WDM/FDM STAR COUPLER WITH GAIN USING FIBRE AMPLIFIERS

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Indexing terms: Optical couplers, Optical amplifiers, Optical communication, Lasers

An efficient amplified WDM/FDM star coupler is proposed. The size of the coupler can be increased by a factor of m using m fibre amplifiers. Furthermore, the complexity and cost of the proposed scheme are less than those of other configurations.

Introduction: Large $N \times N$ fibre-optic star couplers can be quite useful for high-throughput multiple-access WDM networks [1]. However, its inherent $1/N$ splitting loss may limit the ultimate size of the star coupler. Potential use of erbium-doped fibre (EDF) amplifiers to increase the number of users that a fibre-optic star network can support has been investigated by many researchers [2–4]. Both configurations in References 2 and 3 have the disadvantage that each receiver would require its own EDF amplifier, which can be quite expensive. The main advantage of the configuration in Reference 4 is a lower number of required EDF amplifiers and pump lasers than that of References 2 and 3. However, more components such as m different wavelength-dedicated bandpass filters (BPFs) and bandstop filters (BSFs) are necessary to control the operation of the $m(N-1) \times m(N-1)$ star coupler in Reference 4, and special requirements of m EDF amplifiers with high output saturation power level are necessary to overcome the problem of multiple communication links between different nodes of the network. In this Letter, we propose a novel technique to overcome these aforementioned problems.

Configuration and characteristics: A new configuration for the proposed $mN \times mN$ star coupler is shown in Fig. 1. It is composed of $mN \times 1$ singlemode WDM multiplexers, one $(m+1) \times (m+1)$ passive star coupler, m EDF amplifiers pumped with a single pump laser, and $m1 \times N$ tree couplers. In fully transparent WDM/FDM star networks, each user is transmitting its information on a fixed unique wavelength.

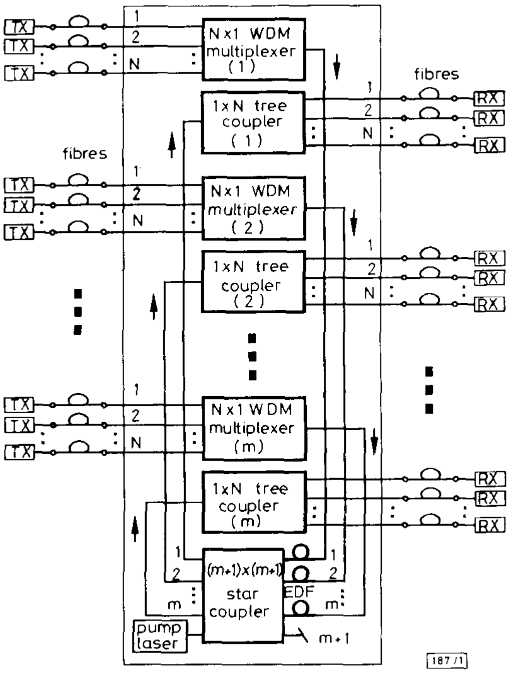

Fig. 1 *Proposed mN × mN WDM/FDM star coupler*

Therefore, for the mN users supported by this network, mN wavelengths and m different multiplexers are needed. For each multiplexer, N users are directly connected via fibre links to its N input ports and its output port is connected to an EDF whose output is connected to one of the input ports of the $(m+1) \times (m+1)$ coupler; each output port of the $(m+1) \times (m+1)$ coupler is connected to a $1 \times N$ tree coupler. The remaining output port of the $(m+1) \times (m+1)$ passive coupler is used to couple the pump laser light and distribute it equally among the EDF amplifier using a backward pumping scheme.

If mN users are distributed uniformly around a circle of diameter D over mN locations, then the number of standard fibres required to interconnect these mN users is $2 . m . N$. A total fibre length of $m . N . D$ and total conduit length of $m . N . D/2$ are needed to implement this star network. The link attenuation, L_T [dB], between any two users in this centralised star network shown in Fig. 1 is

$$L_T = 10 \log (L_{MUX}) + 10 \log [(m+1) . N] + 10 \log (L_{mN}) + 10 \log (\alpha_f D) \tag{1}$$

where L_{MUX} is the insertion loss of each WDM multiplexer, L_{mN} is the total excess loss of the $(m+1) \times (m+1)$ coupler and $1 \times N$ tree coupler, and α_f is the fibre loss per unit length. Although L_T is $\sim 10 \log (L_{MUX})$ [dB] larger than that of the configuration in Reference 4, these WDM multiplexers employ a diffraction grating design and can achieve channel spacing of the order of 1–2 nm such that they can accommodate 40–50 channels with an excess loss of ~ 7 dB per channel [5].

The EDF amplifier with its wide gain profile is suitable for WDM/FDM systems due to its comparatively long gain recovery time, which makes the EDF amplifier immune to the intersymbol interference crosstalk effects over a wide range of bit rates [6]. In the broadcast operation mode, assume the signal gain of each EDF amplifier is the same, then the net gain from one user to another is $10 \log (G) - L_T$ [dB], which is the same for all users. Therefore, the problem of variations of received signals due to multiple communication links between different nodes in Reference 4 is alleviated without using m different BPFs and BSFs. Besides the saving of these wavelength-dedicated BPFs and BSFs, it is found that the number of supportable users by the network of this proposed coupler is m larger than that of the other proposed $m(N-1) \times m(N-1)$ star coupler in Reference 4.

Distributed configuration: In many practical networks, users are geographically distributed in many clusters. Hence, it is better to distribute the components of the centralised star coupler over several nodes to reduce the total fibre length and conduit length as compared with the centralised star network [7, 8]. The proposed configuration in Fig. 1 can easily be modified to form a distributed configuration as shown in Fig.

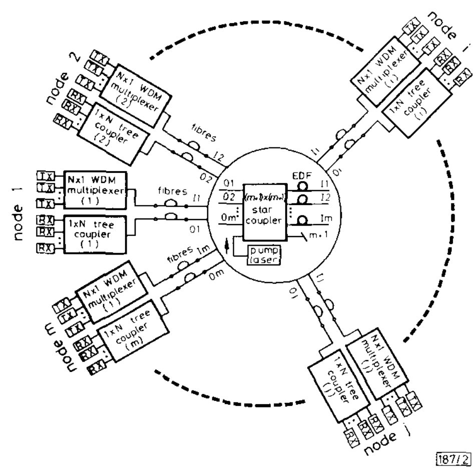

Fig. 2 *Distributed mN × mN WDM/FDM star coupler*

2. Except for the physical separation between its components, this distributed coupler is itself a star network and is identical to the original centralised network and therefore will exhibit the same performance. In general, if mN users are distributed uniformly around a circle of diameter D over m nodes, then the total fibre length and conduit length are mD and $mD/2$, respectively, which are $1/N$ and $1/N$ of those required for the centralised case. Hence, the total fibre length and conduit length required for the distributed star network can be reduced greatly; this further increases the cost effectiveness significantly.

Conclusions: We have proposed a new technique, by which the size of a star coupler in WDM/FDM star networks can be increased m times by using m fibre amplifiers. The complexity and cost of the proposed scheme are so far over than those of other configurations. Furthermore, the required total fibre length and conduit length can be greatly reduced for the distributed configuration, thereby significantly increasing cost effectiveness.

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R-MOSFET STRUCTURE BASED ON CURRENT DIVISION

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Indexing terms: Integrated circuits, Filters, MOSFETs

A parallel-path combination of resistors and MOSFETs is proposed for use in integrated continuous-time filters and other circuits. The technique allows continuous incremental tuning while maintaining significantly better linearity than MOSFET-only structures.

Introduction: High-linearity integrated continuous-time filters employ linear resistors and capacitors. To compensate for tolerances and environmental changes, switchable element arrays are used [1, 2]. The resulting quantised tuning imposes a limit on tuning accuracy (e.g. to ±5%) and can cause disturbances in the output during tuning. If MOSFETs are used in lieu of resistors, a continuous tuning range becomes possible; however, even using special nonlinearity cancellation techniques [3–5], significant distortion is present (typically −60 dB for 1 V peak to peak signals). To achieve a compromise, we can use combinations of resistors and MOSFETs [6, 7] which are based on voltage division across the latter for distortion reduction (compared to the MOSFET-only case). However, these need extra active elements [6] or introduce extra nodes [7] which, at high frequencies, can become vulnerable to parasitic capacitances. In this Letter, we propose an R-MOSFET technique which is instead based on current division, in a manner similar to that used with transconductors [8]; contrary to the latter case, though, here no complicated transconductor circuits need to be designed.

Principle of operation: The proposed scheme is shown in Fig. 1. The boxes in the feedback loop can be capacitors (for an integrator) or resistors (for an amplifier). Some elements in Fig. 1 can belong to switchable arrays for coarse tuning. Block X accomplishes fine tuning; in this block, four identical

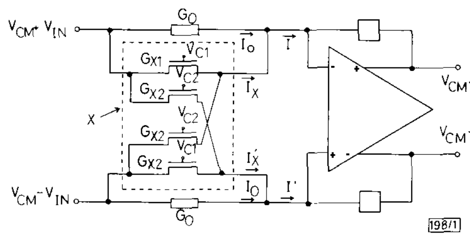

Fig. 1 *Proposed structure connected to balanced-output opamp and two feedback elements*

MOSFETs are operated resistively in the triode region of operation and their nonlinearities cancel out [4, 5]. The circuit is designed so that the differential current $I_X - I'_X$ is a small fraction η of the resistor current $I_0 - I'_0$. The voltages V_{C1}, V_{C2} are tuning voltages and V_{CM} is a common-mode voltage.

In the following, by 'conductance' we mean the ratio of the linear part of the differential output current to the differential input voltage, $2V_{IN}$. The effective conductance of block X is [4, 5]

$$G_X = \mu C'_{OX} \frac{W}{L} (V_{C1} - V_{C2}) \tag{1}$$

where the symbols have their usual meaning. Nominally $V_{C1} = V_{C2}$ and the effective conductance of the entire combination is G_0. By making $V_{C1} \neq V_{C2}$, the effective conductance can be tuned by the factor $(1 + \eta)$, where

$$\eta = \frac{G_x}{G_0} \tag{2}$$

and η can be made positive or negative as seen from eqn. 1.

Distortion: Let I_{NLX} be the residual nonlinear component in $I_X - I'_X$ due to second-order effects and mismatches [4]. The same component appears in the total differential $I - I'$, which, however, contains in addition the much larger linear component $I_0 - I'_0$; the fractional nonlinearity in $I - I'$ is improved, compared to that in $I_X - I'_X$, by a factor of approximately η.

Thus for any distortion measure (harmonic distortion, intermodulation distortion, etc.) we have

$$D \simeq \eta D_X \tag{3}$$

where D refers to the combined structure, and D_X to block X. If this performance is not adequate, we can consider replacing