HISTORY OF RADIO FLIGHT NAVIGATION SYSTEMS

PREFACE

The development of instrument landing systems and flight navigation systems go hand in hand and as such their history is presented together in this book. Much of this history is not known to aviators or the public in the English speaking countries because the documentation of the early technical development has been printed in German and never translated into English. As such I thought it would be appropriate to translate some of the German published information, combine it with the modern navigation technology, and make it available for anyone interested in this most interesting topic. Many aviators and pilots today, take for granted, the history of the development of the navigation aids that are aboard their aircraft. Their interest lies mainly in learning how to use the equipment but the technological development is over looked.

The first navigation highways in the sky were radio beams transmitted by ground stations. Today most navigation is done with the “global positioning system” called GPS. Certainly the GPS, which uses satellites to give the pilot a fix on where his is located in relation to the world around him, is a major recent breakthrough in navigation and it is hard to imagine today flying without it. However, most general aviation (GA) aircraft today still use the VHF onmidirectional radio range (VOR) equipment as a primary or back up navigation aid. They still use the ILS system developed many years ago. These systems are still powered by radio and Klystron tubes. No! not everything is controlled by microchips.

The history behind the development of the GPS is not discussed even though it is an out growth of the early navigation systems. But the development of the VOR and ILS are covered.

I am especially thankful and deeply indebted to Dr. Peter Aichner of Brixen, Austria for providing me with the German copies for this very interesting, hard to find and out of print historical data. Reference to these documents is made at the end of this book.

The cover shows the navigation instruments in my composite material Stallion aircraft and the navigation antennas at the home of the Stallion, Monterey Airport. At the top of the instrument stack is a Bendix/King, KX 155 NAV/COMM with a VOR/LOC converter and a built –in 40 channel glideslope receiver. The COMM (communications) transmitter power is 10 W. At the lower end of the instrument panel is a KLN 90 GPS with a 3.3 inch diagonal, high resolution, cathode ray tube (CRT). In the middle of the cover is a KI 206 VOR/LOC/Glideslope Indicator and to the left the Marker Beacon Receiver. At the bottom right is the navigators station in a Ju 88, 1937 and a UHF ILS 119N Telefunken receiver.

Top right is the glide slope transmitter at Runway 10. Below that is the localizer beam transmitter for that runway and left of that the localizer beam transmitter for Runway 27. The VOR transmitter is shown in the lower right hand corner.

INTRODUCTION

Although the first ideas of using radio beams for guiding aircraft goes back as far as 1904, the practical use of such systems did not take place until 1932 with the German Lorenz A. G. Companies instrument landing system which was proposed and developed by the "father of instrument landing," Dr. E. Kramar. At that time instrument landing systems and navigation systems were called "Bordfunkgeraete" in Germany. Translated this simply means "onboard radio devices." However, in 1948 the term "Instrument Landing System" or ILS was coined in the USA and the modern terminology will be used herein.

FIRST TESTS

RADIO BEAM NAVIGATION

Contrary to a radio signal transmitted in all directions and a rotating beam antenna which allows aircraft to approach from all directions, the guided beam is used to set up a specific approach vector or path.
A beam (or better a beam plane) can be established with two separate antennas which transmit rhythmic alternating dot/dash signals. When an aircraft is at the center of these beams, a constant hum is heard. When to the right or left of the beam, a dot/dash or a dash/dot, is heard. In Morse Code, A= · – and N= – · Hence this method of navigation was named the A-N System. Various modulation methods are also used to identify the guiding beams. A radio beam can be deflected which noticeably increases its range. By deflecting both beams, the approach vector can be shifted right or left to account for wind conditions. Four antennas are also used to establish beams for four-course low-frequency range patterns.

O.Scheller (Lorenz. A. G. Company) was granted a patent as early as 1904 for an instrument landing system. With the use of four antennas, alternating, complimentary signals of A/N could be heard in two zones with the letter A, and in two zones with the letter N. In the overlapping zone a continuous sound is heard. Scheller defined a rotating antenna in another patent in which the signals could be pointed in any direction. In 1914, the German Navy began testing of Scheller's four beam navigation system using four antennas with overlapping beams. At the same time, Professor Kiebitz, without the knowledge of Schellers work, began tests with two horizontal array antennas with overlapping beams. However, the beams could not be received at small angle of elevation and work was discontinued. It was not until 1928 that work on Schellers ideas was continued.

INSTRUMENT LANDING SYSTEM TESTS

The purpose of an ILS is to allow an aircraft to land in bad weather and to guide it to land safely to the runway. To do this the following information is needed.

- Heading or azimuth information, left or right, from a localizer beam.
- Altitude information from a glide slope beam.
- Two or more distance identifiers to the landing touch down spot from vertical marker beacons.

In 1931, the German Aeronautic Research Institute, DVL (Gloeckner) built a navigation direction beam transmitter in Berlin that operated on 64 MHz. A glide path receiver was mounted in a test aircraft, a Fw “Buzzard.” This receiver consisted of a horizontal array antenna with detector, amplifier, display unit for beam strength. Upon reaching a certain signal strength, the aircraft would follow the localizer beam by maintaining the signal strength until reaching the ground. However, because of poor reception in bad by weather the tests were discontinued.

ILS BEFORE 1945

GROUND STATIONS

C. Lorenz A. G. Company (Dr. Kramar) began development of a Very High Frequency (VHF) ILS in 1932. The transmitter, named a “Ansteuerungsfunkfeuer” (AFF) unit in German, was located at the far end of the runway. The frequency of the500W transmitter could be tuned from 30 to 33.3 MHz and it was modulated with a constant 1,150 Hz. A vertical array antenna was used. Reflector array dipoles were mounted at a ¼ wave length to the right and left the center which was controlled by an open/close relay. The transmission could be broken by this relay which turned off the signal. By opening and closing this relay a Morse Code of dot (E) or dash (T) could be transmitted by the two dipoles. The overlapped area of the beams constituted the approach slope (glide slope) path.

At an altitude of 200m the pilot intercepts this approach slope by listening to a constant hum. If he deviated to the left, he would hear a dot and if flew to the right he would hear a dash. The localizer beams accuracy was plus/minus 3 degrees. At the same time a needle moved right and left to show which side of the localizer beam he was on. A second needle displayed the field strength of the signal to indicate the range to the transmitter. After flying over an outer marker beacon 3 km from the landing spot, the pilot knew his distance from the airport. This beam was transmitted vertically on 38MHz with a power of 5W. The ton could be heard at 700 Hz and a small lamp lit up to show that the aircraft was over the beam. A prescribed sink rate was maintained and the field strength of the localizer beam was monitored by the pilot. An inner marker beacon, located 300M from the airport, operated on the same frequency and power as the outer marker beacon transmitter. It transmitted a higher sound at 1,700 Hz and the a lamp also lit up. Just before touching down, the pilot had to be able to see the runway.

GROUND STATION

The next ILS unit from Lorenz (Dr. Kramer, Dr. Johannsen) was the Type EB1 introduced to Lufthansa. It was made up of a two circuit, five tube receiver with whip antennas, a separate Audion with an strip antenna on the bottom of the fuselage for the marker beacons, a battery box with battery, and one to two needle indicators. One year later this unit was replaced with a six tube receiver operated by a battery. This unit was called the EB2 and it used two receiver circuits. The battery was charged by an alternator.

Beams were recognized by the dot dash ton. The dot was made up of a signal of a 1/8 second duration and the dash by a 7/8 second signal. When the aircraft received the dot transmission, the steady currant increased for 1/8 second to a higher value. After differentiation by a transformer, a positive pulse was recorded at the start of the dot dash transmission and a negative pulse at the end of the transmission. At the end of each transmission a 7/8 second pause at a higher value was used. On the other side of the beam the signal strength was higher for the dash then for the dot. The aircraft instrument was constructed so that it could identify the right side from the left side of the beam and a needle would point to the left or right depending on what side of the beam the aircraft was flying. As the aircraft flew closer to the beam, the deflection of the beam was reduced.

In the year 1934, Telefunken GmbH also developed an ILS to the same specifications which was given the number 119N. The onboard, six tube receiver, was given the part number E408 N2/36. The system was used by Lufthansa and later by the German Air Force in the all weather Fw 58. A further development of this system used the RV 12 P2000 tubes. The E 455 F2/41 unit was used by Lufthansa only as a prototype in 1941.

As of 1937, the Lorenz A. G. Company developed an ILS designed to German Air Force specifications. The EB3 used two independent receivers with tunable frequencies from 30 to 33.3 MHz with four amplification steps. It also used the EBl 1 Audion with five NF 2 tubes to receive the marker beacons signals on 38 MHz. As of 1941, this unit was used in all German Air Force multiengine aircraft. The receiver mast antenna was housed in a plastic fairing. For the EBl 2 receiver a longitudinal strip antenna was located on the bottom of the fuselage. This antenna was often damaged by rocks thrown up by the wheels.

OTHER GROUND STATIONS

In 1937 the Lorenz Company set about improving the marker beacons with the first patents filed by Dr. Kramar who designed a ground transmitter with two antennas located one above the other. The antennas could be sequentially operated such that two vertical beams were produced with one beam below the 3 degree approach path. This beam would give the pilot the lower limit of his approach path. This idea was reinvented and employed in the USA in 1940.

The concept was first tested at the Leipzig Airport. It was located at the side of the runway and used a 100W UHF transmitter operating at 35.8 MHz. Further development was stopped at the beginning of the war.

Just south of Munich a UHF ILS was installed in 1938. The system was oriented in the south-west for Alpine traffic with the dash signal over the mountains and dot over the flat lands. In Berlin a 80W amplified marker beacon unit was installed.

The Lorenz Company also supplied UHF ILS to most major foreign countries of the world in 1938. In Australia the antennas for transmitters for ILS were located on large towers which instantly gave the beam signals. In areas were bent beams were needed, using a phase shift for reflected signals, made it possible to provide ILS with different approach angles. The outbreak of war brought an end to Germany supplying ILS to other countries.

It should also be mentioned that it was possible to provide instrument landings in two directions (90 deg and 270 deg). Of course the marker beacons had to be relocated. With a marker beacon transmitter power of 500W and with an aircraft altitude of 200m, a distance of 30 km could be expected.

AUTOMATED ON BOARD RECEIVERS

In 1941 the Siemens LGW Company (P. E. Koester) developed an automated ILS. This unit used the following components.

Three axis autopilot, DK12.
Navigation instruments made up of;

- Distance measuring equipment in addition to the PeilG V.
- Beam auxiliary equipment in addition to the FuBl I.

Altitude measuring system in addition to FuG 101.

This system allowed automatic airport locating, automatic pattern holding at the airport equipped with an ILS. A typical landing was made as follows.
The aircraft approached the airport with the autopilot controlling roll (heading) at an altitude of 150m. The elevator control was fixed. As the aircraft flew over the outer marker beacon, the elevator was engaged by the autopilot and the aircraft descended to and maintained 50m above the airport. Upon reaching the inner marker beacon, the pilot would cut power and the aircraft would land automatically. Continued development on this system was stopped in 1941.

IMPROVED GROUND STATIONS (FuBl= 2, FuG 125)
As of May 1940 German fighter aircraft were equipped with the “AN Navigation” and “Return Path” System (Rueckmarshwegen) to guide them to their targets and allow them to return home. In the UHF radio beam system and code named “Knickebein” developed by the Telefunken Company (Lohmann) a number of crossing beams were used to give fixes to fighter aircraft. The development of this system was based on the ILS FuBl 1 (30 – 33.3 MHz) system. Since the EB1, two circuit receiver, was too insensitive for this application. It had a range of 200km at 6,500 m altitude with only two tunable frequencies which could be easily jammed by the opponent.
The Lorenz Company (Dr. Kloepfer) developed a new, seven RV 12 P 2000 tubes, EBl 3 H receiver based on the FuG 17 receiver. The unit could be tuned to 34 frequencies in the 30 to 33.3 MHz range and allowed a range of 500 to 600km at an altitude of 6,500m. The new receiver could be simply plugged into the “Knickebein” mounting. The improved version was given the name FuBl 2 H. Later a modified version of the new receiver was given the part number EBl 3 F. It could be mounted anyplace in the aircraft and 33 frequencies which could be fine tuned to the frequency of the receiver.
For new installations, the strip antenna was located under the fuselage in a housing which protected it against rocks thrown up by the wheels.
The Lorenz Company also developed a very compact navigation receiver the EB4 or FuBl 3. Little is known about this system and it had limited application by the Air Force.

Yet another receiver was developed by the Lorenz Company (Dr. Kramar) which was designated FuG 125, code named “Hermine.” The receiver was made up of the EBl 3 F receiver, the FBG 2 remote control, a V3a amplifier for volume control. A FuG 16 ZY antenna was connected in parallel. This unit was designed for Instrument Flight Rule weather. On the 14th of September 1944 an order of 18,000 units was given to the Strassfurter-Rundfunk-GmbH. In the last part of the war only a few dozen units were delivered and used in the Me 109, Fw 190, Ta 152, Do 335 and 15 Me 262.

INSTRUMENT COMBINATIONS FuG 16 ZY + FuG 125 PROVIDED THE FOLLOWING COMBINATIONS

FuG 16 ZY 38.5 – 42.3 MHz	Transmit and receive in heavy traffic and Distance Measurements. Receiving transmissions from FuG16 region. Instrument navigation using ground stations or other aircraft.
FuG 125 30 – 33.3 MHz	Receiving transmissions from FuBl 2/FuG 125 region. Receiving of ground reports. Instrument landings on UHF beams and UHF ILS.

FIGHTER ILS
During the emergency fighter program in Germany at the end of 1944, the FuBl 2 receivers were only installed in the Ju 88 since the EBl 3 had been installed in the other aircraft (Ar 234, Do 335, Me 109, Me 262 and Ta 152).

FIGHTER LANDING SYSTEM
This meant that the EB1 2 was not to be the predominately used receivers. To obtain an audio signal when flying over the outer and inner marker beacon, the other receivers operating on 38 MHz were rebuilt to operate on 30 – 33.3 MHz. In this manner they could operate on the same frequency as the new EB1 2 receiver.
In addition, the localizer beam transmitter which had a range of 40 km, was located at the far end of the runway. The marker beacon transmitters were also relocated from 3 km to 20 km for the outer marker beacon and from 750 m to 3 km for the inner maker beacon along the side of the runway. With this modification, the pilot was able to approach the airport from above the clouds and fly through the clouds in a straight path without having to make instrument turns. This also allowed more time for altitude corrections which made landings easier for young pilots who did not have the instrument training that the older pilots had.

UHF-BEAMS FOR BOMBER NAVIGATION
“WOTAN 1”
In 1933, Dr. Hans Plendl from the DVL mad a suggestion for a VHF-Precision-Navigation System which would allow the dropping of bombs in bad weather without visual contact with the target. In the spring of 1934 he received a contract for the development of this “X-System.” Dr. Plendl was appointed the director of the RL Department of the DVL in Rechlin (later the Group F at the Research Institute of the Air Force at Rechlin). The “X-System” worked on the principal that a guiding beam was directed over the target and served as a course beam. Two other beams on different frequencies intersected the course beam at right angles prior to the target. The beams allowed the pilot to determine his speed over the ground with a special “X-Clock” to determine the correct release time for his bombs.
After extensive testing by the group headed by Dr. W. Kuehnhold, the “Wotan 1” UHF-Navigation System working on 66 – 77 MHz was operational in 1937. The antenna was made up of two vertical arrays one which transmitted a continuous a signal and the other an intermittent 120 cycles per minute signal. A series of 14 beams with a width of plus minus 0.05 degrees each with Dot/Dash signals modulated to 2,000 Hz were transmitted. A larger

version with 18 beams was also developed. Using 14 beams was necessary obtain a high beam resolution. This made it difficult for the user and also his opponent to determine which one of the beams was the correct one to use. The antenna was later supplemented with two reflectors which made it possible to increase the range. Eight of these systems, also called the "Multi-Beam Rechlin System," were installed around Germany in 1938. At the end of the year most of them were transferred to the western front. After the capitulation of France, ten of these systems were transferred to the channel coast.

"X-RECEIVER"

Working in the E-Group at Telefunken (H. Hahnel, Dr. Rucklin) developed the "X-Receiver" (FuG 22) code name "Anna" which operated on a frequency of 66-77 MHz. The receivers were produced by Siemens. The circuit was similar to the EB1 2 receiver, however an amplifier was added to differentiate pulsed signals. The display, AFN 2, was used and connected to two anodes such that one needle showed the localizer beam and the other the transverse beams. The "X-Receiver" was installed in He 111 H aircraft and used in September 1939 against Poland and England in August 1940 to June 1941 from Vannes and from then on from Chartres.

"**X-SYSTEM"**

The system was used as follows: The frequency of the UHF-beam (A) was tuned into the first receiver which was tracked by the pilot. See the figure on the next page. The flight engineer manned the second receiver and it was his job to determine the time that the aircraft crossed the transverse beam signals (B) and (C) which transmitted at different frequencies. Usually these beams were detected 18 and 6 km before the target and used to determine the ground speed of the aircraft. A "X-Clock" (fabricated by Hartmann & Braun, later by Beurle & Sons) was used to calculate the time to the target. Wind drift, altitude, aircraft speed was measured and accounted for. The clock would then show the time for the aircraft to drop its bomb.

BEAM NAVIGATION AFTER 1945

FOUR-COURSE TRANSMITTER (RADIO RANGE)

After the Second World War, Medium Frequency , MF, radio ranges sprang up around the globe. They operated at a frequency of 200-400 kHz and they were used as navigation and homing beacons. Antennas were improved so that it was easier to home in on a beacon using a radio compass. These systems were more reliable in bad weather. On board the aircraft, MF receivers were required for the picking up the localizer beams as well as the marker beacons. With the introduction of VOR (Very High Omnirange) rotating beam transmitters, the radio range transmitters were taken down. In most countries the UHF-four course "Visual and Aural Range" VAR was still being used at 108-112 MHz with A/N signals were modulated from 90 Hz to a new frequency of 150 Hz so that the "To and From" signals were not needed. The range for the longwave (50 – 150 W transmission power) is 200 – 500 km. For the UHF-four course transmitter it is 200 km at a flight altitude of 3 km. The beam width is plus/minus 1.5 degrees.

INSTRUMENT LANDING SYSTEM

GROUND STATIONS

After the use of the four-course dot/dash signals at 480 MHz in 1942 in Great Britain, a landing system was developed in the USA in 1943/44 for military purposes which was soon to be used for civilian purposes. This system was called the ILS which is presently in use at most airports around the world. A ground transmitter is used to generate a Localizer Beam made up by two overlapping patterns. One pattern is modulated at 90 Hz and the other at 150 Hz. The width of the beam is plus/minus 2.5 degrees. The receiver picks up both signals and a course indicator displays on what side of the locator beam the aircraft is on by the deflection of a needle to the right or left.

The glide slope, GS, is transmitted by two beams which are also modulated at 90 and 150 Hz. Again a needle in the display unit is used to show up or down. Upon approaching the airport, an outer marker beacon transmitted at 400 Hz, and located 7 km from the airport lets the pilot know how far he is from the landing spot. A middle marker beacon is located 1 km from the landing spot and is modulated at 1,300 Hz. A third marker beacon (Z-Marker) is located 70 m from the landing spot and it is modulated at 3,000 Hz. These marker signals are heard in the headset as well as being displayed by lights (blue, brown, white) on the instrument panel.

The Localizer Beam is transmitted at 40 W at a frequency of 108-112 MHz and the Glide Slope Beam is transmitted at 10 W at 328-336 MHz. Both main Marker Beacons are transmitted vertically at 1 W on 75 MHz. A range of at least 30 km is possible at low altitudes. The Z-Marker operates at 75 MHz and a power of 5 W.

New landing system transmitters using concentrated beams are less susceptible to clutter and reflection from housing and mountains. Since the beam width are now plus/minus 10 degrees, they are easier to intercept by the pilot.

As of 1951, the German ILS was built be the Lorenz A.G. and later by the Standard Electric Lorenz A. G. in Stuttgart. From 1969 on the ILS 3000 was fully transistorized. From 1984 on System 400 was fully digitally modulated for both the Localizer and VOR transmitter.

ILS GROUND STATIONS

Three antennas and three receivers are needed. One for the Localizer Beacon (LOC) one for the Glide Slope (GS) and the third for Marker Beacons (MKR). One Display with two needles is used to show the LOC (right and left) and GS (up and down) and three lights for the MKR are located on the instrument panel of the aircraft. Since all ILS transmitter antennas are horizontally polarized, a strip array antenna is used for the LOC and GS. The GS antenna is located on the underside of the fuselage and is mounted in a plastic V formed or wing shaped housing. The receiver for the LOC (108-112 MHz) is also designed to receive the VOR signal at 112-118 MHz and is sold as a single NAV receiver which can accommodate 200 channels with 50 kHz intervals from 108 – 117,950 MHz. LOC or VOR is selected by using the frequency knob. The knob allows the selection of the GS receiver with 40 channels in intervals of 150 kHz from 329.15-335.00 MHz. Reading the output for the LOC and GS is relatively easy. The output exists of two parallel circuit active filters for 90 Hz and 150 Hz with diodes which can be tuned for the side correction of the LOC or vertical correction for the GS indicators. The needles of the indicator deflect left or right from the mid position for the LOC and up or down for the GS. For the MKR receiver at 75 MHz only one sensitivity of 200 μV is necessary and sometimes two, in-series-circuits are used with a filter for 400 Hz (outer marker), 1300 Hz (middle marker) and 3,000 Hz (Z-marker). The signals are displayed with lights and modulated for audio signals in the headset.

ILS/VOR receivers were first used in German aircraft in 1967. The Becker Company was the first company to came out with a single VHF-NAV Receiver NR200. This receiver has 27 transistors and is able to develop 200 frequency channels with intervals of 50 kHz by mixing the output frequencies with three oscillators that can switch to interval steps of MHz, 100 kHz, and 50 kHz. In this manner only 19 crystals are needed instead of 30. Sensitivity is 1 μV and the unit weighs 1.6 kg. The display unit, Type NCI 201 weighs 1.3 kg and uses one needle for the LOC and one needle for the GS. A connection for the GS receiver is also provided.

In 1973 Becker developed the NAV 2000. The receiver, NR 2030 used a digital frequency tuning which could also be used for VHF communication. Model NR 2020/40 comes with the MKR receiver. A converter-indicator with built in Marker receiver and lights, Model NI 2030 with GS indicator has a total weight of 2.4 kg.

MEMOIRS OF Dr. E. KRAMAR
Translated by M. Hollmann and Peter Aichner

FORWARD

Several requests were made to document the history of the Lorenz Co and instrument landing systems. I was hesitant to respond because I was aware of the scope of the task to recall the past 30 years.

Since 1930, I have been involved in the direct development and I had the responsibility for the work performed in the utilization and deployment of aircraft navigation and instrument landing systems and here is that story.

HISTORIC MILESTONES

The name Scheller and his guiding beams play an utmost important role in our history. It has not been documented how Ott Scheller from 1909 became Technical Director of Lorenz. However he was far advanced when in 1907 he proposed "marking of ship lanes with the use of two beams, one from each of two radio transmitter, which crossed each other," as he disclosed in his patent number 201,496 "Wireless Course Lane and Telegraphy." This "guided beam" principal, whose realization was not possible at the time, found its first application in 1925 with the "four-course-navigation-system." This system was still used in 1978 in many parts of the world.

In 1929 we started testing a Medium Frequency Beam Transmitter at Lorenz Company at the Eberswald Facility and we received the support of Lufthansa and the DVL. We tested a miniature, transportable, four-course-beam system for the Navy to allow ships to enter a harbor. As expected, the affects of weather and evening mist caused the unreliable reception of radio beams and the work was suspended.

W. Hahnemann, Technical Director of Lorenz as of 1927, General Director as of 1933, suggested in his lecture of 1929 in Wien, Austria, "The Wave Length of Wireless Telegraphy and there Practical Significance" the limited application of Medium Frequency beams. He was the first one to recommend using wave length less than 10 m for the communication and guidance between an aircraft and a ground station. As such he supported my ideas in 1932 to use UHF guided beams despite of the poor economic conditions at that time.

The simple solution to guide an aircraft using vertical array antennas with two alternate operating reflectors and UHF transmitted beams was demonstrated by Dr. Petzel in 1932. It was shown that the terrain and surroundings did not interfere with the first tests to horizontally guide and aircraft to land at the Berlin-Tempelhof-Airport. In the Winter of 1932, two Marker beacons were added. The tremendous success of these tests with Lufthansa were reported by me in the November 1933 issue of the Proceedings of the Institute of Radio Engineers (IRE). The manuscript was submitted in May, 1933 with a full description of the equipment and installation. The delay in publishing this information was a little hard for me to understand since the Americans, the French, and especially the Dutch were working hard at standardizing their Medium Wave Length development. In mid 1937, when we were invited by the US Civil Aeronautics Administration (CAA) to demonstrate our equipment in Indianapolis we had a hard time finding equipment to take with us since, because of the promotional effort by Lufthansa of our instrument landing system at Tempelhof, we had already installed 35 instrument landing systems in Europe and a number of others in countries outside of Europe.

The successful demonstration in the USA and the forums presented by Mr. Hahnemann and I at the IRE meeting in Washington about the “Lorenz-Instrument-Landing-System” and the forum on “Use of UHF-Beacons for Long Range Navigation” in New York, helped to promote our landing system and we continued to develop the system based on requirements of the CAA at the Federal Labs of ITT. This ultimately led to the international standardization of our ILS by the ICAO in 1947. Even our Glide Slope Patent of 1937 is still used in ILS of today. Two intersecting vertical beam patterns are created by reflectioned beams from the ground. The beams are transmitted by two antennas located one above the other. And the intersection of the patterns form the straight glide path.

Our invention to use a reflector antenna system mounted on 30 m towers to achieve greater range was realized in our ILS installation in Australia in 1936. This system allowed constructing a navigation system from the East to the South coast of Australia. The system was operational for many years.

1935 saw the first use of UHF-omni range transmitters with reflector array antennas which slowly rotated. The receiving signals were coupled with the rotation of the antenna and the signals were counted automatically from the start signal (North). By allowing the antenna to rotate at high speeds we came on to the idea of creating a fan diagram and measuring the phase against the modulated transmission signal which was used as a reference frequency. Patented by us in 1940.

In addition to development of directional signals we switched to the development of directional reception of beams. A study which had been dominated by Telefunken Company. After all our competition had also become interested in our success in instrument landing systems. Attempts to improve transmission against night affects with special circuits (patented in 1934) did not prove successful and as a consequence we devoted our time into looking at the “Adcock Developments” and how the screened antenna transformer worked. We were especially interested in the very effective Ferrit-Goniometer which was later used in array transmitters. We developed a special receiver together with another department to put on aircraft for homing reception.

At the start of the war a large number of our projects were directed toward military use. A guiding beam transmitter with an adjustable UHF transmitter code named “Karussell” was built in 1939. It was mounted on a rotating platform and used narrow concentrated beams with a high power. At the same time we developed the three mast array transmitter “Elektra” which used a multitude of beams as a “Small Basis Hyperol System” in which the phase shift of the waves in the outer arrays were used to control and adjust the direction of the beams. By coupling the identification signal with the slow and continuous phase shifting, this long wave system was a form of rotating beam system which was later rebuilt into the “Sonne” in 1940. This system is still used today as a “Consol” for navigation in the North Sea and its access channels to the Pacific by a number of Norwegian and Russian stations as well as by Irish and French fishing fleets. Working together with the DVL a UHF System with a high range and using rotating Hyperbole fields was developed. The system was called “Erika.” Another system called “Komet” using a short wave rotating beam transmitter was developed. Both systems were built and deployed between 1942 and 1944. To guide night fighter aircraft to their airports at night, we developed the UHF rotating beam transmitter “Hermine” and a large number of these units with simple on board receivers were delivered.

After discussing our most important projects, I would like to tell about the scope of our responsibilities and how we worked together. Our navigation department had the goal to develop radio systems and equipment and to overview projects from the beginning to the end. However in many cases we only partially developed and built the systems. Our involvement did include; responsible for the transmitters and the receivers and their delivery to the customers, detail design of how data was input and output, modulation forms, direction antennas, Goniometer, display units. We were responsible for maintenance, evaluation, testing and installation. We also worked closely with our customers.

By a division of labor we were able to save considerably on the number of experts needed. However we did keep pace with the latest technological developments which we incorporated into our radio systems. All the departments and personnel at Lorenz worked closely together which can be credited to some extent to Dr. Rochow and I as department head. However, the real credit goes to our workers and engineers who always put forth their outstanding efforts during some very difficult times during the war years.

The development of special systems such as “radar”, which required completely new concepts and systems and had little to do with our work on information systems, were not handled by us.

During the war our company grew in size and personnel. The first navigation system units were demonstrated by me while working in the transmitter department headed by Dr. Rochow. I started work on machine and constant wave units MF rotating beam antenna transmitters in the experimental group in Eberswalde. After transferring to the Main Lorenz Plant in Berlin in 1930, I started research on using UHF waves for guided beams that led to the “reflection beam” methods. Already in 1932 we started on the flight tests of our first unit at the Berlin Tempelhof Airport. I worked with a mechanic and many good suggestions alone and experienced all the problems one can imagine using this new technology for aircraft.

It was not until 1934 that we had the good fortune to hire Dr. Johannson, a clever physicist and receiver expert. The expellant results and the expanding scope of work required hiring more personnel. The experimental group was equipped as a transmitter group and starting 1935 we became a “Navigation Laboratory.” At the end of 1935 we had 12 personnel which included 6 research scientists. At the start of 1936, Dr. Goldmann, an outstanding physicist and mathematician, came to work with us. Until the end of the war, he was the group leader for the transmitter division and Dr. Johnannson the group leader for the receiver division. By 1940 we were 18 development scientists and a number of technical engineers.

In 1940, I also took over the lead for the radar group which had been until then under the leadership of Dr. F. Gerth. This research laboratory had been established by W. Hahnemann in 1935 with three research scientists. Under the direction of Dr. G. Mueller it grew to 100 personnel by the end of the war. The total number of employees in the Navigation and Radar group was about 220 by the end of the war.

I want to also point out that starting in 1935, Lorenz dedicated some of its resources on development of radar on the decimeter wave length. The was a very progress step to take for this early date. During the war the radar development was performed in strictest secrecy. Dr. G. Mueller started working in 1935 on radar at Lorenz. He designed the 60 cm wave length FuMG 39L and the 50 cm wave length FuMG 40L, code name “Hehentweil” used in aircraft. At the end of the war this unit was also used on ships and as a ground station. The design of the FuG 200 with its many variants was headed by Dr. K. Christ. Lonrenz also worked on the 2 m band panorama radar “Jagdhaus.” Dr. M. Messner and Dr. Schnabel lead this effort.

AFTER THE WAR

Several days before the collapse of the Reich on the 9^{th} of April 1945, at the request of Major Schmid, I left Berlin to head up a new group made up of our department and other Lorenz departments from Auerbach, Falkenstein and Nordboehmen. We moved South to our Machine Shop in Landshut. Through the efforts of ITT, on the 15^{th} of June, a convoy made up of a number of US military vehicles allowed 20 families to leave Thuringa and escape to Landshut so they would not fall into the hands of the Russians. An attempt by Dr. Kloepfer and Dr. Christ to retrieve more Lorenz equipment with the US military vehicles was not successful. Both gentlemen were detained by US officers and put into an interrogation camp for several month.

After several lean month in Landshut, we received a contract from US Military Headquarters in Frankfurt to make the “Stuttgart Navigation System” built by Lorenz operational. Although, we had a limited number of technicians, we gladly accepted the job and we worked under the direction of Mr. Hertenstein.

In 1946, our engineering group moved again to Pforzheim of which 70% had been destroyed during an air raid 23 February 1945. Despite help from ITT, Mr. Hertenstein and care packages we had housing and survival problems. Only a few receiver experts were capable of earning a living by repairing radio stations and household utilities for the citizens of Pforzheim. Others simply did their best to exist until the new currency was circulated in 1948.

In the mean-time, our radio tube factory had been successfully transported out of Muehlhausen in Thuringa and rebuilt in Esslingen under the direction of Dr. Herringer and Dr. Doering. Our Lorenz tube factory was able to built a special klystron tube required for the refurbishment of the “Stuttgart Navigation System.” Further parts were obtained from the large Mannheim US Military depot for confiscated radar units. In 1946, Dr. Kloepfer from past experience developed and built a frequency modulated voice communication system for the police in Pforzheim. We were in competition with an AM system built by Telefunken and our system showed distinct advantages during police evaluation in Stuttgart.

In the fall of 1947 we received a large contract from the military government to build a short wave telephone system with a transmitter located in Frankfurt and a receiver in Eschborn. This system was also to replace the military communication system from Frankfurt to New York by the mid 1948 and it was to be installed and operated by the German Bundespost. Working together with our Berlin plant we were able to actually build the system in 9 month. Another job, “Eurocom” contract, soon followed to build a short wave communication system, 40 – 70 MHz, for the US Army. This included building a number of relay stations. Work for the engineering department was secured.

The post war navigation programs did not fare that well. Neither our group in Landshut nor the engineering group in Pforzheim had a single one of my former colleagues. One of my group stayed in Berlin, all Austrians returned to their homes, some had changed their jobs, and others had simply disappeared or had been killed. Further development of one technology would not have been possible since we were not allowed to work on the electromagnetic beams used for detecting of aircraft or ships (radar) according to Regulation 43. However even before the regulations had been relaxed in 1950, some activity did exist in radar research. We exchanged technical data and articles and talked with the Americans on radar. The conferences included Dr. Zetzmann from Siemens, Dr. Ullbricht from Telefunken, Mr. Boettcher later from Siemens, Mr. Trost from the Echterdingen Airport and others.

Among the directors was Dr. Klett and his colleagues. The Stuttgarter Airport Administration was responsible for safety and labor unions representing the German Commercial Airports (ADV). Many discussions and meetings were held. For example in January 1947, a meeting was held for the purpose of planning the expansion of airports for international regulations.

Dr.Leo Brandt in Duesseldorf, director of the Institute of Transportation of Nordheim Westfalen, ordered educating all airport navigation technicians. In May 1950, a meeting took place at Director Brandt's office to discuss the German air transportation situation. In attendance was Director Kerschbaum from Siemens had just returned from Russia and he gave a presentation on the radar and navigation industry and research in that country. I presented a forum on the limited and reduced development of radar in Germany since 1945. Based on this and other meetings in Duesseldorf, we formed the Committee for Radar with Prof. Dr. Leo Brandt as its director from September 1951 to March 1966. In December, 1961 group was renamed the "German Committee for Radar and Navigation." In 1950 in Duesseldorf a large meeting sponsored by the ADV on "flight safety" took place. Among the many forums was one on "aircraft beam navigation and airspace observation" and "navigation aids in West German airspace" presented by Mr. von Hautenville. In October 1950, I was able to take part in a meeting held in England. The trip was sponsored by the DECCA Company for Prof. Brandt and representatives of the Air and Sea Transportation Administration.

In March 1951 I represented the Lorenz Co. at the "ITT Technical Committee, 3-D European Sector" meeting between Germans and Americans which was directed by Mr. Lizon. As of 1960 this committee was called "Technical Committee 14" and in 1964 it was named "Committee 34-1". Since then it has been called "Task Force 6."

Based on our presentation in Indianapolis in 1937, at the end of 1949 the US Civil Aviation Administration (CAA) of the US Occupation Forces (Mr. van Cott) in Wiesbaden and later the British Civil Aeronautics Board (CAB) contacted us to build an instrument landing and aircraft navigation system in the US sector of Germany. At first the US instrument landing system (ILS) in Echterdingen was in desperate need of major improvement. Second, we received a US built VOR from the Federal Labs. Because of its faulty design, this unit burned down when it was first turned on. Despite having blue prints from the CAA and the Federal Labs, Mr. van Cott was eager to improve these ILS and VOR transmitters with such things as frequency modulation and other refinements which included switching to German tubes and new antennas to demonstrate that we could deliver significantly better units than the US companies. At first, our transmitter department under the leadership of H. Heinecke and Dr. Bosse in Berlin and the antenna development under Dr. Crone in Stuttgart did not trust our colleagues from overseas.

In April 1951 I was able to accept an invitation from the CAA in Washington with Mr. van Cott in which I visited ITT in New York and the CAA in Washington and Indianapolis. There I met many old friends from our 1937 demonstrations. I also met new engineers with which I could discuss the development of air navigation system during war and their influence on present civil use. These new contacts were important in future contracts which we received. On the return flight we visited Santa Maria on the Azores and Madrid to discuss our VOR and "Sonne" system with Lieutenant Gorozarri.

In 1955 Dr. Steiner returned to us with his small group of scientists to develop the Doppler radar using VHF and UHF. Field tests using mechanical switching of a circular antenna showed a large advantage over the Adcock antenna transmitter. A well developed transportable UHF Unit with electronic switching (about 1960) unfortunately did not lead to a future contract. As such, further technical development was canceled. In 1958, this idea for transmitters lead to the twin band Doppler VOR patent which was the basis for our Doppler VOR which was modified by the Earp suggestion for alternate switching of the side bands (ABS system).

This study stimulated using dipole antenna movement along straight paths. This brought about the idea for FM-guided beams (asymmetric motion of two dipole antennas on one target), code name “Zwilling.”

More successful was my SETAC suggestion which used movable hyperbole beams such as used in the “Sonne” and “Erika” systems. The unit used a TACAN system similar phase field in any selected sector with improved accuracy. Two separated antennas are used with one antenna transmitting a different travel speed and received as a amplitude modulated signal with a higher frequency (15 Hz). The beam can be received in a 36 degree sector by a normal TACAN receiver with 10 times the angular accuracy for measuring an approaching aircraft with continuous distance measurement.

From 1950 to 1955 I was involved in 50 trips traveling to most major European cities to survey airports and promote our VOR and ILS units and give lectures. Part of these trips involved attending ITT Committee meetings as the German representative and the ICAO and IATA conferences in Paris and Montreal. 1950 was especially important to us since after a three week stay in Washington and New York and many negotiations with the FAA competing with the local companies, we won a US contract from RCA to deliver 100 VOR systems to underdeveloped countries. Another 50 trips abroad until 1967 were important. An invitation in September 1958 to a large navigation symposium held by the FAA in Washington with a demonstration in Indianapolis at which I saw the first US developed Doppler VOR system. I also took part of the ICAO Conference at which the VOR/DME controversy took place against the DECCA system.

In the same year I attended a three week meeting at Nippon Electric in Tokyo to inform the Japanese about our VOR/ILS activities and educate their engineers about how they operate.

In June 1957 I handed over my position as director of the navigation system group to Dr. Haessler and was put in charge of the coordination of navigation groups in our company. As of December 1969 I retired and became a consultant until 1977 for SEL.

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