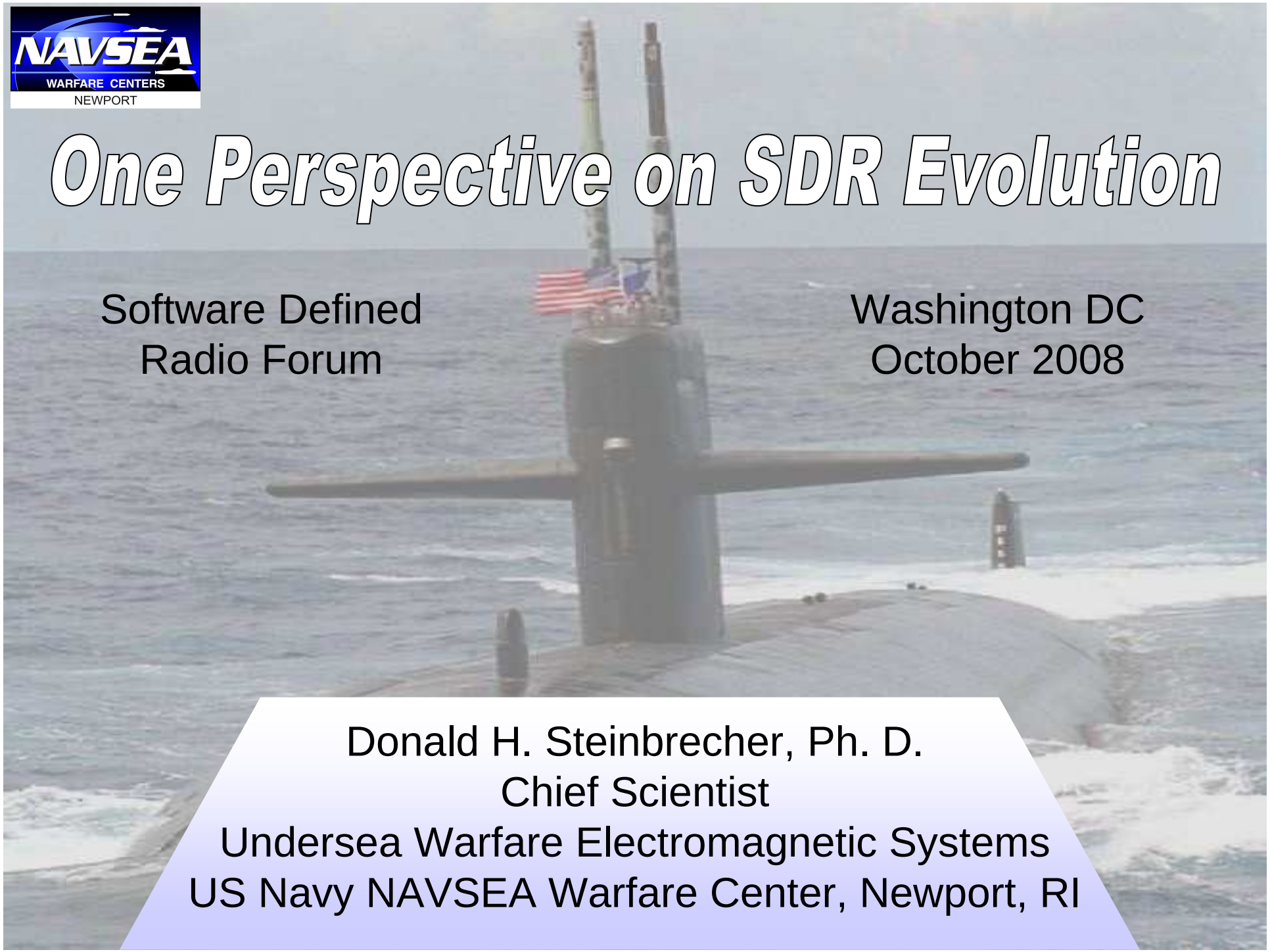

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One Perspective on SDR Evolution

Software Defined
Radio Forum

Washington DC
October 2008

Donald H. Steinbrecher, Ph. D.
Chief Scientist
Undersea Warfare Electromagnetic Systems
US Navy NAVSEA Warfare Center, Newport, RI

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One Perspective on SDR Evolution

1970: Frequency Translation

1980: A/D Conversion

1990: RF-to-Digital Converters

1998: Vanu Corporation

2008: Software Defined Air Interface

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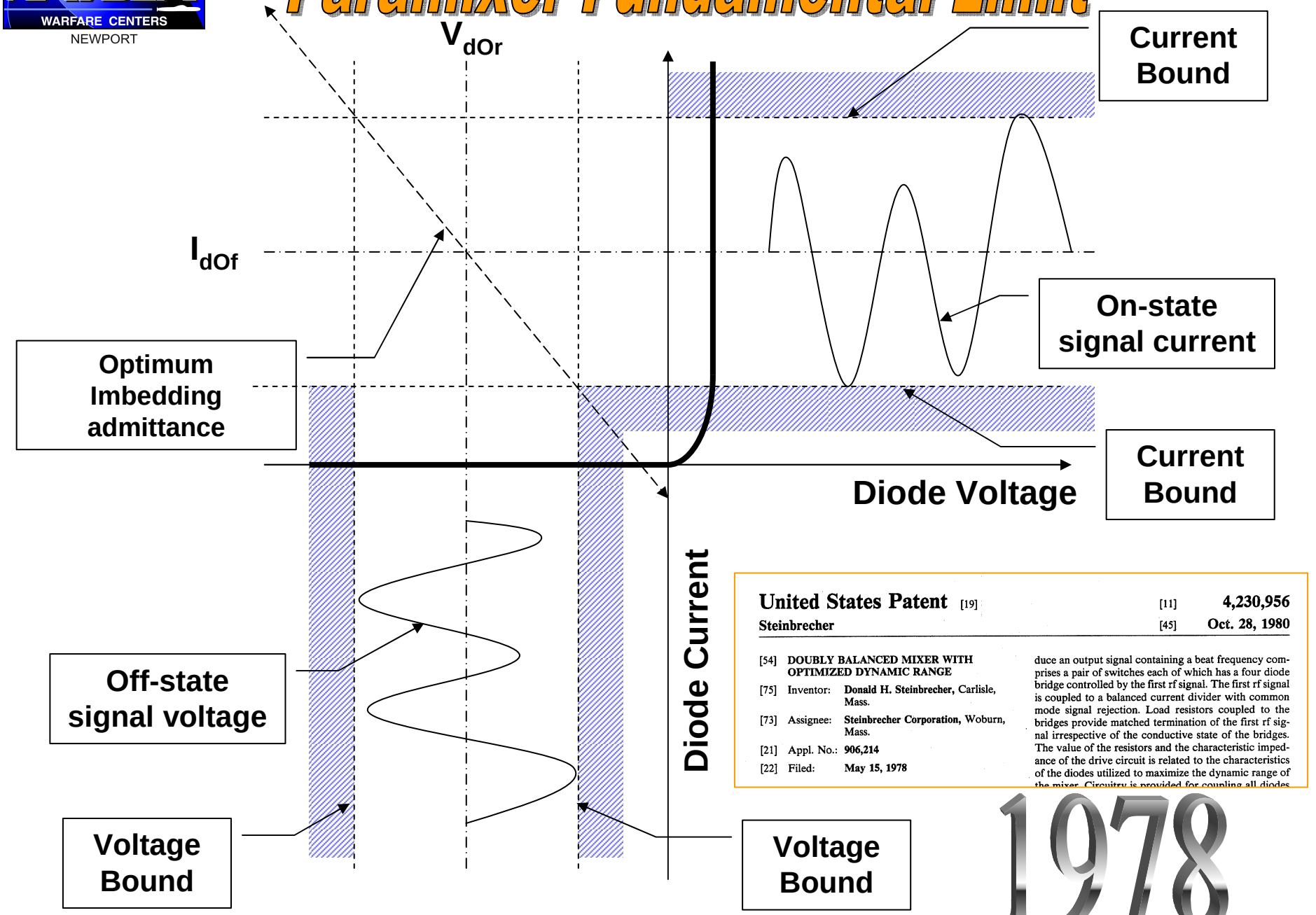
Paramixer Fundamental Limit



United States Patent [19] [11] **4,230,956**
Steinbrecher [45] **Oct. 28, 1980**

[54] **DOUBLY BALANCED MIXER WITH OPTIMIZED DYNAMIC RANGE**
[75] Inventor: **Donald H. Steinbrecher**, Carlisle, Mass.
[73] Assignee: **Steinbrecher Corporation**, Woburn, Mass.
[21] Appl. No.: **906,214**
[22] Filed: **May 15, 1978**

duce an output signal containing a beat frequency comprises a pair of switches each of which has a four diode bridge controlled by the first rf signal. The first rf signal is coupled to a balanced current divider with common mode signal rejection. Load resistors coupled to the bridges provide matched termination of the first rf signal irrespective of the conductive state of the bridges. The value of the resistors and the characteristic impedance of the drive circuit is related to the characteristics of the diodes utilized to maximize the dynamic range of the mixer. Circuitry is provided for coupling all diodes

1978

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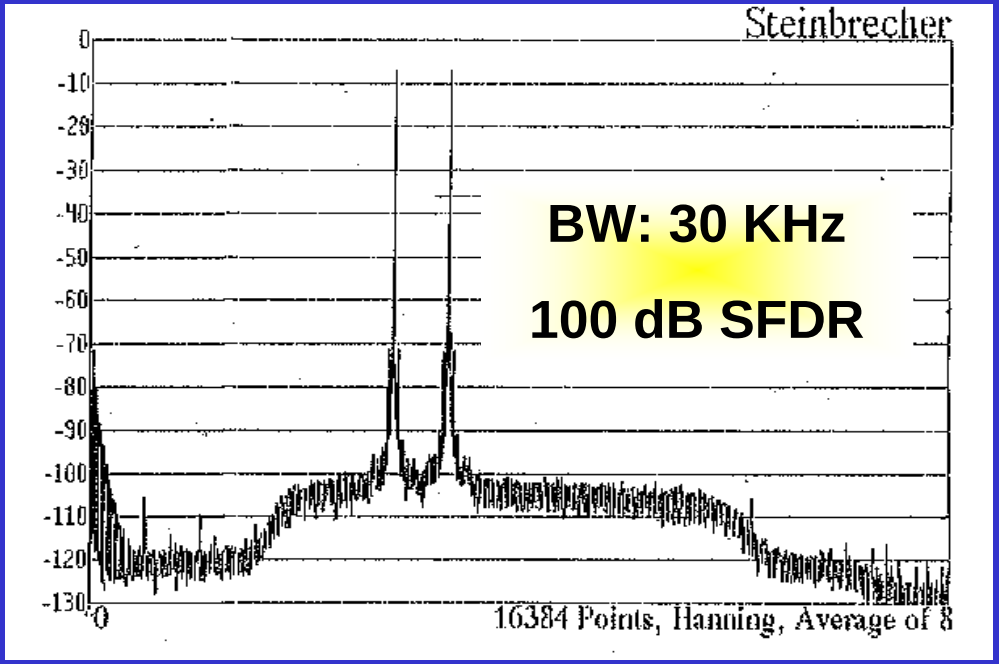
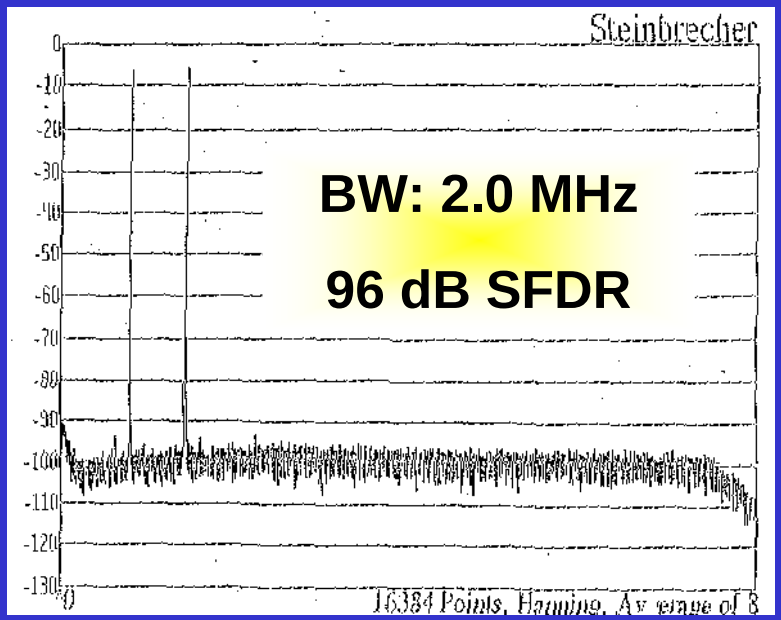
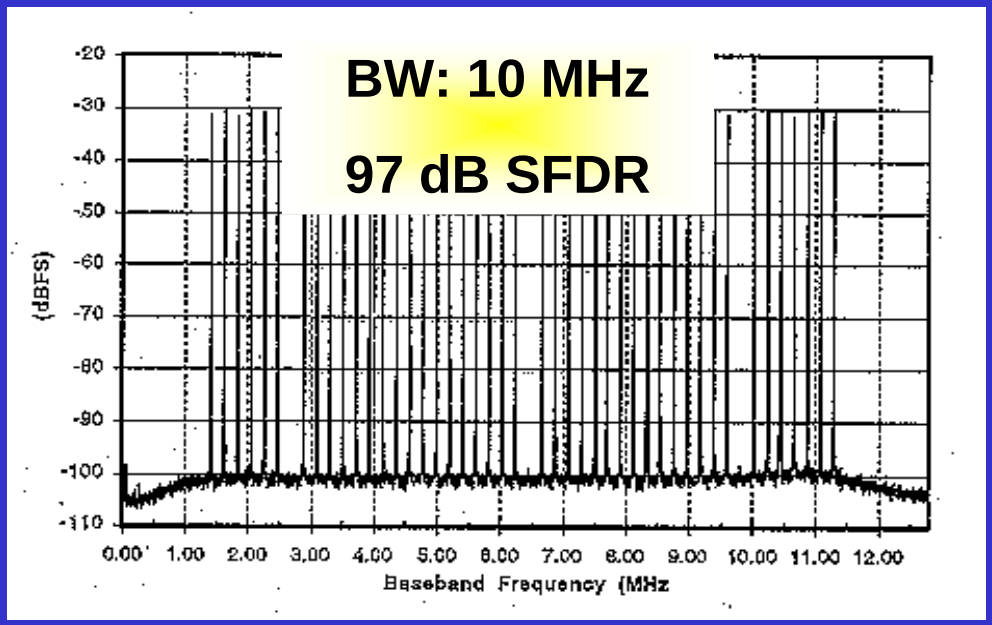
Signals Intercept Systems (SD)







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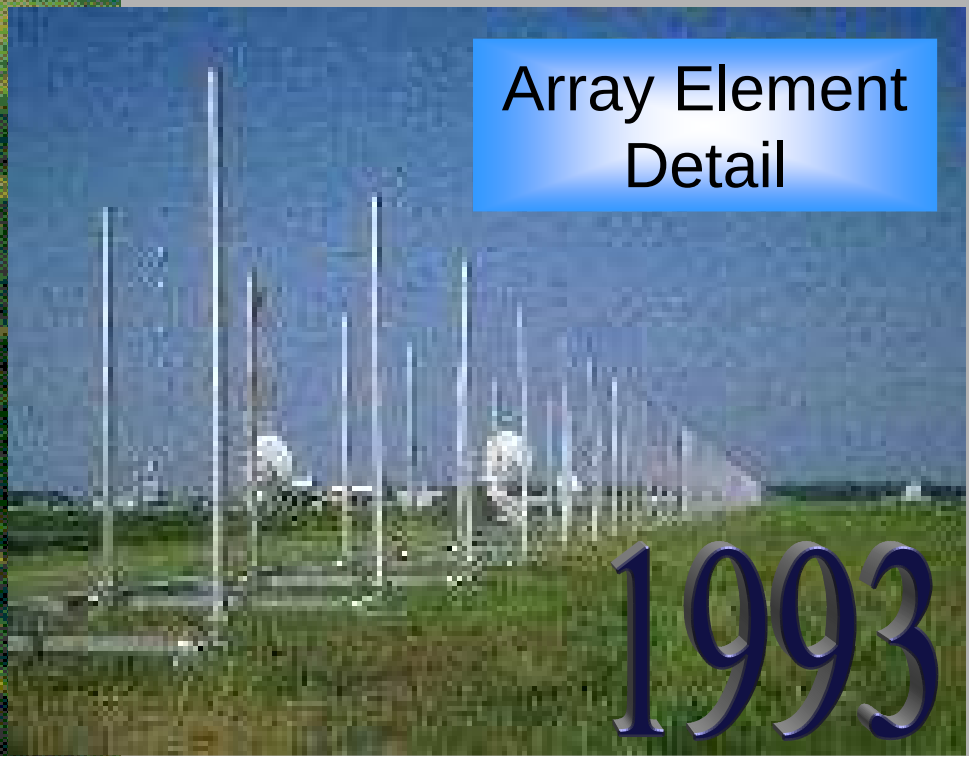
US Navy ROTHR System

Virginia: 372; 8,474 ft

Texas: 372; 8,474 ft

Vieques: 250; 5,695 ft



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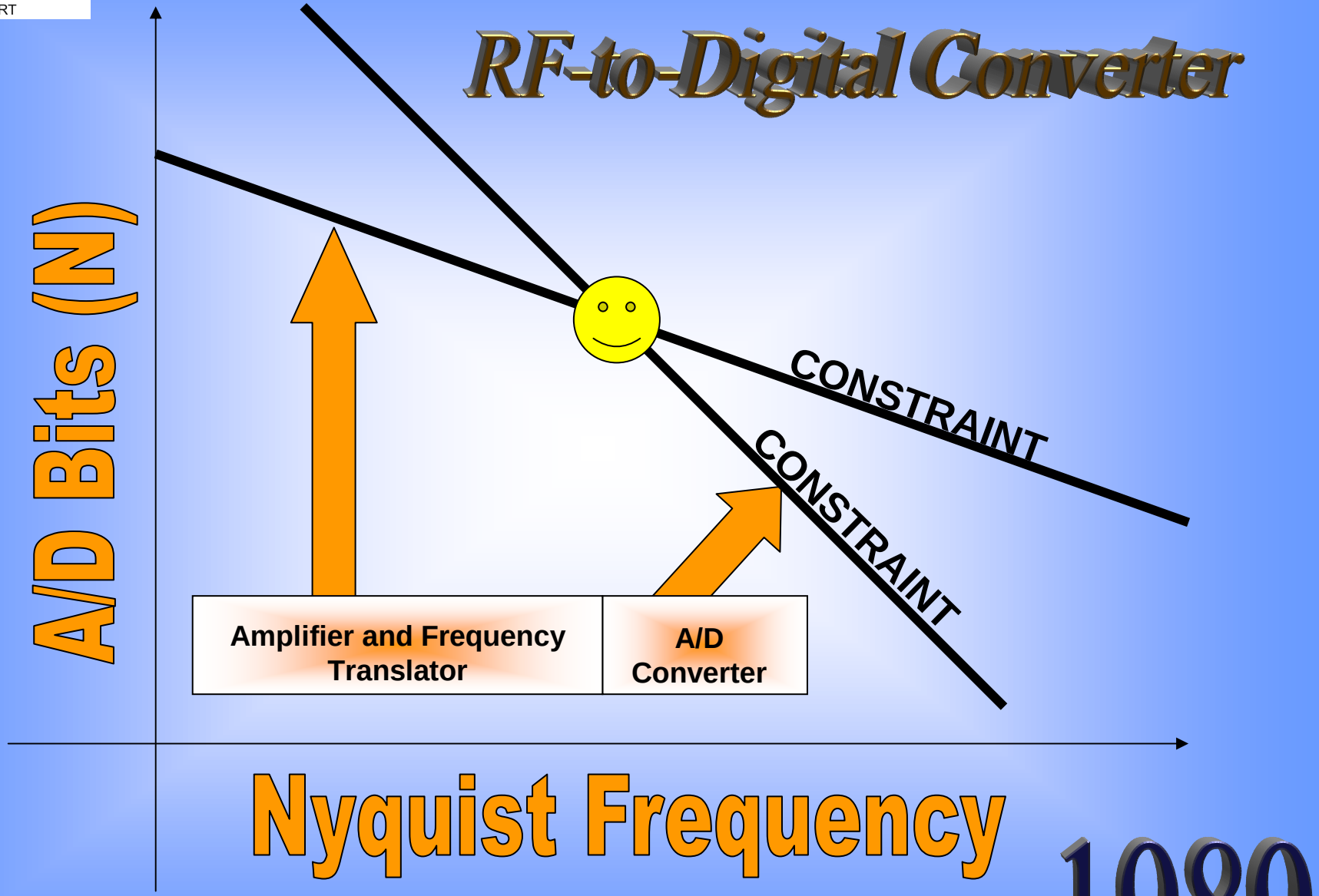
RF-to-Digital Converter



1989

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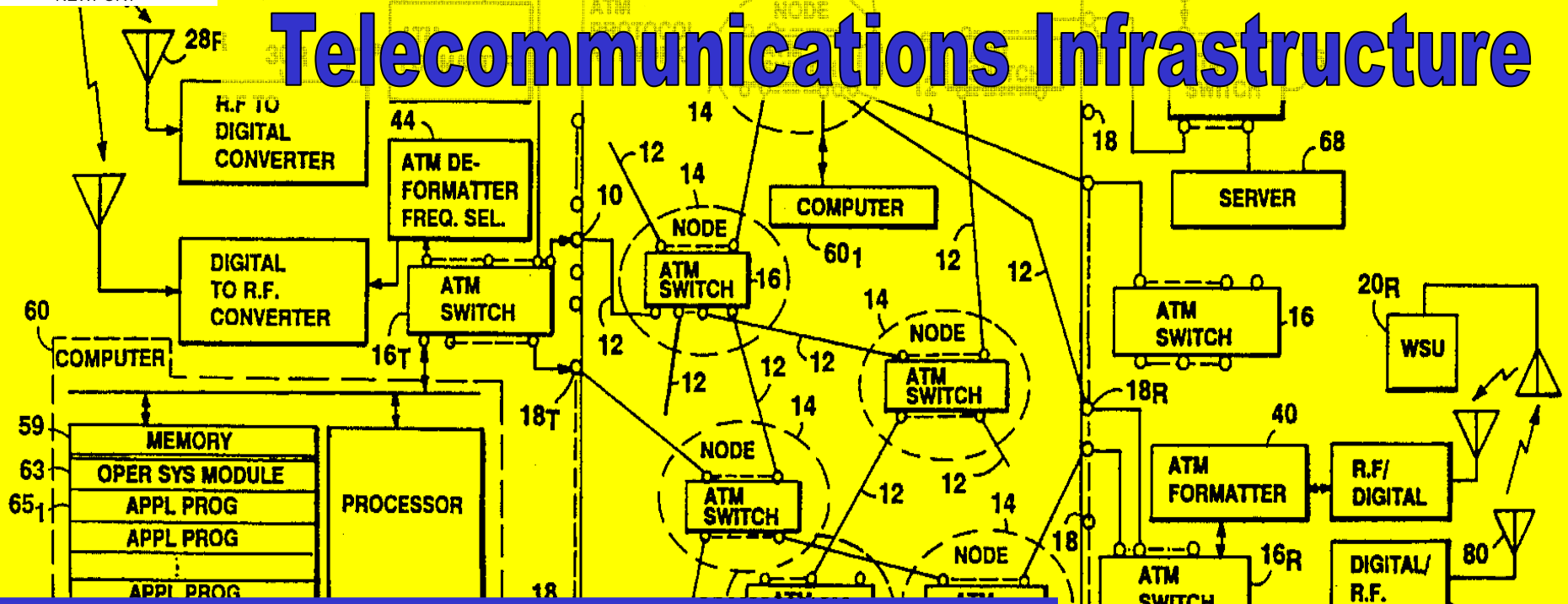
The Generic Telecommunications Infrastructure



United States Patent [19]

Steinbrecher

[11] **Patent Number: 5,566,173**

[45] **Date of Patent: Oct. 15, 1996**

[54] **COMMUNICATION SYSTEM**

[75] Inventor: **Donald H. Steinbrecher**, Brookline, Mass.

[73] Assignee: **Steinbrecher Corporation**, Burlington, Mass.

[21] Appl. No.: **322,101**

[22] Filed: **Oct. 12, 1994**

[51] **Int. Cl.**[6] **H04B 7/212**

[52] **U.S. Cl.** **370/79**; 370/85.13; 370/95.1; 370/60.1; 379/58

5,363,369	11/1994	Hemmady et al.	370/60
5,375,118	12/1994	Rao et al.	370/60.1
5,388,258	2/1995	Larsson et al.	370/58.2 X

Primary Examiner—Douglas W. Olms
Assistant Examiner—Russell W. Blum
Attorney, Agent, or Firm—Fish & Richardson, P.C.

[57] **ABSTRACT**

A communication system having a communication network, such network having a plurality of communication paths interconnected at various nodes of the network. A plurality of subscriber units is adapted to exchange information through the network. A computer is provided having a processor and a memory, such memory being adapted to

1994

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The VANU Evolution

1998

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A New Paradigm:
The Software-Defined Air Interface

Fundamental Limit

$$p = \frac{W_{XIS}}{W_{MDS}} \frac{B_d}{f_N} \left[\frac{2}{3} 2^{-2N} \right] \frac{F_{SYS}}{F_{SYS} - 1}$$

(12) **United States Patent**
Steinbrecher

(10) **Patent No.: US 7,420,522 B1**
(45) **Date of Patent: *Sep. 2, 2008**

(54) **ELECTROMAGNETIC RADIATION INTERFACE SYSTEM AND METHOD**

(75) Inventor: **Donald H. Steinbrecher**, Brookline, MA (US)

(73) Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 403 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **10/956,526**

(22) Filed: **Sep. 29, 2004**

6,215,448	B1	4/2001	DaSilva et al.
6,285,495	B1	9/2001	Baranov et al.
6,292,140	B1	9/2001	Osterman
6,295,032	B1	9/2001	Podgorski
6,297,774	B1	10/2001	Chung
6,300,918	B1	10/2001	Riddle et al.
6,329,955	B1	12/2001	McLean et al.
2001/0003444	A1	6/2001	Mangenot et al.
2001/0033207	A1	10/2001	Anderson et al.
2001/0033377	A1	10/2001	Welch et al.

* cited by examiner

Primary Examiner—Michael C Wimer
(74) *Attorney, Agent, or Firm*—James M. Kasischke; Michael P. Stanley; Jean-Paul A. Nasser

(57) **ABSTRACT**

An electromagnetic radiation interface is provided that is suitable for use with radio wave frequencies. A surface is provided with a plurality of metallic conical bristles. A cor-

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A digital engineer named Joe seeks a fundamental limit for Software-Defined Radio


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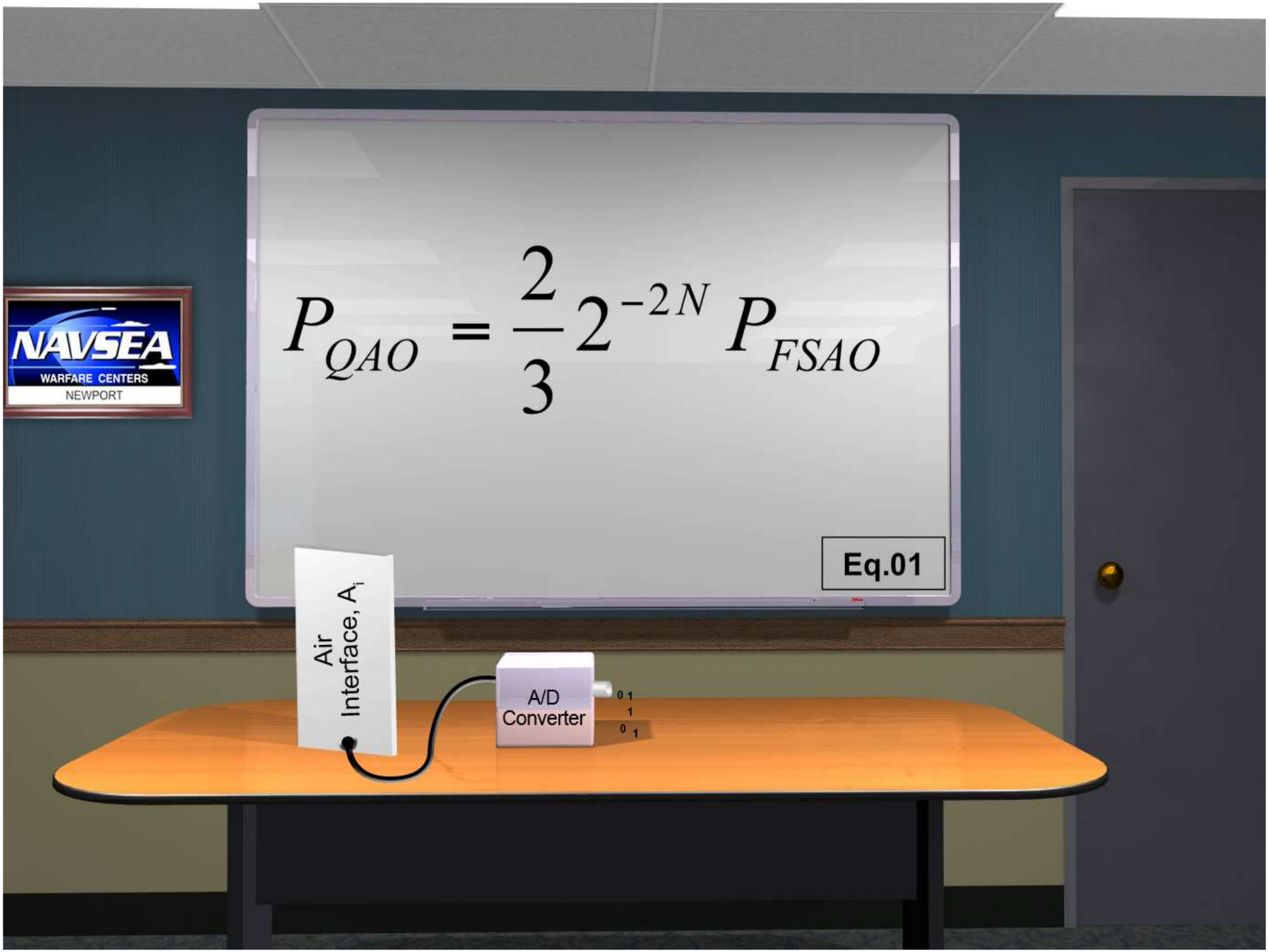
Fundamental Limit?


Air Interface, A_i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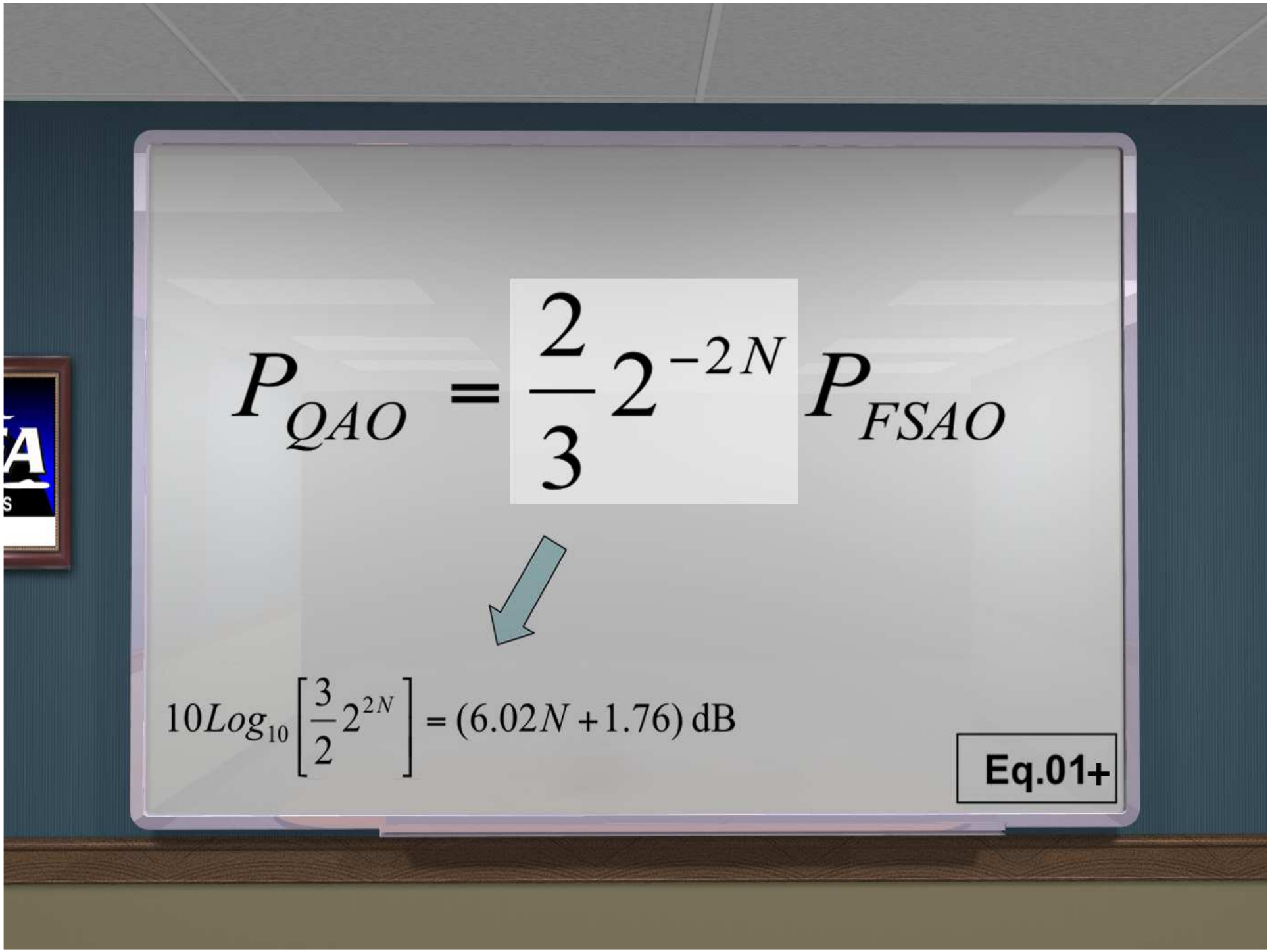
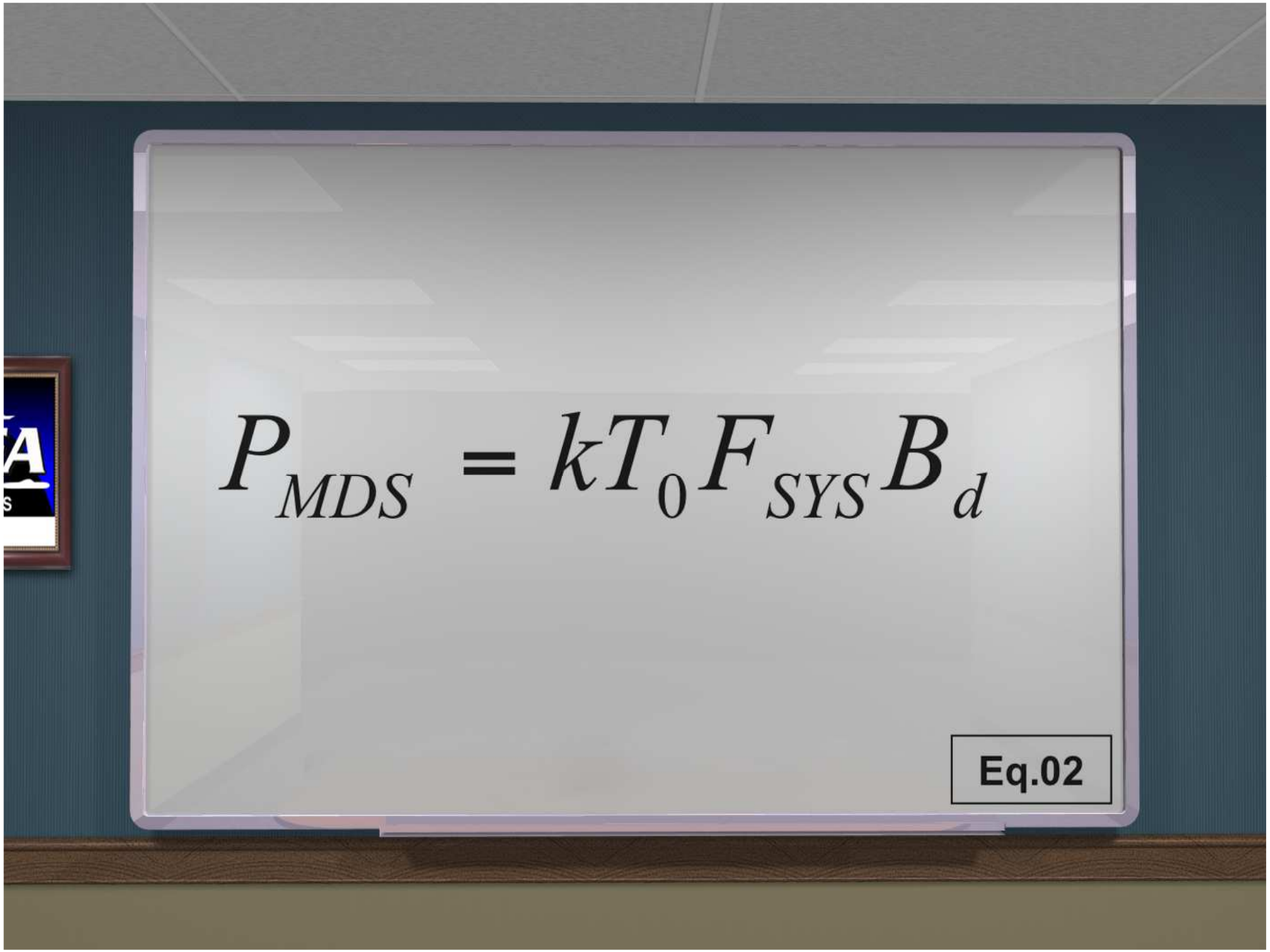
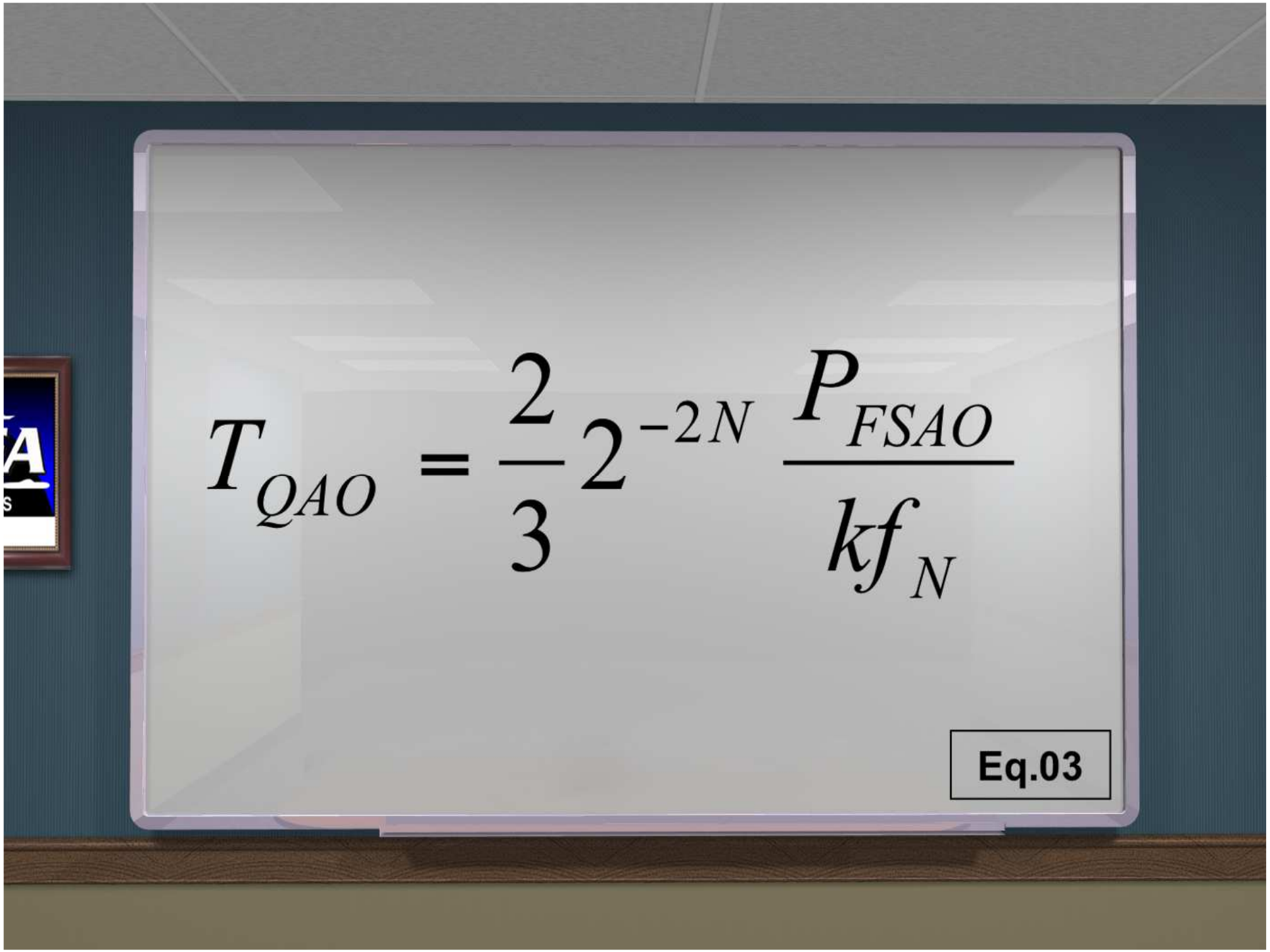
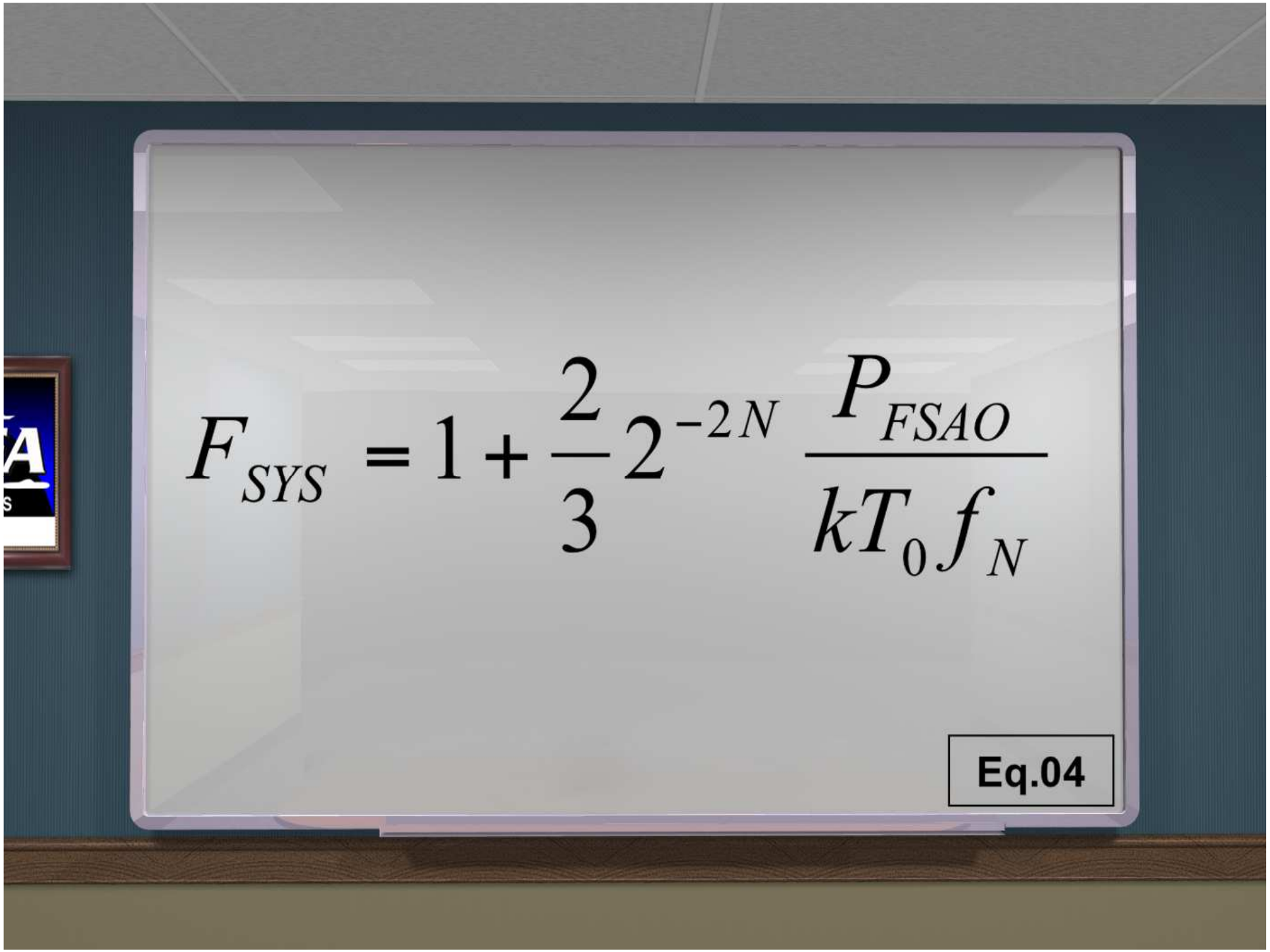
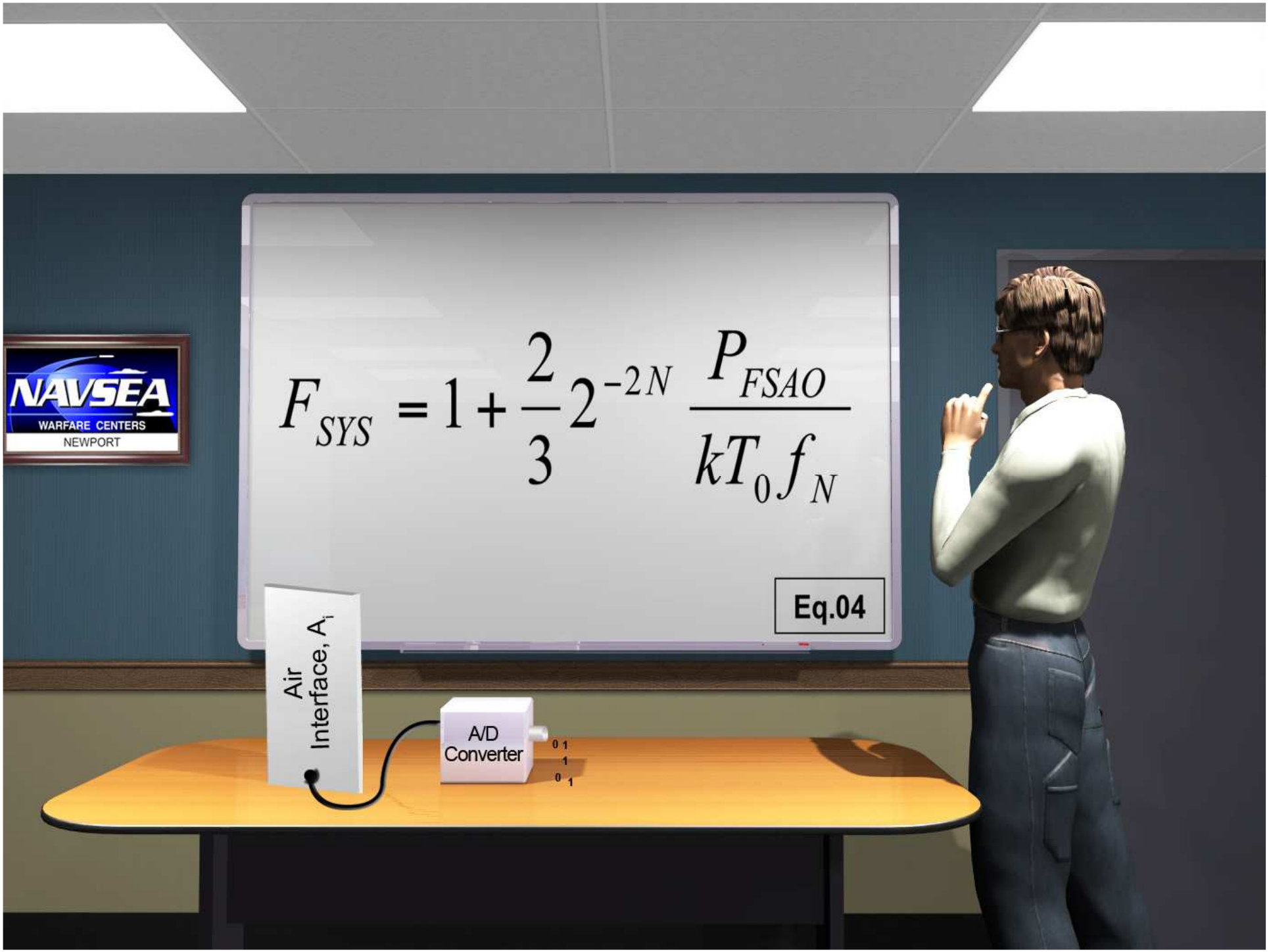
$$P_{QAO} = \frac{2}{3} 2^{-2N} P_{FSAO}$$
Eq.01
Air Interface, A_i
A/D Converter
0 1
1
0 1


$P_{QAO} = \frac{2}{3} 2^{-2N} P_{FSAO}$
$10 Log_{10}\left[\frac{3}{2} 2^{2N}\right] = (6.02N + 1.76)\ \mathrm{dB}$
Eq.01+


$P_{MDS} = kT_0 F_{SYS} B_d$
Eq.02


$$T_{QAO} = \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kf_N}$$
Eq.03


$F_{SYS} = 1 + \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N}$
Eq.04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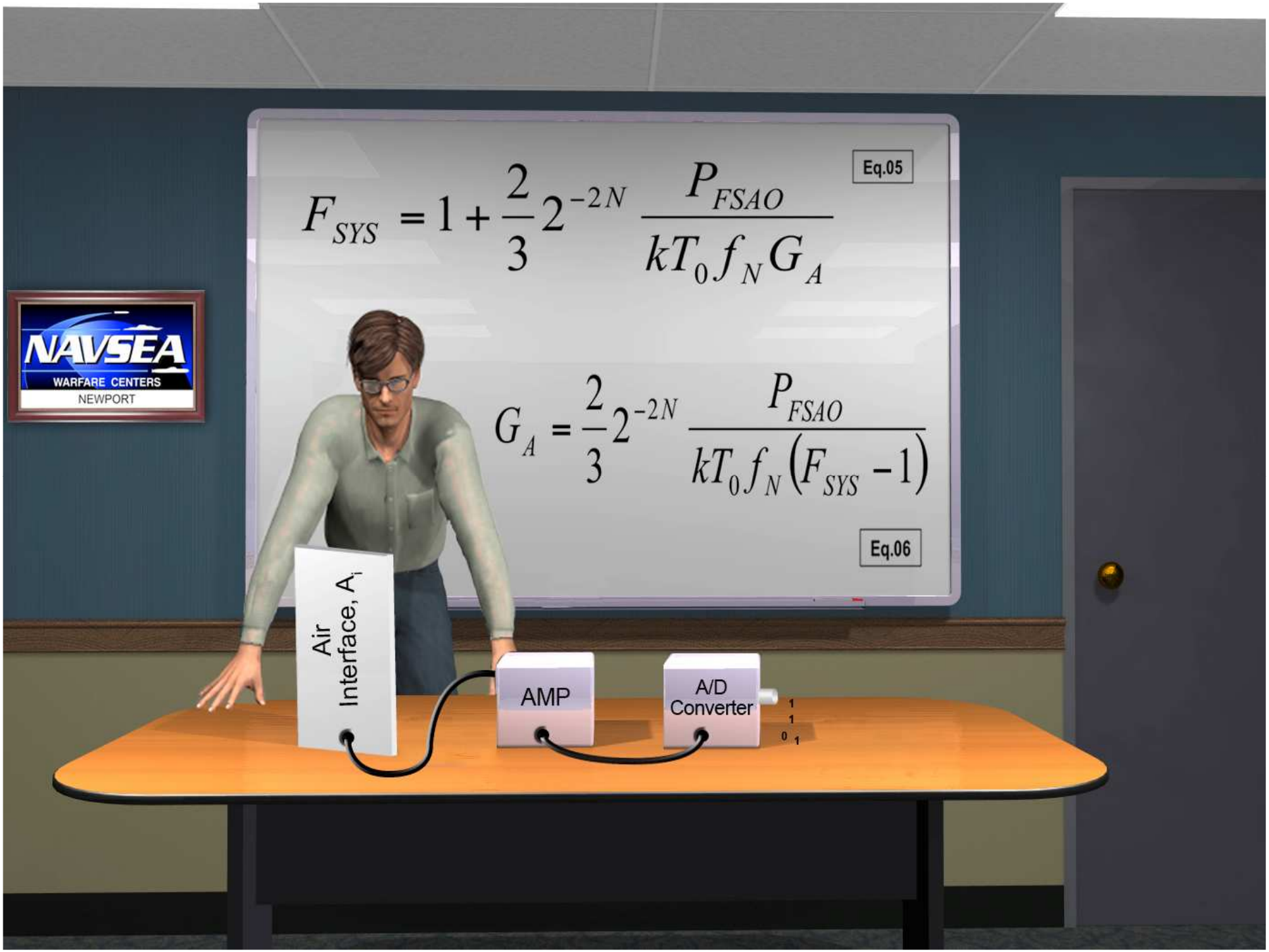
$F_{SYS} = 1 + \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N}$
Eq.04
Air Interface, A_i
A/D Converter
0 1
1
0 1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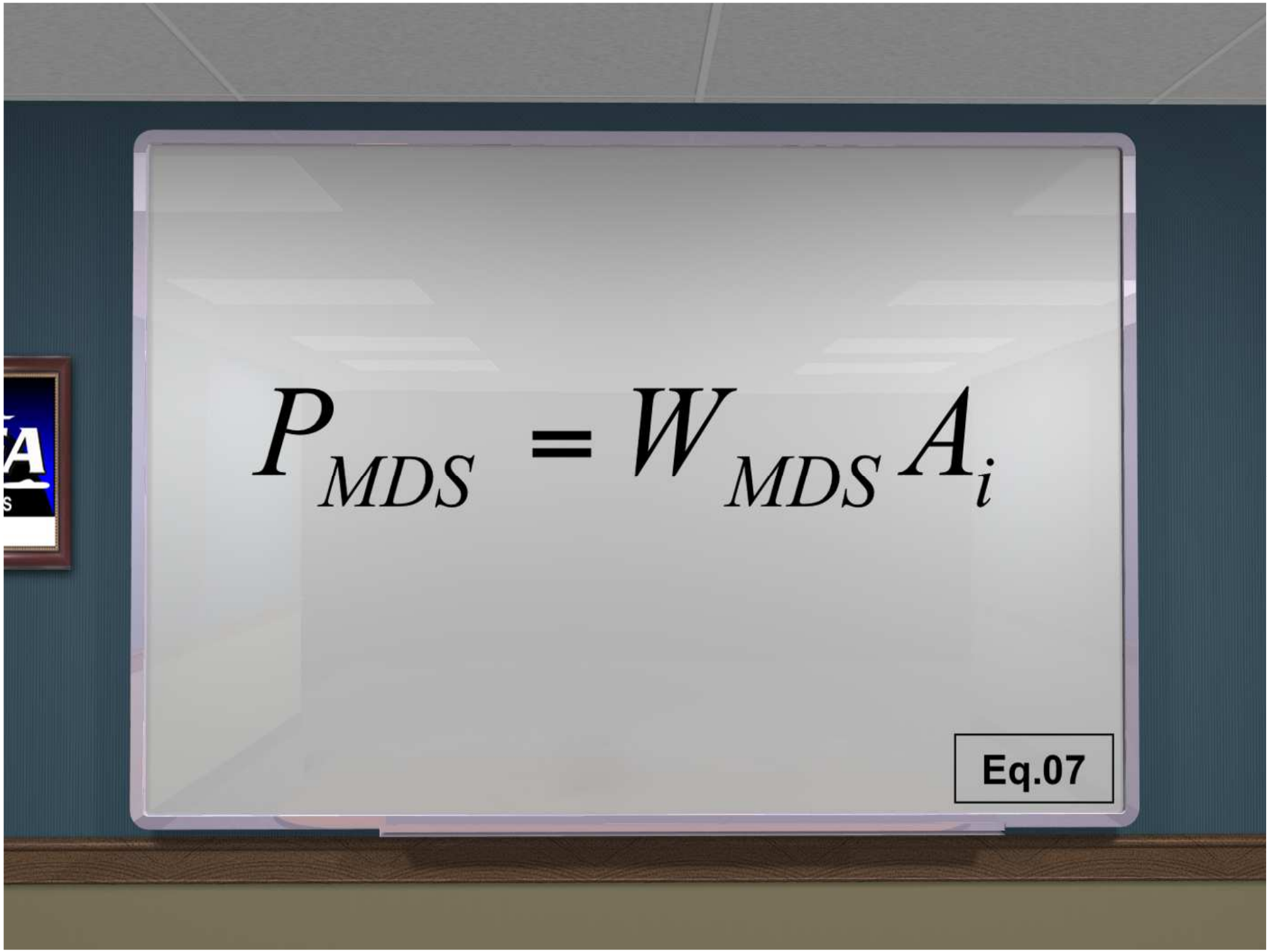
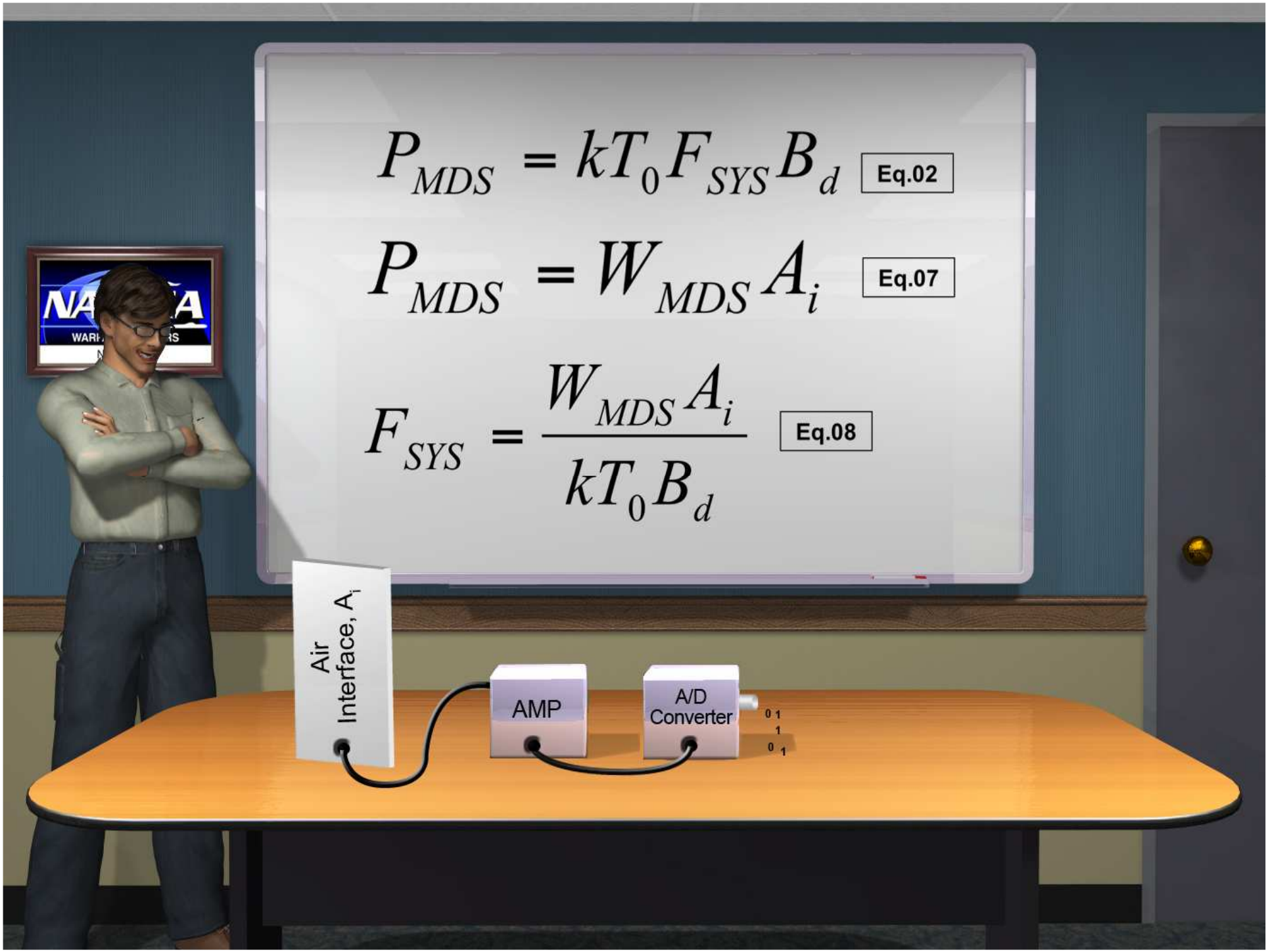
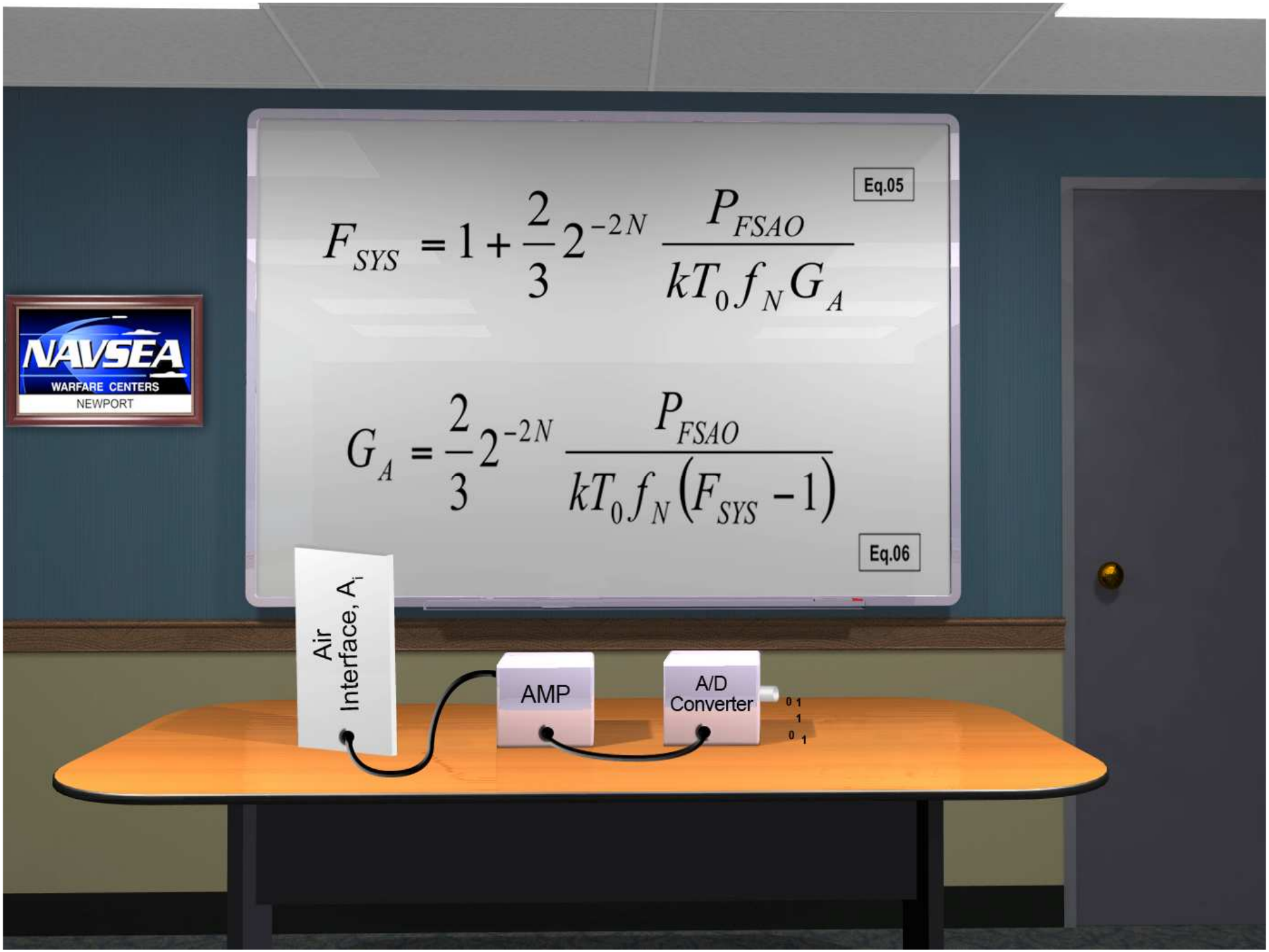
NEWPORT
$F_{SYS} = 1 + \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N G_A}$
Eq.05
$G_A = \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N (F_{SYS} - 1)}$
Eq.06
Air Interface, A_i
AMP
A/D Converter
1
1
0
1


$P_{MDS} = W_{MDS} A_i$
Eq.07


$P_{MDS} = kT_0 F_{SYS} B_d$ Eq.02
$P_{MDS} = W_{MDS} A_i$ Eq.07
$F_{SYS} = \frac{W_{MDS} A_i}{kT_0 B_d}$ Eq.08
Air Interface, A_i
AMP
A/D Converter
0 1
1
0 1


NAVSEA
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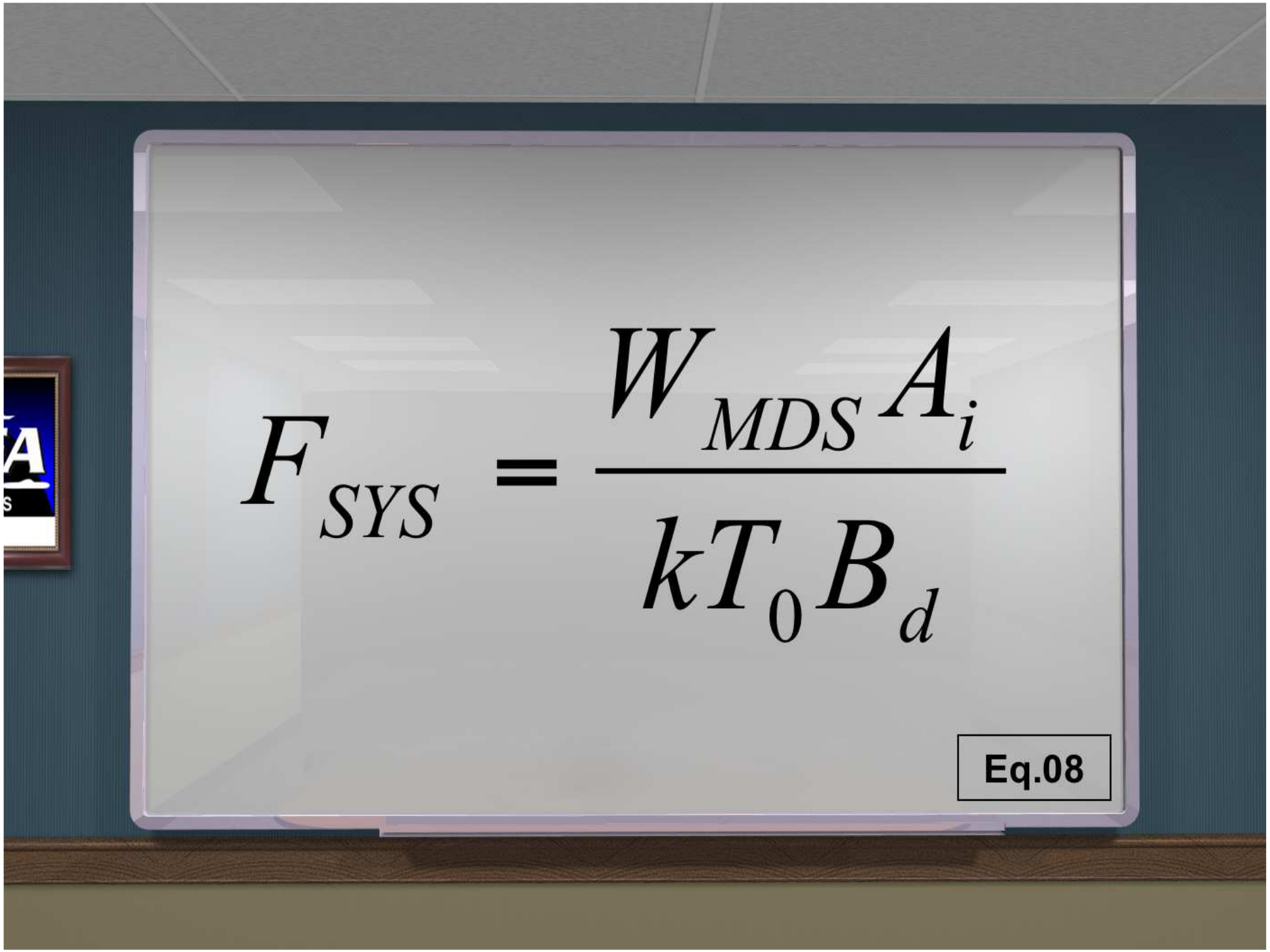
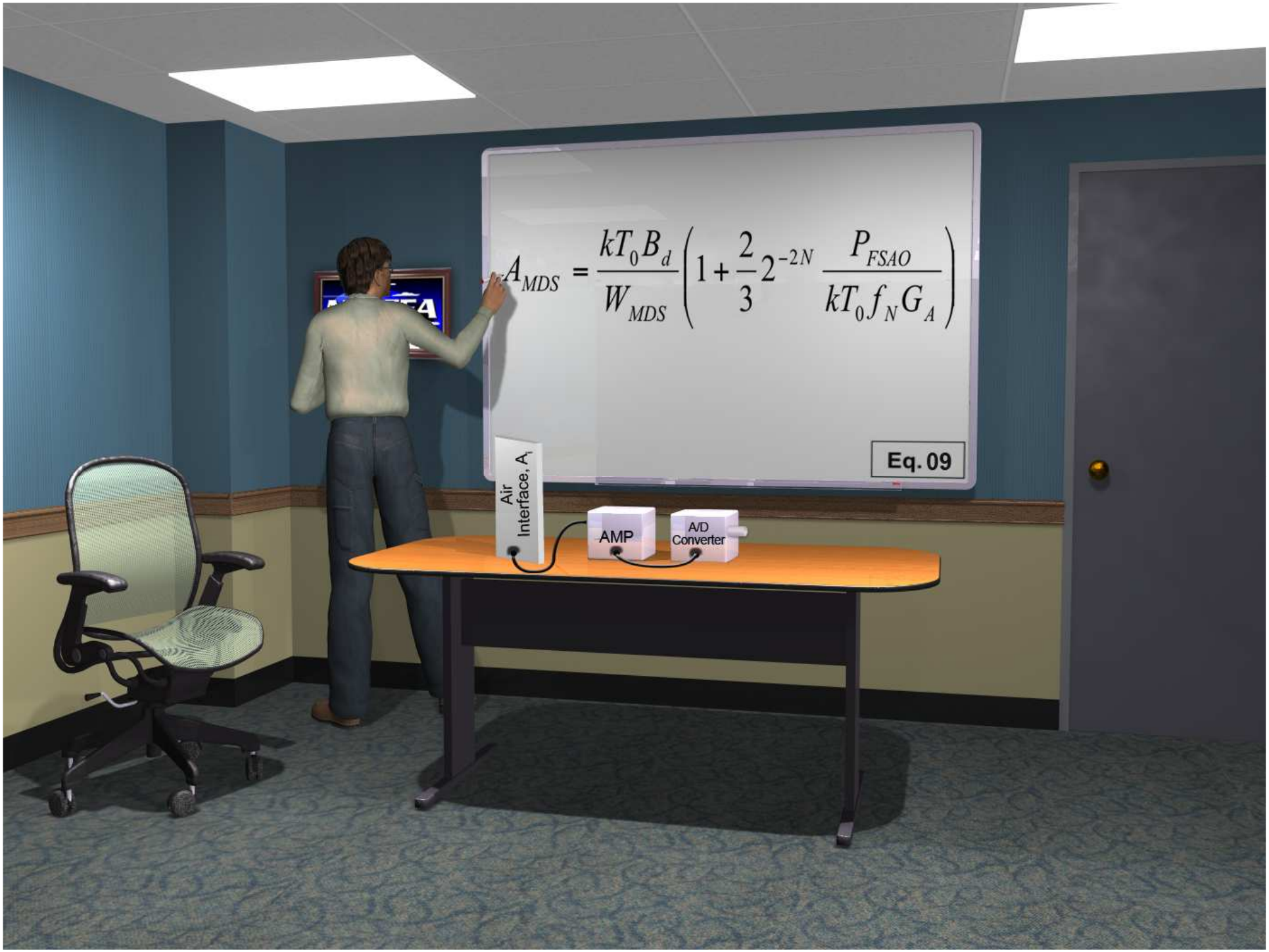
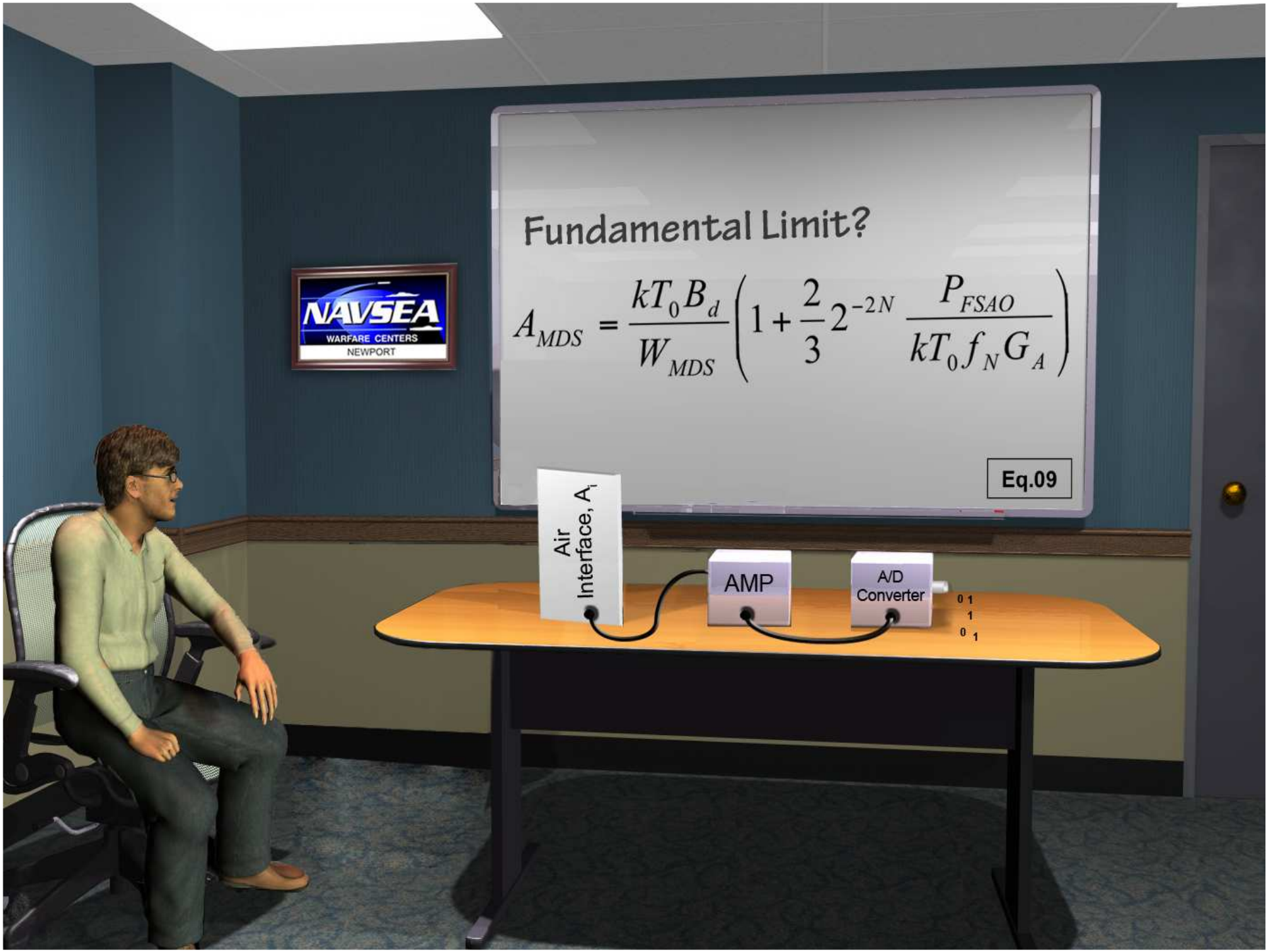
$$F_{SYS} = 1 + \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N G_A}$$
Eq.05
$$G_A = \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N (F_{SYS} - 1)}$$
Eq.06
Air Interface, A_i
AMP
A/D Converter
0 1
1
0 1


$$F_{SYS} = \frac{W_{MDS} A_i}{k T_0 B_d}$$
Eq.08


$A_{MDS} = \frac{kT_0B_d}{W_{MDS}}\left(1+\frac{2}{3}2^{-2N}\frac{P_{FSAO}}{kT_0f_NG_A}\right)$
Eq. 09
Air Interface, A_i
AMP
A/D Converter


Fundamental Limit?
$A_{MDS} = \frac{kT_0 B_d}{W_{MDS}} \left(1 + \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N G_A} \right)$
Eq.09
NAVSEA
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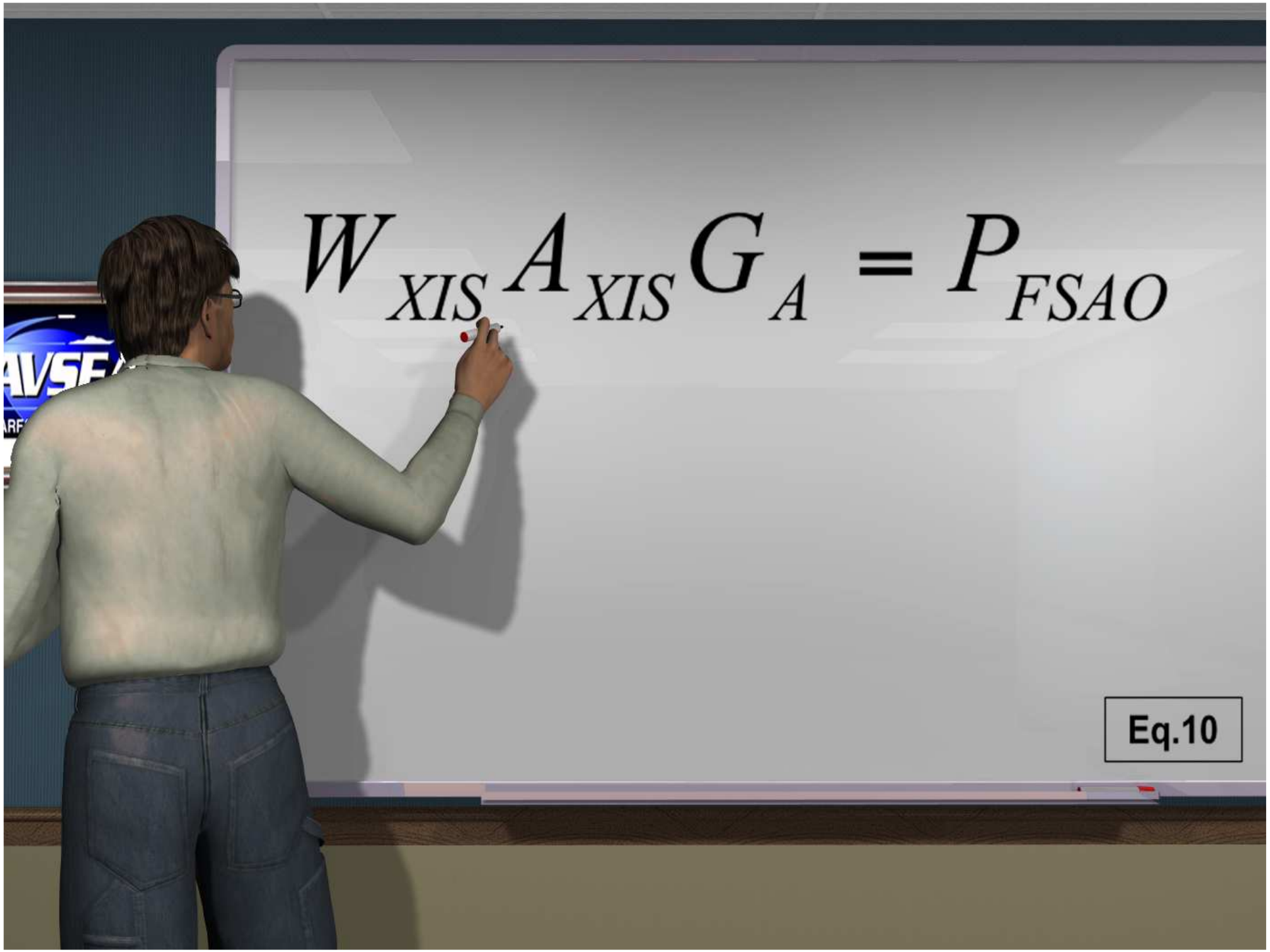
NEWPORT
Air Interface, A_i
AMP
A/D Converter
0 1
1
0 1


$W_{XIS} A_{XIS} G_A = P_{FSAO}$
Eq.10

Eq.09

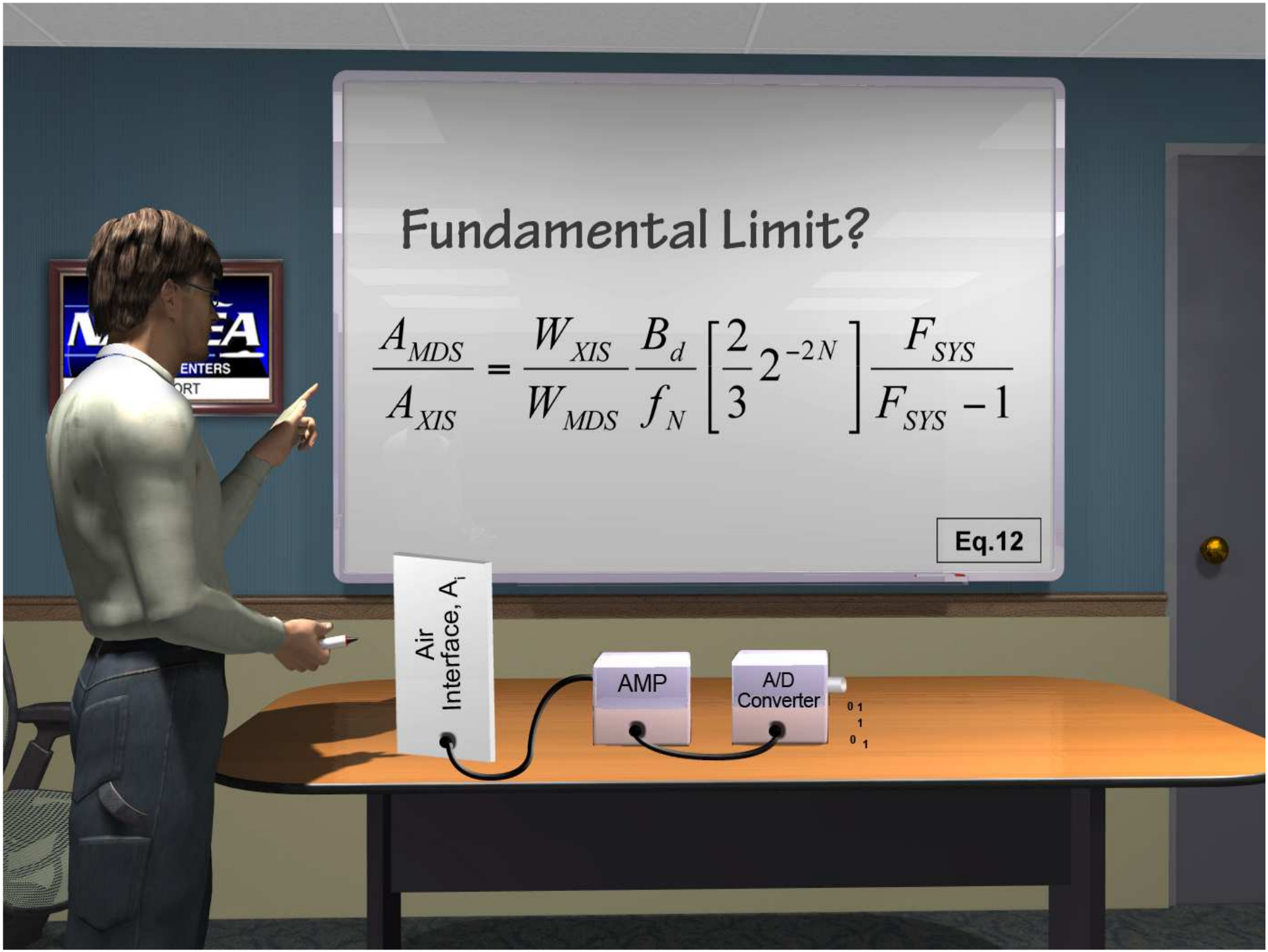
$$A_{MDS} = \frac{kT_0 B_d}{W_{MDS}} \left(1 + \frac{2}{3} 2^{-2N} \frac{P_{FSAO}}{kT_0 f_N G_A} \right)$$

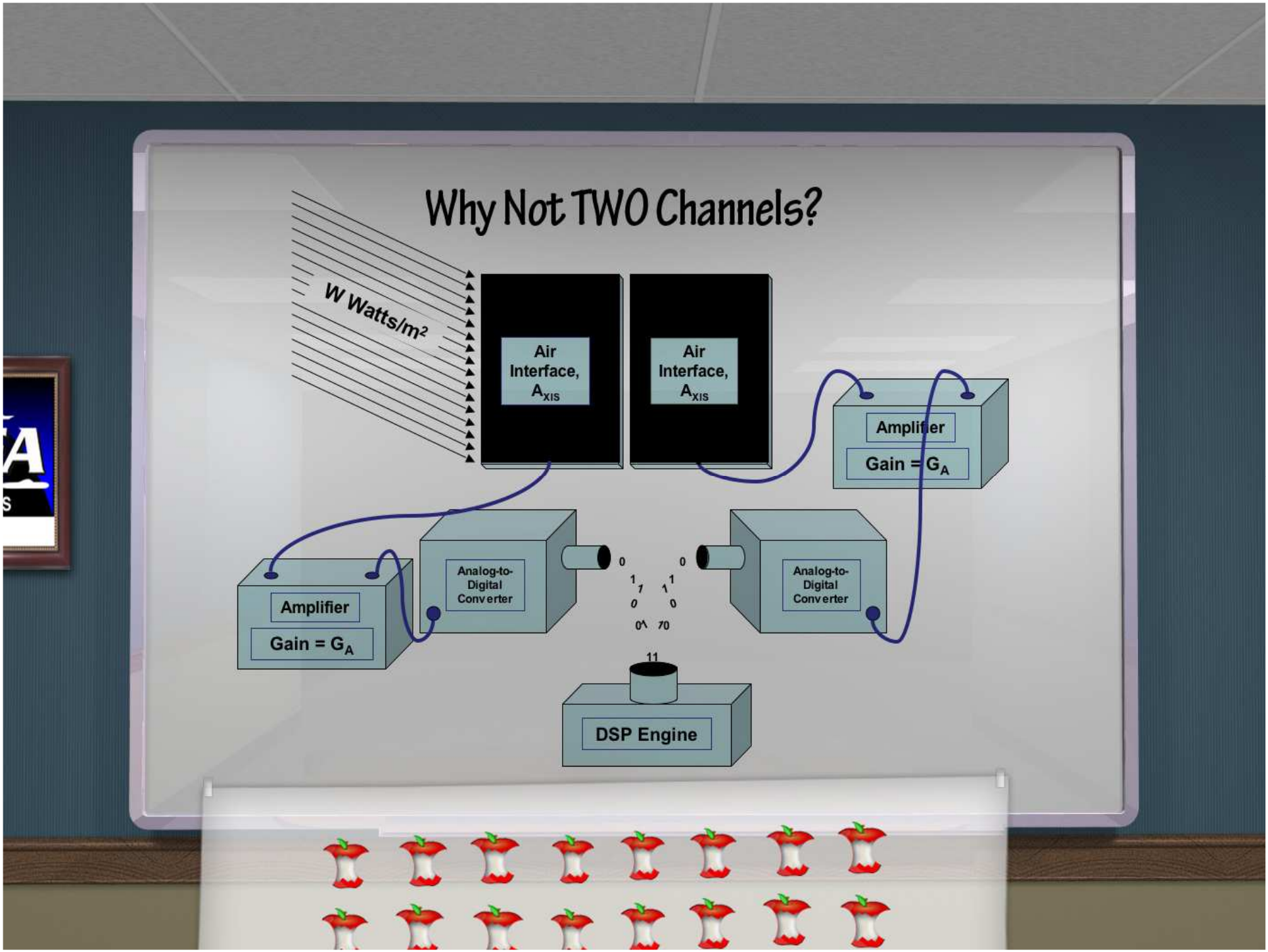
$$W_{XIS} A_{XIS} G_A = P_{FSAO}$$

Eq.10

$$\frac{A_{MDS}}{A_{XIS}} = \frac{W_{XIS}}{W_{MDS}} kT_0 B_d \left[\frac{G_A}{P_{FSAO}} + \frac{2}{3} 2^{-2N} \frac{1}{kT_0 f_N} \right]$$

Eq.11


Fundamental Limit?
$$\frac{A_{MDS}}{A_{XIS}} = \frac{W_{XIS}}{W_{MDS}} \frac{B_d}{f_N} \left[\frac{2}{3} 2^{-2N} \right] \frac{F_{SYS}}{F_{SYS} - 1}$$
Eq.12
Air Interface, A_i
AMP
A/D Converter
0 1
1
0 1


Why Not TWO Channels?
W Watts/m²
Air Interface, A_XIS
Air Interface, A_XIS
Amplifier
Gain = G_A
Amplifier
Gain = G_A
Analog-to-Digital Converter
Analog-to-Digital Converter
DSP Engine

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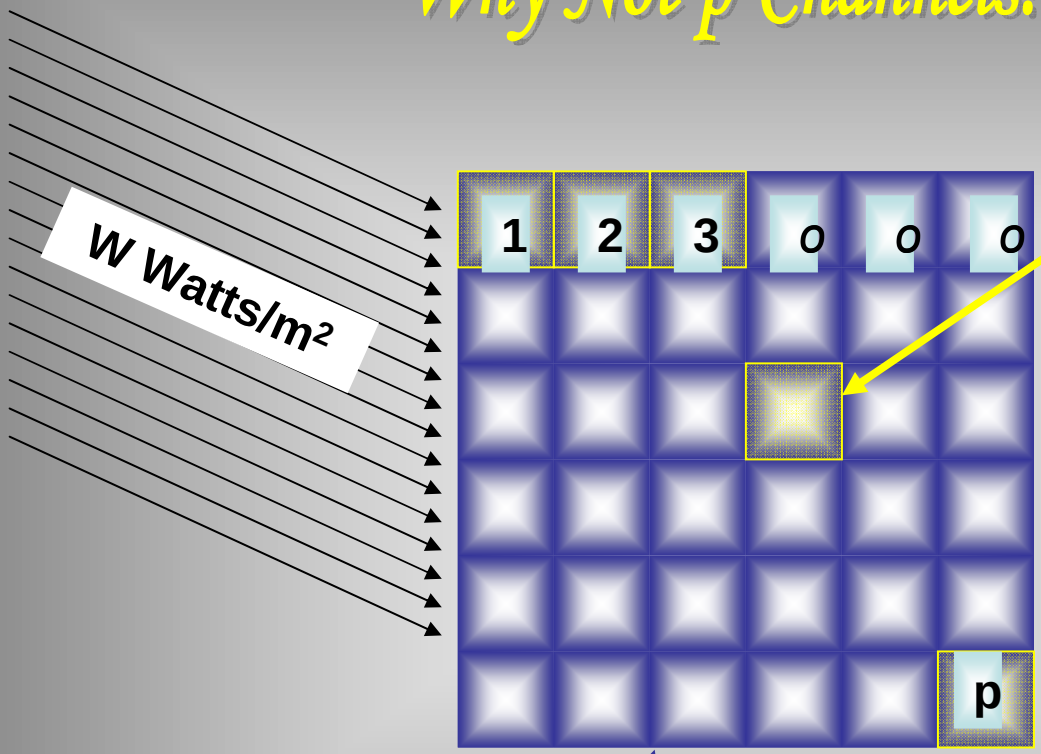
Why Not p-Channels?



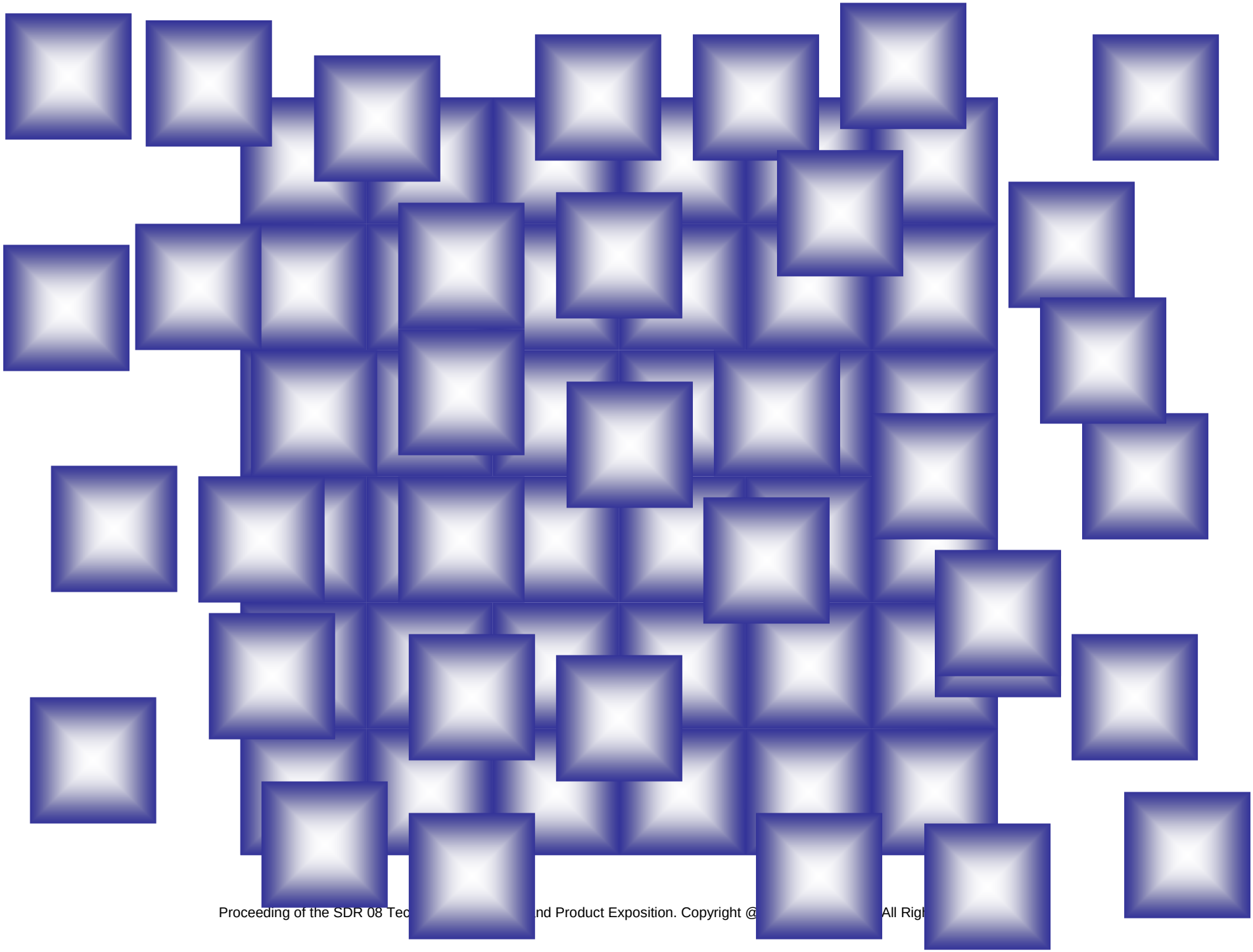
W_{XIS}

$W_{MDS} = p\ W_{XIS}$

Fundamental Limit

$$p = \frac{W_{XIS}}{W_{MDS}} \frac{B_d}{f_N} \left[\frac{2}{3} 2^{-2N} \right] \frac{F_{SYS}}{F_{SYS} - 1}$$

Eq.13



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Eplane

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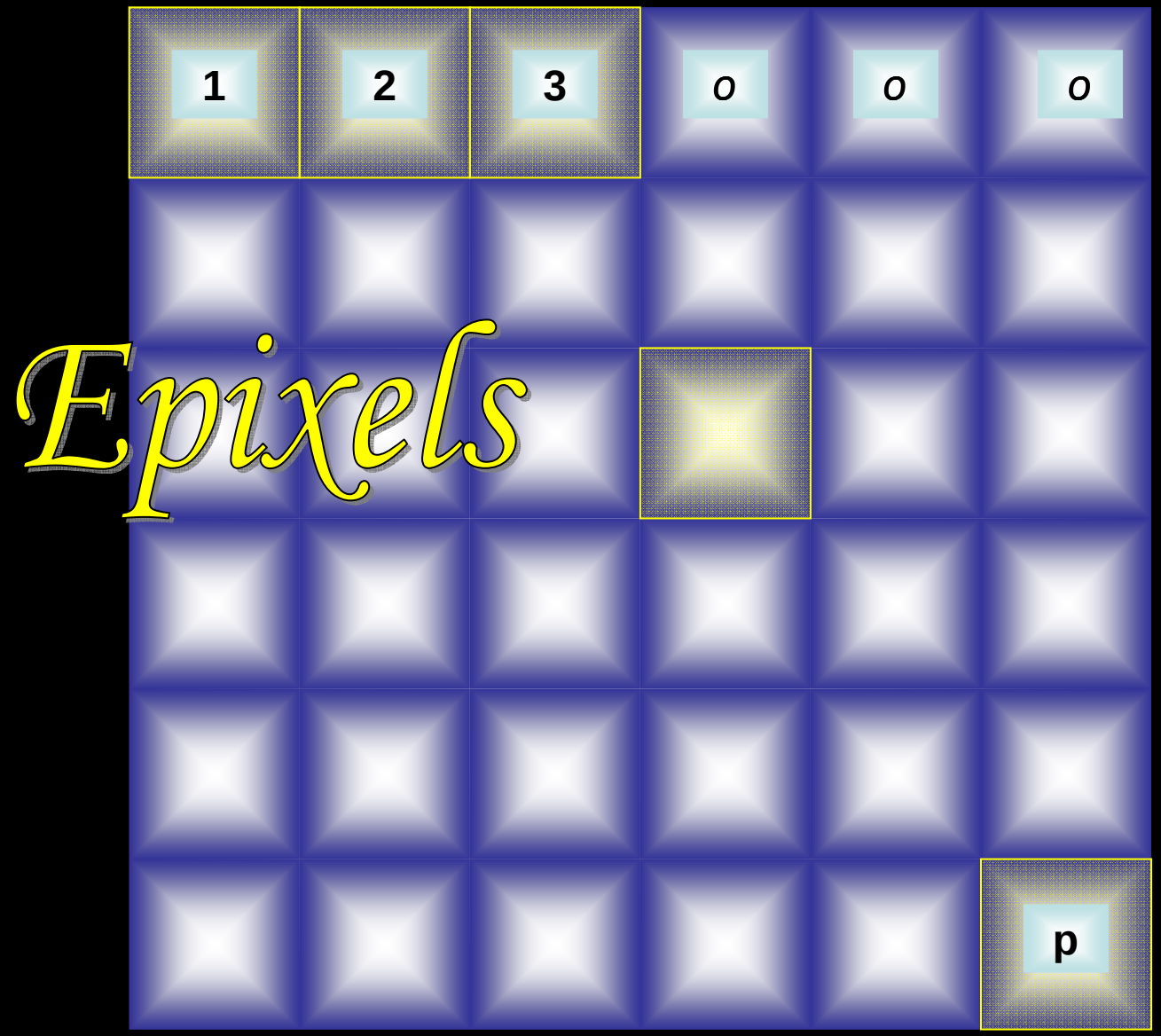

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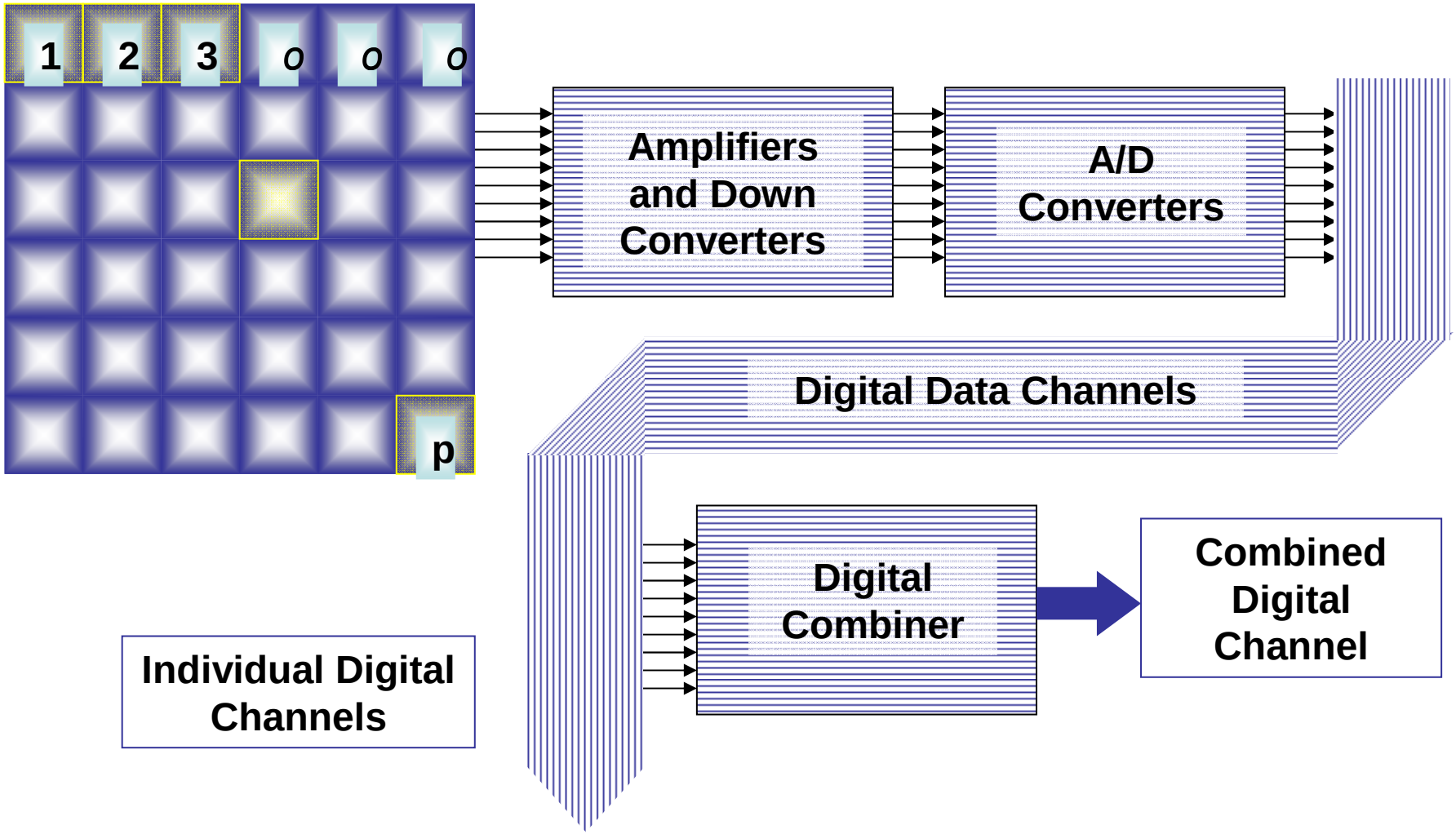
P-Channel Software Defined Signal Acquisition System



Eplane area (meters^2):

$$Eplane = \frac{kT_0 F_{SYS} B_d}{W_{MDS}}$$

Eq.14

Epixel area (meters^2):

$$Epixel = \frac{kT_0(F_{SYS} - 1)f_N}{W_{XIS}}\left[\frac{3}{2}2^{2N}\right]$$

Eq.15

$$p = \frac{W_{XIS}}{W_{MDS}} \frac{B_d}{f_N} \left[\frac{2}{3} 2^{-2N} \right] \frac{F_{SYS}}{F_{SYS} - 1}$$

Eq.13

$$Eplane = \frac{kT_0 F_{SYS} B_d}{W_{MDS}}$$

Eq.14

$$Epixel = \frac{kT_0 (F_{SYS} - 1) f_N}{W_{XIS}} \left[\frac{3}{2} 2^{2N} \right]$$

Eq.15

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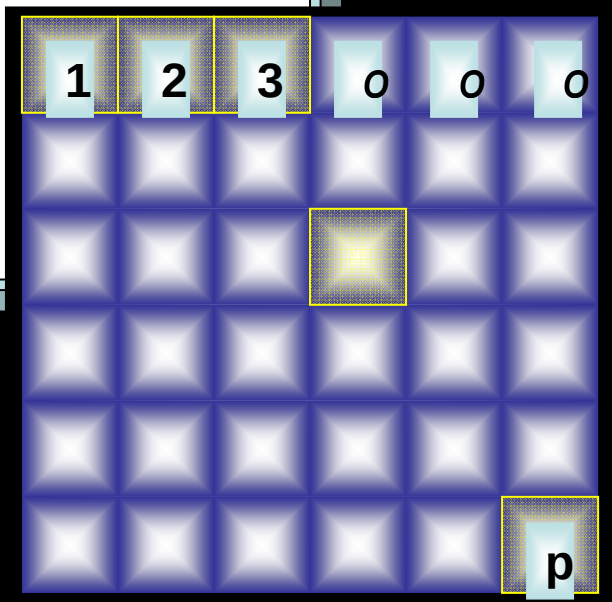
Fundamental Limit

$$p = \frac{W_{XIS}}{W_{MDS}} \frac{B_d}{f_N} \left[\frac{2}{3} 2^{-2N} \right] \frac{F_{SYS}}{F_{SYS} - 1}$$



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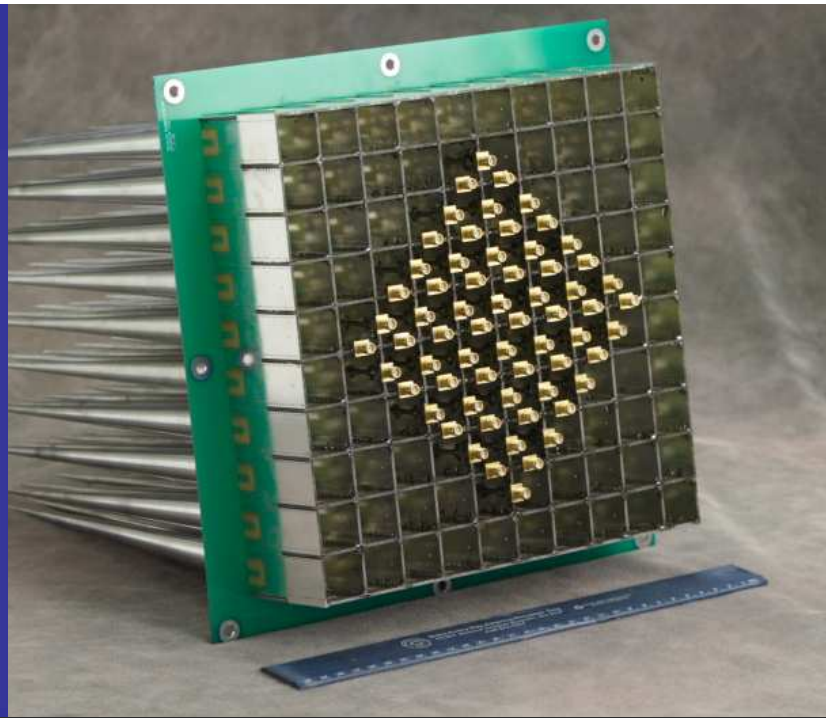
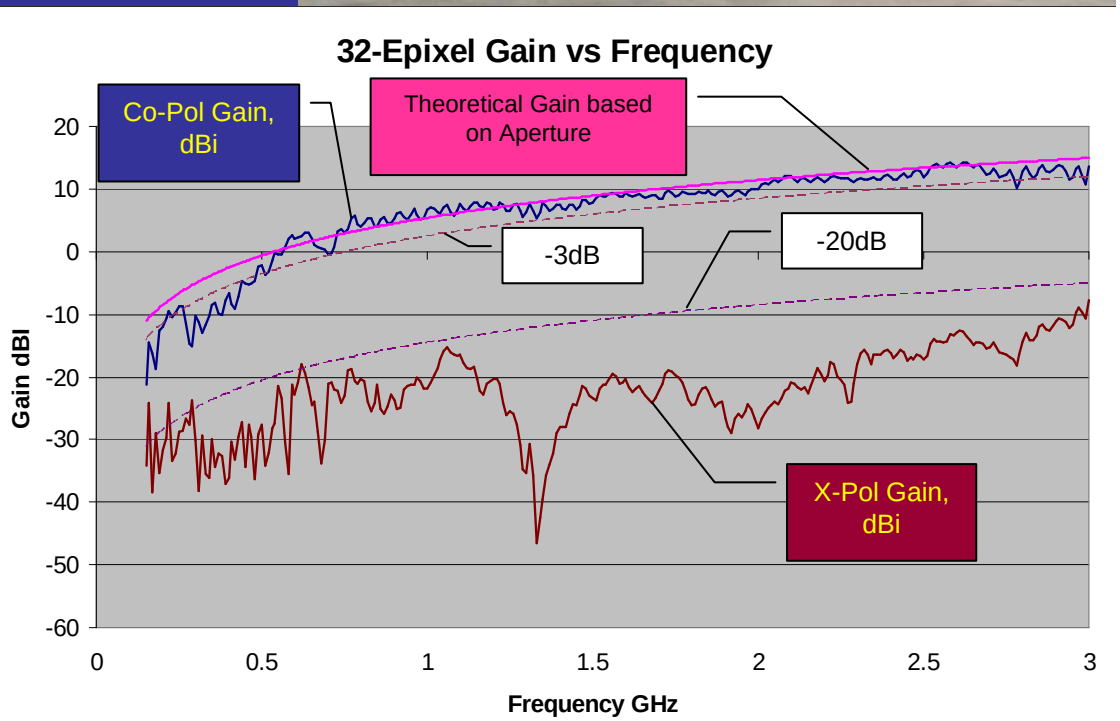
White Nail Air Interface





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A New Paradigm:
The Software-Defined Air Interface

A comparison of the White Nail Signal-Intercept Concept with the Status Quo

Parameter	SQ: Status Quo	Performance Comparison	WN: White Nail
System Noise Temperature	SQ		WN
Bandwidth	SQ		WN
Dynamic Range	SQ		WN
Aperture Efficiency	SQ		WN
Radar Cross Section	SQ		WN
Structure	SQ		WN
All digital processing	SQ		WN

Donald H. Steinbrecher, Ph. D.
Chief Scientist
Undersea Warfare Electromagnetic Systems
US Navy NAVSEA Warfare Center, Newport, RI