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DEPARTMENT OF DEFENSE
ADVISORY GROUP ON ELECTRON DEVICES
WORKING GROUP B (MICROELECTRONICS)

SPECIAL TECHNOLOGY AREA REVIEW

ON

MIXED-SIGNAL COMPONENTS

April 2000

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FOREWORD

Periodically, the Advisory Group on Electron Devices (AGED) conducts Special Technology Area Reviews (STARs) to evaluate the status of an electron device technology or defense application. STARs focus on understanding the military requirements for a particular technology while analyzing the present status of the technology compared to those requirements. The output of the STAR is a report that presents findings and recommendations that are offered to the Office of the Secretary of Defense for strategic planning. To focus each STAR, a "Terms of Reference" document is prepared to describe the purpose, objectives, and issues for the technology focus area.

This STAR report documents the findings from the reviews and assessments of the Mixed-Signal Components STAR, (originally titled *The Future of Silicon-Based Analog Integrated Circuit Components STAR*) that was held in two sessions, on 17 September 1997 and 11 December 1997, by AGED Working Group B (Microelectronics) at Palisades Institute for Research Services, Inc., Arlington, VA. The goal of the STAR was to assess the future military needs for mixed-signal components, the availability and capability of current and emerging mixed-signal components, and to provide recommendations concerning technical directions and investment strategies necessary to ensure that the Department of Defense's (DoD's) future needs are met. Presentations were made by a distinguished panel of experts selected from both industry and government. Working Group B members are subject matter experts in microelectronics technology. The group includes representatives from the Army, Navy, Air Force, National Aeronautical and Space Administration (NASA), Defense Special Weapons Agency (DSWA), National Security Agency (NSA), Department of Energy (DoE), Ballistic Missile Defense Organization (BMDO), and Defense Advanced Research Projects Agency (DARPA), as well as consultants from industry and academia.

On behalf of Working Group B, I would like to take this opportunity to express appreciation for the efforts of the many contributors to this effort, who are listed on the following page. Dr. Susan Turnbach, Office of Director of Defense Research and Engineering/Sensors and Electronics (ODDR&E/S&E), in particular, provided support and encouragement to the project. We thank Dr. Isaac Lagnado, who proposed this topic for a STAR and provided guidance for the STAR's organization. Mr. Ron Bobb of the Air Force Wright Laboratory and Mr. Tim Doyle of Palisades Institute, are particularly thanked and commended for their significant contributions to analyzing the significant amount of data involved in this study and their primary role in producing this report.

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REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

EXECUTIVE SUMMARY

The purpose of this STAR was to provide the DoD with recommendations about how to meet future military needs for mixed-signal components. The STAR convened two sessions of expert presentations. The first focused on ascertaining the DoD's need for analog IC components for various applications. The second session brought together a panel of experts to address the ability of current and anticipated designs in meeting the identified needs.

Both sessions clearly revealed that military systems typically contain a higher percentage of analog components than commercial systems. The unique importance of analog ICs to the DoD was particularly apparent as the system requirements for future military systems were outlined. In addition to performance issues for analog components, the availability of these parts, in particular Analog-to-Digital Converters (ADCs), was of great concern.

Detailed examination of data demonstrating the progress in ADCs, showed that, as technology improves, these analog components advance at a very slow rate compared to that of advances in digital circuitry. These devices are challenging to design and produce. There appear to be basic issues yet to be understood to improve their performance.

The business for analog components is modest and focused on commercial requirements for low cost, low speed analog to digital converters. The demand for higher performance analog components for near term system insertion continues, but the sources for these devices are decreasing and the performance is insufficient.

The continued demand for higher performance continues to provide impetus for the development of Gallium Arsenide (GaAs), Indium Phosphide (InP), and Silicon-Germanium (SiGe) technologies for analog components. In particular, the military’s need for high bit rates and high speed, stimulate the search for higher performance device parameters to support device performance demands. This interest is also stimulated by the realization that integration alone is not always the most promising approach for increasing system performance and reducing costs. The advances of a higher performance technology in reducing the down-conversion stages involving expensive analog components can offer the best solution for increasing system performance and reducing costs.

Most Government and commercial programs, including research and development efforts, target producing devices that meet the requirements for individual applications. This focus, rather than investigation of the basic challenging technical issues, may be contributing to the limited rate of progress in ADCs. In general, the goal has been on producing prototypes or products rather than understanding underlying technical barriers.

These findings highlighted the importance of basic work needed to understand the current limitations inhibiting progress in ADCs, and the desirability of investments by the DoD to explore and resolve these issues. For the greatest effectiveness in this research, projects should include the entire cycle of development, modeling, analysis, design, fabrication and test.

Considering the magnitude of the cost reductions that specialty (non-Commercial Off the Shelf (COTS)) components can leverage for a system, the value of such components should be examined and measured. The benefits of their use may drive some infrastructure investments by the DoD to accelerate their availability. The limited potential of the military marketplace should be considered and expectations for cost sharing, zero fee, sharing of intellectual property, etc. should be tempered to encourage participation and investment. This is particularly true for the radiation-hardened, low power analog IC market needed for the military's move into space, which is being abandoned by suppliers.

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

INTRODUCTION

Analog ICs are widely used in systems applications where analog interfaces to the external environment are coupled to digital signal processing systems. These include applications in modern telecommunications, consumer products, and automotive electronics. However, DoD systems, in particular, utilize large numbers of analog ICs with high performance and reliability demands. These are used to couple critical military sensor data with signal processing so that information can be analyzed and utilized. The juncture between the analog and digital worlds can be problematic. This is especially true for: (1) the high frequency, low noise, low voltage, and low power regions in which portable telecommunications and computational devices are designed to operate, and (2) the high voltage and radiation-tolerant circuitry required by the military.

Several issues exist for matching sensor-to-sensor interface circuits to achieve high performance and reliability. Although the integration of sensor interface circuits and digital control logic has been successful in a few cases (notably for temperature, pressure, and chemical sensing), integration is usually associated with serious difficulties. In “smart sensor systems,” the electronics incorporated in sensors reduces and alleviates these deficiencies. However, designing sensor interfaces for broad multipurpose applications continues to be a major challenge.

The technical realities of the analog IC area, in conjunction with the economic and business considerations governing that area, suggest two issues. One, that continuing research and development investment is needed to produce devices that meet the needed performance requirements. And second, that an infrastructure that supplies critical military and commercial products is basic to ensuring technological leadership on the battlefield and in the marketplace.

The STAR investigated military needs for analog ICs on three levels:

- Devices – analog IC functions common to a variety of applications
- Applications – specific analog IC devices critical to communications, radar, electronic warfare and missile control applications
- Infrastructure – aspects of the life-cycle management of analog IC devices in systems including computer-aided design requirements, radiation hardness needs, parts obsolescence issues, and provisions to improve and streamline system maintenance.

Correlating with the drive in the commercial sector to develop digital solutions for analog functions, ADCs were the principal focus of concern for the experts who presented information to the study. In fact, three of the seventeen presentations specifically focused on ADC technologies, and in the presentations by the other speakers, ADCs were prominently addressed. Current state of the art digital processing capabilities do not support operation at radio frequencies. Therefore, the ADC must down-convert signals from radio frequencies to speeds at which the signals can be digitally processed. Present efforts to improve ADCs are centered on ways to reduce the number of links in the chain of analog down-conversions.

TECHNOLOGY BACKGROUND

Traditionally, IC devices have been broadly classified as either analog or digital. That is to say, they are designed to operate with either continuously or discretely varying electromagnetic signals. Different functions naturally lend themselves to one or the other of these two types. However, digital signals offer a distinct advantage in their ability to withstand distortions due to the noise and interference inherent to the propagation paths through which all electromagnetic signals must pass. Because of this advantage, considerable effort has been expended to develop "digital solutions" to situations that, in the absence of noise and interference, are more naturally analog in character. Conventional wisdom now understands "digital" to be synonymous with "better" and defines advances in electronic technologies as the replacement of analog products with digital ones.

There are, however, natural limits to the types of functions for which digital solutions can be applied. The propagation of Electromagnetic (EM) waves through the atmosphere (e.g. radio, television, cellular telephones and radar) depends on creating EM fields whose strengths vary continuously with time. In most applications, these EM waves are necessarily transmitted at frequencies that exceed state-of-the-art digital processing capabilities. In these situations, analog ICs fulfill the critical role of coupling radio frequency signals with digital processing circuits.

Today, most organizations (private companies, government agencies, academic institutions, etc.) pass the majority of their electronically encoded information among individuals located within a collection of buildings. In contrast, military units typically pass EM data among a variety of environments, systems and platforms. Many of these platforms cannot afford in their operation to have their freedom of motion limited by an umbilical "wire." Military applications, in a relative sense, are more heavily dependent on analog ICs than commercial systems. Table 1 below gives some indication:

System	% Analog ICs of Total IC Count
Trident	43
MM-III GRP	69
GPS IIR	20
THADD	24
EKV	47

Table 1 – Analog Percentage of Total IC Count for a Sample of Military Systems

SOURCE: Mr. David Emily, Presentation to AGED Working Group B (Sept. 17, 1997)

Interpretation of these figures is difficult because of the different natures of analog and digital ICs. To be fair, advances in the ability to reduce the feature size of elements on an IC (e.g., the number of transistors per sq. cm.) have been more successful and rapid for digital applications. Therefore, one would expect the digital percentage of the total IC count to decrease with each system generation and a consequential rise in the analog portion. However, the causes aside, it is still clear from the data that the need for analog ICs to implement system functions are significant

Given the commercial sector drive to develop digital solutions for analog functions and in the wake of changes to DoD procurement procedures, this study has focused on anticipated military needs for analog ICs and the approaches and mechanisms for fulfilling these requirements.

SESSION ONE PRESENTATION SUMMARIES
Military Needs for Mixed-Signal Components

DR. ROBERT WALDEN – HUGHES RESEARCH LABORATORIES
ANALOG-TO-DIGITAL CONVERTERS: SURVEY AND ANALYSIS

Dr. Robert Walden gave two presentations at the STAR. His first presentation was a short tutorial on ADCs. The tutorial covered basic definitions of the more common terms used when describing an ADC. He also introduced a Performance term, $P = 2^{SNRbits} \times f_{samp}$ and from this established an ADC figure of merit, F = Performance/power dissipation. Dr. Walden has accumulated data on more than 150 converters and plotted these ADCs vs. their figure of merit. Dr. Walden also presented his now famous graphs of Signal to Noise Ratio (SNR) bits vs. Sample Rate and Spur Free Dynamic Range (SFDR) bits vs. Sample Rate, as shown in Figures 1 and 2.

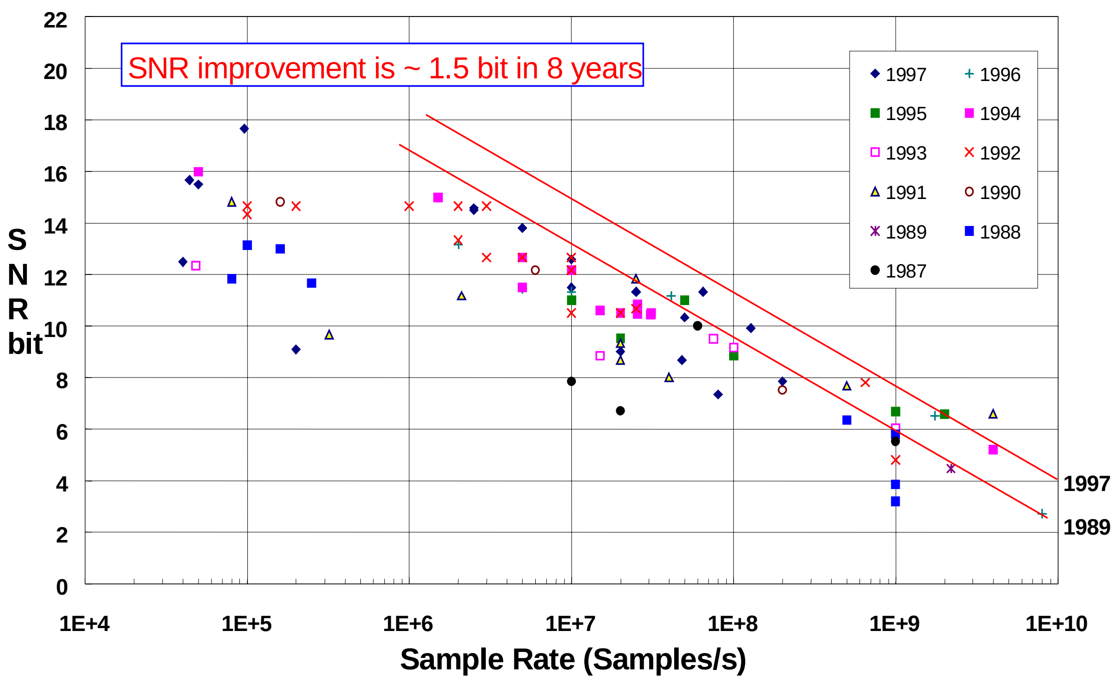

Figure 1 – SNR Bits vs. Sample Rate

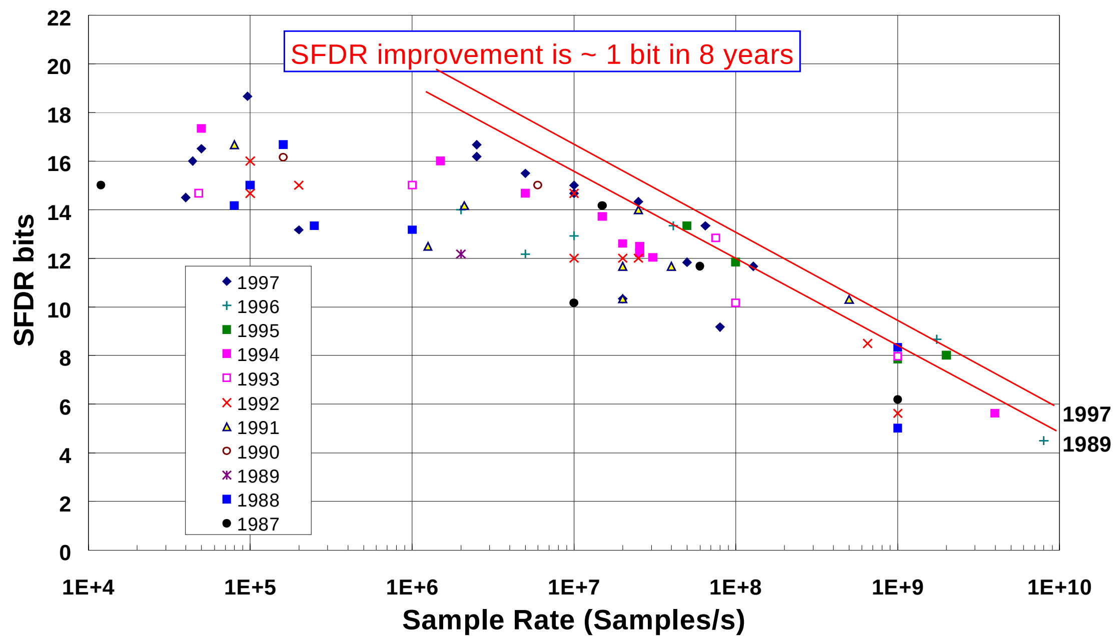

Figure 2 – SFDR Bits vs. Sample Rate

The updated charts used by Dr. Walden show that SFDR improvement is ≈ 1 bit in 8 years and SNR improvement is ≈ 1.5 bits in 8 years. It was suggested that slow improvement in ADC performance in recent years can be attributed to 1) de-emphasis in R&D, 2) fundamental limitations of individual technologies (thermal noise, regeneration time constant, aperture jitter, etc.), and 3) lack of a large commercial pull for the type of high performance ADCs needed for military applications. (This was also made obvious by Dr. Buss' subsequent presentation.) Conclusions drawn from this portion of Dr. Walden's presentation were that the fundamental ADC limitations need to be thoroughly studied and understood and the Government needs to continue investing in this area of work if significant progress is going to be made in performance regimes of interest.

Dr. Walden's second presentation covered Communications for Dr. Michael Delaney from Hughes Space and Communications Government Electronics Business Unit. This talk contained proprietary data that cannot be included in detail in this document. However, a number of salient points can be noted. Among the issues for this application, were: Plastic Encapsulated Microcircuit (PEM) vs. hermetic packaging; new materials needed for analog IC packages; lack of space qualified analog ICs; commercial parts meeting all requirements; and, a strong need for analog Monolithic Microwave Integrated Circuits (MMICs) and Microwave Integrated Circuits (MICs) which span the frequency range from C to W-band. The types of parts that are needed include Low Noise Amplifiers (LNAs), Phase Locked Loops (PLLs), mixers, mixed-mode Application Specific Integrated Circuit (ASICs), analog components for power supplies, and Direct Digital Synthesizer (DDS) chips. Again the main point of this presentation was that there is a need for a wide range of analog ICs for communications which are presently beyond commercial state-of-the-art, mandating continued development activities in high speed technologies like SiGe and III-Vs.

MR. BRIAN WONG - TRW
ANALOG-TO-DIGITAL CONVERTERS FOR FUTURE MILITARY SYSTEMS

Mr. Brian Wong presented TRW's view regarding requirements for digital receivers for military applications. This is encapsulated in Table 2, below. The traditional desire is to move the ADC closer to the antenna/sensor in order to maximize the digital content of the receiver, thereby reducing the size, weight, power and cost while increasing the receiver's flexibility. While much of the digital circuitry following the ADC can leverage the considerable commercial Complementary Metal Oxide Semiconductor (CMOS) investments, the requirements for military ADCs far exceed their available commercial counterparts.

MISSION	SAMPLE RATE (Bandwidth)	SNR/SFDR (Effective # of Bits, ENOB)	POTENTIAL AVAILABILITY FOR ADC
COMM	250 MSPS (100 MHz)	85 dB / 100 dB 14 ENOB	5 to 10 Years 16-bit / 250 MSPS
RADAR	100 MSPS (>20 MHz)	75 dB / 85 dB 12 ENOB	3 to 5 Years 14-bit / 100 MSPS
EW/ESM	3 GSPS (1 GHz)	56 dB / 65 dB 9 ENOB	5 to 10 Years 10-bit / 3 GSPS

Table 2 – Requirements for Military ADCs

TRW has selected III-V Heterojunction Bipolar Transistor (HBT) technology as the technology of choice to meet these stressing ADC requirements. They have been developing ADCs and ADC components in both GaAs and InP for a number of years. These developments have been primarily funded by the Government due to the limited commercial pull for these high performance components. With continued DoD investment in technology for ADCs, the following prediction is made by TRW:

	0 to 5 Years	5 to 10 Years	10 to 15 Years
High Resolution ADC	12-bit / 160 MSPS	16-bit / 250 MSPS	16-bit / 500 MSPS 18-bit / 250 MSPS
Wideband ADC	9-bit / 3 GSPS 10-bit / 1 GSPS	10-bit / 3 GSPS	10-bit / 8 GSPS

Table 3 – Predicted Availability for High Performance ADCs

As indicated in the two tables above, no single ADC will meet all the requirements demanded for the military. The high resolution ADCs will more than likely be fabricated in advanced CMOS, thus leveraging the commercial pull for this technology. These ADCs will meet the requirements for Communications and Radar as stated above. However, the wideband ADCs needed for Electronic Warfare (EW)/ Electronic Signal Measurement (ESM) do not have a commercial pull. To foster the development of these high performance ADCs, continued Government funding in device technology and analog design will be needed.

MR. ANTHONY SPEZIO – NAVAL RESEARCH LABORATORY (NRL)
ANALOG ELECTRONIC SIGNAL PROCESSING

Mr. Anthony Spezio started his presentation by identifying the domain of analog signal processing in today's military systems. Analog processing has some significant advantages over current state-of-the-art digital signal processing. Analog processing also has well-known disadvantages which have been cited by many. These include inflexible algorithms (not programmable), susceptibility to noise and temperature and cost.
Mr. Spezio showed the following figure that depicts the ideal sensor system provided that ADC and digital technologies meet the targeted requirements.

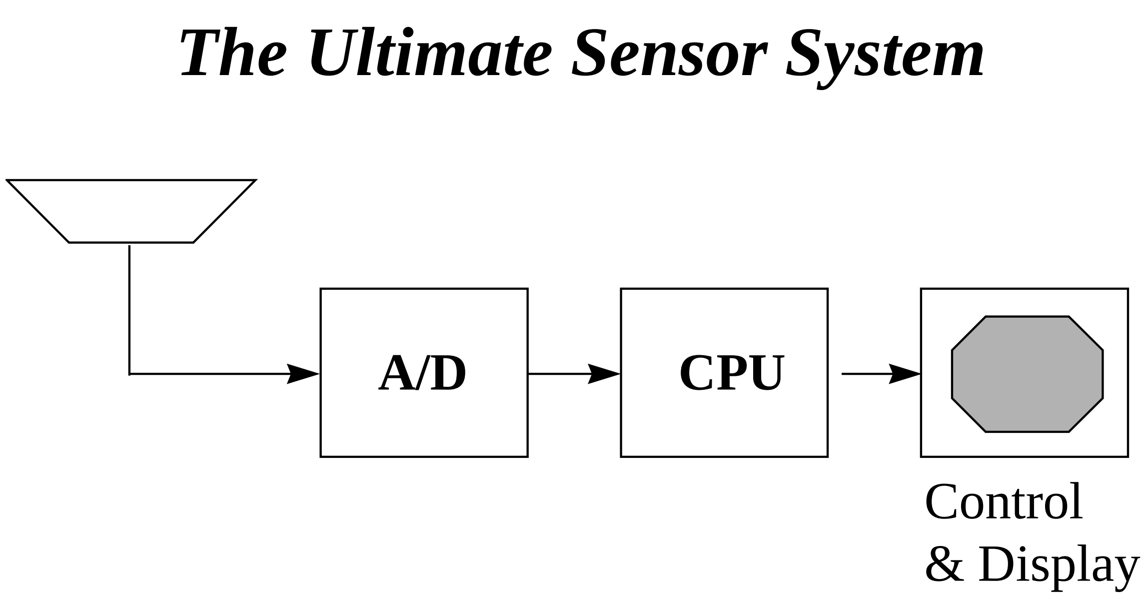

Figure 3 – Ultimate Sensor System

The analog signal is converted directly to a digital one at the antenna, thus, no analog amplifiers, downconverters, mixers, etc. are required.

Unfortunately, current ADC and digital technologies are not yet at this point. The following Digital Signal Processing (DSP) shortfalls were noted: 1) wide bandwidth, high resolution signal conditioning and digital conversion; 2) parallel channel simultaneous signal conditioning; and, 3) high computational capacity transforms and algorithms.

Mr. Spezio went on to define the EW environment, functional requirements and the signal processing space for the EW efforts in which he is involved in at NRL. This is captured in the following table.

EW Environment		
Observable Emitters From Ship From Aircraft	 100 2000	
Environment Density	> 10^8	
Copulse Probability	≈ 100%	
Functional Requirements		
	Warning	**Surveillance**
Time to Classify	2 sec	60 sec
Time for SEI Sort	10 sec	120 sec
Time to ID		300 sec
Time to Unambiguous Bearing	2 sec	120 sec
Time to Locate		300 sec
Revisit	2 sec	300 sec
Signal Processing Space		
Feature	**Characteristic**	
	Current	Projected
Operating Frequency	0.5 to 20 GHz	0.1 to 100 GHz
Frequency Resolution	100 kHz	1.0 kHz
Spatial FOV	2 PI steradians	2 PI steradians
Bearing Resolution	10^{-6} steradians	10^{-8} steradians
Time Resolution	10 nsec	0.1 nsec
Signal Event Duration	100 nsec	1.0 nsec

Table 4 – EW Environment and Requirements

Mr. Spezio gave several examples of analog signal processing by citing several receiver modules and individual components that have been developed or are underway at NRL. The conclusions drawn from his presentation are as follows: 1) analog signal processing will continue to be a necessary system technology; 2) integrated analog signal conditioning and digital conversion are required; and, 3) multichannel analog and digital are necessary for timely results.

MR. TODD KASTLE – AIR FORCE WRIGHT LABORATORY
RADAR REQUIREMENTS FOR ANALOG INTEGRATED CIRCUITS

Mr. Todd Kastle presented an overview of airborne radar requirements for a notional fighter. The technology drivers for this radar are:

Apertures
- Wideband
- Observability
- Modules

Receivers - Channelized/Superhet
- MMICs
  - LNAs, Mixers, Filters
- A/D Converters
- Filters
- Digital Signal Processing
- Channel Match (Channel to Channel)

Direct Digital Synthesis
Narrowband/Wideband
- D/A Converters
- High Speed Waveform Generator
- Phase Compensation
- Filters

Processing
- Flexibility
- Degrees of Freedom
- Interference Reduction Effectiveness

Waveforms
- Algorithm Software Capability

Design Tools
- Utility
- Trade Space Capability
- Fidelity
- Accuracy

Systems Analysis
- Threat Analysis/Projection
- ConOps
- Tactical System Design

The briefing covered a wide range of material from basic definitions of commonly used terms, to mission scenarios, to a brief explanation of the trade space used for requirements flow down vs. performance parameters. One of the key points of this presentation was that multimode tactical airborne radar presents ADC designers and manufacturers with some very difficult requirements. Some of these requirements are as follows:

Mode	HRM*	MPRF/RGHPRF**	HPRF***
Signal Bandwidth (BW)	60 MHz 600 MHz (Growth)	5-10 MHz	1 MHz
SNR	34 dB	75 dB	90 dB
ENOB	5.5	12.5	15
SFDR	53 dBsat	96 dBsat	117 dBsat

Table 5 – Requirements for Multimode Tactical Airborne Radar Modes:

* High Resolution Mode (HRM)
** Medium Pulse Repetition Frequency (MPRF)/Pulse Repetition Frequency (RGHPRF)
*** High Pulse Repetition Frequency (HPRF).

The trend to push the digital interface closer to the antenna/sensor as evidenced in the presented receiver technology roadmap will continue to challenge ADC suppliers. Mr. Kastle concluded his presentation with the following table of radar requirements:

	Multi-Mode Strike	**A/G Surveillance & Weapon Delivery**
RF Operating Bandwidth	L to X-band 200 MHz to > 4 GHz BW	X to KU-band 200 MHz to > 4 GHz BW
IF BW	50 MHz typical, mode selectable	> 50 MHz
Dynamic Range (Spur Free)	45-75 dB (mode specific)	45 to > 60 dB (mode specific)
A/D Bits (Effective)	12-16 bits (mode specific)	8-12 bits (mode specific)
# of Receive Channels	2-8 typical	1-2 typical
Stability (typical)	-95 dBc/Hz	-70 dBc/Hz
Linear FM BW	10-30 MHz	100-600 MHz or more

Table 6 – Requirements for Radar

MR. DAVID EMILY – NAVAL SURFACE WARFARE CENTER – CRANE
RADIATION-HARDENED ELECTRONICS REVIEW

Mr. David Emily gave a presentation on radiation hardened analog components, in particular, describing Crane's experience in working with commercial manufacturers and radiation hardening for their processes. Since the market for these specialty components is so small, manufacturers are reluctant to consider process modifications, making screening the alternative for obtaining rad-hard devices. The CMOS analog components exhibit greater sensitivity to exposure. Although he predicted the ratio would shift in the future, he described military systems as currently having large fractions of analog compared to digital components.

He described some of the challenges in defining an effective screen, and that analog is intrinsically soft compared to digital. The higher voltages make analog circuits more susceptible to dose rate and latchup problems. He described an enhanced low dose rate sensitivity phenomena affecting bipolar devices, especially circuits containing commercial type lateral PNP elements, where circuits may fail at 1/10 or less than the expected level. Applications such as satellite systems are particularly vulnerable to these issues. However, since the total volume for that market is quite small, it is not a major driver for investment.

The most common approach to this risk for satellites, is using conservative design margins, and special screening. This adds a significant premium to the parts cost. For strategic hardness levels, however, the situation is much more problematic since components produced for the commercial market are unlikely to meet the requirements.

He estimated that there are only two real suppliers remaining, down from six, for rad-hard devices. He saw divergence between commercial and military requirements in the operating voltage, which is higher for more demanding performance. He predicted that bipolar and bipolar-Silicon on Insulator (SOI) would continue to dominate.

Mr. Emily's recommendations for the DoD in this scenario included:

- Assess commercial processes
- Leverage commercial processes
- Develop analog electronic design analysis (EDA)
- Improve process modeling
- Assess emerging technologies
- Consider SOI starting material

MR. MAJOR FECTEAU – REDSTONE ARSENAL
ANALOG INTEGRATED CIRCUITS FOR NEXT GENERATION TEST EQUIPMENT

Mr. Fecteau presented the Army's approach to General Purpose Test, Measurement and Diagnostic Equipment (GP-TMDE). Their focus is on embedded diagnostics, in particular, on-chip diagnostics that are able to display data or diagnostic information eliminating the need for external test equipment.

He showed a challenging example – the modern day warrior with headmounted audio/visual system, central processor, battery pack, best-mounted electronics and radio frequency (RF) communications. The types of analog ICs cited as needed, all at low cost, include:

- "intelligent" analog ICs, including ADCs with data logger capability
- MMICs
- thermal micro-sources
- temperature, humidity, pressure (including altitude), shock/vibration sensors

MR. KEITH MEYER – TRACOR ENGINEERING SYSTEMS
AFTERMARKET SUPPORT CAPABILITIES FOR ANALOG INTEGRATED CIRCUITS

Mr. Meyer noted that historically, the analog market has been more stable than the digital market. However, despite this usual scenario of a steady and profitable business, the presence of analog devices is shrinking in the overall IC market. Of the top ten analog IC manufacturers, only three address military requirements. The growing consumer and telecommunications market has captured the attention of the analog suppliers.

The multi-faceted approach followed by his organization includes:

- Purchase discontinued product lines from aftermarket suppliers
- Purchase die from original equipment manufacturer (OEM) and perform custom assembly
- Reverse engineer needed devices
- Substitute pin-pin replacements or functional equivalent, or attempt to up screen.

DR. ROBERT EWING – AIR FORCE INSTITUTE OF TECHNOLOGY (AFIT)
THE CHALLENGES & SOLUTIONS TO ANALOG DESIGN

Professor Robert Ewing presented an overview of the current status of Computer Aided Design (CAD) tools available for analog circuit design. His briefing pointed out that today's analog CAD tools have severe limitations. Current tools lack accurate high frequency models, are application dependent, very slow, inaccurate for submicron regimes and are not integrated in a framework. Current tools also lack a common data structure. This prohibits the tools from interacting and also impedes connecting behavioral and structural simulation tools. Many of these problems are compounded with the emergence of MicroElectroMechanical Systems (MEMS) technology. The concept of "Mechatronics" (Figure 4) was introduced as a new engineering discipline in which the entire system is considered in terms of modeling.

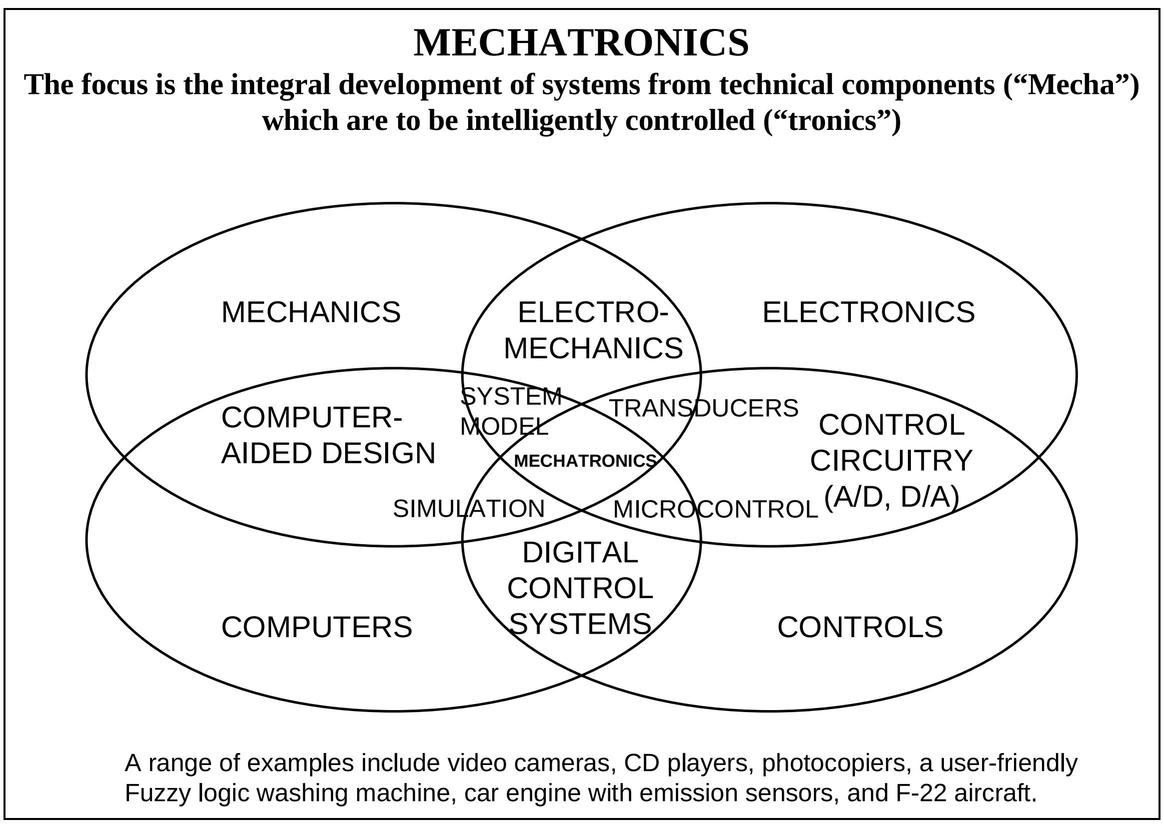

Figure 4 – Mechatronics – Modeling of Entire System

During the briefing a framework structure for analog/digital design was proposed which will enable multiple CAD tools (behavior/structural/simulation/synthesis) to analyze the state equation Matrix for simulation and synthesis applications. This is the same Matrix form used by SPICE and is accessible within Wright Lab and AFIT's version of SPICE called TOTAL. The idea is then to develop tools around this Matrix form. Both VHSIC Hardware Description Language (VHDL) and VHDL-Analog Mixed Signal (VHDL-AMS) would be parsed into the SPICE Matrix form. It was suggested that an industry standard analog library designed around an operational amplifier parameterized model be included as part of this analog CAD package. Within this proposed framework, device scaling issues will be handled with Dimensional Analysis and transistor matching issues will be solved with Quantitative Feedback Theory (QFT). As a starting point for robust analog designs, a proposed ideal educational oriented CAD package combination would be ACACIA from Carnegie Mellon University and the TOTAL package from AFIT and Wright Laboratory.

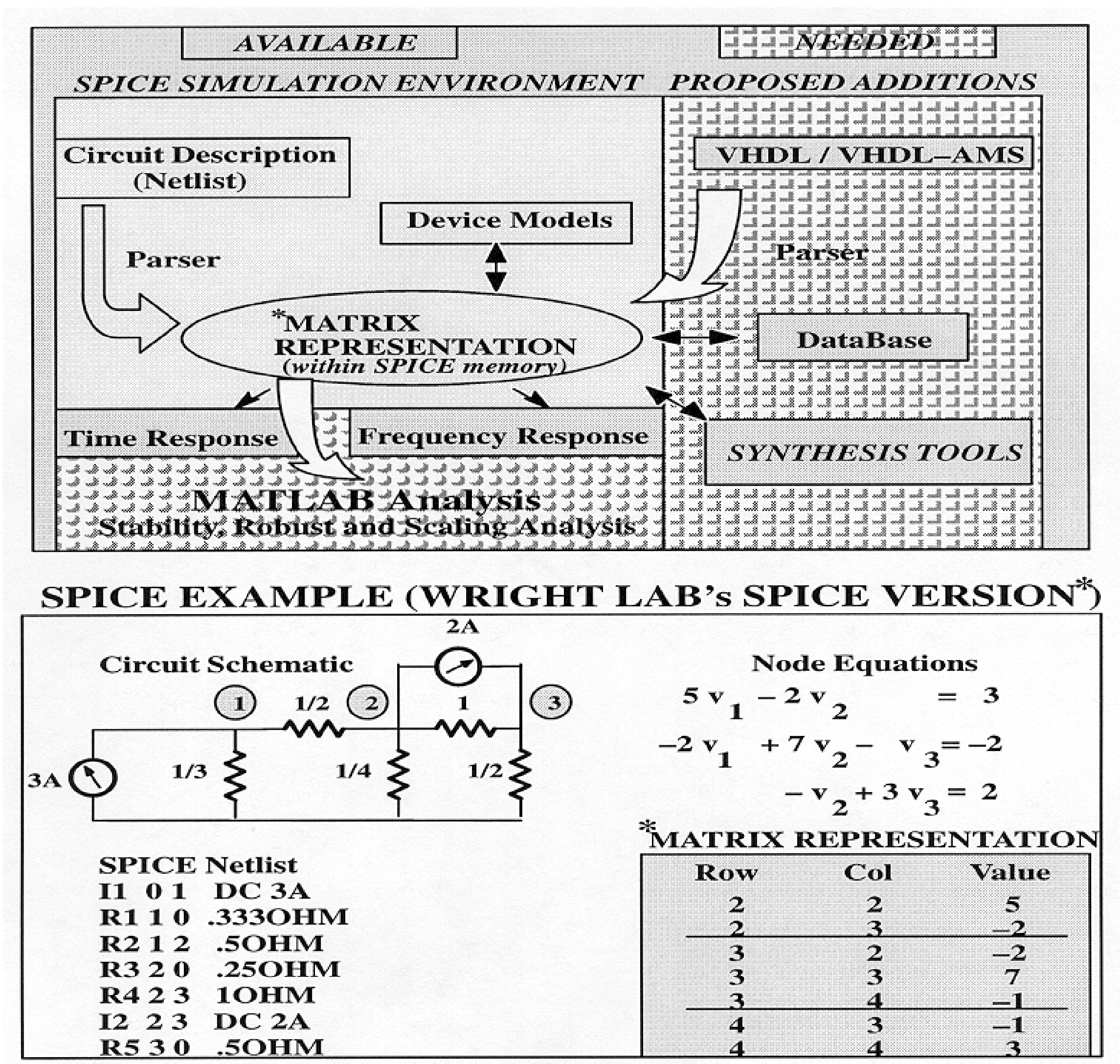

Figure 5 – Framework for Analog/Digital Design

Reference: Dr. Ewing distributed at the STAR

MR. J. P. LETELLIER – NAVAL RESEARCH LABORATORY
RADAR NEEDS FOR ANALOG DEVICES

Mr. J. P. Letellier gave a presentation for Dr. Ben Cantrell on Future Surveillance Radar. The objective of this effort is to develop concepts and technologies for a new large power-aperture, cost-effective, shipboard volume surveillance radar. This radar has a potential 10-year market of 250,000 L-band units, 1,000,000 X-band units and 400,000 S-band units. For such a large volume of units, cost is obviously a prime consideration. Three specific analog components along with their required specs were identified for this radar. These components are listed in the table below:

DEVICE	REQUIREMENTS
Solid State Power Amplifier	• high gain : 30 dB in single MMIC chip • 25% bandwidth • UHF (250W), L(100W), S(75W), X(20W) • low phase noise: -130 dBc/Hz/per Amp • low cost: $100 each
MMIC Receivers	• monolithic; up to triple conversion • external filter connections • large dynamic range: >100 dB in, >80 dB out • low noise
A/D Converters	• >100 MHz analog input • >90 dB dynamic range

Table 7 – Analog Components with Required Specifications

The presentation also covered new technology investigations for Transmit/Receive (T/R) modules for the Future Surveillance Radar (FSR). A brief discussion on Δ-Σ data conversion techniques was given and how these techniques can be applied to both the ADC and Digital-To-Analog Converter (DAC) functions of the T/R modules. Several configurations for the T/R module were given from all digital to increasing analog content. The configuration of choice will depend on the availability of digital parts and their associated costs. In the case of Option 3 where dual up/down conversion techniques are used, the ADC requirement (14 bit, 65 MHz) could be met with COTS parts in the near future. However, on the same chart that depicts the block diagram for the dual up-/down-conversion, a 17 bit ADC was preferred. If the same output data rate is desired, this is clearly beyond what is available or soon to be available from the commercial market.

Another area where new technology is being considered is the power amplifier. Currently available COTS amplifiers have low gain and as a result, several have to be ganged together to achieve the necessary gain. The preferred approach is to use a single high gain amplifier. Low yield and high costs are current barriers to this approach.

DR. DENNIS BUSS – ANALOG DEVICES
TRENDS IN COMMERCIAL ANALOG-TO-DIGITAL CONVERTER TECHNOLOGY

Dr. Dennis Buss' presentation was probably better suited to the second session, rather than the first session of the STAR. His briefing did not identify analog component requirements, but rather, the chips that were available from his company. As the title of his briefing suggested, his approach to meeting the DoD's stressing analog component requirements is to use COTS parts.

The DoD is no longer the dominant volume market for high speed ADCs. Communications and consumer electronics now drive the market for advanced ADCs at Analog Devices. The requirements for these applications can be met with commercial silicon processes, either bipolar or CMOS, in many cases. Dr. Buss' recommendation was that if the DoD has requirements that can not be met by their current line of products, then change the architecture so that needs can be met with one of Analog Devices' products. Members of the audience recognized that for a shipboard application, for example, it may be possible to channelize receivers and use their COTS ADCs. However, when there are size and weight constraints, e.g., as in missiles, satellites and tactical aircraft, this approach is not always practical.

The remainder of the briefing went on to discuss trends in commercial technologies. One key point that came out of this part of the talk was the fact that voltage scaling will complicate SNR limited designs. For analog circuits at the SNR limit, a lower supply voltage will actually result in an increase in power.

MR. RAYMOND IRWIN – ARMY NIGHT VISION LABORATORY
ELECTRONIC WARFARE ANALOG INTEGRATED CIRCUIT REQUIREMENTS

Mr. Raymond Irwin from the Army's Night Vision Lab provided material for the EW area that highlighted the following analog needs:

- RF Jammer Transmitters
  - Solid state devices that support many octaves of bandwidth and several hundred watts of Continuous Wave (CW) output power for High Frequency (HF) (2-30 MHz),Very High Frequency (VHF) (30-100 MHz), and Ultra High Frequency (UHF) (100-1000 MHz).
  - Microwave Power Modules (MPMs) consisting of a solid state front end with approximately 30 to 40 dB gain followed by a CW Traveling Wave Tube (TWT) with 30 dB of gain with a built-in power supply. The microwave bands of interest are 2-6 GHz and 6-18 GHz. Typical millimeter wave bands are 30-40 GHz for EW and 42-45 GHz for Satellite Communications (SATCOM).

- Microwave and Millimeter Wave Power Module Components
  - Switching transistors for power supply.
  - Drivers, solid state devices in the bands of 2-6, 6-18 ,18-40, and 40-45 GHz. The trend is for solid state devices to produce approximately 0.25 watts CW and have TWTs amplify to the 50 to 100 watts level.

- InfraRed (IR) Missile Warning: IR Focal Plane Arrays (** This is probably outside the scope of this STAR **)
  - 256 X 256.
  - Multi-color operation: Several detection bands in 3 to 5 microns.
  - Operation at high temperatures: Thermoelectric (TE) cooled (no cooling the goal).

- Synthesizers for receiver Local Oscillators (LOs) and transmitter exciters
  - Octave or better tuning.
  - Tune in less than 1 μsec.
  - Bands: A through M.
  - Typically placed in SEM-E plug-in modules for aircraft and custom modules for ground vehicles (RF standard for ground vehicle not established).

SESSION TWO PRESENTATION SUMMARIES
Investment Strategies for Mixed-Signal Components

MR. CHARLES TABBERT – HARRIS SEMICONDUCTOR
RADIATION-HARDENED ANALOG TECHNOLOGY DEVELOPMENTS

Mr. Tabbert presented the supplier and the user perspective, from his background managing component engineering on Global Positioning Satellite (GPS) and MILSTAR. He presented a number of proprietary charts outlining Harris' strategy for supplying military components while effectively leveraging and pursuing the commercial market. He cited a need to dial-in the hardness required for a particular application, through both processing and design.

He noted that Low Earth Orbit (LEO) commercial satellite builders are more aggressive than military designers in defining specifications. He defined the current process with a feature size at 0.6 micron and bonded wafers, which are also used in commercial technologies. He noted the importance of the design tools that must be supported, as well as the process. Harris has worked with its major customers in a Design Center format, and offers a number of different processes with variations to serve its targeted market segments.

Mr. Tabbert noted that while the DoD cannot direct the marketplace as in the past, it can steer interested manufacturers through its spending. He also commented that the real issue for systems is parts obsolescence rather than process obsolescence. He recommended timely DoD investments in design automation and enhanced CMOS processing.

MR. THOMAS "STONY" EDWARDS – NATIONAL SEMICONDUCTOR (NSC)
FUTURE OF SILICON-BASED ANALOG INTEGRATED CIRCUIT COMPONENTS

In FY97, NSC received six percent of their revenue from Mil/Aero, the largest portion of any semiconductor supplier. Also, NSC is currently operating five fabs, (previously seven), and two assembly locations (previously seven). The NSC corporate strategy is to offer "systems on a chip" leveraging analog technology for key, trend setting customers with a short (six month) time to market. They are consolidating multiple technologies into a few and further merging these into single designs. A similar approach is proposed for military business.

Unique military challenges include temperature range, life cycle, Diminishing Manufacturing Sources (DMS), performance, radiation and need for "special" product and technology development. Common commercial and military needs are communications, security, mobile applications, and low cost.

The NSC views Very Large Scale Integration (VLSI) Mixed Signal Design on CMOS, High Speed (>1 GHz) Circuits, and High Density Processing as key areas for investment. Their proposed working solutions are: cost-shared research and development (R&D), mil-temp capable core technologies, development of "dual-use" packages, development of leading edge analog/mixed-signal design and simulation tools, buying of Mil parts to sustain infrastructure and promoting dual-use technology funding.

NSC's Mil/Aero Strategy is to bring the latest technology to their DoD customers. This will be done by tying similar DoD and Commercial needs together, in the areas of Telecommunications, Computing, and Systems-on-a-Chip. This involves co-funding innovative technologies with multiple markets, including, process/manufacturing technology, rad-tolerant process development, Low Temperature Cofired Ceramic (LTCC) Wireless and Adaptive Computing.

MR. BRAD LITTLE – TEXAS INSTRUMENTS
TEXAS INSTRUMENTS' FUTURE PLANS FOR MIXED SIGNAL INTEGRATED CIRCUITS

Mr. Little presented an overview of the military mixed signal offerings from Texas Instruments, and illustrated the product life cycle of a mixed signal circuit. For operational amplifiers for example, these included Bipolar Field Effect Transistor (BIFET), CMOS and bipolar circuits. He noted that the military life cycle may be extended compared to the commercial life cycle, depending on the volume and program commitments.

He showed a chart (Figure 6) of where Texas Instruments' views the applications for ADCs of various performance levels.

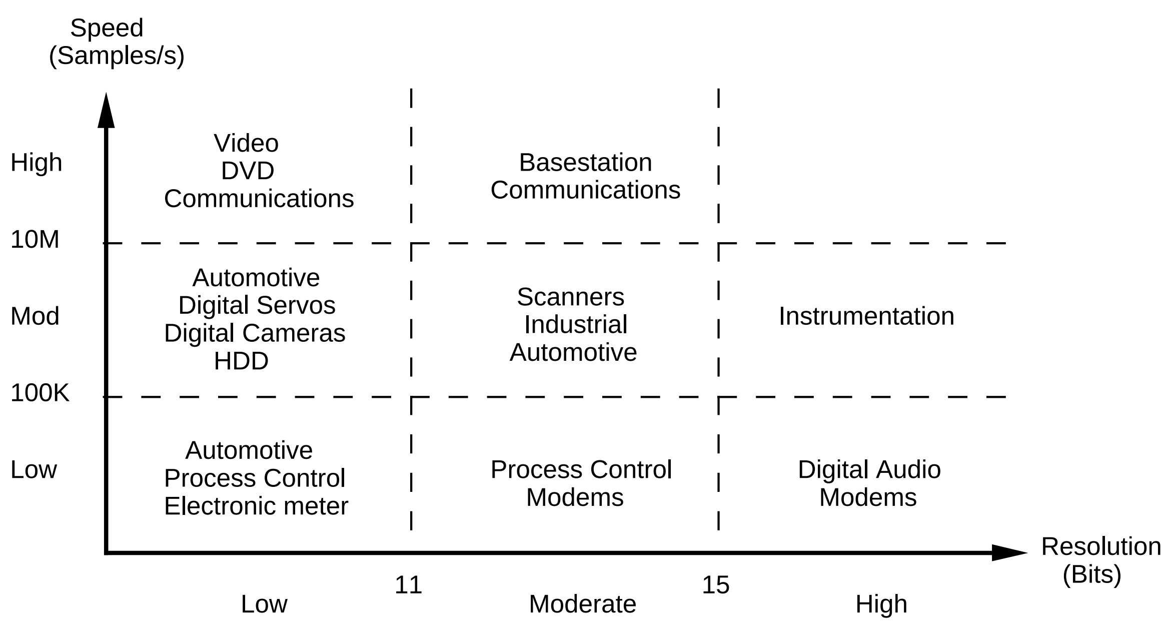

Figure 6 – Applications for Performance ADCs

DR. HENRY CHANG - CADENCE
MIXED SIGNAL DESIGN IN SYSTEM-ON-A-CHIP TRANSITION

Dr. Henry Chang began by showing the market drivers for mixed signal chips, including the applications, the levels of integration, and product design cycles. He forecast the transition to systems-on-a-chip, moving from the ASIC, to complex ASICs with a few Inputs-Outputs (IOs), to plug and play systems on chip. He also illustrated the phases of the mixed signal transition and the primary features and players in making this happen.

He predicted that, in the future, design would be top down, with constraints added at each level as applicable. This will offer the benefits of a systematic design approach which documents and implements the trade-offs made at each stage of the design cycle as well as reflecting, to the maximum possible extent, the designer's intent at each level. This strategy should provide both a reduced design time, and protection against over-designed systems. The implementation of a design environment that supports this futuristic scenario will be challenging, since it will require standards for capturing design data as well as ones that enable a large team to collaborate on a design simultaneously, and perhaps remotely. If design constraints are introduced too early, or for reasons other than to address true functional requirements, a heterogeneous design environment (one incorporating a variety of design tools) may not be capable of efficiently generating a complete design, and the reuse of design blocks may only be possible within the tools that initially were used to create them. Dr. Chang continued with the description of an alternative design approach which he felt would provide better tool integration: the use of predesigned functional blocks containing both analog and digital circuits and having functions described less specifically than is the case for current library design blocks.

Different types of designs are needed to provide functionality, connectablity between blocks, and to tie system functionality to specifications and requirements. These requirements drive the need to provide design blocks which have multiple “views” that collectively incorporate all of these considerations in a usable manner, as well as providing more detailed information such as the semiconductor processing required, the physical design data related to the logical design, and an enumeration of the design tools that can utilize the data.

Dr. Chang cited the need for increased participation in such projects and described Cadence’s strategy:

- Practical staged methodology
- Linchpin technologies for each stage
- Methodology/technology transition services
- Partners/services to help build portfolios

He commented that all of these are happening today.

Dr. Ronald Reedy – Peregrine Semiconductor
Ultra-Thin-Silicon (UTSi)Technology and Its High Reliability Applications

The key element of Dr. Reedy's presentation was that Thin Film Silicon on Sapphire (TFSOS) CMOS has the high-reliability requirements essentially built-in at the die level. Therefore, no special wafer processing or design is required to meet special high-reliability performance issues. Special back-ends such as packaging, test and qualification must be applied, but the critical elements of design and fabrication are provided by established manufacturing lines. As back-end support is much easier to find and maintain than design and fabrication, high-reliability products can be supplied (by Peregrine and others) with the same confidence as commercial products.

A second point, strongly emphasized, was that, since TFSOS (or UTSi, Peregrine trademark) products are CMOS based, the path to the future is the same as that of CMOS. His view was that exotic processes without commercial pull will always be endangered. With the costs of fabrication and the opportunity of value of design driving all companies to commercial markets, use of non-commercial design and fabrication will be at risk due to potential supply discontinuities.

Finally, for integrated RF products, he stated that the key issue is the substrate, not the transistors. He commented that while GaAs is an acceptable substrate, in his view, it cannot match the availability, integration complexity, flexibility (digital logic, p-channel device), low power and cost of TFSOS CMOS. Any other solution using a finite resistivity substrate will suffer from lack of isolation between its various circuit functions, specifically between the digital and analog portions.

Mr. Aaron Corder – Army Space and Missile Defense
U.S. Army Approach to Analog Silicon Integrated Circuit Investments

Mr. Corder addressed the need for radiation hardened high performance electronics. He focused on the needs for satellite and missile systems, and how electronics that had not been specifically hardened are employed for hardened system applications. To that end, he displayed roadmaps showing the upgrade paths in CMOS and bipolar technologies for a variety of key systems. The approach centered around leveraging advancing commercial technology through introducing design and process modifications to achieve the required hardness.

In reviewing the attributes of technology candidates to meet these needs, Mr. Corder noted that XFCB (eXtra Fast Complimentary Bipolar) technology provides transistors resistant to total dose and latchup from heavy ions or ionizing dose. He cited a number of part types being produced and good radiation testing results on NPN and PNP transistors. He detailed the radiation tolerance of Analog Devices' ADCs, available in different qualification levels for commercial and military temperature environments. The strategy he outlined involved investment in commercial foundries, Analog Devices, multi-level radiation foundries, Honeywell, Lockheed, and Harris; and, linear radiation multi-level design automation tools as well as testing.

DR. BERNARD XAVIER – HUGHES NETWORK SYSTEMS
BROADBAND METAL OXIDE SEMICONDUCTOR (MOS) RADIO RECEIVER CIRCUITS

Dr. Xavier emphasized several points, which are summarized as follows.

He noted that CMOS RF is currently an active area of research for many companies and universities. The motivation behind this investment is derived from the potential cost benefits the technology promises to bring to commercial products in the communication arena. He described that CMOS has several unique benefits which bipolar technology does not offer. The technology offers high performance sampled data systems such as switched capacitor filters. This in turn enables the development of high performance Delta Sigma ADCs and DACs that are not available in a bipolar technology.

Modern communication equipment employ complex modulation schemes that benefit from enhanced signal processing of the received and transmitted signals. Thus, receivers require ADCs and DACs in order to operate. Wider dynamic range ADCs and DACs allow the expensive and bulky filter specifications to be relaxed which results in a direct cost savings and size reduction in the receiver equipment. Eventually more and more of the RF/ Intermediate Frequency (IF) functionality of the receiver will migrate towards CMOS technology because of cost and size, which are the major market drivers for commercial products.

The reason that CMOS offers improved dynamic range over bipolar technology in circuits such as mixers and LNAs is because the square law equation that governs device operation is a weaker non-linearity than the exponential law that predicts bipolar device operation. This has already been cited in numerous papers. Silicon-on-Sapphire (SOS) has some benefits unique to this technology since the substrate is insulating. These benefits are derived mainly from the isolation of the process which leads to wider range automatic gain control (AGC) circuits, better stop band performance of on-chip filtering, lower switching noise feedthrough which would otherwise degrade the performance of Delta Sigma modulators, and higher Q spiral inductors because eddy currents flowing in the substrate are reduced.

To qualify CMOS as an RF process, several circuits along with measured results were discussed. A Gilbert Cell mixer and dual-gate mixer were presented and contrasted with a typical bipolar mixer. Very wideband circuits were discussed including a distributed amplifier and a distributed mixer that had bandwidths from 300 kHz through 4 GHz. These circuits can only be realized in Field Effect Transistor (FET) technology.

There are still some unresolved issues associated with the wide spread development of CMOS RF ICs, such as the effect of the Electrostatic Discharge (ESD) diode, process variations and 1/f noise contributions. However, companies specializing in CMOS TFSOS RF such as Peregrine have some patents pertaining to CMOS ESD structures that largely overcome this issue. The use of wide range AGC, which TFSOS implementations offer, corrects for process variation. The 1/f noise leads to close in carrier noise around the LO signal in a Voltage Controlled Oscillator (VCO). This noise is up-converted by the non-linearities associated with the transistor. However, CMOS has a lower conversion gain than bipolar technologies, and thus, this may not be the issue it at first appears.

DR. LAWRENCE LARSON - UCSD
THE FUTURE OF SILICON-BASED ANALOG INTEGRATED CIRCUIT TECHNOLOGY

Dr. Larson described the changing system scenario in which there is an increasing amount of silicon with the III-V components focusing on the highest performance. He commented that for many RF applications, standard silicon technologies now have sufficient speed. He noted that SiGe HBT performance is comparable to GaAs Metal Semiconductor Field Effect Transistors (MESFETs) at 2.4 GHz.

However, there are a number of outstanding, unsolved problems in analog/RF ICs. These include:

- High Q, tunable, linear, microelectronic filters.
- Power amplifiers, with high efficiency over a full range of output powers.
- Data converters with higher resolution and speed.
- Low cost higher frequency (5-60 GHz) technology for wideband wireless data applications.

He concluded that analog/RF microelectronics is moving towards more highly integrated combinations of digital and analog signal processing that will have major impact. However, for the highest performance levels, he noted that new architectures are still required for fundamental breakthroughs.

COMMITTEE FINDINGS AND RECOMMENDATIONS

FINDINGS

- Military systems have higher percentages of analog components than commercial systems.
- The greatest concerns in the area of analog components focused on the performance and supply of ADCs.
- Analog components, in particular ADCs, do not enjoy the same rate of improvement as digital circuits as technology improves. There appear to be fundamental limitations that are not thoroughly understood.
- While there is a considerable, albeit not large, business in analog components, it is focused on commercial requirements for low cost, low speed ADCs.
- The demand for higher performance analog components for near term system insertion continues, but the sources for these devices are decreasing and the performance is insufficient.
- This demand for higher performance provides an incentive for the development of GaAs, InP, and SiGe technology for analog components.
- Most Government programs, including research and development efforts, target requirements for individual applications rather than the challenging technical issues limiting progress in ADCs. Emphasis has been on exploitation rather than understanding underlying technical barriers.
- Integration, i.e., a single chip, is not the most likely solution for increasing system performance and reducing costs.

RECOMMENDATIONS

1. Programs exploring the current limitations of ADCs and the underlying causes would be worthwhile investments for the DoD.
2. Projects should address the entire life cycle, analysis and design, as well as proof of principle through fabrication and test.

3. Consider that significant system cost reductions may be achieved through the use of key specialty (non-COTS) components that reduce overall parts counts or simplify architectures.

4. Invest where other investors support the infrastructure costs.

5. Be prepared to reduce or waive expectations for cost sharing, no fee, IP sharing, etc. for areas where markets for DoD requirements are small, to encourage participation and investment.

6. Programs investigating space requirements (i.e., radiation-hardened, low power) for analog ICs are a needed DoD investment as the military migrates its assets to space. The current trend of major IC suppliers abandoning the military IC business will make this an increasingly difficult task.

APPENDIX A

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW
ON
MIXED-SIGNAL COMPONENTS

AGENDA: SESSION 1
Military Needs for Mixed-Signal Components
17 September 1997

Analog-to-Digital Converters: Survey and Analysis
Dr. Robert Walden
Principal Research Scientist
Microelectronics Laboratory
Hughes Research Laboratories
9:00

Analog Integrated Circuit Requirements for Government Systems
Presented by
Dr. Robert Walden
For
Dr. Michael Delaney
Chief Scientist
Government Electronics
Hughes Space and Communications
9:30

Analog-to-Digital Converters for Future Military Systems
Mr. Brian Wong
Manager
Mixed Signal Products
TRW
10:00

Analog Electronic Signal Processing
Mr. Anthony Spezio
Supervisory Engineer
Electronic Warfare Systems
Naval Research Laboratory
10:30

Radar Requirements for Analog Integrated Circuits
Mr. Todd Kastle
Acting Technical Director
Radar Branch
Air Force Wright Laboratories
11:00

Radiation-Hardened Electronics Review
Mr. David Emily
Manager
Technology Development Branch
Naval Surface Warfare Center – Crane
11:30

LUNCH
12:00

Analog Integrated Circuits for Next Generation Test Equipment
Mr. Major Fecteau
Physicist
Army Test, Measurement and Diagnostic Equipment Activity
1:00

Aftermarket Support Capabilities for Analog Integrated Circuits
Mr. Keith Meyer
System Engineering Technologist
Tracor Engineering Systems
1:30

The Challenges & Solutions to Analog Design
Dr. Robert Ewing
Adjunct Professor
Department of Electrical Engineering
Air Force Institute of Technology
2:00

Radar Needs for Analog Devices
Mr. J. P. Letellier
Branch Head
Advanced Radar Systems
Naval Research Laboratory
2:30

Trends in Commercial Analog-to-Digital Converter Technology
Dr. Dennis Buss
Vice President of Technology
Analog Devices
3:00

Electronic Warfare Analog Integrated Circuit Requirements
Material submitted for review by
Mr. Raymond Irwin
Chief Engineer
Night Vision & Electronic Sensors Directorate
Army Communications and Electronics Command
3:30

APPENDIX A (cont.)

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW
ON
MIXED-SIGNAL COMPONENTS

AGENDA: SESSION 2

Investment Strategies for Mixed-Signal Components

11 December 1997

Radiation-Hardened Analog Technology Developments
Mr. Charles Tabbert
Manager of Technology for the Military and Space Line
Harris Semiconductor
9:00

Future of Silicon-Based Analog Integrated Circuit Components
Mr. Thomas "Stony" Edwards
Managing Director, Government Technology Unit
National Semiconductor
9:30

Texas Instrument's Future Plans for Mixed Signal Integrated Circuits
Mr. Brad Little
Strategic Marketing, Military Products
Texas Instruments
10:00

Mixed Signal Design in System-On-A-Chip Transition
Dr. Henry Chang
Consulting Staff Member
Cadence
10:30

BREAK
11:30

Ultra-Thin-Silicon Technology and Its High Reliability Applications
Dr. Ronald Reedy
President and Chief Executive Officer
Peregrine Semiconductor
11:45

U. S. Army Approach to Analog Silicon Integrated Circuit Investments
Mr. Aaron Corder
Linear Technical Manager
Army Space and Missile Defense Command
12:15

Broadband MOS Radio Receiver Circuits
Dr. Bernard Xavier
Director of VLSI
Hughes Network Systems
12:45

The Future of Silicon-Based Analog Integrated Circuit Technology
Dr. Lawrence Larson (via telephone)
Professor of Electrical and Computer Engineering
University of California at San Diego
1:15

APPENDIX B

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW
ON
MIXED-SIGNAL COMPONENTS

TERMS OF REFERENCE

Purpose

The purpose of this STAR is to provide the DoD with recommendations about how to meet future military needs for mixed-signal components. The STAR will convene two sessions of expert presentations. The first will focus on ascertaining the DoD's need for analog IC components for various applications. The second session will bring together a panel of experts to address the ability of current and anticipated designs in meeting the identified needs. This meeting also will compare the costs and benefits of silicon-based versus III-V-based material technologies in analog IC applications. The final report will include a characterization of the current silicon-based analog IC supply base and anticipated developments within this industry. For the purpose of the STAR, silicon-based material technologies will include: (1) bulk silicon, (2) silicon-germanium, (3) silicon on insulator, and (4) silicon on sapphire.

Supporting Objectives

- To survey future military needs, in terms of parameters and/or functions, for analog IC components (both classified and unclassified).
- To determine the *ability* of state-of-the-art silicon-based analog IC technologies to meet future military needs.
- To ascertain the *availability* of both COTS and custom analog IC components for meeting future military needs and to classify providers according to capabilities.
- To compare ongoing silicon-based analog IC research initiatives sponsored by DoD with future military needs so as to determine how best to focus support.
- To identify which DoD silicon-based analog IC research initiatives have the necessary commercial infrastructure to support product development.
- To evaluate the *adequacy* of commercial design protocols for meeting future DoD design needs and to assess the cost-effectiveness of opportunities for developing new design tools/simulators that may be required for higher performance silicon-based analog ICs.
- To gauge commercial sector *interest* in developing new design capabilities for mixed-signal components (possibly via a “NSA-type” approach wherein prototype chips are sent to suppliers to determine which have the capability to manufacture them).
- To establish the relationship between COTS components and final system products meeting military specifications and to assess the need for developing standard tools to

facilitate the transfer of product developments between design and manufacturing organizations.

- To judge the ability of DoD to *routinely identify* its emerging needs for mixed-signal components and to *regularly assess* industry design and manufacturing capabilities for meeting those needs. The final report will make appropriate recommendations in this regard where necessary.
- To *gather information* about anticipated commercial developments in silicon-based analog ICs for DoD to use in planning future systems using this class of devices.

<u>Key Issues</u>

- Evolving DoD needs. What aspect of the current state of analog IC devices creates the greatest hindrance to further development of the technology? What are the technology drivers? The following factors will be considered:

  - Performance. Example: ADCs (higher resolution, bandwidth, lower power).
  - Integration levels. Examples: MEMS, mixed signal, physical-to-analog converters, and microwave applications.
  - Process reproducibility/design simplicity. Example: OPAMP 740.
  - Cost/affordability.

- Anticipated development of the technology. Although the upward trend in world market revenues for analog ICs is expected to continue (+11% from 1993 to 1997), the market share of analog versus total ICs will remain fairly constant (25.9% in 1993; 26.2% in 1997).

  - What technology advances will be needed to ensure cost-effective fabrication of silicon-based analog ICs? How difficult will these advances be to implement? How far and how fast can DoD progress with present technologies (such as dielectric isolation)? What components, circuits, and systems will silicon-based analog ICs make possible? When? Are ongoing research projects addressing these needs? What are the limitations currently preventing the fulfillment of military applications (such as radiation-hardened requirements)? Is DoD cost limited? Technology limited? Market limited?

  - Identify and assess major potential problems including:

    - Model and design tool adequacy.
    - Voltage level and scaling issues. (The problems of shrinking dimensions and scaling paths for silicon-based analog ICs have not been worked out; there is no protocol for shorter dimensions or lower voltage levels.)
    - Transistor matching concerns. (This is a tougher problem at smaller dimensions for analog ICs).

- COTS suitability. Compared to a digital final product, it is more difficult for an analog final subsystem to meet the needs of the military (particularly radiation hardness and temperature range). Consequently, one may anticipate that there will be fewer COTS parts available to satisfy military analog circuit requirements. This raises a number of important issues:

    - Is there a risk for silicon-based analog ICs to be "out of the digital industrial mainstream"? What will be the resulting technical and business impact? How might the dissimilarities (analog vs. digital technologies) be lessened?

    - If one were to generate an "analog" roadmap, how many technology/process/design deviations (from the digital industrial infrastructure) should be implemented? What resources should be allocated? Over what time periods?

- Economic and manufacturing issues. The following will need to be fully analyzed:

    - Si (bulk) vs. SiGe vs. SOI vs. SOS
    - Will industry be able to satisfy military requirements? Where should the bulk of silicon-based analog IC (DoD and industry) funding be applied? Over what time periods? At what levels? At what priority?

APPENDIX C

REPORT OF SPECIAL TECHNOLOGY AREA REVIEW ON MIXED-SIGNAL COMPONENTS

ACRONYMS, ABBREVIATIONS AND DEFINITIONS

A/D, A/DC, ADC .... Analog-To-Digital Converter
AFIT .... Air Force Institute of Technology
A/G .... Air to Ground
AGC .... Automatic Gain Control
AGED .... Advisory Group on Electron Devices
ASIC .... Application Specific Integrated Circuit
BIFET .... Bipolar Field Effect Transistor
BMDO .... Ballistic Missile Defense Organization
BW .... Bandwidth
CAD .... Computer Aided Design
CD .... Compact Disk
CMOS .... Complementary Metal Oxide Semiconductor
COMM .... Communications
CONOPS .... Concept of Operations
COTS .... Commercial-Off-The-Shelf
CPU .... Central Processing Unit
CW .... Continuous Wave
D/A, D/AC, DAC .... Digital-To-Analog Converter
DARPA .... Defense Advanced Research Projects Agency
DDS .... Direct Digital Synthesis
DMS .... Diminishing Manufacturing Sources
DoD .... Department of Defense
DoE .... Department of Energy
DSP .... Digital Signal Processor
DSWA .... Defense Special Weapons Agency
EDA .... Electronic Design Analysis
EM .... Electromagnetic
ENOB .... Effective Number of Bits
ESD .... Electrostatic Discharge

ESM.. Electronic Signal Measurement
EW.. Electronic Warfare
FET.. Field Effect Transistor
FM.. Frequency Modulation
FMBW... Frequency Modulation BandWidth
FOV.. Field-Of-View
FSR.. Future Surveillance Radar
GaAs.. Gallium Arsenide
GPS .... Global Positioning Satellite
GP-TMDE.. General Purpose Test, Measurement and Diagnostic Equipment
GSPS .... Giga Samples Per Second
HBT.. Heterojunction Bipolar Transistor
HF.. High Frequency
HPRF... High Pulse Repetition Frequency
HRM.. High Resolution Mode
IC... Integrated Circuit
ID... Identification
IF .... Intermediate Frequency
InP .... Indium Phosphide
IO... Input-Output
IR... Infrared
LEO .... Low Earth Orbit
LNA... Low Noise Amplifier
LO.. Local Oscillator
LTCC... Low Temperature Cofired Ceramic
MEMS .... MicroElectroMechanical Systems
MESFET.. Metal Semiconductor Field Effect Transistor
MIC .... Microwave Integrated Circuit
MMIC.. Monolithic Microwave Integrated Circuit
MOS .... Metal Oxide Semiconductor
MPM .... Microwave Power Modules
MPRF .... Medium Pulse Repetition Frequency
MSPS... Mega Samples Per Second
NASA .... National Aeronautical and Space Administration
NRL... Naval Research Laboratory
NSA... National Security Agency
NSC .... National Semiconductor Corporation

NSWC .... Naval Surface Warfare Center
OEM .... Original Equipment Manufacturer
OPAMP .... Operation Amplifier
OUSD (A&T)/DDR&E/SE&BE....... Office of the Undersecretary of Defense for Acquisition and Technology/Director of Defense Research and Engineering/Sensors, Electronics and Battlefield Environment
PEM.. Plastic Encapsulated Microcircuit
PLL.. Phase Locked Loop
QFT .... Quantitative Feedback Theory
R&D .... Research and Development
RF .... Radio Frequency
RGHPRF .... Range Gate High Pulse Repetition Frequency
SATCOM .... Satellite Communications
SEI... Specific Emitter Identification
SEM... Standard Electronic Module
SFDR... Spurious Free Dynamic Range
Si .... Silicon
SiGe... Silicon Germanium
SNR .... Signal to Noise Ratio
SOI .... Silicon on Insulator
SOS .... Silicon on Sapphire
SPAWAR .... Space and Naval Warfare Systems Command
STAR... Special Technology Area Review
TE .... Thermoelectric
TFSOS... Thin Film Silicon on Sapphire
T/R... Transmit/Receive
TWT .... Traveling Wave Tube
UHF... Ultra High Frequency
UTSi .... Ultra Thin Silicon
VCO .... Voltage Controlled Oscillator
VHDL.. VHSIC Hardware Description Language
VHDL-AMS...................................... VHDL-Analog Mixed Signal
VHSIC... Very High Speed Integrated Circuit
VHF... Very High Frequency
VLSI .... Very Large Scale Integration
XFCB .... eXtra Fast Complimentary Bipolar