

# A comparative study of conventional optical fibre cable technology and new emerging Micro-Blown Cable Technology (April 2006)

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**Abstract**—Due the ever increasing demand for broadband services a trend to utilize optical fibres closer to the end user started to develop as optical fibres have very high bandwidth capabilities. This situation brings about new challenges as limited space and more challenging rights-of-way issues are encountered in the access/metropolitan environment compared to long haul networks.

## Keywords

Conventional fibre optic cables, Micro-blown fibre optic cables, Fibre excess, Strain-free window, Loose tube, Miniaturization, Blown installation.

## I. INTRODUCTION

The loose tube fibre optic cable design is the workhorse of the fibre optic cable industry. For years it has provided the mechanical, thermal, and environmental robustness needed to ensure optical performance in the rugged applications it's been exposed to. As there is a strong desire to enhance fibre density of cable duct systems in the access/metropolitan network environment, the need to reduce the size and weight of optic fibre cables also came to life. A new generation of miniaturized optic fibre cables evolved to fulfill this need. As these miniaturized cables do not have same amount of strength and fibre strain-free window compared to conventional types, there may be concerns with regards to their performance and life expectancy characteristics.

The purpose of this paper is to discuss the critical design considerations for optic fibre cables deployed in underground ducts and to compare the characteristics of conventional cables, to that of new emerging micro-blown fibre optic cables.

Micro-blown cables are installed by blowing them into micro-ducts. The blown cable installation method utilizes compressed air and does not exert any longitudinal pulling forces on the cable. It is due to this "strain-free" method of installation that miniaturization was made possible.

Note that micro-blown optic fibre cables are aimed at the access/metropolitan network environment.

## II. CABLE DESIGN AND PROPERTIES

Only cable designs for installation in underground ducts

are considered in this paper, as it is the most appropriate way of installing cable in the metropolitan environment. The following cable designs were analyzed:

- Conventional duct types
- New emerging micro-blown cable

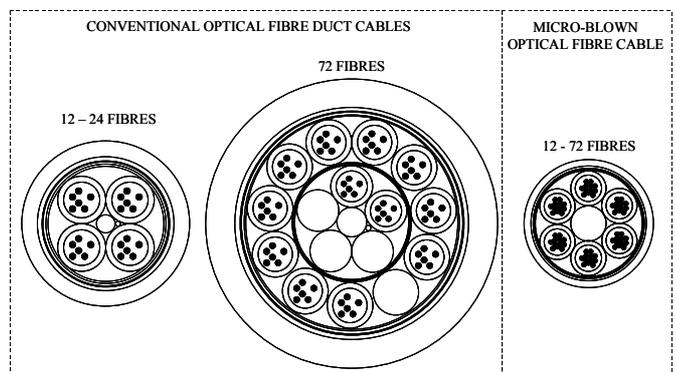


Fig. 1.

Figure 1 shows some of the most popular conventional and micro-blown cable types. Typical characteristics are as shown in table 1

PROPERTY	CABLE TYPE		
	CONVENTIONAL 12/24 FIBRE	CONVENTIONAL 72 FIBRE	MICRO-BLOWN 12 - 72 FIBRE
Cable diameter (mm)	9.4	14.7	6.2
Cable weight (kg/km)	63	145	33

Table 1

### A. HELICAL GEOMETRY

The helical geometry in conjunction with optical fibres being de-coupled from other cable materials in stranded loose tube cables provides a strain-free window. Note that the optical fibres are normally exposed to strain once the strain-free window is exhausted either due to too much cable contraction or elongation.

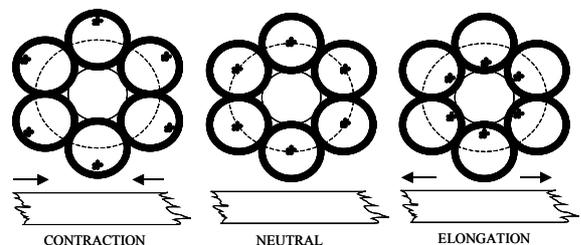


Fig. 2.

Figure 2 shows the effect of elongation and contraction on fibres in a stranded loose tube cable. The centre diagram shows the fibres with zero strain i.e. the fibres lie along the centre line of the tube. During elongation or contraction of the cable the fibre will reposition itself to achieve a minimum energy configuration. Therefore, when the cable contracts the fibres will eventually lie along the wall at the most distant point from the centre line of the cable. Similarly, when the cable elongates the fibre will eventually lie along the tube wall at the nearest point to the centre line of the cable.

## B. CRITICAL DESIGN CONSIDERATIONS

Excessive bending, pressure or longitudinal forces applied to an optical fibre will increase its attenuation. Excessive strain on a fibre will also detract from its life expectancy. Strain applied to fibres in a cable is mainly caused by:

- a. Mechanical stresses due to handling of the cable during installation and subsequent forces after installation.
- b. Due to elongation(expansion) and contraction with temperature variation.

## C. FIBRE FAILURE MODE

Possible fibre failure modes are mainly caused by excessive tensile elongation of the cable or thermal deformation at very low temperatures as follows:

- a. Minimum Fibre Bend Radius

When deformed into a small radius a fibre will attenuate. This process is well defined with minimum bend radius values available from fibre manufacturers (Typically 20mm for single mode fibres). **Macrobend loss** will be induced in the fibre should it's minimum bending radius be exceeded.

- b. Compressive Force of Side Pressure on a Fibre

A radial compressive force will also cause a fibre to attenuate. Therefore, if a fibre is radially constrained e.g. pressing against the wall of a tube it will attenuate. The magnitude of this effect is not well defined i.e. the pressure required to produce significant loss is not known, it must therefore be assumed that any side pressure will cause the fibre to attenuate and should be avoided. In practice this means that e.g. a fibre can touch the wall of a tube but not press against it. This process is known as **Microbend loss**.

- c. Fibre Strain (Elongation)

The amount of strength member material incorporated in a cable construction is dependant on the tensile load the cable may be exposed to during installation and subsequent loading during operation. Note that once the available strain-free window is exhausted when a cable elongates due to an applied tensile load, the fibres will find themselves up against the tube wall at the nearest point to the centre line of the cable. Fibre strain will be induced should the cable be elongated beyond this point. It is imperative not to exceed a third of the fibre's proof strain test value (normally 1 %) as strain beyond this point will reduce the fibre's life expectancy. The process of applying strain to a fibre may also cause the fibre to attenuate and fibre strain should therefore be contained to acceptable limits.

## D. CABLE STRENGTH

The possibility the optical fibres being exposed to strain due to mechanical influences are governed by the size of the strain-free window and the strength and amount of strength elements incorporated. Conventional cables are generally installed by means of the hauling method (i.e. a tensile load is applied). Micro-blown cables are installed by means of blowing them into micro ducts by compressed air and are therefore not exposed to tensile loading. For cable design purposes it assumed that a tensile loading would also be applied to micro-blown cables in order to determine the worst-case cable elongation.

Cables are generally designed to meet a "2W" cable installation tension rating (The fibre strain at this tension should not exceed 0.33%, a third of the proof stain value).

$$T_{cab} = 2 \times 9.81 \times W_{cab}$$

Where:

$T_{cab}$  is the maximum cable installation tension

9.81 is acceleration due to gravity (9.81 m/s)

$W_{cab}$  is the cable weight in kg/km

Strength member materials have unique properties, however the applied load on them can be calculated from:

$$T = E_y \times A \times \gamma \times 100 \%$$

Where:

$\gamma$  is the percentage strain applied to the cable,

T is the applied tensile load in N,

$E_y$  is Young's Modules of elasticity in MPa.

The fibre strain is calculated from:

$$\gamma_f = (\gamma - \gamma_T) / (\cos^2 \theta_f)$$

Where:

$\gamma$  is the strain applied to the cable,

$\gamma_T$  is the threshold strain at which a fibre will experience strain,

$\theta_f$  is the helix angle for the minimum fibre diameter at which this fibre strain is exhibited.

## E. CABLE THERMAL PROPERTIES

All materials incorporated in a cable are subject to thermal deformation, i.e. when a cable is heated or cooled it will expand or contract. It is possible with the knowledge of the expansion characteristics of each material in the cable to determine the extent of this deformation. A distinction must be made however, between contraction and shrinkage:

- a. Contraction is defined as the reversible reduction in linear (or radial) dimension of the cable and can be calculated.
- b. Shrinkage is defined as the non-reversible reduction in linear (or radial) dimension of the cable. Shrinkage is a phenomenon normally observed after a material was subjected to extreme temperatures, where for example polymeric materials have passed the glass transition point.

As normal working temperatures are assumed, only contraction will be considered.

The expansion or contraction of materials,  $\epsilon$ , can be determined from the coefficient of expansion,  $\alpha$ , and the temperature difference experienced,  $\Delta T$ .

$$\epsilon = \alpha \cdot \Delta T$$

$\alpha$  can be positive or negative. If  $\alpha$  is positive then the material will expand with a positive change in temperature and contract with a negative change in temperature. If  $\alpha$  is negative then the material will contract with a positive change in temperature and expand with a negative change in temperature. Aramid yarn (Kevlar ®™) for example, has a negative coefficient ( $-2 \times 10^{-6} \text{ }^\circ\text{C}^{-1}$ ).

Each material type in the cable can have a different coefficient. This suggests that each component material of the cable will expand or contract at different rates. This is not necessarily the case. It is assumed that the components are constrained enough to influence the expansion or contraction of the complete cable rather than deform at their own rate. This assumption allows a net coefficient of expansion to be found that will determine the deformation of the complete cable.

Net Coefficient of Expansion:

$$\alpha_{\text{cab}} = (\sum_i \alpha_i E_i A_i) / (\sum_i E_i A_i)$$

Where: -

$\alpha_{\text{cab}}$  is the net coefficient of expansion of the cable ( $^\circ\text{C}^{-1}$ ),

$\alpha_i$  is the coefficient of expansion of the  $i^{\text{th}}$  material ( $^\circ\text{C}^{-1}$ ),

$E_i$  is Young's Modulus of Elasticity of the  $i^{\text{th}}$  material (MPa),

$A_i$  is the cross section area of the  $i^{\text{th}}$  material ( $\text{mm}^2$ ).

**TABLE 2**  
TYPICAL E AND  $\alpha$  VALUES AT  $-25^\circ\text{C}$

Material	E/MPa	$\alpha/(10^{-6} \text{ }^\circ\text{C}^{-1})$
<i>Low Density Polyethylene (LDPE)</i>	250	139
<i>High Density Polyethylene (HDPE)</i>	850	106
<i>Polybutylene Terephthalate (PBT)</i>	1450	60
<i>Glass Reinforced Polymer rod (GRP)</i>	50000	6
<i>Aramid Yarn</i>	100000	-2

Material uses:

- 1) LDPE and HDPE are used as sheathing.
- 2) PBT is the loose tube material.
- 3) GRP is the central strength member.
- 4) Aramid yarn is the peripheral strength member (not present in micro-blown cables)

It must be noted that both  $\alpha$  and E are temperature dependant.

For purpose of studying the cable's elongation (expansion) properties, we will only look at the elongation due to tensile loading as discussed under clause D (Cable Strength). Note that elongation due to tensile loading always exceeds expansion due to an increase in temperatures.

Also note that when calculating  $\alpha$  for cables incorporating yarns it should be noted that yarns have no longitudinal compressive rigidity.

## F. EFFECTS OF TEMPERATURE ON CABLE GEOMETRY AND CALCULATION OF TEMPERATURE RANGE

It is possible to calculate the total bend induced in optical fibres in a stranded loose tube cable construction.

### F1. CALCULATION OF MINIMUM BEND RADIUS OF FIBRE IN A CABLE

The minimum bend radius for the fibre, R, is calculated by summing the reciprocals of the bend radius of the fibre within the tube,  $r_f$ , and the radius of curvature of the helix of the tube,  $r_t$ .

$$1/R = (1/r_f) + (1/r_t) \quad (1)$$

The radius of curvature of the tube,  $r_t$ , is given by

$$r_t = D_p / 2\sin^2\theta \quad (2)$$

Where  $\theta$  is the lay angle of the tubes and  $D_p$  is the pitch diameter of the tube given by:

$$D_p = D_o + D_c \quad (3)$$

Where:

$D_o$  is the diameter of the tube

$D_c$  is the diameter of the centre member

The minimum bend radius of a fibre within a tube,  $r_f$ , is given by:

$$r_f = 25/2e(D_i - d_{\text{eff}}) \quad (4)$$

Where:

$D_i$  is the inner diameter of the tube

$d_{\text{eff}}$  is the effective diameter of a fibre bundle

$e$  is the percentage fibre excess

Substitute (4), (3), and (2) into (1) and rearranging gives:

$$R = (25/2) \times ((D_o + D_c)(D_i - d_{\text{eff}})) / ((25\sin^2\theta)(D_i - d_{\text{eff}}) + e(D_o + D_c))$$

### F2. CALCULATION OF OPERATIONAL TEMPERATURE RANGE

It is assumed that the cable will expand at temperatures above the manufacturing temperature and contract at temperatures below the manufacturing temperature if  $\alpha_{\text{cab}}$  is positive. If  $\alpha_{\text{cab}}$  is negative the cable will contract at temperatures above the manufacturing temperature and expand at temperatures below the manufacturing temperature.

Let  $L_T$  be the length of fibre/lay at temperature T

$$L_T = |L(1 - 5.5 \times 10^{-7}(T_m - T))|$$

Where L is the length of fibre/lay for zero excess at the tube manufacturing temperature  $T_m$ .

Let  $\epsilon_T$  be the expansion (or contraction) of the cable across the temperature range  $T_m$  to T,

$$\epsilon_T = |1 - F\alpha_{\text{cab}}(T_m - T)|$$

Where F is a safety factor of 2

The tube lay length at temperature T,  $S_T$ , is given by:

$$S_T = S_{\epsilon_T}$$

For contact with the upper inside wall, fibre length l is given by:

$$l = \sqrt{(\pi^2(D_c + 2D_o - 2t - d_{\text{eff}})^2 + S_T^2)}$$

Where t is the tube wall radial thickness

For contact with the lower inside tube wall, fibre length l is given by:

$$l = \sqrt{(\pi^2(D_c + 2t + d_{\text{eff}})^2 + S_T^2)}$$

The fibre excess  $e_m$  at the manufacturing temperature  $T_m$  necessary to touch the wall at temperature T, is given by:

$$e_m = ((l - L_T) / L_T) \times 100$$

Note that knowledge of the fibre excess created in the tube during manufacturing is also required in order to deduce the operational temperature range.

### III. CABLE ANALYSIS

An analysis was carried out on conventional and micro-blown cable types in terms of their elongation and contraction properties due to tensile loading and thermal conditions they may be exposed to. The formulae already mentioned were built into a Microsoft Excel spreadsheet for calculation purposes.

#### 1) TENSILE PROPERTIES

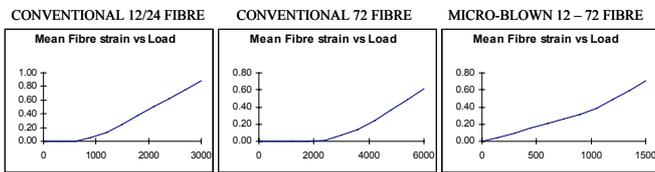


Fig. 3

PROPERTY	CABLE TYPE		
	CONVENTIONAL 12/24 FIBRE	CONVENTIONAL 72 FIBRE	MICRO-BLOWN 12 – 72 FIBRE
Maximum Installation Tension ( $T_{\text{cab}}$ )	1236 N	2845 N	650 N
Cable Strain at $T_{\text{cab}}$	0.52 %	0.51 %	0.41 %
Fibre Strain at $T_{\text{cab}}$	0.141 %	0.101 %	0.202 %

Table 3

#### Discussion (Tensile properties)

Table 3 shows the values obtained for maximum installation tension ( $T_{\text{cab}}$ ), the cables may be exposed to. This tension equates to the hauling tension for installing at least 2km of cable in an underground duct (assuming normal installation conditions). The cable and fibre strain,  $\gamma$  and  $\gamma_f$  respectively, are also shown in table 3. All cables have fibre strain values below 0.33%.

Note that it is unlikely that micro-blown cables will see the strain mentioned as they are installed by the blown method.

Figure 3 shows graphics of the various cables indicating the change in fibre strain with applied load.

#### 2) THERMAL PROPERTIES

The thermal properties (contraction), for each cable type were calculated over the temperature range 20°C to -25°C. Figure 4 is a graphical presentation of the calculated values.

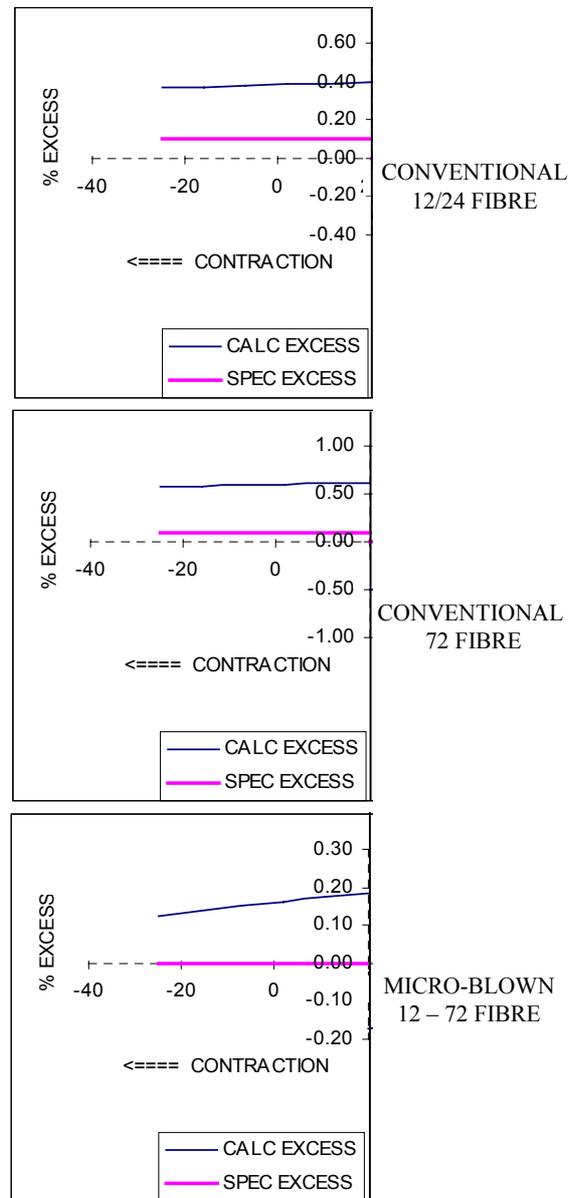


Fig. 4

#### Discussion (Thermal Properties)

SPEC EXCESS values are related to the amount of fibre excess inside the tube. During manufacturing of a loose tube a small amount of fibre excess can be generated, i.e. the length of the fibre is longer than the tube length. The SPEC EXCESS values are slightly positive (0.1%), for conventional cables as they are normally exposed to a tensile loading during installation (This implies that the fibres are lying slightly above the centre line of the tube). Micro-blown cables are not exposed to tensile loading during installation hence, the SPEC EXCESS value is zero.

Note that as the cable contracts due to lower temperatures the fibres are moving towards the most distant point from the centre line of the cable, which is represented, by the CALC EXCESS line.

It is evident that the conventional cables have higher fibre excess values and this is mainly due to larger tube sizes and fewer fibres per tube. However, the micro-blown cable with its miniaturized tubes has sufficient fibre excess and strain-free window to operate at very low temperatures.

PROPERTY	CABLE TYPE		
	CONVENTIONAL 12/24 FIBRE	CONVENTIONAL 72 FIBRE	MICRO-BLOWN 12 – 72 FIBRE
Cable coefficient of expansion $\alpha_{cab}$	$7.13 \times 10^{-6}$	$9.15 \times 10^{-6}$	$14.46 \times 10^{-6}$
Fibre excess in tube (Min. Spec. Excess)	0.1 %	0.1 %	0 %
Calculated fibre excess at 20°C	0.395 %	0.611 %	0.186 %
Calculated fibre excess during contraction at -25°C	0.366 %	0.574 %	0.125 %

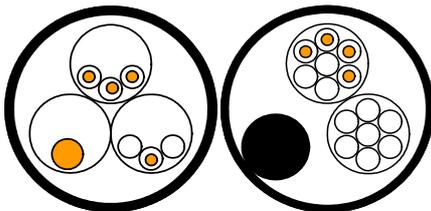
**Table 4**

Table 4 shows actual values relating to the graphs in Figure 4.

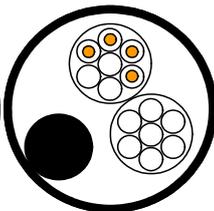
#### IV. MICRO-BLOWN CABLE TECHNOLOGY

Micro-blown cable technology provides a fast and efficient means of building a network. It is generally deployed where future network expansion is expected and also where customer location may be uncertain at the outset. The system utilizes compressed air to blow the cables into micro-ducts. The outer diameter of micro-ducts is typically 10mm and they are normally installed inside standard ducts (e.g. 32mm or 40mm). Principle benefits are:

- a. Initial expenditure costs are minimized, Empty ducts are deployed initially with fibre cables deployed on demand only. Major capacity release of existing infrastructure is also possible due to the small size of ducts and cables.



**Fig. 5**



**Fig. 6**

Figure 5 shows a 110mm duct containing three 40mm ducts. One 40mm duct contains a conventional fibre cable. Installing several 10mm micro-ducts in the empty 40mm ducts and blowing in micro-duct cables as required can release capacity.

Figure 6 shows 2 ducts, each containing seven 10mm micro-ducts being installed over an existing copper cable. A 72-fibre micro-duct cable in each micro-duct provides 1008 fibres.

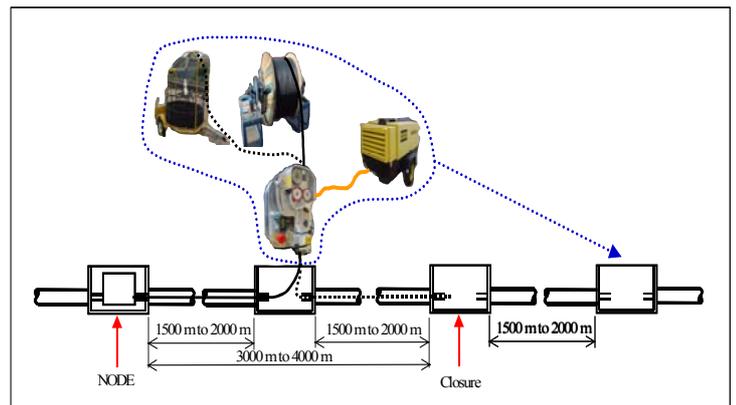
- b. Network planning is simplified, Flexible duct pathways are deployed via quick-fit connectors. Mid-span access is possible at any point.



**Fig. 7**

Figure 7 shows several 10mm micro-ducts inside a standard duct with quick-fit connectors branching out to alternative destinations.

- c. Customer connections are much easier and more flexible.
- d. Fibre splicing is reduced.
- e. Highly efficient installation.



**Fig. 8**

Figure 8 shows the typical set-up required to install micro-blown fibre cables (Cable blowing machine, compressor, cable trailer and reeling device). Cables are blown at a speed of 60 m/minute. Cable lengths of up to 2 km are possible depending on the route configuration.

## V. CONCLUSION

This paper considers the most critical design parameters of underground fibre optic cables and compares conventional and new emerging micro-blown cables based on a theoretical analysis. The analysis shows that micro-blown cables have sufficient strength and fibre strain-free window to accommodate the mechanical stresses and thermal changes it may encounter during installation and operation.

The paper also touches briefly on the proposed uses of micro-blown cables, e.g. high growth areas such as the access and metropolitan network environment, where additional bandwidth needs to be deployed rapidly, and briefly demonstrates the method of installation.

ATC fully developed micro-blown optical fibre cables and is currently in discussion with Telkom's Mr. A. du Toit in order to conduct a proof of concept test.

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### **Author** (Paul van Zyl, Technical Manager, ATC)

Paul joined the cable industry in 1983. His initial work was alongside experienced design engineers contracted from Germany.

On 1 May 1986 he was appointed Cable Development Engineer at ATC (Pty) Ltd. His first major project at ATC was to investigate the pros and cons of different optical fibre cable types available at the time in order to determine the company's future direction in this regard. During 1990 he was appointed Senior Design Engineer and was responsible for all cable design activities (Copper and Optical fibre cables).

On 1 July 1996 he was appointed Technical Manager at ATC and was responsible for the technical function of the company.

Paul also traveled extensively due to ATC's technology agreements with European fibre and cable manufacturers. He also attended several international telecommunications conferences to date.