RTT TECHNOLOGY TOPIC
August 2018

From Silk Worms to Smart Phones

In last month's technology topic, Smoke to Smart Phones, we suggested that long distance communication started after humans succeeded in making and managing fire and realized that smoke could be used for long distance signalling. This may have been as long ago as one million years.

Fast forward to 10,000 BC and fire played an equally important role in extracting copper from its ores, the Mesopotamians around 5000-6000 years ago are generally acknowledged to be the first society to exploit copper on a wide scale. The inherent softness of copper made it ineffective as a tool or weapon but the addition of tin produced bronze, a material that was harder and could be forged and cast, an early example of combining two metals to produce a new base property to which manufacturing innovation could be applied. Adding zinc to copper for example produces brass. We discussed how bronze, and later, brass, was used to produce trumpets, resonant devices that produce frequency specific amplification and referenced the use of trumpets as instruments of war (long distance audio signalling). Material combinations including copper nickel alloys also came to be used in early coinage probably from the third century BC.

In this month's technology topic, ***From Silk Worms to Smart Phones, Resonance, the role of materials and manufacturing innovation in mobile phones***, we take the story forward to the recent past and the invention of the FBAR filter, the work horse of 4G and 5G phone RF front ends, with a case study of how the device was invented, developed and manufactured.

Read on

Temperature has always been important in the metal manufacturing process. The start of the Iron Age in Britain around 650 BC coincided with the importation of blast furnace techniques. Iron tipped plough shares meant that heavy clay soils could be tilled. In the 19th century, air blasting techniques and the Bessemer process allowed the impurities in iron to be separated as slag to produce steel, the foundation for the built world of the 20th Century. The addition of chrome (and silicon, nickel, carbon, nitrogen and manganese) produced stainless steel.

As our ability to produce and manage heat has improved, we have been able to make materials with ever more exotic properties; Titanium for example, first discovered at the end of the 18th century, has a melting point of 1667 degrees Celsius and a boiling point of 3287 degrees Celsius. The ability to weld titanium has been crucial for high performance fighter planes, commercial and military jet engines and rockets. Materials and material combinations have no practical purpose if they cannot be manufactured to produce something useful.

Materials do not always come from the ground but can come from nature. One of the earliest and certainly most commercially important examples is silk production, developed around 5000 years ago in China. The techniques involved remained a closely guarded secret for 2000 years. There is little that the Western world can teach China about intellectual property protection.

http://www.silk-road.com/artl/silkhistory.shtml

The secret of silk sericulture is a blind sightless moth, Bombyx Mori, that lays 500 eggs in 5 days and then dies (hence the name). Controlled evolution produced the moth that today cannot fly but can only mate and produce eggs. The 'silk secret' was partly based on diet (to prevent premature hatching) and a controlled temperature where the eggs are kept at 65 degrees Fahrenheit (or presumably the Chinese contemporary equivalent), increasing to 77 degrees at which point they hatch. Then you need a ready supply of mulberry leaves every half hour delivered to the worms. The worms become fat very quickly. The newly hatched silk worm multiplies its body weight 10,000 times within a month. The worms during this period have to be protected from loud noises, drafts, strong smells and the odor of sweat (don't we all?). The worms produce a jelly like substance in their glands that hardens when it comes into contact with air.

The silk worms spend four days spinning a cocoon. Then, rather sadly, they are steamed or baked and dipped into hot water to loosen the tightly woven elements which are then unwound onto a spool to produce a filament between 600 and 900 metres long. Between five and eight of these filaments are twisted together to make one thread.

At this point you might begin to wonder how silk worms can possibly be connected with FBAR filters. The answer is the violin. Andrea Amati of Cremona (1511-1577) is generally credited as the maker of the first violins and their larger cousins (the cello and double bass). He was however drawing on a long tradition of stringed resonance probably starting with the Arabic Rabab in the 9th century. The Rabab consisted of two strings made of silk attached to an end pin used to tune the strings in fifths with the fundamental frequency and harmonics amplified and response filtered by a pear shaped body made of gourd and a long neck. The instrument had found its way into Europe by the 11th century as the rebec with three strings (many of the original Amati's had three strings) and a wooden body.

In the late early 90's a young violin playing engineer employed in Hewlett Packard's filter division was thinking about how the performance of a surface acoustic wave filter could be improved and if possible to use bulk modes (with higher velocities) and using different stiffer materials to increase the velocity and the Q.

The use of materials to produce a specific frequency reference dates back to the discovery of the piezo electric effect by Pierre and Jacques Curie in 1880. The Curie brothers discovered that when pressure was applied to certain crystals, an electrical voltage was generated. Conveniently for the radio industry, this proved to be a bi directional effect. Applying electrical voltage to certain crystals would cause them to vibrate at a specific frequency.

In 1917, Paul Langevin used quartz crystals in a sonar device for submarine detection and from then on quartz became the basis for detecting and creating specific audio and radio frequencies. In the Second World War, similar research in the US, Japan and the Soviet Union showed that certain classes of ceramics exhibited piezo electric behaviour. Courtesy of World Wars One and Two we were provided with a choice of quartz crystals and or ceramic based devices capable of providing accurate frequency and time referencing in radio products. The invention of the transistor in 1947 and the integrated circuit in 1958 used in combination with these devices provided the basis for the power efficient and spectrally efficient radio transceivers which have powered the wireless industry for the past 60 years and the cellular industry for the past forty years.

In 1965 a young Professor and graduate student at UC Berkeley Richard White co-wrote a paper with his colleague FM Voltmer discussing the theory and practice of etching interdigitated transducers (IDT's) on to a piezo substrate. ('Direct coupling to surface elastic waves'. *App.l Phys. Lett. 7,1965).* These devices came to be known as a Surface Acoustic Wave (SAW) filters with an early application in the 45 MHz IF stages of TV receiver front ends.

SAW filters use semiconductor processes to produce combed electrodes that are a metallic deposit on a piezoelectric substrate. In a SAW device, the surface acoustic wave propagates, as the name suggests, **over** the surface of the device producing a reference resonance which can be used as a filter or any form of tuned circuit. SAW filters became and still are an essential component in televisions and cellular phones and any device where locally generated transmit power has to be separated from the local receive path and constrained within a pass band. The performance of SAW devices has steadily improved and they remain a cost effective and compact alternative to traditional ceramic filters.

However the young engineer at HP had a feeling that the roll off characteristics (poor Q) and large frequency drifts over temperature of SAW filters could be improved by sandwiching a thin film of piezo electric material **between** two metal electrodes. When an electric field is created between these electrodes, an acoustic wave is launched **into** the structure. The vibrating part is either suspended over a substrate or manufactured on top of a sacrificial layer and supported around its perimeter as a stretched membrane, with the substrate etched away.

The devices are often referred to as Thin Film Bulk Acoustic Resonators (T-FBAR) or more specifically 'Free-standing Bulk Acoustic Resonator' (FBAR) to distinguish between the two kinds of bulk acoustic resonators (BAW) — solidly mounted resonators (SMR-BAW) and free standing resonators (FBAR). The piezoelectric film is made of aluminium nitride deposited to a thickness of a few microns or less; the thinner the film, the higher the resonant frequency.

BAW devices are useful in that they have the highest Q, the best power handling and the lowest temperature coefficient of frequency drift of any technology in the piezoelectric family. BAW filters are orders of magnitude smaller than microwave ceramic filters and have a lower height profile.

However in 1993 there was no prior experience of making such a device and minimal understanding of how to reliably and repeatably deposit thin highly textured aluminium nitride such that it could be deposited uniformly across a whole wafer (then 4” now 8” diameter)-that (although not known at the time) would need to scale to production quantities of millions (and subsequently billions) with uniform performance at a cost of much less than a dollar per device. And so began a development project that for the next ten years grappled with the material and manufacturing challenge of producing a technically and commercially viable FBAR device finally yielding a product that could be sampled to handset manufacturers designing first generation handsets.

However the performance advantage of FBAR filters came with a cost disadvantage relative to SAW devices (which were and are simpler to manufacture). What FBAR filters needed was a problem to solve that would be difficult to solve with standard SAW devices. Fortuitously this was provided by the PCS 1900 band plan in the US which combined an ambitiously wide pass band with an ambitiously narrow duplex gap and two inherently noisy radio standards (TDMA and CDMA) which needed to be kept apart.

This single problematic band provided the basis for a stable and financially viable FBAR market subsequently sustained by the introduction of LTE and a general widening of pass bands and narrowing of duplex gaps right across the cellular radio spectrum (from 450 MHz to 3.8 GHz)

The filter division of HP no longer exists but morphed into Avago which then acquired Broadcom (where the huge success of FBAR became the economic driver for both the LSI and the Broadcom acquisitions), but the FBAR filter remains an exemplary case study of how a long term development programme drawing on the leading edge of materials and manufacturing technology can create a long lasting profitable market opportunity. The inner secrets of this process are as fiercely protected as the secrets of the silk worm (including the temperatures used) though keeping the secret for 2000 years may be over ambitious and probably not useful.

The role of resonance in radio is however likely to remain harmonically fundamental to future communication systems and explains why companies with unique manufacturing capabilities and the engineers they employ remain highly valued.

It is also a reminder that we live in a digital age in an analogue world and that is never going to change.

Ends

Our thanks to Rich Ruby still working on new and disruptive resonator technologies and new non-filter applications and his long term co-worker William Mueller for their helpful and perceptive inputs to this technology topic.

And a correction of last month's Technology Topic in which 1844 in Baltimore was suggested as a breakthrough date for electrical communication. John Liffen, Curator Emeritus at the Science Museum comments '*The use of the electric telegraph was presaged as a practical communications device in London in September 1837 and first adopted for commercial purposes in 1840 on the London & Blackwall Railway. Public access to the electric telegraph for sending personal messages was perhaps first achieved at Baltimore but it depends on what you mean by 'breakthrough'.*

New Book

And a holiday event

If you happen to be in central London next week and like Jazz, come along to the Spice of Life in Soho on Wednesday evening August 8 – Let's Get Lost recreates four decades of concert and studio recordings by Chet Baker- should be a great evening

www.retrochet.com
http://www.wegottickets.com/event/444747

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