Telephoning was yesterday. Today's cell phones, here the iPhone, are lifestyle objects with multimedia entertainment options (photo: Deutsche Telekom)

Communication. The archetypal telephone has changed continuously over the decades reflecting developments in materials and processing techniques as well as the available communications technologies. This has been especially true for the cellular phone, which has long since evolved from a purely functional device to an individualized lifestyle object with a high-tech heart. The decisive design factor for these devices is the need for the casing to protect the electronics whilst providing an attractive exterior.

One of Human Nature's Basic Needs

RALF ACKERMANN

The need to communicate is as old as mankind itself. Before the beginning of the technical age of information people were only able to use their biological and spiritual abilities for communication. These abilities were allegedly so advanced in highly developed societies such as the Egypt of the Pharaohs and the kingdom of the Incas that human beings could communicate telepathically at a high level over great distances. It was only with the invention of the telegraph and the telephone about 150 years ago that communication was revolutionized from a technical standpoint allowing the transmission of information and speech.

The story of the telephone goes back to the middle of the 19th century. In 1876 Alexander Graham Bell was granted a patent in the USA for a non-functional telephone, which went on to be challenged in nearly 600 proceedings from, amongst others, Antonio Meucci and Elisha Gray who had developed enabling technology. It was only later that Bell was able to use his electromagnetic telephone outside of his laboratory on an 8.5 km test line in Boston.

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The History of the Telephone

Bell benefited from a wealth of preparatory work in which other researchers had considered electrical information transmission. Among the names that will forever be associated with this are Samuel Finlay Morse, after whom the most famous of all codes is named, Georg Ohm, who developed the laws of electrical resistance, and Benjamin Franklin, the inventor of the lightning conductor. Many people, however, regard the German physicist Philipp Reis as the father of the "Telephon" who as early as 1860 could transmit speech via electrical signals and gave the device the name that in the end established itself in many other languages such as English.

However, it took a long time for the telephone developed by Bell and his assistant Thomas A. Watson to become a commercial success **(Fig. 1)**. In 1881 the first manual local telephone exchanges were built in Germany and the first transatlantic connection between London and New York was established in 1928. A few years later it was possible to communicate between all of the great cities of the world. It did not take long for this luxury, which in the early years was reserved for the privileged classes, to develop into a utility for all levels of society without which the modern world could not be conceived of **(Fig. 2)**.

Portable, but as Heavy as a Suitcase

In Germany, the first car telephone was installed in a taxi in Bremen in 1952. It had the dimensions of a suitcase, weighed 16 kg and was three times as expensive as a VW Beetle of the day. In 1958 the "A" network was set up in Germany. However, at this time mobile telecommunication was so expensive that only a few could make use of it. Even the standard B72 phone from TeKaDe cost the unbelievable sum of DM 15,000.

It took a further three to four decades before the size and weight of the devices could fulfill their mobile purpose **(Fig. 3)**. By the beginning of the 1980s it was possible to take a "B" network telephone out of the automobile with a hand grip. However, it was only with the introduction of the high performance "C" network in 1985 that cell phones became more compact, lighter and more efficient in terms of reception and standby times.

Fig. 2. Extension telephone based on the W28 in a 1936 office (photo: Siemens Corporate Archives)

The Future of Mobile Telephony Has Begun

The digitalization of the telephone network at the end of the 80s and practically simultaneous introduction of ISDN gave mobile communication the impetus that made it possible for everybody today to be contactable almost anywhere on the globe at a cost that can be afforded by all. The introduction of the D2 network and digitizing microelectronics in combination with SIM cards as well as the implementation of the European mobile communication standard (GSM: Global System for Mobile Communications) was associated with an almost paradoxical development. The devices themselves became ever smaller, but their performance grew by the same extent **(Fig. 4)**.

Far from pure speech telephony mobile communication devices developed into tiny all-rounders that in the end conquered the mass market. The ability to send texts using the short message service (SMS) triggered a sea change in user behavior. In the time that followed further innovations came to market, for example communicators complete with organizer and internet browser which allowed surfing the World Wide Web with a cell phone and MDAs (Mobile Digital Assistants), stylus controlled mini-computers (PDA, Personal Digital Assistant) with an integrated cell phone.

UMTS mobile networks with their higher data transmission rates allow for the quick exchange of large volumes of data and thus for features such as speech telephony, i. e. order and brokerage services that include automatic messages. Integrated digital cameras, MP3 players, MMS, DMB (Digital Mobile Broadcasting) and the profusion of apps have turned modern cell phones into multifaceted multimedia devices **(Fig. 5)**.

Alongside these numerous technical innovations the devices continuously appear in new designs often drawing jealous looks from the next table. Whilst at the beginning of this century colors conquered the surfaces where previously they had all been black and a multitude of skins were on offer in order to allow personal expression today's devices attract users with a mix of haptic and optical effects, ergonomics, ease of use and fascinating technology.

Fig. 1. An old wall-mounted telephone with a hand crank (photo: Wilfried Wittkowsky/Wikimedia)

Bakelite Revolutionizes the Industrialization of the Phone

Although initially far less appreciated, materials technology surrounding the telephone developed at just as fast a pace. Following the start of industrial production of crude oil in 1854 it was clear that some crudes polymerize in air and thicken on storage in the lab. In 1907, Leo Baekeland developed the phenolic plastic that to this day is known by the name of Bakelite. The German chemist Hermann Staudinger (1881–1965) proved that polymers are built from macromolecules, a term that he himself coined. This gave the chemistry of polymers a powerful boost in the middle of the 20th century.

The historical telephones from the time between 1877 and 1890 were developed and designed following the example of Bell. Initially the devices were manufactured in wood. Metal was used for the electrical components and the sometimes ostentatiously mounted double bells. In the beginning pure brass was used in the manufacture, but as numbers increased galvanically nickel plated brass castings, black painted sheet metal and ceramic components were used **(Fig. 6)**. →

Fig. 3. The first mobile telephones were the size of suitcases. It was not until the 1990s that the size and weight of the devices really fulfilled their mobile function (photo: Nokia)

Unlike these well known materials of the time as witnessed by flimsy wood and dented metal housings Bakelite, the first thermosetting material, retained its shape and state no matter what and could be joined to practically every other material **(Fig. 7)**. Bakelites have high temperature resistance, are chemically stable, impact resistant and most importantly non-conductive. The new material made a new and generously proportioned design of the casing possible, virtually forcing free flowing shapes. Undercut and flimsy casing surfaces were passé, the sharp cornered boxes evolved into devices with beautifully formed curves.

Sharp Cornered Boxes Take on Beautiful Curves

The W36 to W48 models from Siemens with their freeform surfaces optimized for Bakelite processing embodied for the first time a consequent implementation of what the public at large associate with “design in plastic”. For many collectors today the W48 still epitomizes the “antique” telephone **(Fig. 8)**. Up until 1928 Siemens produced the W28, a black painted telephone with a Bakelite handset, in Germany. The base unit continued to be made out of pressed sheet steel, whilst the cradle, its base and the dialing disc were still being made in cast aluminum. The W28 was the forerunner of the W36 and W38 manufactured entirely in Bakelite. Developments in other countries followed a similar path. In Sweden Ericsson launched its first Bakelite phone in 1931 **(Fig. 9)**.

At this time electrical insulation and fire protection were still a significant challenge in the mass production implementation of the products. Thermosets therefore dominated the manufacture of electrical components.

The Colorful Sixties and a Liberalized Telephone Market

The standard color for thermosets was black. Only a few models were marketed as luxury versions in ivory. This changed with the continuous developments in thermoplastic polymers. From 1960 onwards standard models were overwhelmingly manufactured in ABS **(Fig. 10)**. Smooth and glossy, mouse gray surfaces were typical.

The flower power era at the end of the 60s and the hippie movement were loud and colorful. With the arrival of large pattern colorful wallpaper the color palette of telephones had to change too. From the 70s onwards there were therefore increasingly colored models on offer **(Fig. 11)**.

Competition livened up the business. With the liberalization of the telephone market in the 1980s the number of suppliers and product variety exploded. Di-

Fig. 4. Originally only available in black with an external antenna, cell phones later became colorful, ever smaller and occasionally equipped for outdoor activities (photos: Nokia 2110, Siemens M65)

Fig. 5. The first small color displays were soon followed by large ones that in turn allowed the integration of digital cameras with even higher performances. Size increases forced by this development could be in part counteracted by slide and clamshell functions. Touch screens, music and film playing functions as well as countless apps have turned today’s cell phones into versatile multimedia devices (photos: Motorola Aura, Samsung B5722, Nokia 5235 CWM, SonyEricsson Xperia X10)

Fig. 6. The 1919 desk model "SA 19 (07) F" already contained parts in Ebonite, a forerunner of Bakelite, alongside painted sheet metal and components in cast nickel (photo: Siemens Corporate Archives)

Fig. 7. The 1928 Fuld telephone, often described in antique shops as the "Bauhaus telephone", was named after the German industrialist Harry Fuld. Only the handset is made from Bakelite (photo: Supplement from „Das Neue Frankfurt" Newspaper, 1930)

Fig. 8. The classic W36/38 telephone was manufactured entirely out of Bakelite, on the right a gilded special model for the Greek royal family (photos: Siemens Corporate Archives)

aling discs made out of SAN were for the first time replaced by key pads. Design and color defined the range of corded telephones **(Fig. 12)**.

After a brief fad for transparent and translucent designs customers since the beginning of 2000 have laid more emphasis on haptic and visual appearance. Metallic paints and metalized trim (chrome) dominated the trend. Cell phones dictated and still continue to dictate the pace of change **(Fig. 13)**.

From Bakelite to High-performance Polymers

Whilst design determined the exterior appearance, miniaturization in the cell phone market demanded further significant efforts in the area of materials development. At the same time the demands on electromechanical properties increased.

A typical cell phone today can be split into the following component groups (see **Table** on page 67):

- Middle board,
- front and back covers,
- display,
- antenna,
- batteries and battery compartment as well as
- various small components.

The function of the middle board is to carry the electronic components. This together with the two casing parts determines the size and design of the model. Depending on how the keypad, display and small parts such as the on/off button or volume control are integrated into the cover very high demands are made on the stiffness and the surface finish of the respective polymers. At the same time these materials have to be paintable and metalizable.

The display, which continues to be the most expensive component, has to fit precisely into the front cover and have high transparency **(Fig. 14)**. In the new generation with integrated touch screen there are additional electronic functions. Internal as well as external antennas are technically just as demanding components and are manufactured from die cut metal or partially metalized plastic parts (MID components).

The batteries which today in comparison have very high performance are becoming increasingly flat and determine in many cases the maximum thickness of the cell phone. Therefore the battery compartments have to be injected with extremely thin wall sections. Small parts such as buttons and keys as well as electronic components such as loudspeakers and earphones also have to meet particular specifications and the same goes for the high transparency lenses of digital cameras.

The profusion of requirements for the individual components requires a very precise interaction between the various polymers. This requires all the materials to have excellent and stable shrinkage performance in order to enable mass production. Cross-compatible assembly of the individual components requires very high dimensional stability. The range of materials used today is accordingly very wide. In addition the devices have to fulfill water splash (IP54) and drop tests. To do this manufacturers undertake a wide range of loading and service life testing in their labs in advance of mass production and subject the plastic parts to harsh treatment.

Yesterday, Today, Tomorrow

The essentially parallel developments in polymer technology and microelectronics have allowed the economic miniaturization of the devices whilst at the same time permitting a high level of individualization. Old style telephones have, via mobile speech devices, developed into multimedia cell phones whose final →

Fig. 9. In Sweden Ericsson launched a Bakelite telephone in 1931 (photo: Holger Ellgaard/Wikimedia)

Fig. 10. The 1953 T&N (Telefonbau und Normalzeit) telephone designed by Arno Kersting was probably the first telephone in Germany to be made out of thermoplastics (photo: Günter Lattermann)

Fig. 11. Colorful models replaced the ubiquitous mouse gray telephone (photo: Kunststoff-Museums-Verein)

Fig. 12. Keypads replaced the rotary dial users had been familiar with for decades. The 1986 DfeAP 381 Dallas model already showed the promise of mobility (photos: Siemens Corporate Archives)

Fig. 13. A solid metal frame and keypad give the SL400, the flattest cordless Gigaset phone to date, a high end look (photo: Gigaset)

chapter has not by a long way been written. Absolutely every new communication technology that comes along is absorbed and playfully integrated. In parallel to this, particularly in the corporate world, speech transmission via the Internet (VoIP) is establishing itself.

The future of mobile telecommunication, according to the opinion of experts, is going to expand into many additional fields and functionalities. For instance, the integration of a credit card like payment system into the cell phone is in the testing phase. It is very likely that the miniaturization and integration processes advance and new user interface concepts such as multi-touch technology and voice control will increasingly gain ground. Pupil and thought control are no longer idle day dreams, but rather already reality in development labs.

In terms of design there will be flexible and cold or warm surfaces. Just how far some of the already established technologies such as film back molding (IMF), leather, wood veneer and textile applications can continue to succeed remains to be seen. Natural materials such as lignin on the other hand will have to improve their mechanical properties first before they can be considered for such applications. The ever larger displays are significantly changing the external appearance of cell phones and are increasingly determining the nature of the devices **(Title picture)**.

The function dependent use of the display **(Fig. 15)** has been made possible by OLED touchpad technology where only the functions needed for the respective application are visible. A further reduction in energy consumption could-lead to a giant step forward for the integration of solar cells into the casing and make cell phones independent of the power grid **(Fig. 16)**. With the use of biopolymers **(Fig. 17)** and easy to separate materials such as metal and glass, telephone suppliers should be able to strengthen their endeavors to make “green” products. Fuel cell technology is heading in this direction as well. Cell phones are therefore no longer purely utility devices, but rather have achieved the status of individualized lifestyle objects with high-tech hearts.

Huge Data Volumes in the Ether

Ever growing data transmission rates and the associated flood of data will be a challenge that cell phones, manufacturers and network operators will all have to manage at the same time and the upcoming mobile communication standard „Long Term Evolution“ (LTE) is a step in this direction. We can certainly be curious to know which groundbreaking technology will serve us in future so that, just like the ancient Egyptians and Incas, we will be able to communicate at a high level over any distance. ■

Fig. 14. The display has to fit precisely into the front cover and have a high level of transparency (picture: iSuppli Corporation)

Component	Materials	Requirements	Process Technology
Front and back cover or top and bottom cover 	Decorative film, e.g. based on PC+PBT blends Wood veneer, leather, textile/fabric (recently wood-based materials)	Visible parts … Focus on design, haptic, optics	In-Mold-Labeling (IML): Back injection of a film laid in mold Back injection of inserts made from natural materials
	Polymer blends: mainly PC+ABS (sliding elements partly POM)	… and functional parts: very high stiffness, clip and/or screw connectors	Standard injection molding
	TPE, TPU	Soft touch	2-component injection molding, hard/soft composites
	Paints Metal applications	Piano black, high gloss, matt or decorative	Tampon or screen printing Painting, in some cases only partially Partial metalizing, part PVD coating or metal frame (hybrid technology)
Middle Board 	ABS+PC in some cases up to 60 % glass fiber-reinforced	Mounting of the electronic components, very high stiffness, seamless joining to the housing components, clip and/or screw connectors	Standard injection molding Depending on the application metalizing or painting
	TPE, TPU	Integration of functional parts (On/Off switch)	2-component injection molding Hard/soft composites
Display	PMMA, PC	Visible parts: very high transparency, scratch resistance	In-Mold-Decoration (IMD), film just the carrier for the printed image), also injection compression molding, in part combined with IMD
Touchscreen	Glass, PC, PMMA	Touch technology based on resistive, capacitive or infrared technologies	Complex laminating and/or assembly processes Bonding to the frame with adhesive or ultrasonic welding techniques
Internal or external antenna 	LCP, ABS	Quality of the transmission power and received power	Single or multi-component injection molding MID technology
	Metals		Hybrid technology
Battery Cover 	LCP, ABS+PC TPE, TPU	Visible and functional parts often made using thin wall technology, high stiffness, clip connectors	Single or two component injection molding Hard/soft composites Injection compression molding, IML Painting, metalizing
Loud speaker and ear phone	LCP, PA	Acoustic components	Micro-precision injection molding
Switches, keys, connectors, SIM blocks, frame parts, etc. 	POM, LCP, PPS, ABS, PC+ABS, PBT blends TPE, TPU	Electromechanical decorative and functional parts, Hard/soft composites	Hybrid technology: Metal/polymer composites Die cut and injection molding technology 2-component applications, painting, metalizing
Key mat	Silicon or PC, MABS	Functional and visible parts	Injection molding, tampon or screen printing; film back injected (hard caps); metalized, laser marked
Air cushion film (key body lies on this)	Polydome film in PC	Dome or pressure point under every key	Printed with a carbon pad followed by hot stamping
Light guide	PMMA, PC	Light scattering	Injection molding and/or film technology

This overview of polymers used does not claim to be comprehensive. The rapid changes in telecommunication require a permanent adaption to the available and latest processing technologies. External antennas for instance now belong to the past. Middle boards with electronic components are being replaced with intelligent film technologies. The design is increasingly determined by the screen. Through the use of touch screens the need for conventional functional components such as keys is removed. The same is true of the color scheme. User selected color and light accents, photos and videos as background pictures or screen savers in combination with acoustic signals give every cell phone a personal touch (pictures: Ticona, LPKF)

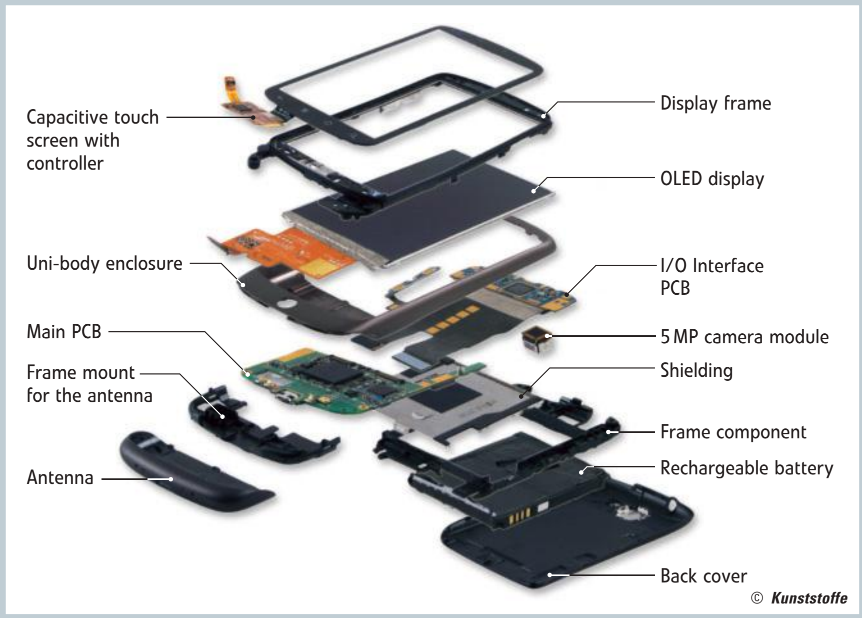

Fig. 15. A modern cell phone comprises the following major components: casing parts, display and electronic components; the picture shows an exploded view of the HTC Google Nexus One (picture: iSuppli Corporation)

Fig. 16. The "Solar" design study: The use of solar cells in cell phones is currently still a long way off (photo: Gigaset)

Fig. 17. The "Leaf" design study: The use of biopolymers could address the ecological conscience of buyers (photo: Gigaset)

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THE AUTHOR

DIPL.-ING. PLASTICS TECHNOLOGY RALF ACKERMANN, born in 1958, is Managing Director and a shareholder of FreeLeaves GmbH, Bad Oeynhausen, Germany, which delivers individual and future orientated development concepts for medium sized companies in the plastics processing industry. Ackermann, who is a qualified tool maker, held positions as an application technologist at the injection molder manufacturer Arburg, group leader of injection molding at Franz Kirsten, a specialist electromechanical manufacturer, and following their takeover by Eaton-Controls GmbH & Co. KG advanced to head of the pre-production department before being elected to the board of Balda AG as COO/CTO. In this role he was responsible for the development of high-end technology and the worldwide expansion of their manufacturing facilities within the corporation.