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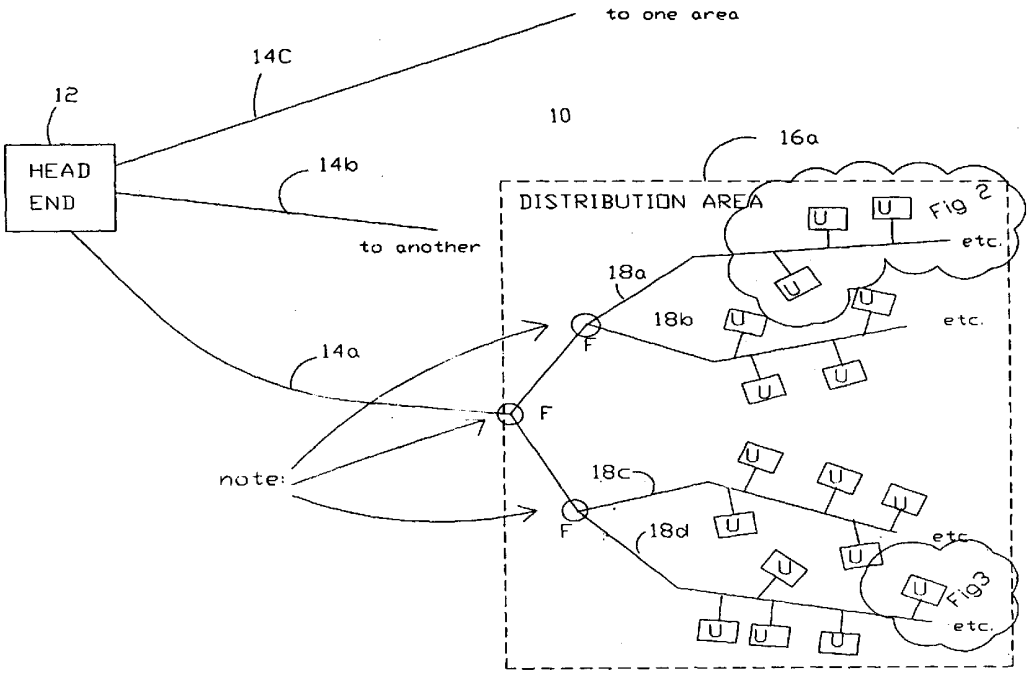
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(54) Title: LOCAL ACCESS FIBER OPTICS COMMUNICATION SYSTEM



(57) Abstract: A fiber optic network (10) having a head-end station (12) to send signals to individual users (U). The fiber optic branches (14) one or more times and at each branch (14) there is an optical frequency filter (24) which allows certain wavelength channels to travel along one branch (14) and other wavelength channels to travel along another branch (14). The branching continues until one final branch (14) carries one optical frequency channel to one individual user (U).

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Title

Local Access Fiber Optics Communication System

Field of the Invention

Fiber optic local access communication system, carrying both addressed and broadcast traffic.

Description of the Relevant Art.

Fiber optic systems currently in use do not carry signals all the way to the user premise. Copper systems do go to the user premise but usually devote one wire from the head end to each user and do not multiplex multiple signals onto one wire. Coax broadcast systems carry signals all the way to the user but carry all signals to each user. Some channels are encrypted lightly and the key to unscramble is made available to selected subscribers only. This facilitates pay-per-view but is often defeated by hackers. In any case present systems carry low bandwidth and do not usually deliver addressed multiple simultaneous signals through one "wire" to the user. By "wire" I mean copper wire, fiber, or coax cable.

Brief Summary of the Invention

The present invention comprises a fiber optic network and the method embodied in the network, the components of the network, e.g. an optical frequency filter, remote pumping of an amplifier and optical frequency shifter, the network having a fiber leading from a "head-end" station outward toward users and carrying signals to be delivered to those users. In one embodiment the fiber branches one or more times but at each branch there is an optical frequency filter which allows certain wavelength channels to travel along one branch and other wavelength channels to travel along another branch. The branching continues until one final twig carries one optical frequency channel to one individual user.

In another embodiment the branches, if any, do not have filters but simply divide the power, and finally the last segment which we call a "street line" taps off a small amount of power to each user. The tap is followed by a filter that allows only one channel to pass to the customer premise.

At the head end one optical frequency channel is allocated to each user. These channels are multiplexed onto one fiber leaving the head-end and are routed by means of filters so that the channel allocated to a certain user is delivered only to that user.

Therefore, scrambling is not necessary for privacy though it may be provided for additional security against eavesdroppers who may cut into one of the main fibers going along the street.

The optical frequency channel assigned to each user has a very large bandwidth compared to any single signal now used and is divided into sub-channels as needed by the user with each sub-channel carrying a separate signal.

Signal traffic from the user back to the head-end is carried, in one embodiment, back to the head-end through a filtered, branched network like the one just described. In this case the filters are not absolutely necessary but they conserve signal power at the branch points and they prevent one user from encroaching on the inbound channel of another user.

In another embodiment the same branched network which carries outbound traffic also carries in-bound traffic.

In either case an inbound signal obtains an un-modulated source line to be modulated by an electrical signal by either filtering out an un-modulated line sent by the head-end to the user and using that line or by generating the line with an on-premise laser tuned relative to the out-bound un-modulated line.

In the case where the in-bound traffic travels on the same networks as the outbound traffic the in-bound channel is displaced in optical frequency to lie beside the out-bound channel and the filters have a pass-band sufficient to pass both inbound and outbound.

In a preferred embodiment of the invention the sub-channels assigned to each user are accompanied by a heterodyne line. The signals go into a detector which produces electrical signals with beat frequencies corresponding to the optical frequency difference between each signal and the heterodyne line. The individual signals are then recovered by electrical filtering of the beat frequencies. This has the distinct advantage that the optical signals may be in analog form and the final detected electrical signal will be in a form suitable for the most common kinds of terminal equipment, such as telephones or television. However, other sub-channels can carry signals in digital format destined for computers or the like.

In a preferred embodiment of this invention, neodymium doped optical fiber amplifiers operating in the 1.06 micron wavelength window are used. They are preferably side pumped.

Other amplifiers may be used if they are so-called "4 level" laser amplifiers.

Amplifiers which require the ground state to be depleted go black when pump power fails. 4-level amplifiers remain transparent. It is also desirable to have large gain bandwidth and a fairly smooth gain curve which can be easily flattened by filtering.

Brief Description of the Drawings

Fig. 1 is an illustration of a fiber optic network distribution system embodying the invention;

Fig. 2 is an illustration of the line drops on a particular street.

Fig. 3 is an illustration of the optical connections and system of a typical end user.

Fig. 4 is an alternative embodiment of the invention wherein there are a small number of broadcast channels delivered to all customers leaving the channel selection to be done on premise.

Fig. 5 is an illustration of a multi-pass Fabry Perot interferometer;

Fig. 6 is an illustration of the head end handling source lines;

Fig. 7 is an illustration of the distribution of un-modulated source lines;

Fig. 8 is an illustration of illustration of sub-channels accompanied by heterodyne lines;

Fig. 9 is an illustration of exemplary frequencies using heterodyne detection;

Fig. 10 is further illustration of various frequencies using heterodyne detection;

Fig. 11 illustrates a frequency shifter;

Fig. 12 is a schematic of multiple detectors at the user end;

Fig. 13 illustrates one signal arrangement for using fiber optic line for both outgoing and incoming traffic.

Description of the Preferred Embodiment(s)

The invention will be described in reference to the following non-limiting example.

The total useful amplification width of Neodymium in the 1.06 micron window is about 10^{13} Hz. Assuming the network has 200 users (although a larger number is possible) the bandwidths can be spaced around 10^{10} Hz and each customer can be assigned a 1×10^{9} Hz bandwidth channel.

In one embodiment of the invention, broadcast channels are delivered to a user by the user selecting a desired channel from a bus at the head end by means similar to present day channel selection by a TV set. The selected channel (electrical signal) then

modulates an optical source line at the head end which is assigned to the user making the selection. This signal is then treated like any "addressed" signal destined for that user.

There are two advantages to putting the channel selection process at the head end. The first advantage occurs if there are a large number of channels on a bus or buses at the head end. For example, if there are 100,000 channels then it would require a large amount of signal power to deliver them all to all users. Whereas if there are 200 users on one common line then only 200 channels are delivered on that line except that some users will have 2 or 3 TV sets of course.

The second advantage is that the channel selection occurs beyond the customer's reach and can be programmed and controlled. For example, pay-per-view can be monitored and billed at the head end channel selector so the user cannot by-pass the billing – as is often the case now.

Also the user can appear in person at the head end and program the channel selector to reject certain types of programs, such as pornography or violence. If this self-censorship is attempted on the user premise then adolescent children are likely to be able to defeat the self-censorship.

In another embodiment of the invention, a small number of channels, for example 50 , can be delivered to all customers leaving the channels selection to be done on-premise. Since most users will probably be watching no more than 20 channels total this saves, to some extent, on the cost of channel selectors at the head end.

In this embodiment, a separate fiber carries all these "common" channels. In another embodiment, to save fiber, bypass filters carry theses broadcast channels (on optical sub-channels within a large channel). Around all filters so that this one broad channel is delivered to many users.

The head end channel embodiment and the "common channel" embodiment can be done together or separately. That is, a particular system, may embody either scheme or both.

Referring to Fig. 1, a system is shown generally at 10 and comprises a head end 12 and single fiber optic lines 14a, 14b, and 14c, each of which branches into a service area 16, only 16a shown. Four street lines 18a-18d are shown with the ultimate user or customer designated U.

Referring to Fig. 2, the line 18a is shown and comprises neodymium optical amplifiers as needed, a partial lateral couple 22 followed by a filter 24 located between the user and the street line.

The amplifier is gain flattened as needed. Gain flattening is well understood in the art.

Referring to Fig. 3, the bandwidth, e.g. $1x10^9$ Hz, for that selected user flows through the filter 24 and the signal is amplified by a neodymium optical amplifier 26 if needed. If the amplifier is used an additional filter 28 eliminates spontaneous amplifier emission. There is a partial couple at 30 and a detector at 32. In this example, there are three tunable electronic filters 34a-34c to select beat frequency between a heterodyne line and the channel to be used by the tuner 34. A return signal to the head end flows from the tap 30 to a filter 36 to pick off the heterodyne line. A modulator 38, puts the electric signal into optical form. This signal is coupled back into the incoming line.

An isolator 40 prevents incoming signals from traveling in the reverse direction.

Referring to Fig. 4, in an alternative embodiment of the invention, a system is shown wherein a broad-channel containing several broadcast sub-channels delivered to all customers, for example 50 channels. The channel selection for these is done on-premise. The filters 52 and the branching of a fiber optic line 54 function as described for the preferred embodiment. The filter F_n 56 allows the addressed channel to pass to the user which is then combined with broadcast channels C_o.

Obviously, the schemes of Figs. 1-3 and 4 may be used separately or in combination.

Amplifiers

Referring to Fig. 1, it is expected amplifiers will be needed every about 10 kilometers in the long stretch between the head end and the distribution area D. Referring to Fig.2, amplifiers are inserted as needed to boost signal power. A pump beam is preferably generated on the user premises by laser diode and carried up to the amplifier 20 on the fiber. Preferably, two or more such pump beams originating from different users are provided for each amplifier—so that no single pump failure can disable the amplifier. The laser diode on the customer premise is preferably powered by a rechargeable battery so that if the electric power system fails the amplifiers will continue to operate.

Users are assigned an optical frequency channel and traffic to the user is modulated onto the assigned channel at the head end and routed to the user by optical frequency filtering. To get good separation, the channel widths are made small compared

to the channel separation, e.g. $1X10^9$ Hz width with 10^{10} Hz separation.

Filters

A 2-arm fiber interferometer can be used for filtering and can be temperature stabilized by putting it in a constant temperature housing. Alternatively, a portion of the length of the shorter of the 2 arms can be put in a positive expansion device to compensate for temperature changes. Finally, after all the path splits, a different kind of filter 24 is used to drop to the users on the last branch.

These filters can be multi-layer dielectric filter which can separate channels 10^{11} Hz apart (at 1.06 micron wavelength). With a total spectral width of 10^{13} Hz, 100 channels can be separated.

Where there is closer spacing between channels on the street line, for example, when there is no filtering at the branch points and all channels are carried on each street line, we use a different filter between the street line and the customer premise. This filter is illustrated in Fig. 5 at 70.

This is a simple Fabry Perot interferometer with 2 parallel partial mirrors separated by a zero thermal expansion spacer. The mirrors are tilted enough so the reflected light does not go back into the input fiber.

For sharper filtering the filtered light goes back through the mirrors as illustrated in Fig. 5 at 71.

For even sharper filtering the output fiber can circle around and send the filtered light back in for two more passes through the filter. This can be continued for several more passes.

Head-End

Referring to Fig. 6, at the head end 10 a signal coming from the central system, is detected at 60, modulated at 62 and transferred to the main fiber 14 outbound which serves the intended user.

One main distribution fiber might serve 200 users. The exact number will depend on costs of various components. Referring to Fig. 7, a "bank" 64 is provided in the head end 10 with 200 unmodulated source lines (if there are 200 users per field line) and split so that each source line serves each of the field lines.

A wide channel, for example $1X10^9$ Hz is allocated to each user and is divided into optical frequency sub-channels as needed to carry a variety of signals.

In a preferred embodiment, these channels are de-multiplexed by the receiver using heterodyne detection, Fig. 8.

In the cleanest, simplest embodiment, the heterodyne line is spaced so that the lowest beat frequency is higher than the highest beat between sub-channels. This reduces interference between signals.

In order to carry out the heterodyne detection with multiple optical frequency sub-channels, it is necessary to have multiple unmodulated source lines, each going to a separate modulator and each modulator driven by a signal. This is possible, but a less expensive embodiment provides one unmodulated line (which is used as the heterodyne) and each signal electronically drives a RF (radio frequency) line. So the signals which drive the single modulator are:

$S_1(t)\sin w_1 t$

$S_2(t)\sin w_2 t$

$S_3(t)\sin w_3 t$

$S_4(t)\sin w_4 t$

etc.

Where the frequencies corresponding to w_1, w_2 start at, 10^9 Hz for example. For a video analog signal, the next f_2 is higher than f_1 by about 7×10^6 Hz, for example. Each signal produces 2 "side-bands", see Fig. 9.

One side band can be filtered out before putting the signals on the field line. The double or quadruple pass Fabry Perot shown in Fig. 5 would be suitable for this.

An optical frequency shifter can be used instead of simply modulating with the RF carriers. The "frequency shifter" is simply a single side band device as shown in Fig. 11.

One modulator drives "in quadrature" with the other and we adjust the phase between the two paths such that one side band exits A and the other B. This device is based on the trigonometric expression $\sin(w_1 + f)t = \sin w_1 t * \cos ft + \cos w_1 * \sin ft$. The optical phase adjustment is "semi-permanent" – not variable.

In all cases, the RF frequencies can come from an electronic bank of frequencies. At the user's end, the total batch of optical signals is detected and RF filters separate the signal channels in the electric domain after detection in much the same way that a channel selector chooses TV channels.

At the head end, there can be addressing logic to assign an incoming signal to one of the several RF carriers. For example, if the user has his fax machine permanently

tuned to receive channel f_5, then at the head end the logic will recognize that a certain incoming signal addressed to this user is a fax signal and will modulate it onto f_5. If the incoming signal is a voice phone signal, it will modulate it onto whatever RF channel the user has his phone tuned to. In one embodiment, the "tuning" can occur at the user end instead of the head end. In a more general embodiment, there is some tuning at head end and some at the user end.

For example, if there are 3 voice telephones on the user premises, they can be assigned to f_5, f_6, f_7. An incoming call can be addressed at the head end to any one of them that is not in use. At the receiver end, the next incoming voice call can be directed by local tuning to a certain one of the phones.

The incoming signals to the user can be detected and distributed in electric from to various pieces of terminal equipment or distributed optically and then detected at the terminal equipment. Both are shown in Fig. 12.

From User to Head-End

In one embodiment, the signals from the user to the head-end are carried on the same fiber that carries the out-bound traffic. In the simplest version sub-channels are assigned for return traffic, see Fig. 13.

One can filter out the heterodyne line and modulate it for the return traffic. In a preferred embodiment, a local laser is provided and is tuned to operate at the heterodyne optical frequency or is tuned at a fixed spacing from the heterodyne. Local signals are put on RF carriers just as they are at the head end and combined and modulated onto the local oscillator line. Again, care is taken to displace the unwanted side bands so they cause no confusion or to filter them out.

The return traffic passes backward through all the routing filters and arrives at the main fiber and is carried back to the head-end. There it passes through a filtered routing system very similar to the one described before—so that each user's inbound signals are directed to one point – where they are heterodyne detected and electronically separated to be used for transmission in the central communication system.

In the embodiment where traffic is carried in both directions on the same fiber it is prudent to space the channels so that no signal can act as a Brillouin pump for other signals.

The power level of the signals should be high enough so that quantum statistics doesn't produce perceptible noise. For a "virgin" pulse of photons in digital modulation

about 100 photons per bit is sufficient. That is to say 100 detected photons.

A convenient simple approximation of photon statistics after a virgin batch of photons has been amplified, attenuated, split, etc., is given by:

$$N_{effective} = \frac{1}{[1/N_0|+|1/N_0-1/N_1| + |1/N_1-1/N_2| + \text{etc.}]}$$ (the sign | --- | means absolute value.)

Where $N_{effective}$ is the number of "virgin" photons which would have the same spread as the processed batch.

When the signal is in analog form and the range of maximum signal to minimal detectable signal is about 1,000, it is necessary to carry 10,000 photons per "pixel" (and I'm using the term figuratively) to get a fairly noise free signal. The worst noise is obviously at the low end. If 10,000 represent level 1,000 then 10 photons represent the lowest level.

So there is a probability of about 50% that the number will be seen as 1.4 instead of 1.

If the signal is converted to logarithmic form so the number of photons transmitted is proportional to the $(\log)^2$ of the signal and then at the receive end the signal is converted back to its original form then about 900 photons is sufficient for the maximum signal "pixel".

What this transformation does is keep the noise level (in decibels) throughout the range from 1 to 1,000. And at 900 photons for the 1,000 level, the noise is such that there is about a 50 % chance of being off by 2 dB - - throughout the whole range.

Converting to the log form will depend on whether the network complexity drives the power level too high—either in terms of cost or non-linear effects.

There is one other problem that must be considered in the design of the distribution system and that is "amplifier noise". There is a fundamental equation regarding optical amplifiers:

$N_{out} = (N_{in} + 1)*\text{gain} - 1$

Where N_{in} is the number of photons per Hertz (Hz) per second entering the amplifier and N_{out} is the same exiting the amplifier. Actually the equation is for one polarization state. If there is no incoming signal then the number exiting is:

N_{out} = (1*Gain - 1) times 2 to account for both polarizations.

If the gain were 10 (linear not decibels) and were flat over 10^{13} Hz , then N_{out} would be 18 x 10^{13} photons per second. As an approximation the actual gain curve of

Neodymium would give about 10^{14} photons per second.

If a 10dB amplifier were placed just before detection you would get those photons going into the detector. So the signal to be detected must be large compared to this noise. At 1.06 micron wavelength there are about 3 x 10^{15} photons per second per milliwatt—so the signal needs to be of order 10 milliwatts exiting the 10dB amplifier or 1 milliwatt entering. The point of all this discussion is that, in the practice of this invention the system should be designed so that either the signal is large compared to the amplifier noise or there must be some optical filtering after the last amplifier to reduce the noise.

To some extent heterodyne detection is a form of filtering and is helpful. When more filtering is needed just before detection perhaps the most economical filter is a planar dielectric milt-layer filter. These can be made at a reasonable expense to pass about 10^{11} Hz and reject the rest of the optical spectrum of the amplifier at 1.06 microns.

The foregoing description has been limited to a specific embodiment of the invention. It will be apparent, however, that variations and modifications can be made to the invention, with the attainment of some or all of the advantages of the invention. Therefore, it is the object of the appended claims to cover all such variations and modifications as come within the true spirit and scope of the invention.

Having described my invention what I now claim is:

1. An optical communications signal distribution network which is subscribed to by a plurality of users which system comprises:

means to transmit a separate and distinct optical frequency channel to each user on a branched optical fiber having a final branch going to each user.

means to optically filter the network to insure that each user has access only to the channel assigned to him; and

at least one optical amplifier in the network to maintain the power at levels high enough that photon quantum noise does not degrade the signal.

2. The system of claim 1 wherein the optical amplifiers are neodymium doped fiber amplifiers operating in a 1.06 micron gain window.

3. The system of claim 1 wherein the amplifiers are neodymium doped fiber amplifiers operating in a range between 1.35 to 1.45 microns.

4. The system of claim 1 wherein the frequency bandwidth of the channel allocated to each user is greater than 10^7 Hz and each dedicated channel is subdivided into sub-channels, each adapted to carry a separate signal.

5. The system of claim 4 wherein the signals are in digital form.

6. The system of claim 4 wherein the signals are in analog form.

7. The system of claim 4 wherein some of the signals in separate sub-channels are in digital form and some in analog form.

8. The system of claim 1 which comprises at the users end:

means for optical frequency filtering between a last amplifier and a detector sufficient to keep down the level of spontaneous photons so that they do not interfere unduly with the detection of the signal(s).

9. The system of claim 1 which comprises:

means to provide an unmodulated heterodyne spectral line in each dedicated channel, which line after detection produces electronic signals with a beat frequency corresponding to the difference in optical frequency between the heterodyne line and

each signal sub-channel.

10. The system of claim 9 which comprises:
means to separate the electronic signals by electronic filtering.

11. The system of claim 1 in which the distal branches of the network terminate in the premise of the user.

12. The system of claim 11 which comprises:
several individual stations within the user premise.

13. The system of claim 1 which comprises:
means to deliver signals from at least one user to the head-end with the outbound network carrying these signals to the head-end.

14. The system of claim 13 which comprises:
means to filter the signals from the user to the head-end to prevent the user from sending any signals outside the frequency bandwidth dedicated to the user for return signals.

15. The system of claim 14 which comprises:
optical amplifiers to raise the signal power as needed from the user to the head-end.

16. The system of claim 15 in which the amplifiers are neodymium doped fiber amplifiers.

17. The system of claim 13 in which the fiber optic network carries both the signals transmitted from the head-end to the user and the signals from the user to the head-end.

18. The system of claim 14 in which at least one user has a fiber optic laser tuned relative to the heterodyne line provided to that user within his dedicated channel and that user has means to modulate the tuned laser output to generate signals to send back to the head-end.

19. The system of claim 13 in which at least one user has means to filter out the heterodyne line and means to modulate and amplify the heterodyne line to send signals back to

the head-end.

20. The system of claim 9 which comprises:

means to separate the heterodyne line by frequency from the nearest signal channel by an amount greater than the frequency spread between the two extreme signal sub-channels.

21. The system of claim 1 in which the effective photon count is greater than 50 but less than 500 photons per second per Hz of signal bandwidth.

22. The system of claim 1 in which the effective photon count for digital signals is at least 50 photons per bit but less than 500 photons per bit.

23. The system of claim 1 in which means are provided at the head-end select one or more broadcast channels into the optical frequency channel dedicated to the user.

24. The system of claim 1 in which a small group of common broadcast channels is modulated into one common optical frequency channel which by – passes all filters and is delivered to several or to all subscribers.

25. An optical frequency shifter comprising a power splitting tap followed by a modulator on each arm after the split, one modulator driven by sin wt and the other by coswt where w is the amount of the shift, followed by a combining tap with phase adjustment of the optical path length of the two arms so as to route a single side band of the modulation into one leg after the combining tap.

26. An optical frequency filter comprising means for directing a collimated beam of light against a planar Fabry Perot consisting of two mirrors parallel to each other, both being highly reflective but slightly transparent followed by a highly reflective mirror slightly tilted relative to the two mirrors such that the spectral region of the incoming beam which passes through the Fabry Perot filter is reflected back through the Fabry Perot and is filtered again , the twice filtered light traveling – at a slight angle compared to the incoming beam and therefore collectable by a lens into an output aperture.

27. A filter of claim 26 where the twice filtered beam is collected in a fiber and said fiber is curved around and brought back and its output collimated and sent through the assembly

again so that its final output has been filtered 4 times.

28. A fiber optic amplifier on a transmission line pumped by a pump line generated remotely more than 100 feet away and carried to the amplifier in an optical fiber.

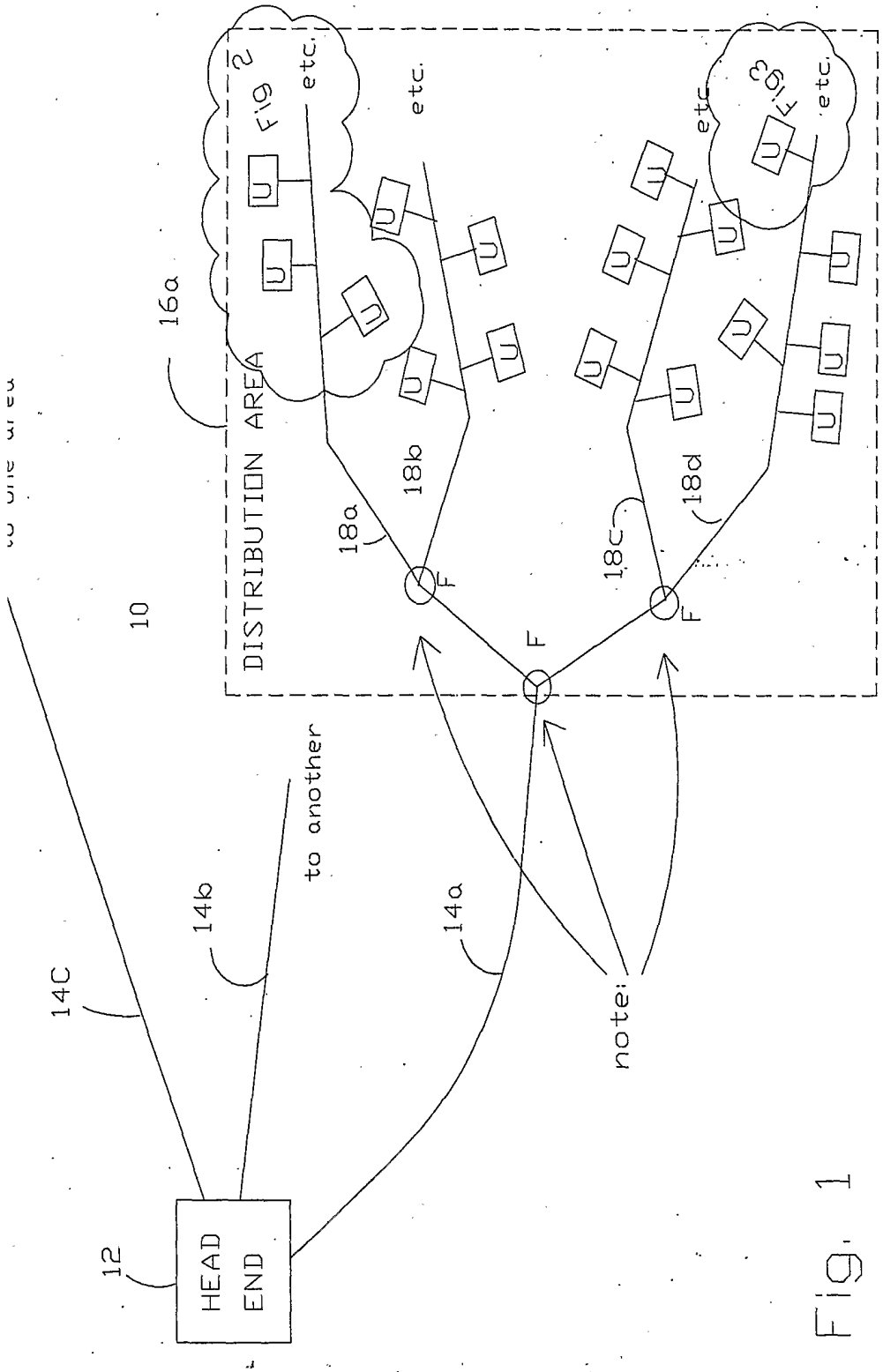

HEAD END
12
14C
14b
14a
to another
10
16a
DISTRICTION AREA
18a
18b
18c
18d
F
F
F
U
etc.
etc.
etc.
etc.
note:

Fig. 1

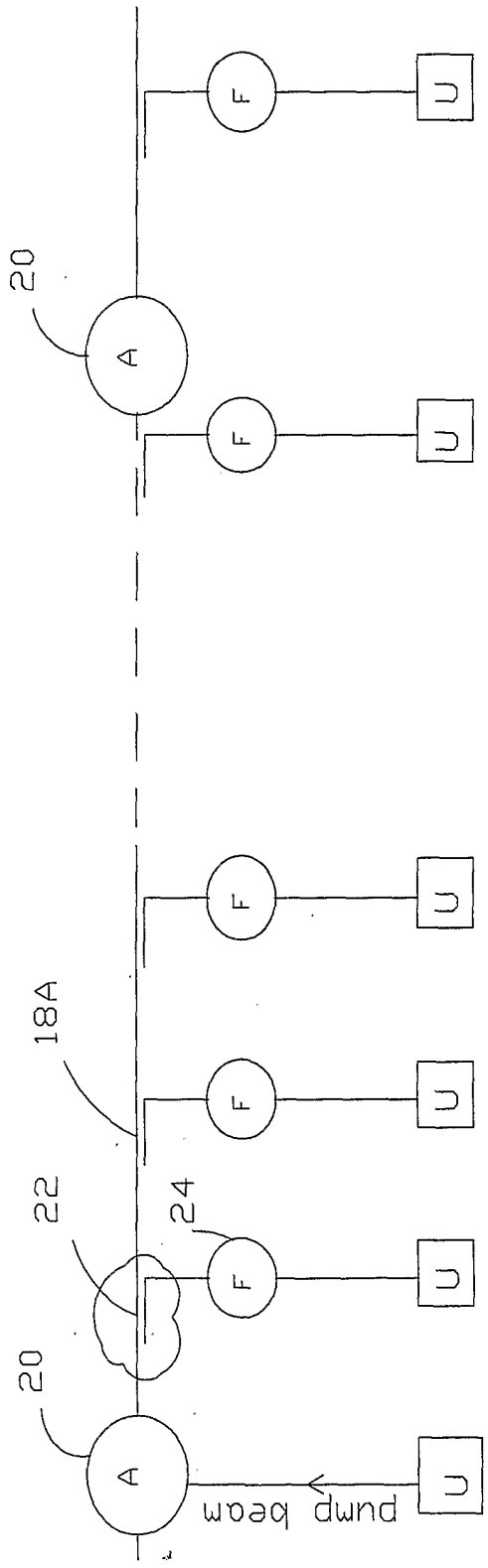


Fig. 2

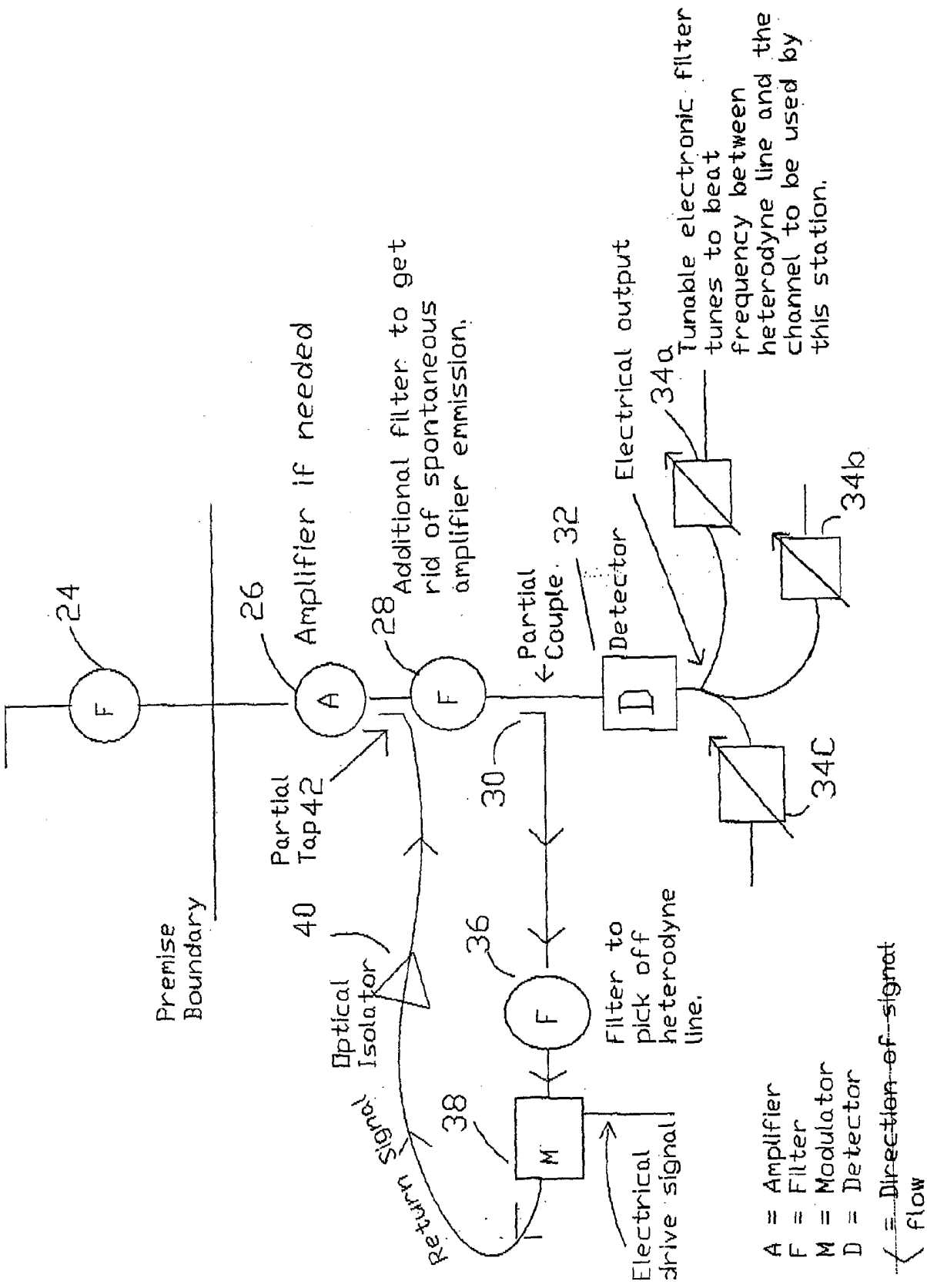

24
F
26
A
Amplifier if needed
28
F
Additional filter to get rid of spontaneous amplifier emission.
Partial Couple
32
D
Detector
Electrical output
34a
Tunable electronic filter tunes to beat frequency between heterodyne line and the channel to be used by this station.
34b
34c
Premise Boundary
Partial Tap
42
40
Optical Isolator
Return signal
30
36
F
Filter to pick off heterodyne line.
38
M
Electrical drive signal
A = Amplifier
F = Filter
M = Modulator
D = Detector
= Direction of signal flow

Fig. 3

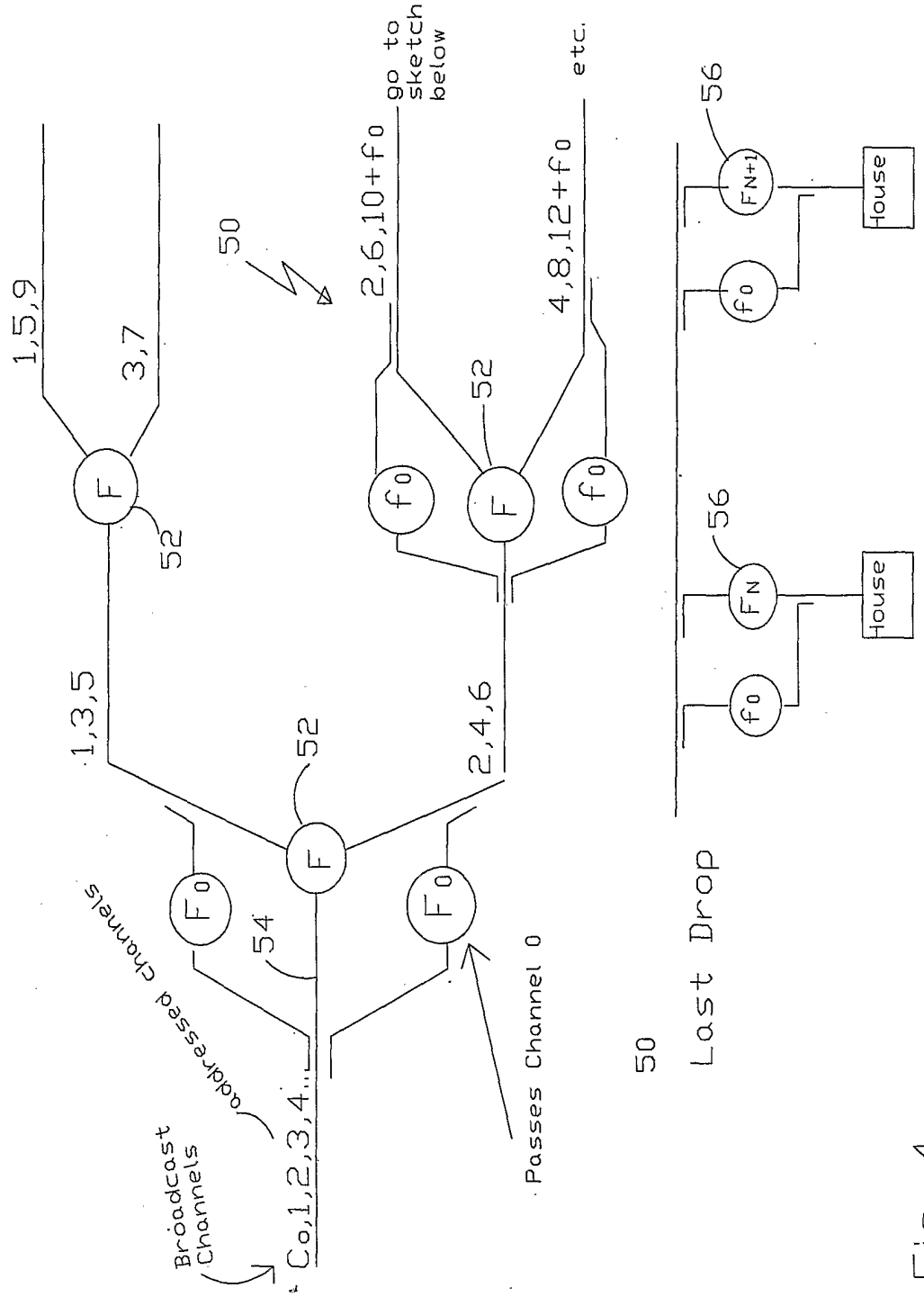

Broadcast Channels
Co,1,2,3,4...
addressed channels
54
F0
F
52
1,3,5
2,4,6
1,5,9
3,7
50
2,6,10+f0
go to sketch below
4,8,12+f0
etc.
Passes Channel 0
Last Drop
56
FN
FN+1
House

Fig 4

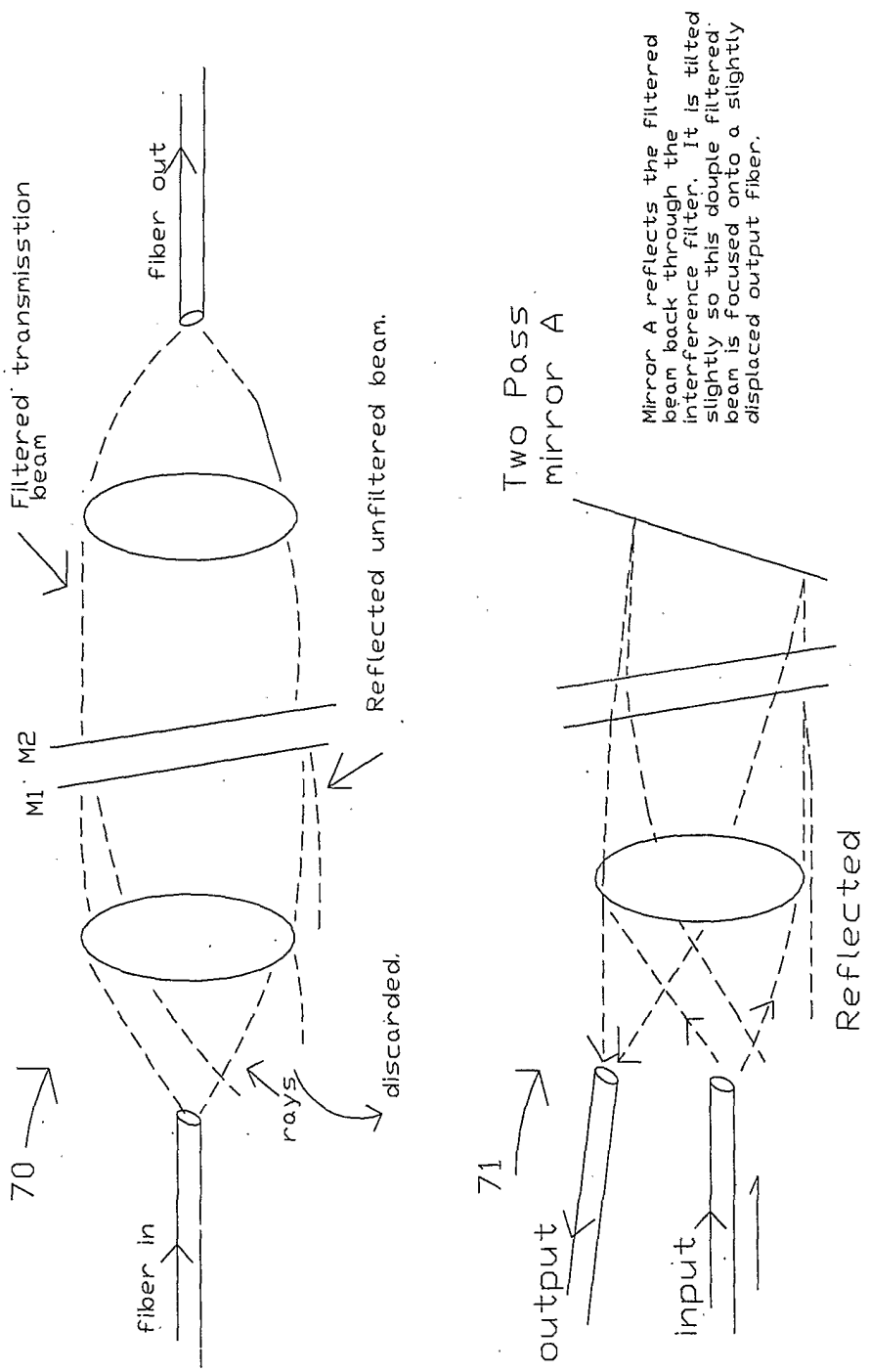

Filtered transmission beam
fiber out
M1
M2
Reflected unfiltered beam.
70
rays
discarded.
fiber in
Two Pass mirror A
Mirror A reflects the filtered beam back through the interference filter. It is tilted slightly so this double filtered beam is focused onto a slightly displaced output fiber.
71
output
input
Reflected

Fig 5

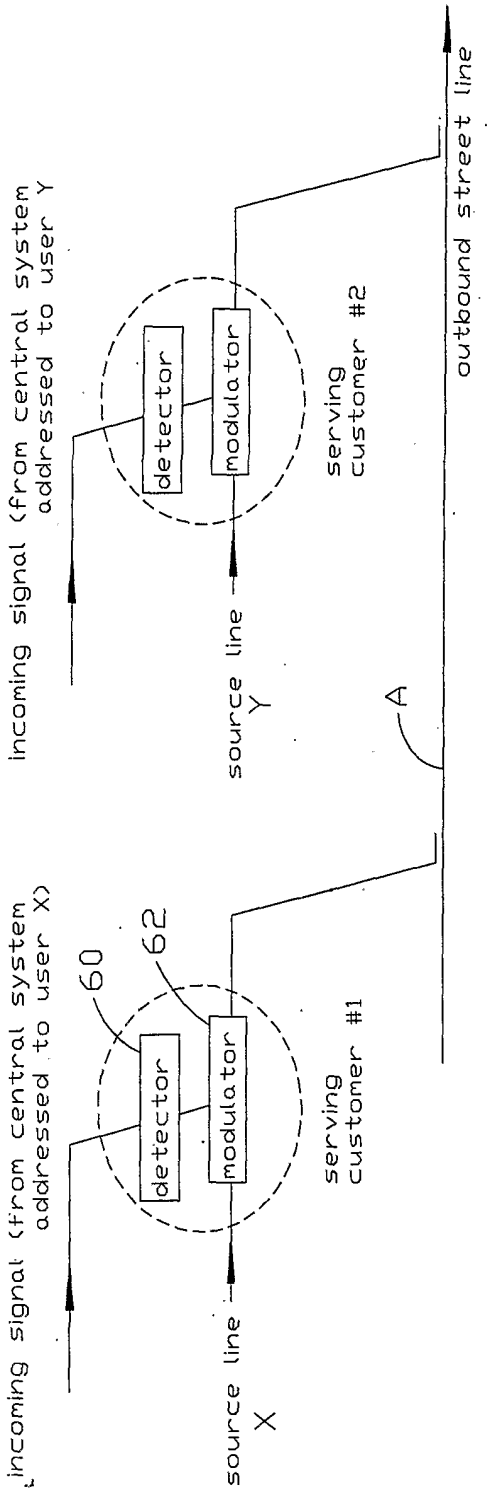

incoming signal (from central system addressed to user X)
incoming signal (from central system addressed to user Y
60
62
detector
modulator
source line X
source line Y
serving customer #1
serving customer #2
A
outbound street line

Fig. 6

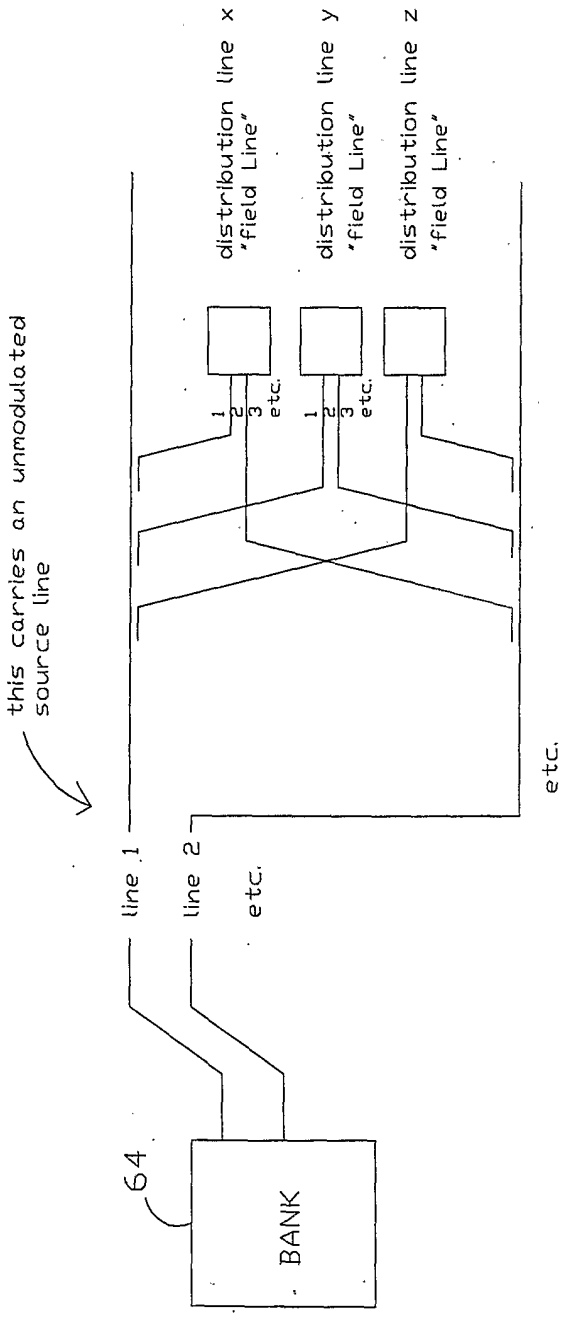

this carries an unmodulated source line
line 1
line 2
etc.
64
BANK
distribution line x "field Line"
distribution line y "field Line"
distribution line z "field Line"
1
2
3
etc.
1
2
3
etc.
etc.

Fig 7

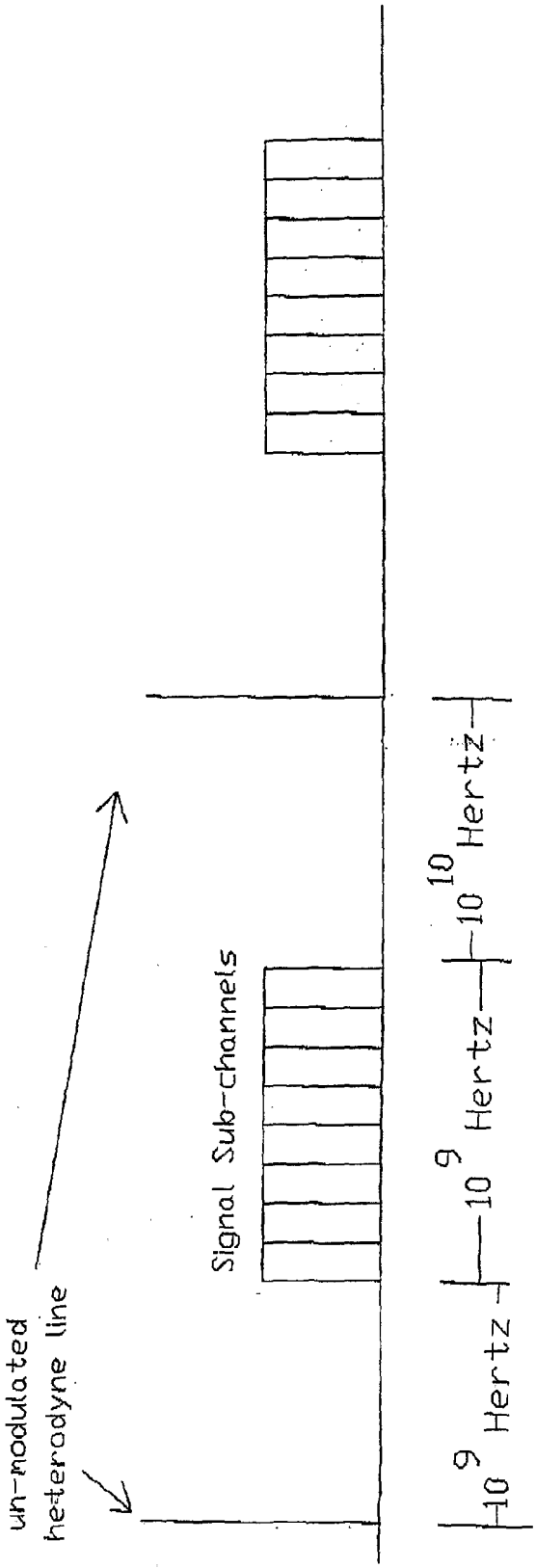

un-modulated
heterodyne line
Signal Sub-channels
10^9 Hertz
10^9 Hertz
10^{10} Hertz

Fig. 8

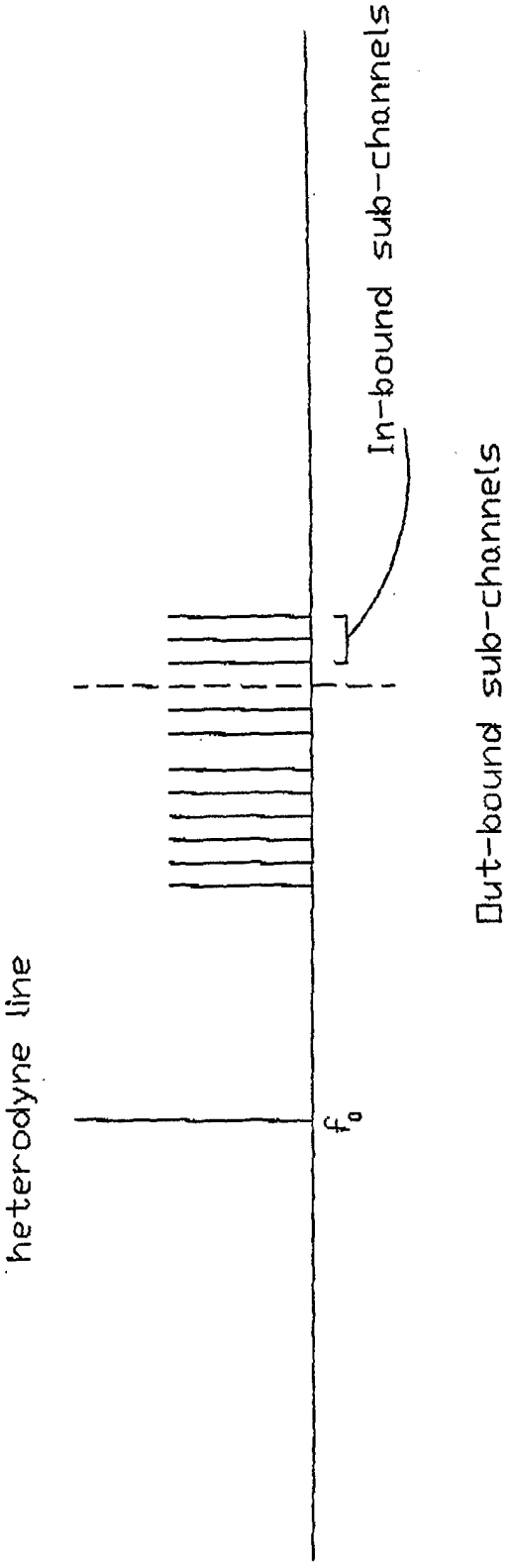

In-bound sub-channels
Out-bound sub-channels
heterodyne line
f_0

Fig 9

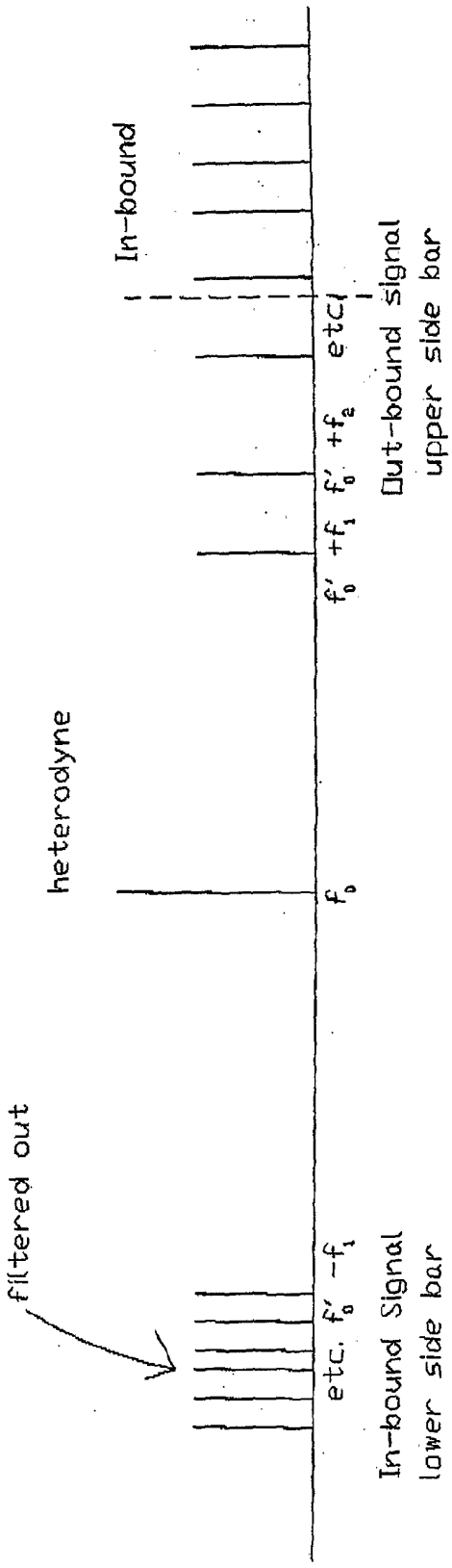

In-bound
heterodyne
filtered out
f_0
$f_0' + f_1$
$f_0' + f_2$
etc
etc. $f_0' - f_1$
In-bound Signal
lower side bar
Out-bound signal
upper side bar

Fig. 10

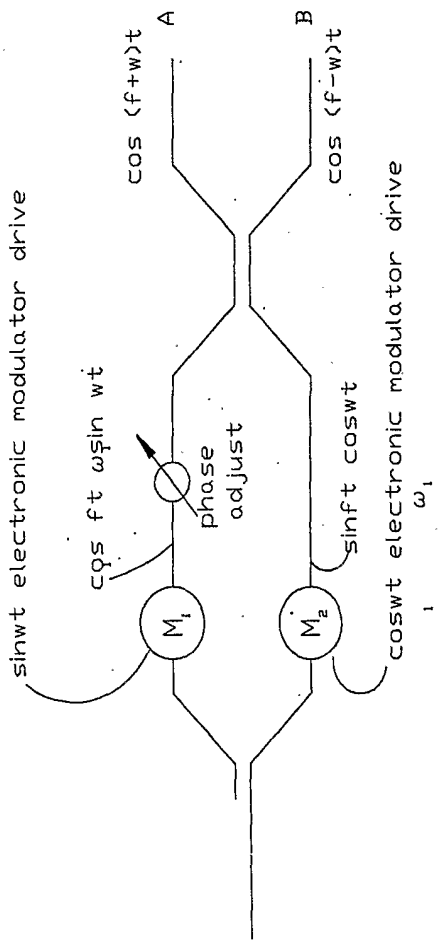
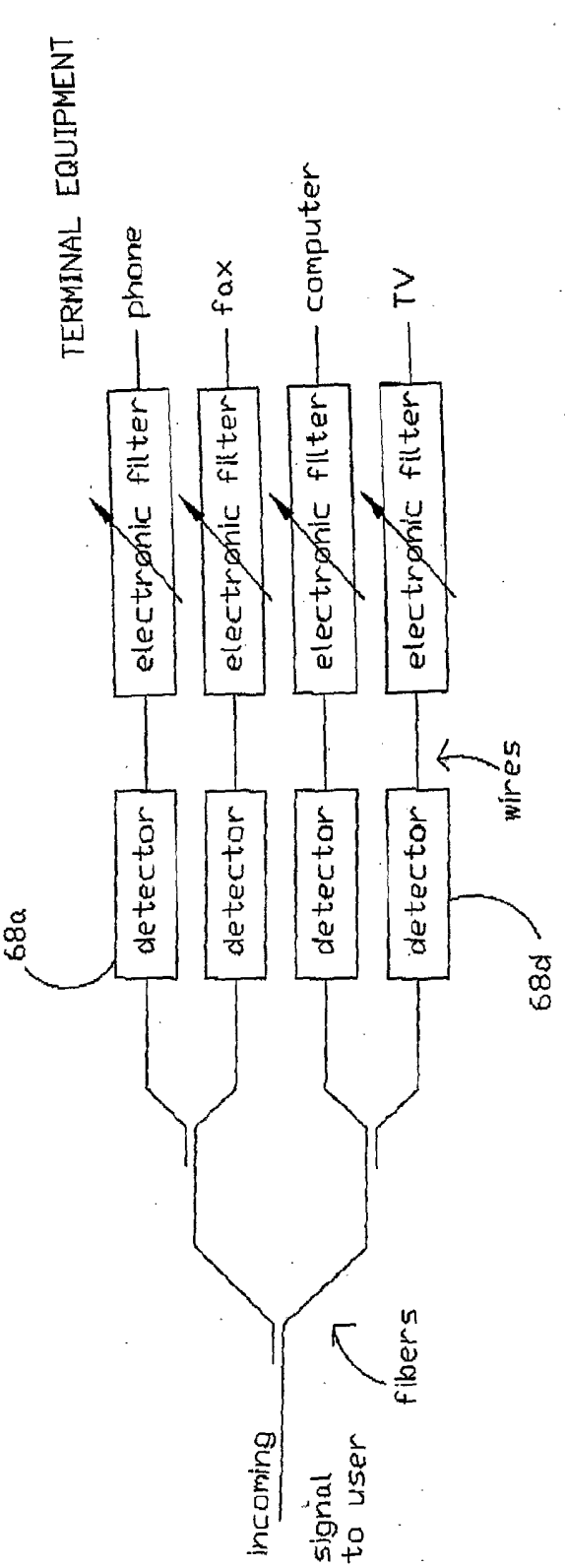

sinwt electronic modulator drive
cos ft ωsin wt
phase adjust
cos (f+w)t
A
B
cos (f-w)t
sinft coswt
coswt electronic modulator drive
ω1
M1
M2

Fig. 11


TERMINAL EQUIPMENT
phone
fax
computer
TV
electronic filter
detector
68a
68d
wires
fibers
incoming
signal to user

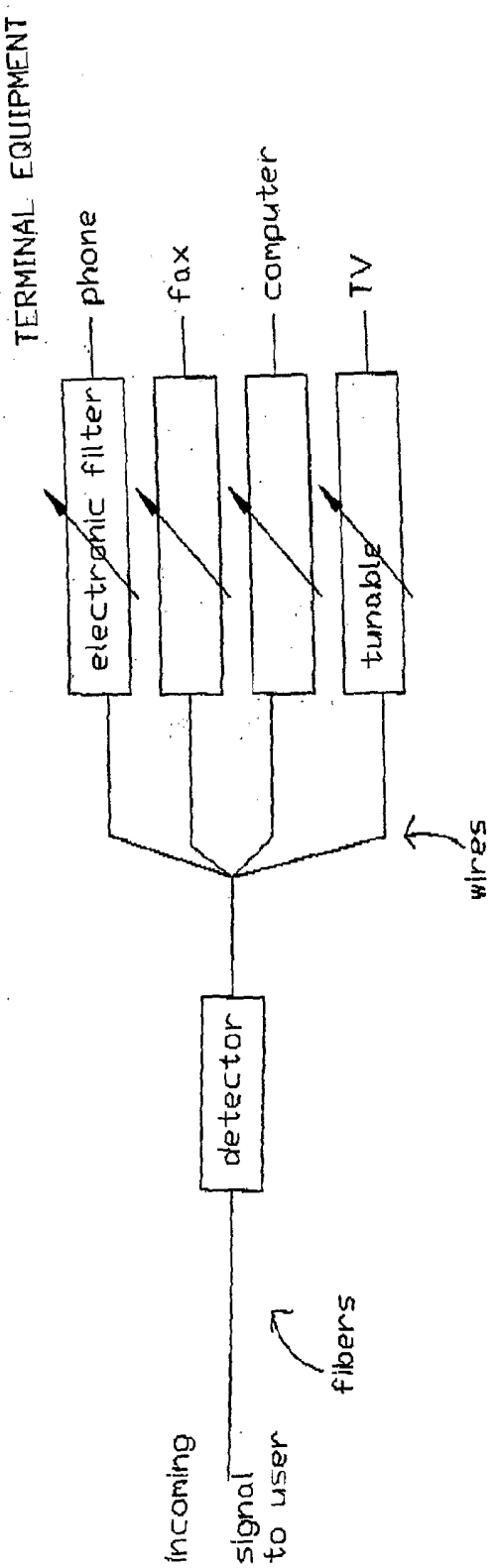

TERMINAL EQUIPMENT
phone
fax
computer
TV
electronic filter
tunable
detector
wires
fibers
incoming
signal to user

Fig. 12

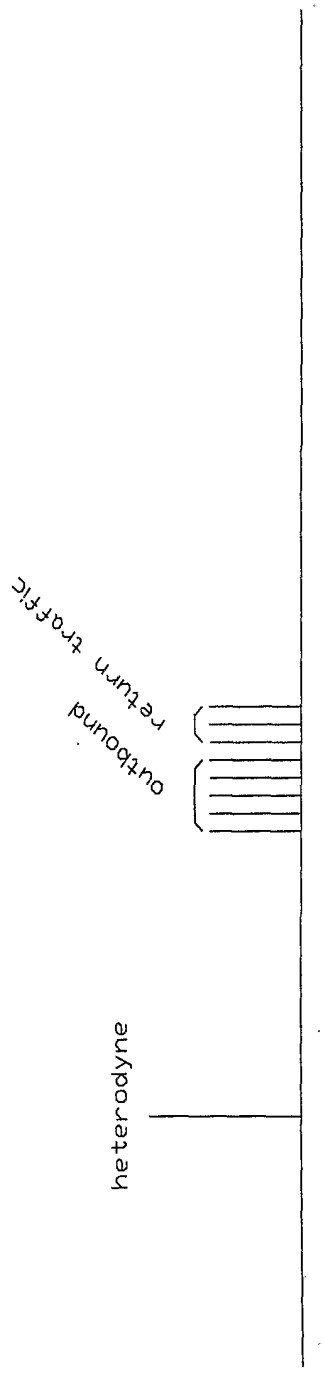


Fig. #3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/23485

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H04J 14/02
US CL : 359/125, 130, 131, 133

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 359/115, 124, 125, 130, 131, 133, 137

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,956,166 A (OGATA et al) 21 September 1999 (21.09.1999), col. 2, lines 3-41, Fig. 1.	1-24
Y	US 5,596,436 A (SARGIS et al) 21 January 1997 (21.01.1997), col. 1-50, Fig. 1.	1-24
Y	US 4,726,644 A (MATHIS) 23 February 1988 (23.02.1988), col. 2, lines 17-37, Fig. 1.	1-24
Y	US 5,835,199 A (PHILLIPS et al) 10 November 1998 (10.11.1998), col. 3, lines 13-67, col. 4, lines 1-21, Figs. 2-4.	25-27
A	US 5,896,211 A (WATANABE) 20 April 1999 (20.04.1999), col. 13, lines 61-67, col. 14, lines 1-34.	25-27

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 October 2001 (11.10.2001)	11 JAN 2002
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Jason Chan Telephone No. 703-305-4700

Form PCT/ISA/210 (second sheet) (July 1998)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US01/23485

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be examined, the appropriate additional examination fees must be paid.

Group I, claim(s) 1-24, drawn to an optical communications signal distribution network.

Group II, claim(s) 25, drawn to a frequency shifter.

Group III, claim(s) 26-27, drawn to a frequency filter.

Group IV, claim(s) 28, drawn to an optical amplifier.

Continuation of B. FIELDS SEARCHED Item 3:

EAST

search terms: wdm, filter, amplifier, frequency shifter.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/23485

Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
Please See Continuation Sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.: 1-27

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.