FUSE

Demonstrator Document

AE 1713

Programmable logic simplifies assembly and test and reduces cost of VHF/HF transceiver

Abstract AE 1713: HF/VHF Transceiver

Satelliet Televisie Nederland BV (STN), founded in 1982, in is a small company with three of in total 7 persons in product development. The sales of the company mounts up to 750 KECU. The products are all sorts of professional CATV equipment, delivered as OEM to big companies. Besides this, some transmission and measurement equipment is produced under the STN brand name. Production is subcontracted. The market for all STN products is for 90% found in NL, D, B and F. There is some export to the USA. The expertise of STN is RF design.

The objective of the AE is to improve the existing short-wave transceiver with a digital FPGA (FPGA, Field Programmable Gate Array). This digital technique is planned to take over all analogue frequency generation in all STN products. The digital products are much more stable and reproducible. The existing short-wave transceiver kit had an analogue variable frequency generator and tubes in the power amplifier and no digital functions. The product is sold as an assembly kit for radio amateur enthusiasts. The new FPGA technology assures a high reproducibility for the transceiver kit and gives also more digital control functions as several memory functions, easy frequency band switching, automatic mode switching, etc. A solid state amplifier will improve the robustness of the design. During development, it is very useful that changes in the trial design can easy be implemented just by reprogramming the FPGA. Moreover, the flexibility of reprogramming ensures easy adaptation for different technical demands in foreign countries and adaptation for later (possible) changes

The AE started on 01/01/1996 and ended at 31/01/1997. In this 13-month experiment 75 KECU was spent on education, on FPGA design, on solid-state power amplifier design and on digital design. The predicted payback period was 27 month after introduction, in 1997. Net ROI predicted was about 300% over three years. However, due business and market circumstances it is doubtful if the payback will be reached with this product.

STN is now capable of designing FPGA building blocks in other products. The markets of these products still are professional CATV equipment users, OEM products and the own STN RF products, (measurement equipment etc). Increment in capability of supplying more functionality is the most important for STN. The combination of FPGA and RF technology has generated, in 1997 and 1998, additional sales of 500 KECU and important market leads. The pay back of the investment has been realised by the end of 1998.

Being accustomed to asynchronous digital techniques, developing a FPGA demand a complete different design philosophy based on synchronous digital techniques. Next to STN learned, that specification phase of the design is very important. Thirdly, it was experienced that a complex design needs very stringent timing simulation and this is the only way to let this result in a correct working device.

***Key* Words**

RF Radio, Digital RF, FPGA, Small Company, Satellite TV.

Signature: 3 0410 540 0172 2 3230 1 32 NL

1. Company

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2. Company size

The emerging satellite television market was the trigger for founding STN in 1982, employing seven people now with sales of 750 KECU.

3. Company business description

STN has an own portfolio of products based on their core competence: RF technology. STN designs and manufactures cable television (CATV) products, accounting for about 16 % of the sales. As products can be mentioned: QUAM modulators, amplifiers, signal distribution units, signal input protection units, stereo television and radio modulators, frequency converters, satellite receivers, radio receivers, etc. for mainly the Dutch market. The radio transceiver kits generates 4 % of the sales. The rest of the sales, 80 %, comes from the development and production of OEM equipment. Some products are sold via well-known brand names to France, Germany and Holland. For these markets, no STN marketing is necessary. Most developments are done on customer request, requiring an intensive account management.

Current developments are addressing the migration to interactive cable networks with high-speed data channel amplifiers in both directions and signal distribution and collection modules.

STN got into contact with other FUSE companies during dissemination in Paris. With Procorp, Syscom and SS&S project were started following this event. All projects involve the special RF expertise of STN.

4. Company markets and competitive position

The market of STN for this radio amateur transceiver kit is formed by a large number of licensed radio amateurs in the whole world. For 1994 for a few countries these numbers were:

Japan	1,300,000	USA	632,000
Germany	64,000	United Kingdom	62,000
Indonesia	60,000	Spain	47,000
Canada	44,000	Russia	38,000
Italy	30,000	Brazil	27,000
Netherlands	10.000		

The total market in these countries is about. 2,3 million. The 95% majority buys ready to use Japanese radios. The Japanese serves 80 % of this majority of the market and the other 20 % are served by USA based suppliers. The 5% left build their own radio and buy radio kits. STN is aiming at this market. For a start, the market in The Netherlands, the UK and Germany are considered the most fruitful. This is in total 64.000+62.000+10.000= 136.000 radio amateurs. The market for self build radio kits in these three countries implies 6800 potential customers. STN plans a market share of 20%, meaning 1360 sets sold. Presently STN has 2.5% of total market with sales of 30 KECU.

Competition comes from TenTec Inc, (50 employees) the United States. These kits offered, are only single band or HF bands transceivers. In The Netherlands, a similar transceiver, only for HF, is offered under the brand “CHN.”

“The CHN” product is designed and marketed by a one-person company in Amsterdam. Further, do it yourself kits are presented by SSB Elektronik (20 employees) in Germany, this are sub units, which are not working ‘stand-alone” but together with already existing equipment. They offer extra frequency bands added to the existing equipment and add-on power amplifiers, mainly for the VHF and UHF bands. Companies in other countries offer similar kits.

Pricing of the competition (CHN) is in the range 500 ECU (for a single band transceiver) to 2000 ECU (for an all band set). STN positions its transceiver in the top segment performance radios, for competitive price. The features offered (e.g. digital tuning by optical decoded knob, 2 digital frequency memories with easy access, very compact construction and automatic band switching are not met by the competition, which only have simple radios without digital functionality. No market shares or other market analyses are available.

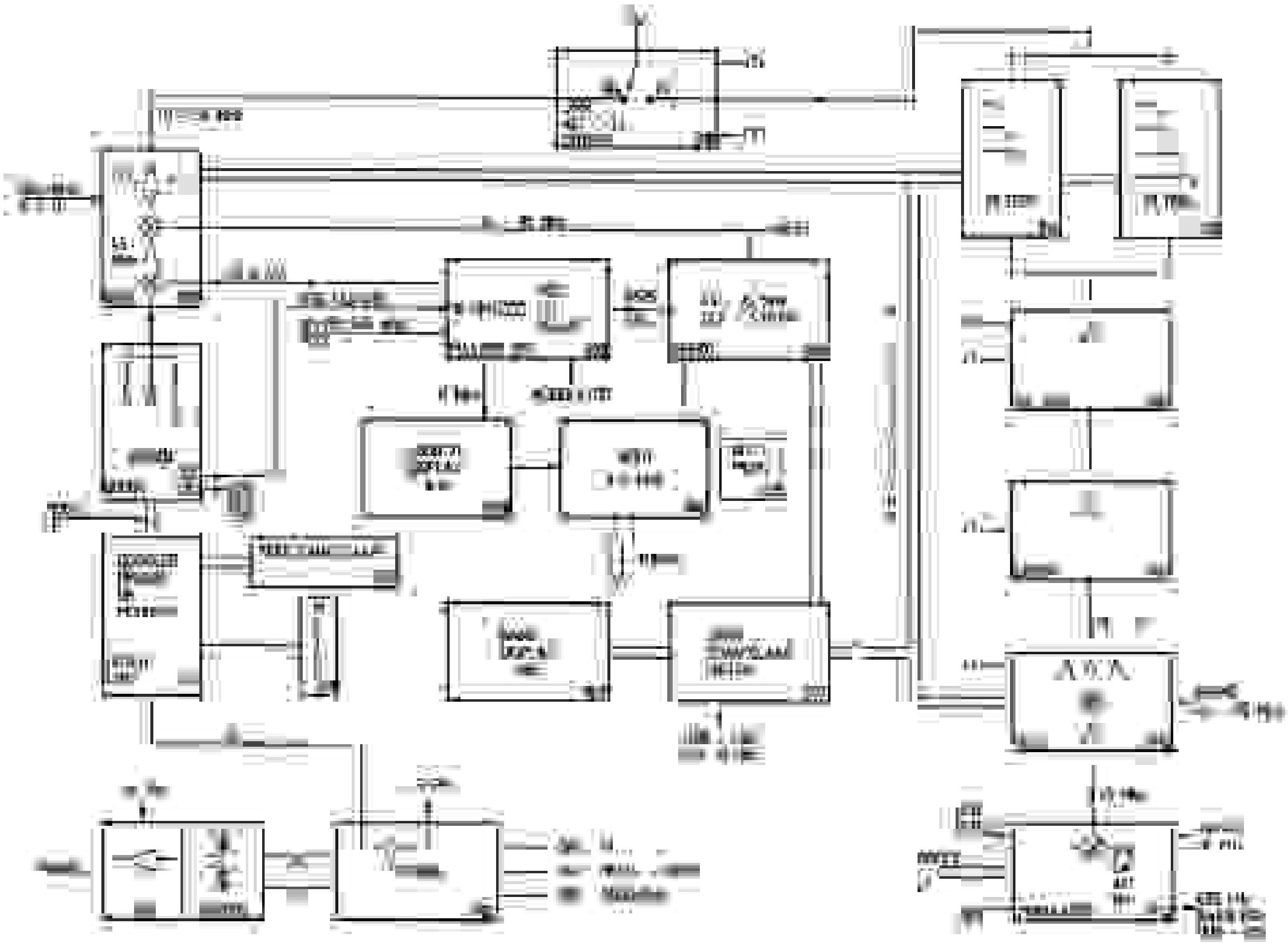
The existing product was launched onto the market in 1993 with the following sales figures over the years.

	1993	1994	1995	1996
Units	15	25	22	18
Sales kECU	19	31	27.5	22.5

It proved in 1995 in comparison with competition that the product was build with “old fashioned” frequency generation and tube power-amplifiers. Newest technology means for these items: digital frequency generation, frequency memory functions and all solid state design.

5. Product to be improved and its industrial sectors

The existing product is designed for radio-amateur enthusiasts. As a hobby, radio transceivers are designed, build and used for making connection with other radio-amateurs around the world. For this, the radio transceiver is connected to an antenna system what radiates the RF power from the transceiver as electromagnetic waves.



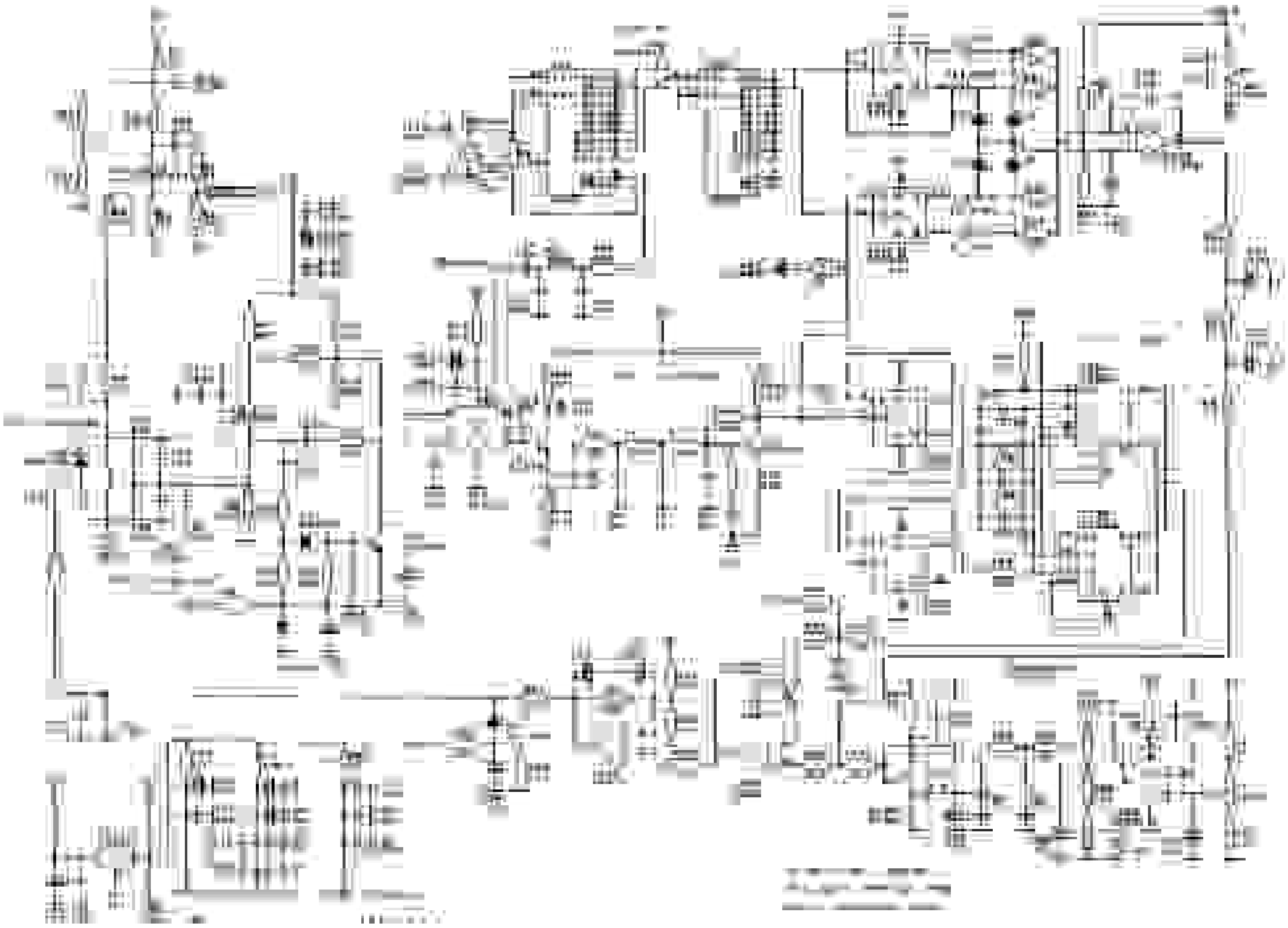
Some users are professionals; some have absolutely no related profession in electronics. What they have in common is their love for new and challenging techniques and ease of use of equipment.

The product to be improved was build with “old fashioned” frequency generation and tube power-amplifiers. Newest technology means for these items: digital frequency generation, frequency memory functions and all solid state design.

In the existing transceiver, the design implies an additional tuning once a transmitting frequency was chosen. This is caused by the necessity to match the high impedance of the small-band tube output circuit to the mostly 50 Ohms antenna circuits. Modern designs are broadband designs, meaning that tuning is not necessary any more. Consequently working with these modern designed transceivers is much more convenient.

Functional specification of the existing HF/VHF transceiver

Frequency bands:		
Receiver:	3.6MHz to 30 MHz	
Transmitter:	CEPT amateur bands from 1.8 MHz to 30 MHz	
Modes of operation:	CW-USB-LSB	(Receive and transmit)
Receiver sensitivity:	3.6 to 30 MHz	2µV for 10 dB S/N (SSB mode)
Transmitter output power:	1.6 to 30 MHz	50 W
Transmitter final stage:	HF	valves
Tuning:	Variable Frequency Oscillator (VFO) (Transmitter and receiver)	
Frequency readout	analogue scale	



As already mentioned, this product was not very sophisticated in the sense that not very much (digital) convenience was available since the VFO consisted of only discrete transistors and that the power RF stage was not solid state and consequently not easy to tune.

The old equipment has a large component count as is shown in the schematic above (about 160 components), where only the ‘analogue” way of frequency generation is shown.

With the FPGA solution, the component count has reduced to approximately 25 parts!

It will be clear to the reader that the complexity of the PC board and the amount of labour for the analogue concept are much more translated in price, compared to the FPGA solution. It is estimated that the cost price of the new product can be reduced by approximately 30 %.

6. Description of the technical product improvements

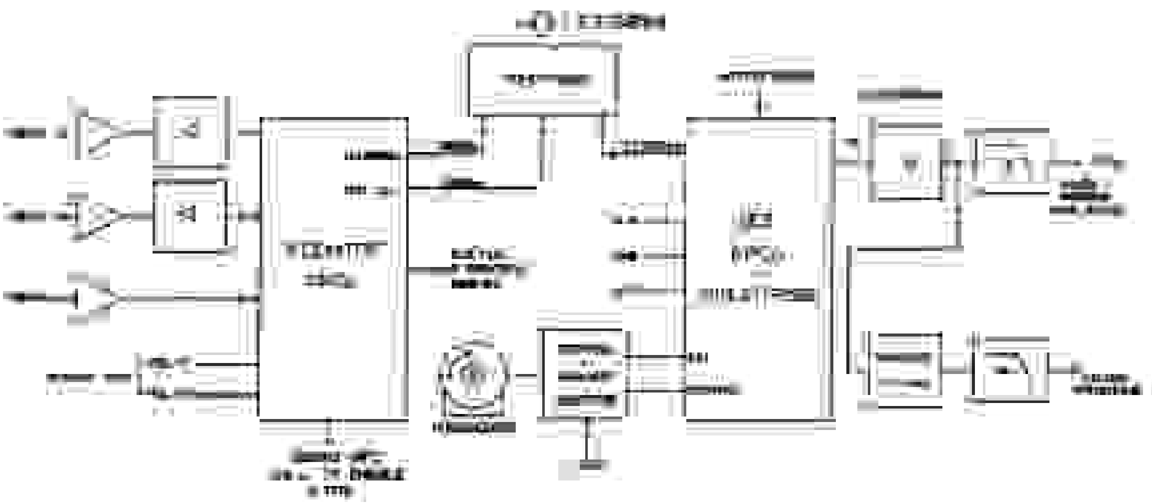
The new transceiver looks very fine. Its front panel is redesigned and offers great comfort in handling frequency switching, mode switching, LF signal filtering etc.

Functional specification of the ***new*** HF/VHF transceiver

Frequency bands:		
Receiver:	30 kHz to 60 MHz, 110 MHz to 150 MHz	
Transmitter:	CEPT amateur bands from 1.8 MHz to 146 MHz	
Modes of operation:	CW-AM-FM-USB-LSB-DATA (Receive and transmit)	
Receiver sensitivity:	1 to 30 MHz	2µV for 10 dB S/N (SSB mode)

	50 MHz	0.2 µV for 10 dB S/N (SSB mode)
	145 MHz	0.2 µV for 10 dB S/N (SSB mode)
Transmitter output power:	1.6 to 30 MHz	50 W
	50 MHz	35 W
	145 MHz	25 W
Tuning:	direct digital frequency synthesiser (transmitter and receiver)	
Tuning steps	16 Hz	CW-USB-LSB-DATA
	256 Hz	AM-FM
Tuning memories	2	independently chosen and tuned
Band switching	1 MHz steps	
Frequency readout	8 digits (digital)	FPGA specially designed counter
	with IF compensation and tuning scale (quasi-analogue LED bar)	
Transmitter final stage:	HF/VHF	solid state with power MOSFETs

The new transceiver kit should be easily assembled and tested by radio amateurs. Power needs for new electronic functions were not an item, but physical size is, as well as ease of reproduction and alignment. For the new final amplifier, the ease of tuning was very important, as well its robustness. For the final amplifier is a FET balanced (class AB) amplifier designed.



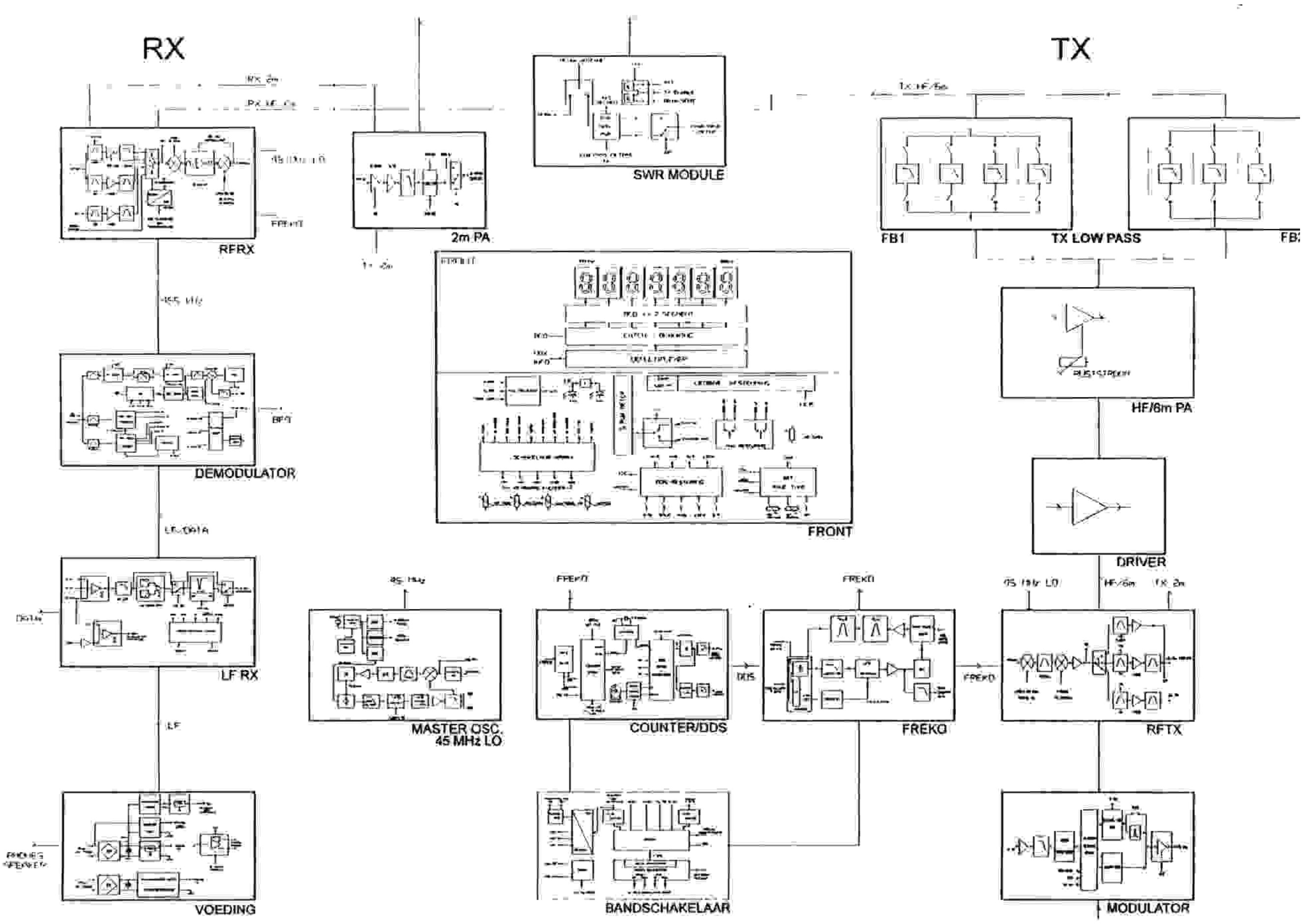
For the frequency generation, a Direct Digital Synthesiser was implemented in a FPGA. A Direct Digital Synthesiser (DDS instead of a VFO) is small, has unconditional frequency stability, a small tuning resolution, and has the possibility for memory functions. For the complex digital functions of this transceiver, a high level of integration, ease of assembly and small dimensions are required and a FPGA meets these requirements.

Instead of a LC circuit, the sinus form is read out of a memory. The speed in which this happens controls the desired frequency. The frequency is put in a down counter, and at the clock ticks of a crystal oscillator, the down counter is triggered. This crystal oscillator is the main drift source and is build with 0 temperature tolerance components in an isolated compartment. All digital components, including a frequency counter for the front read out of the transmitting and receive frequency are integrated in the FPGA circuits.

The two FPGA circuits have a combined complexity of 5400 standard gates, far more components than STN has ever designed in a circuit. Without the modern design tools this would never been possible to handle for a small company as STN.

Finally, the cost of the new product compared with the old product is an advantage.

The new product is approximately 30 % cheaper than the old one due to a less component count and thus assembling time (time is money) and smaller PC boards (material / production cost) and more easy to route the smaller PC boards (less interconnections).



In the block diagram, the units to be improved are clearly visible in the centre. Besides the base functions mentioned, an additional memory is also integrated in the FPGA, offering easy frequency switching and split frequency working.

Compare to the competition in the radio-amateur kit market, STN offers now more digital control functions of its transceiver. The comfort in control is much higher than the competitors offer.

7. Choices and rationale for selected technologies, tools and methodologies

As a technology, STN chose an FPGA for implementing the main circuits. Selecting this technology took some time. An FPGA is a good choice for several reasons. Compared to standard digital logic building blocks:

-An FPGA is cheap
-It is fast
-Its capacity allows us to integrate all logic elements of the DDS in one chip
-It is re-programmable, so a change in design is easily possible
-Fits in the view of the future STN product developments
-Lower assembly costs
-Intellectual Property Rights (IPR): not easy to copy

Time to market is shorter because adaptation for different demands in different countries is quick and relative easy done where we talk about digital functionality. Time to market for a re-programmable FPGA is about two weeks, while for the old product one has to take into account some 12 weeks due to design, ordering and manufacturing time.

This is also the case for other products where the FPGA technology is implemented: e.g. in our new television modulator. (this can now be easily adapted to different countries thanks to the FPGA). For this product, a great American company has shown interest.

In this AE, the task was to design a great number of (digital) functions as stable frequency generation, frequency memory functions, automatic band switching, frequency counting etc. in as small as possible board area. In traditional CMOS logic, the design would have taken 2 to 3 euro-card sizes PCB's. The solution in two FPGAs is very small indeed, only _ an euro-card. Selecting of the FPGA was done in co-operation with the subcontractor.

One of the important requirements in the design was that it should be easy reproducible. The existing analogue VFO design did not meet this requirement. Digital logic could do the job.

The solution with standard logic building blocks (e.g. 74HC series) would have mend hundreds of solder joints more, extra connectors and more costs. The FPGA and PCB costs about 25 ECU, the traditional solution would have cost 75 ECU (material costs).

An ASIC is also considered. This would result with a 1000 piece run in a price of 250 ECU: much too expensive for our batch size of 100 pieces and less flexible to market demands. The time to market of the reprogrammable FPGA is extremely fast: about two weeks. The PCB design is 10% of the standard logic design, the costs involved in redesign even lower: the redesign does not need a new PCB, but is simply reprogramming the FPGA. All these point lead to the selection of an FPGA for the DDS.

A high-speed (RISC) microprocessor is also studied. After advice from the FUSE consultant and calculating the pros and contras, the company decided not to take this path. There would be no price advantage, but more (memory) functionality could be incorporated in the design. The complexity was considered too great to manage with a microprocessor. After the experiment some developments are started with microprocessors, but these address only relatively slow control functions and not the high speed RF frequency generation and important real time aspects as the DDS in the FPGA does.

To be able to alter the design easily, STN sought for a re-programmable FPGA. The Xilinx series are RAM controlled and do an excellent job in the final design, but on top of that were numerous times re-programmed during development. This automatically selected the tools needed for this component. Available were schematic entry and VHDL (programming language for hardware design) besides low level entry in the FPGA design. No other FPGAs have been investigated.

It was decided to work with schematic entry because this has a low barrier, and gives an easy to read function of the inner design of the FPGA (the schematic itself).

Development methodology was adapted to the way STN designed before this experiment. Via schematic entry, the digital logic was entered in the computer. After digital logic and timing simulation (new for STN) the circuit was actually build and tested. Several redesigns were needed, but with the help of the subcontractor, all went out to work perfectly at the end.

The Original specifications were very compact. The original VFO was the starting point, so no complex methodologies were needed here. Specifying the DDS design itself turned out to be difficult. Tightly organised, step by step working together with the subcontractor, was the solution. Partitioning of the design solved the complexity problems. The transceiver was designed using the well-known RF design techniques. Simulation was also done.

Tools for this project:

XILINX	XACT	FPGA digital design and simulation tool
RF DESIGNER	ARRL	RF network synthesis CAD tool
ORCAD 386		Schematic entry tool
PUFF		µ wave design tool

These tools were selected by STN on its own expertise as far as it concerns RF design tools. The rest is chosen in collaboration with the subcontractors.

The hardware of the transceiver was entered through schematic entry. For the FPGA circuits timing simulation was done. The bi-layer PCBs were manually designed with an automatic place and route program. The PCBs were build with standard components, some of them SMD type components. For the rest, the boards are produced with standard techniques.

During development, module test and measurement were done with: spectrum analyser, (micro) voltmeter, R.F. power meter, signal generators (LF and RF), network analyser, oscilloscopes etc. to check all the DC and RF parameters required.

Special care was given to a simple and straightforward test procedure, repeatable in the field, easy executable by the customer.

8. Expertise and experience in microelectronics

The expertise of STN is design of analogue RF circuitry and a little digital discrete CMOS. This knowledge is acquired during the existence of STN developing various products of STN. Before entering STN, personnel worked with Swiss and Dutch telecom companies, like PTT etc. in the field of RF technology. The breakthrough of the company came during the design and installation of the Amsterdam cable network, for which all amplifier and distribution equipment was designed and produced. The company has grown from the knowledge of specialists. CAD tools, as schematic entry and analogue simulations, are common practice at STN. The staff allocated to the project had skills in RF design using discrete devices.

9. Workplan and rationale

The project was divided into five phases.

Task 1: Management
Management, planning and documentation of the project
Workload: STN 27 days
Deliverables: technical and financial documentation of the project

Task 2: Specification
STN studied digital techniques and improved the specs.
Workload: STN 8 days; subcontractor HF: 2 days
Deliverable: complete specifications.

Task 3: Training
In this phase, STN studied with two electrical engineers in the field of FPGA, variable oscillator techniques and solid state RF power amplifiers. They followed a special course, and used external subcontractor expertise. Principles were worked out and simulated. Education came from subcontractor Rodelco for the FPGA part, from subcontractor Harte for the RF power amplifier part. The training took part in the design phase as training on the job'.

Additional assistance was called in during the eight re-designs of the front-end and the re-designs of the detector. The TTN assisted in the complexity handling and planning of the design.
Workload: STN 46 days; FPGA subcontractor: 5 days; HF subcontractor: 26 days

Task 4: Design.
Principles were designed and simulated. In this phase, the hardware of all units was designed. PCBs were designed and build which contained the FPGA, RF power amplifiers, etc. These boards were thoroughly tested. It proved that the technical specifications of the receiver were almost beyond the capabilities of the technological capabilities of STN. The training as foreseen in WP3, was done in the design phase as training on the job'.

This resulted in eight iterations of the front-end design and testing and three iterations of the MF detector, field strength indicator and squelch circuit. The planned days for the design were exceeded by 17 days.
Deliverables: Working digital units and RF hardware
- Digital RX/TX variable oscillator, direct digital synthesiser
- RF power amplifier
- Receiver units incorporation (non FUA)
- Power units for the above mentioned (non FUA)
- Digital Packet Radio interfaces

Workload: STN: 62 days
Consumables: 11.7 KECU

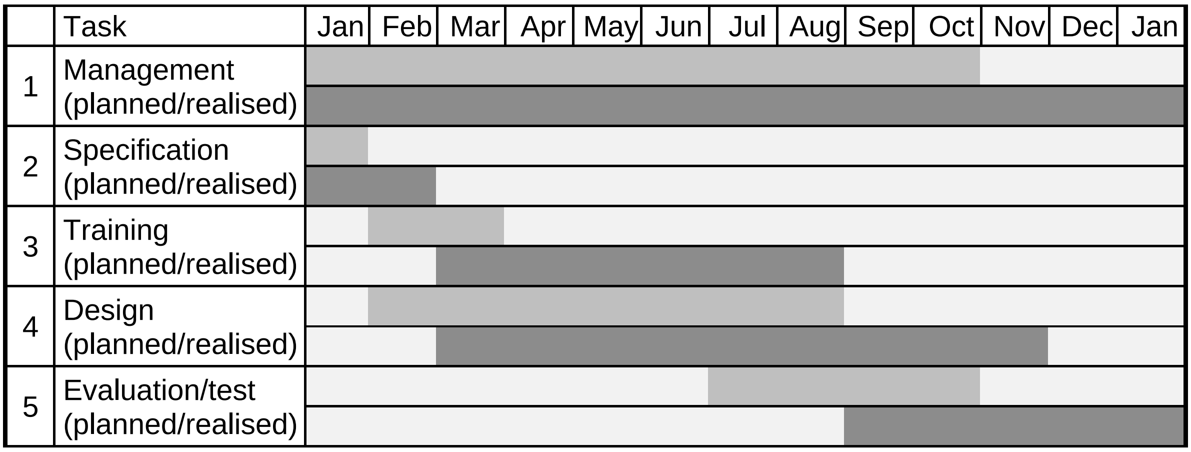
Task 5: Evaluation.
In this phase the prototypes were build and tested according to test descriptions followed by a field test. Due to the re-designs the evaluation was exceeded by 33 days.
Deliverable: Working prototype HF/VHF transceiver.
Workload: STN: 53 days

An overview of planned and actual budgets

	STN				Rodelco		Harte		Tot. Costs Subctr		Other Costs
	Actual		Planned		Act	Plan	Act	Plan	Actual	Planned	Actual
	days	ECU	days	ECU	days	Days	Days	days	ECU	ECU	
WP 1: Management	27	8.166	20	9.400							
WP 2: Specification	8	2.386	8	2.560	---	1	1	1	177	800	
WP 3: Training	46	13.722	36	11.520	6	6	24	30	4.251	13.000	
WP 4: Design	62	18.532	45	14.400							Consumables: 11.710
WP 5: Evaluation	53	15.661	20	6.400							
	196	58.467	129	44.280	6	7	25	31	4.428	13.800	

Subcontractor Rodelco was for free, and Mr. Harte offered at a fixed price.

Due to the re-designs, the planning was extended by 3 month up to 13 month.



The subcontractor costs of Rodelco were zero as part of their customer service and the costs of the HF subcontractor were at a special price. Therefore, the subcontractor costs of the project do not reflect actual market prices.

<u>Conclusions on the performed workplan</u>

It proved that the risk analysis was not properly done. STN was not aware they were developing at their technological limits. Especially the influence of the digital components, working on high clock frequencies, on the analogue parts was underestimated. The trail-and-error way of working to solve the problems illustrates the unfamiliarity with the phenomenon of digital interference. Most of the iterations in the design are put down to this.

No problems exist with subcontractor files etc. in STN. All the know-how, gained with this AE, is kept and can be used for new products. All Intellectual Property Rights are with STN, as was agreed with the subcontractors.

All specification, design, simulation and testing efforts were done by STN. STN learned during the project to build solid state RF power amplifiers, digital RX/TX variable oscillators and the use of FPGA, digital control and user interface.

10. Subcontractor information

Subcontractor 1: Rodelco Electronics

FPGA subcontractor Rodelco was chosen on the following grounds:

- The company was recommended by several business contacts with other companies.
- The company as several years experience in FPGA design.
- Rodelco showed to have al lot of knowledge and the ability and willingness to transfer this to STN in the AE.

During the many visits and working together STN got a rich input of technical application expertise from Rodelco. Practical use of the hard and software was explained, simulated, showed and all this knowledge was put into the design, together with STN. Rodelco was very flexible and willing to help in solving our problems and teaching how to design FPGA circuits and to get grip on the complexity aspect.

To get familiar to the world of digital logic programmable devices and their specific possibilities and problems, without the help of the subcontractor, would have cost a considerable amount of time. This is particularly important if you have to decide whether a certain programmable device is suited for your problem or not. Rodelco has a good knowledge of the broad product range of programmable logic, and good application expertise, what turned out to be very useful in the selection of the most cost effective FPGA. From Rodelco the FPGA's were bought, their training was for free. There was no contract between FU and subcontractor involved.

Subcontractor 2: JLL Harte

For the RF power amplifier, subcontractor Harte was chosen because:

- The long experience in HF power amplifier design.
- Several advisors recommended Harte.
- Harte was willingly to work in a project that incorporates knowledge transfer.

The expertise we got from this subcontractor also came during the "designing together." The philosophy of the calculations was done in such a way that if the need for a new design with other specifications arises; STN is able to do these calculations on its own. The way the subcontractor worked with STN was again flexible and well orientated to STN wishes. A prototype was built and tested by STN together with the subcontractor. Afterwards STN build four other amplifiers to test several aspects like reproducibility, specification checks and to enable duration tests.

Doing this job without a subcontractor would mean a long study of complex matching theory of RF power devices that requires a specific skill not often found in The Netherlands. This application is in more octave concept, which means many extra difficulties in the design. This part of the AE was ready in time. The work would have been difficult and very time consuming if done by STN alone.

Mr Harte was an ex-employee from a big company and offered a fixed price contract, at a special price. There was a very good human fit between subcontractor

Barriers perceived

The following barriers existed before using the new technology:

- Lack of knowledge of how to convert complex digital circuitry in a small FPGA.

- Instead of constructing circuits that are accessible for measurement and fault detection (formerly all point could be accessed and tested), now a circuit simulation had to be done and test strategy had to be followed. The design has to be 100% ok, testing is only possible via input and output pins of the FPGA. This requested for a new design philosophy.

- No knowledge of HF power electronics. Due to the business of STN HF knowledge was present, but the special HF power electronics knowledge, having to do with high currents in printed circuit board wires and power Mosfet behaviour, was completely new.

- No knowledge about how to plan complex designs. For a typical HF design, about 100 components form an already complex circuit. The FPGA consists of much more components. The step from low to high component count design asked for a formal planning of the design, with tests and formal release.

- Without the funding of FUSE, it was doubtful if the regular banking channels would have financed such a development to such a small company.

- The influence of the digital components, working on high clock frequencies, on the analogue parts was underestimated. The trail-and-error way of working to solve the problems illustrates the unfamiliarity with the phenomenon of digital interference.

11. Steps taken to overcome the barriers

For the FPGA, the starting point was the standard CMOS design made by STN. To realise an optimal knowledge transfer it was decided to plan and design together with the subcontractor.

By “training on the job” STN personnel learned:
- Working with FPGA design software
- Translation of CMOS logic in FPGA logic
- Synchronous design
- Library module designing

The FPGA subcontractor explained in what direction a solution could be found for design problems. STN designers then realised, with help of the subcontractor, the design of that module. If the results were not satisfying, the subcontractor corrected the design, so the feeling about what was good and bad in FPGA designing was developed. Besides this, a lot of background information was given concerning the internal structure of the FPGA, necessary for construction of an optimal solution.

The TTN advised and contributed in the circuit design. In the FPGA, several problems were only solvable by adopting a new system view. Especially the synthesiser frequency switching and counting was very tricky in this respect.

For the design of the solid state HF power amplifier a similar “training on the job” approach was followed. In several “lessons” the way of designing and calculating HF MOSFET amplifiers was explained. The designs made were than checked and tested, after which a redesign and explanation of faults was done.

With the HF design, the knowledge transfer consisted mainly in “how to...” and “why not to do…” lessons and rules. The several sessions with the subcontractor were very explanatory and resulted in a stable and robust HF power amplifier module.

Since the digital interference on the analogue parts was not foreseen to be a problem, the trail-and-error way of working was used to solve the problem. At the end, when a good working prototype was achieved, STN concluded that the followed approach was wrong and should have been more fundamental: 1) computer simulation on HF, 2) gain distribution, 3) level calculation.

Planning the design and signing off the deliverables was the part that took care of the complexity of the design. By carefully follow the module set up and the management of design in release versions enabled STN to produce a complex and reproducible transceiver. This way of working is now adapted for other projects in STN as well. This planning was several times adapted to the actual situation. The TTN greatly contributed to these planning efforts. At the end of the project it turned out that the initial 10 month overall project length estimation was excellent.

12. Knowledge and experience acquired

STN got a lot of knowledge from its subcontractors. As stated before, the selecting of a subcontractor took place in an informal way, on recommendation of other companies. With these references, it turned out to a good way to get in touch with capable subcontractors.

STN learned from the subcontractors how to choose the right semiconductors to its needs, how to calculate matching networks to get 50 _ impedance at the in- and output and how to measure the performance. Besides this also how to protect the semiconductor for faulty situations such as load mismatching and thermal overload.

The learning process consisted of:
- Specification set-up, learning the way the subcontractor analysed goals.
- Selecting MOSFET semiconductors on the requested behaviour.
- Learning how calculations are made for the matching networks the chosen semiconductor.
- Applying new test methods. Together with the subcontractor the completed amplifier was tested and characterised.
- A review of the design process, together with the subcontractor.

STN also learned what kind of functionality can implemented in a FPGA, what the speed limits in a FPGA are and how this can be affected by the way the design is made. STN is now able to estimate the size of a FPGA needed for a given problem, and can optimise cost/performance. The essential stage of the learning process was the working together with the FPGA subcontractor. They showed how to use the tools, getting the best performance in FPGA designs.

In general, the use of a planning with milestones and deliverables was new and very useful in this project. Specifying was already important at STN but planning and the use of milestones and deliverables will be adopted in future projects.

13. Lessons learned

There were problems during the AE caused by incorrect estimation of the time needed for development. Besides, it turned out that STN had an incorrect system philosophy. The concept concerning the frequency generation in the transceiver had to be corrected. The counter principle had to be adapted to the real time needs of displaying the counting results. This was done concurrent with the RF system design, mentioned before. At start, each oscillator was counted and the result of addition or subtraction of these frequencies was displayed. Now premixing the oscillators and counting the result afterwards does this adding and subtracting. Due to some faster design phases later, it turned out to be possible to complete the project in 13 months.

How to work with complex digital design software was also an important lesson learned. For a typical HF design, about 100 components form an already complex circuit. Digital circuits have 1000 to 5000 and often more components. Simulation and verification, formal planning of the design, with tests and formal release, are important new skills learned in this AE. In the same way, STN learned to think in modules and systems instead of designing with discrete components. Specification of the design turned out to be very important.

STN was very positive about simulation with FPGA designing and advises other companies to do the same: design, simulate and only build after approving the simulation.

From the experience how the unexpected digital interference on the analogue parts was solved by following a trail-and-error method, STN learned the value of a formal approach to these problems. In projects following this AE the possible interference is incorporated in the risk analysis and in the followed design approach.

Marketing of consumer equipment turned out to be more complex than thought at the start of the AE. The market reacted different from STN expectations. Due to too early marketing at the start of the project, 200 sets were planned, as ordered up-front. At the time the kits were about to be produced, these customers already had selected another supplier and cancelled their initial order due to too late delivery. A full year between first contact and start-up of shipping turned out to be disastrous from a consumer-marketing view. (In the for STN well known OEM market this was common practice.) Consequently the estimated turnover in the first year will not be reached. The general lesson: do not start too early with marketing, not before your design is ready and done. This causes for STN a sales drawback of 1,5 years.

Additional benefits are that STN is now able to develop a very modern professional TV stereo modulator (new product). All the complex digital logic to realise this is integrated into one FPGA. This gives STN all cost and reproducibility advantages as mentioned earlier. Besides this there is the security aspect: it is not easy for competitors to see how the hardware works.

The market of STN shifted from offering purely RF electronics to offering a complete package, including digital control.

14. Resulting product, its industrialisation and internal replication.

The resulting product is of professional quality, offering the latest RF techniques for the radio-amateur kit market. Special care is taken for the ease of reproduction, especially because in this case the product is not produced in a factory, but build by the end user. For this a manual and clear test procedures are an essential part of the whole product. The product variations are taken care of by the design process, which incorporated Monte Carlo statistic analysis of product parameter variations.

However, the expected market size turned out to be smaller than expected. This is due to too early marketing, which resulted in very long, waiting time for serial production, and the initial price turned out to be too high, because the market seems to be more price sensitive that thought of. Marketing is done via advertising in the special amateur radio magazines, like

Electron, by means of booths on the annual spring and autumn radio meetings, in AHOY and RAI, as well on radio markets all over the country. All marketing energy is concentrated on The Netherlands for the time being, to create a stable home market and to see if any problems arise in the building of the kits, before export is started. However it has to be mentioned that consumer marketing in a fragmented market, is quite different from OEM-marketing which deals with large identifiable accounts. Long term marketing exposure is necessary to generate sales. The activities were planned at a yearly basis: six advertisements in Electron and two national fairs. Total costs do include promotion material, advertisements, costs of the fairs and amounts 2500 ECU yearly.

STN is now independent of subcontractors for future development and production of products with FPGA and HF power technologies. STN maintains the learned skills by continuously using this knowledge in the design process of new products. The software the company got familiar with is now continuously updated to the newest version, to prevent outdated designs due to outdated software, by not using the latest possibilities in design software.

In the period 1997/98 several replications have been realised, combining RF and FPGA technology.

- STN has developed 100 special purpose power amplifiers, with a sales value of 50 KECU
- The TV modulator is adapted to the Dutch market and sold to a cable operator. This is a contact gained the International Broadcasting Convention, in 1997 held in Amsterdam. Actual sales are running up to 425 KECU, and further orders are expected.
- An adapted version for the American market has been developed.. This is a very promising opportunity. In co-operation with this multinational a digital MPEG2 QAM modulator, in combination with our existing modulator brings a complete new product that is state of the art and asked for by the market. Actual sales of 35 KECU have been achieved. Further sales are expected.
- Licence negotiations with an American distributor for the European market of the modulator are taking place
- A new medium wave measurement receiver for the American market has been developed, with digital control of the main functions.

15. Economic impact and improvement in competitive position.

The development cost of the analogue transceiver was about 12.5 KECU. Sales in 1995 and 96 were about 50 KECU accounting for 40 units. The variable costs came up to 20 KECU, leaving a profit of 17.5 KECU. However STN had an internal sales forecast of the old product which gives a decreasing sales volume, because it was thought that the product would become obsolete.

	Units	Sales ECU	Yearly Gross Profit
1995	22	27.500	16.500
1996	18	22.500	13.500
1997	12	15.000	9.000
1998	10	12.500	7.500
1999	8	10.000	6.000

Anticipated on the introduction of the new product in 1997, the sales were stopped.

However, in 1997, STN experienced a severe storm because of the loss of important clients in the OEM and CATV market. This forced the company to explore new markets with the just acquired FPGA expertise. This brought a breakthrough in new markets and new customers, accounting for sales of 500 KECU, offsetting the sales loss.

Consequently, the introduction of the new transceiver was postponed. The revised forecast is given below.

Year	Products sold	Turn over	Balance
1995	0 units	0 KECU	- 17 KECU
1996	0 units	0 KECU	-34 KECU
1997	30 units	48 KECU	-19 KECU
1998	120 units	192 KECU	+60 KECU
1999	500 units	800 KECU	+250 KECU

The improvement of profitability over the same period, excluding both investments was estimated at 230 KECU, as can be derived from the tables above. The predicted payback period was 27 month after introduction, in 1997. Net ROI predicted was about 300% over three years. However, due business and market circumstances it is doubtful if the payback will be reached with this product. Actual 50 units have been sold, due to

- Company's resources had to be allocated to other prospective markets.
- STN failed to live up to the market expectations, so potential customers bought other products
- Japanese companies entered the market at very low prices
- Marketing of consumer product is quite different from marketing OEM products.

However, acquiring the FPGA expertise within the FUSE program, did survive the company with as result the breakeven of the investment in 1998 and a prosperous outlook.

16. Target audience for dissemination

This AE describes the development of a transceiver which covers the amateur bands from 3,5 MHz to 145 MHz.

The experiment demonstrates the value in this marketplace of having a flexible technology which can respond to market needs quickly, as well as the other benefits of cost, size etc against discrete analogue devices.

The heart of the system is formed by 2 FPGAs which fulfill the main functions of frequency generation and counting / displaying the tuned frequency.

The company involved in this project is small and used to work with analog RF design and standard C-MOS IC design. The lack of knowledge is related to design digital circuitry in FPGA and design of RF power amplifiers.

The technical benefit of this AE would be to implement large digital circuits into FPGA in order to create a relative compact system with much functionality in it, compared to discrete way of building.

Target companies to benefit from this AE are small to medium companies, which want to make the step from discrete digital design to FPGA design, of product with small to medium product runs.

The group of enterprises interested in this acquired know-how is to be found in companies still working with analogue techniques. They probably also have activities in the field of RF applications in the telecommunications sector. These can be e.g. the manufacturers for local broadcast services, CATV systems, and telemetry and control equipment. For The Netherlands the target, audience is about 10 companies comparable with STN and active in the same field. If the view is widened, all small companies applying only analogue electronics will form a target audience of about 100 companies.

These companies can be found with PRODCOM codes

- 30010 – Office machinery
- 31620 – Other electrical equipment
- 32201 – Telegraph and telephone apparatus and equipment
- 32202 – Radio and electronic capital goods
- 32300 – Television and radio receivers, sound and video recording
- 33200 – Instruments & appliances for measuring, checking and testing
- 33300 – Industrial process control equipment

Target companies are small; the manager is mostly the owner and the chief engineer. In general, the have a niece market, special expertise, and they operate as OEM.

These companies can learn from this AE that digital FPGA electronics can not only improve a product, but influences the whole product line and can boost profits or can give a major advantage over the competitors.