RTT TECHNOLOGY TOPIC
January 2012

Next 25 January 25

On the 25 January every year, people celebrate the birth of a famous Scottish poet, Robert Burns (1759-1796), a pioneer of the romantic movement.

A few years ago he was voted as the world's greatest Scot by a Scottish Television channel. Well possibly but Alexander Graham Bell and Alexander Fleming are two strong alternative candidates.

In this month's technology topic we argue the case for James Watt as 'the great scot' both for his role in the industrial revolution but also because his life and work have contemporary relevance to telecommunications power and bandwidth theory and engineering practice.

This gives us an excuse to talk about an event being held at the Science Museum, Next 25 January 25 that aims to demonstrate how the past informs our future, the process of looking twenty five years back in order to look twenty five years forward and the new RTT book, Making Telecoms Work - from technical innovation to commercial success which is **now available.**

The Scots National instrument is the bag pipe. Bag pipes date back to 1000 BC but our story starts with another equally old instrument.

Why trumpets don't work as communication devices

In last month's technology topic we argued that mobile broadband networks are power limited rather than bandwidth limited. The implication is that power efficiency is more important than spectral efficiency and has a greater impact on EBITDA and ROI. Power efficiency improves profitability and determines economic efficiency.

Power efficiency is a composite of how a system generates power and handles power with the end objective being to transmit and receive **information energy**. A more efficient mobile broadband dongle or smart phone will work for longer and send more data than a less efficient device and or will be able to transmit voice and data over a longer distance.

This is not a new concept. The Ancient Greeks invented the trumpet as a military communications system, turning a small amount of energy into a large amount of noise. Modern communication systems work on similar principles but need to discriminate more efficiently between multiple noise sources, differentiating the energy of interest (information energy) from other unwanted received energy.

The dynamic range of the receiver determines how much power can be processed; the selectivity of the receiver determines the efficiency with which wanted energy can be separated from unwanted energy.

Increasing the dynamic range of an active device increases the amount of current drawn by the device. Improving the efficiency of this process produces a gain in overall system efficiency. The combined efficiency of the transmitter and the receiver therefore determines overall system efficiency.

Watt next? lessons from the first industrial revolution

The first industrial revolution was based on the acquired ability to turn heat into 'useful' energy. Improving the efficiency of this process improved the effectiveness of the process which improved the profitability of the process.

In 1969 Rodney Law, the Curator of Mechanical Engineering at the Science Museum unearthed a brass cylinder from the top of James Watt's workbench.

When James Watt died in 1819 (at the age of 83) his workshop in Birmingham had been locked and its contents left undisturbed as an 'industrial shrine'. In 1924, the complete workshop, including its door, window, skylight, floorboards and 434 objects used or created by Watt, were removed and transported to the Science Museum.

James Watt was considered by contemporaries as the founder of the Industrial Revolution. His improved engine meant that steam could be used in breweries, potteries and textile mills. Watt was the first engineer to have a statue in Westminster Abbey and was arguably the first 'scientific entrepreneur', 'turning science into money' generating wealth with his partner Matthew Boulton.

Watt's workshop includes the world's oldest circular saw, parts for flutes and violins (no bag pipes), the oldest surviving pieces of sandpaper, a roller press for copying letters and a device for standardizing coins for the Royal Mint.

The brass cylinder turned out to be Watt's original 1765 model for the first separate condenser, the greatest single improvement to the steam engine ever made and the basis for the industrial revolution.

Scientist or engineer? Introducing Mr Joule, Mr Newton, Mr (Lord) Kelvin, Mr Cavendish, Mr Faraday, Monsieur Ampere and Signore Volta

Was James Watt a scientist or an engineer? That depends on the definition of science. If that definition includes working from observation and practical experimentation then yes. Theoretical scientific understanding lagged behind engineering practice in the same way that the science and understanding of electricity lagged behind contemporary experimental practice.

In 1882 the Association for the Advancement of Science announced that the basic unit of power would be described as 'the watt', one watt being the rate at which work is done when an object's velocity is held constant at one meter per second against a constant opposing force of one newton, the newton being the amount of net force needed to accelerate a mass of one kilogram at a rate of one meter per second squared also equal to one joule per second.

Kelvin (1824 to 1927) took the body of work undertaken by Isaac Newton (1642 to 1727), Watt (1736 to 1819), Henry Cavendish (1731-1810), Michael Faraday (1791-1867) and Joule (1818-1889) and applied the principles of energy conservation and dissipation to electro magnetism with the watt being the rate at which work is done when an amp (Andre Marie Ampere 1775 to 1836) of current flows through an electrical potential difference of one volt (Alessandro Volta, 1745 to 1827).

Knowledge acquired through observation and experimentation and measurement (metrology) was transformed into technology (steam engines or electrical circuits) that had engineering applied to that was described scientifically and mathematically so that standardized products could be developed that made existing processes more efficient and effective which in turn created market and business opportunity.

Steam power is also credited with helping Wellington defeat Napoleon and telecommunications can be argued to have largely determined the outcomes of most if not all twentieth century conflicts. The ability to use power efficiently at an engineering level translates into military advantage with consequent political gain.

Social gain is possible too but can be elusive. Economic gain may be unevenly distributed with collateral costs, the impact of steam power on Indian textile manufacturers being an example.

Technology transformations often result in an increase in economic value but also a shift in ownership of that value.

Back to Mobile Broadband

But back to mobile broadband. We have stated that power efficiency is more important than spectral efficiency. This is an over simplification because spectrum is now auctioned not allocated which means that improving spectral efficiency improves the return on spectral investment. However the most cost efficient way to improve spectral efficiency is to improve power efficiency, the ability to generate and handle power.

Power is used in all telecommunication systems to generate a carrier which is launched into guided media such as cable, copper, fibre or unguided media such as radio or optical free space. The carrier will be at a specific frequency and amplitude. Information can be applied to the carrier by changing the frequency and or amplitude and or phase of the carrier.

The overall system efficiency is determined by the efficiency with which the carrier wave is generated, the efficiency with which the information is applied to the carrier and the efficiency with which information is taken off the carrier. Like the steam condenser, the objective is to minimize wasted energy.

Efficiency gains in telecommunications are generally achieved by a combination of materials and mathematical innovation. SAW and FBAR filters are an example of materials innovation used in more or less all mobile broadband user devices.

Signal processing in the transmit and receive path is an example of mathematical innovation. Andrew Viterbi and his eponymous Viterbi encoder/decoder provide a contemporary example of an efficiency gain achieved through an elegantly applied mathematical construct.

Wi FI and Wide Area Wireless system innovation

Wi FI provides an example of how wireless systems are evolving in the frequency, phase and amplitude domain. The **IEEE Very High Throughput working group** is presently specifying a new physical layer 802.11ac to be applied in or across the existing 2.4 and 5 GHz bands.

As with present Wi Fi, OFDM the channel bandwidth is 20 MHz but with optional 40 MHz, 80 MHz and 160(80 plus 80 MHz) bandwidth options an FFT size of 64,128 or 256 and modulation that can either be BPSK,QPSK, 16 QAM or 64 QAM. Up to 8 spatial MIMO streams can be supported. A parallel proposal implements a 2 GHz physical layer at 60 GHz known as 802.11ad. Both physical layer options are claimed to be capable of supporting up to 7 gbps throughput.

Achieving this theoretical throughput in practice is dependent on generating the carrier power efficiently, modulating the carrier efficiently, transmitting the modulated waveform efficiently, receiving the carrier efficiently and efficiently demodulating the wanted information from the carrier.

The high level modulation states in particular require close control of amplitude and phase errors introduced at any stage of the signal chain and the envelope variation on the composite signal implies a high order of linearity. As with existing OFDM systems, pilot symbols are used as a way of characterizing and mitigating channel impairments and distortions.

This is a bit like **Charles Babbage and his calculating engine**. Babbage new what he wanted to achieve but could not achieve the accuracy he needed from the mechanical components –

manufacturing tolerances in the 19^{th} century were just not up to the challenge.

Similarly there is not enough digital signal processing power yet available to make the 802.11 ad or ac physical layer work efficiently though unlike Babbage we are talking three to five years away rather than thirty to fifty years.

The challenge is then to scale this to wider area systems like LTE where the user equipment output powers and system dynamic range are significantly higher.

Not much has changed

So really not a lot has changed. Many modern research laboratories are every bit as untidy and apparently chaotic as Watt's laboratory but the principles are similar – materials innovation, measurement, manufacturing and mathematical innovation creates market opportunity which creates business opportunity.

The quality of curiosity – why (some) engineers live longer?

And to finish on a positive note, it is noticeable that innovators in general, excluding the ones that accidentally get electrocuted or poisoned or run over, in most cases live to a happy old age, Tesla and Edwin Armstrong being two exceptions.

Curiosity, a fundamental driver behind innovation, may be a reason for this longevity.

The engineer is dead? Only when the engineer runs out of energy and that often takes a surprisingly long time.

A Chance to join the Watt Next Tour during the 'Next 25' event at the Science Museum Wednesday 25 January 2012

Watts Workshop has been painstakingly rebuilt in the Science Museum and we have been provided with privileged access with a visit hosted by Ben Russell, the Curator of Mechanical Engineering.

The 6500 objects with most of their original dust intact are now on display alongside his iconic early steam engines in the Museum's **Energy Hall.**

Two years ago we helped co-promote an event which marked the 25^{th} anniversary of the mobile phone industry in the UK. **Cellular 25** was organised by Cambridge Wireless, chaired by Sir David Brown and featured presentations from the UK cellular operators and five key vendors, followed by a dinner and a large sponsored birthday cake.

The event helped to raise funds for the new gallery at the Science Museum, The Making of Modern Communication, opening in 2014.

Two years later the Museum are, as you might expect, two years closer to the launch of the gallery and have some exciting plans that they would like to share with us.

These include a number of projects that engage with different sectors of the telecoms industry drawing on the archive resources of the Science Museum including a book project, **Making Telecoms Work – from technical innovation to commercial success** with the international publishing house, **John Wiley and Sons.** These projects are part of **on-going fund raising initiatives** that also help to demonstrate **the contemporary relevance of the Science Museum to present and future strategic decision making in the telecoms industry,**

Join us for NEXT25 on January 25 to hear about the new book, to learn about follow on projects, to get an update on progress with the gallery and to debate and discuss how the industry will change over the next 25 years.

Details on the event can be found **HERE**

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RTT Technology Topics reflect areas of research that we are presently working on. We aim to introduce new terminology and new ideas to help inform present and future technology, engineering, market and business decisions although as you can tell we sometimes stray into more philosophic territory. There are over 130 technology topics **archived on the RTT web site**. Do pass these Technology Topics and related links on to your colleagues, encourage them to join our **Subscriber List** and respond with comments.

About the new book from RTT
The new RTT book 'Making Telecoms Work- from technical innovation to commercial success ' is now available and can be **ordered from the publisher John Wiley and Son** or from **Amazon**

Contact RTT
RTT, the Jane Zweig Group and **The Mobile World** are presently working on a number of research and forecasting projects in the mobile broadband, two way radio, satellite and broadcasting industry. If you would like more information on this work then please contact
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