Chapter 5
Mesmerized by the Moving Image

A combination of an inquisitive young mind, lots of spare time and inspiring reading has propelled many inventors into their successful careers. For a twelve-year-old youngster called Philo T. Farnsworth, this kind of fruitful cohesion happened after his family moved to a large farm in Rigby, Idaho, in 1918.

While investigating his new home, Farnsworth found a pile of books and magazines about technology in the attic, devouring their contents during his spare time.

The house also had a feature that was novel to Farnsworth and greatly tickled his curiosity—a rudimentary generator of electricity, supplying the electric lights of the farm. This was a huge improvement over the simple oil-lamp lighted log cabin Farnsworth had lived in in Utah before the move.

Farnsworth learned the quirks of the somewhat unreliable generator and, to the joy of his mother, proceeded to install a salvaged electric motor to run the manual washing machine of the household.

The books and magazines that Farnsworth had found contained references to the concept of television, although no functional wireless demonstrators were yet available. The state-of-the art in wireless at the time were simple audio transmissions, but the idea of transmitting pictures over the air was speculated on widely in technology-oriented journals.

The current idea for television at the time was based on a mechanical concept called the *Nipkow disk* that had been patented in 1884. In a Nipkow disk-based system, the image is sliced into concentric arcs by a circular plate that has holes evenly placed along its radius, and the light at each arc is used to modulate an electronic light sensor. Then by reversing the process on the receiving side in sync with the transmitter side, the dynamically changing view that is projected on the transmitting Nipkow disk can be reproduced.

This was a clumsy approach at best: having a large disk spinning at high speed would make the setup noisy and prone to spectacular mechanical crashes.

The very first functional Nipkow disk-based system was created by Russian Boris Rosing in 1907, and he continued actively working on his designs over the years. Rosing got several patents for his system and his demonstrator was presented

P. Launiainen, *A Brief History of Everything Wireless*,
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in an article published by the *Scientific American* magazine, complete with system diagrams.

Unfortunately, Rosing became one of the victims of Joseph Stalin's purges, and died in exile in Siberia in 1933.

Farnsworth understood the fundamental limitations of a mechanical approach, and started drafting a fully electronic version while he was still in high school. His conceptual design consisted of horizontally scanned, straight lines that would be stacked and repeated in rapid succession to form a continuous stream of individual image snapshots, *frames*. If these were shown fast enough in succession, they would give the impression of a moving image.

According to Farnsworth, he got the idea for *scan lines* while plowing the family fields.

Thanks to the fact that he discussed his idea with his high school chemistry teacher, giving him a schematic drawing of his planned system, he inadvertently created a valuable witness who would later help him win an important patent dispute against the broadcasting behemoth *RCA*.

Another inventor, Karl Braun, had already solved the solid-state display side of the television concept in 1897 with the *Braun tube*, the predecessor of all *cathode ray tubes (CRTs)*, which were fully electronic and fast enough to create an illusion of seamless movement. Therefore, no moving components would be needed on the display side of any television solution. Even the early version by Rosing had used a CRT for the display side.

Braun was also one of the early pioneers in wireless technology, having made many advancements in the area of tuning circuitry. This earned him the Nobel Prize in Physics in 1909, shared with Guglielmo Marconi, as discussed in Chapter 2: ***"It's of No Use Whatsoever"***.

Removing mechanical parts from the transmitter side of a television system needed a totally new approach for image processing, and Farnsworth's solution for this was called an *image dissector*:

A traditional camera lens system is used to project an image on a light-sensitive sensor plate, causing each area of the sensor to have a tiny electrical charge that is directly proportional to the amount of light being exposed on the corresponding location on the plate. By encasing this sensor into a vacuum tube-like structure with electric grids in both horizontal and vertical directions, an electron beam can be deflected along the sensor's surface, resulting in a constantly varying electron flow that is proportional to the amount of light arriving at each scanned location.

As the image dissector is fully electronic, this process can be repeated with high enough speed to cover the full sensor area several tens of times per second, and hence the successive set of still images becomes rapid enough to be perceived as continuous movement by the human eye.

By using the output of an image dissector as a modulating signal for a transmitter and embedding suitable timing control information into the signal, the stream of captured still images can thereafter be reconstructed at the receiving end, and the existing CRT technology could be utilized for displaying the received transmission.

Farnsworth's functional image dissector prototype was the first device providing the principal functionality of a *video camera tube*, and paved the way towards high-quality, easily maneuverable television cameras.

It took Farnsworth several years to finally turn his idea into a system that actually was able to transmit an image, but his faith in the huge financial potential of his invention was so strong that he even asked for an honorable discharge from his early employer, the prestigious *United States Naval Academy*. This ensured that he would be the sole proprietor of any patents he would file in the future.

Farnsworth was able to convince two San Francisco philanthropists to fund his research with 6,000 dollars, and this injection of money, equivalent to about 75,000 dollars today, enabled him to set up a lab and concentrate fully on his television idea.

With a working prototype of an image dissector, he succeeded in sending the first, static image in 1927. When the stable image of a simple, straight line of the test transmission picture appeared on his receiver's CRT, he had no misunderstanding of what he had just proved, commenting:

There you are – electronic television.

Farnsworth also showed that he had a good sense of humor: as his financial backers had constantly pushed him to show financial return for their investments, the first image he showed them was an image of a dollar sign.

In 1929 he managed to remove the last mechanical parts from his original setup and transmitted, among others, an image of his wife—the first live television transmission presenting a human subject.

But the competition was heating up, and it came with deep pockets:

Despite having a working electronic image dissector system, with relevant patents to back up his claims, Farnsworth ended up in a bitter dispute with *RCA*, which tried to nullify the value of Farnsworth's patent. *RCA* had had its own, big budget development ongoing for video camera solutions that followed the same principle as Farnsworth's version, and David Sarnoff wanted to ensure that *RCA* would be the patent owner, not the patent licensee.

Sarnoff had tried to buy rights to Farnsworth's patents for the lofty sum of 100,000 dollars and an offer to become an employer of *RCA*, but Farnsworth preferred his independence as an inventor, aiming to profit from licensing instead. This was against Sarnoff's fundamental idea of avoiding licensing fees, and he started a litigation process against Farnsworth. In court, the *RCA* lawyers openly belittled the idea that a farm boy could have come up with a revolutionary idea of this magnitude, but despite the money and manpower *RCA* was able to throw in, they eventually lost the case. A crucial witness statement that supported Farnsworth's claims came from the aforementioned chemistry teacher, who could present the original image dissector schematics drawing that Farnsworth gave him several years earlier.

This important detail dated Farnsworth's work on the subject further back in time than the work done in *RCA's* laboratories by Vladimir Zworykin, who also had filed several early patents in the area of television technologies.

What made *RCA*'s case even weaker was the fact that Zworykin could not provide any functional examples of their claimed earlier works. His patents were also overly generic. Farnsworth, on his side, had a working prototype that accurately matched his patent application, although it had been filed four years later than the version that *RCA* was pushing through the courts. Sarnoff saw the weak position that *RCA* was in, but decided to drag the case as far as possible, relentlessly appealing against the decision. His plan was to keep Farnsworth occupied with the process, draining his funds and reducing the remaining active time of the patent protection.

RCA had basically lost the case already in 1934, but it took five more years of costly, lost appeals until *RCA* finally was forced to accept the inevitable and settle the case with Farnsworth.

Farnsworth was paid one million dollars over a ten-year period, plus license payments for his patents—a considerable improvement over the original 100,000-dollar offer made by Sarnoff.

Although this seemed like a major win for Farnsworth at the time, fate was not on his side: Japan's attack on Pearl Harbor forced the United Stated to join the Second World War, and this put all development in the area of television broadcasting into the deep freeze for the next six years.

After the war, Farnsworth's patents expired just before the television hit its hockey stick curve: to the major loss of Farnsworth, the promised license payments never materialized.

The fixed payment, however, remained, and with his newly acquired financial independence, Farnsworth went on to study a multitude of different subjects, ranging from nuclear fusion to milk sterilization systems. He also patented the idea of *circular sweep radar display*, which is still the conceptual basis of modern air traffic control systems.

Despite having filed some 300 patents during his lifetime, Farnsworth did not ever succeed on the same scale as with his television invention, finally losing his wealth and falling into bouts of depression and alcoholism. The same personal issues had already been apparent during the stressful litigation process by *RCA*.

Philo T. Farnsworth died of pneumonia at the age of sixty-four.

Later in the same year of 1971, his major opponent David Sarnoff also died, at the age of eighty.

It's hard to determine whether David Sarnoff was a true genius, or just a ruthless businessman who over and over again happened to be in the right place at the right time. But it is clear that the relentless litigation from *RCA* against Farnsworth was the prime cause of Farnsworth's mental and physical breakdown later in his life.

Although some sources even dispute the existence of the original *Radio Music Box Memo*, referred to in Chapter 4: ***The Golden Age of Wireless***, there is no doubt that *RCA* became the first true broadcasting conglomerate under Sarnoff's lead. But he was not shy of trying to wipe out Farnsworth from the pages of history: the 1956 *RCA* documentary *The Story of Television* makes no mention of Farnsworth—the storyline has "General" Sarnoff and Zworykin somewhat clumsily praising each other as the two masterminds behind television and citing only *RCA's* achievements as “history firsts”. According to *RCA*, the television age started from the speech and subsequent demonstrations that Sarnoff made in the *New York World’s Fair* in 1939, although Farnsworth’s experimental television system had been on the air five years earlier.

This kind of creative storytelling is a prime example of the power that big companies with well-funded Public Relations (PR) departments may have in rewriting history to their liking.

But in the 1930s, David Sarnoff, having just experienced the radio broadcasting boom, clearly understood the huge business potential of television and was determined to get the biggest possible slice of it. *RCA* had made a formidable war chest from the radio broadcasting business, and Sarnoff wanted to ensure similar success with this new medium.

Although the basic principle of various video camera tube solutions that started emerging in the 1930 and 1940s followed Farnsworth’s approach, there was no agreed method for converting the image information into electric signals—the actual implementation of video transmission methods across the early solutions created around the world varied wildly. Even in the United States, *RCA* initially used different standards for different geographical areas, which in practice wiped out any potential for large-scale deployment of television.

To sort this out, *RCA* ended up spending over 50 million dollars to perfect the image capture, transmission and display processes and standards for black-and-white television only. This was an enormous sum at the time—slightly more than the cost of the Empire State Building in New York, or about twice the cost of the Golden Gate Bridge in San Francisco.

But this work was essential: in order to become a nationwide success in the United States, television needed a common standard, and in 1941, a 525-line transmission model was adopted, just before the Pearl Harbor attack stopped all further television activities.

After the war, with a common standard in place, the manufacturers were able to start producing compatible television receivers with ever-lowering prices, opening the way to explosive consumer growth that was similar to what had happened with broadcast radio some twenty years earlier. The concept of broadcasting remained the same, but the end-user experience was now immensely improved by the added power of moving imagery.

The enhancement work that *RCA* made in the field of video camera tubes has an interesting twist: before the litigation process had started, Farnsworth gave Zworykin a step-by-step walkthrough of his image dissector tube creation process, in the hope of getting *RCA* to finance his research. Instead, Zworykin send a detailed description of the image dissector manufacturing process back to *RCA*’s offices in a telegram, so that when he returned to the laboratory, a copy of Farnsworth’s image dissector was waiting for him.

Therefore, even though the ongoing patent litigations were still in full swing, the vast resources of *RCA*’s laboratories were busy at work, now helped with the information that the competitor had voluntarily presented to Vladimir Zworykin. A stream of new generation video camera tubes flowed from the laboratories, each sharper and more sensitive than the previous one. Yet there was still plenty of room for improvement: the very early versions had needed immensely bright lights in the studio, and the presenters were forced to wear green and brown face makeup as the video camera tubes had problems with intensive colors like red lips and bright white skin.

And the presenters were originally all white.

The first African-American news anchor, Max Robinson, had already been the invisible voice of television news for ten years before getting his place under the bright spotlights of a live studio. He had actually deliberately shown himself on the air in 1959 and was fired the next day as a result, only to be immediately hired by another station. Eventually he got his spot in front of a camera, and became a very successful news anchor for the *Eyewitness News* team in 1969.

On the other side of the Atlantic, the *BBC* had been busy transmitting TV broadcasts in central London since 1929, the same year that Farnsworth managed to get his first all-electronic image dissector up and running. But the British system was based on a mechanical setup, created by a Scotsman John Logie Baird, who had demonstrated a functioning Nipkow disk-based apparatus in 1926.

The mechanical system had a severely limited resolution: Baird's first demonstrator only supported five scan lines for the whole image. After studying the resolution required to show a distinguishable human face, Baird changed the number of lines to thirty. Over the years he improved the scanning mechanism and managed to reach a resolution of 240 lines, which was very high for a mechanical system.

Baird was very prolific with his television experiments: he kept on adapting the system to cover many new use cases, succeeding in sending long-distance transmissions via phone line from London to Glasgow and later even to New York. All this progress was very impressive, considering that it happened around the same time as Farnsworth was developing the very first fully electronic version of his image dissector.

But with heavy, fast spinning disks, these systems were clumsy and noisy, and worst of all, very limited in terms of active focus depth and acceptable light level: during the *BBC* test transmissions, the presenters had to do their performance in an area of about 0.5×0.5 m in order to produce a sharp image.

In his early public transmission experiments, Baird was using the nightly downtime of a *BBC* radio transmitter, but this transmitter could send only video or sound at one time—therefore the transmissions had alternate segments of mute video and blank image with sound, which made it very awkward. It was like the silent films, except that the text frames were replaced by real audio. Eventually the *BBC* became interested enough in his work to provide him with two dedicated transmitters: one for video and one for sound. Hence, Baird became the first person in the world to provide actual television broadcasts with simultaneous video and sound.

An interesting anecdote about Baird and Farnsworth is that these two pioneers actually met in 1932: Farnsworth was looking to raise money to cover the cost of the *RCA* litigation by selling a license to Baird, not knowing that Baird actually was not a very wealthy man. During this meeting they both made demonstrations of their respective systems, leaving Baird really worried: what he was shown by Farnsworth appeared to be miles ahead of his mechanical television solution, and to be able to ensure a positive outcome to his future work in the face of impending defeat in the system wars, he suggested a cross-licensing deal. Although this was not financially what Farnsworth came to London for, he accepted.

With the continuous advances in the field of electronic television, the writing was on the wall for Baird's mechanical solution: a British joint venture, the *Marconi-EMI Television Company*, had acquired rights to *RCA's* picture tube technology, and invited the experts from the *BBC* to see a demonstration of their fully electronic television. As a result, the *BBC* started running the Baird and the *Marconi-EMI* systems on alternate weeks through its transmitters. The idea was to get fair customer feedback on the comparative quality of these systems, although by just looking at the specifications, there was no true competition: 240 scan lines per frame and severely restricted studio-only focus simply could not compete against *Marconi-EMI's* crisp 405 scan lines with normal, film-like depth perception. The feedback came not only from the viewers, but also from the performers, who begged the producer not to assign them to be on the air during the "Baird weeks".

The duality of the *BBC's* transmissions forced Baird to adapt his commercial receivers, creating the world's first dual-standard television *Baird Model T5*, which could display both his and *Marconi-EMI's* transmissions.

When the electronic television was chosen as the system of choice also in Germany, it was evident that the future of television would not have space for mechanical solutions. Still, to commemorate the father of the first patented method of television, the first German television station was called *Fernsehsender Paul Nipkow*.

The *BBC* switched to *EMI* electronic video cameras in 1936, the quality of which kept on improving: in May of 1937, a version called *Super-Emitron* was sensitive enough to provide the first outdoor transmission from the coronation of King George VI.

Although the loss in the systems fight initially frustrated Baird, he understood that the *Marconi-EMI* system had truly won on merit, and moved his own experiments into the electronic domain as well, thanks to the cross-licensing deal with Farnsworth. Fate also stepped in: Baird's laboratory, with his latest mechanical prototypes, was destroyed in the fire at London's iconic Crystal Palace on November 30th, 1936, making it easier to start with a clean slate. The results of the fire were not as bad as they could have been, as Baird had an insurance policy covering his equipment at Crystal Palace.

Baird kept on innovating in this area, creating the first functional demonstration for color television in 1944, and even patenting his 500-line 3D-television prototype.

After the war, Baird presented a grand plan for a 1000-scan line color television, *Telechrome*, managing to get the *BBC* initially interested in funding the creation of such a system.

In terms of picture quality, *Telechrome* would have been almost on par with today's *digital High Definition (HD)* television systems, but as an analog system, it would have needed a massive amount of bandwidth per channel. This, in turn, would have limited the total number of television channels available, for reasons which are explained in TechTalk ***There is No Free Lunch***.

Unfortunately, the ongoing post-war effort in Britain put a major damper on available resources, and *Marconi-EMI's* 405-line version remained in place.

All television transmissions had been halted for the duration of the Second World War, but when the *BBC* restarted the transmissions in 1946, television in Britain hit the hockey stick curve: 20,000 sets were sold in the first six months alone, which is a lot for something that was still considered as a luxury item after the war.

At the same time in the United States, commercial television had been off the air during the war, as all prominent electronics manufacturers participated in the war effort.

Ironically, Philo T. Farnsworth's *Farnsworth Television & Radio Corporation* had its best financial run while manufacturing radio equipment for the U.S. Army during the war, including a high-frequency transceiver with type designation *BC-342-N*, which was a 115-volt version of a widely used field and aviation radio *BC-342*. But despite the ample funding provided by this lucrative wartime contract, *Farnsworth Television & Radio Corporation* went out of business just before the post-war television manufacturing hockey stick curve started in the United States.

Farnsworth's name lived on after the war, though: thanks to their reliability and ease of use, thousands of surplus *BC-342-N* radios by *Farnsworth Television & Radio Corporation* found a new life as Radio Amateur equipment.

Although there were good technical reasons why the whole world could not use the same television standard, national protectionism also had its share in this game. Yet, the basic concept of capturing and displaying images based on stacked scan lines was the same in all of them—only details like the number of scan lines and the number of frames per second were different, and thanks to this, the makers of the television sets were able to isolate the necessary bits that made up the regional differences, paving the way for a true mass-market production—most of the components needed for a television set remained the same, independent of the target market.

Later down the line, some television manufacturers followed the *Baird Model T5*-approach, dynamically supporting multiple standards, which was a boon for people living near to the boundaries of regions that had adopted different broadcasting formats.

On the technical side, the reason for having different quantities of scan lines and frame rates in different countries stemmed from the frequency used for the distribution of electric power. For example, Europe uses 50 Hz Alternating Current (AC) power, whereas the United States and many other countries have 60 Hz as the standard.

The human eye is not fast enough to detect the fact that certain lamp types actually dim and brighten up in sync with the power line frequency, effectively blinking continuously with high speed, incandescent lights being some of the worst to exhibit this phenomenon. But the scan speed of television cameras is fast enough to detect this, and thus has to be synchronized with the power distribution frequency—if there was a mismatch, moving bands of darker and brighter areas would appear on the television screen due to the *stroboscopic effect*. This could be avoided by selecting a frame rate of 25 frames per second for countries with 50 Hz AC power frequency and 30 frames per second for countries using 60 Hz AC power frequency: although the sampling would occur only by half of the power frequency, the samples would always hit the same phase of the ongoing power cycle.

The resulting frame rate, together with the available bandwidth of the transmission channel, assert further mathematical limitations on the number of scan lines that can be embedded inside a single image frame.

Other variables that added to the plethora of television standards that were used in different geographical areas included the *frequency separation* of audio and video portions in the transmission signal, and eventually, the method used for color information encoding, which was a bolt-on enhancement to existing black-and-white television transmissions.

As a side note, there really was no reason to have different frequencies for AC distribution—it all boiled down to protectionism between markets: at the beginning of the 20th century, the United States, with the suggestion by Tesla, chose 60 Hz, whereas Britain went with the German 50 Hz version, both effectively making it more difficult to import each other's electric motor-based devices. As a result, the rest of the world was simply divided according to which side of the Atlantic happened to have a greater local influence at the time of rolling out the local electric power networks.

In Britain, the next post-war technology step happened when the *BBC* switched to the 625-line Western European base standard in 1964. Yet, despite sharing a common European standard, the United Kingdom still chose a different frequency separation between audio and video portions within the television transmission signal.

I had a somewhat humorous personal experience based on this minor incompatibility when I moved from England to Finland and brought my British TV set along: an electrician came to install a television antenna on the roof of my house while I was away, and he spent hours re-tuning and tweaking the system, trying to figure out why he was getting a perfect picture but no sound, assuming that the antenna amplifier would somehow be the culprit.

He was relieved when I arrived home and explained the reason for this mysterious behavior. The actual problem was easily circumvented by using my multi-standard video recorder as a front-end tuner, delegating the television to a monitor mode through the *Syndicat des Constructeurs d'Appareils Radiorécepteurs et Téléviseurs* (*SCART*) connector: the chunky European standard connector for high-quality analog video.

When dealing with fundamental systemic upgrades in an established mass-market environment, one important aspect is the drive for *backwards compatibility* whenever possible: a good example of how this could be handled was the way stereophonic sound was added to FM radio, as discussed in Chapter 4: ***The Golden Age of Wireless***.

The introduction of color into television transmissions had to be provided in a similar manner, so that the television sets that were already out in the market would not become obsolete.

The existing scan lines in the black-and-white television signal essentially already contained the brightness, or *luminance* information, of each line, so all that was needed was to get the color information, or *chrominance* information somehow added into the existing structure of a video signal.

This was done by embedding a high-frequency *color burst* into the transmitted signal, timed to happen between the transmission of two scan lines. This was a period during which black-and-white televisions were not expecting any information, thus effectively ignoring it. But the new color television receivers were able to extract this additional chrominance information, join it with the luminance information of the received scan line, and then proceed to display the scan line in full color.

As the luminance and chrominance information for a single scan line did not arrive exactly at the same time, the whole process of resynchronizing them was quite tricky to implement with the analog circuitry of the time, but this solution provided full interoperability with the millions of black-and-white television sets that already existed.

Both the addition of stereophonic sound and color video are great examples of a solution in a situation where an existing, widely adopted system cannot be fundamentally changed—the human ingenuity beautifully steps in to create a fix that is backwards compatible and does not disrupt the existing customer base.

As for the analog color systems, the United States was first with the idea of an embedded color burst as an extension to their 525-line black-and-white *National Television System Committee* (*NTSC*) solution. To accommodate this additional data burst so that it did not cause interference with the luminance information, the frame rate in the United States had to be slightly tweaked from 30 frames per second to 29.97 frames per second.

Unfortunately, the straightforward, first-generation color encoding solution used in this system had a tendency to distort colors in certain receiving conditions, and the NTSC acronym jokingly got a new meaning: "*Never the Same Color*".

The color distortion was mainly caused by *multipath propagation interference*, in which the received signal reaches the antenna both directly and via a reflection from a nearby object.

This inherent limitation of the NTSC system led to the creation of the *Phase Alternating Line* (*PAL*) standard, which, in the late 1960s, became the standard in Western Europe as well as in Brazil, although Brazil had to use a slightly modified, 30 frames per second version due to their 60 Hz power line frequency. As the name of the standard describes, by alternating the color pulse phase between scan lines, it effectively evens out any phase errors in the received signal, providing a consistent color quality.

A third major system, *Séquentiel couleur à mémoire* (*SECAM*) was developed in France. It was taken into use in France and many of the former colonies and external territories of France. SECAM was also chosen by the Soviet Union and forced upon most of the Cold War Soviet Bloc countries, not due to technical merits, but to reduce the “bad western influence” that might be caused by watching western TV transmissions.

As a result, along the borders of the Iron Curtain, you could still see the neighboring TV transmissions, but unless your TV was a multi-standard version, you were limited to watching a black-and-white image without sound. Therefore, it was no surprise that one of the best-selling electronic upgrades in East Germany was a PAL-to-SECAM conversion kit for television, as somehow the West German programming was perceived to be more relevant than the East German one, especially when it came to news.

In the end, even the television sets made in East Germany had PAL-compatibility built in.

This politically driven, artificial East–West technological divide, however, was not entirely complete across the regions: Albania and Romania had PAL in place, and outside of the Soviet dominance, Greece had also originally selected SECAM, although they migrated to PAL in 1992.

It is hard to exaggerate the propaganda value of television: daily access to this “bad western influence” probably played a big part in the crumbling of the Cold War divide that led to the fall of the Berlin Wall and the reunification of Germany.

The introduction of color television added to the potpourri of standard combinations in use, so when the *International Telecommunication Union* officially defined the approved set of analog television standards in 1961, there were fifteen slightly different versions to choose from.

When the world eventually migrated to digital terrestrial television, we still ended up with four different terrestrial transmission standards: Japan, Europe, United States and South America all decided on different formats, based partly on their technical merits, partly on pure protectionism again.

Yet we have gone down from fifteen terrestrial standards to four, so there has been a clear improvement in the past 50 years.

Concepts like *analog* and *digital* are discussed in TechTalk ***Size Matters***.

All this analog mix-and-match is now slowly but surely vanishing into history with the global deployment of digital television. The predecessor for this step up in image quality was *Sony's* 1125-line analog *High Definition Video System (HDVS)*, which was introduced in Japan at the end of the 1980s.

Thanks to cheap, ultra-fast digital signal processing and improvements in computing power, it is now possible to compress both video and audio content into a digital data stream which requires much less bandwidth than what would be needed for transmitting the same content in analog format. The issue with any analog television transmission is that it is constantly hogging the full available channel bandwidth, whether it is showing just a black screen or a scene packed with action.

In contrast, digital television transmission structure relies on the existence of local image memory in the receiver, and in essence only transmits fine-grained differences between individual frames. This means that the amount of bandwidth required to transmit video at any given time varies greatly depending on the ongoing content. The maximum available bandwidth dictates the upper limit for the picture quality during the most demanding scene changes: with lots of movement, like during explosions or aggressive camera motions, noticeable *pixelation errors* may therefore become visible for a very brief moment.

Another major enhancement stemming from the extreme malleability of a digitally formatted data is the possibility of not only selecting the desired resolution of the channel, but also bundling several digital channels together into one data stream. This allows one physical television transmitter to broadcast multiple channels simultaneously inside a single broadcast signal, only to be finally extracted into separate channels at the receiving end. This was briefly mentioned already in the discussion about Digital Audio Broadcast (DAB) in Chapter 4: ***The Golden Age of Wireless***.

As a result, if you take advantage of the lower required bandwidth for digital channels and bundle up four channels, you can turn off three physical transmitters and still enjoy the same number of channels as before. The fact that all these four channels actually come through a single transmission stream is totally transparent to the end users.

This brings along several benefits:

First of all, a considerable amount of electricity can be saved, as television transmitters tend to need power in the range of tens or even hundreds of kilowatts and are often running 24/7.

Secondly, maintaining the transmitters and antenna towers is costly, and, by bundling the channels into one actual broadcast transmission, a lot of this hardware can be decommissioned.

But most importantly, this method saves the precious radio frequency spectrum, which can then be reused for other purposes. This kind of freed spectrum is actually extremely valuable wireless real estate, and the benefits of reusing it are discussed further in Chapter 10: ***Internet in Your Pocket***.

If we continue with the example above and only decommission two transmitters, changing the remaining two into four-channel digital ones in the process, we have not only saved a lot of bandwidth and running costs, but as a bonus, now have twice the number of channels at our disposal. These extra channels can then be leased to the highest bidder, providing more potential income for the network providers.

More discussion of bandwidth issues can be found in TechTalk ***There is No Free Lunch***.

An additional benefit of switching into the digital domain comes from the fact that both audio and video quality remain much more consistent when compared with traditional analog transmissions: in good enough reception conditions, the only limiting factor for the video and audio quality is the maximum allocated bandwidth on the channel.

The negative effect that follows from digitalization is the fact that any errors in reception are usually much more annoying than was the case with analog television: as the digital video signal is heavily based on only managing the differences between frames, any gaps in the reception can leave big chunks of the image distorted or frozen for a couple of seconds, and cause nasty, screeching and metallic-sounding artifacts in the audio part of the transmission. These issues are most pronounced in mobile reception conditions—with fixed terrestrial television setups and cable or satellite television, as long as the received signal strength is above a certain threshold, the received picture and audio quality remains as good as it can theoretically be.

The flipside of switching into digital television is that there is no way to remain compatible with the old analog television transmissions, so this is a true generation change. All new digital television receivers still have circuitry to handle analog transmissions, but as the transmitters are switched from analog to digital mode, old analog television receivers are eventually going to go the way of the dodo.

The enhancements brought by digital television's better quality and lower required bandwidth were first taken into use in satellite television at the turn of the 21st century. The savings gained from cramming the maximum number of channels into one transmitted microwave beam from the satellite were significant, and the high quality achieved by digital transmissions was paramount for service providers that were competing against cable television.

To receive satellite television, a special receiver is always needed, so it was possible to add the necessary electronics for converting the digital signal into an analog one, making it easy for the consumers to keep using their existing television sets in monitor mode.

The main driver of the digitization of satellite television was the cost of setting up the required space infrastructure: the lighter you can make a satellite, the cheaper it is to launch into space, so you try to minimize the number of individual, heavy microwave antennas and the required parallel transmitters. Less electronics means fewer items that can break during the expected lifespan of the satellite, and a reduced number of beams means that lighter solar panels can be used to power the satellite, again reducing the overall weight and complexity.

Because the launch and actual development of a space-grade satellite were by far the costliest items in setting up a satellite distribution system, adding some expensive, leading-edge digital circuitry to reduce the number of beams actually meant that the overall cost of a satellite launch was reduced.

On the receiving side, customers tend to have multi-year relationships with their satellite television providers, so the additional cost caused by the digitalization of the satellite receivers could be reaped back over the years as part of the monthly subscription.

You can read more about satellite television systems in Chapter 7: ***Traffic Jam over the Equator***.

Although cable television systems are not wireless, they have been an essential part of the broadcast television revolution, and hence are worth a sentence or two in this context:

Most urban areas offer cable television systems for transmitting hundreds of channels, effectively creating an isolated version of the radio spectrum inside the cables of their distribution network. The extra benefit of the shielded cable environment is that there are no other transmitters or regulatory limits to worry about:

all those frequencies in this tiny, completely isolated universe inside the cable belong to the cable company, and they can divide and conquer them as they please.

This setup can even be utilized for two-way traffic, which is now widely used by the cable companies to provide Internet and fixed phone line services in addition to traditional cable television programming.

As the number of available cable channels can now be calculated in the hundreds, going digital was the only way to cater for the ever-increasing demand for capacity and the quest for improved picture quality. As with satellite providers, this transition to digital delivery was helped by the fact that many cable companies still deliver their subscription-based programming through separate set-top boxes, which can then convert the signal to analog format: although the incoming programming stream is digital, customers do not need to upgrade their television sets.

The latest approach to television content delivery is to go fully digital, using the Internet as the delivery medium: instead of having all the channels stacked up inside the distribution cables in parallel, the customer picks up the digitized video stream of the channel of interest, and the content is then delivered like any other Internet-based data.

The use of the Internet has also opened the formerly very expensive-to-enter market of broadcasting to entirely new *on-demand* providers, like *Netflix*, *Amazon* and *Hulu*, and these new players now threaten both the vast satellite television business and the traditional cable television business. Those incumbent providers that are not already active within the massively growing Internet-based delivery approach will most likely face major problems with this latest technological shift, and therefore it is no surprise that hybrid solutions are already being announced by proactive companies. As an example, the prominent satellite television provider *Sky Plc* has announced that its complete subscription television package will be available via the Internet across Europe in 2018.

Thanks to the new access mode offered by the Internet, even the good old video recorders are going virtual. The content of every channel is constantly recorded at the network provider's digital storage system, and the customers can go back in time at will, accessing the digitized media from a shared, single storage.

This kind of *time shift-capability*, together with the rise of on-demand providers, is fracturing the traditional television consumption model. Apart from certain media content that has clear and inherent immediate value, like live sports events or breaking news bulletins, customers can now freely choose the time, and increasingly also the place of their media consumption.

Time shifting also makes it possible to skip advertisements, which poses a major risk for providers of non-subscription services, whereas subscription-based services are booming as customers are happy to cut out annoying advertisement breaks from their media consumption time in exchange of a few dollars per month.

But whatever the method by which the programming is delivered, television has totally revolutionized the way people spend their waking hours. The time spent watching television has grown year after year, and is currently a major chunk of our lives: in 2014, the average American, the current record holder, spent 4.7 hours daily watching TV. If you take off time spent sleeping, eating and working, not much is left for other activities. Only recently the Internet has finally risen as the new contender for eyeball time.

The lure of television stems from the fact that humans are visual beings: up to 40% of our brain's *cerebral cortex* surface area is dedicated to vision.

Because our survival used to depend on detecting potential predators before they came close enough to make a meal of us, evolution optimized our perceptive skills to be attracted to even the slightest movement in our field of vision. Hence a switched-on television set is constantly demanding our attention. This is a "built-in" feature in our brains, and thus very hard to resist.

Due to its addictive nature, television was by far the most significant change brought into our lives by the application of radio waves—until mobile phones came around.

As technology advanced, we have been able to cram ever more information into the limited radio spectrum that is available to us. Thanks to the advances in solid-state electronics, sensor elements for video cameras no longer need a vacuum and an electron beam to extract the image frames. Likewise, on the receiving side, bulky CRT screens have become relics of our analog past, replaced by *Light-Emitting Diode* (*LED*) and *Liquid Crystal Display* (*LCD*) based flat screens.

None of this recent progress takes away the fact that everything you see on television only became possible through the hard work and ingenuity of Philo T. Farnsworth and his peers, who built their solutions on top of the inventions and theories of Hertz, Maxwell, Marconi, Tesla and so many others.

This ability to constantly improve and expand the work of earlier generations is one of the most prolific aspects of humanity, and it still drives the utilization of the invisible waves that were first harnessed just over one hundred years ago.

But as Tesla demonstrated in the very early days of the wireless revolution with his remote-controlled prototype, these invisible waves can also be used for entirely other purposes than just transmitting audio and video to consumers.

One of the most prominent of these alternative uses that most of us are totally oblivious of is enabling millions of air travelers to get safely from A to B every day, in almost any kind of weather. Let's take a look at these *Highways in the Sky* next.