Maximum Capacities in Submarine Cables With Fixed Power Constraints for C-Band, C+L-Band, and Multicore Fiber Systems

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***Abstract*—Achieving greater transmission capacity in submarine optical cables is of great interest as data traffic demands continue to increase worldwide. A significant constraint unique to submarine cable systems is that of electrical power that must be delivered to the entire cable from the terminals at the landing points. Recently, much focus has been on how to maximize the overall cable transmission capacity within fixed electrical power feed constraints. Until recently, all repeatered submarine cable systems were built using the erbium-doped fiber amplifier C-band, but C+L-band systems are now being considered and deployed. In parallel, there has been intense interest in spatial division multiplexing technologies, such as multicore fibers, as potential means to enabling greater transmission capacity in terrestrial and submarine systems. In this work, we examine maximum submarine cable capacities for three types of systems based on single-core fibers with C-band only or C+L-band transmission, and general multicore fiber systems with C-band-only transmission. The analysis is performed on the basis of common fixed power constraints and received signal-to-noise requirements, and comparable fiber-core characteristics. Additional losses for devices, such as C/L-band splitters and fan-in/fan-out modules, are accounted, and their impact on maximum cable capacity is estimated. For multicore fiber systems, other potential effects, such as higher fiber attenuation and crosstalk between cores, are also analyzed and evaluated with respect to capacity impacts. We find that single-core C-band systems offer the highest cable capacity, provided cable designs can accommodate the number of fiber pairs suggested.**

***Index Terms*—Capacity, fiber optics communications, multicore fiber, submarine cable.**

I. Introduction

GLOBAL traffic demands continue to grow at high rates, fueling significant research in recent years to develop technological approaches to enable greater capacity in transmission systems [1]. In particular, spatial division multiplexing (SDM) technologies such as mode division multiplexing (MDM) and multicore fibers (MCFs) have attracted a great deal of attention as potential paths to greater capacity [2]–[5]. This focus on spatial parallelism to create higher capacity comes after higher level and advanced modulation formats bring spectral efficiency gains that move systems closer to the Shannon limit [6]–[8] and coherent systems already use two orthogonal polarizations. In terms of the spectral dimension, dense wavelength division multiplexing (DWDM)) systems commonly use the full C-band, and C+L systems are beginning to attract attention to provide another means to boost capacity in a single fiber [9]. Lately, other amplification approaches have also been studied as a way to increase the spectral bandwidth of transmission systems beyond C+L [10], [11], although such technologies are not as mature and not used commercially yet.

While both terrestrial and submarine systems are experiencing traffic growth and need ways to increase capacity, there are significant differences between the two system types. In particular, submarine transmission systems must operate under electrical power constraints in which all power to the in-line optical amplifiers is generated from the terminals and delivered in the cable in a conductor along with the optical signals propagating in the optical fibers. Given fundamental physics, there are limits to the DC voltage drop that can be created and thus power limits to the amplifiers in the cable depending on cable length, resistance, and number of repeaters. There have been multiple studies in recent years that have addressed the question of submarine cable capacity maximization in the context of a fixed power supply constraint [12]–[16]. In general, these studies have demonstrated that higher cable capacities can be achieved through system and cable designs that spread the fixed electrical power over more spatial dimensions (fiber pairs or cores or modes) while channels are operated at lower optical powers and lower signal-to-noise ratios (SNR) [17], [18]. In [19], Sinkin *et al.* showed that there is an optimum SNR that maximizes the power efficiency and that this optimum is in the linear transmission region where optical nonlinear effects have little effect. Dar *et al.* took a different approach in which they determined cable designs based on minimizing a cost/bit metric [20]. In previous studies, we investigated the numbers of fiber pairs predicted to maximize cable capacity for target SNR values [21], [22].

In [22], we estimated maximum submarine cable capacities for equal SNR targets for three system types: single-core (SC) fibers with C-band only transmission, single-core fibers with C+L transmission, and multicore fibers with C-band only transmission. We extend that work here with a more accurate analytical SNR calculation including the "signal droop" effect [19], consideration of a wide range of SNR values, two different link

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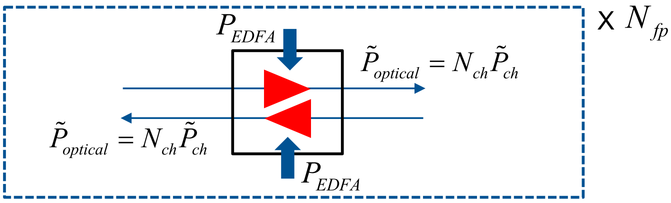

Fig. 1. Schematic illustration of submarine repeater.

lengths, preliminary evaluation on the basis of a cost/bit metric, and inclusion of potential crosstalk impairment effects in the multicore fiber analysis. Differences in cable capacity between the system types account for extra losses such as C/L bandsplitters, fan-in/fan-out (FI/FO) devices used with multicore fibers, and splice losses. Multicore fibers are treated in a general way that does not depend on specific fiber characteristics such as number of cores, spacing, geometry, etc.

The remainder of this paper is organized as follows: Section II describes the general system model and approach to calculating the maximum cable capacity. Section III presents the fiber and system characteristics assumed for the analysis, Section IV presents the results, and Section V offers a summary and conclusions.

II. System Model and Cable Capacity Calculations

A general representation of a submarine repeater is shown in Fig. 1, illustrating an individual erbium doped fiber amplifier (EDFA) for each transmission fiber, for a total number of $2N_{fp}$ EDFAs in each repeater for a cable with N_{fp} fiber pairs. The total optical output power of each EDFA is given by

$$\tilde{P}_{optical} = N_{ch}\tilde{P}_{ch} \tag{1}$$

where the system has N_{ch} optical channels, each with $\tilde{P}_{ch}$ launch power. Each EDFA consumes P_{EDFA} units of electrical power. The relationship between the EDFA electrical power consumption and the optical power output is given by

$$P_{EDFA} = \frac{\tilde{P}_{optical}}{\eta} \tag{2}$$

where η is the electrical-to-optical conversion efficiency which takes into account all factors such as driver efficiency, current for pump ageing, gain flattening filter loss, pump conversion efficiency, etc. [23]. The total repeater power consumption can be expressed as

$$P_{rep} = \frac{2N_{fp}P_{EDFA}}{(1-\varepsilon)} \tag{3}$$

and ε represents a fraction of the total repeater power for control circuitry not related to optical power conversion.

With the assumption of a fixed cable voltage V_{PFE} from power feed equipment (PFE) and optimum current such that the total voltage drop is divided equally between the repeaters and the cable, we can write the optimum repeater electrical power consumption as

$$P_{rep,opt} = \frac{(V_{PFE})^2}{4N_{sp}LR_0N_{rep}} \tag{4}$$

where N_{sp} is the number of spans, L is the span length, R_0 is the cable resistance, and N_{rep} is the number of repeaters [12]. The relation in Eq. 4 represents the maximum power transfer condition for a fixed cable voltage. Combining (1) through (4), we obtain the following for the maximum number of fiber pairs supported as

$$N_{fp} = floor\left[\frac{(1-\varepsilon)\,\eta V_{PFE}^2}{8N_{ch}\tilde{P}_{ch}N_{sp}LR_0N_{rep}}\right]. \tag{5}$$

The total maximum theoretical cable capacity is expressed as

$$C_{cable} = 2N_{fp}N_{ch}B_{sym}\log_2\left[1 + SNR\left(\tilde{P}_{ch}, L\right)\right] \tag{6}$$

where N_{ch} is the number of channels, B_{sym} is the symbol rate, and received signal-to-noise ratio (SNR) is dependent on the optical channel power and span length, among other factors. In this work, we assume that the channel spacing is the same as the symbol rate for Nyquist WDM transmission. We calculate the channel SNR by using the Gaussian noise model for nonlinear transmission [24] with the signal droop effect in the linear regime [19] to accurately model SNR at both ends of the channel power range. Thus channel SNR can be expressed as

$$SNR = \frac{\tilde{P}_{ch} - \tilde{P}_{ASE}}{\tilde{P}_{ASE} + \beta\tilde{P}_{ch}^3} \tag{7}$$

where $\tilde{P}_{ch}$ is the nominal channel power at launch and $\tilde{P}_{ASE}$ is the ASE noise power in the channel bandwidth given by

$$\tilde{P}_{ASE} = h\nu B_{sym}N_{rep}\left(FG - 1\right) \tag{8}$$

G is amplifier gain equal to the span loss in linear units, F is amplifier noise figure, and β is calculated from fiber and link parameters according to (36) and (40) in [24]. In principle, the nonlinear interference noise power $\beta\tilde{P}_{ch}^3$ should also be subtracted in the numerator of (7), but this is neglected because the effect is negligible for all channel power levels at or below the optimal nonlinear channel power for practical link distances considered here.

The general approach used in this analysis compares total cable capacity between the three considered system types on the basis of equal SNR values for each system. For a given SNR value and span length, the channel launch power is determined that produces the target SNR, and then the number of fiber pairs (or fiber core pairs) that can be supported for a fixed cable voltage is calculated according to (5). The relative cable capacities as obtained from (6) are then determined by the relative number of fiber pairs since the channel SNR values are equal between system types. The maximum cable capacity in each case is determined by searching over a range of span lengths from 40 km to 100 km. The relationship between SNR and channel launch power includes fiber parameters and extra losses from other devices in each system. For a system using uncoupled core MCFs, we will also address the effect of crosstalk level on total capacity.

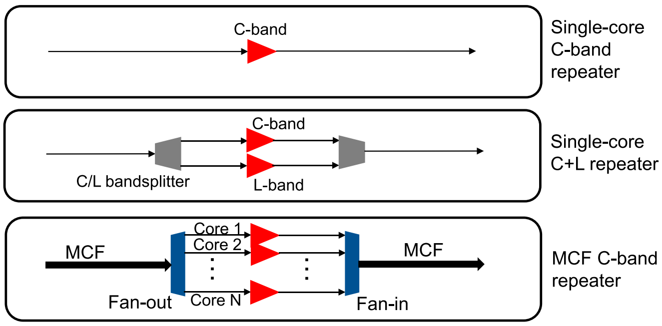

Fig. 2. Schematic diagrams of repeater optical paths in three system types.

TABLE I
FIBER PARAMETERS

Parameter	**Single-core C-band system**	**Single-core C+L system (C/L)**	**MCF C-band system**
Fiber attenuation (dB/km)	0.154	0.154/0.156	0.158
A_{eff} (μm^2)	112	112/116	112
Dispersion (ps/nm/km)	21	21/23	21
C/L bandsplitter loss (dB)		0.5/0.5	
FI/FO loss (dB)			1.0
Intra-span splice loss (dB)	0.02	0.02/0.02	0.1

TABLE II
SYSTEM PARAMETERS

Parameter	**System value**
Link length (km)	6,600 and 10,000
Symbol rate (Gbaud)	32
Number of channels per band	130
EDFA Electrical-to-optical conversion efficiency η (%)	1.5
Control overhead ε (%)	10
Cable resistance (Ω/km)	1
PFE voltage (kV)	15
EDFA NF, C/L (dB)	5/5.5
Distance between splices (km)	10

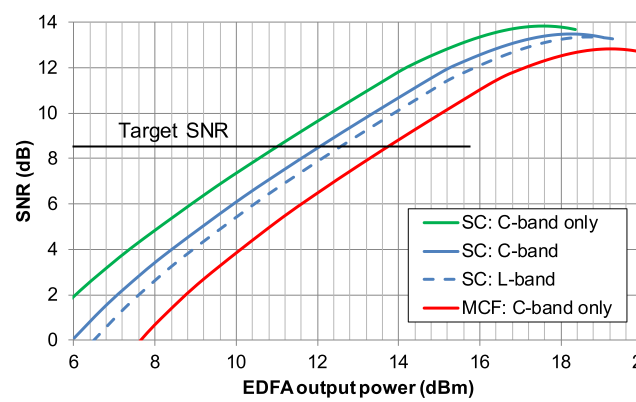

Fig. 3. SNR vs EDFA output power for three system types, with example target SNR indication. Solid blue line is C-band in C+L system, dashed blue line is L-band in C+L system. Link length = 6,600 km, and span length = 60 km.

III. Repeater Configurations and Fiber and System Parameters

Simplified schematic diagrams of the repeater optical paths for the three system types are shown in Fig. 2. Single-core C-band only systems have the simplest configuration with each transmission fiber connected directly to a C-band EDFA. For single-core C+L systems, the C and L transmission bands are split with a C/L bandsplitter, amplified separately with C- and L-band EDFAs, and then re-combined with another C/L bandsplitter at the exit. For MCF systems, we assume that the individual cores will be amplified with separate C-band EDFAs with the aid of fan-out devices and fan-in devices on the input and output sides of the repeater, respectively. This MCF repeater configuration is the most straightforward, and perhaps most likely, approach in the near term although significant research has gone into other MCF amplification approaches such as cladding pumping which would not require fan-it and fan-out devices [25]. We will briefly address the topic of other MCF amplification approaches later with regard to pump efficiency and cable capacity.

The general fiber and system parameters considered for the analysis are given in Tables I and II, respectively. The fiber core parameters are generally representative of optical fibers currently deployed in submarine systems.

For the purposes of this analysis, we have assumed that the electrical-to-optical conversion efficiency is the same for C- and L-band EDFAs, although there might be differences in practice. We have also assumed a nominally slightly higher attenuation for MCFs compared to single-core fibers, given more complex manufacturing processes. No differences were assumed for bend losses incurred in repeater sites.

IV. Modeling Results

Figure 3 illustrates the effects of extra losses from higher fiber attenuation, splice losses, and other optical elements in terms of the received SNR of a signal as a function of the EDFA output power for a 130 channel DWDM system. The results are for a system with 60 km spans and a total link length of 6,600 km, for the three system configurations considered here. On the basis of achieving equal SNR values for all channels, one can observe the differences in EDFA output powers for the different systems. The SC C-band only system clearly requires the lowest EDFA output power, while the C+L EDFAs require higher output power mainly due to the C/L bandsplitter losses, and the MCF system requires the most output power due to the assumed 1 dB FI/FO losses and higher splice losses within the spans. In our modeling approach, the C/L bandsplitter and FI/FO losses are included as lumped losses at beginning and end of the span, while the intra-span splice losses are treated as increasing the average fiber attenuation.

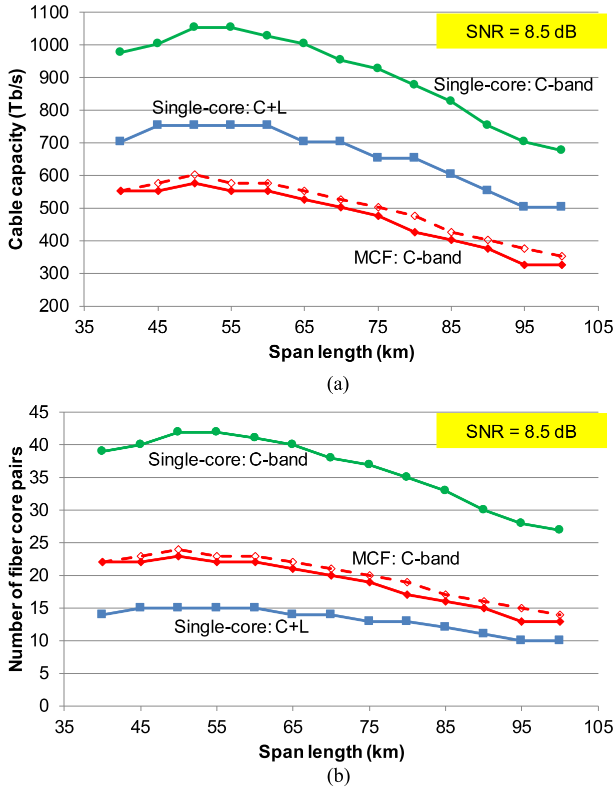

Fig. 4. (a) Maximum cable capacity for 6,600 km link vs. span length for three system types. (b) Number of fiber core pairs supported. Solid red line: MCF with nominal fiber attenuation. Dashed red line: MCF with same fiber attenuation as single-core fiber. Target SNR = 8.5 dB.

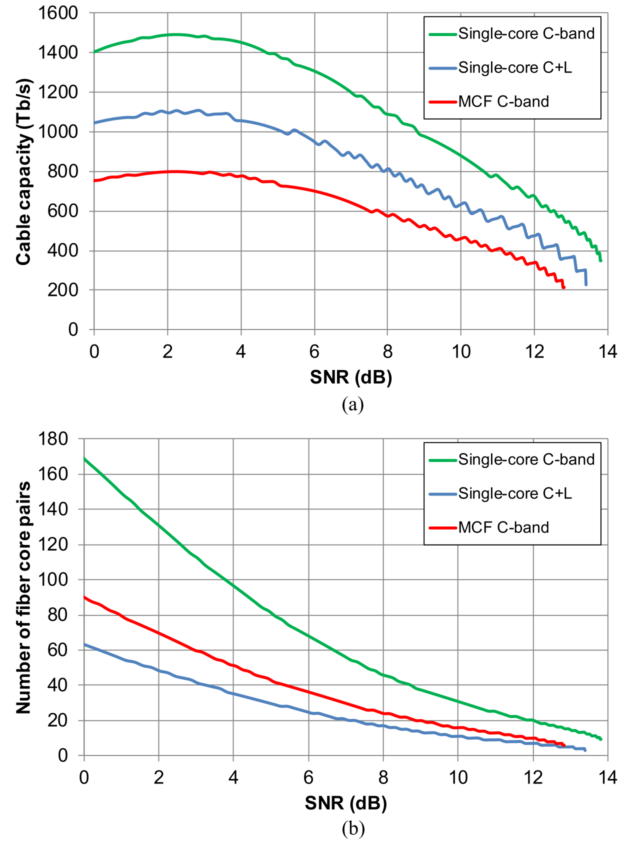

Fig. 5. (a) Maximum cable capacity vs. target SNR for 6,600 km link with 60 km spans. (b) Number of fiber core pairs supported.

An example of cable capacity results according to (6) obtained for 6,600 km systems with a target SNR value of 8.5 dB are given in Fig. 4a as a function of span length. The target SNR value of 8.5 dB chosen here for illustration might represent 3 dB margin over a soft-decision forward error correction (FEC) threshold of 5.5 dB for polarization-multiplexed quadrature phase shift keying (PM-QPSK) signals, for example. To assess the relative role of the assumed nominal increase in fiber attenuation for the MCF, we have included results when the attenuation is the same as for the single-core fiber (red dashed line). For this SNR target, the extra optical losses incurred with the C+L and MCF systems reduce the maximum cable capacity as compared to the single-core C-band only system by about 29% and 45%, respectively. The number of fiber core pairs supported by the fixed voltage of 15 kV is given in Fig. 4b. It is worth noting that while the MCF system provides the smallest capacity of the three system types, the number of fiber core pairs needed is greater than that of the single-core C+L system since each C+L fiber carries twice the total capacity of a MCF core according to our model.

We can assess the relative behavior of the different systems over the whole range of SNR values available by examining a specific span length. This data is given in Fig. 5a, with the corresponding number of fiber core pairs in Fig. 5b for a 6,600 km system built with 60 km spans. The maximum number of fiber pairs indicated at the theoretically optimal SNR value for a single-core C-band system is about 120 for this link length, although considerations such as FEC threshold may suggest minimally practical SNR targets of at least 5 dB, which would lower the number of fiber pairs required significantly.

The relative capacity levels between the three system configurations remains essentially constant for all target SNR levels, with the SC C+L and MCF systems having approximately ∼73% and 53% of the SC C-band maximum capacity, respectively. We note that the behavior of cable capacity agrees well with the theoretical prediction in [19] in that a maximum exists for SNR ∼2.4 dB. For comparison, similar cable capacity vs. SNR data is given in Fig. 6 for a longer 10,020 km link. The granularity induced by the requirement for an integer number of fiber core pairs is more pronounced for the longer system because fewer core pairs can be supported with the same fixed voltage limitation. The maximum number of fiber core pairs corresponding to the maximum cable capacity at 2.4 dB SNR for the SC C-band only, SC C+L, and MCF systems is about 35, 12, and 18, respectively. Those numbers are smaller for higher target SNR values, reducing to about 22, 8, and 12, respectively, for a target SNR = 5 dB.

A. Dependence of MCF Capacity on Losses and Pump Power Inefficiency

The results in Figs. 4–6 show that the MCF system has the smallest cable capacity for any target SNR because of the larger optical losses. As Fig. 4 shows, the slightly higher fiber

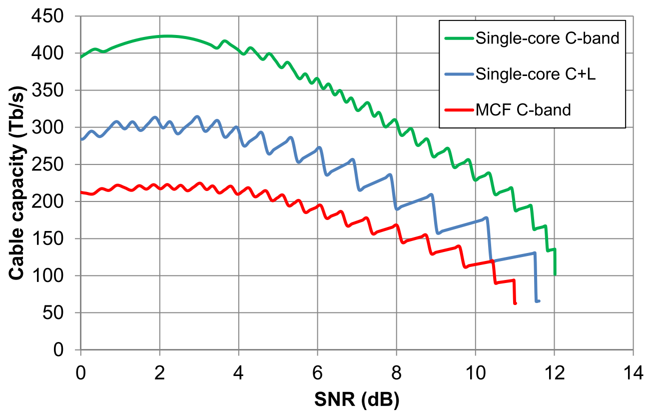

Fig. 6. Maximum cable capacity vs. target SNR for 10,020 km link with 60 km spans.

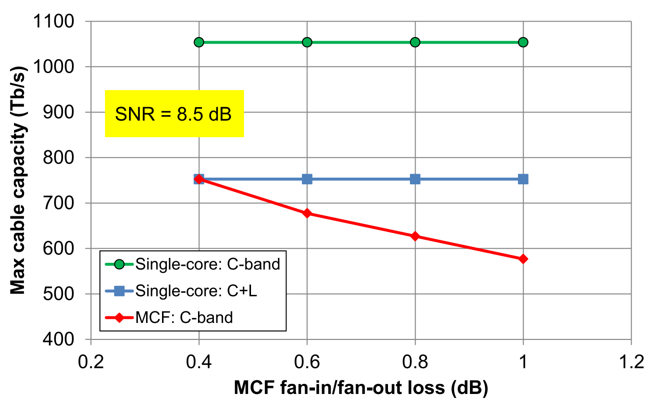

Fig. 7. Maximum cable capacity of MCF system as a function of FI/FO loss for target SNR of 8.5 dB. Link length = 6,600 km.

attenuation makes little difference, making the assumed 1 dB loss for the FI/FO devices the primary contributor to the reduced cable capacity. Fig. 7 presents data illustrating the cable capacities for the three systems at a given SNR of 8.5 dB as a function of the MCF FI/FO loss. The results show that the FI/FO device losses need to be about 0.4 dB to promote equal cable capacity to the SC C+L system. This makes sense given the C/L band-splitter loss of 0.5 dB, and while the MCF has higher intra-span splice losses, the L-band EDFA has a higher noise figure.

While we have nominally assumed the configuration of the MCF repeater as shown in Fig. 2 in which FI/FO devices are employed and each core is amplified separately, it is worth briefly considering an alternative architecture without such devices and their associated losses. Cladding pumping and individual core pumping schemes have been investigated for MCF amplifiers and these would not involve FI/FO devices [25], [26]. Here, we do not need to stipulate a specific amplifier design but we can examine the relative pump power conversion efficiency by varying the electrical-to-optical conversion efficiency parameter in our modeling. This serves to represent the higher pump powers that may be required by cladding pumping or perhaps individual core pumping if MCF-EDFA components have higher losses than those used with single-core fibers. The results in Fig. 8 suggest that extra pump powers needed for MCF EDFAs

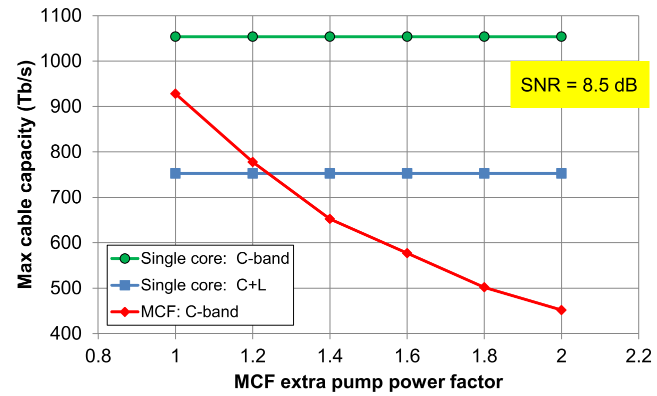

Fig. 8. Maximum cable capacity of MCF system as a function of extra pump power factor for EDFAs without FI/FOs for target SNR of 8.5 dB. Link length = 6,600 km.

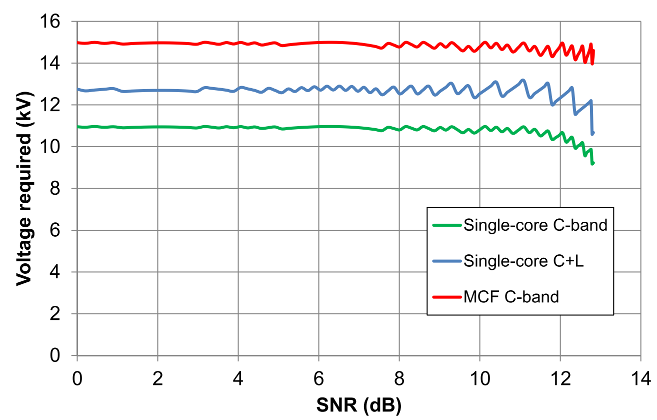

Fig. 9. Voltage requirements for the three system types with equal cable capacities as a function of target SNR. The system is a 6,600 km link with 60 km spans. The capacity at each SNR equals that of the MCF system in Fig. 5a.

without FI/FO devices should be no more than 20% larger than conventional single-core EDFA pumps to produce the same optical signal power levels in order to meet the total capacity of a C+L system. Even if no extra power is required (extra pump power factor = 1.0), the MCF system will still provide somewhat smaller maximum cable capacity than single-core C-band systems because of higher splice losses and potentially higher fiber attenuation.

B. Voltage Requirements for Equal Capacity

Returning to the original configurations and parameters as given in Fig. 2 and Tables I and II, we next assess the relative cable voltage levels required with equal cable capacities for the three system types. For the SC C-band system, this is done by setting the number of fiber pairs equal to the smaller number of fiber core pairs $N_{fp,MCF}$ supported by the MCF system. For the SC C+L system, we set the number of fiber pairs equal to $N_{fp,MCF}/2$ if $N_{fp,MCF}$ is even, or $N_{fp,MCF}/2+1$ if $N_{fp,MCF}$ is odd. For the same target SNR values, this produces equal capacities for the SC C-band and MCF systems, and either equal or slightly larger capacity for the SC C+L system. Results from the modeling are given in Fig. 9 for the 6,600 km

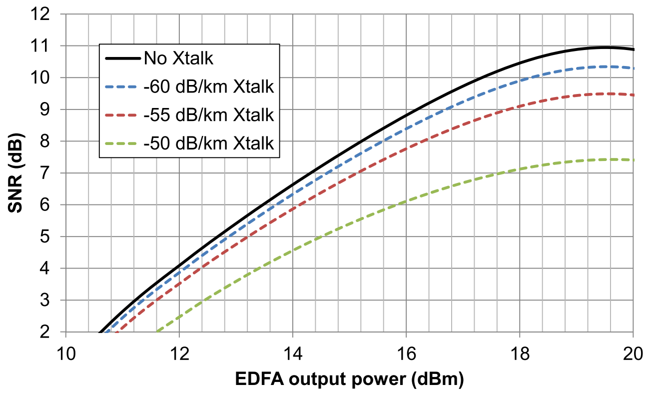

Fig. 10. SNR vs. EDFA output power with MCF distributed crosstalk. FI/FO crosstalk is -50 dB. System is a 10,020 km link with 60 km spans.

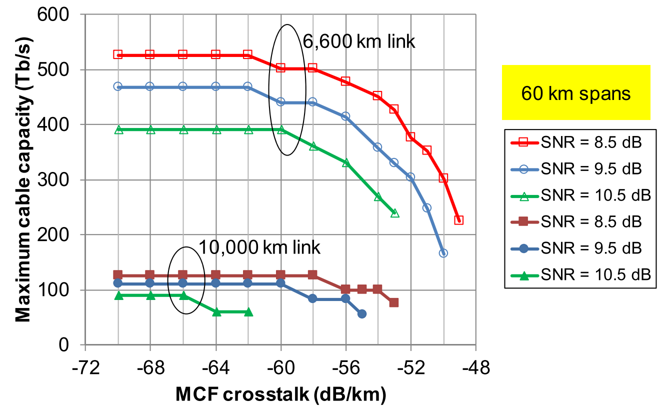

Fig. 11. Cable capacity vs. MCF crosstalk level for 10,000 km and 6,600 km links and different target SNR values. Discrete crosstalk level from FI/FO devices is set at −50 dB. Span length = 60 km.

system with 60 km spans and show that for equal cable capacities, while the MCF system generally requires close to the 15 kV limit, the SC C+L system and SC C-band systems have voltage requirements <13 and <11 kV, respectively.

C. *Effects of Crosstalk in MCFs on Cable Capacity*

Up until this point, we have not made any assumptions about the hypothetical MCFs modeled in terms of geometry, number of cores, etc. The cable capacity calculations were dependent primarily on fiber core characteristics and loss elements as described in Table I. In this section, we consider the additional effect of crosstalk between cores in a MCF system on cable capacity, assuming nominally uncoupled cores. Crosstalk between cores has been a subject of much research recently as this is recognized as an impairment unique to uncoupled MCFs that must be addressed and minimized [27], [28].

As the repeater configuration is shown in Fig. 2, there are two potential sources of crosstalk in the MCF system. One source is the multicore fiber itself, with distributed crosstalk occurring during propagation in the fiber spans. The other source is discrete crosstalk in the FI/FO devices located in the repeaters. The total crosstalk power generated over an entire link can be written as

$$\tilde{P}_{XT,tot} = XT_{tot} \cdot \tilde{P}_{ch} \tag{9}$$

where

$$XT_{tot} = N_{sp} L \cdot 10^{XT_{MCF}(dB/km)/10} + 2N_{rep} \cdot 10^{XT_{FI/FO}(dB)/10} \tag{10}$$

and $XT_{MCF}(dB/km)$ represents the distributed crosstalk in the MCF, and $XT_{FI/FO}(dB)$ is the discrete crosstalk contribution from a FI or FO device. With this definition of the crosstalk power, the signal SNR at the receiver can be modified from that given in Eq. 7 to include the effect of MCF crosstalk as

$$SNR = \frac{\tilde{P}_{ch} - \tilde{P}_{ASE} - \tilde{P}_{XT,tot}}{\tilde{P}_{ASE} + \tilde{P}_{XT,tot} + \beta \tilde{P}_{ch}^3}. \tag{11}$$

An example of how SNR changes for different levels of $XT_{MCF}(dB/km)$ is given in Fig. 10 for a 10,020 km link with 60 km spans. The discrete crosstalk $XT_{FI/FO}(dB)$ arising from the FI/FO devices was set to be −50 dB in these results.

TABLE III
SYSTEM COST PARAMETERS NORMALIZED TO TRANSPONDER COST PER 100 GB/S

Deployment per km (C_D)	0.7
Cable per km (C_C)	0.5
Fiber per km (C_F)	0.005
Optical amplifiers (C_{OA})	2
Transponder per 100 Gb/s (C_T)	1

In Fig. 11, cable capacity data for MCF systems of length 10,000 km and 6,600 km are shown as a function of the fiber distributed crosstalk level. We again assume −50 dB discrete FI/FO crosstalk. The maximum fiber crosstalk level is shown for each system case, beyond which the target SNR can no longer be achieved. The results indicate that for the range of SNR values considered from 8.5–10.5 dB, maximum tolerable fiber crosstalk values are −53 dB/km to −62 dB/km for a 10,000 km link, and −49 dB/km to −53 dB/km for a 6,600 km link. However, fiber crosstalk should be less than about −62 dB/km to incur negligible capacity loss for either link length.

D. *Evaluation on the Basis of a Cost/Capacity Metric*

As mentioned in the introduction, another approach to designing a submarine cable and choosing the number of fiber pairs, span length, and operating SNR is by optimizing a cost/capacity metric [20]. In this section we adopt the cost model suggested in [20] as another means to compare the three system types considered. The cost model assigns relative costs to different components of a submarine cable build, as given in Table III. The total system build cost is calculated as

$$C_{total} = (c_D + c_C) N_{sp} L + 2N_{fp} (c_F N_{sp} L + c_{OA} N_{rep}) + 2c_T C/100 \tag{12}$$

where C is the capacity in one direction as previously defined here. The relative costs in Table III are taken from [20].

For the purposes of this exercise, we assumed that the cost per km of one core in a MCF is the same as the cost per km of a single-core fiber. In practice, differences in fiber core cost

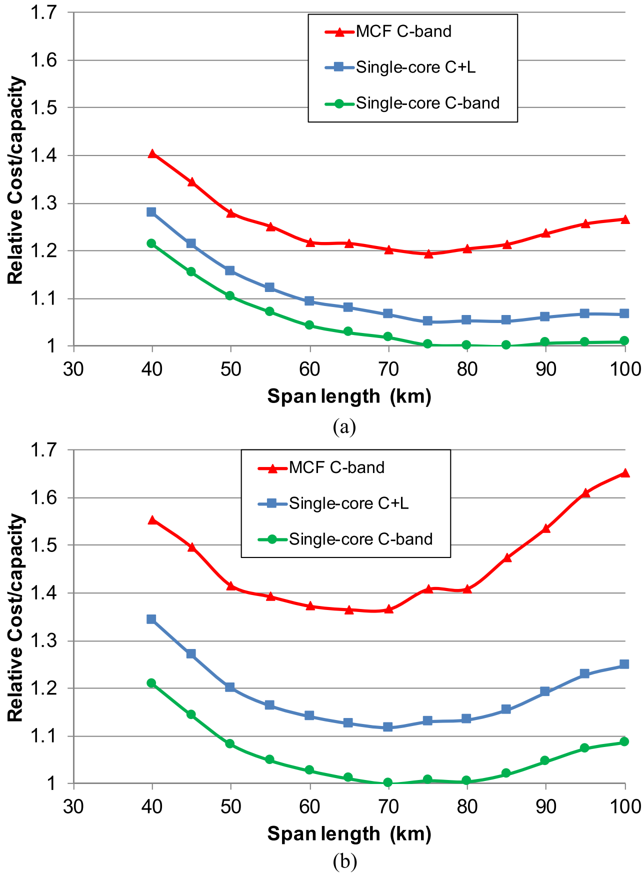

Fig. 12. Cost/capacity metric as a function of span length for three system types. (a) 6,600 km links. (b) 10,000 km links.

are possible due to more complicated MCF manufacturing processes relative to single-core fibers. We also assumed the same cost for C-band EDFAs and L-band EDFAs. We first calculated the maximum cable capacity in the manner described here for span lengths 40–100 km and over a full range of target SNR values for each system type such as shown in Figs. 5 and 6. We then calculated the cost/capacity metric based on the cost model, and chose the optimal target SNR and corresponding number of fiber core pairs for each system type that minimized the cost/capacity metric for each system type at each span length. The results for 6,600 km and 10,000 km links are presented in Fig. 12. For a 6,600 km link, the MCF and SC C+L system minimum cost/capacity values are about 20% and 5% higher than for the SC C-band only system, respectively. For a 10,000 km link, the MCF and SC C+L system minimum cost/capacity values are about 37% and 12% higher than for the SC C-band only system, respectively.

Evaluated at the minimum cost/capacity span lengths, the relative cable capacities are shown in Fig. 13 for the 6,600 km and 10,000 km links. For 6,600 km, the relative capacities of SC C+L and MCF C-band systems are reduced by about 6% and 32% compared to a SC C-band system. The same relative capacity reductions are 23% and 41% for a 10,000 km system. The numbers of fiber core pairs indicated by the analysis in the minimum cost/capacity condition for each link length are given

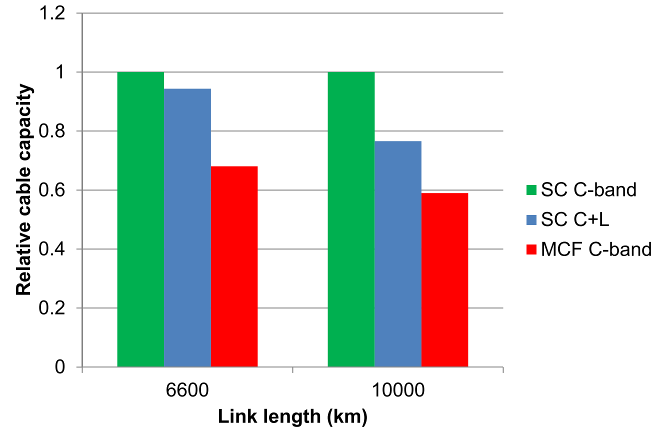

Fig. 13. Relative cable capacity for two link lengths and three system types when calculated in the minimum cost/capacity condition. The data is normalized for each link length to that of the SC C-band system.

TABLE IV
NUMBER OF FIBER CORE PAIRS AT THE MINIMUM COST/CAPACITY OPERATING CONDITION

Link length	**Single-core C-band system**	**Single-core C+L system**	**MCF C-band system**
6,600 km	27	14	21
10,000 km	15	6	10

in Table IV. At the minimum cost/capacity solutions, the SNR values were in the range of about 8–9.5 dB for the 6,600 km link, and 6–7 dB for the 10,000 km link, with the SC C-band system at the upper end of the SNR range and the MCF system at the lower end.

V. CONCLUSIONS

We have compared the maximum cable capacities of submarine transmission systems for fixed power feed equipment voltage with three system configurations: single-core fiber C-band, single-core fiber C+L, and MCF C-band. We find that the extra losses introduced by C+L and MCF systems limit the total cable capacity compared to SC fiber C-band systems. For MCFs, dependence on FI/FO loss, extra pump power for multicore EDFAs, and crosstalk were explored to determine ranges that may be necessary to approach capacities enabled with single-core fiber solutions. The results in general suggest that cable designs that can accommodate larger numbers of single-core fiber pairs offer the greatest capacity and lowest overall cost/capacity for constant voltage supply.

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