ALMA Memo 380
The Correlator at the OSF?

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Executive Summary

This document is intended to provide some costings which could influence the location of the correlator in the final ALMA system. It discusses some design details but it does *not* constitute a final design. It provides a snapshot with current, small-quantity prices of components which suppliers claim to be be available and deliverable. Some components which would improve the design do not seem to be available despite much advertising. Some of the figures have come from distributors in the UK where traditionally there has been a tendency to convert US $ prices into £ Sterling by changing the symbol but not the number. The costings are broadly indicative but will not necessarily be accurate in detail. It is hoped that the other parts of the cost trade offs will tip the scales in favour of a minimum-cost solution.

In the baseline ALMA system, the correlator is housed at the Array Operating Site (AOS) near the telescope array. It might, however, minimise the costs of buildings, construction, and operations, and minimise environmental impact if the correlator were to be housed at the Operations Support Facility (OSF). A previous memo, ALMA Memo 349 [1], has shown that there are no significant technical difficulties in extending the optical fibres as far as San Pedro. In this study, the incremental costs of extra fibres and fibre-optic components for IF data transmission to an OSF in one of two different locations are estimated. One is for the OSF near to San Pedro and the other is for the OSF roughly midway between the AOS and San Pedro. Both options require additional fibre and the *San Pedro* option also needs to use additional optical amplifiers.

Equipment for IF data transmission by fibre optics needs to be installed in up to three locations: at the antenna, at the AOS and at the correlator. The FO equipment on the telescopes is essentially the same for all three options and so are the optical receivers which are integrated into the correlator.

The AOS is required to house, at a minimum, a patch panel to link the 250 antenna pads to a set of 64 optical-fibre amplifiers and the 64-telescope correlator. It would also house the correlator for the *baseline* system. A common requirement for all three options is the need to house, near the correlator, the equipment which demultiplexes the WDM optical signals and which allows some reconfiguration capability via optical switches. The additional set of optical-fibre amplifiers at the correlator for the *San Pedro* option is the major distinction between the options in terms of space requirements.

It is assumed that there are fibre connections between the AOS and OSF in the *baseline* plan and that the trenching or ducting for these would be able to hold the new fibres at no additional cost, apart from the costs of joining together the sections of the fibre cable. It is left for others to cost the effect of changes in the location of the correlator on buildings and construction, to estimate the impact on the environment and the savings, if any, in operating costs.

Current, small-quantity prices, in US dollars, for components and fibre are used but it is only possible to estimate of the costs of making joins, in situ, in a 96-fibre cable. The conclusions are not sensitive to the estimate of $5k per join and it is easy to change the value. The main results of the study are given in Table 1. It shows size, power and incremental cost estimates at various locations for the three options. It leaves out the common elements at the receiver and correlator interfaces. Cost estimates are given only for items additional to the baseline system.

Option	Place	Description	Rack Width† (metres)	Power (kW)	Additional cost ($M US)
Baseline	AOS	FO patch panel	4.2	< 0.3	
	AOS	Optical amplifiers	0.6	< 1.2	
	AOS	Optical Demux/Switch	1.8	< 2.0	
Mid way	AOS	FO patch panel	4.2	< 0.2	
	AOS	Optical amplifiers	0.6	< 1.2	
	OSF	Optical Demux/Switch	1.8	< 2.0	
	Net, incremental fibre-optic cost				0.578
San Pedro	AOS	FO patch panel	4.2	< 0.2	
	AOS	Optical amplifiers	0.6	< 1.2	
	OSF	Optical amplifiers	0.6	< 1.0	
	OSF	Optical Demux/Switch	1.8	< 2.0	
	Net, incremental fibre-optic cost				2.455

Table 1: Summary of costs, space and power requirements.† Available height should be 2.5m.

The space required at the AOS could be quite small for either of the two off-array-site options but there may be requirements for space there to house equipment for photonic-LO transfer and system communications.

It costs only about $0.58M more in IF data transmission costs to house the correlator midway between the array site and San Pedro. It would cost about $2.46M to house the correlator near San Pedro. The difference in these figures reflects the cost of an additional set of optical amplifiers and the increased length of fibre cable. These costings are based on the partial use of a negative-dispersion fibre currently available from only one supplier. If this fibre were not available and commonly-available, non-zero, dispersion-shifted fibre had to be used, the costings would rise to $0.63M and $2.55M for the two options respectively.

There is only a nominal 0.6 dB power-budget margin above the start-of-life design target of 6 dB in the FO links for the *midway* option. This is uncomfortably small and precludes any increase in separation between the AOS and the OSF using a single, optical amplifier per fibre. Adding a second amplifier per fibre would raise the costs of the *midway* option by a further $1.3M for a total, incremental cost of $1.878M. The small margin makes it imperative that a real system be prototyped to confirm the design. If *arrayed-waveguide* WDM combiners and splitters were available, this margin would be much more workable. It is stressed that the margins are based on data-sheet numbers and that not too much reliance should be placed on the margins until a real system has been demonstrated.

The margin in the *San Pedro* option is much higher due to the extra optical amplifiers. The design would cope with any need to increase fibre length and would even permit a dispersion penalty slightly greater than 2 dB to be tolerated.

The increased fibre-optics costs of both options seem modest compared to the likely costs of buildings and operations at the AOS in the *baseline* plan. We suggest that someone evaluates the costs of the *missing* bits so that a decision on which option to pursue can be taken.

1 Introduction

In the baseline ALMA system, the correlator is housed at the Array Operating Site (AOS). There may be advantages, in terms of construction and operating costs, in housing the correlator at the Operations Support Facility (OSF), which might be located roughly midway between the AOS and San Pedro or, alternatively, near to San Pedro. The worst-case lengths of the fibres from the telescopes to the correlator for the three options are 25, 60 and 95 km respectively. A study of the optical-link power budgets, ALMA Memo 349 [1], has established that wavelength-division-multiplex (WDM) techniques are appropriate and that there are no significant technical difficulties in extending the optical fibres as far as San Pedro. We have proposed elsewhere that the design should be confirmed by building a complete system.

The optical components in the IF Data Transfer System (IFDTS) are located at and between the telescope and the correlator. The parts of the baseline IFDTS, apart from an optical fibre per telescope, are

- at the telescopes.
  - 12 optical transmitters
  - an optical multiplexer.
- at the AOS.
  - space for fibre management because of the large numbers of fibre cables
  - an optical patch panel to connect from 250 antenna pads to 64 telescope-inputs of the correlator
  - an erbium-doped fibre amplifier (EDFA) for each of the 64 antennas.
- at the correlator.
  - optical demultiplexers and optical switches for each antenna.
  - triple optical receivers integrated into each telescope input of a quadrant of the correlator.

The correlator is at the AOS in the *baseline* system. For the *San Pedro* option, an additional set of optical amplifiers would be needed at the correlator.

This report examines the costs of the IFDTS for the correlator-location options relative to the costs of the *baseline* IFDTS. Component costs are based on current, small-quantity budgetary quotations from potential suppliers and are in $ US. A number of assumptions have been made and these are clearly stated. Some costs, for example, the costs of splicing together fibre cables, are roughly estimated but the conclusions are not critically dependent on the accuracy of the estimates. Another uncertainty, the cost of the fibres in the baseline system, has been treated algebraically. It should be possible to substitute easily other estimates. Component costs are expected to fall over the time interval up to construction and the final costs are expected to be significantly below any costs that might be deduced from the numbers given in this report.

We have no means of estimating the costs of the buildings, infrastructure and operations. We would encourage others to garner this information so that the *best* system can be determined. In the *baseline* system, the building at the AOS also has to be large enough to house the correlator.

In the other two options, the building at the AOS is much more modest: it just has to house the fibre-management facilities, the patch panel, a set of optical amplifiers and other, array-support facilities such as the control systems and, perhaps, the photonic-LO system. It would not need to be "manned" unless maintenance of the optical amplifiers or an array-configuration change were required.

Amongst the factors to be weighed are:

1. The costs of the IFDTS.
2. The costs of buildings and services at the various locations both during construction and during operation of the facility.
3. Cost savings in designing, for example, the correlator for operation at lower altitude.
4. Savings in test equipment for operation at lower altitude. We note that we have been unable to identify *any* test equipment that is rated for the altitude of the site.
5. Savings, if any, in operations, for example, in increased productivity of personnel.
6. The environmental impacts of the various options.

Since the sizes and the power consumptions of various elements at different sites are relevant to these discussions, estimates of these parameters are also presented here.

2 Assumptions

It has been necessary to make a number of assumptions. The most critical one is that, in the *baseline* system, there is a need for a broadband connection between the correlator at the AOS and the OSF. It is further assumed that this broadband connection requires a number (4?) of fibres to be laid between the AOS and the OSF. Since the number of fibres in a cable has no bearing, within limits, on the cost of laying the cable, apart from joining (splicing) costs, it is assumed that any additional fibres between the AOS and OSF could be laid for just the additional cost of the cable itself and the costs of making the joins in the cable. There would be no additional trenching, ducting, laying or pulling-through charges.

It is assumed that a minimum of eight fibres will be laid from each telescope pad to the AOS. Two might be used for photonic-LO transfer, one would be used for IF data transfer, another one or two would be used for system comms and the rest would be spares.

It is further assumed that these fibres would be standard single-mode fibre since this is the cheapest that will do the job. The LO system may need to use fibre such as *Leaf* fibre from Corning which is capable of handling more optical power.

It is assumed that there will be 64 telescopes in the array.

It is assumed that any additional system comms requirements between the AOS and the OSF can be satisfied by 4 fibres. It is assumed that photonic-LO transfer, if also operated from the OSF, would need not more than 2 fibres. The total need is then for 70 fibres plus some spares. However, because fibre-cable manufacturers charge extra for special cables, we have costed on the basis of an industry-standard, 96-fibre cable between the AOS and the correlator.

The cost estimates which are given here are current, not projections, in US $, are for small quantities and do not include import duty and local sales taxes. It is assumed that the expected falls in prices over the next two years will cover easily any omissions in duty and tax.

3 Sizes and Power Consumptions

The major parts of the system are listed in the Introduction. Figures 1 and 2 show an explanatory key and schematic diagrams of the three options. The *midway* option differs from the *baseline* option in that there is an additional 35 km of fibres between the optical amplifiers at the AOS and the correlator at the OSF. In the *San Pedro* option, the additional fibre is extended to 70 km and the greater losses in this fibre require an additional set of optical amplifiers to be used in the fibres immediately on entry to the OSF.

The on-telescope requirements are not, apart from the specification of the laser-diode transmitters, affected by the choice of location for the correlator. The on-telescope parts will fit, with the NRAO-sourced "digital" boards and the WDM combiner, into 5 standard AT bins.

Quite a bit of space is required at the AOS to allow individual fibres to be separated out from the many incoming fibre cables, *fibre management*, and for the patch panel. A preliminary investigation has shown that these functions will take up to 4.2m of frontage and, assuming a top feed for the fibres, a height of 2.5m will be required. An aspect that needs further investigation is the control of vapours from the chemicals that are used to protect fibre cables intended for outdoor use. It may require either special ventilation or air tight seals and some additional space to make the environment of the patch panel safe. The patch panel is entirely passive but some power, the order of 300W, will be required to power a computer and a display through which the operator can take or give interconnection details.

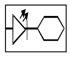
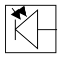
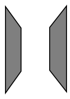
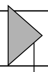
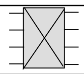
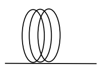
Optical amplifiers are needed in sets of 64. It is proposed that EDFA modules be packaged 8 to a bin and 8 bins to a rack. The end-of-life power consumption of an EDFA module is less than 20 W so a whole set will occupy a standard rack and dissipate less than 1.3 kW. A set of 64 amplifiers is required at the AOS and another would be required at the correlator for the *San Pedro* option.

The optical demultiplexers and optical switch modules have yet to be designed in detail. Provisionally, they might be packaged 4 to a bin and 24 to a standard rack so that 3 racks would be required. Latching optical switches are available: the total power consumption of the demux/switch racks should be less than 2.0 kW.

4 Choices of Fibre and Transmitters

Chromatic dispersion of the light in the fibre has progressively more effect as fibre lengths are increased. The total effect of the dispersion in the fibre depends also on any frequency *chirp* in the transmitter. The net effect of the combination is to degrade the *eye-patterns* of the detected signals and hence to increase error rates. There are many ways in which dispersion can be counteracted but, in this case, the viable options are to use better fibre, better transmitters or both.

Two sorts of fibre are in widespread use. Standard single-mode fibre (SMF) has a dispersion

Symbol	Description
	10Gbit/sec Externally modulated transmitter
	10Gbit/sec Receiver
	Dense DWM (De)Multiplexer
	Erbium Doped Fibre Amplifier (EDFA)
M	Amplifier Monitor
	Optical Switch
A	Optical Attenuator
	Optical Fibre
	Splice
	Connector
P/λ	Power & Wavelength Monitor

Proposed Design for the Baseline Link

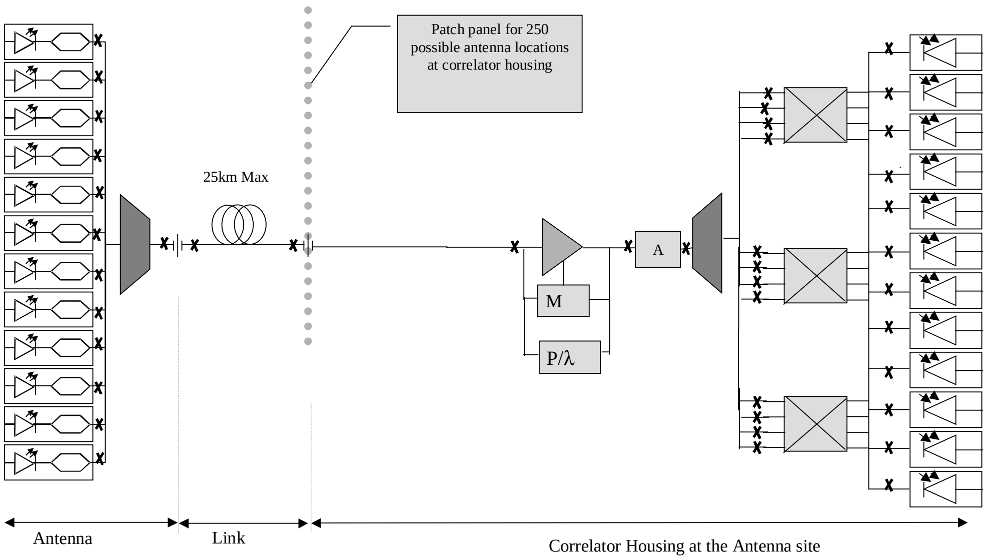
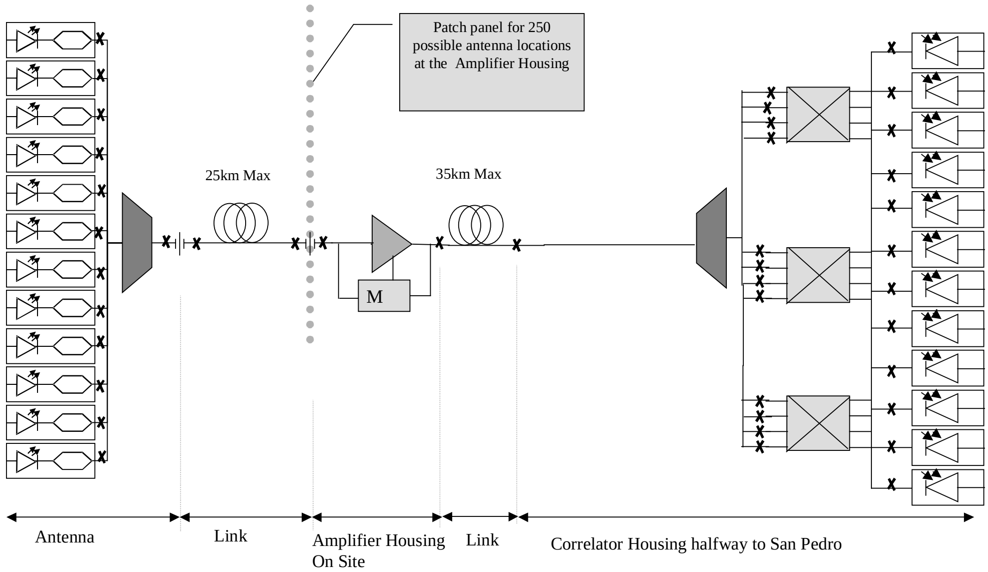


Figure 1: A key to symbols and the *baseline* system

Proposed link design for the midway option



Proposed Design for the Link to San Pedro

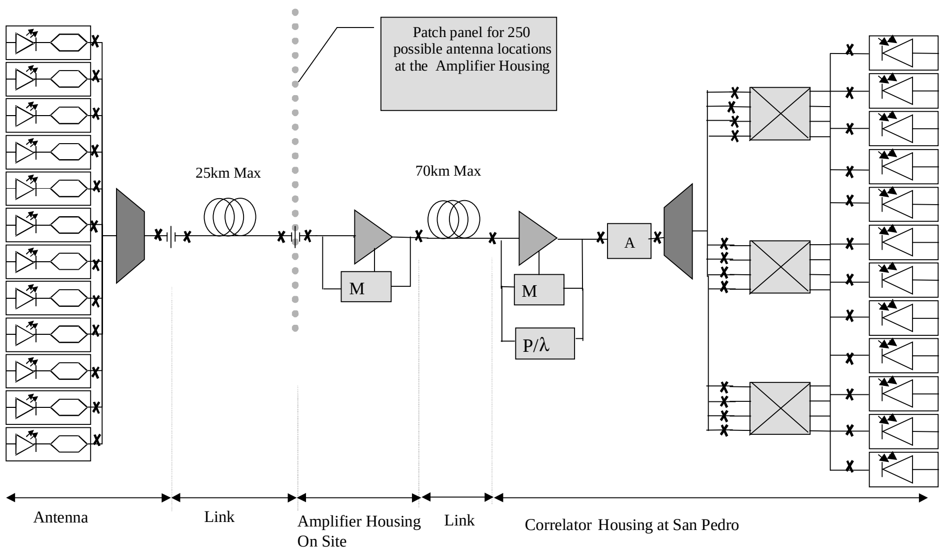


Figure 2: The correlator-at-the-OSF options

of less than +18 $ps\,nm^{-1}\,km^{-1}$ and non-zero, dispersion-shifted fibre (*NZDSF fibre*) has a dispersion of less than +6 $ps\,nm^{-1}\,km^{-1}$ in the EDFA band. A third sort, a negative-dispersion, dispersion-shifted fibre ($NDDSF$), intended for metro use, has recently been introduced. It has a dispersion of greater than -10 $ps\;nm^{-1}\;km^{-1}$. There are fibres which have zero dispersion in the EDFA band but *some* dispersion is desirable to suppress the growth of the products of non-linearities in the transmission properties of the fibres. We have been quoted prices of about \$8200 km^{-1}, \$14000 km^{-1} and \$15400 km^{-1} for 96-fibre SMF, *NDDSF* and *NZDSF* fibre cables respectively. For 4-fibre cables, the corresponding prices are \$1000 km^{-1}, \$1320 km^{-1} and \$1400 km^{-1} respectively. The other properties of these fibres are materially the same.

Our preferred, laser-diode transmitter is a laser-diode, electro-absorption modulator combination assembled in a small package. They are cheaper, simpler and smaller than separate lasers and modulators and the combination is guaranteed to work. Various grades with different chirp characteristics are available. For example, one device is available in two grades with dispersion penalties of less than 2 dB for fibre dispersions of 800 and 1600 $ps\,nm^{-1}$. So far, more-dispersion-tolerant devices are not available for use at 10 Gbps. The current, small-quantity price difference between the two grades is \$1230. For 12 transmitters per telescope and 72 telescopes (allowing for some spares), the incremental cost of using higher-spec transmitters would be an initial \$1.06M and any subsequent replacements would also be more expensive.

The fibre losses in the *San Pedro* option are sufficiently greater than for the other two options that an additional set of 64 EDFA amplifiers would be required. An EDFA module integrated as a plugin module with power supplies, control and monitoring costs around \$20k per amplifier. An additional set of 64 integrated into a rack with the comms system needed for safety reasons between the receivers and the amplifiers would cost a total of about \$1.3M. This figure must be added to the fibre costs of the *San Pedro* options.

With these data, it should be possible to provide reasonably-accurate cost estimates for the three possible locations of the correlator. Unfortunately, there are two sets of uncertainties. One is the unknown cost of the fibre connections between the telescopes and the AOS in the *baseline* plan and the other is the uncertainty in the costs of splicing together any additional fibre runs from the AOS to the correlator.

To the best of our knowledge, there is, as yet, no detailed plan of routes for fibres, etc. between the telescope pads and the AOS so it is not possible to estimate the costs of the fibre cabling required. Let B (\$k) represent the total cost of 8-fibre SMF cable required to connect 250 telescope pads to the AOS. This symbol is used in Table 3 as part of the costs for various options.

The second uncertainty is the cost of splicing together, in situ, the fibres in the cables which are installed in lengths, typically, of a few kilometres. The splicing costs have been incorporated in these estimates by a variable S, the cost, in \$k, of splicing 96 fibres for a cable join. Joins are likely to be required at intervals of 2 km over the extra fibre runs. The 2 km is probably a conservative figure unless the terrain is particularly difficult.

In the lab, it might be possible for 2 men to make 96 splices in a single day but, on site, it would probably take significantly longer. A guess of the magnitude of S would be 4 man-days at \$125 per man-day times 2 for terrain times 5 for commercial overheads giving a figure of \$5000, i.e. $S = 5$. At this rate, the splicing costs would be only a small fraction of the costs of the fibre cables and they would not be determining factors in making a choice.

Four fibre options have been considered: one in which the whole system uses *SMF* fibre, one in which the whole system uses *NZDSF* fibre, and the other two in which the telescope pad to AOS connections use *SMF*, 4-fibre cable and the AOS to OSF connections use either *NZDSF* or *NDDSF*, 96-fibre cable. The mixed-fibre cases allow the unknown costs of the antenna pad to AOS fibres, B, to be factored out. Mixing two types of fibre has no serious disadvantages in this case because of the differing numbers of fibres per cable and because the boundaries between the two types are so clean. The negative dispersion in *NDDSF* over compensates for the positive dispersion in *SMF* but, as can be seen, lower-spec transmitters would still be adequate.

Fibre	Fibre Segment		
	Tel – AOS (0 to 25 km)	Tel – Midway (35 to 60 km)	Tel – San Pedro (70 to 95 km)
SMF	0 to 450	630 to 1080	1260 to 1710
NZDSF	0 to 150	210 to 360	420 to 570
SMF/NZDSF	0 to 450	210 to 660	420 to 870
SMF/NDDSF	0 to 450	-350 to +100	-700 to -250

Table 2: Total dispersions (in $ps\ nm^{-1}$) for four fibre options. The *SMF/NZDSF* and *SMF/NDDSF* entries uses *SMF* for the telescope-to-AOS segment and the *other* fibre from the AOS to the OSF.

Fibre	Correlator Location		
	AOS	Midway ($L_m = 35\,km$ from AOS)	San Pedro ($L_{sp} = 70\,km$ from AOS)
SMF	B	$B + L_m(S/2 + F_S) + H$ $= B + 1435$	$B + L_{sp}(S/2 + F_S) + H + A$ $= B + 3109$
NZDSF	$1.88B$	$1.88B + L_m(S/2 + F_{NZ})$ $= 1.88B + 625$	$1.88B + L_{sp}(S/2 + F_{NZ}) + A$ $= 1.88B + 2550$
SMF/NZDSF	B	$B + L_m(S/2 + F_{NZ})$ $= B + 625$	$B + L_{sp}(S/2 + F_{NZ}) + A$ $= B + 2550$
SMF/NDDSF	B	$B + L_m(S/2 + F_N)$ $= B + 578$	$B + L_{sp}(S/2 + F_N) + A$ $= B + 2455$

Table 3: Cost comparisons of the fibre options in \$k. In the third and fourth options, *SMF* is used between the telescope pad and the AOS, and the *other* fibre is used between the AOS and the OSF. A is the cost of an extra set of amplifiers (\$1300k); B is the cost of fibre for the *baseline* system; F_S, F_{NZ} and F_N are the costs of the various fibres (\$8.2k, \$14k and \$15.4k per *km* respectively for *SMF*, *NZDSF* and *NDDSF* fibres); H is the extra cost of using higher-spec transmitters (\$1060k); L_m and L_{sp} are the extra fibre lengths to reach the OSF (35 or 70 km respectively); and S is the cost of making, in situ, 96 splices for a cable join every 2 km (\$5k); The factor 1.88 is the ratio of the costs of *NZDSF* and *SMF* fibres.

Table 2 shows the dispersions of these options and Table 3 shows the costs for the correlator-location and fibre options in algebraic form. B and S are defined earlier. The 1.88 is the ratio of the costs of *NZDSF* and *SMF* fibres. The *SMF* solution is not the cheapest even for the *midway* correlator location because of the costs of the higher-spec transmitters. The mixed-fibre option is cheaper than the *NZDSF*-only option no matter what the values of B and S just because *NZDSF* is the most expensive of the three fibres. The *San Pedro* option is significantly more expensive than the *midway* option because of the increased use of fibre and the need for an additional set of EDFA amplifiers.

It can be seen from Table 2 that it would only be possible to reach a *midway* OSF using *SMF* with the higher-spec transmitters at a considerable cost penalty. Even the higher-spec transmitters would not reach a *San Pedro* OSF without a dispersion penalty of more than 2 dB. However, there is so much link power-margin to this site that the link *would* probably work satisfactorily. The costs of the higher-spec transmitters probably rules out this option.

The other fibre options are capable of reaching either of the possible OSF locations but the *SMF/NZDSF* combination would suffer more than a 2 dB dispersion penalty for the *San Pedro* OSF. The all-*NZDSF* option option is very expensive because of the cost of the *baseline* fibres and the *SMF/NDDSF* combination is reliant on a single supplier for the *NDDSF* fibre.

There is a small difference between this report and Memo 349 in that here the relative costs of various solutions and the availability of high-quality, integrated transmitters are being considered. The conclusion in the other memo, that dispersion *may* be a problem using *SMF* fibre is based on the use of a chirp-less transmitter. When the availability and the performance of the integrated device is taken into account and the relative costs are considered, the balance swings to the conclusions given here.

5 Link Power Margins

The link power-budget margins are discussed in ALMA Memo 349[1]. The conclusions in that memo are not affected by the choice of fibres. Appendix I in the memo for the *midway* option shows that there is a nominal 3.1 dB excess margin over the design target of a 6 dB, start-of-life (SOL) margin. However, Memo 349 was prepared using manufacturers data for the best components to do the jobs. In practice, no supplier seems to be willing (or able) to quote prices or delivery dates for the *arrayed-waveguide* WDM combiners/splitters considered in the memo. The margin using available, thin-film, WDM combiners/splitters is eroded to only 0.6 dB.

An excess margin of only 0.6 dB is barely adequate. This is uncomfortably small and precludes any increase in separation between the AOS and OSF using a single, optical amplifier per fibre. With two amplifiers, the system would be the full *San Pedro* system. It should be stressed, that the budgets in the memo were derived using many parameters from data sheets. It would be prudent to confirm the accuracy of these numbers by making a working system as we have suggested.

The link margins quoted in Section 6 of the memo for the *San Pedro* option are also eroded by the change in the WDM combiner/splitters but there is still an excess margin of around 14 dB. The gains of more than 20 dB in optical amplifiers are more than sufficient to overcome the losses in extra 35 km sections of fibre. This margin is sufficiently great that it may be possible for a somewhat-greater-than-specification dispersion loss to be tolerated.

6 Conclusions

The costs, space and power requirements of the correlator-location options are summarised in Table 4 on the assumption that the cable-join cost, S, is 5 but the final figures are not very sensitive to this number. The *SMF/NDDSF* combination provides the cheapest solutions but there is not a second source for the *NDDSF* component. The alternative, the *SMF/NZDSF* combination is only marginally more expensive if lower-spec transmitters are used and a small, excess dispersion penalty is tolerated for the *San Pedro* OSF.

Option	Place	Description	Rack Width† (metres)	Power (kW)	Additional cost ($M US)
Baseline	AOS	FO patch panel	4.2	< 0.3	
	AOS	Optical amplifiers	0.6	< 1.2	
	AOS	Optical Demux/Switch	1.8	< 2.0	
Mid way	AOS	FO patch panel	4.2	< 0.2	
	AOS	Optical amplifiers	0.6	< 1.2	
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San Pedro	AOS	FO patch panel	4.2	< 0.2	
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	OSF	Optical Demux/Switch	1.8	< 2.0	
	Net, incremental fibre-optic cost				2.455

Table 4: Summary of costs, space and power requirements.† Available height should be 2.5m.

The main conclusions of the study are that it would cost only about $0.58M more in IF data transmission costs to house the correlator midway between the array site and San Pedro. It would cost about $2.46M more in IF data transmission costs to house the correlator near San Pedro. The difference in these figures reflects the cost of an additional set of amplifiers and the increased length of fibre cable. These costings are based on the partial use of a negative-dispersion fibre currently available from only one supplier. If this fibre were not available and commonly-available, non-zero, dispersion-shifted fibre had to be used, the costings would rise to $0.63M and $2.55M for the two options respectively.

There is only a nominal 0.6 dB power-budget margin above the start-of-life design target of 6 dB in the FO links for the *midway* option. This is uncomfortably small and precludes any increase in separation between the AOS and the OSF using a single, optical amplifier per fibre. Adding a second amplifier per fibre would raise the costs of the *midway* option by a further $1.3M for a total, incremental cost of $1.878M. The small margin makes it imperative that a real system be prototyped to confirm the design. If *arrayed-waveguide* WDM combiners and splitters were available, this margin would be much more workable. It is stressed that the margins are based on data-sheet numbers and that not too much reliance should be placed on the margins until a real system has been demonstrated.

The margin in the *San Pedro* option is more than adequate. The design would cope with any need to increase fibre length and would even permit a dispersion penalty slightly greater than 2 dB to be tolerated.

The increased fibre-optics costs of both options seem modest compared to the likely costs of buildings and operations at the AOS in the *baseline* plan. We suggest that someone evaluates the costs of the *missing* bits so that a decision on which option to pursue can be taken.

7 References

1. ALMA Memo 349: Fibre-Optic Link Design of the Atacama IF Data Transfer System by Roshene McCool.