further be exemplified in this chapter.

Varying pulsed amplifier pumping as for synchronizing purposes may be considered under a broader aspect namely of

gain modulating the optical amplifier on one hand, on the other hand doing so at least in part synchronized with pulsing the laser source. Thereby such a technique may be applied per se to a laser system or in combination with one or more than one of the other aspects considered inventive.

According to fig. 12 a laser source 151 is operated to emit pulsed laser light which is controlled by a pulse-control unit 153 via a pulse control input E_{3P} to laser source 151. The pulsed laser light emitted at the output A_{151} is operationally fed to the input E_{107} of an optical amplifier stage 107. The amplifier stage 107 is gain modulated. Gain modulation is controlled by a modulation control unit 113 via gain control input E_{107G} to amplifier stage 107. At the output of amplifier stage 107 there is emitted gain modulated pulsed laser light as indicated in fig. 12 by G(t)i wherein i is the pulsed laser light emitted from laser source 151. Thereby operation of the gain control unit 113 i.e. variation of the gain G(t) at the amplifier stage 107 is at least in part synchronized with pulsed operation of laser source 151 as shown in fig. 12 by the synchronizing unit 114.

The modulated gain G(t) may be a composite gain signal consisting of a possibly time varying gain component $G_o(t)$ which is not synchronized with the pulsed light emitted from laser source 151 and with a component $G_s(t)$ which is synchronized with the addressed pulsed operation.

In fig. 13, purely as an example, there is shown pulsed laser light i (a), a qualitative gain-course $G(t) = G_o(t) + G_s(t)$ as modulated at the amplifier stage 107 and (c) the resulting pulsed light $G(t) \cdot i$.

As may be seen from fig. 13 gain modulation comprises an unsynchronized gain component $G_o(t)$ and, superimposed thereon, a synchronized component $G_s(t)$. Synchronization is e.g. based on the rising edge r of the laser pulses i and is set by the phasing $\emptyset(t)$. The synchronizing phase $\emptyset(t)$ may thereby be time-invariant or may be varying in time. As may be seen from fig. 13 by the controlled synchronized modulation of the gain G of the optical amplifier stage 107 the time course of laser pulses at the output of the amplifier stage may be most flexibly varied.

These are different reasons for time-varying energy of the laser pulses emitted from laser source 151. In chapter "2. Temperature shift matching" we have discussed how relative spectral shifts between the wavelength λ_L of the laser light and a filter characteristic e.g. of a narrow pass-band optical filter, may significantly affect the energy of output laser light at λ_L and S/N. There we have discussed the approach of temperature shift matching of the wavelength λ_L of laser light and spectral position of downstream filter-characteristic so as to cope with the addressed problem. Instead of this approach or in addition thereto, the output laser energy downstream the amplifier stage 107 as schematically shown in fig. 12 may be watched and a undesired decrease or increase of such energy e.g.

due to the addressed mutual shifts may be compensated. Thereby the technique considered here namely of gain modulation allows to cope more generically with undesired output energy variations irrespective of their upstream origin.

Further targets which may be aimed at by the addressed gain modulation technique are maximum S/N, optimized output pulse-energy versus electrical input power, i.e. optimized wall-plug efficiency.

With respect to modulating gain of the optical amplifier stage different possibilities may be applied in dependency of the type of such optical amplifier stage.

Commonly an optical amplifier for laser light is a pumped amplifier as was already addressed in context with fig. 1. Thereby at a pumped optical amplifier the addressed gain modulation may be controlled by controlling pump light energy and/or pump light wavelength. A further possibility for gain control is to provide at the optical amplifier an optical filter characteristic and to perform gain modulation by spectrally shifting the filter characteristic as was discussed for various optical filters in chapter "2. Temperature shift matching" especially in context with the "active" mode. It is perfectly clear to the skilled artisan that by providing within the amplifier stage 107 an optical filter as was described in the addressed chapter and controllably spectrally shifting its filter characteristic the gain of the amplifier stage 107 may be controllably

modulated. Further for pumped amplifiers, the optical length of excited "active" material may be modulated which length directly affects the gain of the amplifier stage.

In fig. 12 there is further shown a sensing arrangement 115 which senses, downstream the gain-modulatable amplifier stage 107 one or more than one parameters of the pulsed laser light. Such sensing arrangement 115 may e.g. sense actual S/N, pulse energy or averaged pulse energy. The sensed actual value of interest represented by an electric signal at output A_{115} is compared at a comparator unit 117 with a desired value of interest or a respective time course pre-established in storage unit 119. At the output A_{117} of comparator unit 117 a signal-difference Δ is generated which controls, via a controller-unit 121, modulation of the gain of amplifier stage 107 at modulation control input E_{113mod} and/or controls the gain value $G_o(t)$, i.e. the non-synchronized part of amplifier gain G(t). Thereby a negative feedback control for the desired entity at the laser light downstream amplifier stream 107 is established. Clearly instead of providing negative feedback control of the addressed parameters in the laser light downstream the amplifier stage 107 it is also possible to provide open-loop control by adjusting the synchronized component of the gain modulation at E_{113mod} and/or by adjusting the un-synchronized gain modulation $G_o(t)$.

As we have already addressed, providing a gain modulatable optical amplifier stage downstream the laser source allows to substantially compensate temperature caused variations

of laser output energy and of S/N. Thereby similarly to the effects of the previously addressed temperature shift matching technique, significant efforts for temperature stabilization especially of the laser source are avoided. This improves the overall laser system with respect to compactness and power consumption. Such requirements prevail especially for portable or even handheld equipment whereat such a laser system is integrated.

We have already addressed such a laser systems in context with fig. 1 as well as - more generically - in context with laser systems at least in part conceived in optical fibre technique which especially comprise one or more than one pumped optical fibre amplifier stages. The technique addressed here of gain modulating an optical amplifier stage downstream the laser source is especially suited for such highly compact and low power consumption laser systems with pumped optical fibre amplifier stages.

This is addressed in fig. 12 by the dash line representation of pumped optical fibre amplifier 107_a. Thereby and as was already mentioned gain modulation of such pulsed optical fibre amplifier stage 107 may be achieved by means of varying the intensity of pumping light and/or varying the spectrum of pumping light and/or shifting spectrally the filter characteristic of an optical filter within the amplifier stage and/or varying the length of actively amplifying material instead or additionally to modulating the addressed gain by pump-pulse-width modulation.

In fig. 14 there is shown qualitatively pulse width modulated pumping of the optical amplifier stage as of 107 or 107a of fig. 12. In analogy to the representation in fig. 13 "i" denotes the laser light pulses emitted at the output A_{151} of fig. 12. The amplifier stage 107 or 107a is pumped in that pumping light pulses are applied to gain control input E_{107G}. Thereby the pumping pulses as of (b) in fig. 14 are synchronized with the laser light pulses "i" as e.g. with varying time lag Ø(t) (see fig. 13) based on the rising edge r of the laser light pulses "i". Gain modulation is performed by pulse-width-modulation of the pumping pulses whereby as shown in (b) of fig. 14 the duty-cycle defined by the on-time T_{ON} to the pulse repetition period τ is controllably varied. The resulting laser light pulses are shown in (c). As further shown in fig. 14 gain modulation may additionally to pulse-width-modulation be controlled by pumping pulse intensity I_{ON} and/or I_{off}, spectrum of the pumping light represented in fig. 14 by the wavelength λ_P and/or as shown in fig. 12, by geometric variation of the length of absorbing material 5.

In fig. 15 there is shown a part of the laser system as of fig. 1. Thereby pumping of the one or more than one of the amplifier stages 7, 25 and possibly 39 is performed in pulse-width-modulation technique as it was addressed in context with fig. 14. Thereby and synchronized with the laser control pulses from unit 53, separate pulse-width-modulation units 14a, 14b… control the pulsed pumping of

the fibre amplifier stages 7, 25 and possibly 39 via pumping diodes 13a, 13b, etc.

The pulse-width-modulation at the respective units 14 may thereby be open-loop adjusted or, with an eye on fig. 12, negative feedback controlled from a sensing unit 115. The pulse-width-modulation control is done by a respective control signal to the modulation control inputs E_{14mod}. Thereby, the pulse-width-modulation for the respective pumping of the amplifier stages may be set differently as addressed by the separate modulation units 14a, 14b assigned to the pumping diodes 13a, 13b... The difference between setting of the pulse-width-modulations takes into account e.g. different locations of the pulsed amplifier stages along the laser light path. The difference may be with respect to synchronization phasing $\phi(t)$ as of fig. 13 as well as with respect to gain control parameters.
Instead of pumping diodes 13a, b... other pumping sources as e.g. pumping laser sources may be used. Further instead of a diode laser source 1 other laser source types may be used as e.g. solid state laser sources.

By means of the modulatable gain G of the optical amplifier as described in this chapter it most generically becomes possible to counter-act laser light intensity variations which are due e.g. to temperature influence or to aging of the system. The addressed technique is most suited to be integrated in the laser system as of fig. 1, more generically for laser systems as addressed namely for portable or even handheld equipment as for handheld laser

range finders and target designators which have already been addressed.

4. Bi-directional coupler.

In context with fig. 1 we have addressed a coupler unit 49 which his considered under a further aspect of the present invention as inventive per se.

Such coupler unit 249 is more generalized shown in fig. 16. It comprises an input optical fibre or waveguide 135 to an input E_{137} of a circulator 137. The input fibre 135 is to be connected to a laser source. The output A_{137} of circulator 137 is connected to an output optical fibre 145 to be connected to a detector unit as to a unit 43 of fig. 1. The input/output EA_{137} of circulator 137 is connected via fibre 139 to the objective of a laser device. Laser light from the laser source is coupled by the circulator 137 as output light O to fibre 139 and to the objective whereas the laser light R received at the objective e.g. reflected from a target is coupled by circulator 137 from fibre 139 via fibre 145 to the detector unit.

Different possibilities exist for the selection of the fibres 135, 139 and 145.

In one embodiment all these fibres are standard single mode fibres at the wavelength λ_L of the laser light from the laser source. Thereby the overall losses are minimized. The laser light is only guided in the core of the fibres.

Thereby the aperture of the light emitting and of the light receiving optics of the objective is selected equal. The optimum aperture width F/# of the objective may be adapted to the divergence of the fibre 139. Further the detection surface of the detector unit may be adapted to the mode filed diameter MFD of fibre 145.

In a further embodiment wherein all the fibres 135, 139 and 145 are selected as standard single-mode fibres at the laser wavelength λ_L, the emitted light O is only guided in the core of fibre 135 and 139. The received light R is guided in the core as well as in the cladding of fibres 139 and 145. Thereby especially fibres 139 and 145 are selected short so as to minimize losses in the claddings to a negligible amount. The detection surface of detector unit downstream fibre 145 is to be adapted to the cladding size of that fibre. Goupling losses of the received light R is minimized. The numerical aperture of the emitter is selected different from the numerical aperture of the receiver at the objective.

In a further embodiment fibre 135 is optimized with respect to the laser source and fibres 139 and 145 are few mode. As the length of fibre 139 is selected short and this fibre is substantially un-bended, coupling from the fundamental to higher order modes can be neglected and optimum beam quality is achieved. Still in a further embodiment fibre 135 is optimized with respect to the laser source and fibre 139 is a double clad fibre which has the same core MFD as

fibre 135. Fibre 145 is optimized to collect the light guided in the cladding and in the core of fibre 139.

In a further embodiment the fibres 135, 139 and 145 are multi-mode fibres.

If the laser source is a source of polarized laser light, in a further embodiment the fibres are selected as polarization maintaining fibres. This simplifies separation of emitted -O- and received -R- light.

In a further embodiment photonic crystal fibres, single or double-clad, are used which allows high flexibility with respect to the choice of the MFD parameters for emitted -O- and received -R- light.

Commercially available un-polarized circulator units 137 may be adapted to the different fibres as mentioned. Often manufacturers of circulators impose the parameters of fibres to be applied. Therefore, as was already addressed in context with fig. 1, fusion splicing of the optimum fibres to the circulator fibres is to be performed in order to minimize losses.

The circulator unit 137, in one embodiment is a polarization independent circulator which separates the received light R from the transmitted light O and thereby additionally removes background light by filtering.

The all-fibre coupler unit 149 or 49 of fig. 1 has the advantage that it may be applied with un-polarized laser light as especially suited for the addressed range finder and target designator portable applications. No detection limitation due to a coaxial surface ratio, defined as emitter or receiver surface, to total objective surface or due to polarization state of the received light is present.

The application of MFD adaptation at the fibre -139- end of the all-fibre device allows realizing optimal beam divergence of the device with the coupler unit 149 or 49 as of a range finder or a target designator without providing additional lenses. An increase of MFD increases reliability at the end of fibre 139.

The MFD of the fibre 139 directly determines the numerical aperture at that fibre end and is influenced by the geometry and/or refractive index of the wave guiding fibre. The numerical aperture of the fibre end determines the beam side output by the objective and thus the divergence of the laser beam emitted by the device as by a range finder or by a target designator device. Therefore the choice of MFD at the end of fibre 139 influences the performance of such device. In spite of the fact that optimum emitted beam divergence may be achieved by placing optical lenses downstream the end of fibre 139 in one embodiment of the coupler 149 and 49 - as was mentioned - adaptation of the MFD is performed at the end of fibre 139 opposite to circulator 137 which allows the omission of additional

lenses. Different techniques are known to alter and thus optimize the MFD of such fibre 139:

An increase of MFD can be achieved by diffusion of dopants obtained by heating the fibre in a flame according to J. of Appl. Phys.; Vol. 60 No.12 pp.4293, 1986, K. Shigihara et al. or J. Lightwave Technol. Vol. 8 No.8 pp.1151, 1990, K. Shiraishi et al. or Electron. Lett. Vol. 24 No. 4 pp.245, 1988 J.S. Harper et al.

Another known possibility is irradiating the fibre with a CO_2 laser according to Appl. Opt. Vol. 38 No.33, pp.6845, 1999; T.E. Dimmick et al.

Still a further known possibility to increase MFD of single mode fibres is to reduce the core diameter by taperingthe fibre, Electron.Lett. Vol. 20 No.15 pp. 621, 1984; Keil, R.

Further cladding modes have a higher beam diameter than core modes. Therefore coupling the core mode near the end of fibre 139 into a cladding mode allows significant changes in the numerical aperture. This effect has been investigated in Opt. Commun. Vol.183 pp.377, 2000; Y. Li et al.

Lensed fibre ends are presented in the publication of Jarmolik et al. Optik Vol. 110, No.1, pp.37 1999, A. Jarmilik et al. lensed fibre ends.

Generically an increase of the emitted beam diameter allows the applications of higher peak power.

A further technique to increase MFD at the end of fibre 139 is UV-irradiation of a photo-sensitive cladding at a fibre 'Spot size expander using UV-trimming of trilayer photosensitive fibres'; OECC/I00C 2001, Conference Incorporating ACOFT, Sydney, pp. 408, 2001; R.A. Jarvis et al. or 'High-energy and high-peak-power nanosecond pulse generation with beam quality control in 200µm core highly multimode Yb-doped fibre amplifiers'; Opt. Lett. Vol.30 No.4 2005; pp.358; Cheng et al. It has further to be noticed that core-less fibre end caps may be applied to the end of fibre 139 so as to completely eliminate surface damages, as known from US-20040036957 (A. Galvanauskas et al.).

Thus the coupler unit 149 or 49 as of fig. 16 provides single channel laser light emission and reception for polarized or un-polarized laser light. It is ideally suited to be combined with diode or solid state laser sources making use of optical fibre coupling technique as especially for an all-fibre laser system as of an all-fibre MOPA laser system as was described with a help of fig. 1. Thereby optical fibre based laser systems guarantee an increased stability and robustness with respect to environmental disturbances in comparison to systems with free space parts. Such laser systems may have a very high compactness and the availability of the output beam as well as of the reception beam in a fibre tail allows

substantially independent location of the input/output laser port at a respective device with such laser system. Single channel emitting/receiving optics further increase compactness allowing for high system stability. Thereby the all-fibre reception channel to the detector diode couples only light which is present within the fibre to such diode whereby stray-light impinging upon such diode is reduced.

We have described a today's realized embodiment of an all-fibre laser system wherein different features are realized in combination. All these features as especially temperature shift matching, gain modulation of optical amplifiers and bi-directional optical coupler unit are considered per se inventive as being applicable per se or in any combination to laser systems which may differ from the system as realized today.

Claims:

1. A method for producing laser light in a range finder or in a target designator, said laser light having a desired characteristic, comprising the steps of:

(a) generating pulsed laser light in a spectrum range;

(b) amplifying said laser light with an active fibre amplifier;

(c) modulating the gain of said amplifying so as to achieve and maintain a desired characteristic, namely at least one of intensity of laser light dependent on said laser light generated, signal-to-noise ratio of said dependent laser light and of wall-plug efficiency of said dependent laser light,

(d) said modulating being performed by at least one of pumping light intensity for said amplifying, spectrum of pumping light for said amplifying, pulse-width of pulsed pumping light for said amplifying, shift of spectral position of an optical filter characteristic, length of active fibre for said amplifying, and time-synchronized with said pulsed laser light.

2. The method of claim 1, wherein said modulating is performed within a negative feedback control loop for said desired characteristic.

3. The method of claim 1 or 2, further comprising optical filtering laser light amplified by said amplifying.

4. The method of claim 3, further comprising performing said filtering with a filter characteristic which is shiftable with respect to spectral location.

5. The method of claim 4, further comprising performing shift of spectral location of said filter characteristic in dependency of a temperature.

6. The method of claim 5, further comprising selecting said temperature dependent on temperature of a laser source generating said laser light.

7. The method of any one of claims 1 to 6, wherein said generating laser light comprises generating laser light by means of a laser diode.

8. The method of any one of claims 1 to 7, further comprising stabilizing said laser light generated by a stabilizing filter and filtering said laser light after said amplifying by a downstream filter, respectively with a stabilizing filter characteristic and a downstream filter characteristic, both filter characteristics being shiftable with respect to spectral position and matching shift of spectral positions of said stabilizing filter characteristic and downstream filter characteristic.

9. The method of any one of claims 1 to 8, further comprising filtering said laser light before and/or after said amplifying by means of optical fibre filter, said filtering before said amplifying including stabilizing by a stabilizing filter.

10. The method of any one of claims 1 to 9, further comprising emitting laser light dependent on said generated laser light amplified and receiving laser light dependent on said emitted laser light at one common laser input/output port.

11. The method of any one of claims 1 to 9, further comprising emitting laser light dependent on said generated laser light amplified and receiving laser light dependent on said emitted laser light at distinct laser input and output ports.

12. The method of any one of claims 1 to 11, laser light being guided up to a laser output optic in optical fibres.

13. The method of any one of claims 1 to 12, comprising guiding laser light dependent from said laser light generated by means of an optical fibre to a transmitter optic and determining the divergence of a beam of said dependent laser light by conception of an end of said fibre towards said optic.

14. The method of claim 13, said transmitter optic being a transmitter and receiver optic.

15. The method of claim 13 or 14, said optical fibre being an active optical fibre.

16. A method of laser range finding or of laser target designating comprising producing laser light according to any one of the claims 1 to 15, directing laser light dependent on said laser light produced towards a target.

17. The method of claim 16, comprising evaluating multiple laser light pulses received.

18. A laser system in a laser rangefinder or target designator system with a pulsed laser light source, the output thereof being operationally coupled to an input of an active fibre optical amplifier said active fibre optical amplifier having a gain modulation control input whereat at least one of pumping light with modulated intensity for said amplifier, pumping light with modulated spectrum for said amplifier, pulsed pumping light with modulated pulse-width for said amplifier, a control signal for shift of spectral position of an optical filter characteristic in said amplifier, a control signal for a length of an active fibre of said amplifier is input, said gain being modulated in a time-synchronized manner with pulsed operation of said laser light source.

19. The laser system of claim 18, wherein said gain modulation control input is operationally connected into a negative feedback control loop for a desired characteristic of laser light downstream said active fibre amplifier acting as an adjusting member within said negative feedback control loop.

20. The laser system of claim 18 or 19, wherein pumping light is applied to said gain modulation control input.

21. The laser system of claim 20, wherein a pumping light source is operationally connected to said modulation control input whereby said pumping light source comprises a control input for adjusting at least one of light intensity, spectral range of pumping light, pulse-width of pulsed pumping light.

22. The laser system of any one of the claims 18 to 21, further comprising a pulsed pumping source for said active

fibre amplifier and a synchronization interconnected between said pulsed laser light source and said pulsed pumping source.

23. The laser system of any one of the claims 18 to 22, further comprising at least one optical filter, the input thereof being operationally connected with the output of said active fibre amplifier, the filter characteristic of said optical filter being spectrally shiftable.

24. The laser system of claim 23, wherein a temperature sensing element is operationally connected to said optical filter, controlling said shift of spectral location of said filter characteristic.

25. The laser system of claim 24, wherein said temperature sensing element is arranged adjacent to or at said laser light source.

26. The laser system of claim 25, wherein said temperature sensing element is formed by said optical filter.

27. The laser system of any one of claims 18 to 26, wherein said laser light source comprises a laser diode.

28. The laser system of any one of claims 18 to 27, further comprising a stabilizing filter and a further filter element, the input of said further filter element being operationally connected to the output of said active fibre optical amplifier said stabilizing filter and said further filter element having respective filter characteristics the spectral position thereof being controllably shiftable in a mutually matched manner.

29. The laser system of any one of claims 18 to 28, further comprising an optical fibre filter at least one of upstream and downstream said active fibre amplifier whereby a filter upstream said amplifier including a stabilizing filter.

30. The laser system of claim 29, wherein a spectral position of filter characteristic of at least one of said optical fibre filters is controllably shiftable.

31. The laser system of claim 30, wherein said filter characteristic is determined by at least one geometric entity at said optical fibre filter and said geometric entity is controllably varied to establish said shift.

32. The laser system of any one of claims 18 to 31, wherein the output of said active fibre optical amplifier is operationally connected to an input of a circulating unit, an output thereof being operationally connected to a detector unit, an output/input thereof being operationally connected to a laser light transmitter and receiver port.

33. The laser system of any one of claims 18 to 32, wherein laser light is guided in optical fibres up to an output optic.

34. The laser system of any one of claims 18 to 33, comprising a laser light emitting port and a laser light reception port and an evaluation unit operationally connected to said laser light reception port.

35. The laser system of claim 34 said emitting port and said reception port being one common port.

36. The laser system of any one of claim 34 or 35, wherein said evaluation unit performs multiple pulse evaluation.

37. The laser system of any one of the claims 18 to 36, comprising an optical fibre one end thereof being connected to an input of a transmitter optic, said one end of said optical fibre being conceived to determine divergence of laser light transmitted by said transmitter optic.

38. The system of claim 37, said transmitter optic being also a receiver optic for said system.

39. The system of claim 37 or 38, said optical fibre being an active optical fibre.

40. The laser system of any one of claims 18 to 39 being integrated in a portable or handheld device.

41. The laser system of claim 40 being at least a part of a laser range finder system for target distances of at least 1 km throughout up to ranges of at least 10 km.

42. A vehicle with a system according to any one of claims 18 to 41.

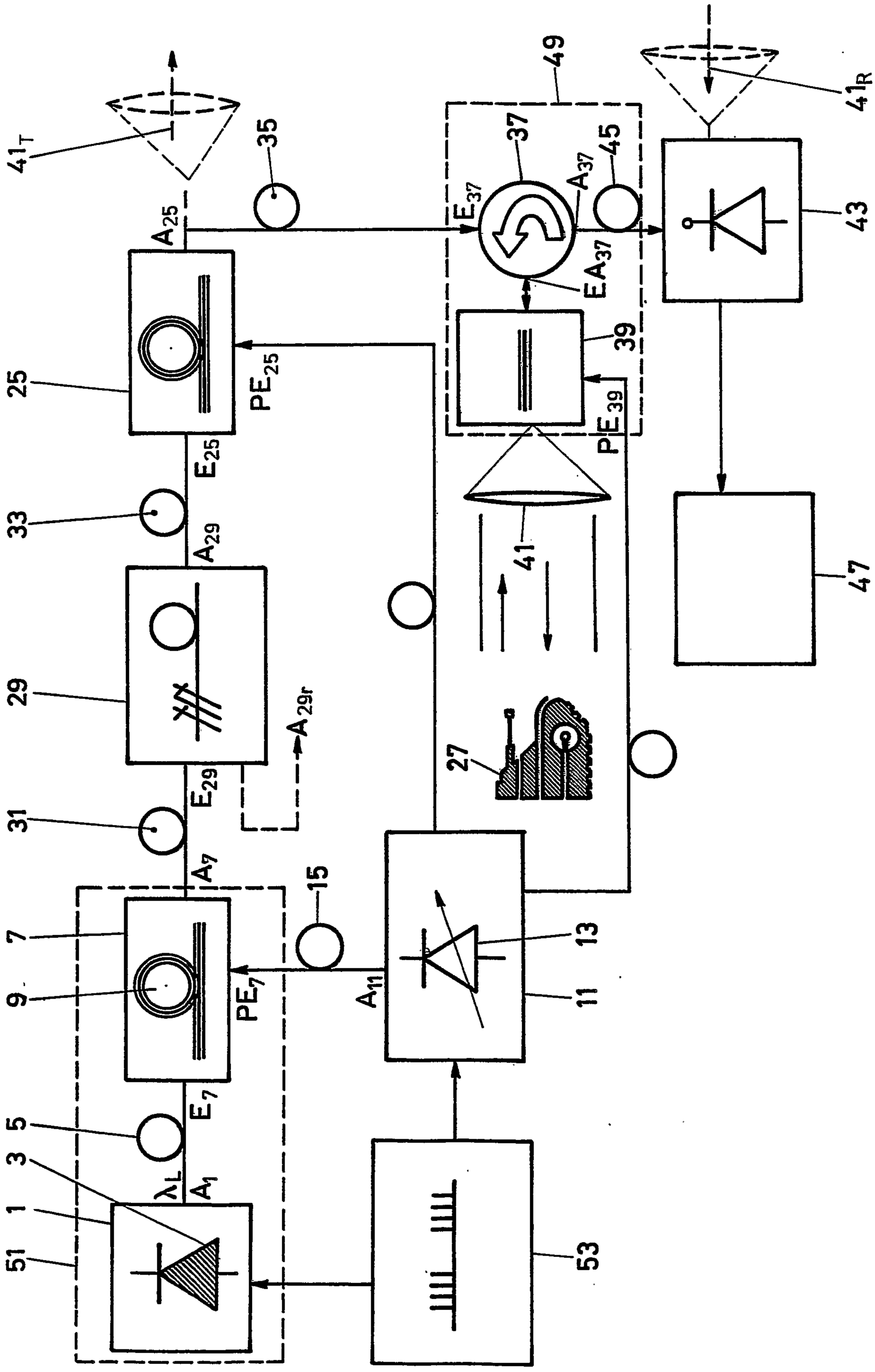

41T
35
49
37
45
41R
A25
E37
A37
43
EA37
25
PE25
39
E25
PE39
33
A29
41
47
29
A29r
27
31
E29
A7
15
7
9
PE7
A11
13
11
5
3
λL
A1
1
51
53

FIG.1

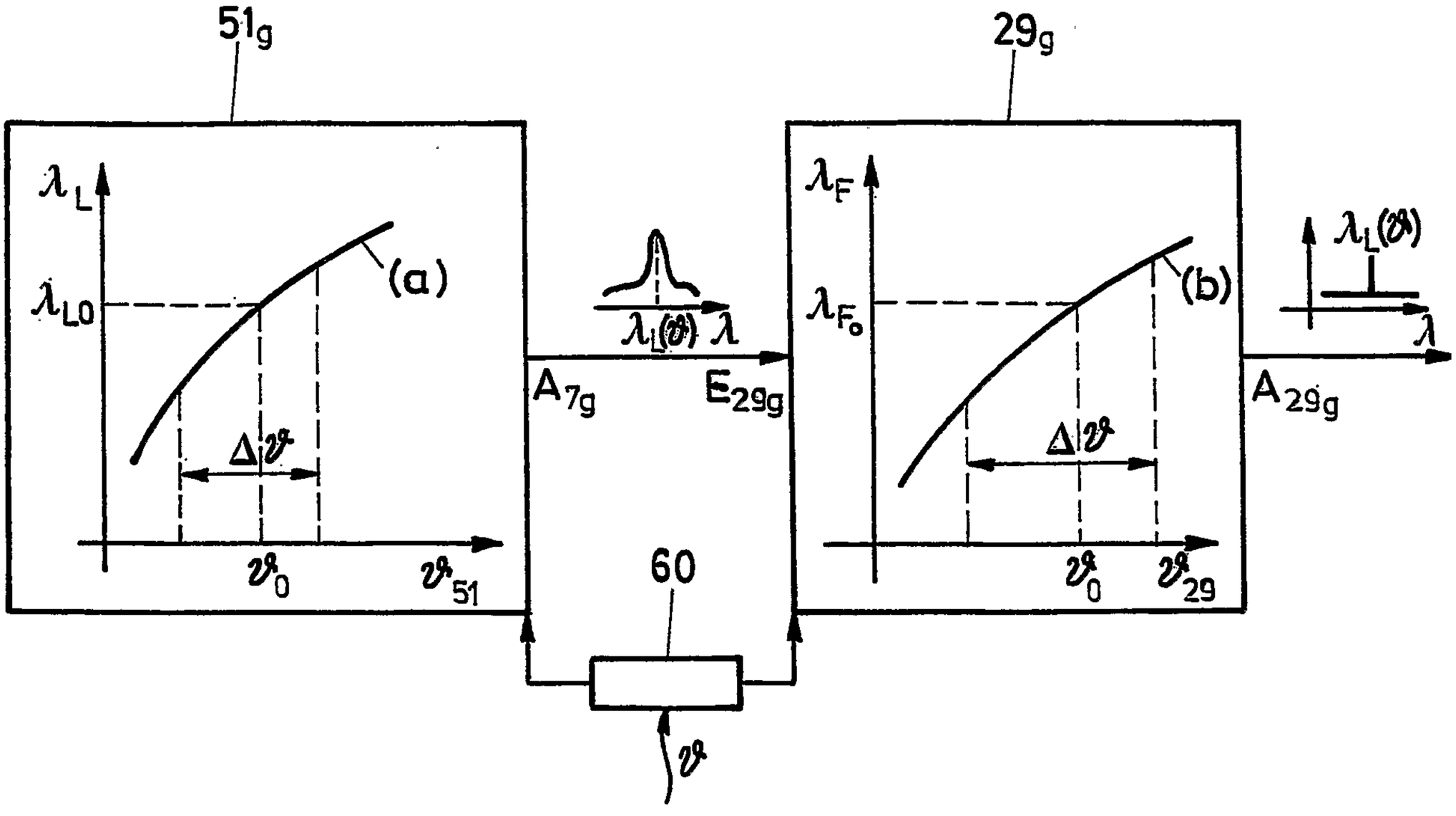

51g
29g
λL
λL0
(a)
Δϑ
ϑ0
ϑ51
λL(ϑ) λ
A7g
E29g
60
ϑ
λF
λF0
(b)
λL(ϑ)
λ
A29g
ϑ0
ϑ29

FIG.2

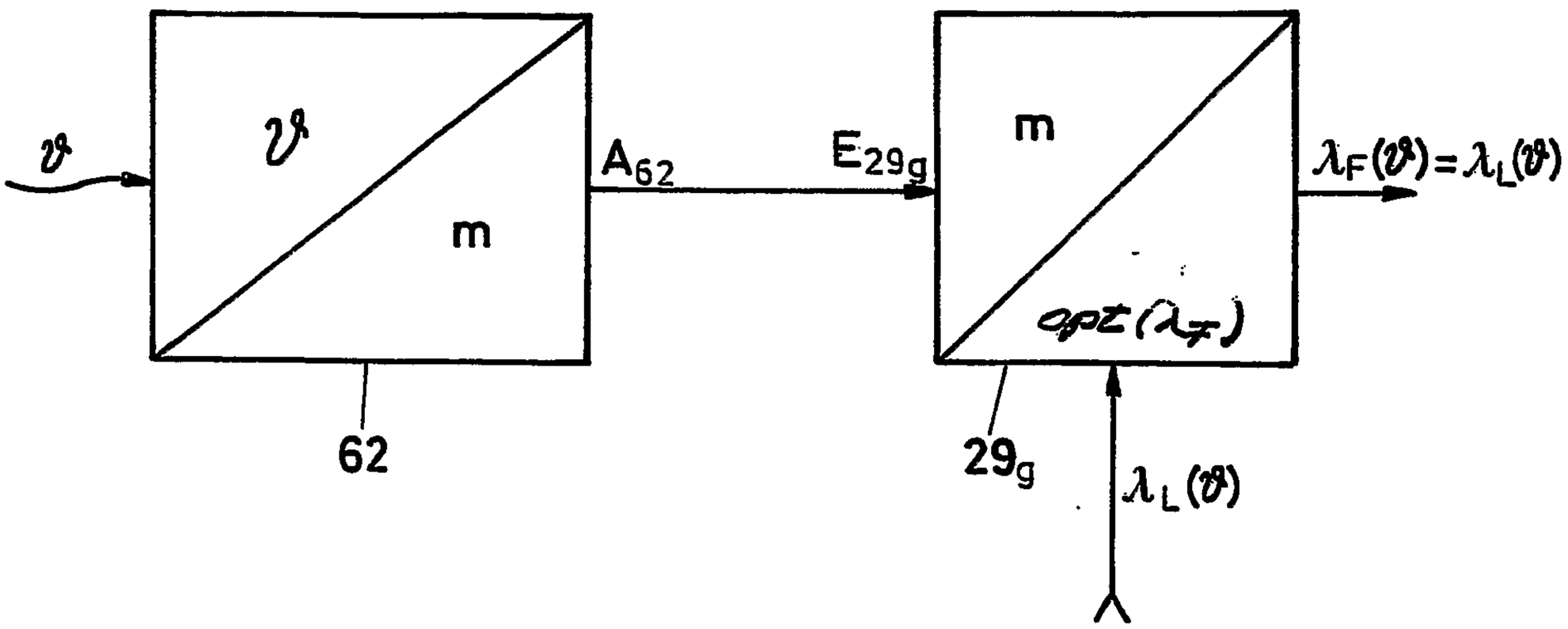

ϑ
ϑ
m
A62
62
E29g
m
opt(λF)
29g
λL(ϑ)
λF(ϑ)=λL(ϑ)

FIG.3

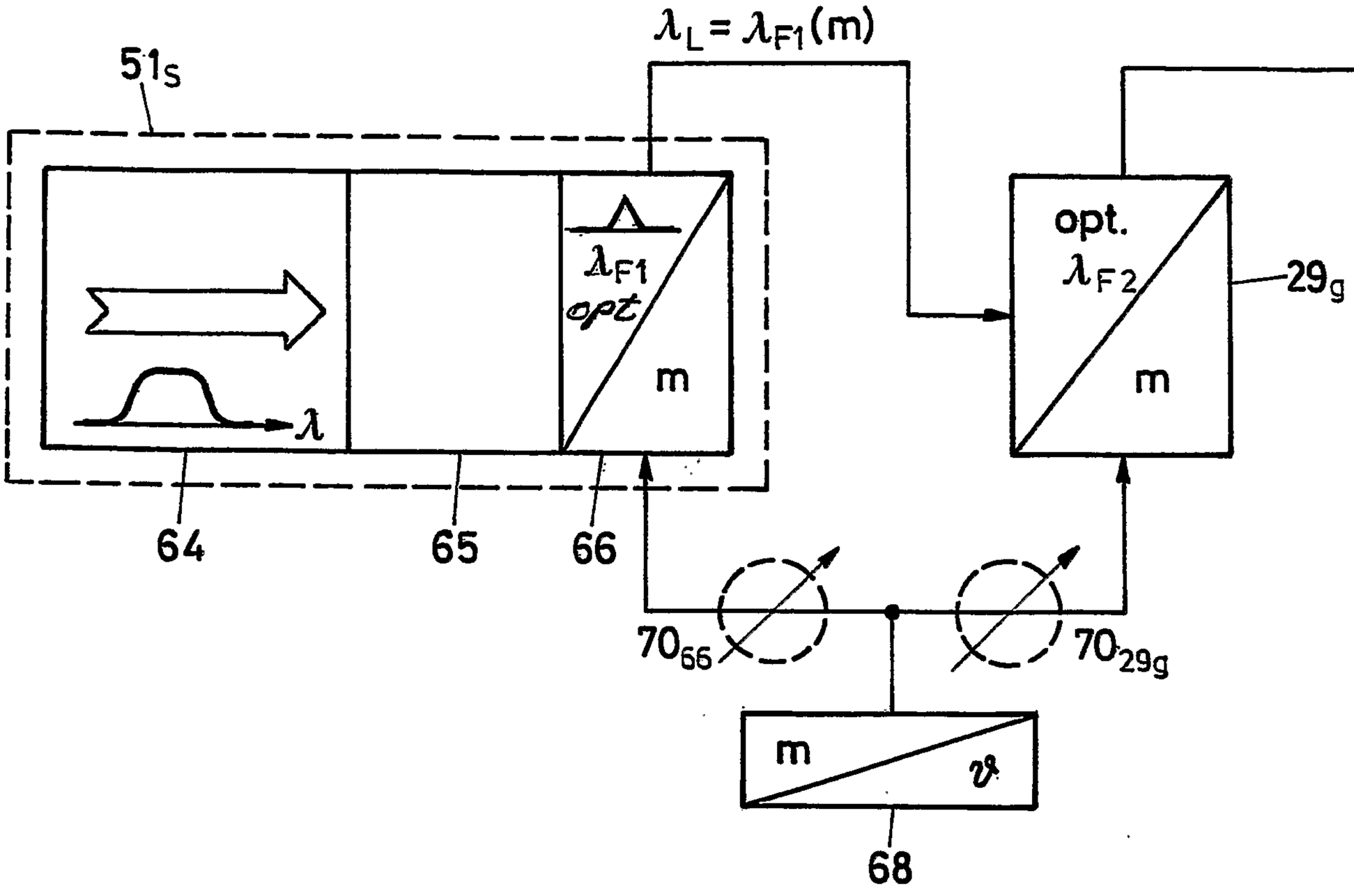


FIG.4

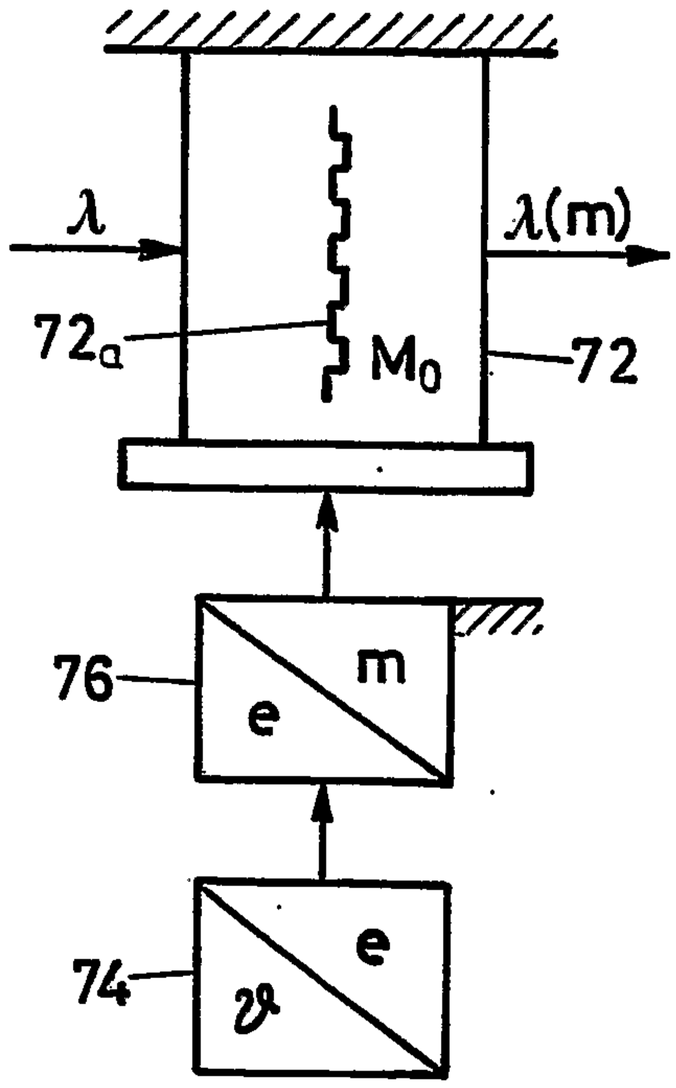


FIG.5

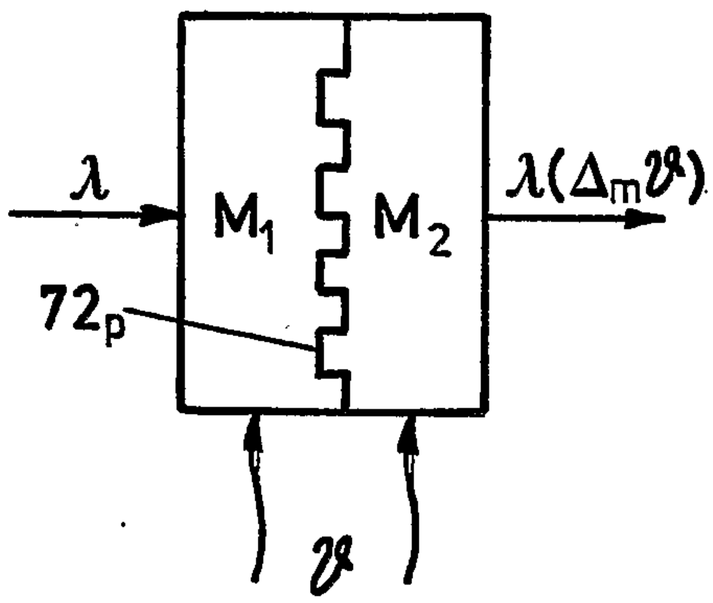


FIG.6

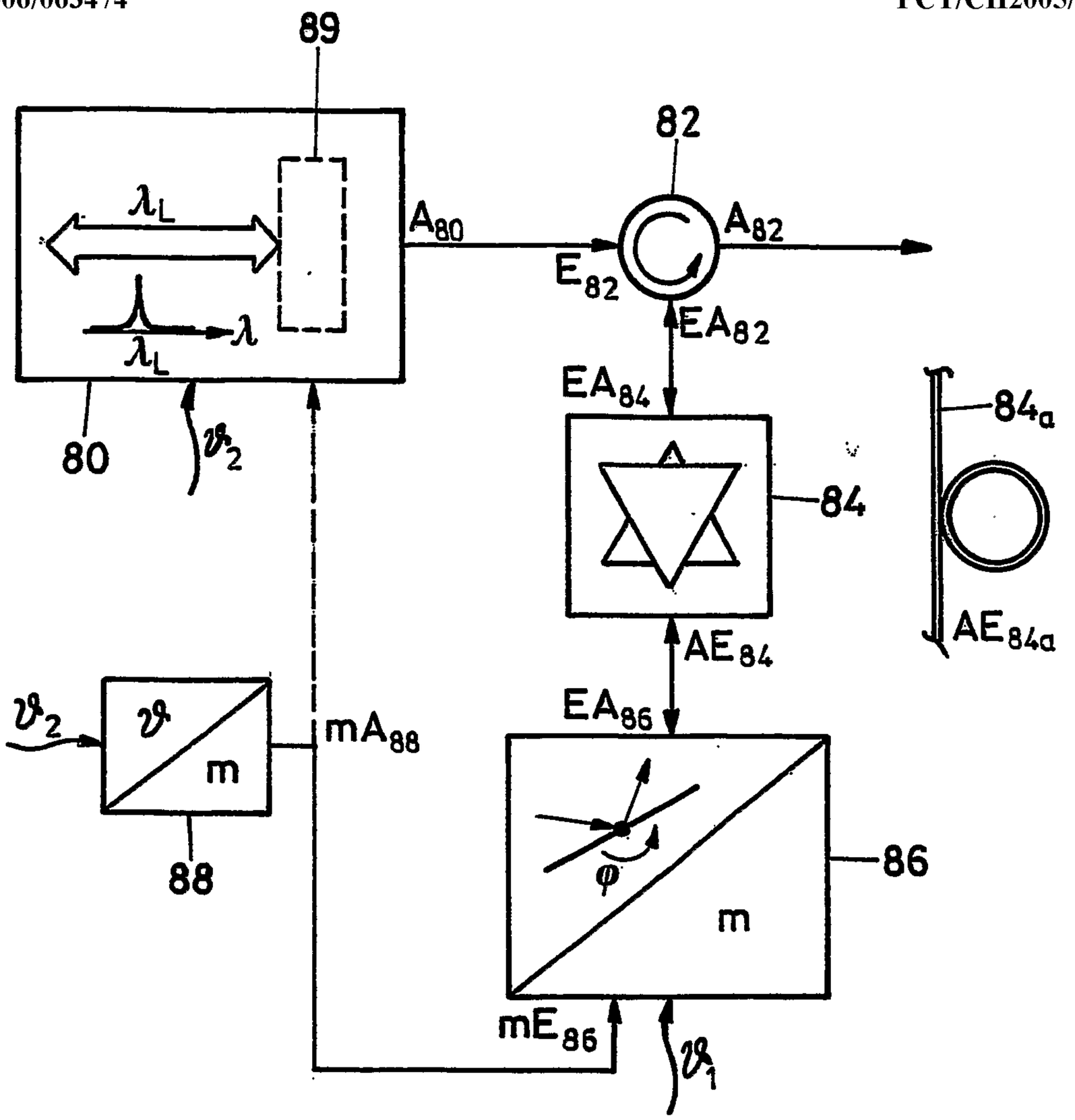

89
82
λ_L
A_{80}
A_{82}
E_{82}
EA_{82}
λ
λ_L
EA_{84}
84_a
80
ϑ_2
84
AE_{84}
AE_{84a}
ϑ_2
ϑ
m
mA_{88}
EA_{86}
88
φ
86
m
mE_{86}
ϑ_1

FIG.7

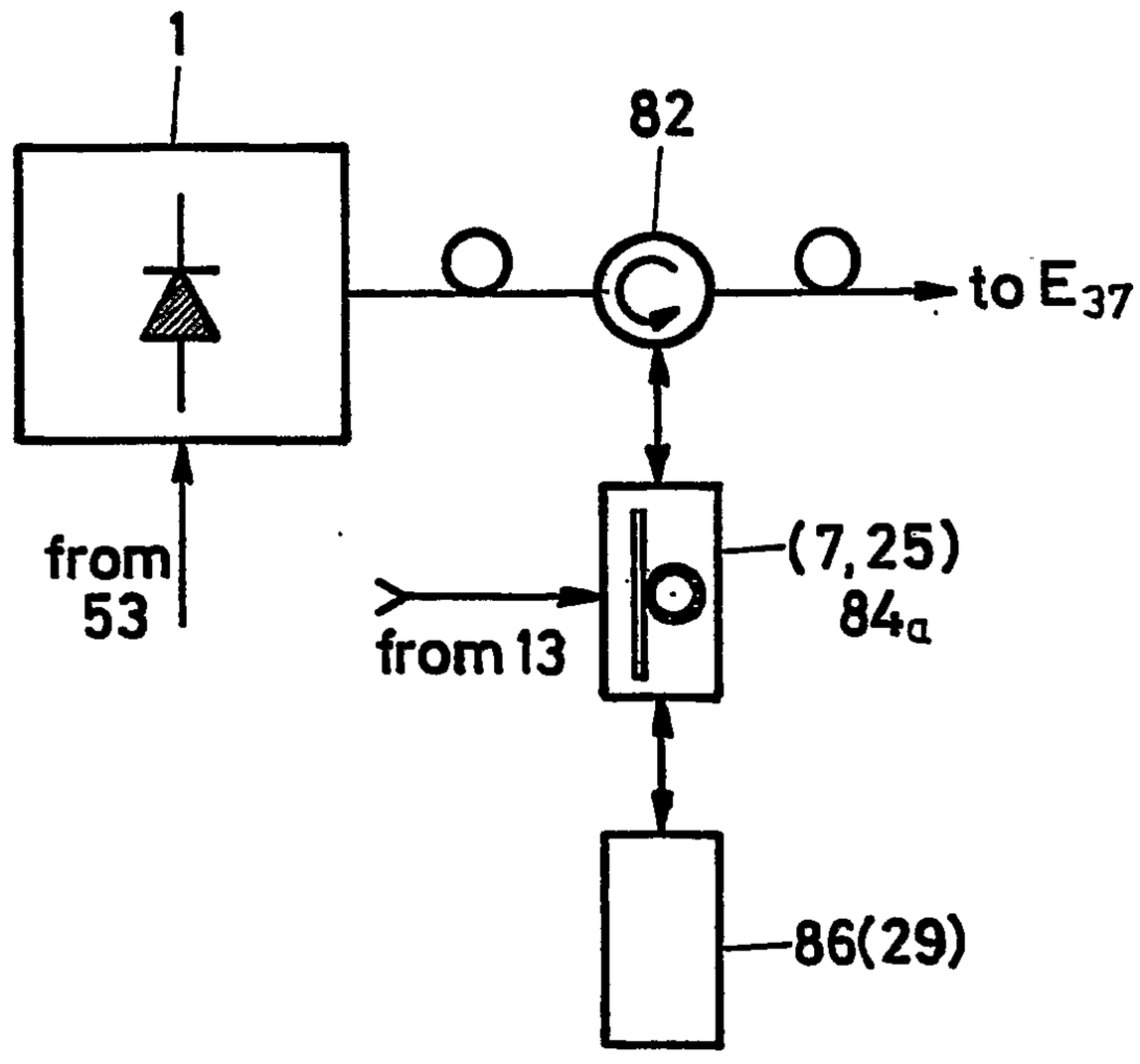

1
82
to E_{37}
from
53
from 13
(7,25)
84_a
86(29)

FIG.8

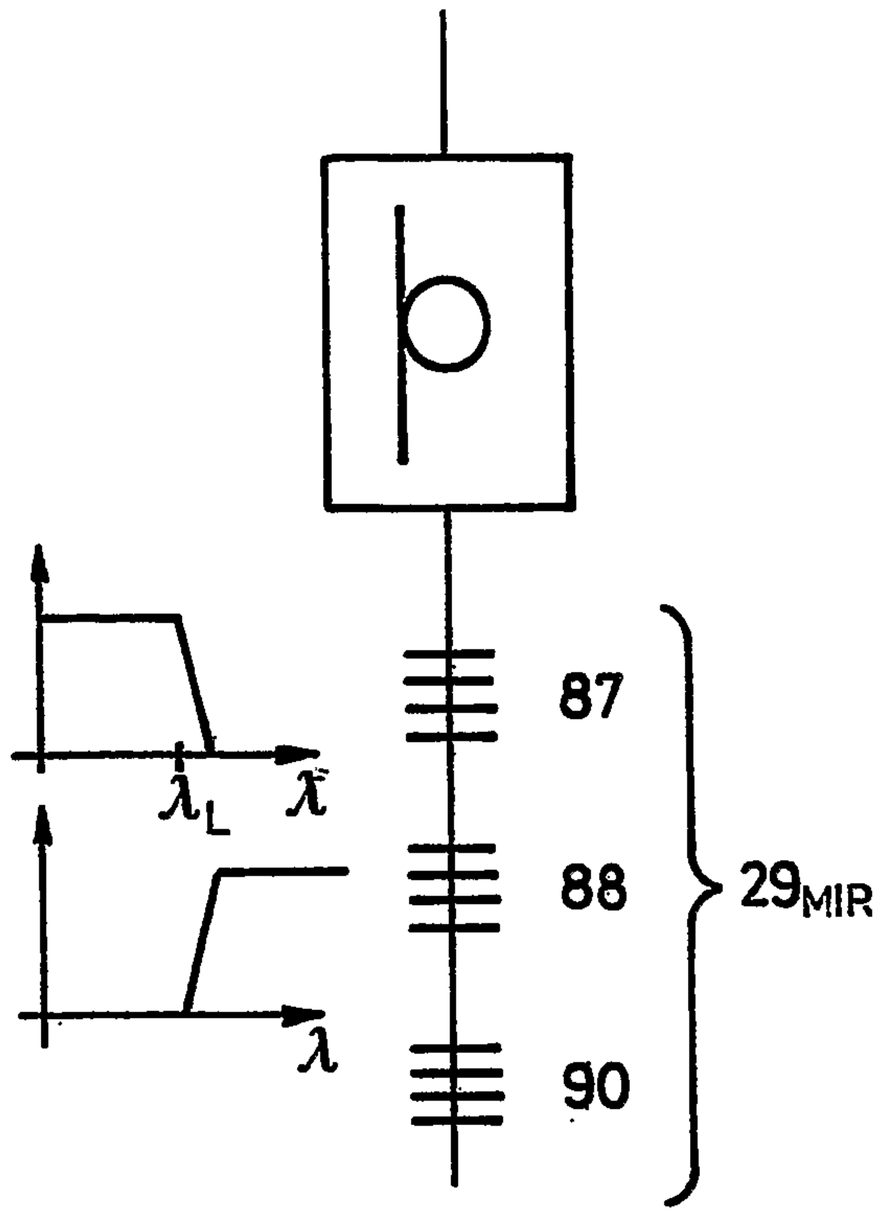


FIG.9

FIG.10

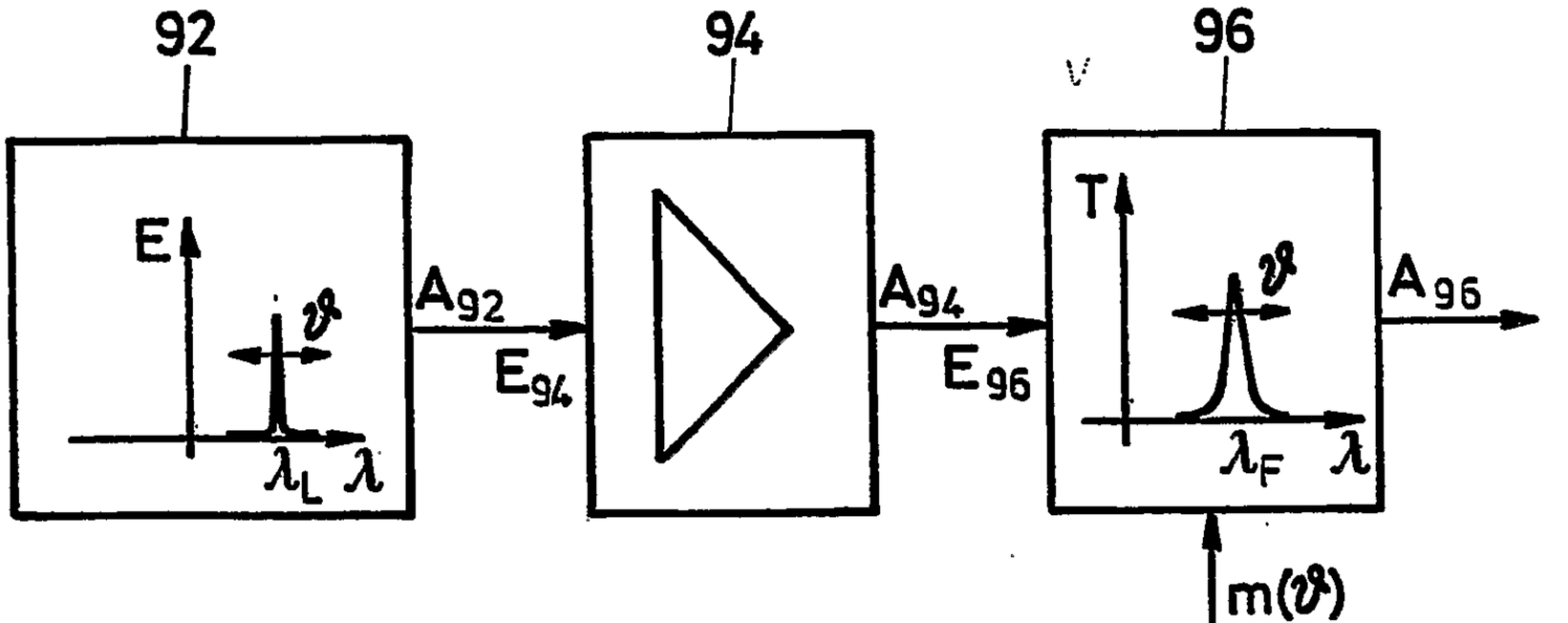


FIG.11

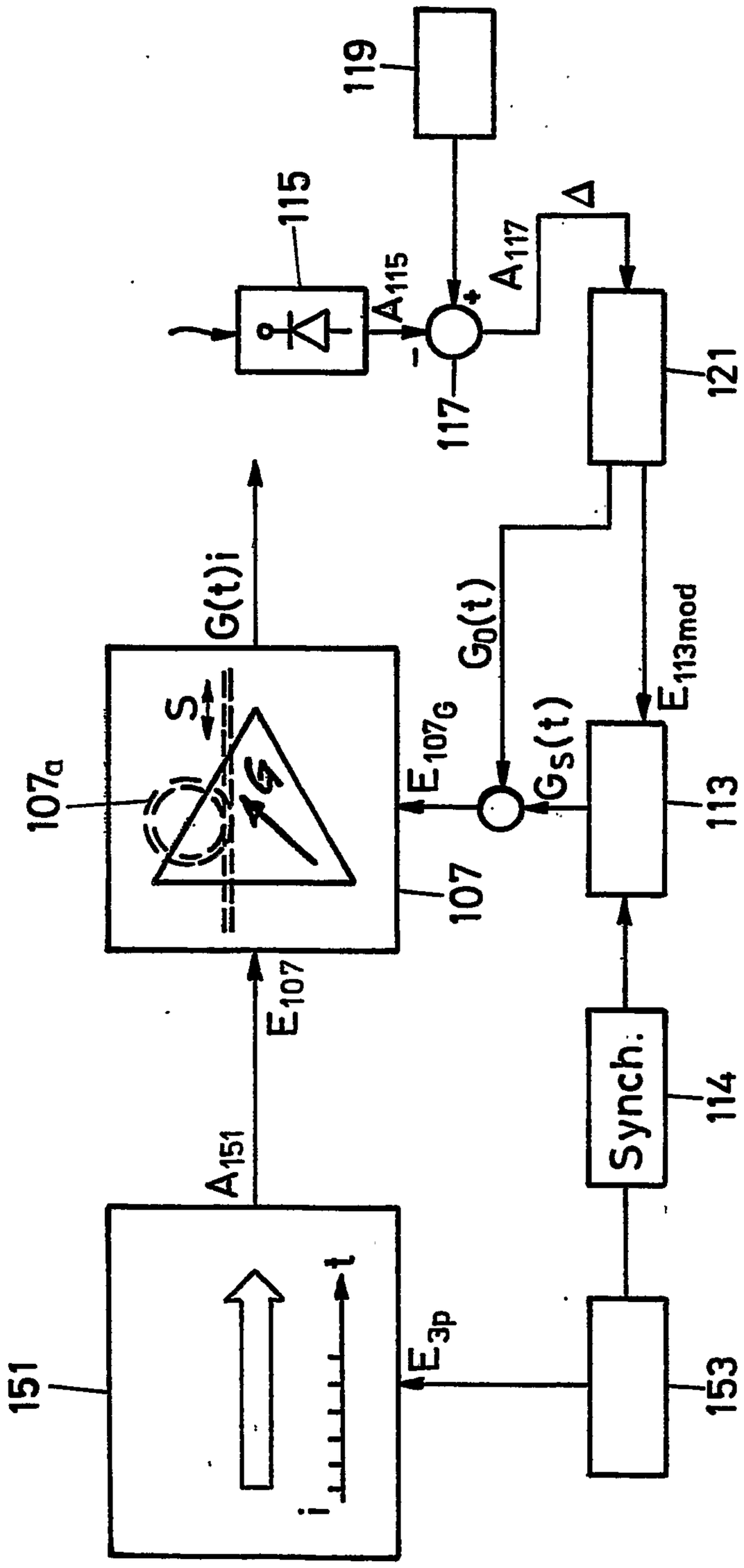

119
115
A_{115}
A_{117}
Δ
117
121
G(t)i
$G_0(t)$
E_{113mod}
S
107_a
E_{107G}
$G_S(t)$
113
107
E_{107}
A_{151}
Synch.
114
t
i
151
E_{3p}
153

FIG.12

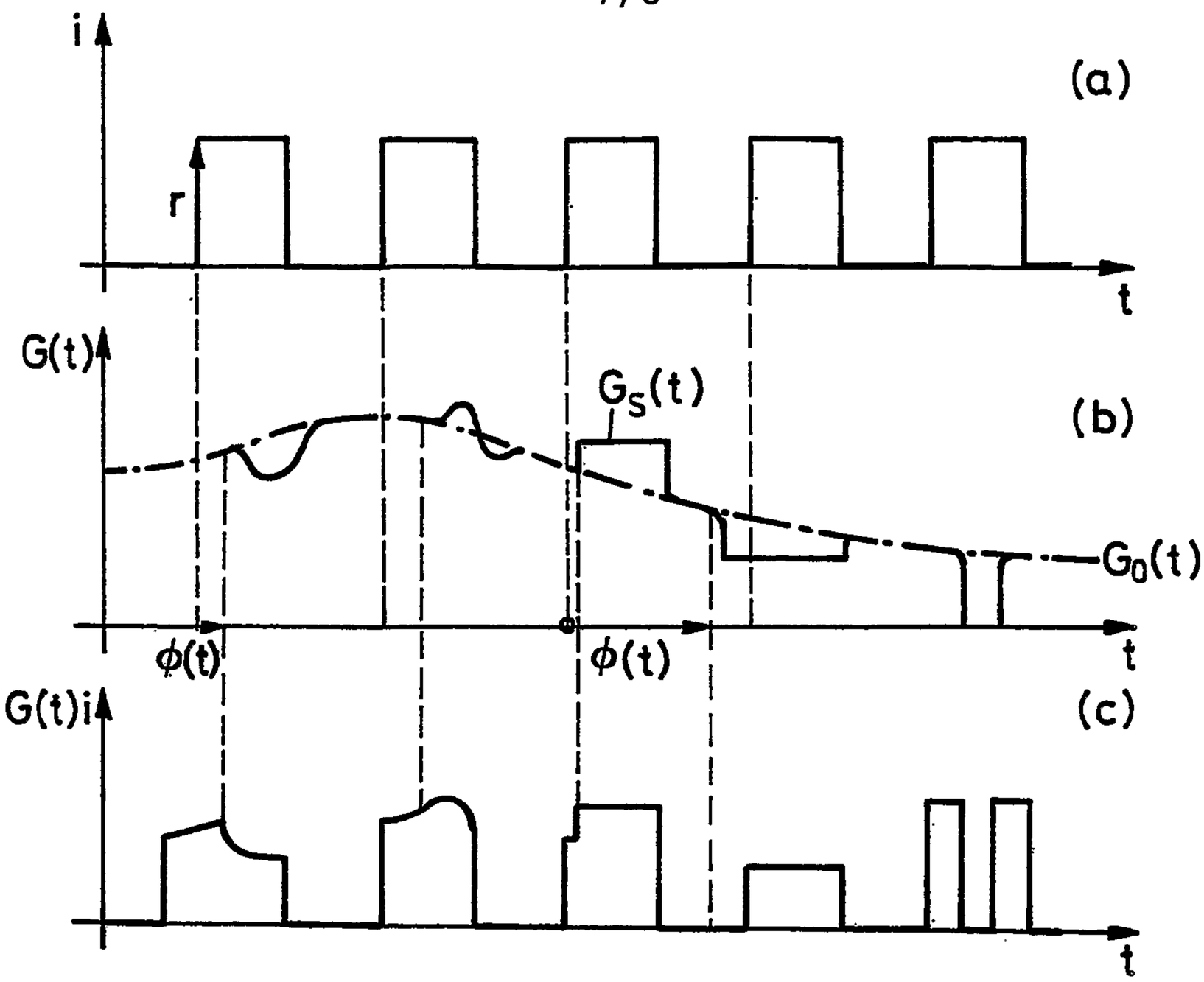

i
r
(a)
t
G(t)
$G_S(t)$
(b)
$G_0(t)$
$\phi(t)$
$\phi(t)$
t
G(t)i
(c)
t

FIG.13

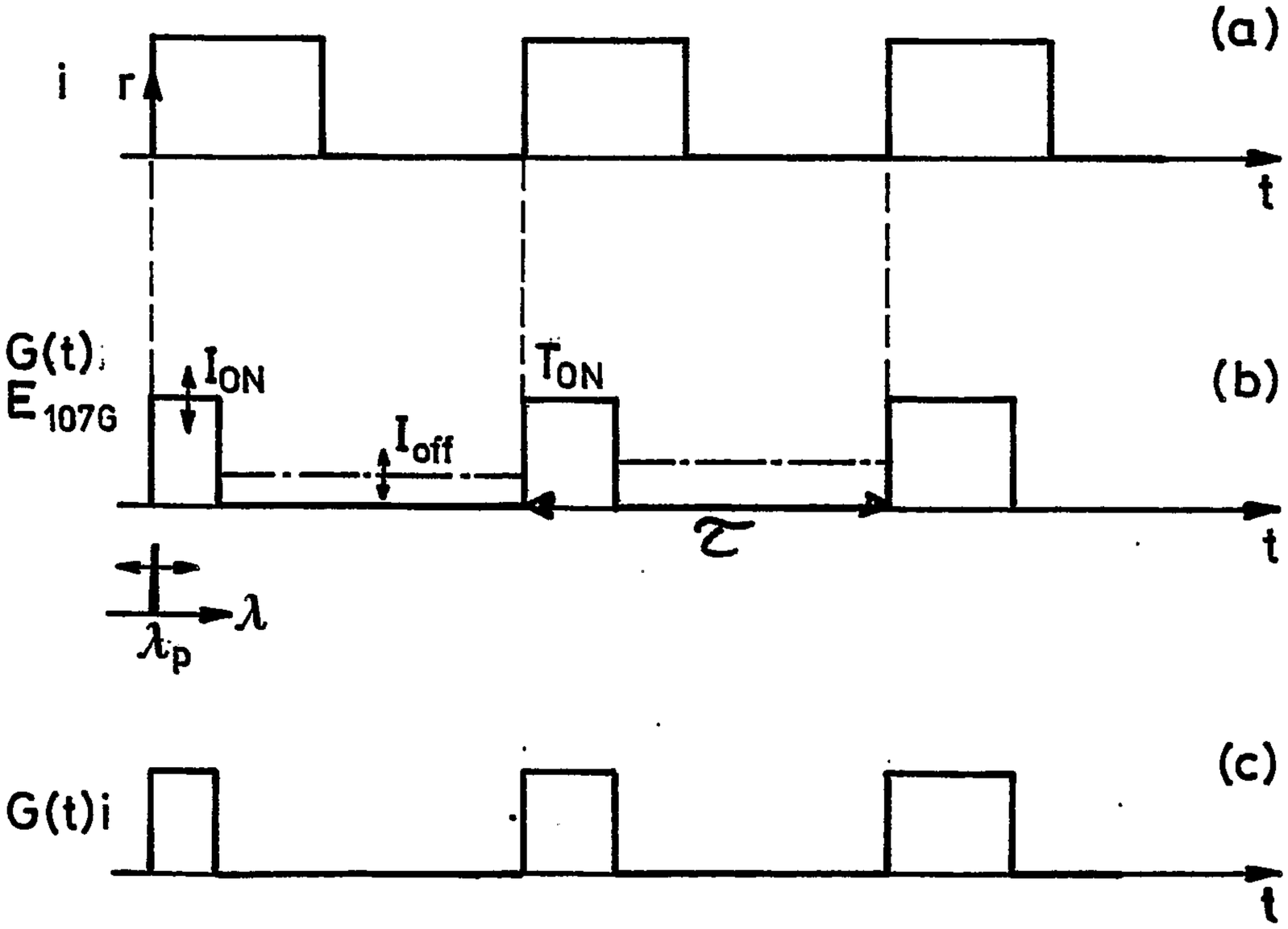

(a)
i
r
t
G(t);
E_{107G}
I_{ON}
T_{ON}
(b)
I_{off}
τ
t
λ
λ_p
(c)
G(t)i
t

FIG.14

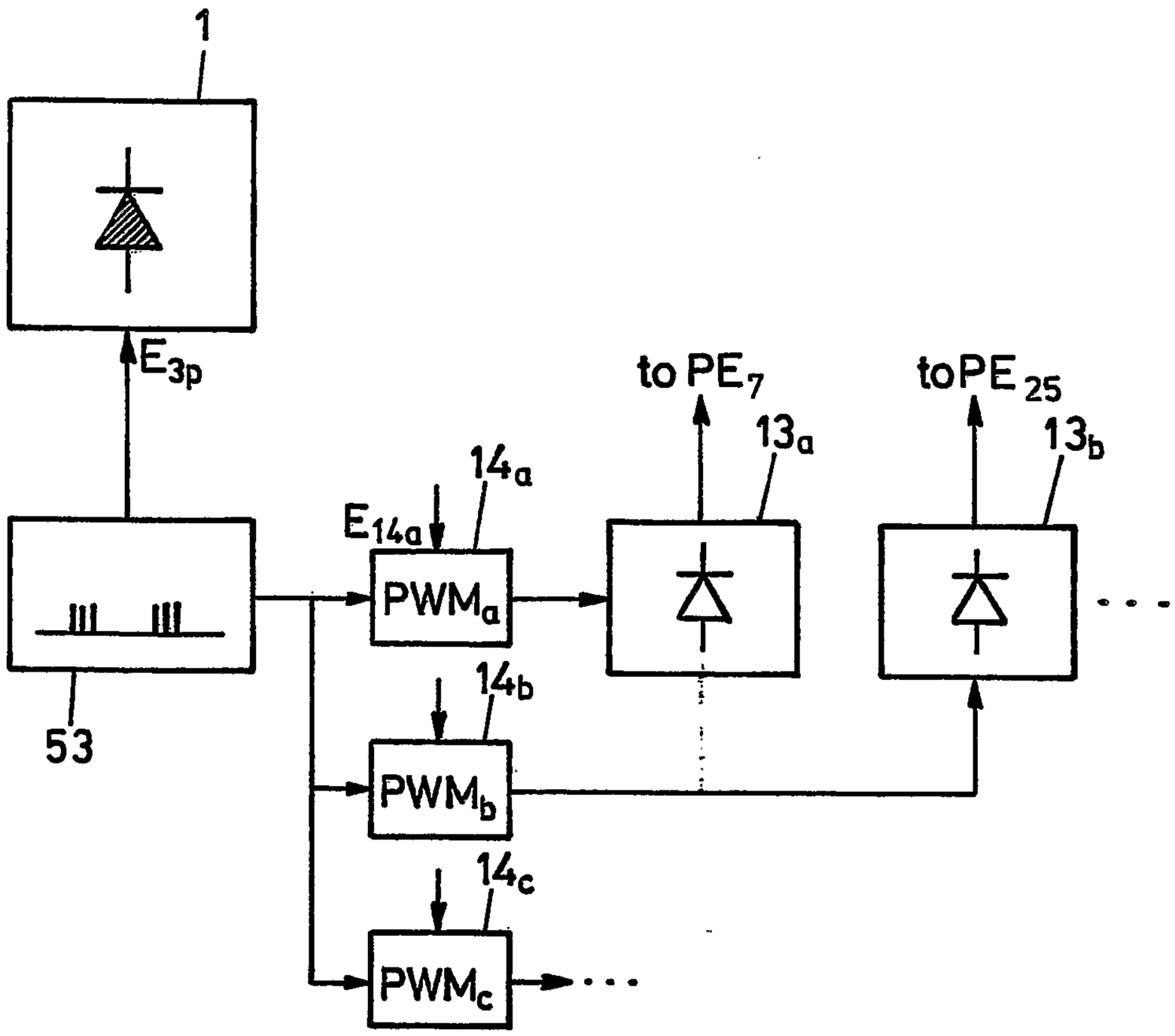

1
E_{3p}
53
E_{14a}
14_a
PWM_a
14_b
PWM_b
14_c
PWM_c
to PE_7
13_a
to PE_{25}
13_b

FIG.15

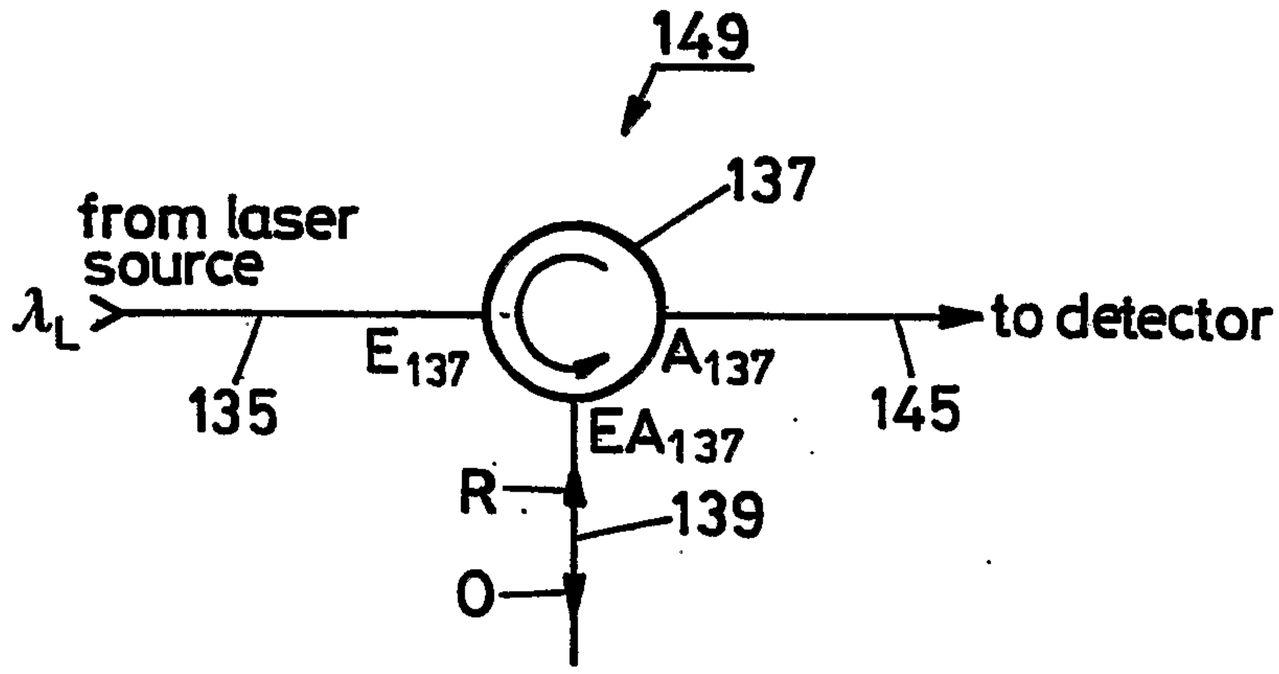
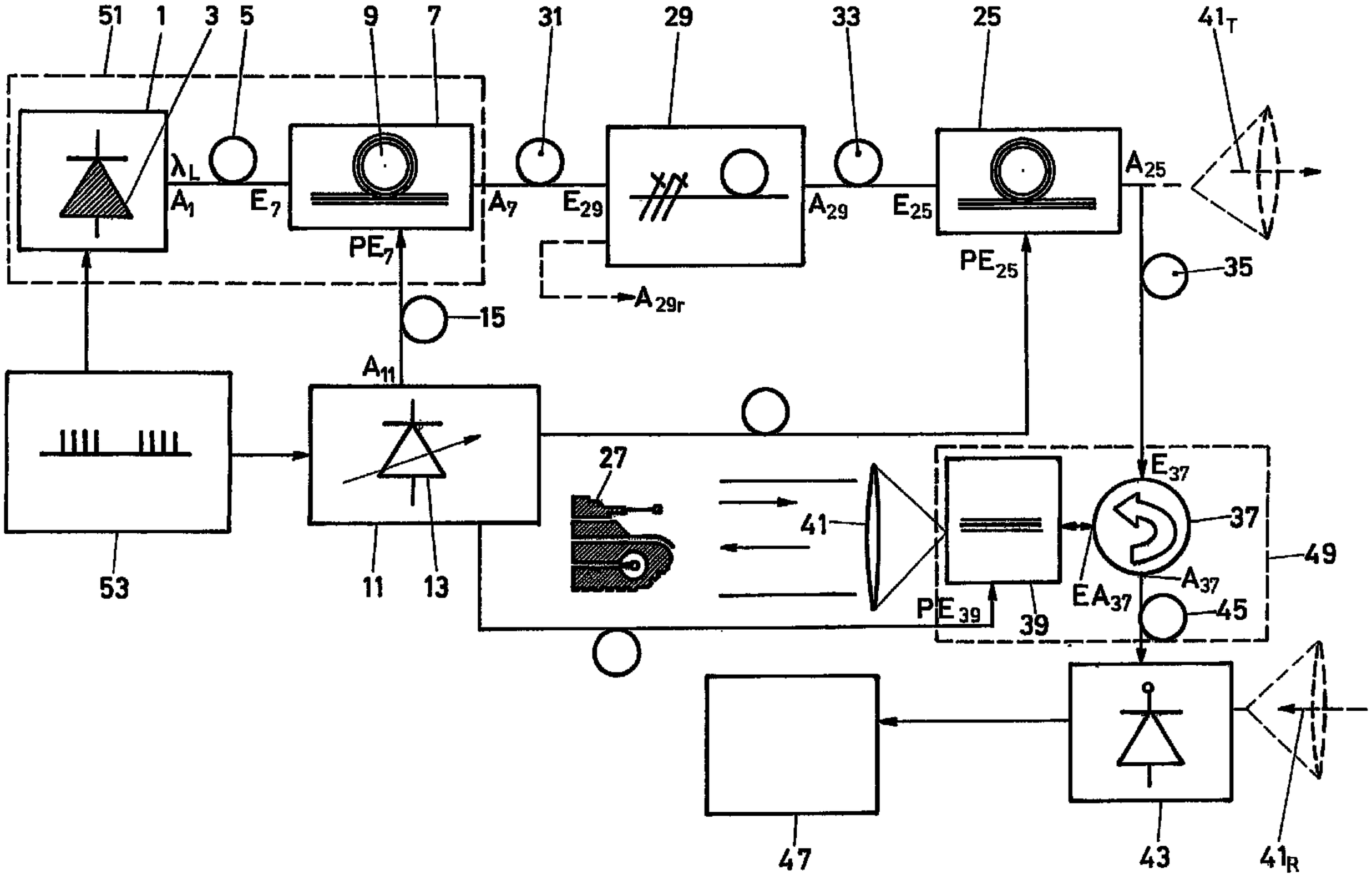

149
137
from laser source
λ_L
E_{137}
A_{137}
to detector
135
145
EA_{137}
R
139
O
to/from Objective

FIG.16


51
1
3
5
9
7
31
29
33
25
41T
λL
A1
E7
PE7
A7
E29
A29
E25
A25
A29r
PE25
35
15
A11
27
41
E37
37
49
A37
EA37
PE39
39
45
53
11
13
47
43
41R