The Photon Connection – The 1982/83 IEE Faraday Lecture
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THE FARADAY LECTURE 1982/1983

THE PHOTON CONNECTION

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Opening A/V module:

Recorded V/O:

We know that it is light which enables us to see.

In the world of the future, light will change the way we communicate, and perhaps the way we live.

STAGE REVEAL

LECTURER:

Within touching distance it is easy for us to keep in touch.

One speaks; the other listens.

Further apart one shouts; the other strains to hear.

Out of earshot, one waves, the other waves back; uncertain of the message.

Over longer distances, we need assistance.

Men have long known that light can be seen from afar.

They lit a chain of beacons to signal the fall of Troy.

They were still at it, 3,000 years later, to signal the approach of the Spanish Armada.

(SFX)

They even did it again, to signal the wedding of Charles and Diana. But most of us watched that on television - and the fireworks too.

(SFX)

Herodotus, in 480 BC, reported that the soldiers in the Persian Wars used their shields to reflect the sunlight and flash a warning across the sky.

It is a technique still employed.

A heliograph reflects sunlight in flashes, off a moveable mirror, like this.

(DEMONSTRATION - MIRROR)

Aldis lamps signal in morse.

(DEMONSTRATION - STAGE LIGHTING)

But all these methods have their limitations.

You must know when to expect the signal. And where to look for it.

Because light travels in a straight line, you need to see the source.

Even then, poor weather can make it hard to pick out the message.

Both sender and recipient must understand the same code.

But, most importantly, none of these devices takes anything like full advantage of the swift speed of light, for they are restricted by the slow speed of man, who can neither send nor receive the information quickly enough.

For centuries, communication marked time.

MICHAEL FARADAY changed all that.

His discovery of the laws of electromagnetic induction made it possible to generate electricity continuously.

And men found ways to use electricity to carry signals over long distances.

Sender and receiver no longer had to be within each other's sight.

Faraday's work led directly to the development ... of telecommunications.

(TURN OFF LECTERN LIGHT)
(WALK OFF TO LEFT)
(A/V SEQUENCE)
(TURN ON LECTERN LIGHT)

But all this is not enough.

Today's worldwide communications network has its limitations, for we need to send more information, more quickly and more cheaply.

Now, one hundred and fifty years after Michael Faraday's discoveries we are turning once again to light to bring us all together.

To see why, and how, we need to understand light, and the way a modern communication system works.

James Clerk Maxwell, the Scottish physicist who took up Faraday's work, demonstrated after years of experiment that electromagnetic forces travel in a similar patterns to light - and at a similar speed.

'We can scarcely avoid the inference', he wrote, 'that light consists in the transverse undulations of the same medium which is the cause of electric and magnetic phenomena'.

In other words, they were variations of the same thing.

One you see; one you don't.

Light is therefore most commonly defined as 'visible electromagnetic radiation'.

So you can see why it is a fit and proper subject for a Faraday Lecture.

Not all electromagnetic radiation is visible, of course.

Most of it is not.

Light occupies only a tiny part of the entire range - the spectrum - of electromagnetic radiation.

We measure this radiation by its frequency and today we usually express frequency in hertz, or cycles per second - a cycle being the period between the peak of a wave passing and the next.

Near the bottom, or low frequency end of the spectrum, are radio frequencies, like ...

(SFX: BBC Radio 4 broadcasting on 200 Khz)

At the top, or high frequency end, are cosmic rays, with frequencies of tens of millions of millions of millions of hertz.

Light - that part of the spectrum visible to our eyes - has a frequency of between five hundred, million, million hertz (red light), and one thousand, million, million hertz (violet light).

Slightly lower in frequency than red light is infra-red (which we cannot see, and which we should properly call radiation, not light).

(You may have seen films of animals taken in the dark by cameras sensitive to infra-red radiation).

Slightly higher in frequency than violet light is ultra-violet which gives us a sun-tan, and causes certain materials to fluoresce.

(DEMONSTRATION - UV LIGHT)

This lectern has been painted with a clear fluorescent paint and you can see how ultra-violet radiation is making it shine in the dark.

We've seen that frequency is generally given in hertz.

Hertz was a German who died very young. He'd set out to answer the question Maxwell had posed: if light can travel through the air, why not other electromagnetic waves?

Hertz showed that they could, and did, in experiments which were to lead to the work of Marconi and the first radio tranmissions.

Marconi gave his name to a company.

Hertz gave his to a measurement; the measurement - of frequency.

Band-width is the measure of the range of frequencies, within the electromagnetic spectrum, employed to transmit a signal.

Telephone speech ranges from 300 hertz to 3,400 hertz.

So the bandwidth of telephone speech is 3,100 hertz.

Hi-fi music occupies a bandwidth of 20,000 hertz.

Colour television: six million hertz.

The bandwidth occupied by one colour television signal is virtually the same as that needed for 1,500 speech signals.

So... the higher the frequency, the wider the potential bandwidth, the more signals we can transmit.

Which is why the high frequency of light is of such value.

The bandwidth available in the visible spectrum - from red to violet - is sufficient for more than fifty million colour television channels broadcasting simultaneously.

Or, for one hundred thousand million telephone callers all talking at once.

Everybody in the world could make a telephone call at the same time and still use less than ten per cent of the available bandwidth.

But there might be one or two practical difficulties!

If you want to talk to someone on the telephone, you need: first...

A microphone, to convert your voice into an electrical signal.

A pair of wires to connect you, through the local telephone exchange, to your friend's house.

The exchange itself - in effect, a very large switch, which connects the pair of wires from your house to the wires from your friend's.

And, last, a receiver, which converts the electrical signal back into an audible sound for your friend to hear.

If you wish to speak to someone on a distant exchange - perhaps on the other side of the world - your call needs to pass through several interconnected exchanges in what are termed the trunk network and the international network.

To do this efficiently, we combine, or 'multiplex', many calls onto one coaxial cable, such as this, or onto a radio signal, or a microwave signal.

Now, as the signal travels along the cable (or through the air) it gets weaker, because of the resistance of the medium.

For your friend to hear you clearly, we have to amplify the signal at intervals of about two to four kilometres.

We do this with devices called repeaters.

But, when we amplify the speech, we also amplify any noise or interference which may have got into the signal.

A way of getting over this problem was invented in 1936 by an STC Engineer called Alec Reeves.

He proposed that the speech signal ... should be sampled - many thousands of times a second.

The values of each of these samples would be coded in binary form.

Noughts and ones.

Pulse - or no pulse.

The signal would then be transmitted as a series of pulses of equal height.

So with Reeves' technique, which he called Pulse Code Modulation - PCM - we don't send the original signal, but information about it.

And this information enables us to reconstruct the signal at the receiving end.

And we can go further.

We can take the pulses representing many individual signals.

And intersperse them.

Then, at the receiving end, separate out the pulses into their proper order and reconstruct the original signals.

This process is called Time Division Multiplexing - TDM - and is one way of sending a large number of digital signals down one cable.

Where we had repeaters before, we now completely reconstruct the original stream of pulses - and only those pulses - and thus virtually eliminate any noise or interference.

So we no longer call these repeaters but regenerators, because they recreate or re-generate the pulses.

Pulse Code Modulation and Time Division Multiplexing therefore enable us to improve the quality, and increase the capacity of telecommunication systems.

And because the speech signal is turned into digital form, it is much easier to transmit data and television signals through the same network.

But even using digital techniques, a coaxial cable can still carry only a tiny fraction of the information we could transmit if we were able to use light.

We saw, however, that light has severe limitations as a communications medium.

How do we overcome them, so that we can use light in today's systems?

We need three things:

A suitable light source.

A receiver to turn the light back into an electrical signal.

And a channel to guide the light so that sender and receiver need no longer be within sight of each other, and so that poor visibility is no longer a hindrance.

First, the source of light.

Ordinary lamps are no good - too slow, too weak.

Far better to use a laser.

Laser stands for Light Amplification by Stimulated Emission of Radiation.

Lasers are widely used today.

There are high powered devices... that can cut steel ... and stone. Some help doctors to treat delicate organs of the body. Others help soldiers to aim, pilots to navigate, surveyors to measure.

The sort of lasers I am talking about are far smaller than those you have just seen, but they have some very special - and very useful - properties.

They are semiconductor lasers, and this is how they work:

(TURN LECTERN LIGHT OFF)
(FILM) FILM ENDS: "... a beam of a precisely defined diameter."
(TURN LECTERN LIGHT ON)

A semiconductor laser emits short pulses of about a hundredth of a watt over a minute area.

This corresponds to five thousand watts per square centimetre - as much energy as the sun emits from the same area of its surface.

The best way to use a semiconductor laser is to switch it on and off very rapidly.

So Pulse Code Modulation - Alec Reeves' system of turning information into digital pulses - is an ideal transmission method for an optical communication system.

Now the receiving end.

Here we're looking for a way to convert light back into an electrical signal.

To understand what happens here, we need to know a little more about the nature of light.

Isaae Newton thought that light consisted of particles, or corpuscles as he called them, which were bounced off the eye like a ball off a wall.

At the time, his - "corpuscular" theory was discarded in favour of the wave theory, which we looked at earlier.

Then, in 1905, Einstein suggested that the energy in light might, indeed, be carried by particles, whose energy depended on the wavelength of that light.

Experiments confirmed his theory, and the particles of light are now called 'photons'.

When certain materials are struck by photons they release electrons.

Electricity is created.

So this is known as the photo-electric effect.

It is used in the photoelectric cells which provide electricity for spaceships and satellites.

They are called solar panels and they take sunlight and turn it into electrical power.

(DEMONSTRATION - SOLAR PANEL)

This model shows how such a panel works.

As light strikes it, you can see from the dial that a current is produced.

So what we need at the receiving end of an optical communication system is a device which exploits this effect.

____

Such devices are called photo-detectors.

But trying to detect each tiny electron is very difficult. We need to magnift or amplify, the signal.

A way to do this is to use a device in which the first electron releases a whole shower of electrons.

This is called an avalanche photo-diode.

Now the medium of transmission.

In order to get the light from the laser source to the detector, we need a material which will contain the light which will guide it round corners, and which will exclude anything that might block it.

Glass perhaps?

We've used it for years to admit light and keep out the weather.

But glass is brittle and, if you look through the edge of a pane, not very clear. So how could it be used for such a purpose?

It was in 1966 that two STC engineers, Charles Kao and George Hockham, found a solution.

They proposed a glass so pure that if we could get a block 35 kilometres thick we should be able to see through it as clearly as through fresh air on a sunny day.

It took ten years of research and development to find such a material - but, with others, they did it!

(Michael Faraday would have been impressed, for he wrote a paper on 'The Improvement of Glass for Optical Purposes', but gave up when his experiments failed to make headway!)

And Kao and Hockham said that to transmit light, this ultra-pure glass should be made into a fibre almost as fine as human hair.

So fine, the eye of a needle seems, by comparison, massive.

Glass this thin will bend. But why won't light simply disappear through its transparent walls as it would through a window?

The answer is that there is a way to contain the light within the fibre.

I'll show you how on this model.

(TURN LECTERN LIGHT OFF)

(DEMONSTRATION - GLASS TUBE)

This tube represents a solid column of glass.

When I direct the light from this laser towards the surface, it passes through it, ~~and its angle changes slightly with refraction.~~

As I tilt the laser, and so alter the angle at which the light hits the surface, you'll see that, instead of passing through, it is reflected from one side to another down the length of the tube.

This phenomenon is called total internal reflection.

We exploit it to bounce our laser.pulses from side to side down the fibre.

How is such a fibre made?

(DEMONSTRATION - TUBE)

The process starts with a tube like this, made from that ultra-pure glass.

(TURN LECTERN LIGHT ON)

(DEMONSTRATION - FIBRE)

You probably can't even see this, but this is a glass fibre.

The fibre is extremely thin.
Yet it is incredibly flexible.
And very strong.

(DEMONSTRATION - FIBRE BUNDLE)

So that you can see light passing through glass fibre, I have got a bundle of fibres, which I can bend in all directions, and you can still see light coming out of the end.

For the sake of demonstration, I was using visible, white light.

In practice optical communication systems employ infra-red radiation, just beyond the limits of human vision.

There's a very good reason for this.

Like any signal, the optical signal gets weaker - or attenuates - over distance. It's one of the properties of glass that infra-red radiation of certain frequencies, suffers much less from attenuation than visible light. A lot of research is being done to find lasers that will generate those frequencies which work most effectively.

We can now ~~put the laser, the fibre and the photo-detector together, to~~ assemble an optical communications system - ~~which looks like this~~.

A laser source ...

an optical cable ...

and a detector.

And this is how it works. An electrical signal is turned by the laser into pulses of light.

These are bounced from side to side along the fibre until they're converted by the detector back into electrical form.

What are the benefits of a system like this?

Because of the enormous bandwidth available in the optical signal, an optical cable can carry far more information than a metallic one, *so it can be much smaller.*

(DEMONSTRATION - CABLE SAMPLES)

This cable, made from glass fibres, could carry many more telephone conversations (or more computer data, or TV signals) than this large, heavy copper cable or this coaxial cable.

Telephone cables normally run in ducts under the streets.

When all the ducts are full, we have to dig up the roads to install more ducts if we want to lay more cables.

We can pull an optical cable into the empty spaces between the existing cables, or remove them and install optical cables with much greater capacity.

As the optical cable need contain no metal, it is immune to electrical interference. This makes it ideal for use in power stations and factories and by electrified railway lines.

And as there is no electric current in the optical cable, there can be no spark - and so no danger of explosion.

It can even withstand being struck by lightning

One of the first optical fibre systems in this country was installed for the Dorset police to link their computers after the <u>metallic</u> cable previously used had been destroyed by lightning.

It is very secure too, for as the light signal does not penetrate beyond the outer surface of the fibre, it cannot easily be 'tapped' as a metal cable can.

Conventional metal cables use large quantities of copper or aluminium, both of which are expensive to obtain and are derived from ores that must, one day, be exhausted.

Optical fibre, on the other hand, is made from silica, a purified sand: one of the commonest materials on the earth's surface.

We saw that, like an electrical signal, the optical signal gets weaker as it travels along the fibre.

So we need regenerators.

But because the optical signal is transmitted so much more effectively, we need fewer *than in a conventional system*.

And as they can usually be housed in existing buildings, not buried underground, they're cheaper to install and maintain.

Already, we can have optical systems with regenerators 50 kilometres apart.

Improvements in materials and components mean we should soon be able to increase this to 75 or 100 kilometres.

One day, we think <u>one thousand</u> kilometres might be feasible.

So, optical systems reduce costs and increase capacity, bringing <u>new</u> services, and making many others far more economical than in the past.

The world's telecommunications authorities have, naturally, not been slow to take advantage of these benefits.

The world's first trial of an optical broadband system using regenerators and carrying normal telephone traffic was in 1977. It was produced and installed by STC, in conventional cable ducts, between Hitchin and Stevenage, a few miles north of London.

The first fully operational system in the UK was completed in August 1981. It connected Croydon to Vauxhall and, appropriately, ended at the Faraday Exchange in London.

Since then, many more systems have been laid by British Telecom, and we can see how the network will grow.

Indeed, British Telecom will probably install no new metal coaxial cable in the trunk network after 1985 - relying, instead, on optical cable.

Major systems are being built, too, in Germany ... France ... America ... Japan ... and several other countries, and many more are planned.

Optical communication will be international.

Cables have been used for over a century to carry telecommunications traffic beneath the sea. At first, they carried telegraph signals.

Submarine telephone cables began to be laid over relatively short distances in Europe in the 1930s; the first transatlantic telephone cable was installed in 1956.

Today, the world's oceans are crossed and re-crossed by a vast network of cables, each able to carry thousands of calls. A quarter of a million kilometres in all, with some ten thousand repeaters; on the sea bed.

Because of the greater capacity of optical cables, and because regenerators can be so much further apart than with conventional technology, optical systems will enormously extend the capacity of international communication links.

In 1980, in collaboration with British Telecom, a trial optical system was laid by STC in the deep waters of Loch Fyne on the West Coast of Scotland.

The first transatlantic optical cable is expected to be in service about 1988.

So optical technology will improve all communication - worldwide.

Is this the end of the story?

~~Far from it~~. *Not quite*.

For we are on the verge of an '<u>information</u> <u>revolution</u>'. Some say it will change our lives, as that first-<u>Industrial</u>-Revolution did.

It will call for even <u>more</u> capacity than today's systems can provide.

To achieve it, we must <u>use</u> <u>light</u> <u>alone</u>.

For this we need to do three things.

To use much more of light's potential bandwidth, we must find a different source.

Today's lasers produce an incoherent beam. one containing several frequencies.

We pulse our signal: on-off-on.

Much better to use light of a single frequency: a light we call - coherent.

And send our pulse by varying its frequency.

We can do this far faster - and so send much more information.

And rather than turn light to electricity and back again to light, we shall regenerate such a signal optically.

To make full use of this capacity, we must switch the light, as well.

(DEMONSTRATION - SEARCHLIGHT)

We can move the fibre directing the beam to the right outlet.

Deflect the light itself, with a prism or mirror.

Or, best of all, pass it through a material that will bend it, with precise control, when a voltage is applied ... thousands of millions of times a second.

Photons, not electrons, will connect us.

When we master these techniques we shall have a resource limited only by our own imagination.

And our imagination is already at work.

We know that we shall not just talk on the phone, but talk and see each other, too.

Send pictures.

Give doctors notes on patients miles from home.

The latest information on their subject.

We'll do <u>this</u>, too, for engineers.

For scientists.
Lawyers.
Architects and artists.

Farmers and financiers.

For <u>students</u>, too!

Send data as far and as fast as we wish.

Run dangerous processes from a safe distance.

We'll shop from home if we like.

Order our goods.

Pay for them.

Book our holiday.

Or an evening out.

Check our balance in the bank!

Vote on vital issues.

Receive our newspapers electronically.

And our mail.

We'll work, perhaps, from home.

We shall have as many television channels as there are human interests.

The disadvantages of distance
will diminish.

And those of time.

We will communicate anything to
anyone, anywhere.

With all the speed of light.

But stop!

(SCREEN TO BLACK)

(SPOT ON SPEAKER)

And think, for a moment, what
this might mean.

Every activity in which we use
information will be simpler,
swifter, surer.

We know new technology brings
its problems as well as its
advantages.

Jobs will change.

What we call work, and what we call leisure.

But this new technology will bring us greater freedom too; help us solve some of our problems.

And there is more to it than this.

We built our way of life on our ability to acquire information, and to communicate it.

And when we have more knowledge,- information understood - many things may change.

The way we do things certainly.

And we ourselves, perhaps.

But <u>we</u> shall be the <u>masters</u> of this new technology, not its servants.

Michael Faraday would be proud of us.

(<u>TURN LECTERN LIGHT OFF</u>)

(KILL SPOT)

(SFX/MIRROR DESCENDS)

END

Script written by

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Scanned and OCR-ed

in memory of

Keith John Saunders (1945-1998)

– who helped me imagine

and believe in the future –

by his eldest son,

Gareth J M Saunders.

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