Nyquist's Contributions to Control and Communication

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Nyquist's Contributions to Control and Communication

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Abstract

Slides from two lectures given at the commemoration of the Nyquist Hall at Karlstad Institute of Technology. The first lecture presents Nyquist's stability criterion and discusses its consequences for the field of Automatic Control. The second lecture (in Swedish) gives a shorter but broader presentation of Nyquist's contributions to communication and control.

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Nyquist's Contributions to Automatic Control

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Lund Institute of Technology

Introduction

Degrees of scientific fame

Practically all engineering students
all over the world learn about:

Nyquist's Stability Criterion
The Nyquist Curve
The Nyquist Frequency
Nyquist Noise

Natural Science and Engineering Science

Many similarities but also differences

Understand **Natural Phenomena**	**Understand** **Technical Systems**
Analysis	Synthesis
Isolate phenomena	Interaction
Look for basic laws	Look for system principles

Nyquist's work a good illustration (feedback, information)

Telecommunication in the 1930's

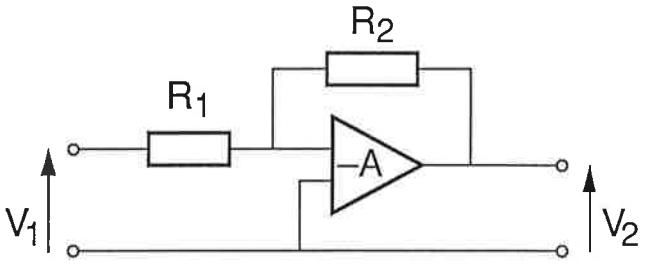
Background

Long lines
Need for repeaters
Feedback amplifier

The problem with "singing" (instability)

What is it?
What does it depend on?
How can it be avoided?

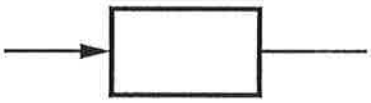
The Feedback Amplifier



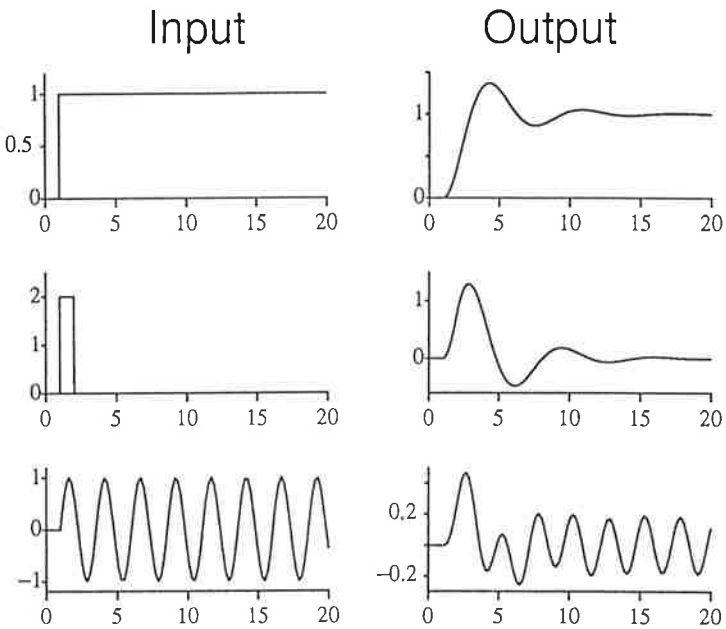
$$\frac{V_2}{V_1} = -\frac{R_2}{R_1} \cdot \frac{1}{1+\frac{1}{A}\left(1+\frac{R_2}{R_1}\right)}$$

How to Describe Behaviour of a Dynamical System

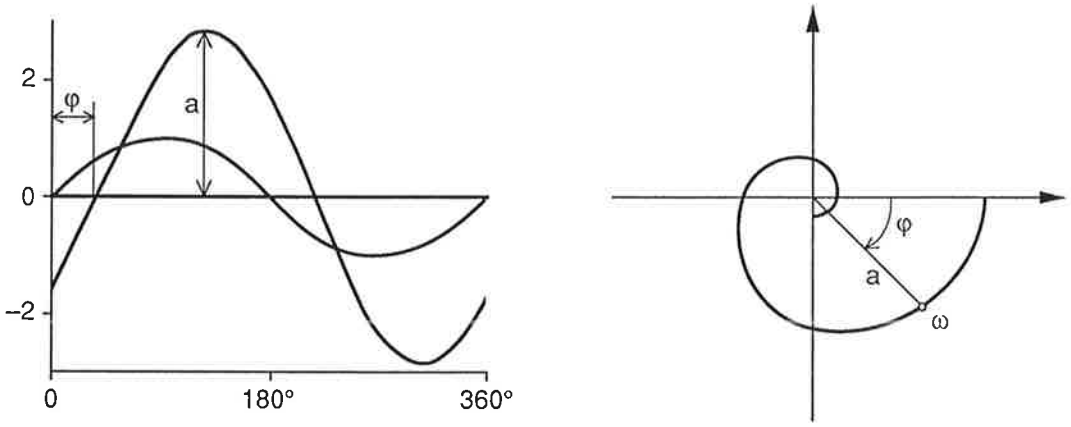
The black box view



Linearity
Superposition
Sinewaves suffice

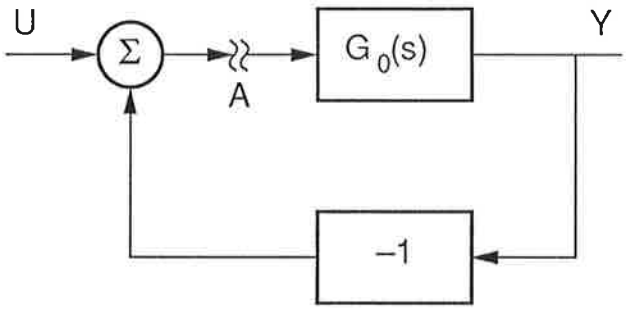


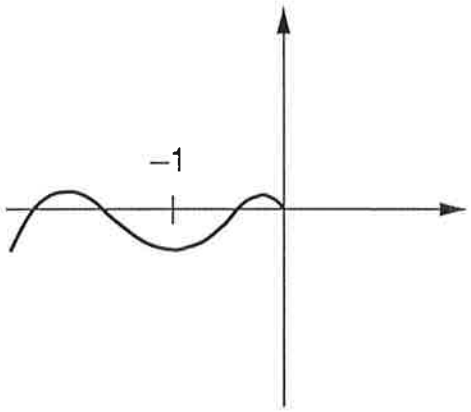
The Nyquist Curve



Can be determined experimentally !

Nyquist's Stability Criterion

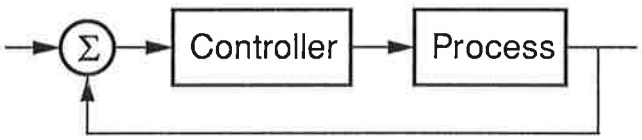




Use of Nyquist's Stability Criterion

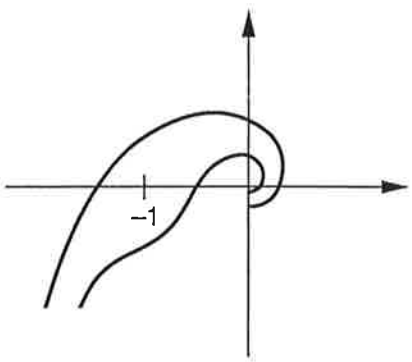
Tool for analysis

Insight and understanding



Design method

- Measure Nyquist curve of process
- Choose controller's Nyquist curve
- Implement controller
- Evaluate by measurement
- Install system



Replaces trial and error

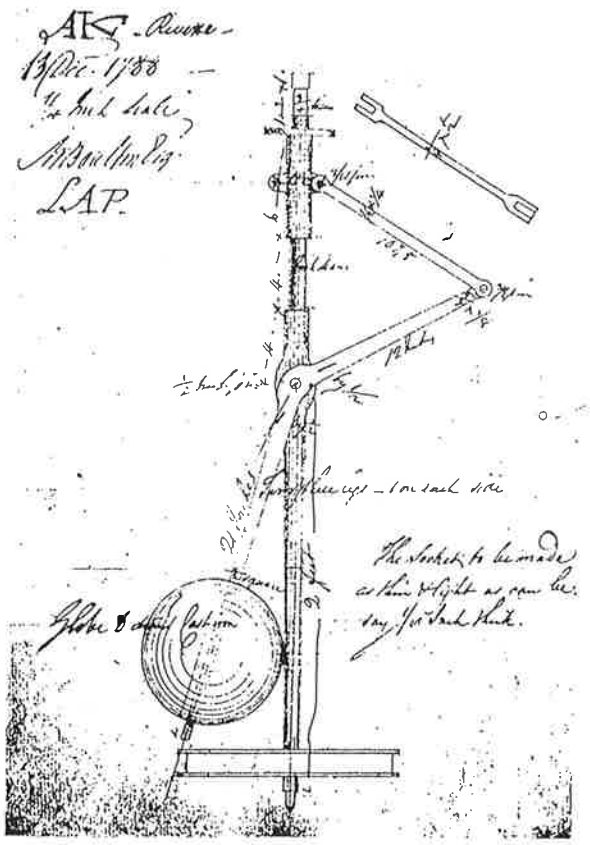
1. Introduction
2. Nyquist's Idea
3. **Automatic Control**
4. An Example
5. Conclusions

A Historical Note

Early use of feedback and observation of "singing"

Windmills ≈1720
Steam engines (Watt) ≈1770
    Maxwell
Turbines 1886
Flight control 1905
    Wright Brothers, Sperry
Telephones

Why were similarities not discovered until 1940 ?



Automatic Control Emerges a Discipline

Driving forces

Inspiration
- Telecommunication
- Industrial automation
- Flight control

Where?
- MIT (Nyquist was there!)
- USSR
- England

System principles
- Feedback
- Feedforward

System theory
Design methods
Application experience
Education
IFAC 1957
Conferences, Journals

A Dynamic Development

Landmarks

Servomechanism theory 1945

Proliteration of applications

Paradigm shift $\approx$ 1960
- Space missions
- Computer control
- New foundation

Current challenges
- Intelligent systems?

Applications

Transportation
Energy generation
Energy transmission
Process Industry
Manufacturing
Entertainment
Biology
Economics?

Impact of Nyquist's Criterion at ASEA

From Bell Labs to Västerås – A long journey

H. Nyquist, Regeneration Theory, *Bell System Technical Journal,* Vol 11, 1932, pp. 126–147.

Regeneration or feed-back is of considerable importance in many applications of vacuum tubes. The most obvious example is that of vacuum tube oscillators, where the feed-back is carried beyond the singing point. Another application is the 21-circuit test of balance, in which the current due to the unbalance between two impedances is fed back, the gain being increased until singing occurs. Still other applications are cases where portions of the output current of amplifiers are fed back to the input either unintentionally or by design. For the purpose of investigating the stability of such devices they may be looked on as amplifiers whose output is connected to the input through a transduce. This paper deals with the theory of stability of such systems.

Aage Garde och Erik Persson, Automatisk djupstyrning av ubåtar, *Aseas Tidning,* 1960, Årgång 52, Häfte 7, sid 127.

Allmän beskrivning av Aseas system för automatisk djupstyrning av ubåtar. Funktionen och konstruktionen beskrivs i detalj, och slutligen ges några exempel på driftresultat.

ASEA	19/5-48		TM 7032	
Thp	ЄP		Reg	6256

Skissblad 1

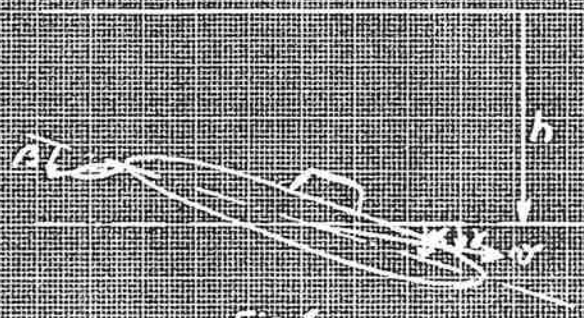


Fig 1

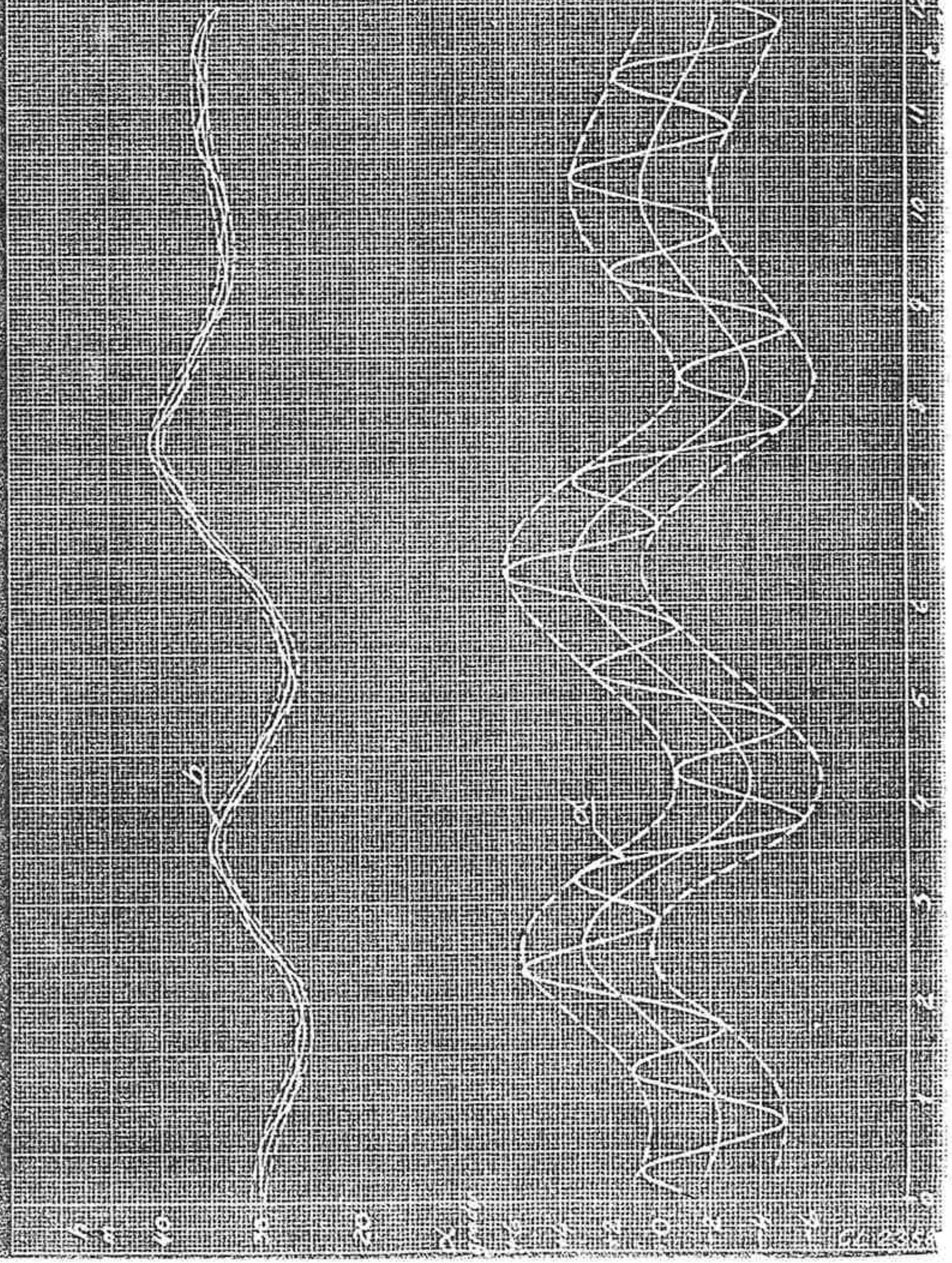
Fig 2

Fig 3

T sek

ASEA	19/5-48	Serie nr 31	TM 7032	
Thp	ЄP	v = 7 knop T = 40 s β̂ = 11,5° ω = 0,157	Reg	6256

Kurvblad 1



Conclusions

- ✧ Nyquist created many useful ideas and concepts
- ✧ Important for telecommunication and control
- ✧ Grew from study of a particular problem
- ✧ Impact far outside the original field
- ✧ Very proper to dedicate this Hall to him

Professor A. Engström:

”Det mest karakteristiska för forskningsverksamheten inom livsvetenskaperna är att den blir i allt högre grad tvärvetenskaplig. Den spänner över matematik, reglerings-teknik, molekylärbiologi, farmakologi, klinik osv. Detalj-kunskaperna ger oss möjligheter att analysera funktionerna mer grundläggande genom att sätta samman de olika reglersystemen allt ifrån molekylär upp till organ- och individnivå. Det är här det teoretiska systemtänkandet kommer in i bilden och kan öka förståelsen för hur levande materia fungerar.”

Harry Nyquist

En pionjär inom ingenjörsvetenskapen

K. J. Åström

Lunds Tekniska Högskola

Kort biografi

7 februari 1889 Nilsby
Emigrerar till USA 1907
BS Univ North Dacota 1915
Ph.D. Yale 1917
AT&T Engineering 1917
Bell Labs 1934
Pensionerad 1954
Konsult

Viktiga idéer
Banbrytande vetenskapliga artiklar
Tekniska system
138 patent
IRE Medal of Honor
Ballantyne Medal Franklin Institute
M. J. Kelley Award AIEE
Rufus Oldenberger Award ASME

Viktiga bidrag

Telegrafteknik
Telekommunikation
Informationsteori
Reglerteknik

Nyquistkriteriet
Nyquistkurvan
Nyquistfrekvensen
Nyquists brus

Naturvetenskap och teknikvetenskap

Många likheter men också skillnader

Förstå fenomen i naturen	**Förstå tekniska system**
Analys	Syntes
Isolering	Komplexitet
Grundprinciper	Systemprinciper

Nyquists arbeten en utmärkt illustration
(återkoppling, information)

Slutord

- ✧ Gratulerar till nya lokaler
- ✧ Trevligt att hylla bygdens söner
- ✧ Andra tider