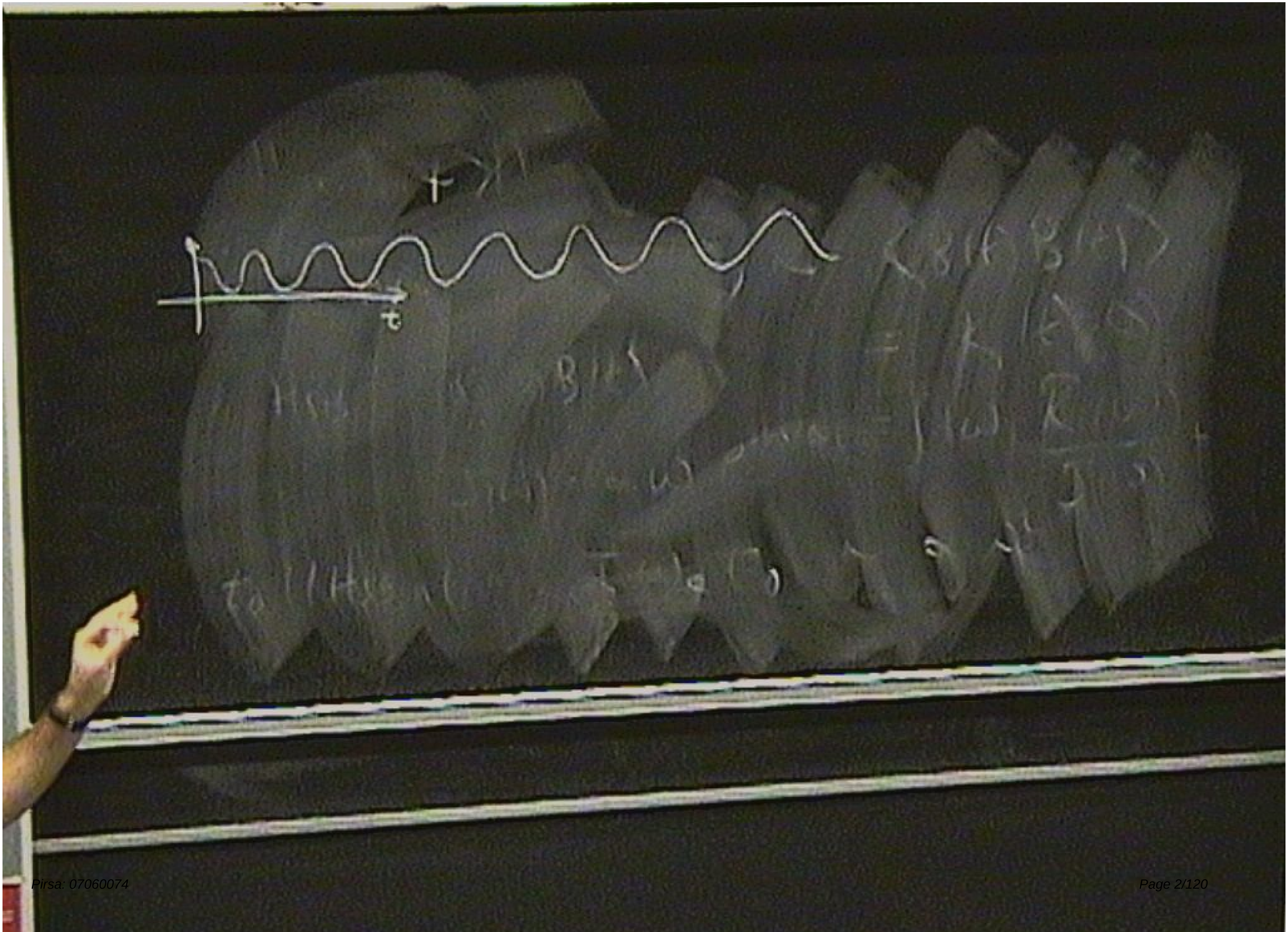
Title: Quantum Information meets Quantum Engineering

Date: Jun 27, 2007 05:00 PM

URL: http://pirsa.org/07060074

Abstract: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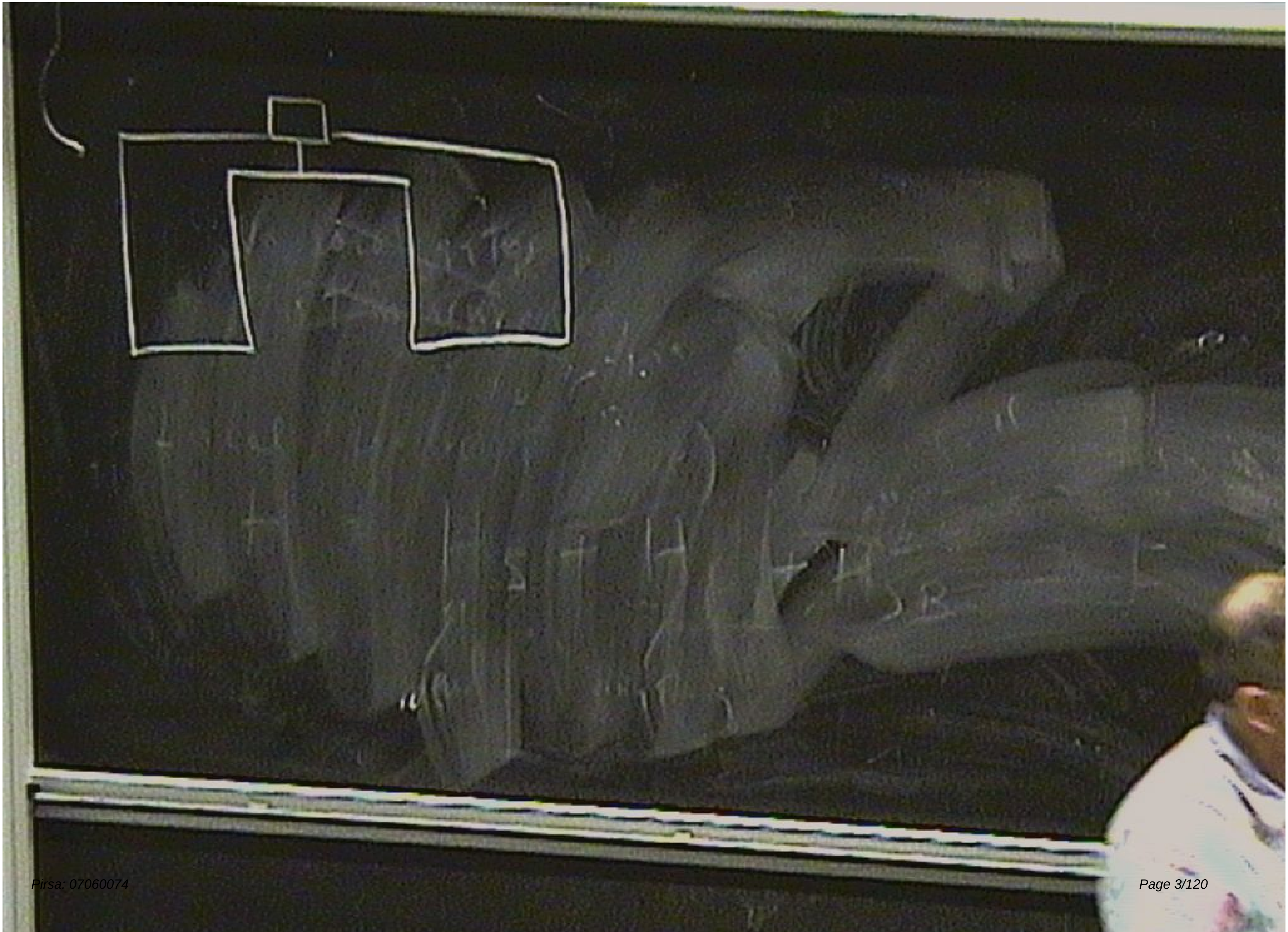

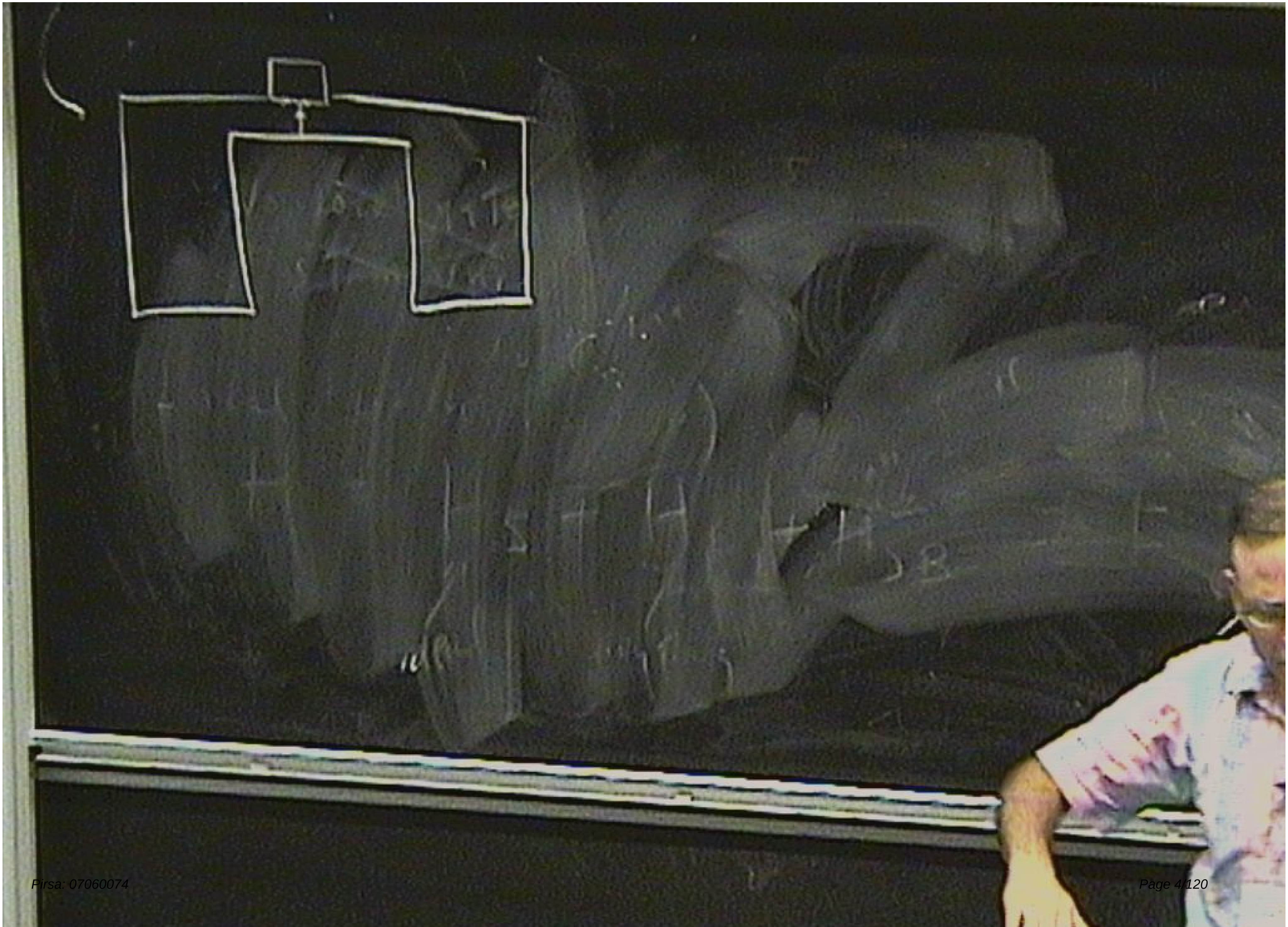

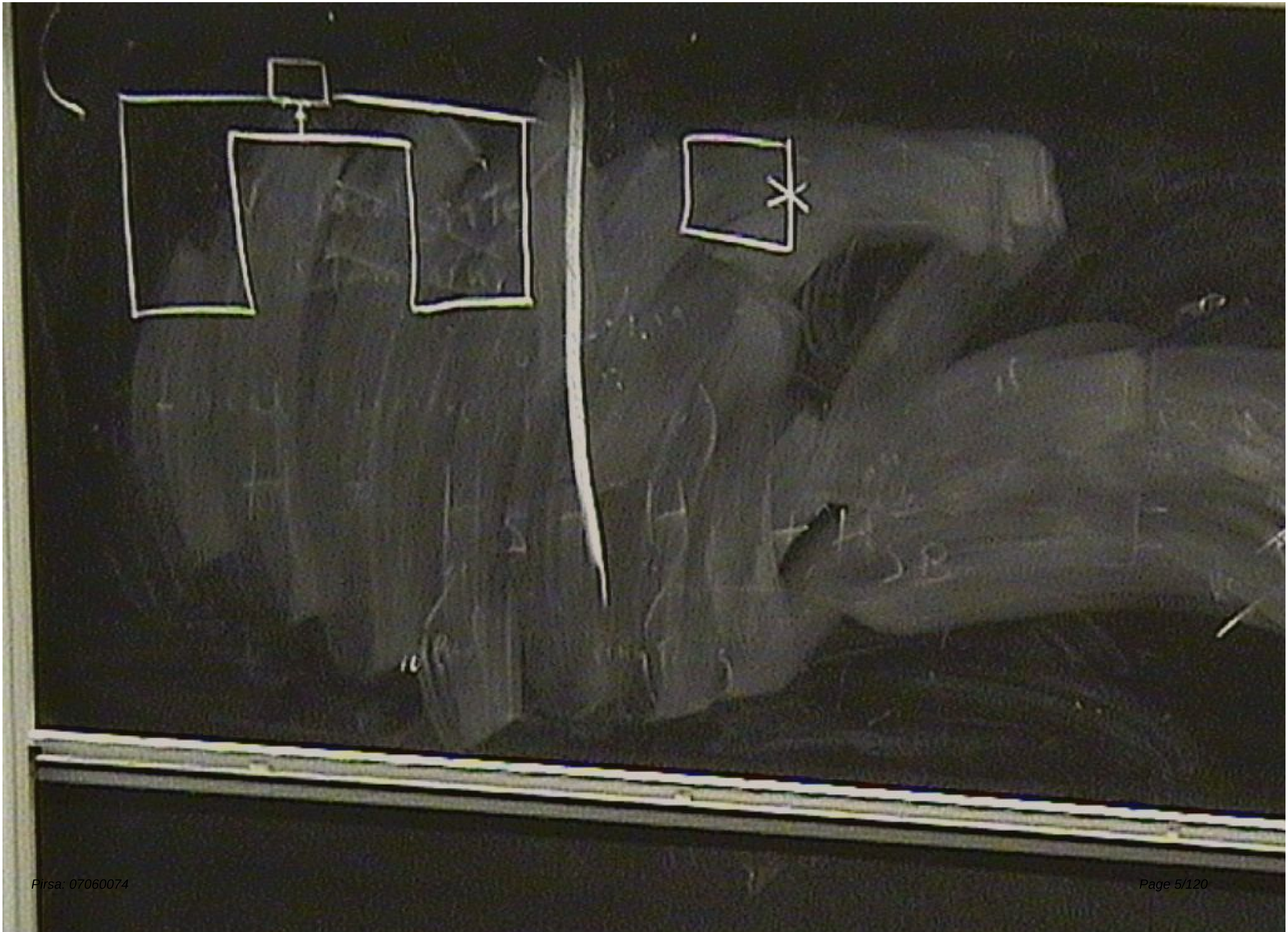

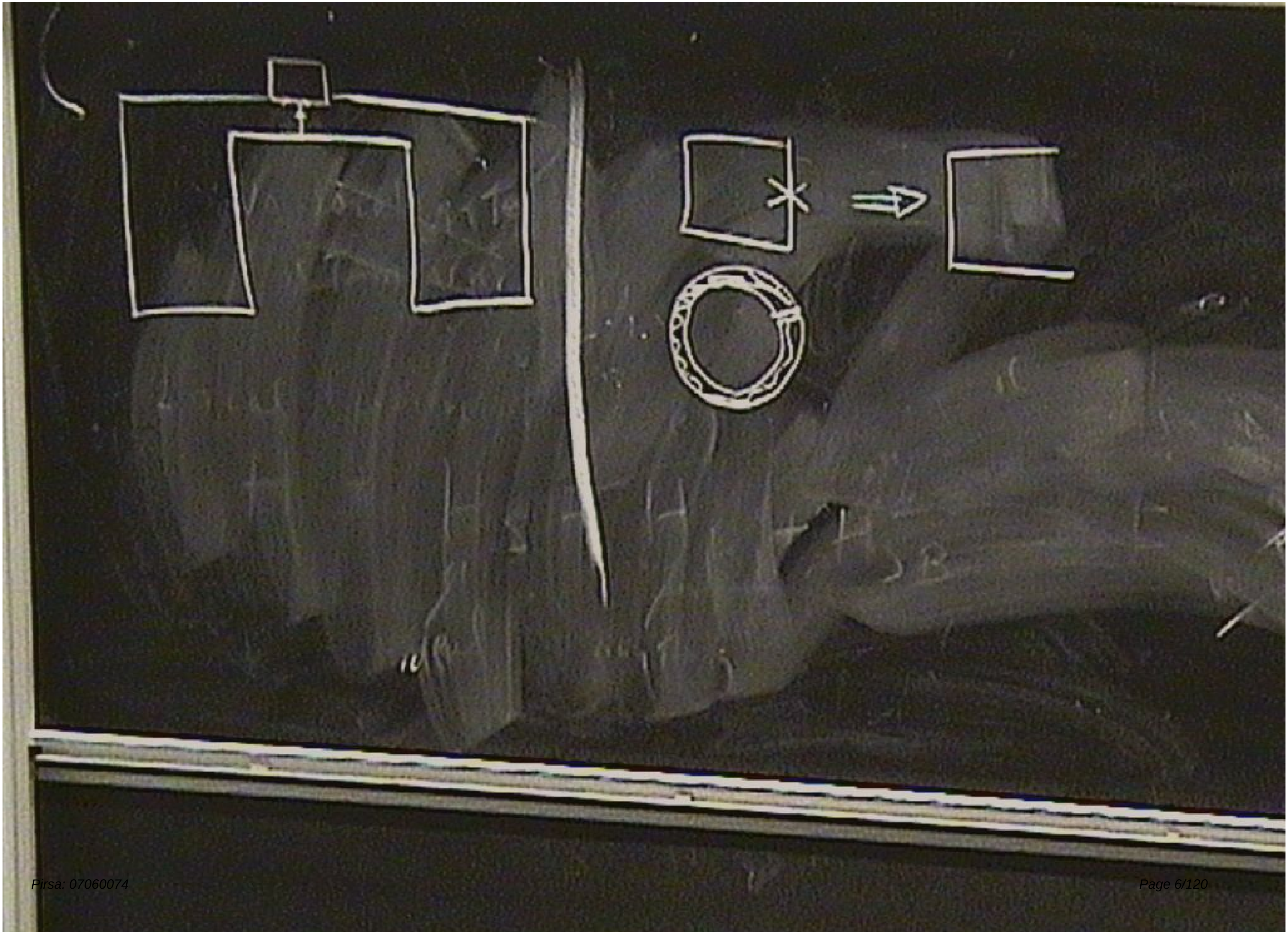

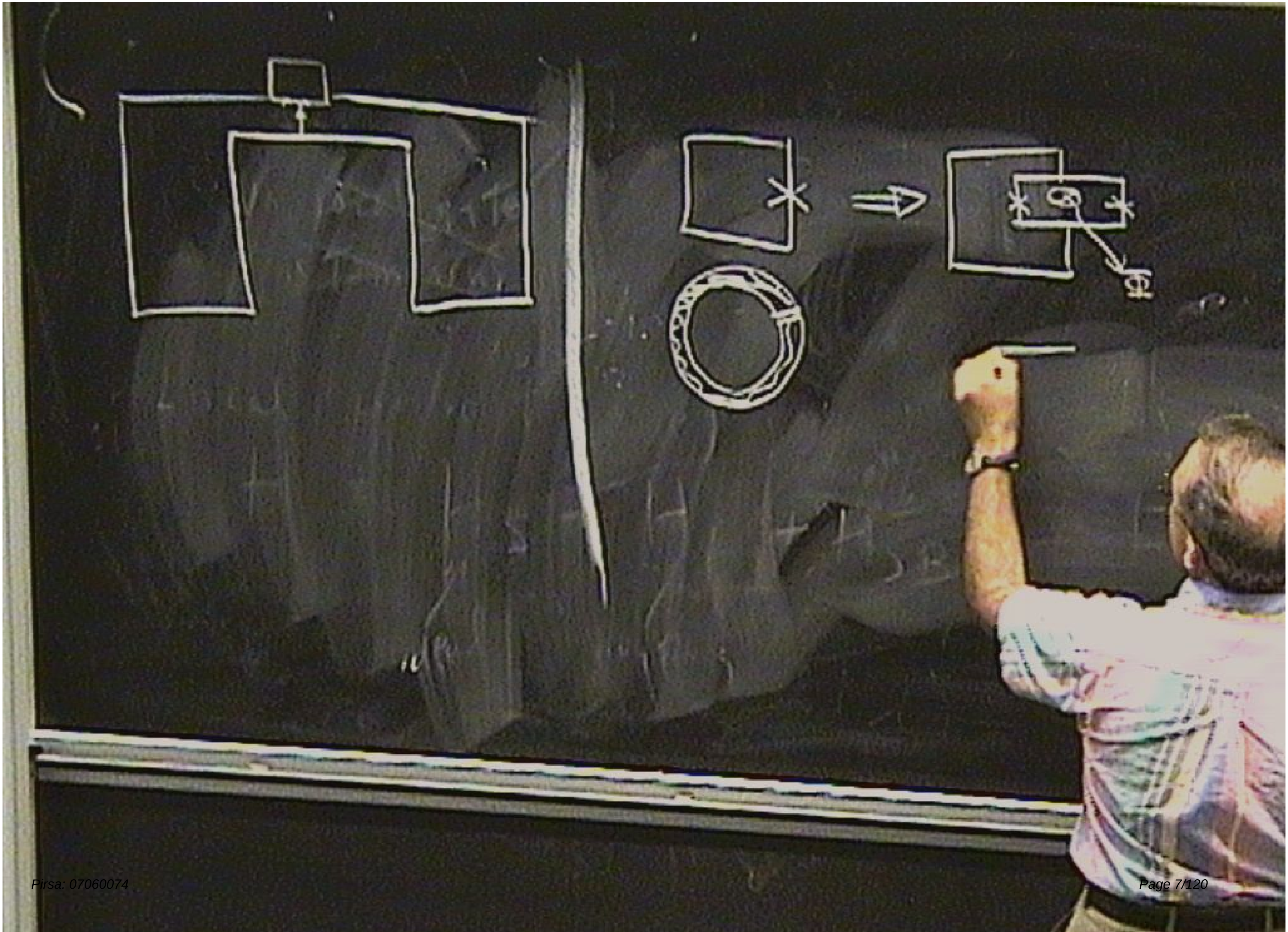

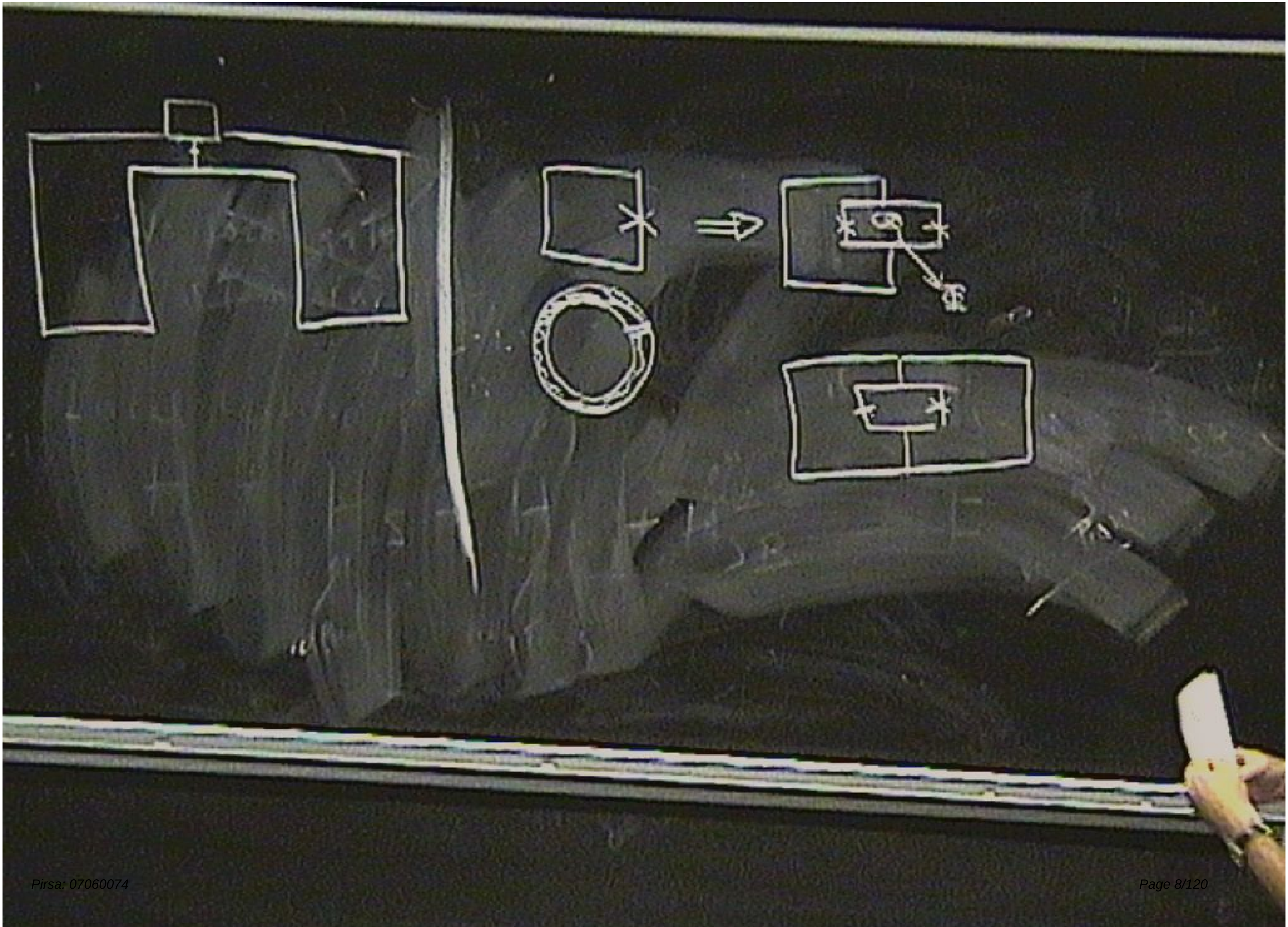

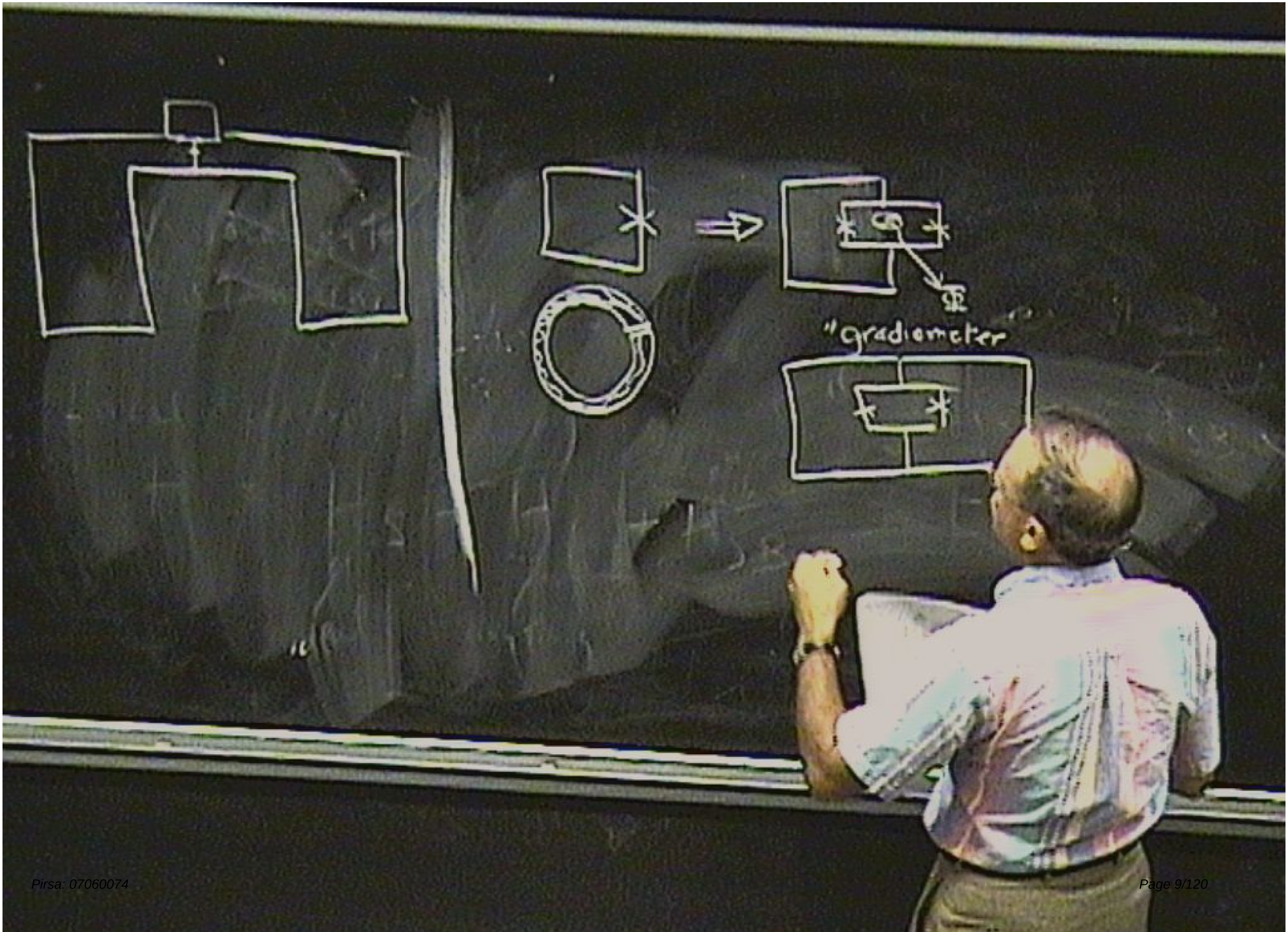
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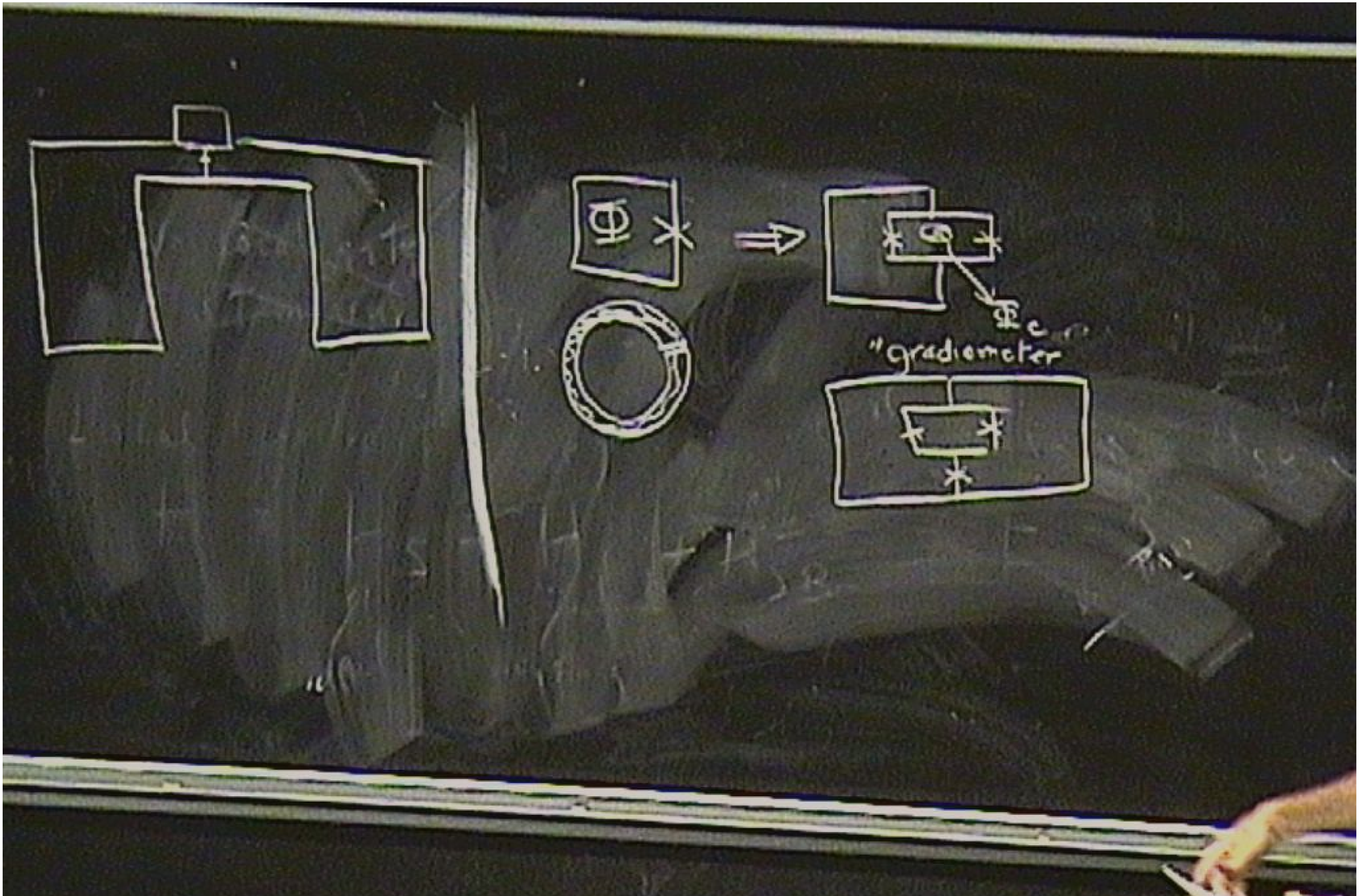
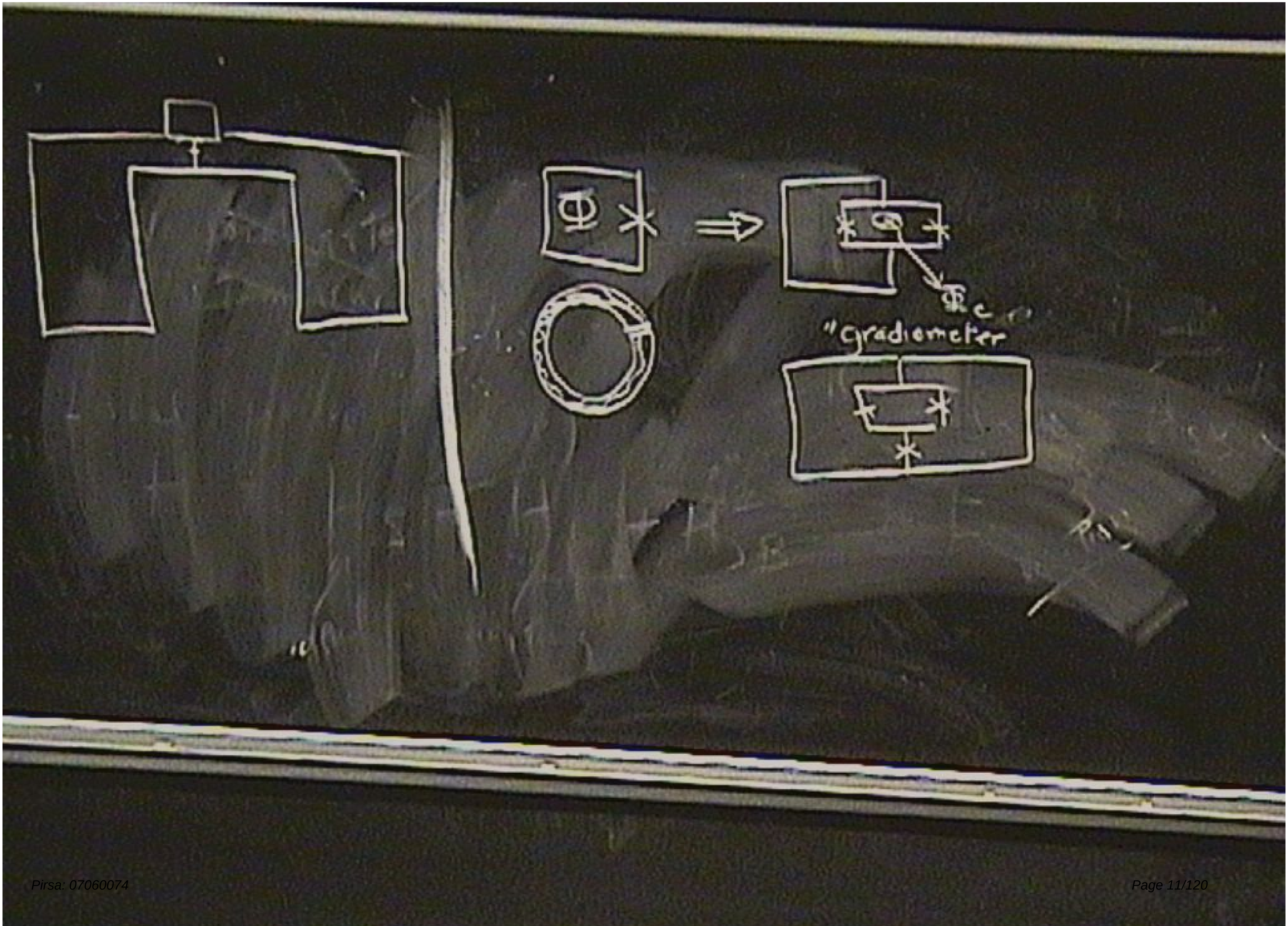
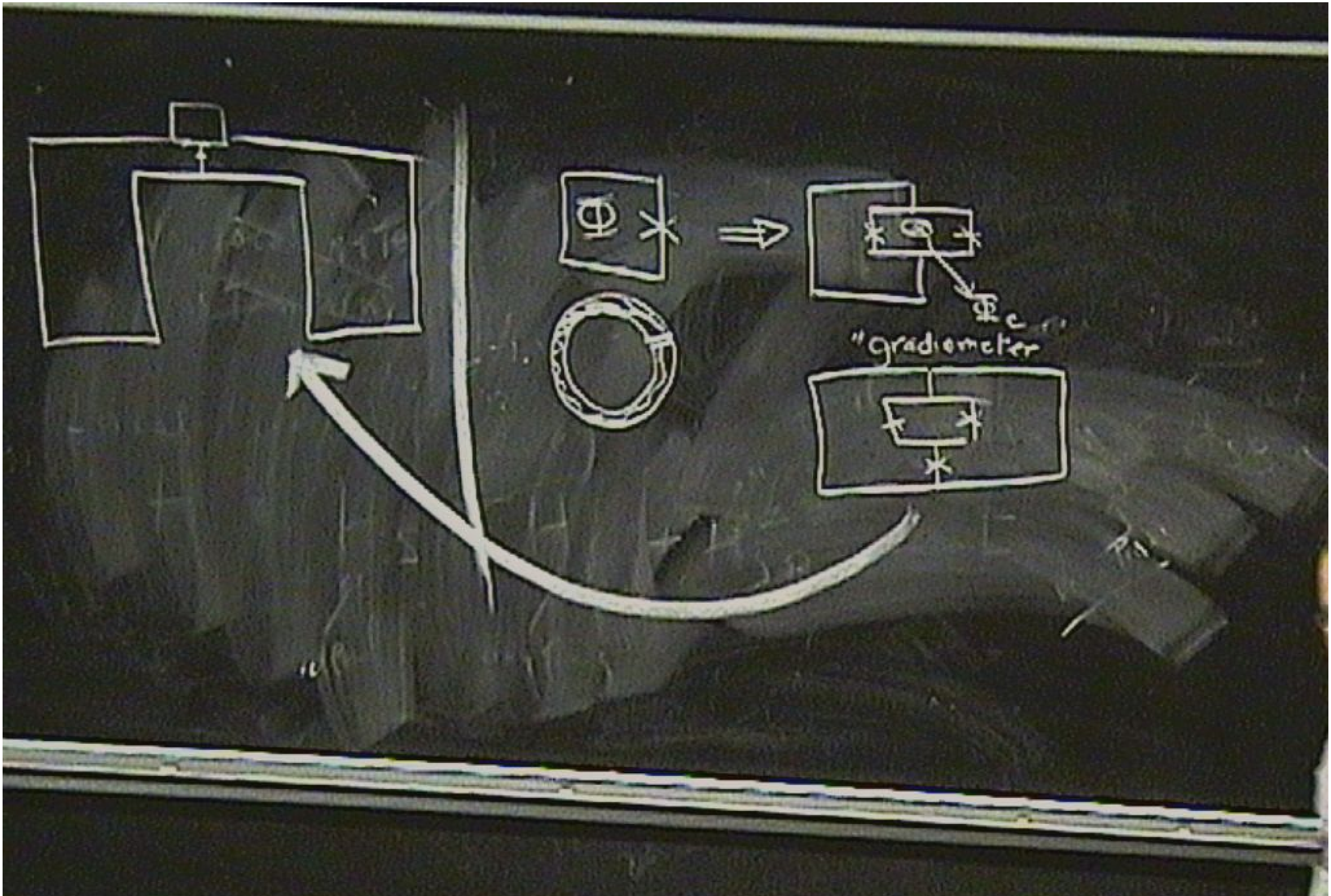

"gradiometer"


"gradiometer"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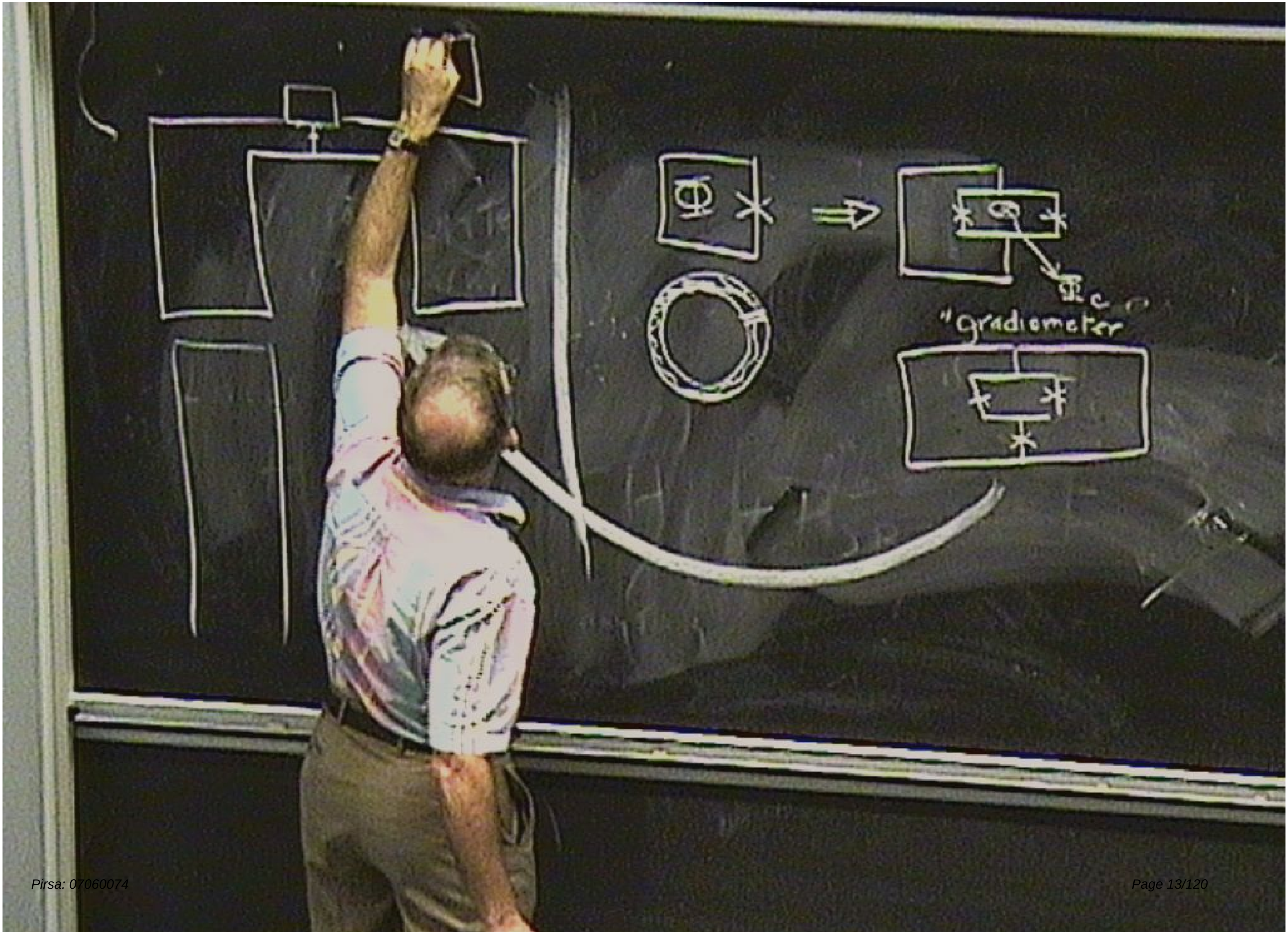
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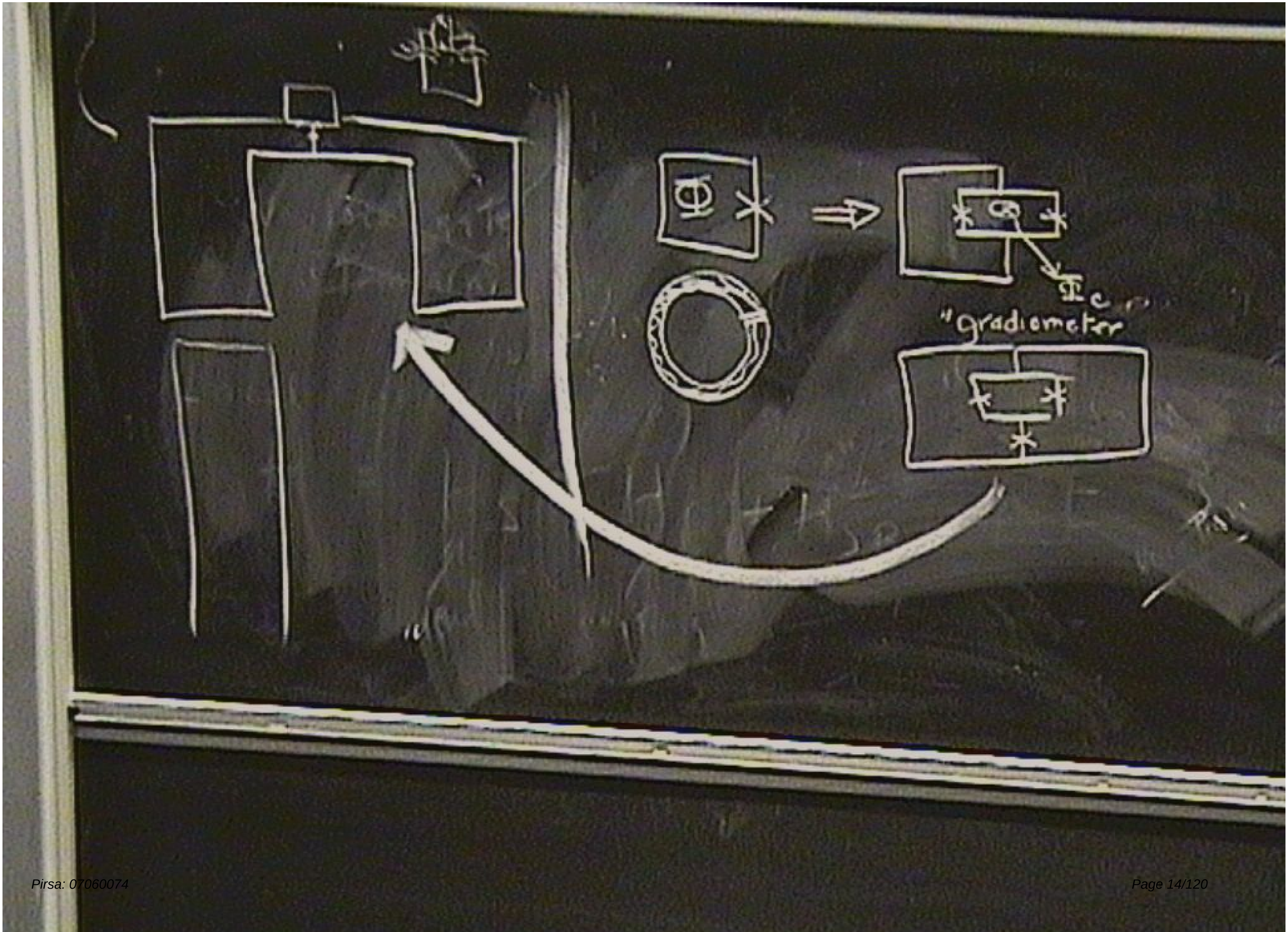

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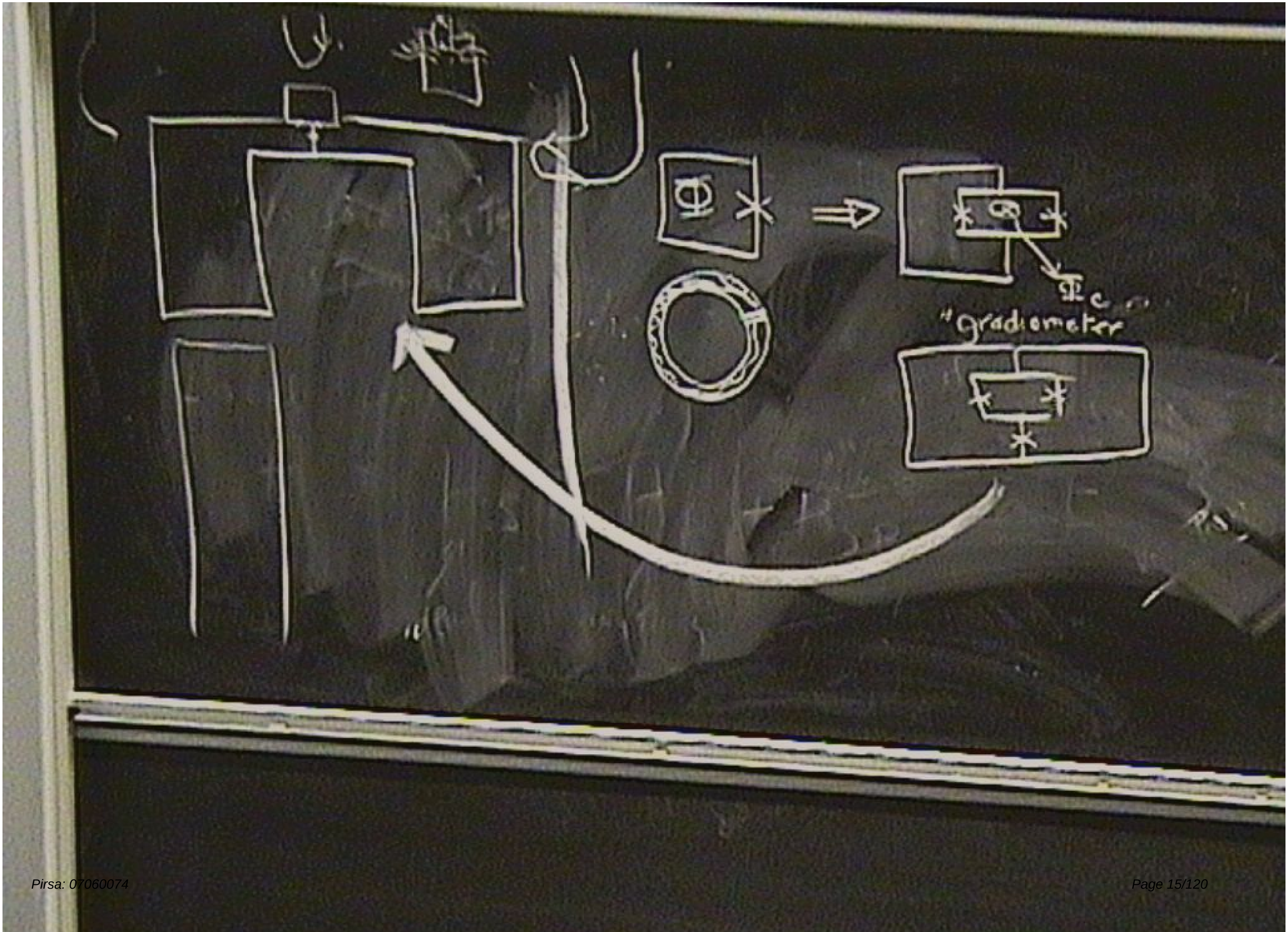
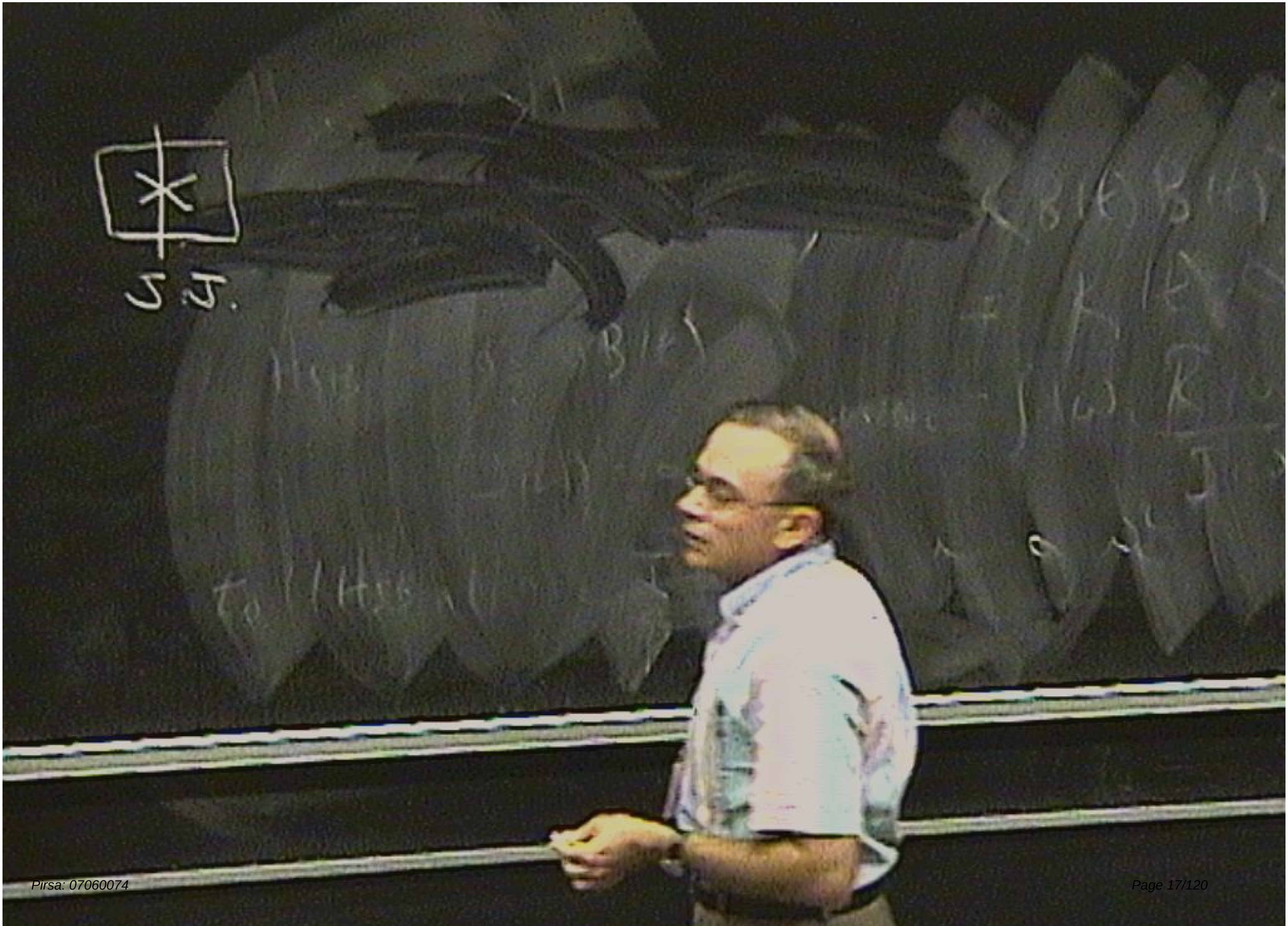
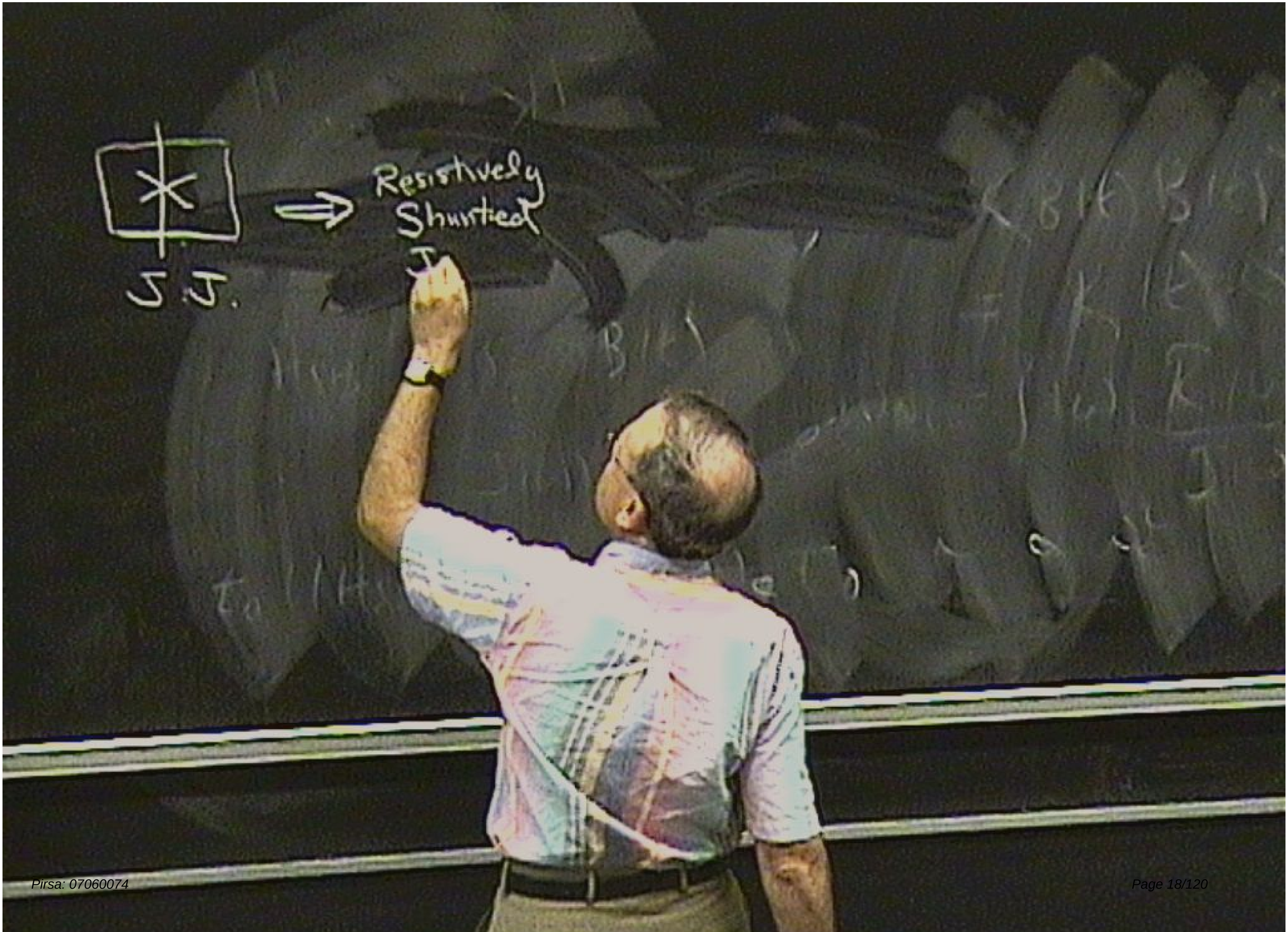
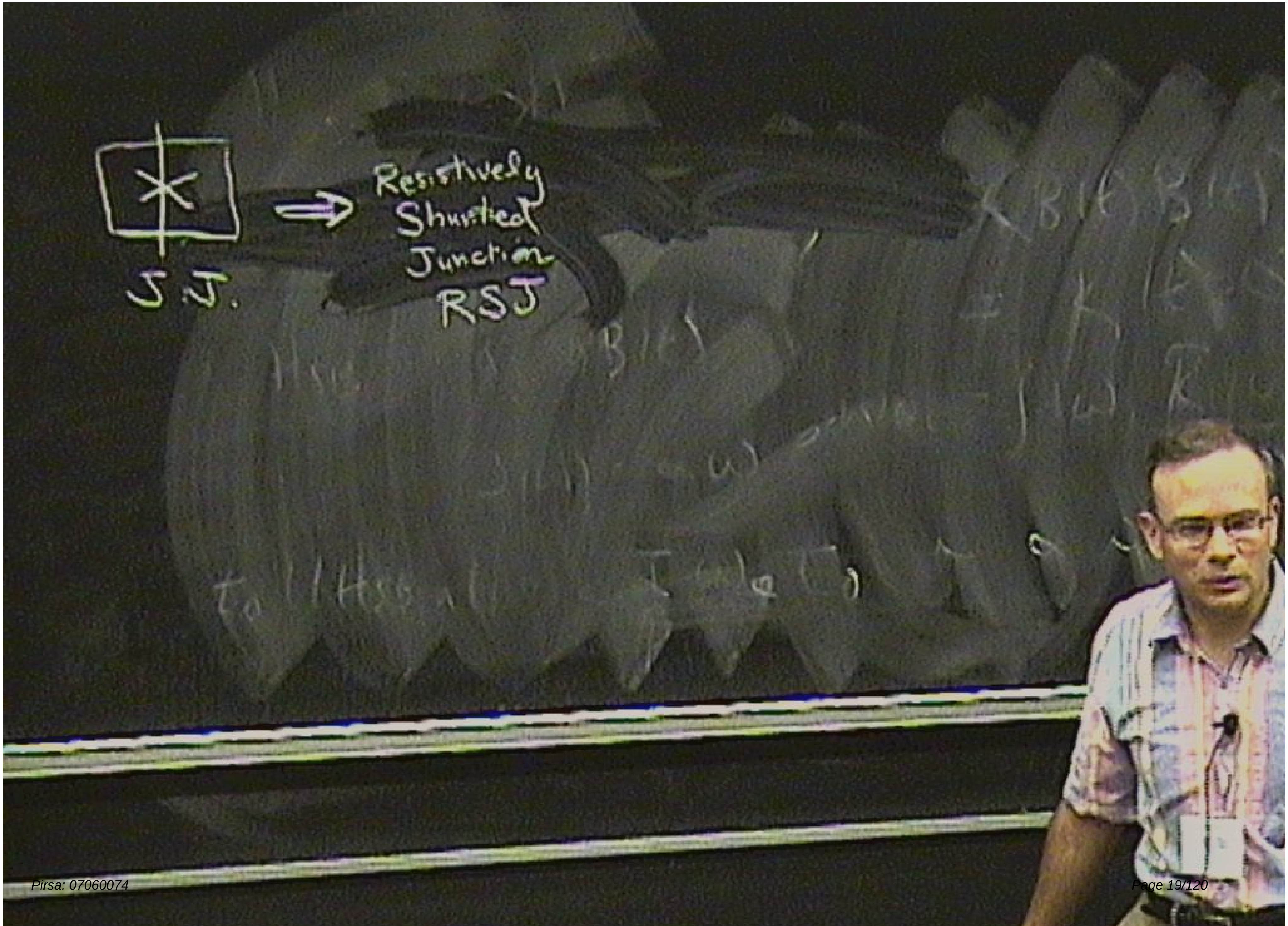
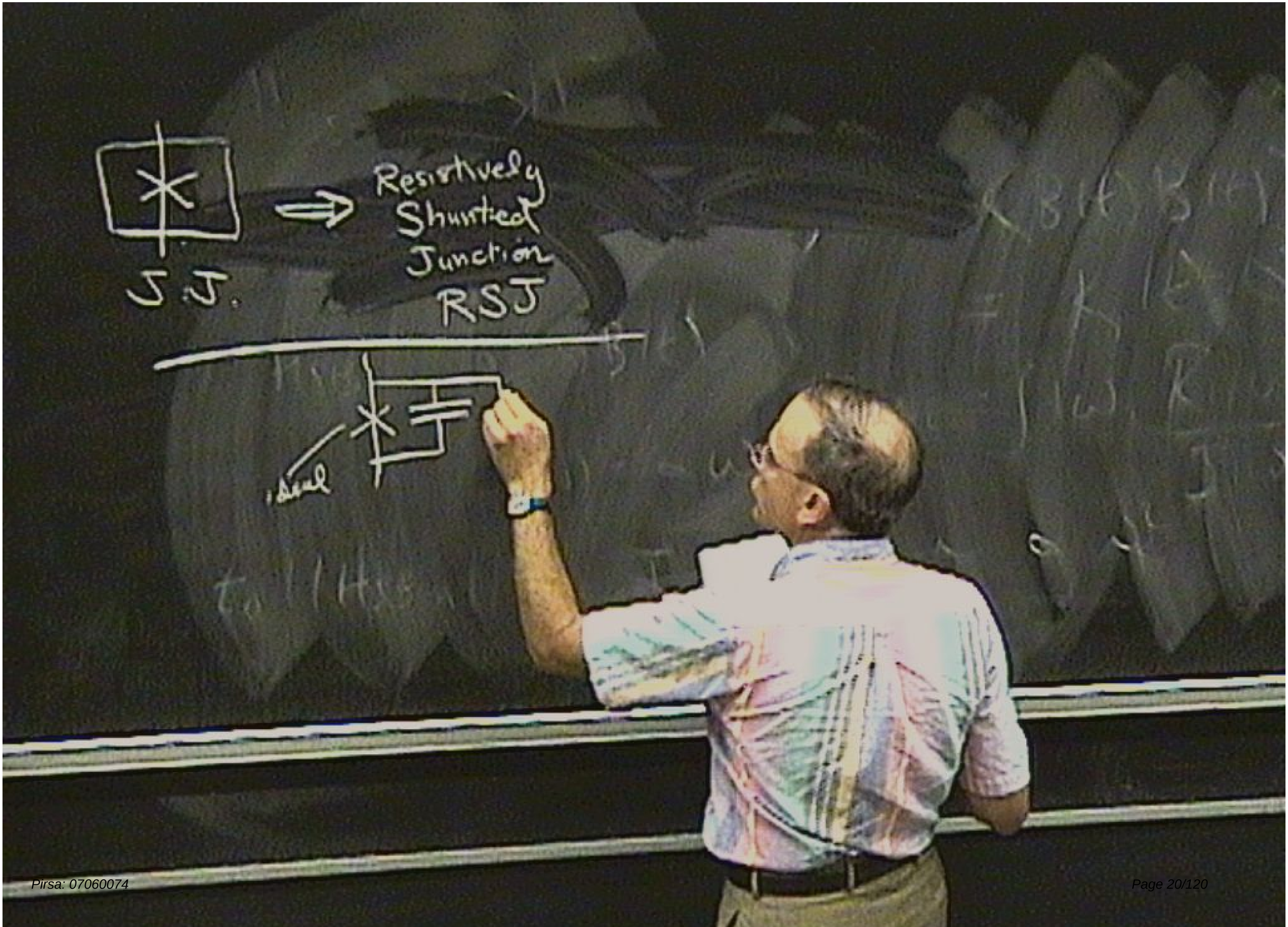

"gradiometer"

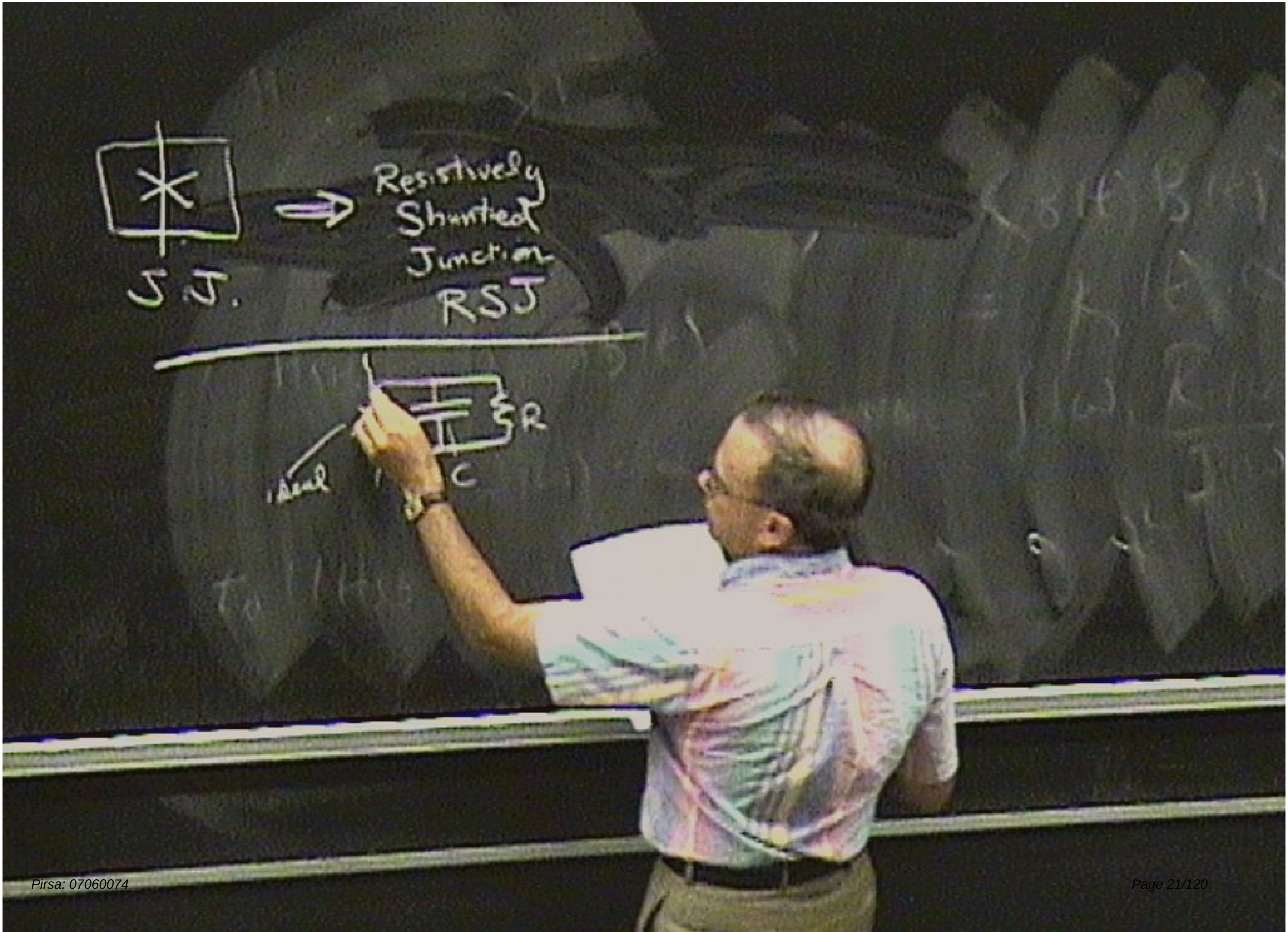

S.J.

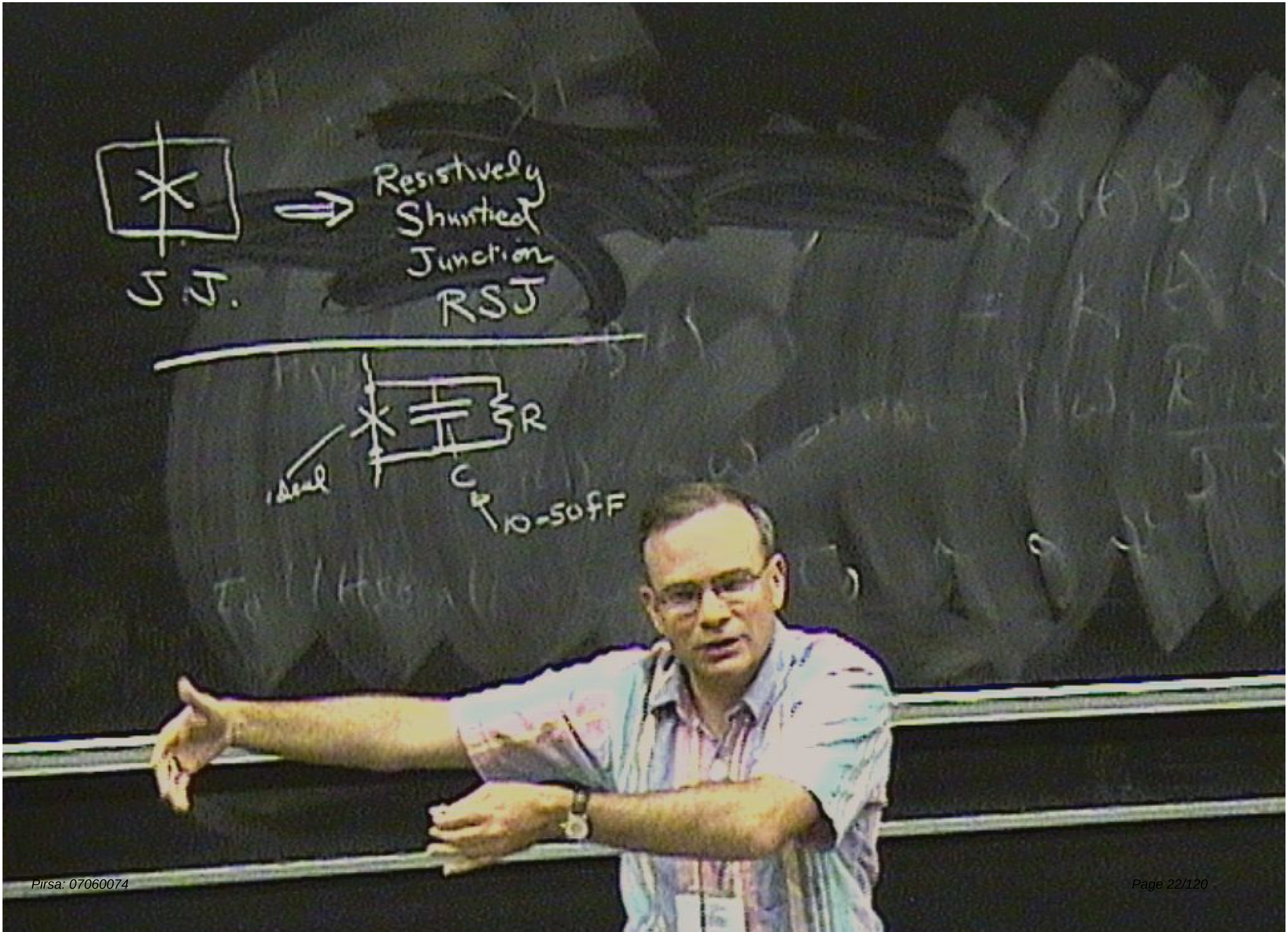

S.J.


Resistively
Shunted
S.J.

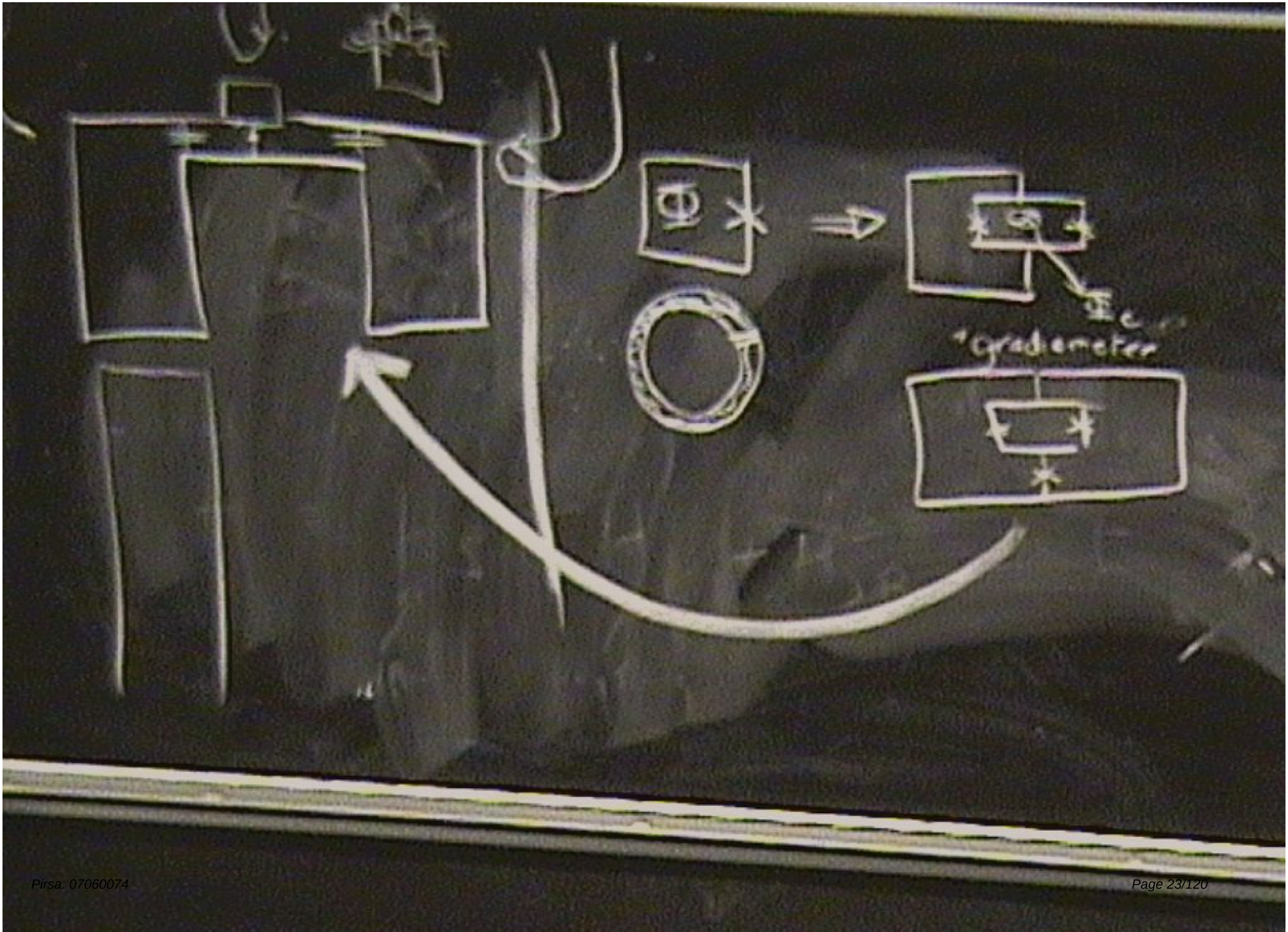

S.J.
Resistively
Shunted
Junction
RSJ

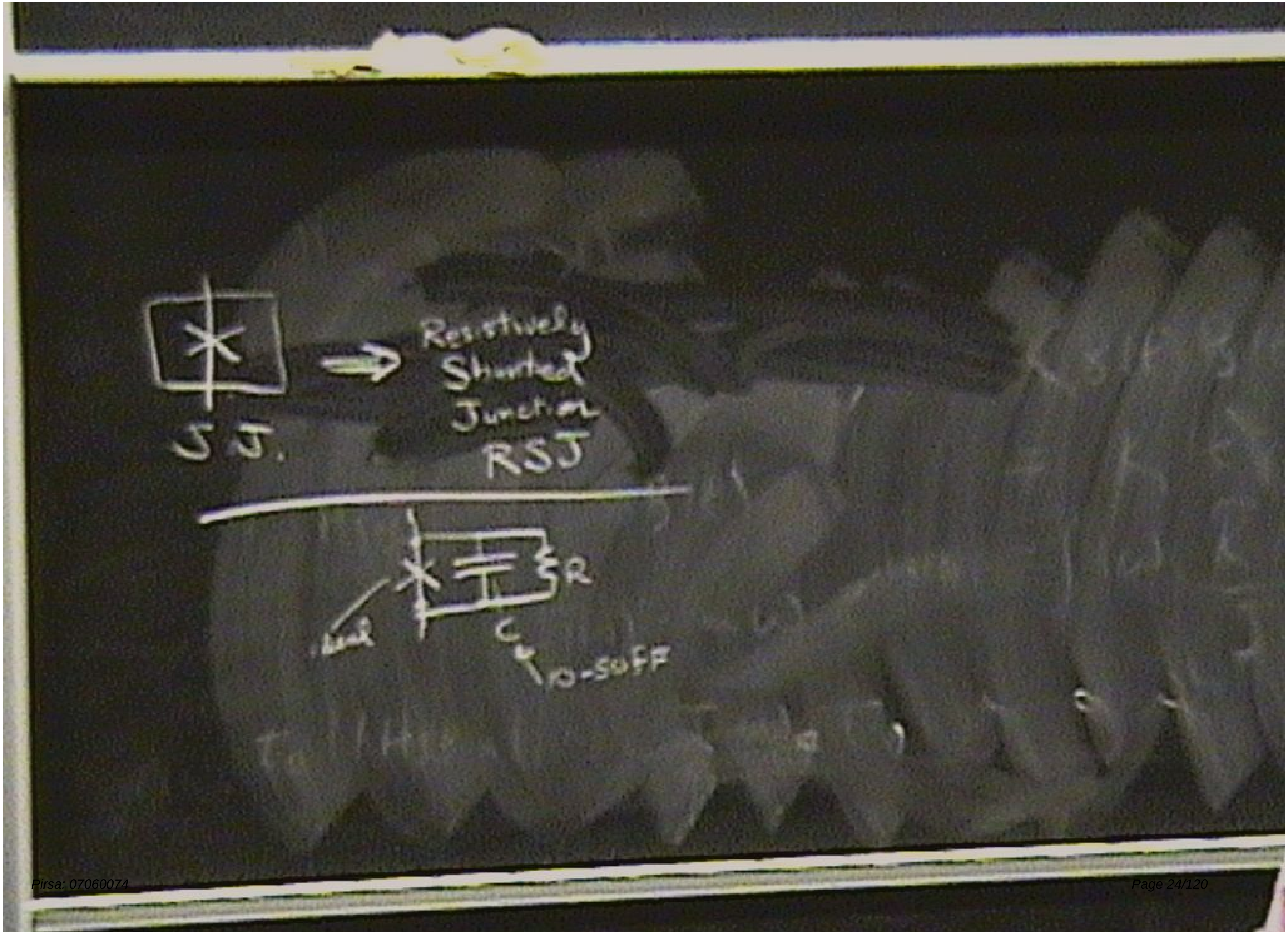

S.J.
Resistively
Shunted
Junction
RSJ
ideal

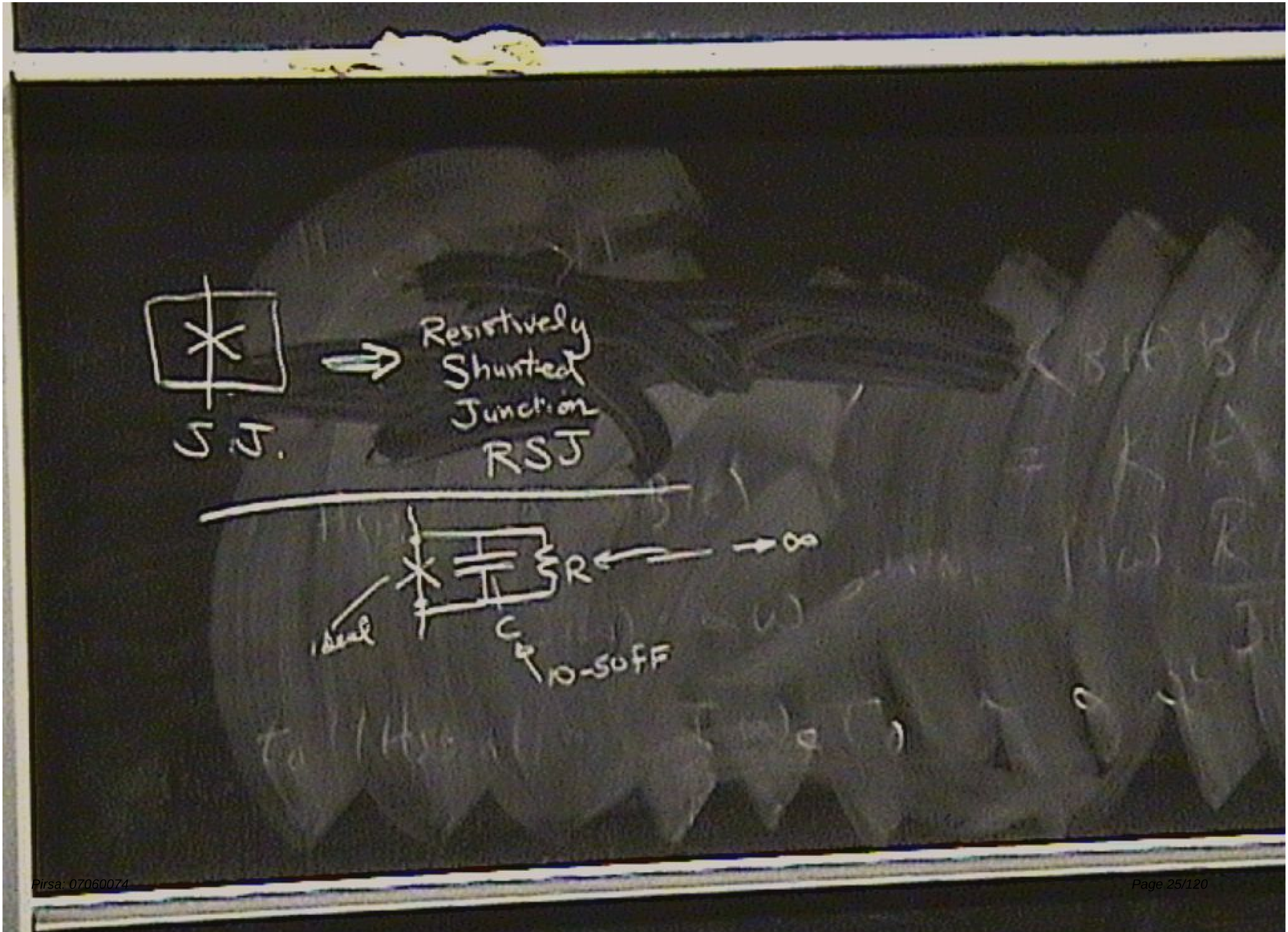

S.J.
Resistively Shunted Junction
RSJ
R
C
ideal

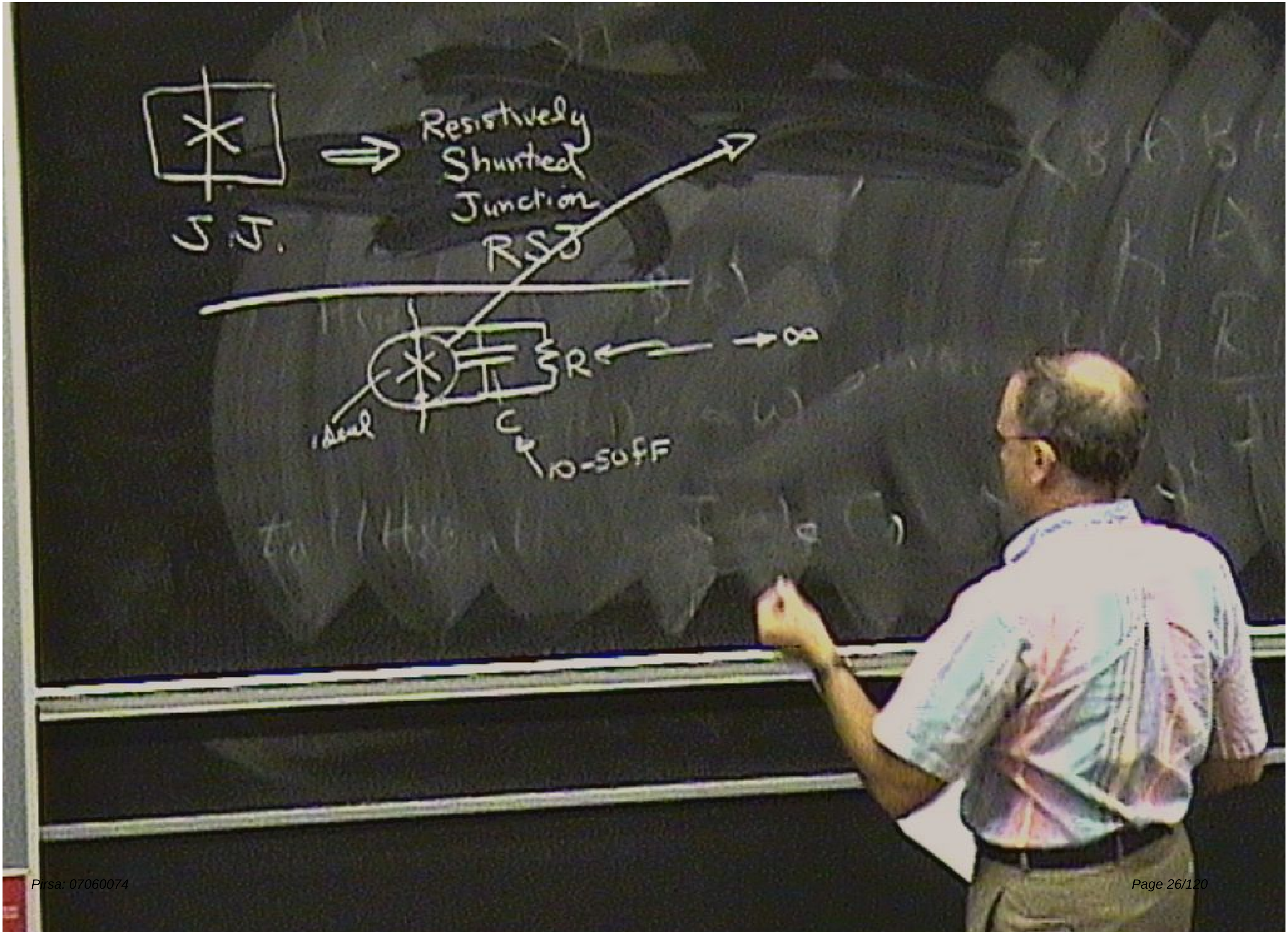


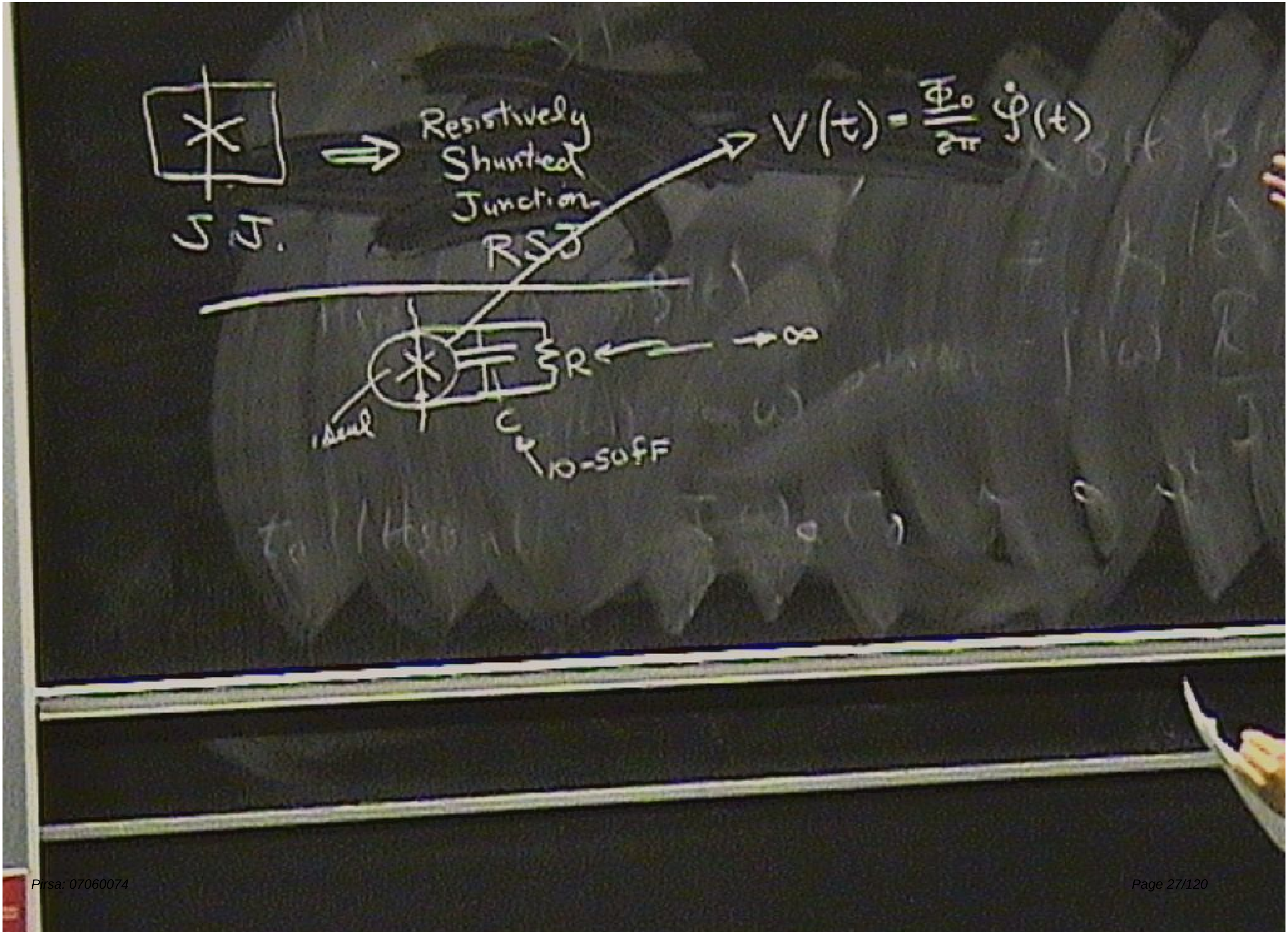
J.J.
Resistively
Shunted
Junction
RSJ
R
ideal
C
10-50fF

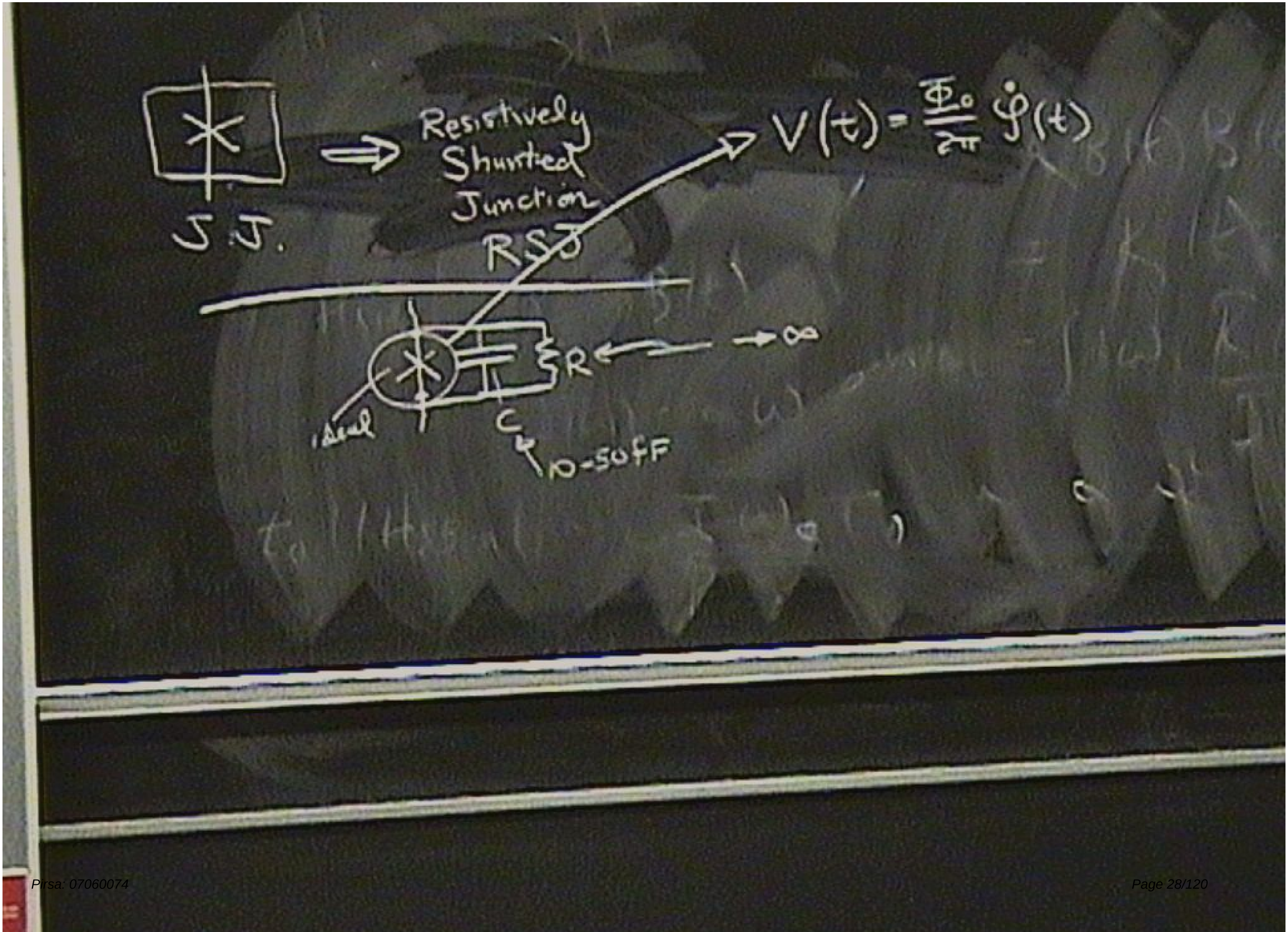

"gradiometer"

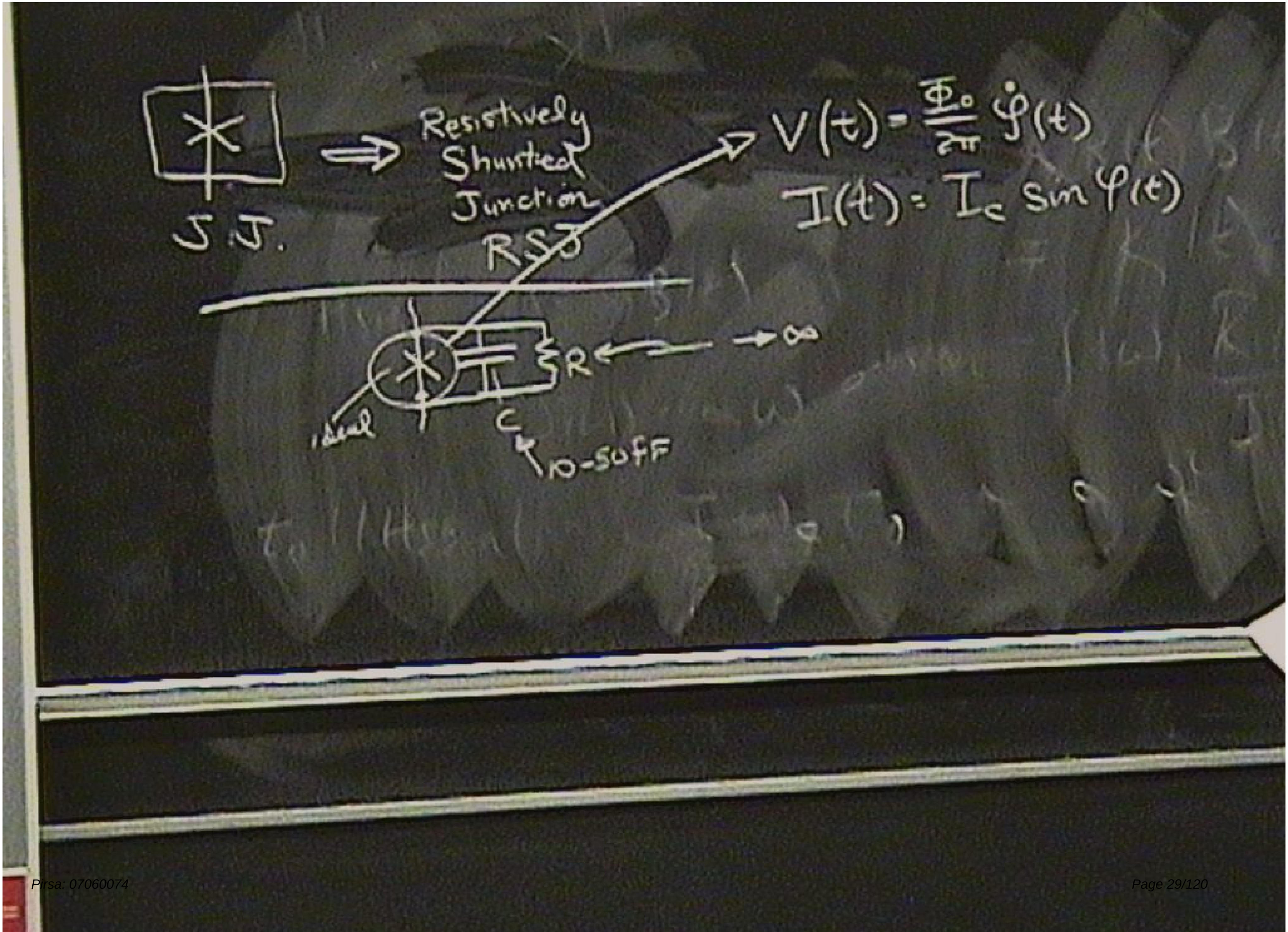

Resistively
Shunted
Junction
RSJ
S.J.
R
C
10-50FF

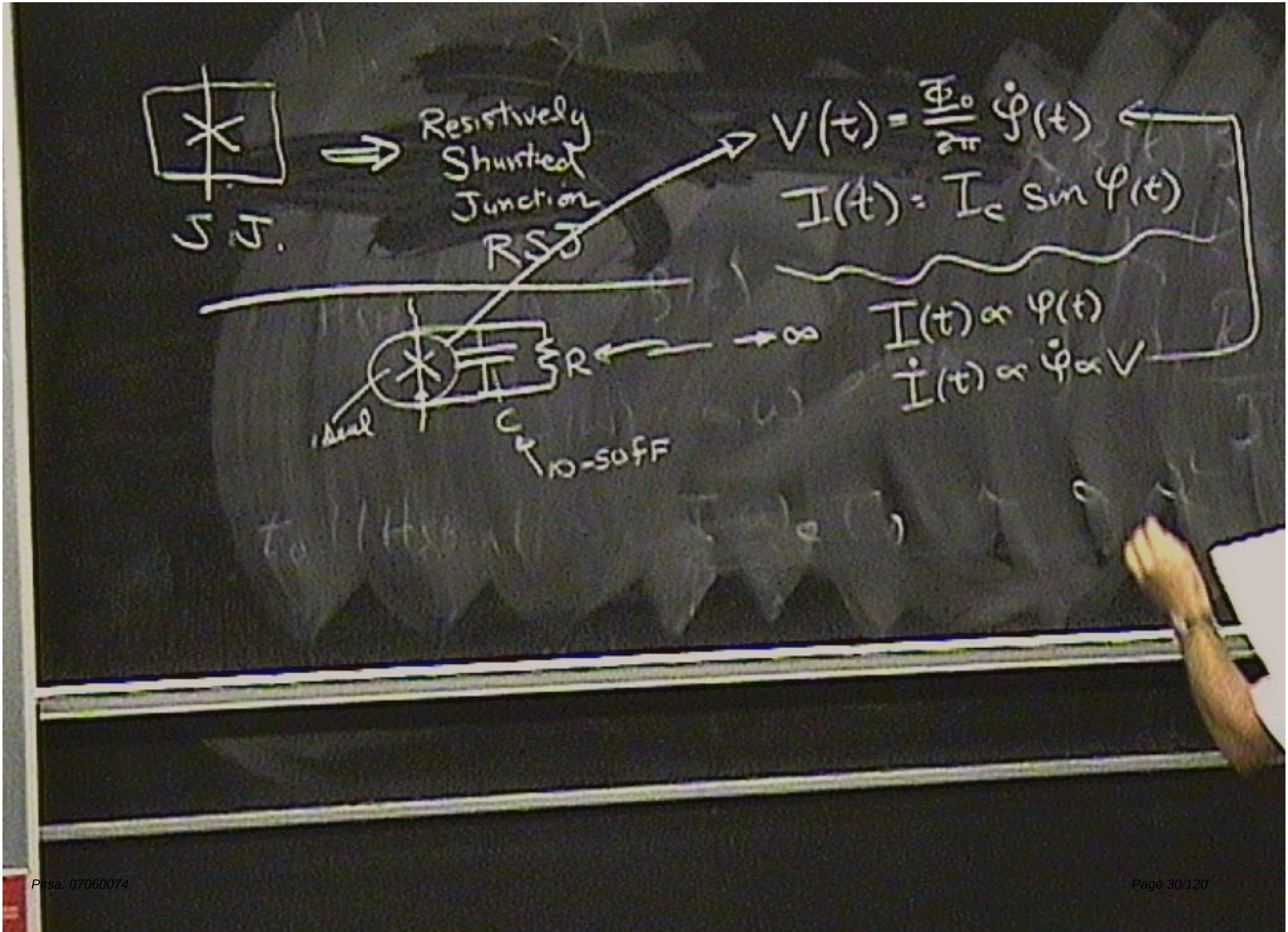

S.J.
Resistively
Shunted
Junction
RSJ
R
∞
C
10-50fF
ideal


Resistively
Shunted
Junction
RSJ
S.J.
R
→ ∞
Ideal
C
10-50fF


S.J.
Resistively
Shunted
Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
R
→ ∞
C
10-50fF
Ideal


S.J.
Resistively
Shunted
Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
R
→ ∞
C
10-50fF
ideal


S.J.
Resistively Shunted Junction
RSJ
$V(t) = \frac{\Phi_0}{2\pi} \dot{\varphi}(t)$
$I(t) = I_c \sin \varphi(t)$
R
∞
ideal
C
10-50fF

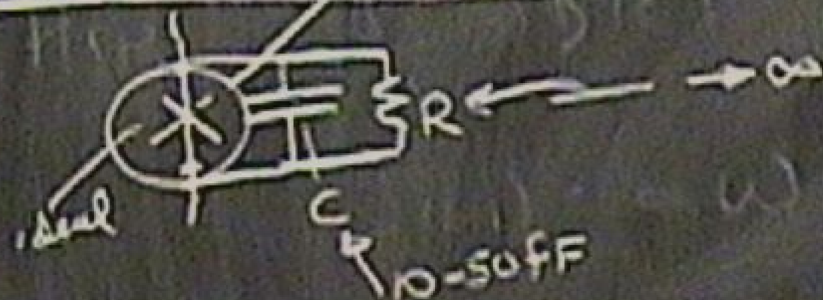


S.J.
Resistively Shunted Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V
R
→ ∞
C
10-50fF
ideal

⟹ Resistively Shunted Junction RSJ

$$V(t) = \frac{\Phi_0}{2\pi}\dot{\varphi}(t)$$

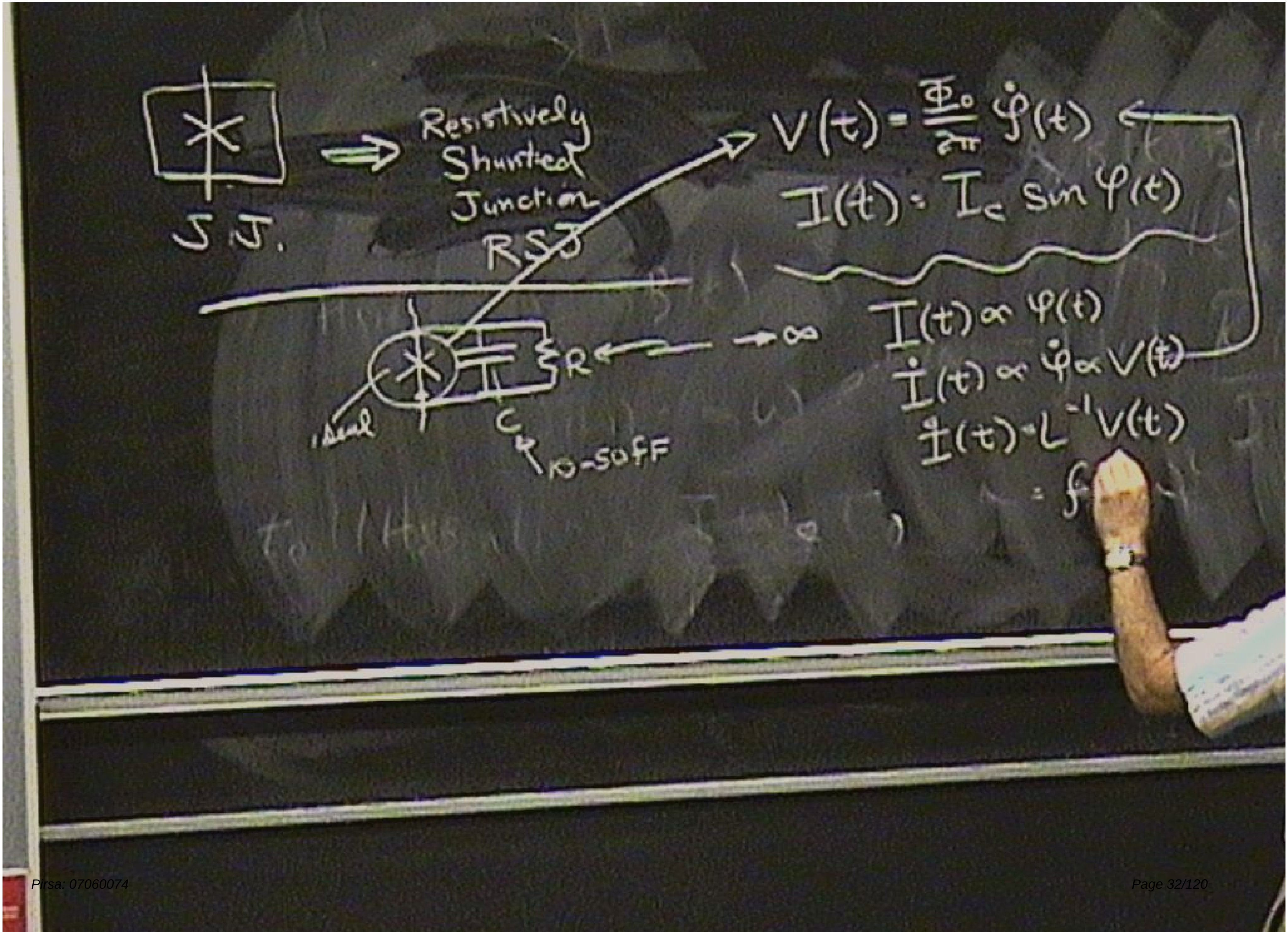
$$I(t) = I_c \sin\varphi(t)$$

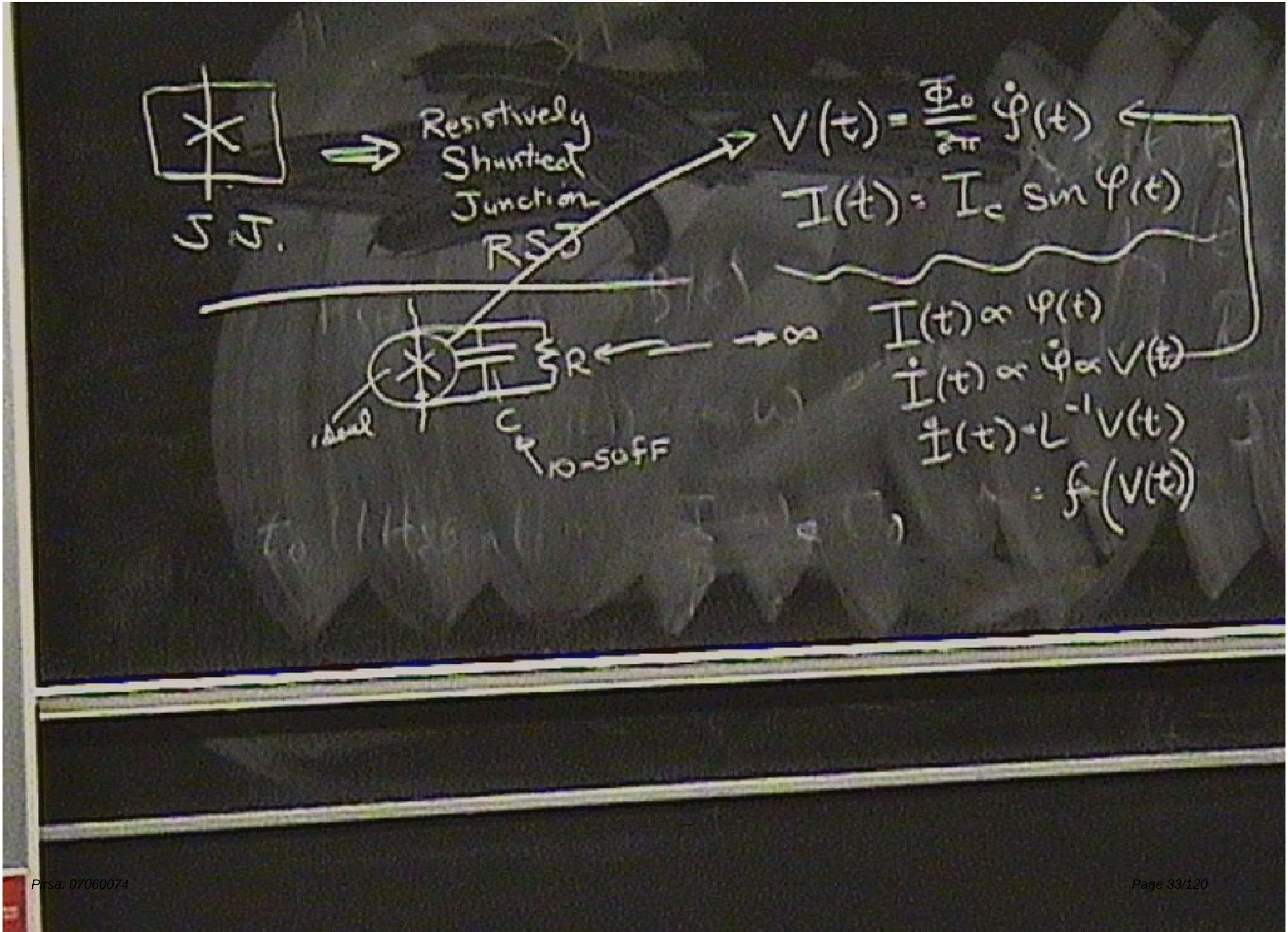


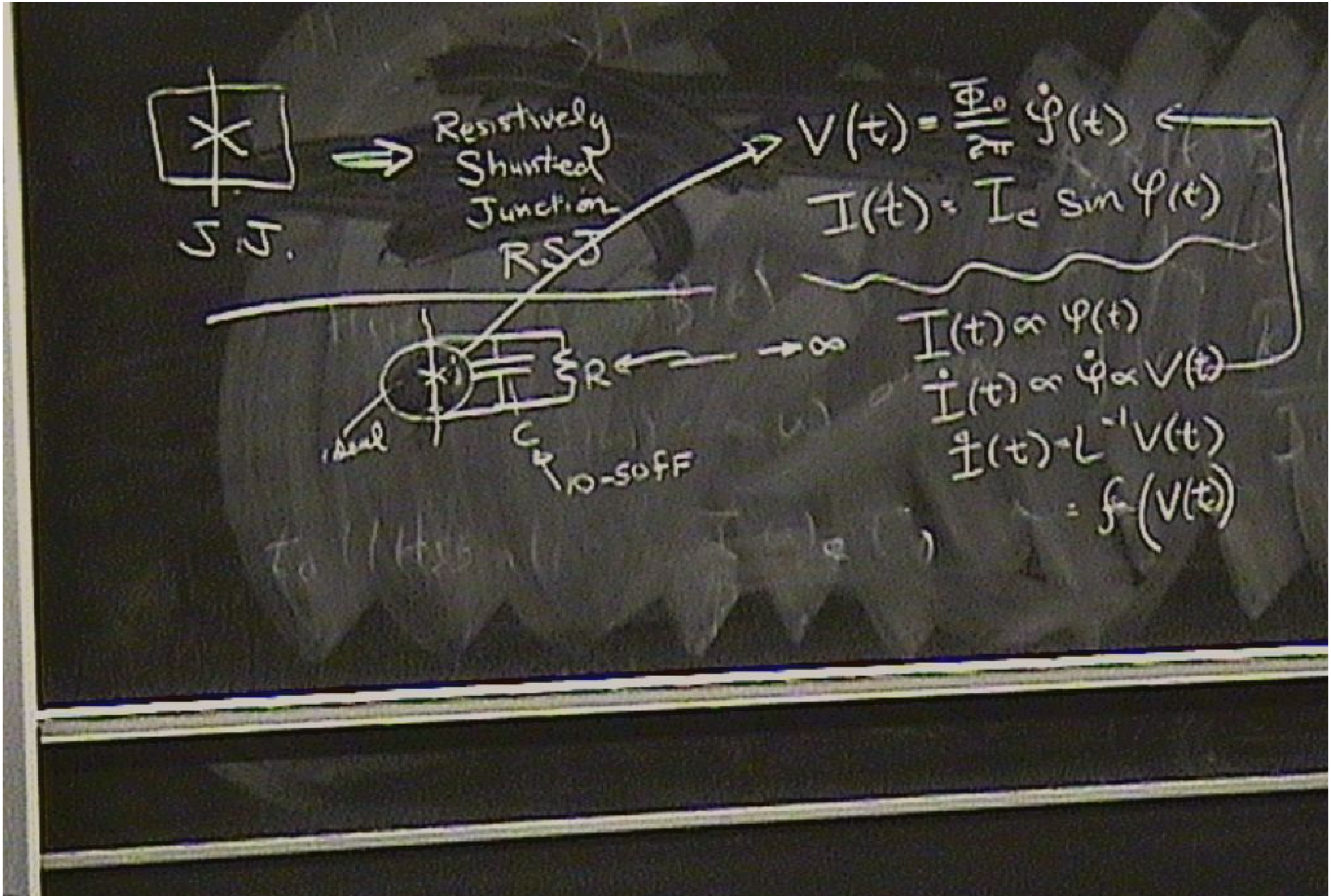
$$I(t) \propto \varphi(t)$$

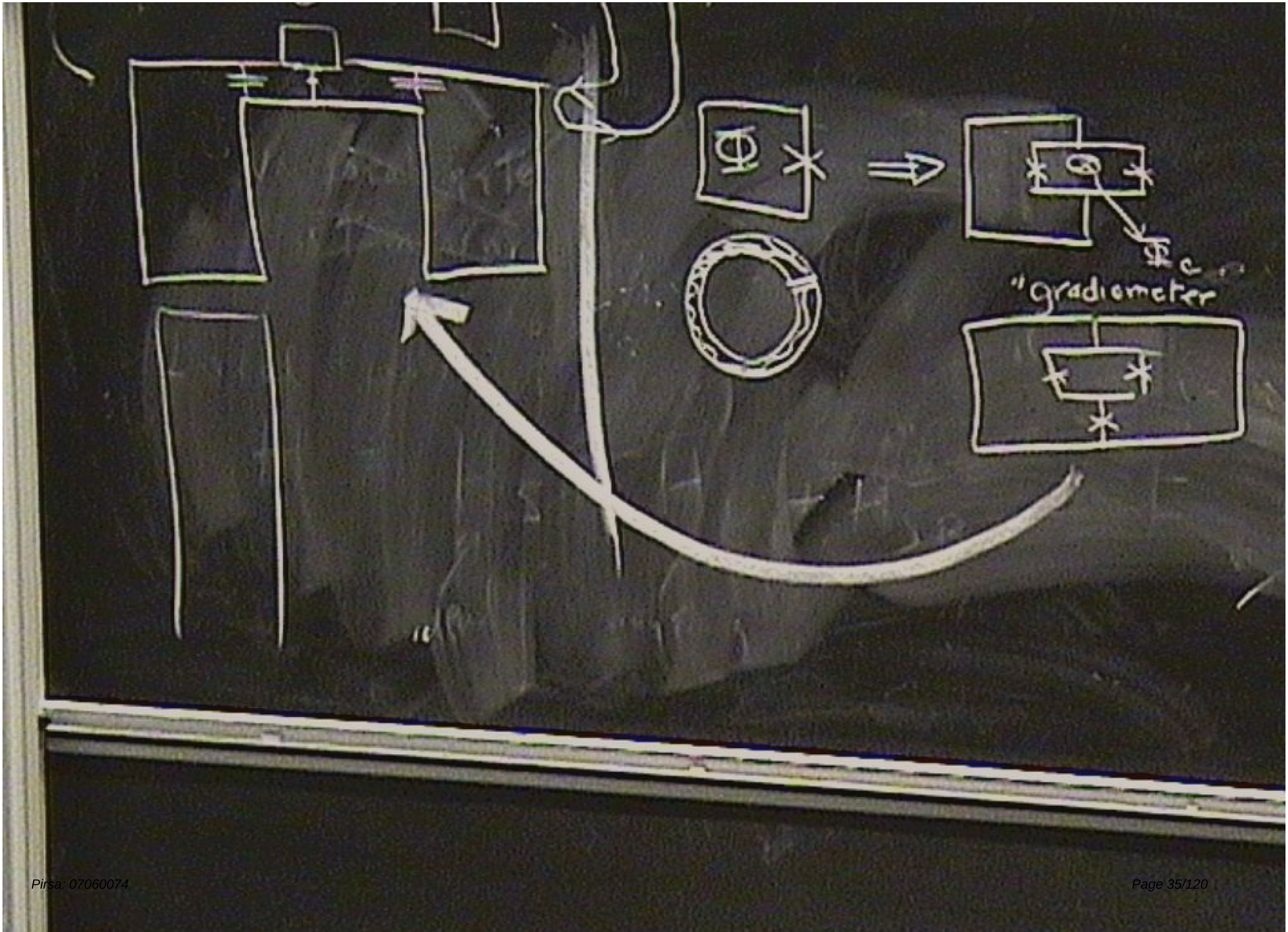
$$\dot{I}(t) \propto \dot{\varphi} \propto V(t)$$

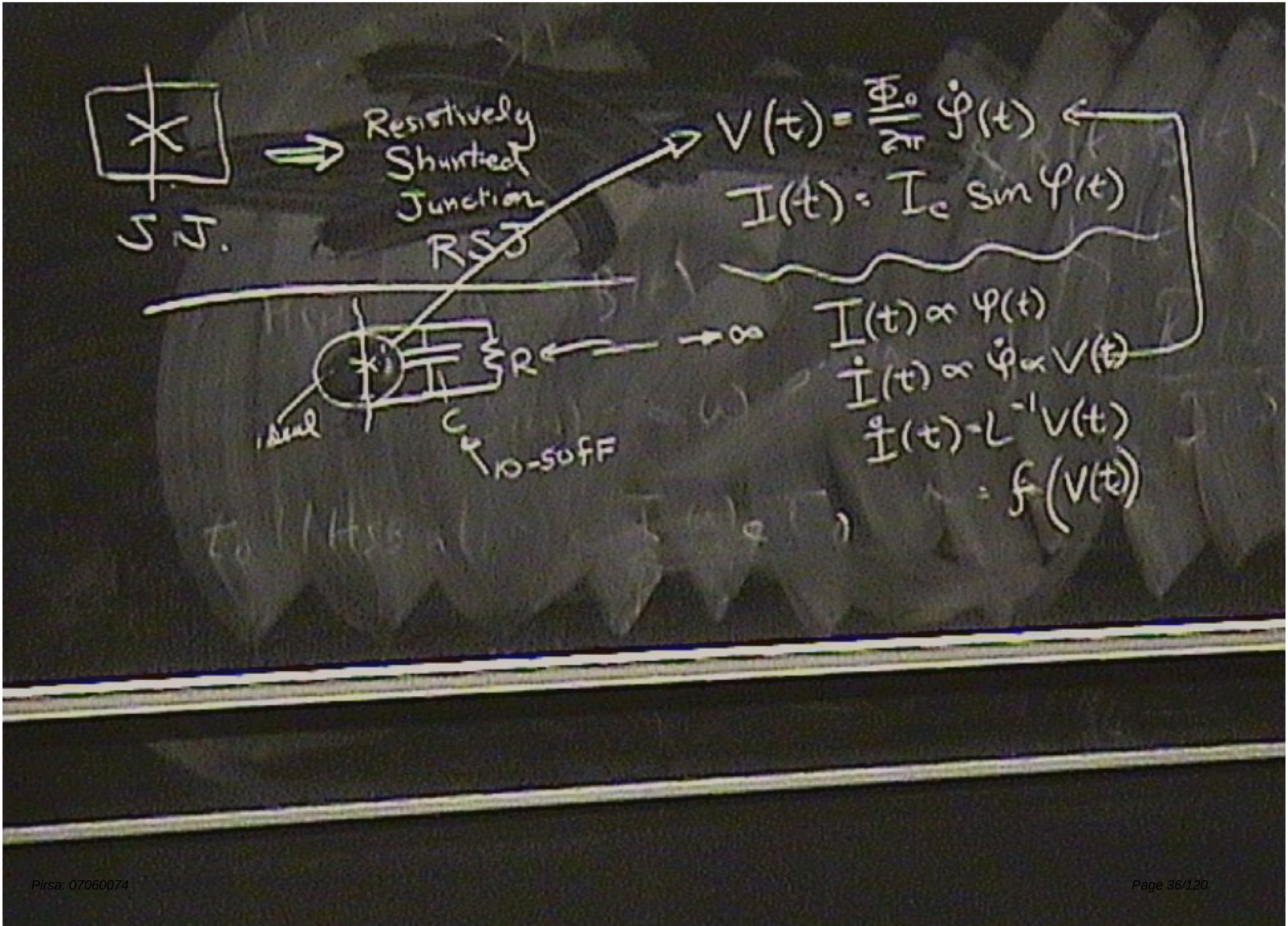
$$\dot{I}(t) = L^{-1}V(t)$$

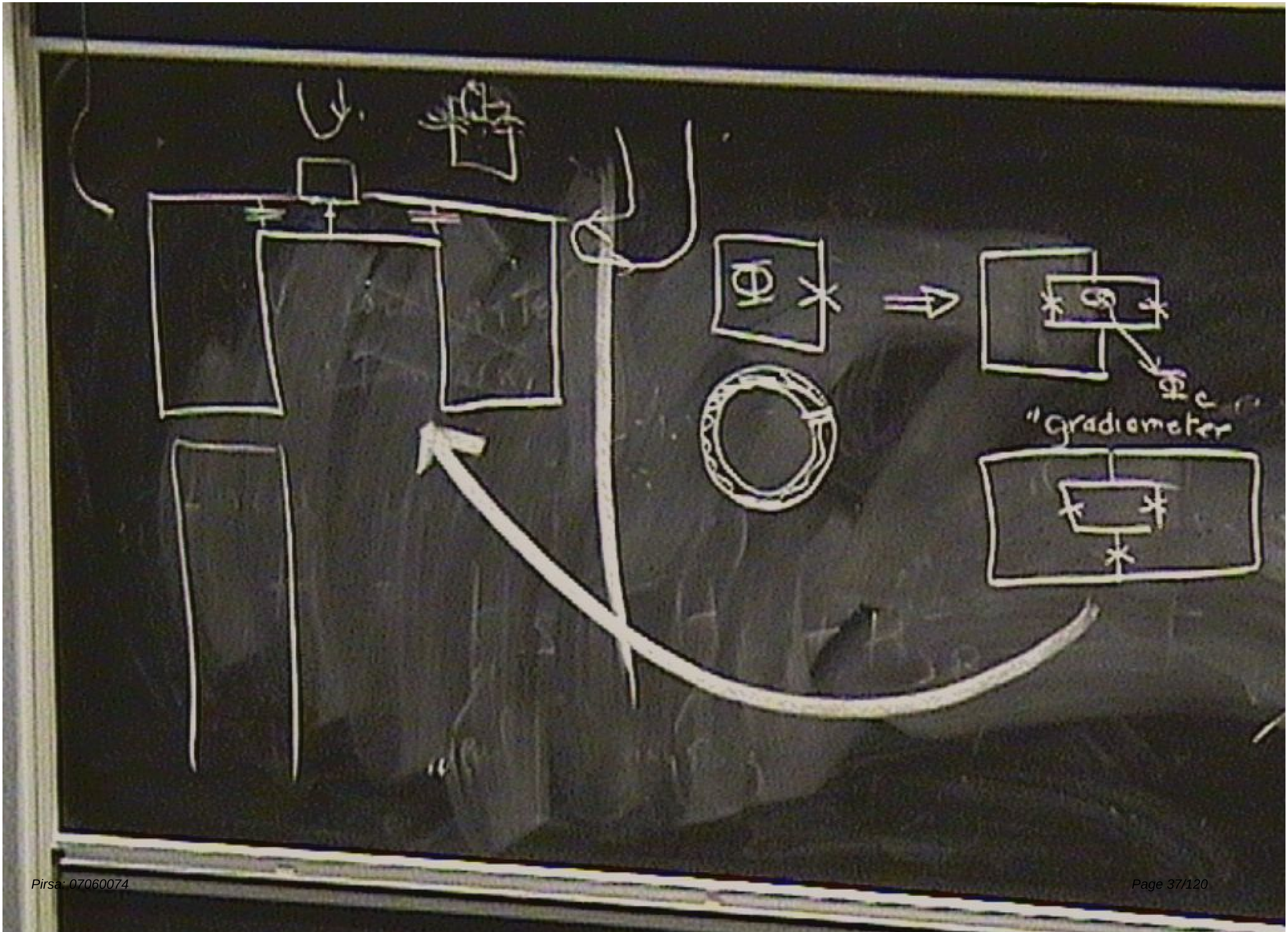

S.J.
Resistively
Shunted
Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
R
C
∞
Ideal
10-50fF

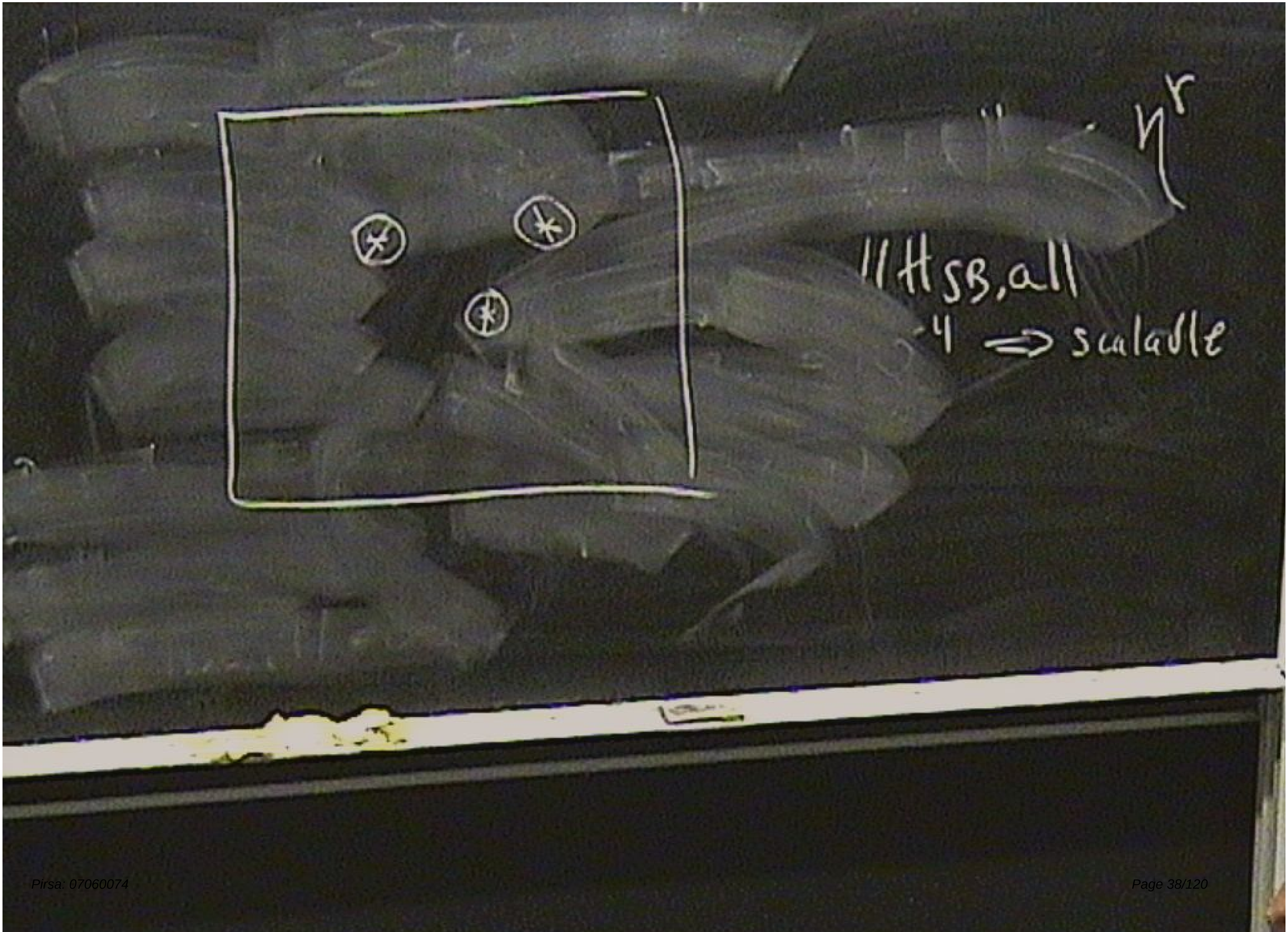

S.J.
Resistively Shunted Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
= f(V(t))
R
C
∞
10-50fF

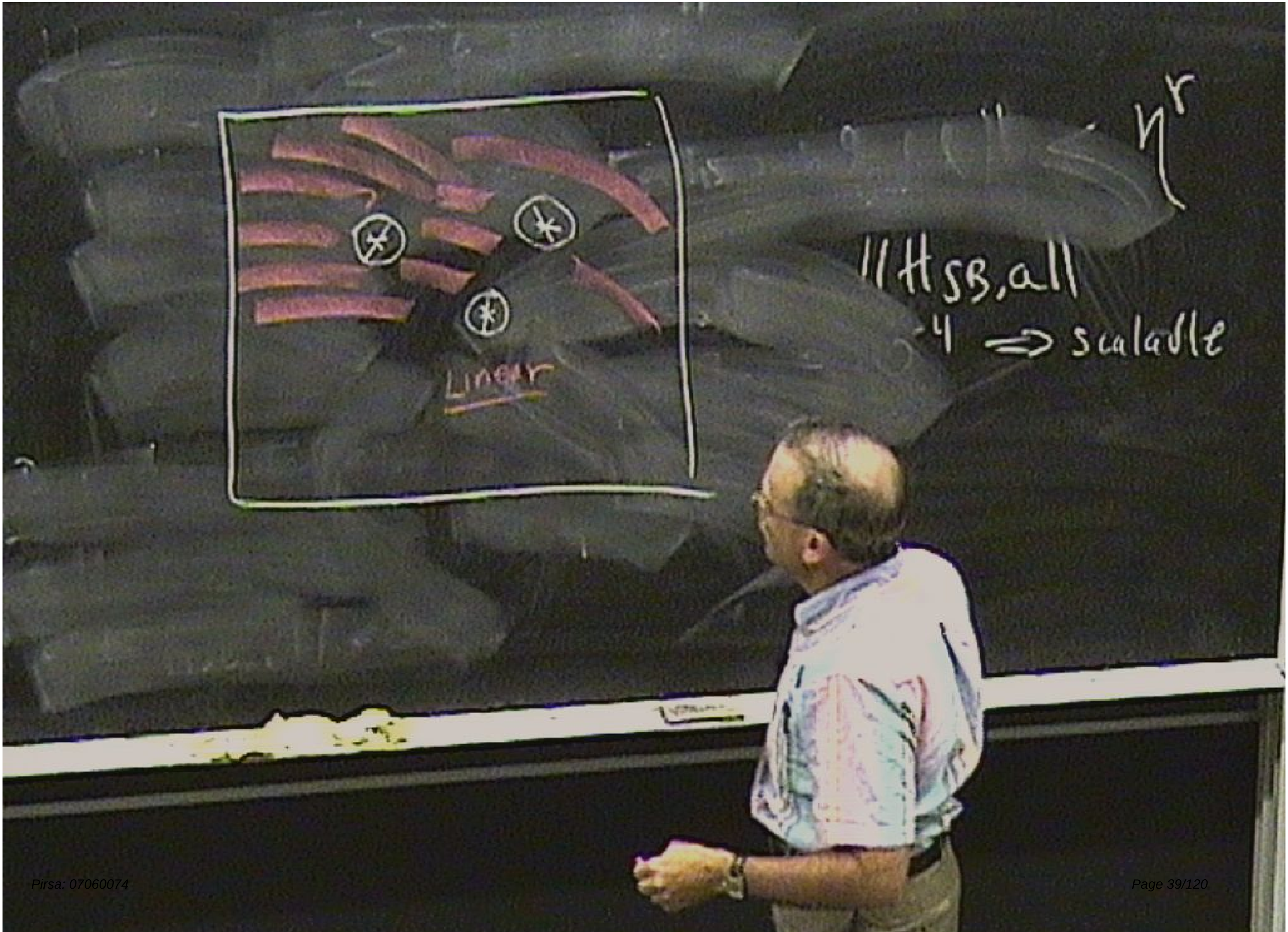

S.J.
Resistively Shunted Junction RSJ
$V(t) = \frac{\Phi_0}{2\pi}\dot{\varphi}(t)$
$I(t) = I_c \sin\varphi(t)$
$I(t) \propto \varphi(t)$
$\dot{I}(t) \propto \dot{\varphi} \propto V(t)$
$\dot{I}(t) = L^{-1} V(t)$
$= f(V(t))$
R
$\to \infty$
C
10-50fF
ideal

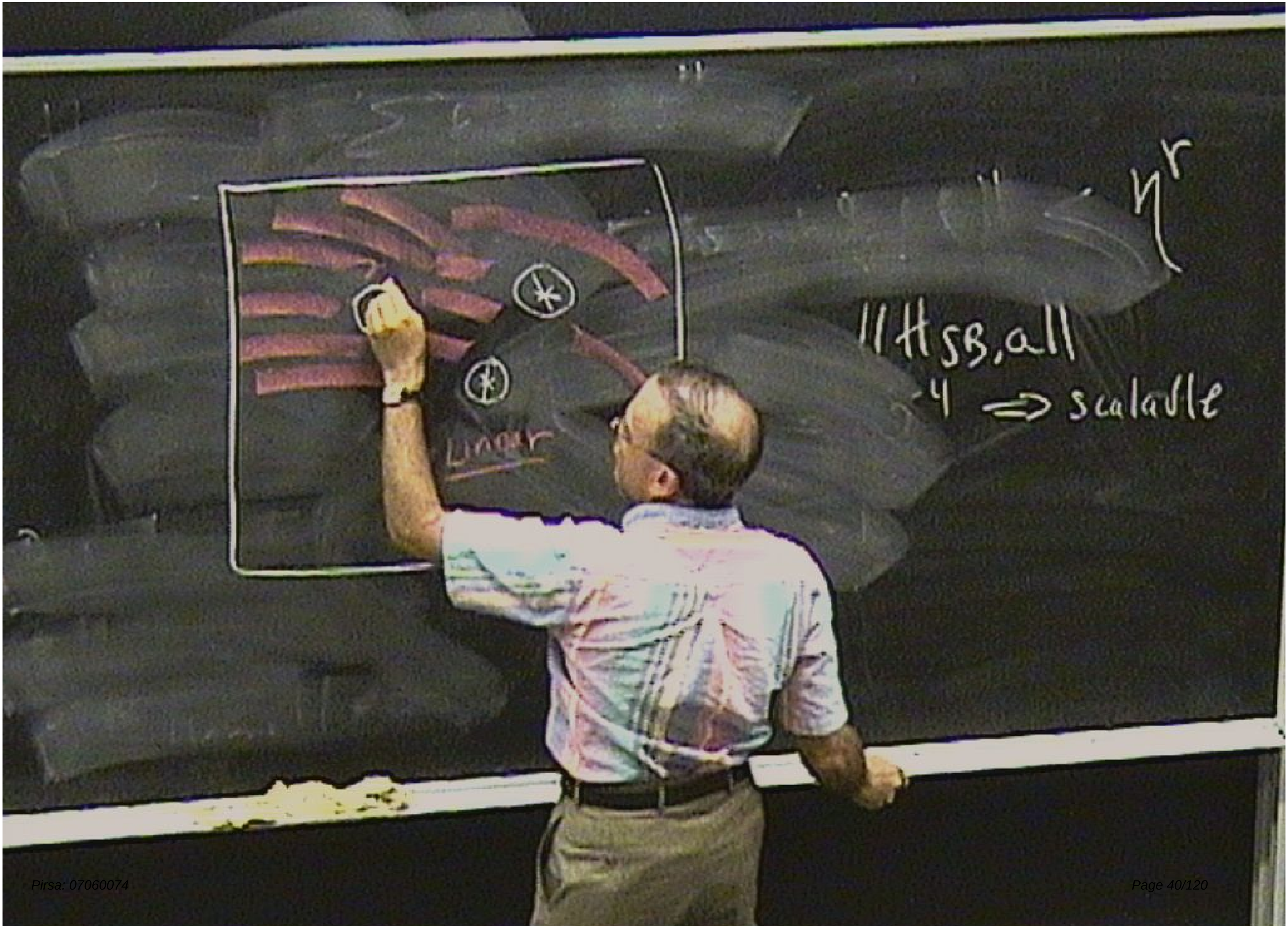

"gradiometer"

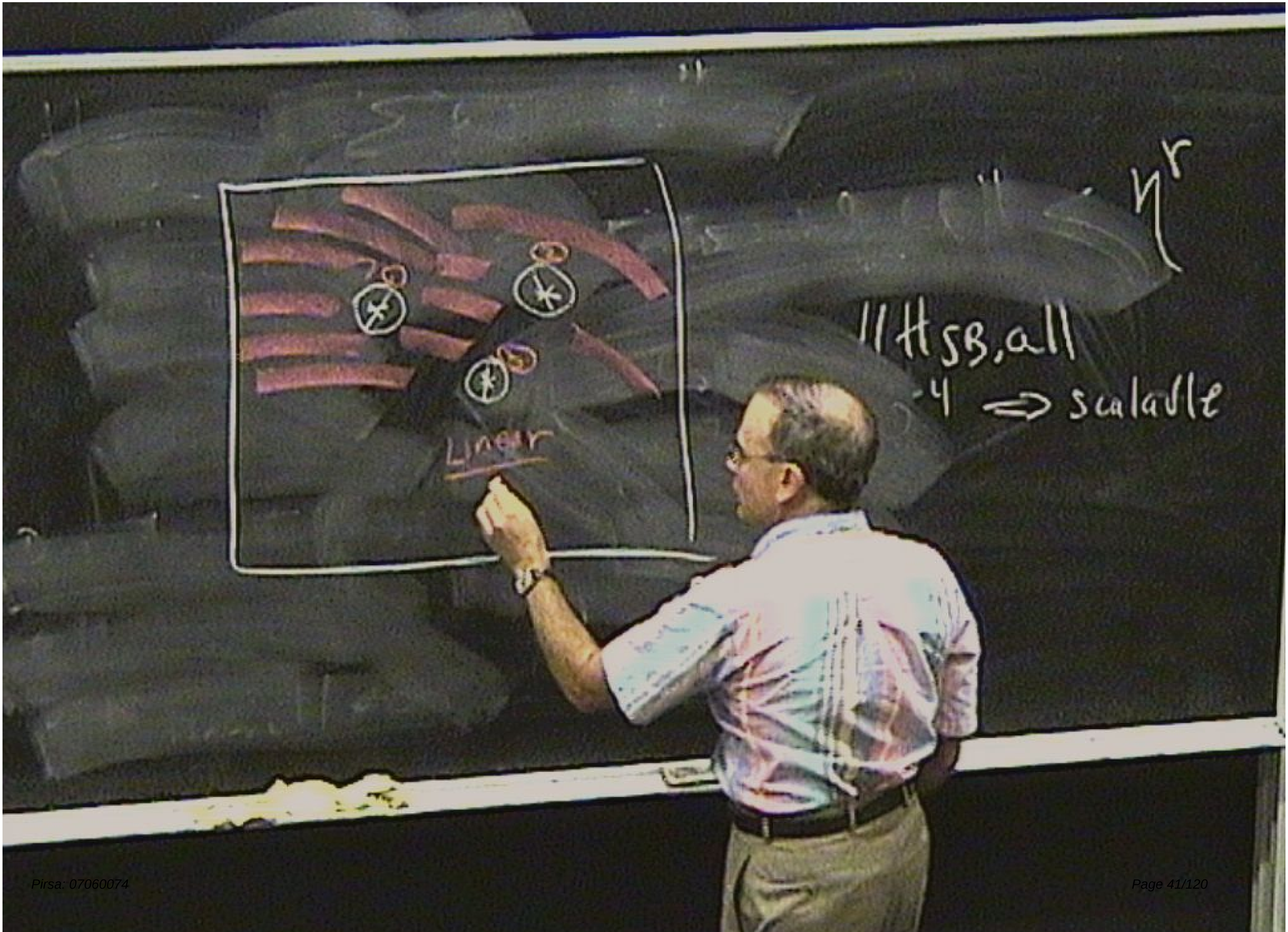

S.J.
Resistively Shunted Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
= f(V(t))
R
→ ∞
C
10-sufF
ideal

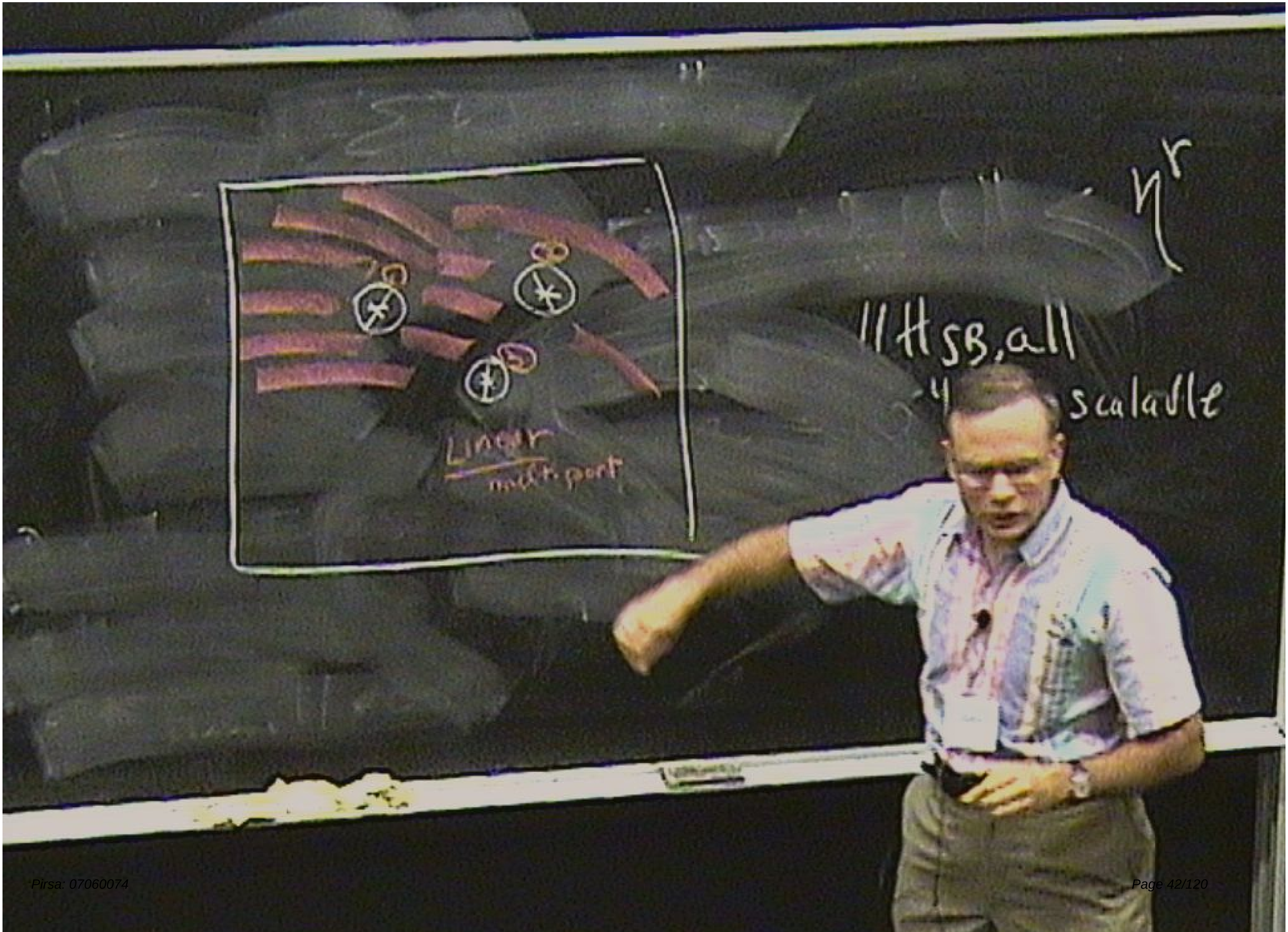

"Gradiometer"


||HSB,all||
⟹ scalable

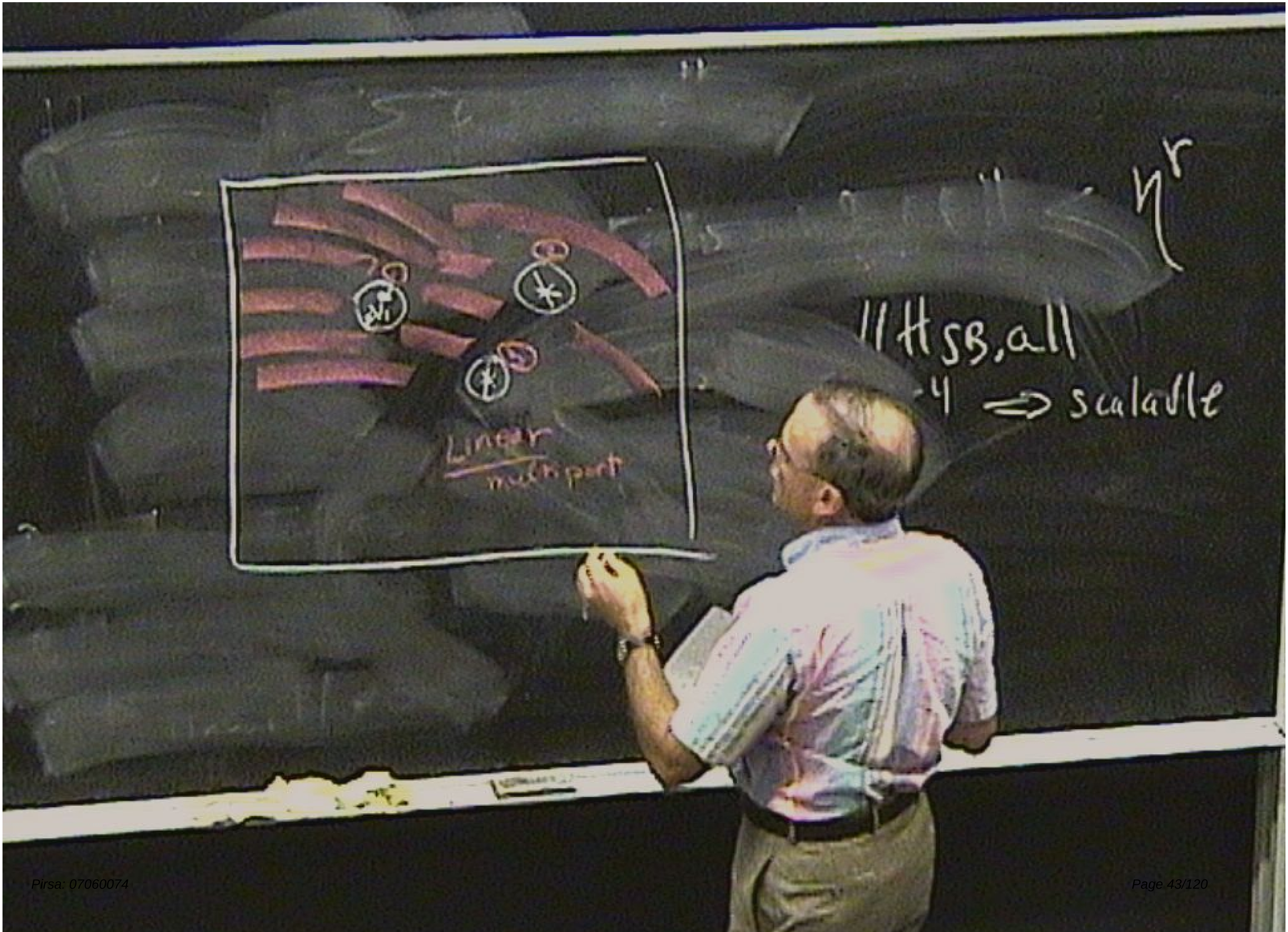

Linear
||HSB,all
⇒ scalable


||HSB,all||
⇒ scalable
Linear

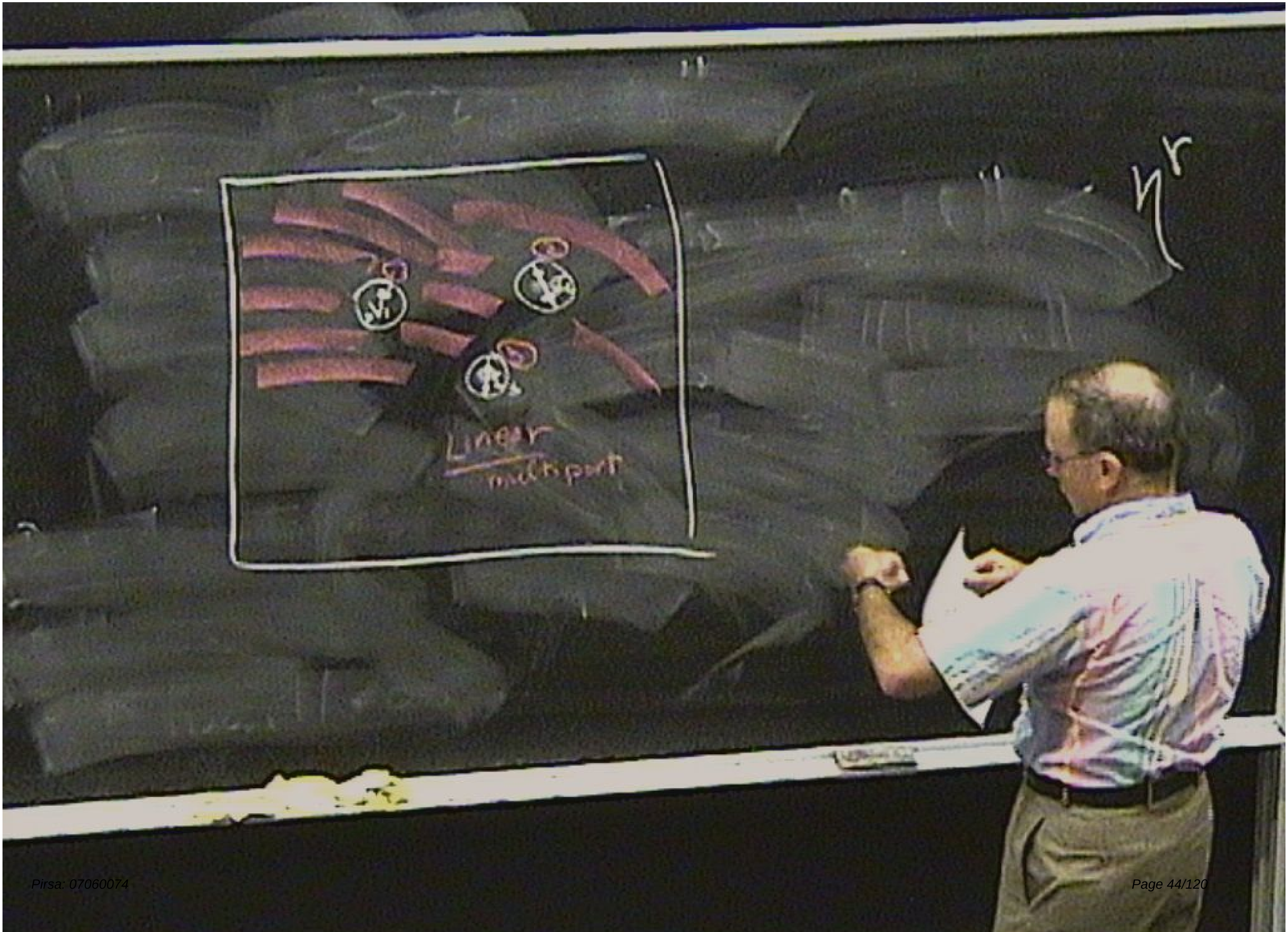

Linear
||HSB,all||
⇒ scalable

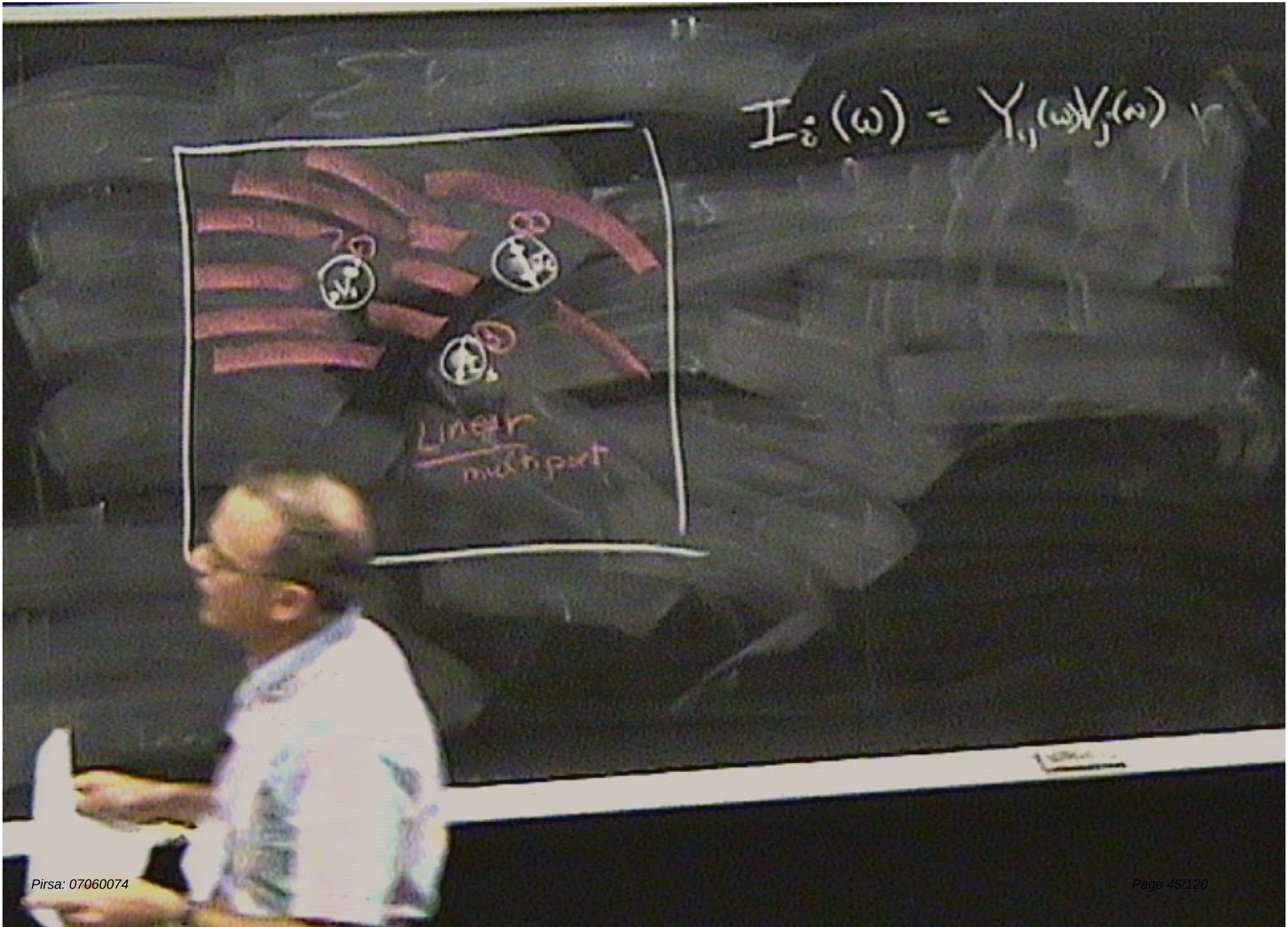


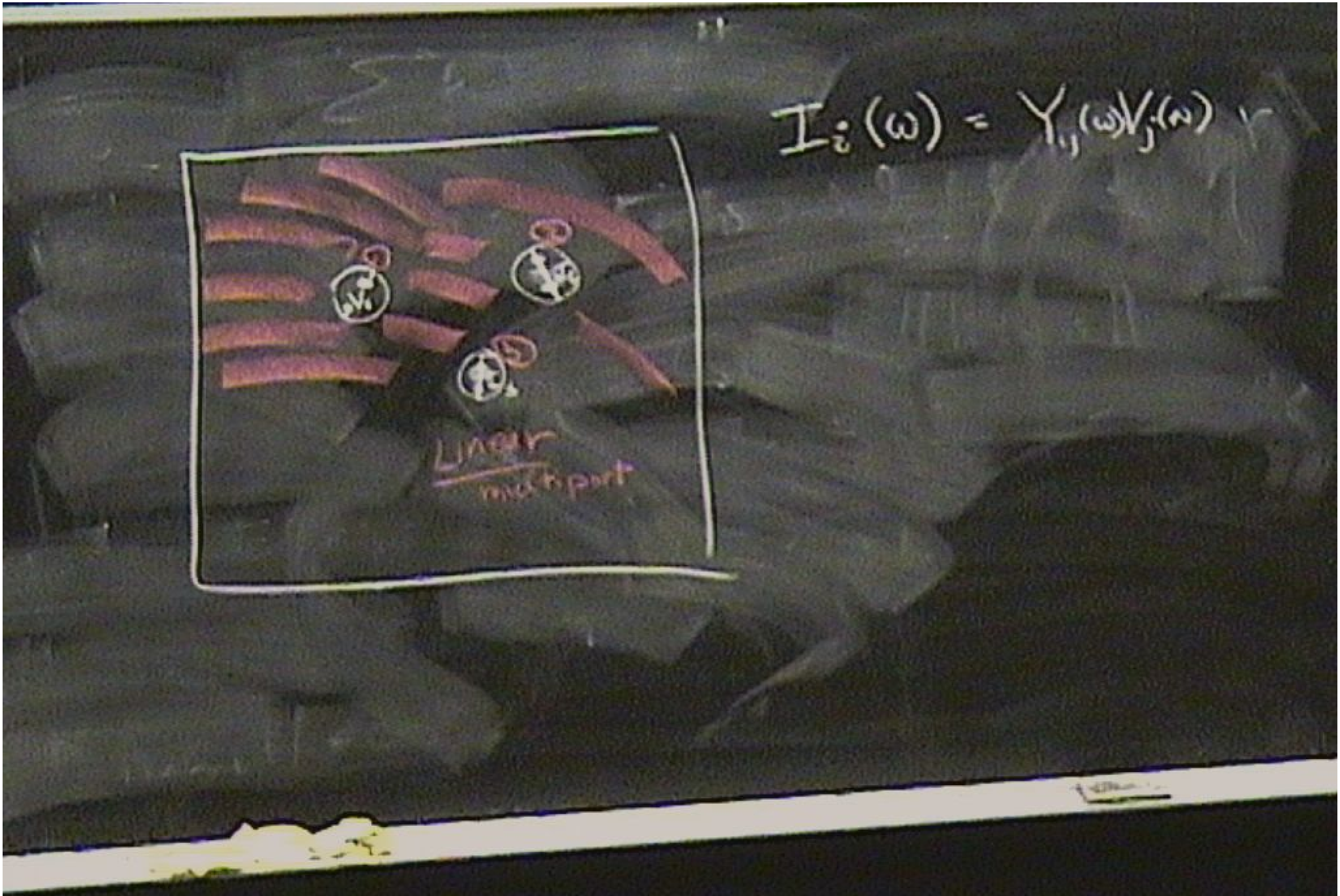
Linear
multi-port
η^r
$\|H_{SB,all}\|$
scalable

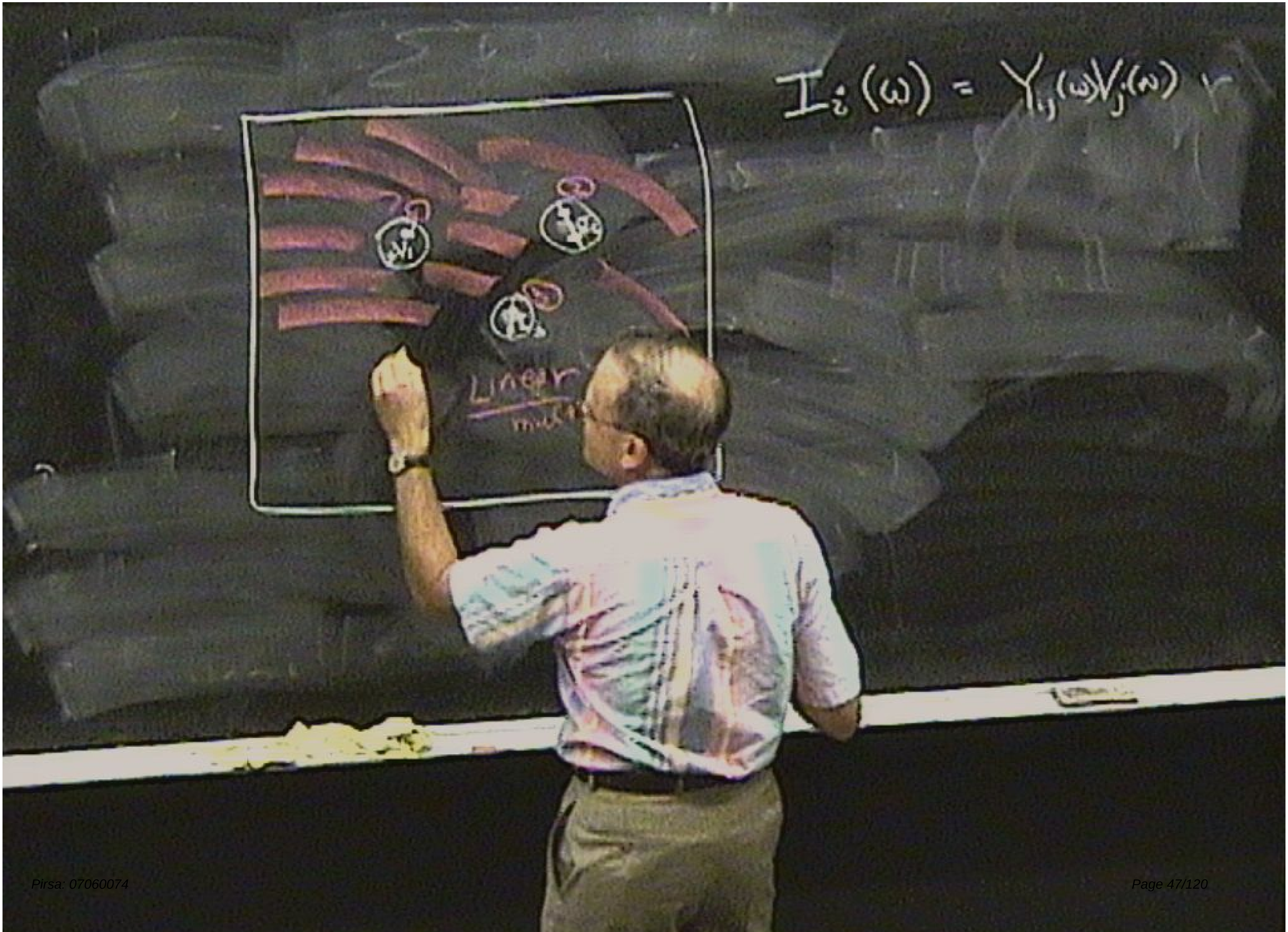


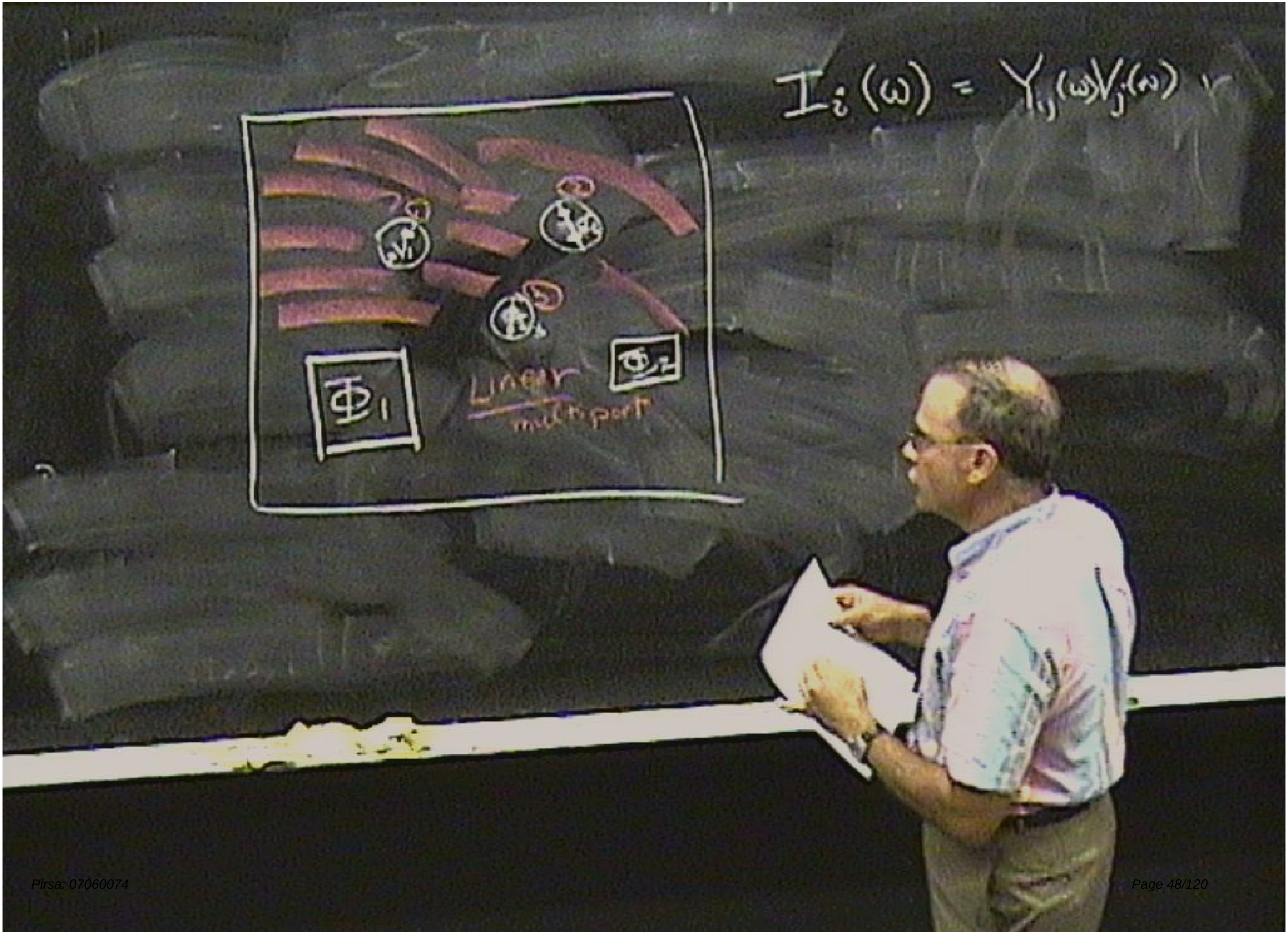
η^r
$\|H_{SB,all}\|$
$\Rightarrow$ scalable
Linear
multipart

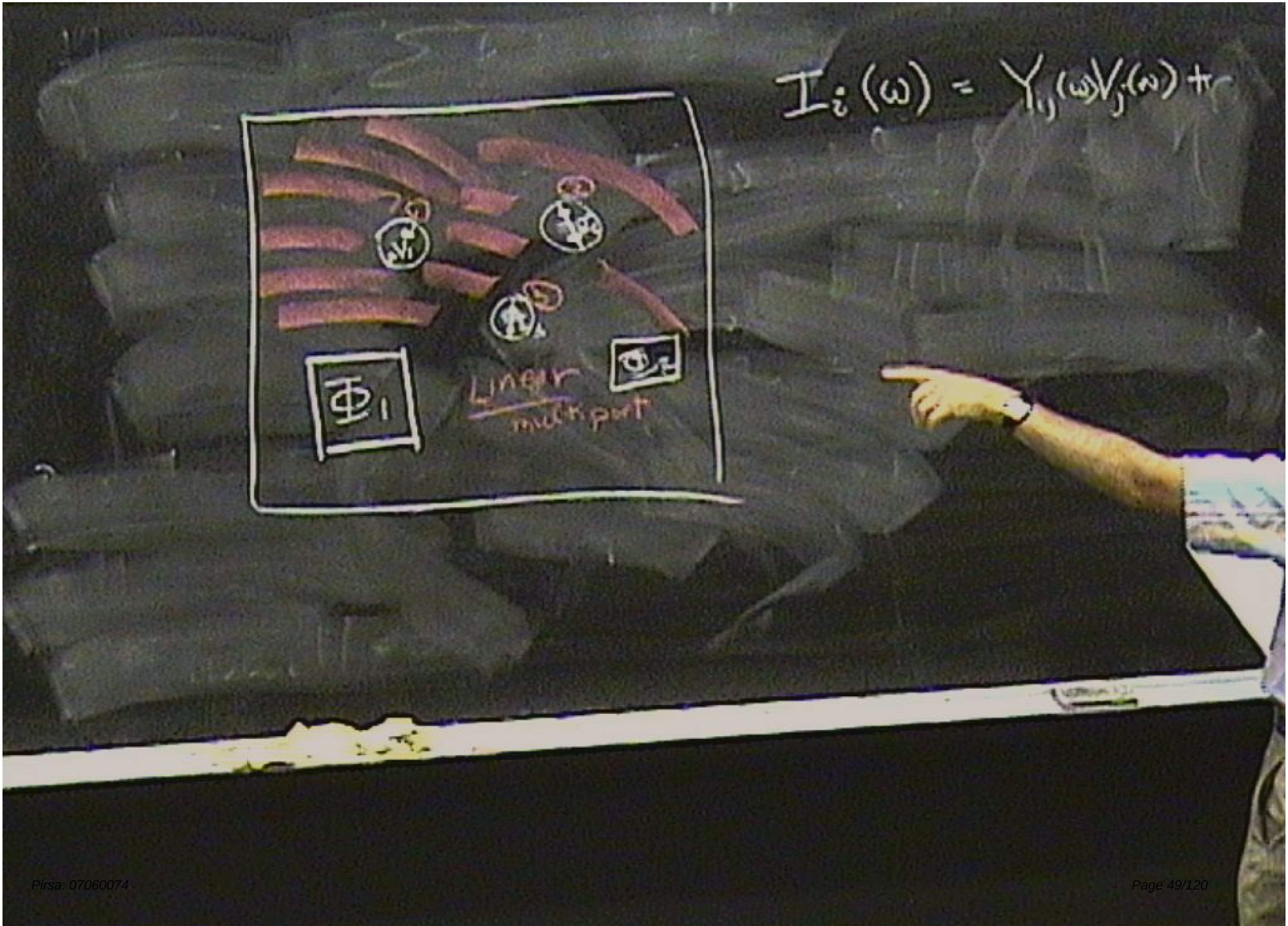

Linear
multiport


$I_i(\omega) = Y_{ij}(\omega)V_j(\omega)$
Linear
multiport

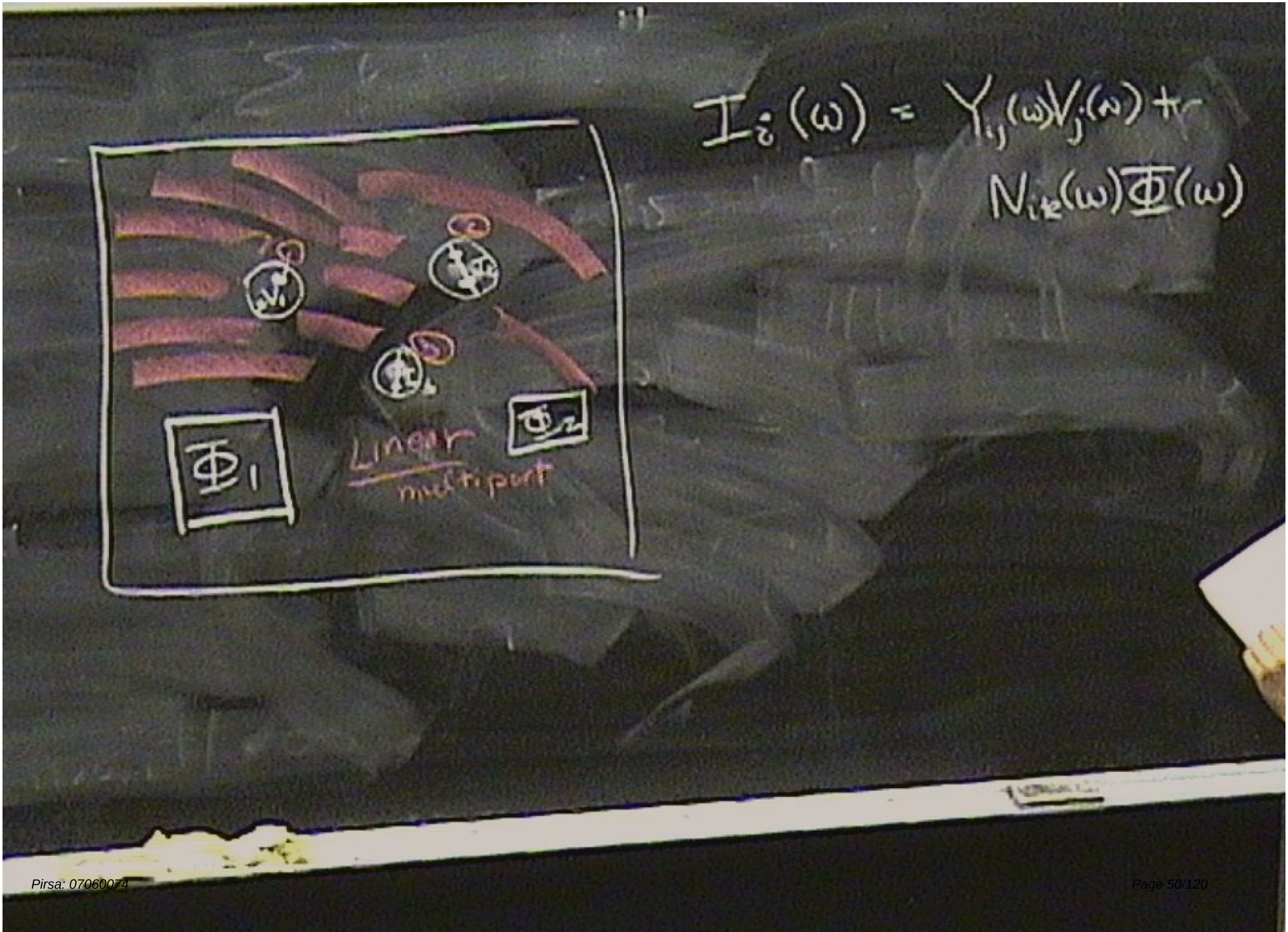

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega)$
Linear
multiport

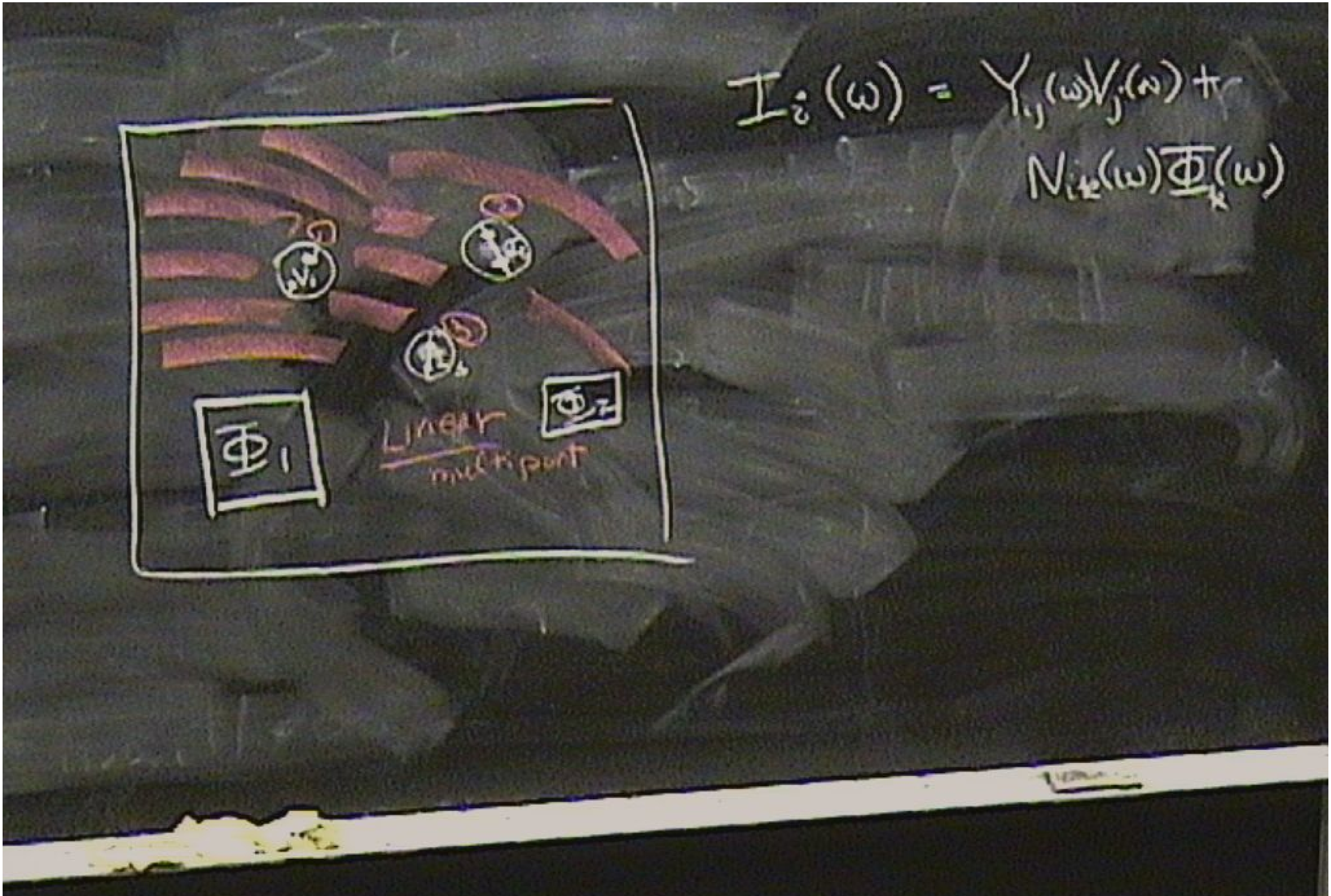

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega)$

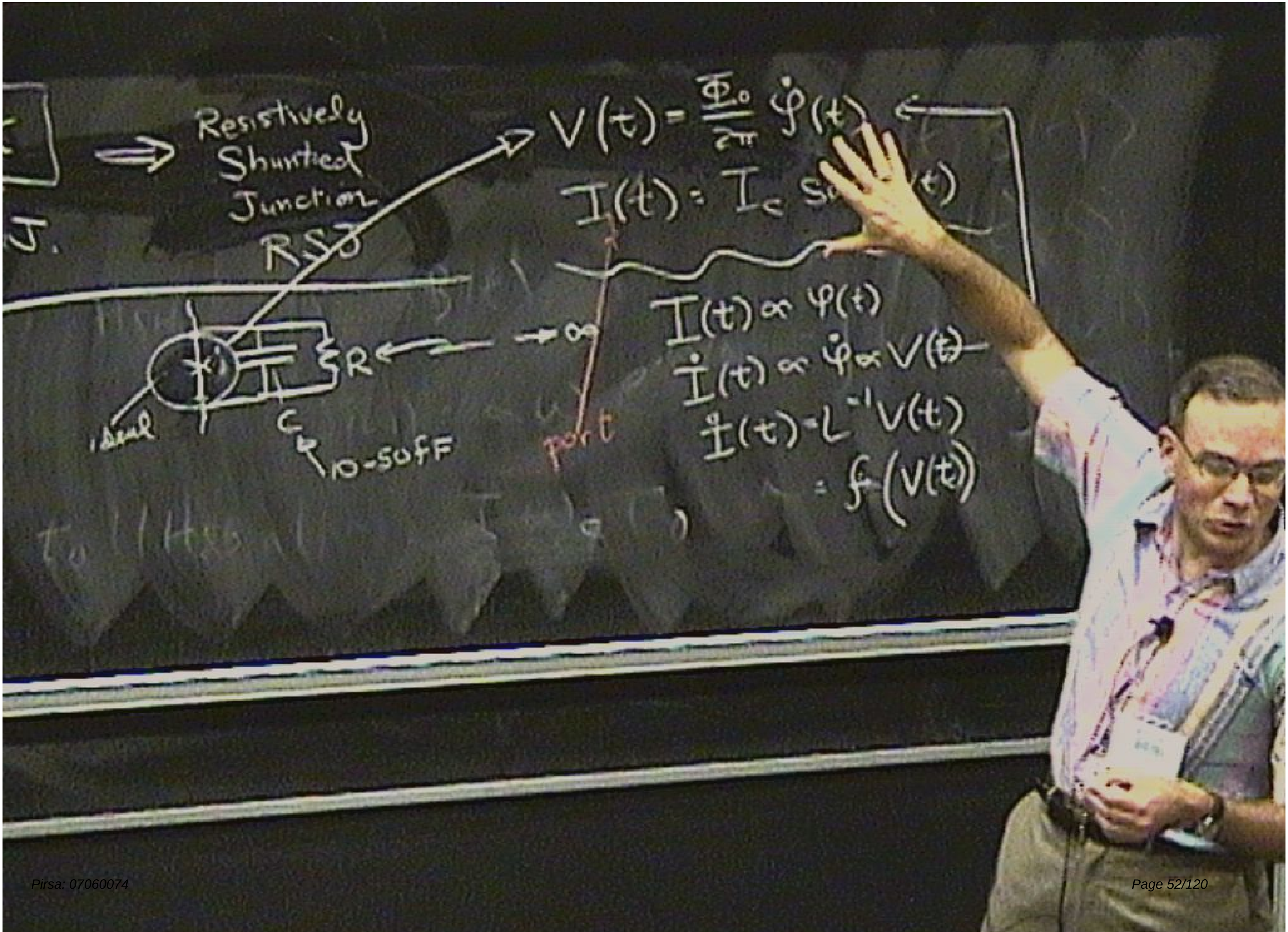

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega)$
Φ_1
Φ_2
Linear
multiport

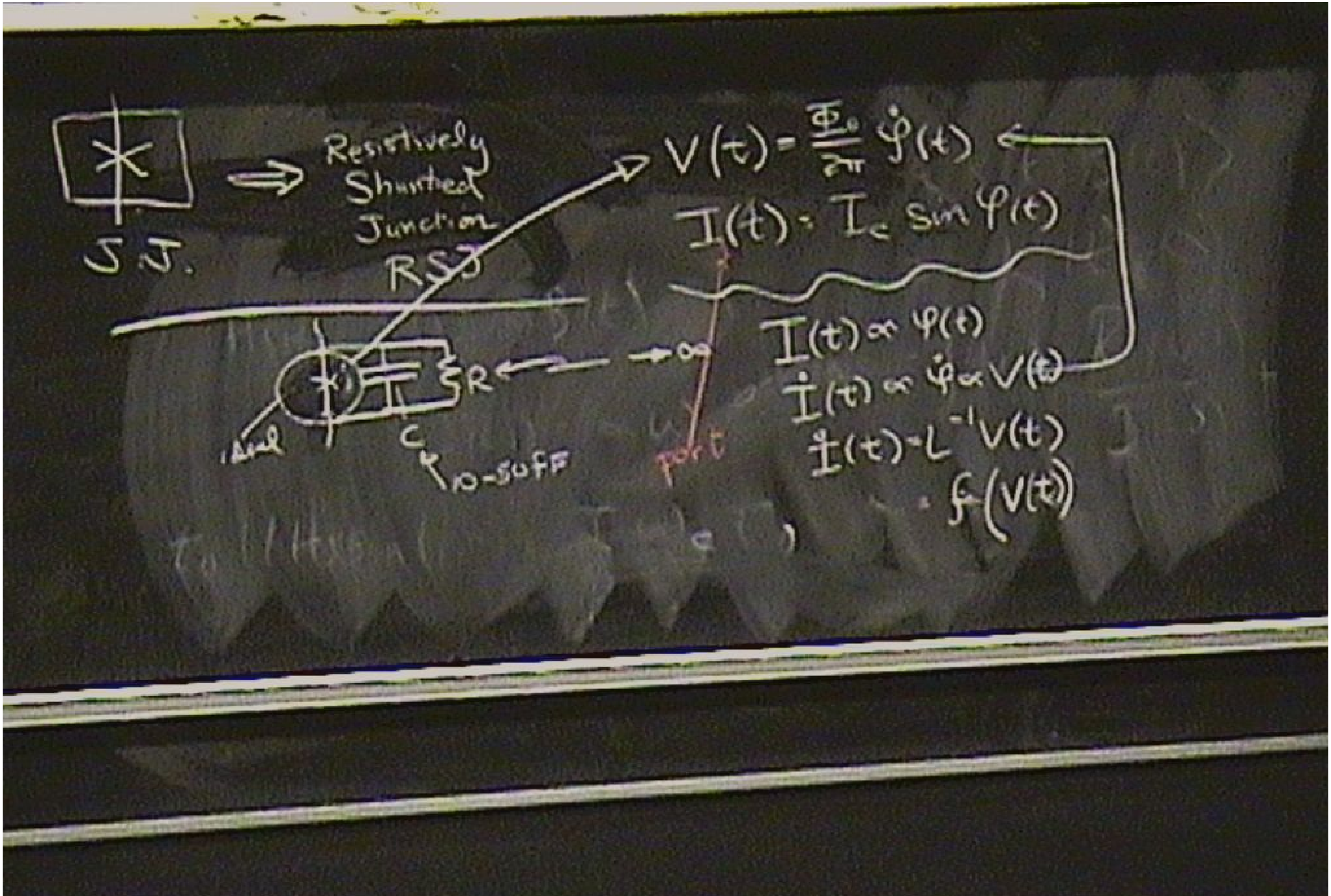


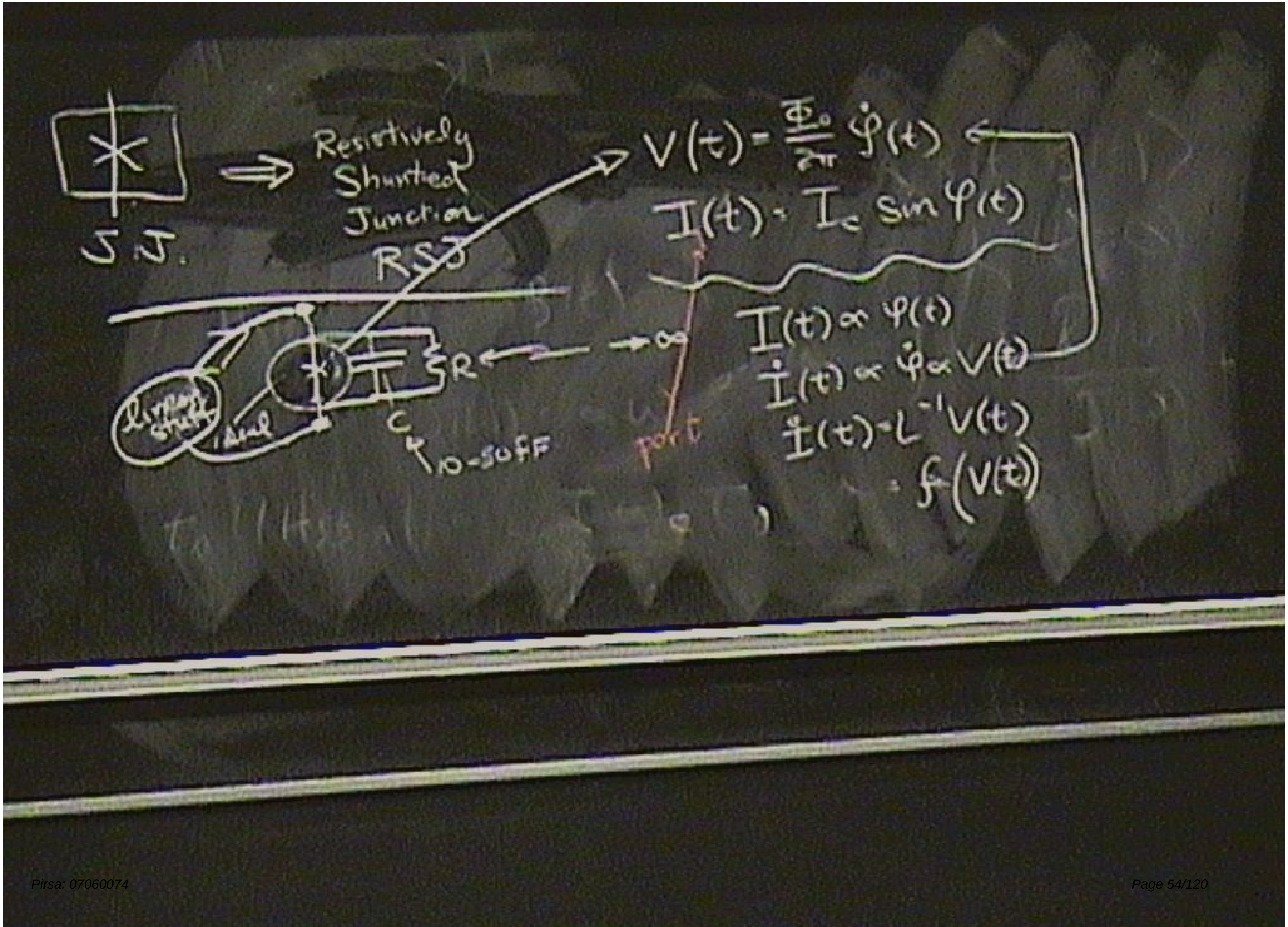
$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) +$
Linear
multiport

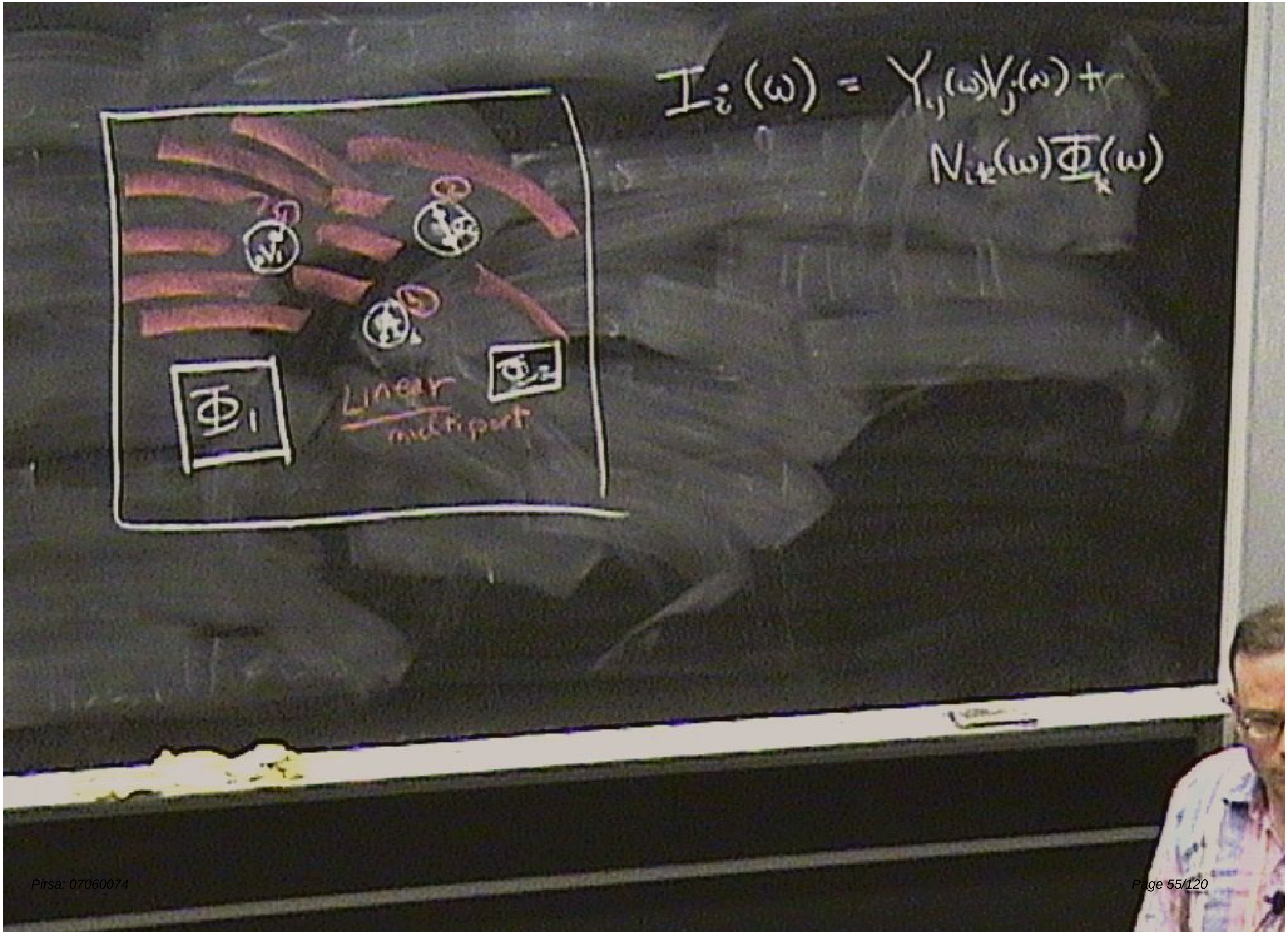

I_i(ω) = Y_ij(ω)V_j(ω) + N_ik(ω)Φ(ω)
Φ_1
Φ_2
Linear multiport

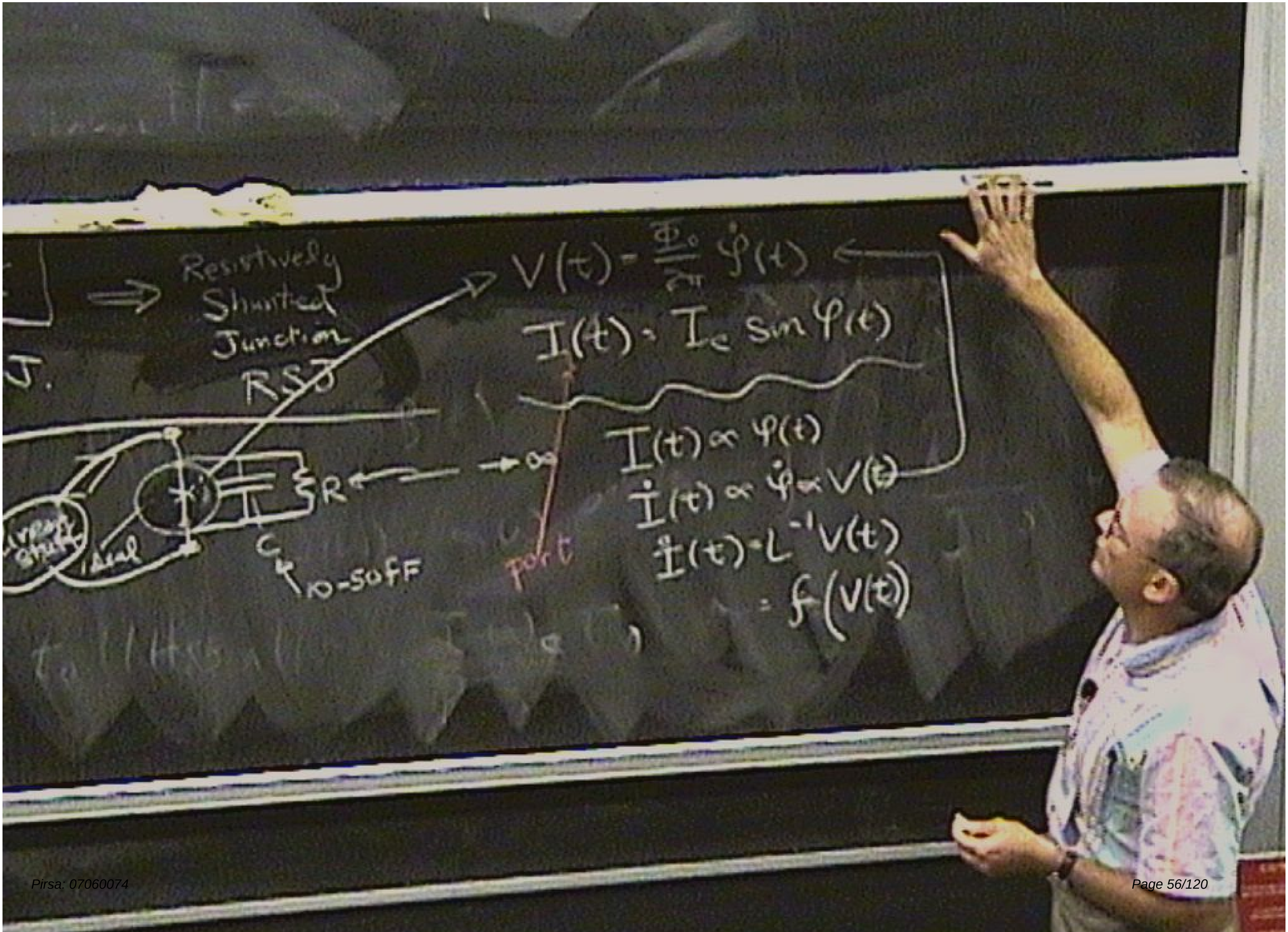

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$
Linear
multipoint
Φ_1
Φ_2

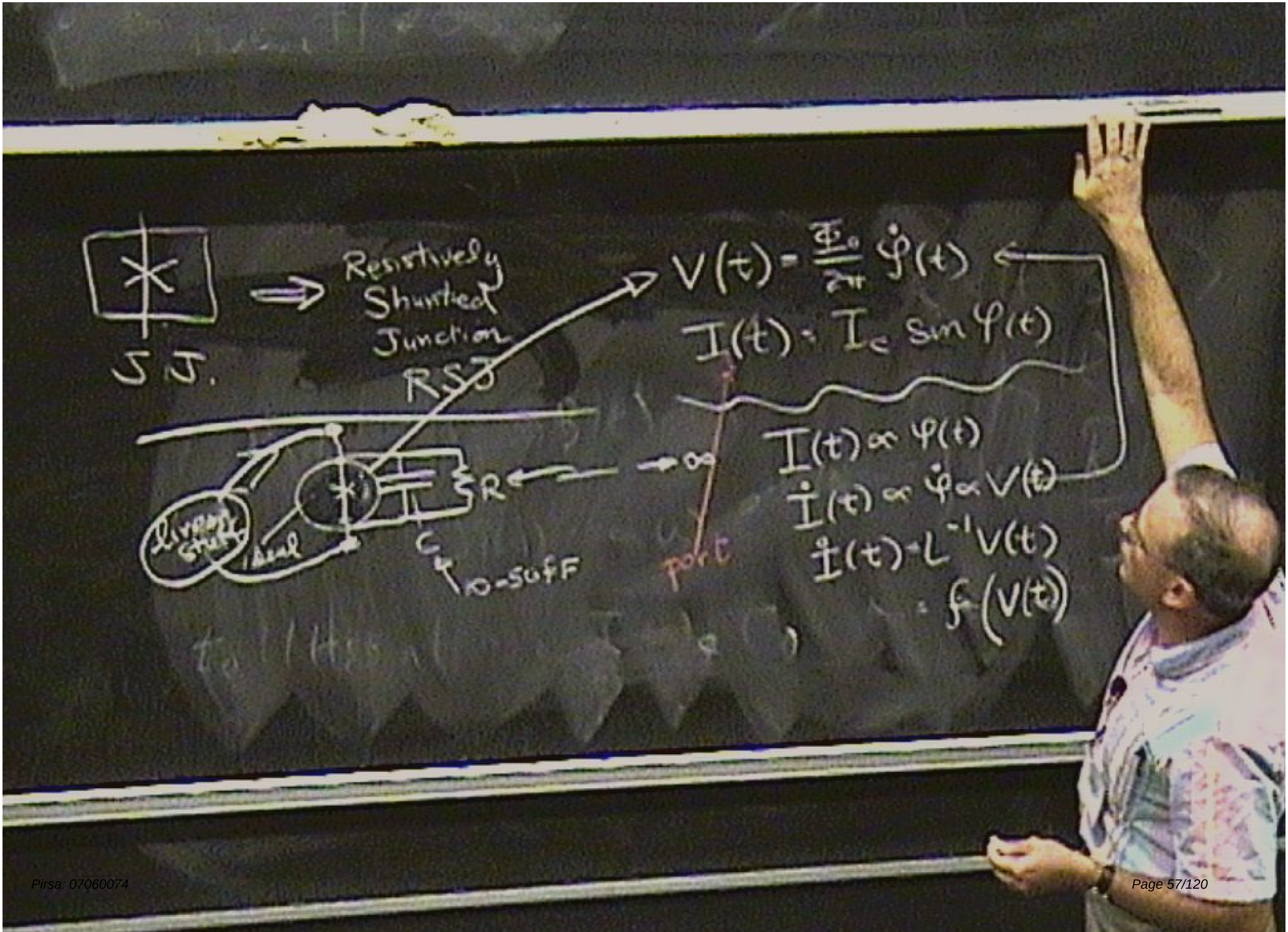

Resistively Shunted Junction RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
= f(V(t))
R
C
10-50 fF
ideal
port
∞

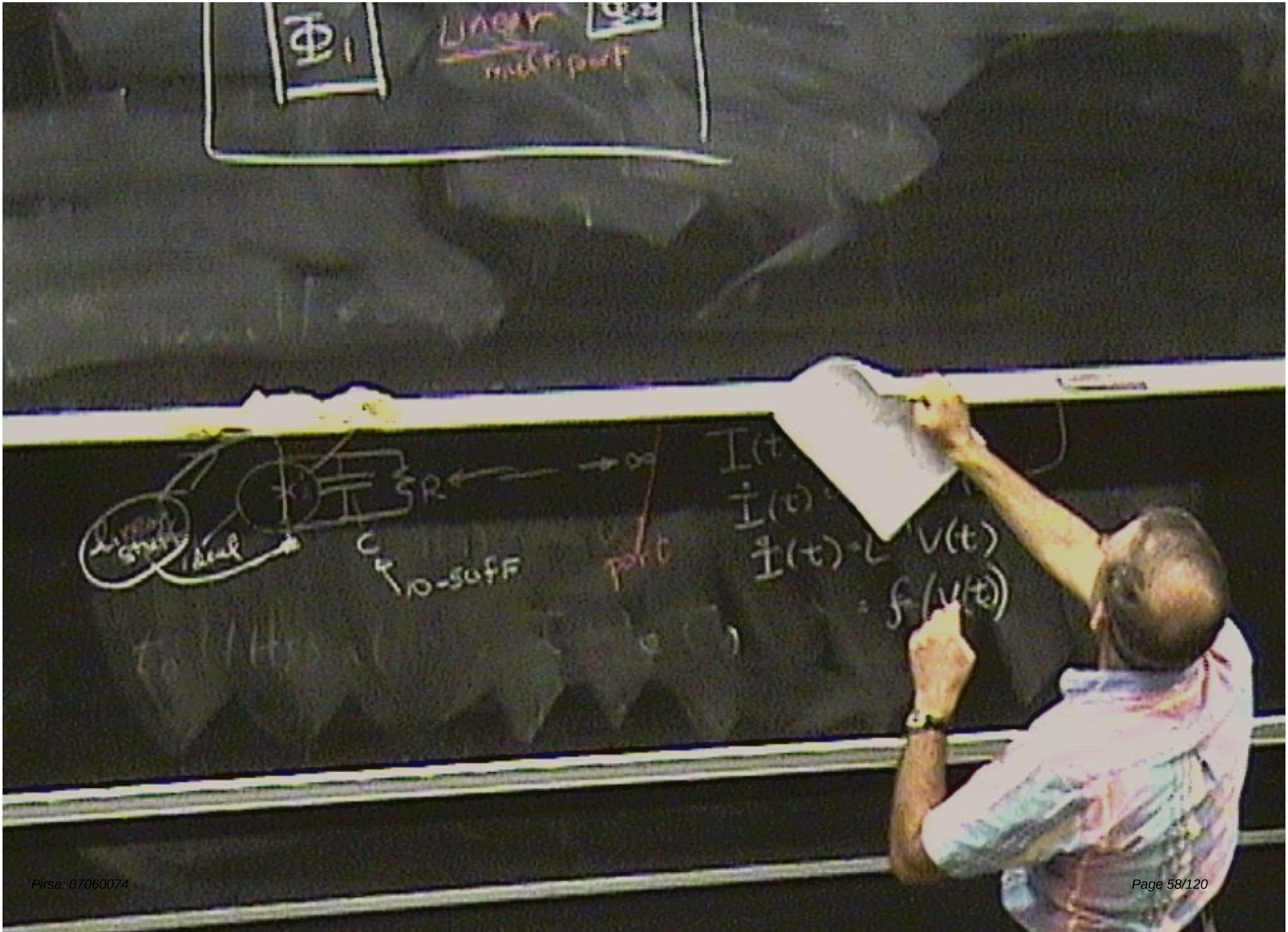

S.J.
Resistively Shunted Junction
RSJ
$V(t) = \frac{\Phi_0}{2\pi}\dot{\varphi}(t)$
$I(t) = I_c \sin\varphi(t)$
R
C
∞
port
$I(t) \propto \varphi(t)$
$\dot{I}(t) \propto \dot{\varphi} \propto V(t)$
$\dot{I}(t) = L^{-1} V(t)$
$= f(V(t))$

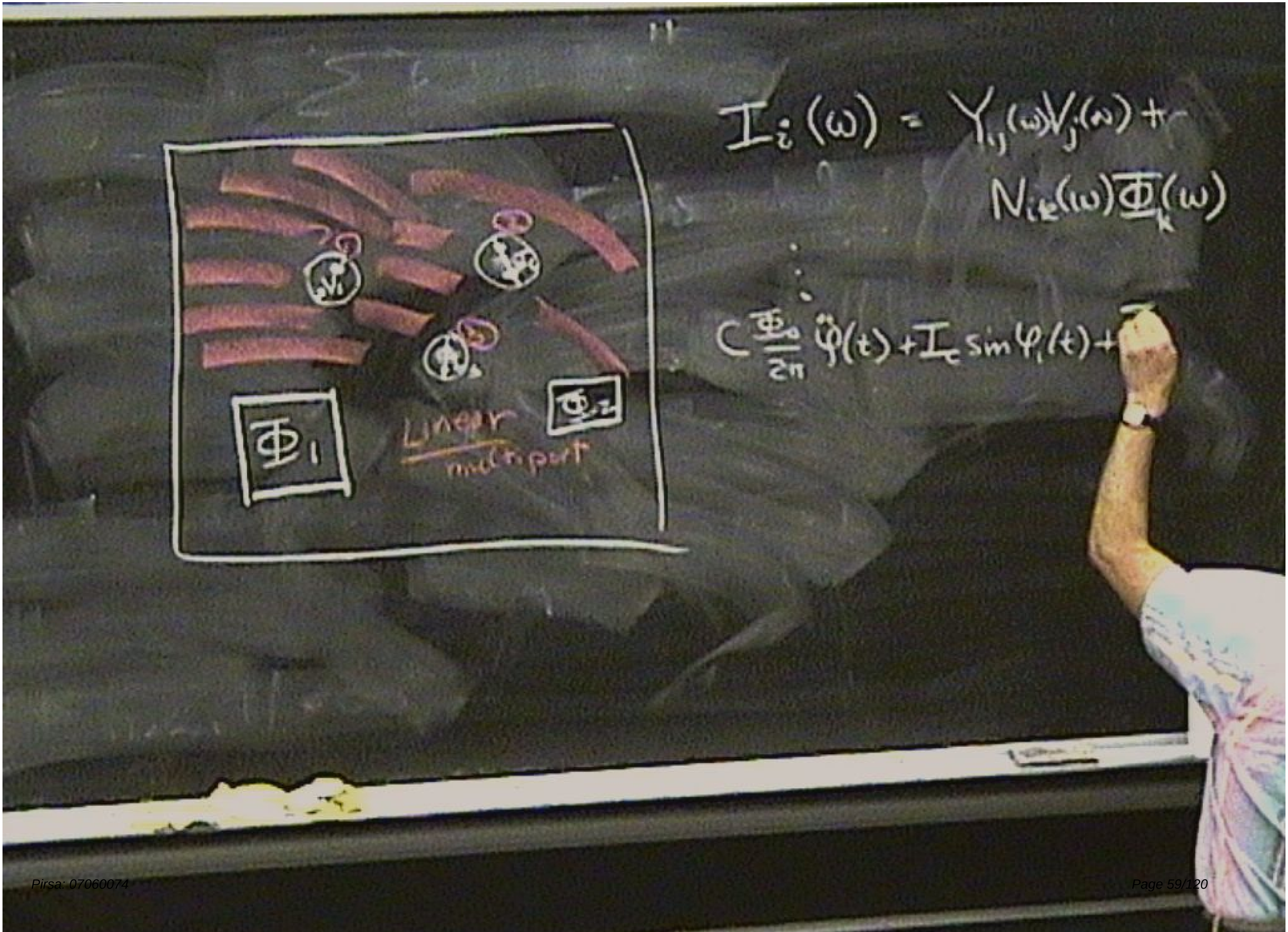

S.J.
Resistively Shunted Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
= f(V(t))
R
C
10-50fF
port

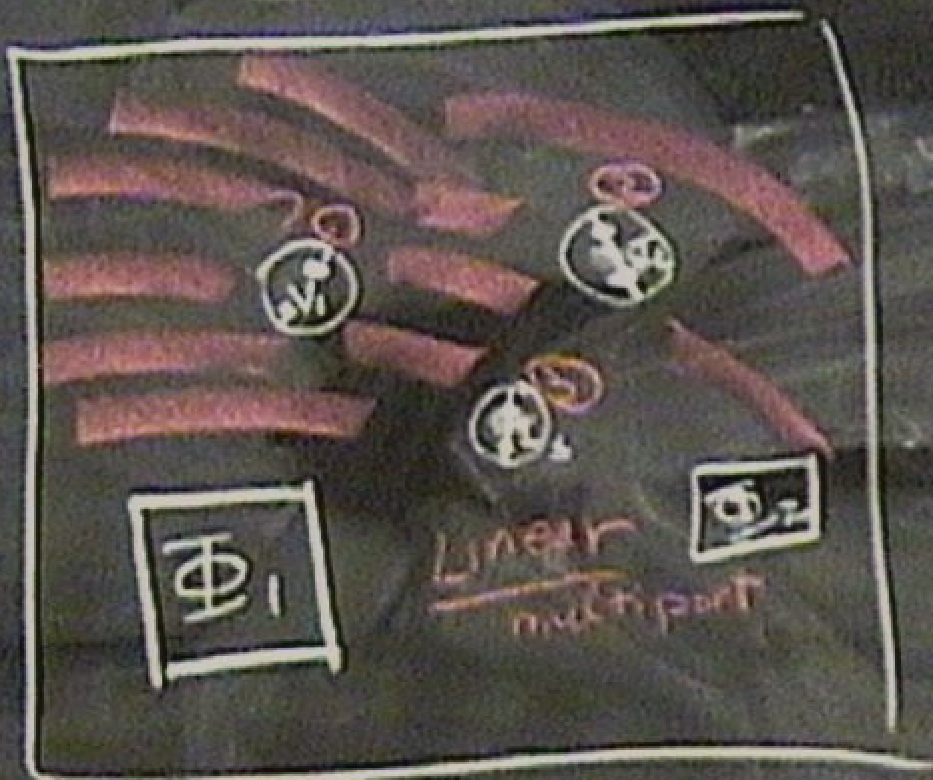

I_i(ω) = Y_ij(ω)V_j(ω) +
N_ik(ω)Φ_k(ω)
Φ_1
Φ_2
Linear
multiport


Resistively
Shunted
Junction
RSJ
$V(t) = \frac{\Phi_0}{2\pi}\dot{\varphi}(t)$
$I(t) = I_c \sin\varphi(t)$
$I(t) \propto \varphi(t)$
$\dot{I}(t) \propto \dot{\varphi} \propto V(t)$
$\dot{I}(t) = L^{-1}V(t)$
$= f(V(t))$
R
∞
C
10-50fF
Ideal
port


S.J.
Resistively Shunted Junction
RSJ
$V(t) = \frac{\Phi_0}{2\pi}\dot{\varphi}(t)$
$I(t) = I_c \sin\varphi(t)$
$I(t) \propto \varphi(t)$
$\dot{I}(t) \propto \dot{\varphi} \propto V(t)$
$\dot{I}(t) = L^{-1} V(t)$
$= f(V(t))$
R
C
10-50 fF
∞
port
ideal



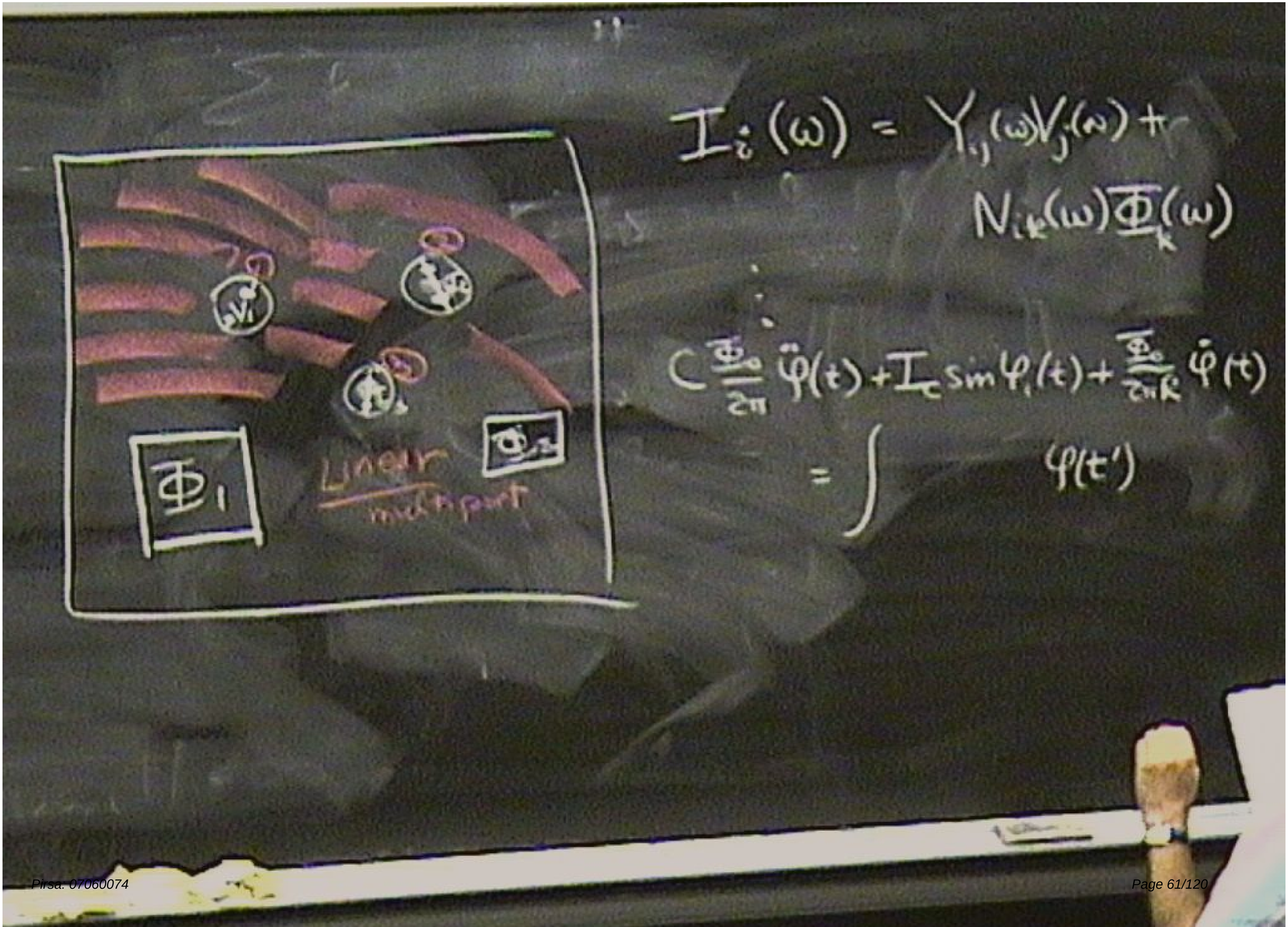

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$
$C\frac{\Phi_0}{2\pi}\ddot{\varphi}(t) + I_c \sin\varphi_i(t) +$
Φ_1
Φ_2
Linear
multiport

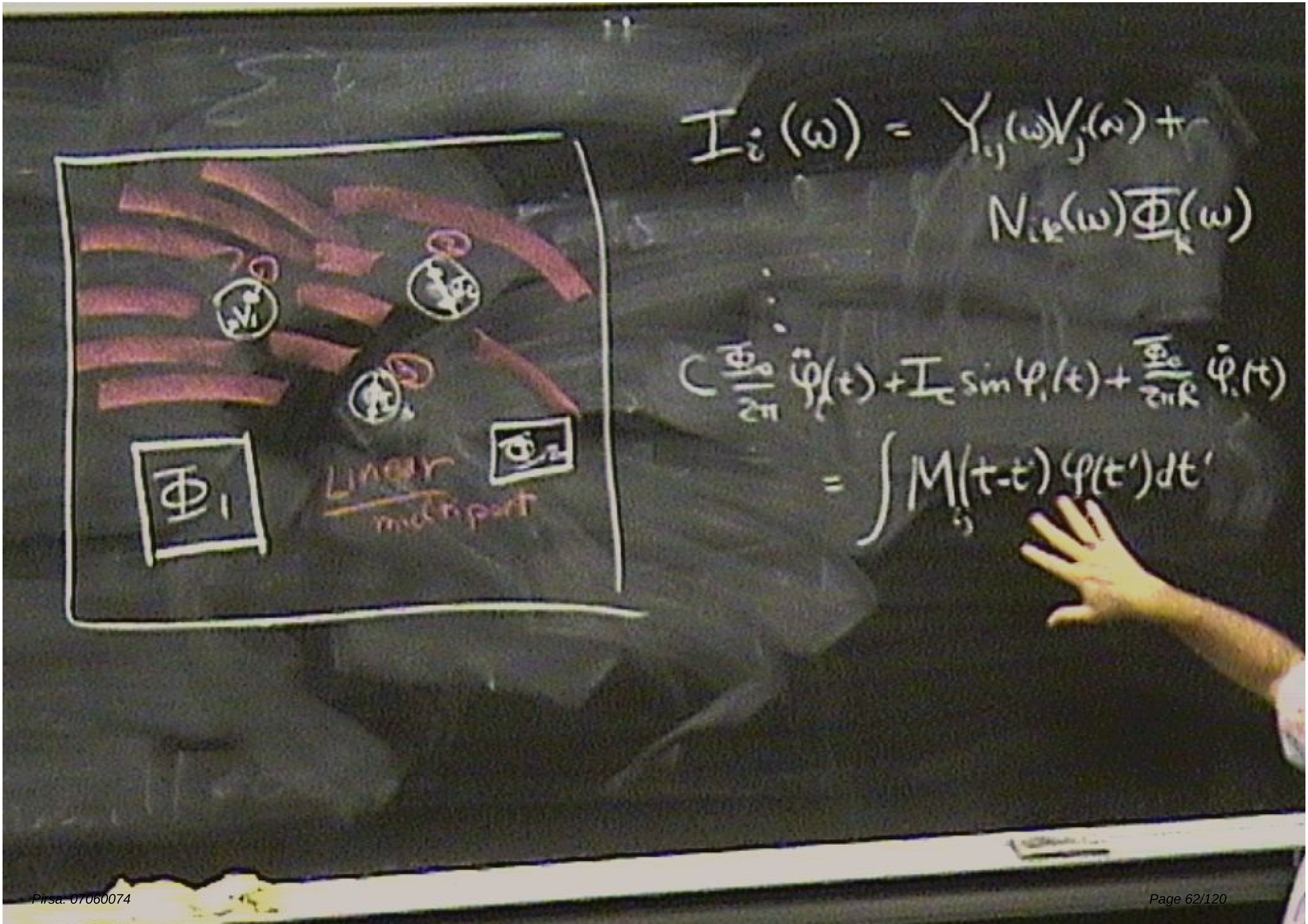


$$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$$

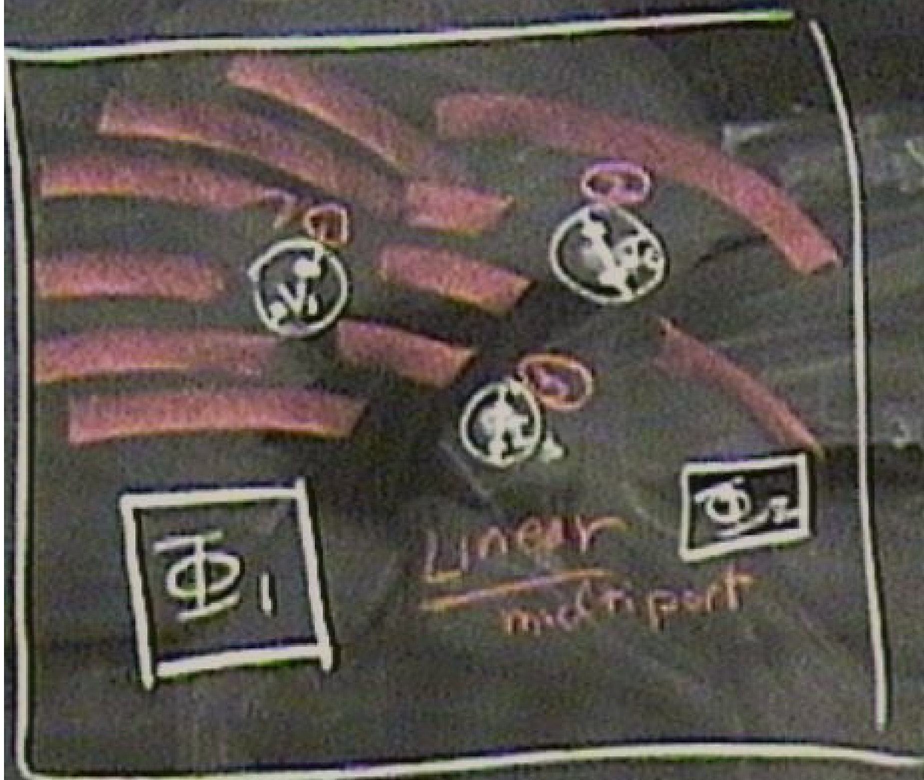
$$\vdots$$

$$C\frac{\Phi_0}{2\pi}\ddot{\varphi}(t) + I_c \sin\varphi_1(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}(t)$$


$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) +$
$N_{ik}(\omega)\Phi_k(\omega)$
$C\frac{\Phi_0}{2\pi}\ddot{\varphi}(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}(t)$
$= \int \qquad \varphi(t')$
Φ_1
Φ_2
Linear
multiport



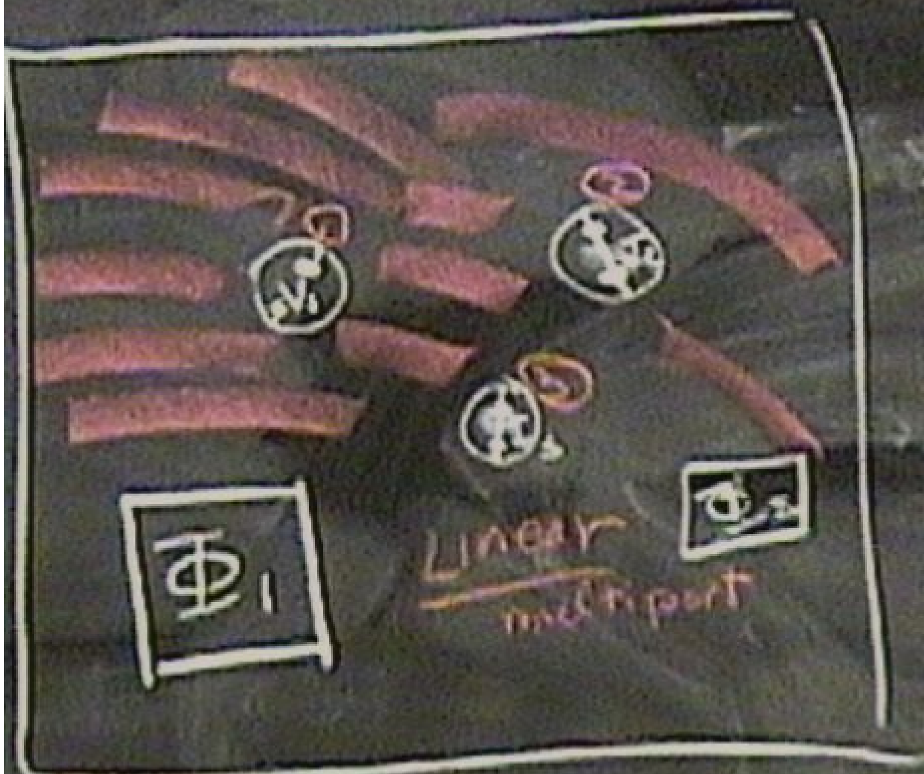
$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$
$C\frac{\Phi_0}{2\pi}\ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}_i(t) = \int M_{ij}(t-t')\varphi(t')dt'$
Φ_1
Φ_2
Linear
multiport



$$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$$

$$\vdots$$

$$C\frac{\Phi_0}{2\pi}\ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi}\dot{\varphi}_i(t) = \int M_{ij}(t-t')\,\varphi_j(t')\,dt' + \int N_{ik}(t-t')\,\Phi_k(t')\,dt'$$

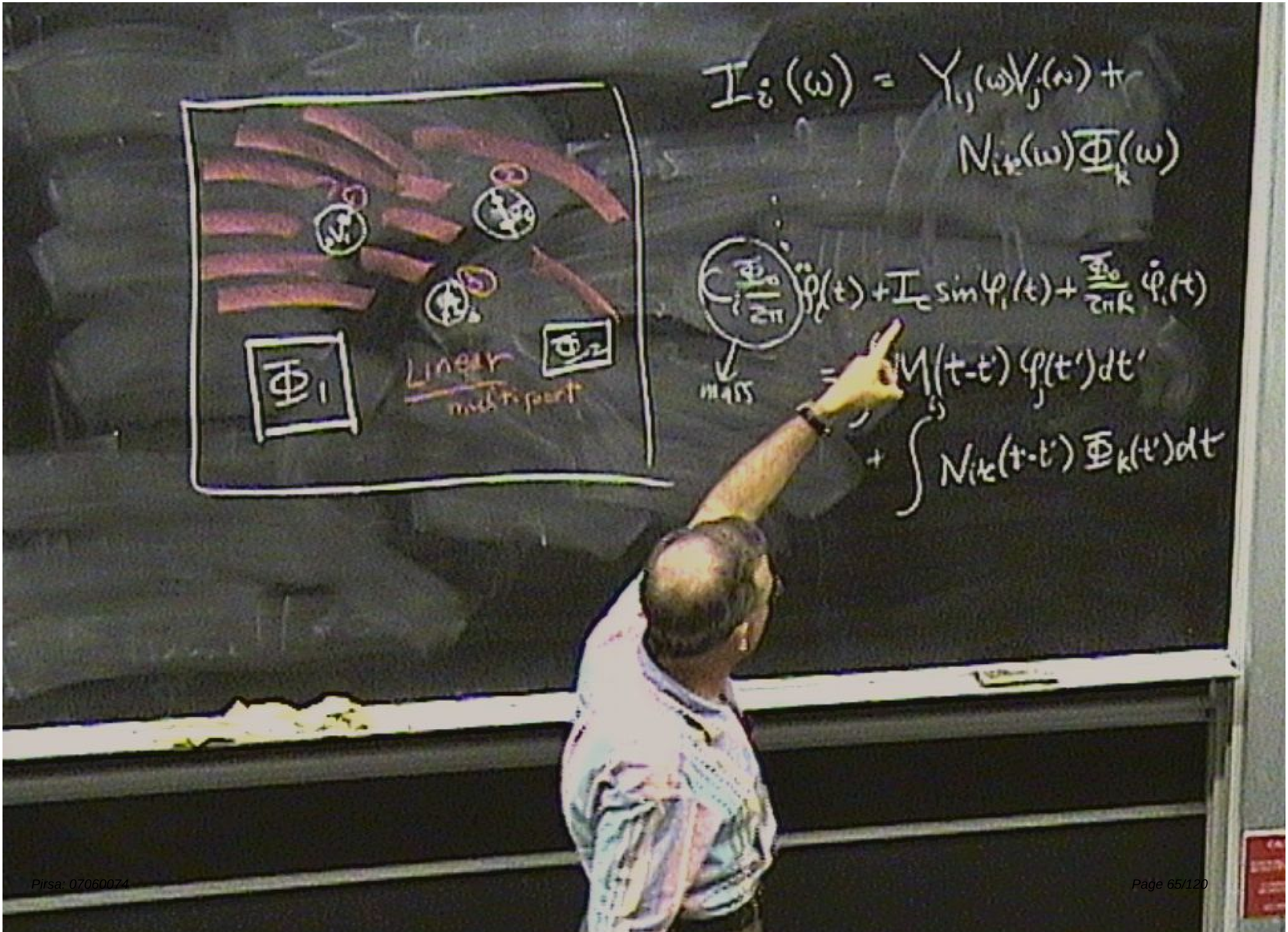


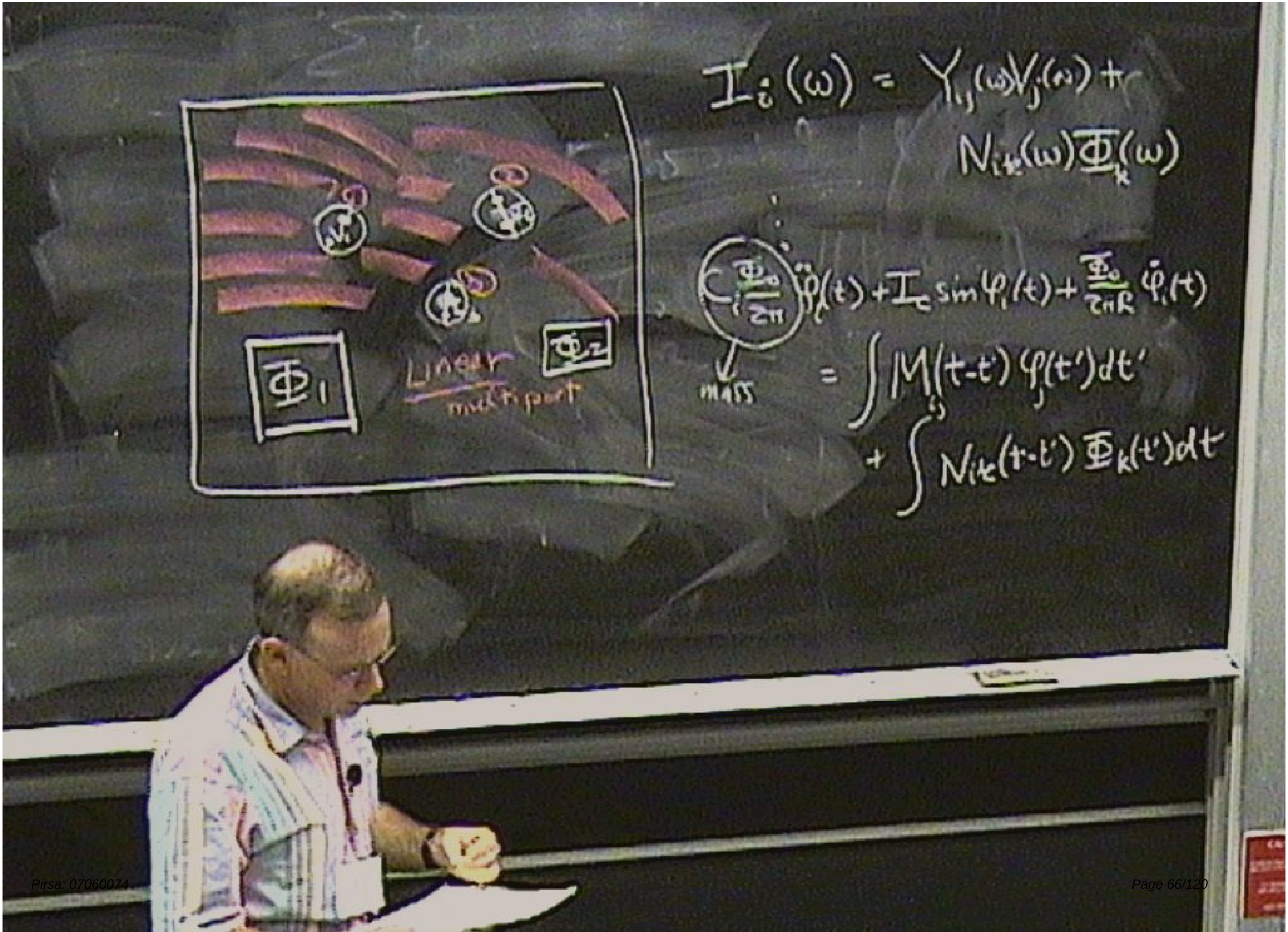
$$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$$

$$\vdots$$

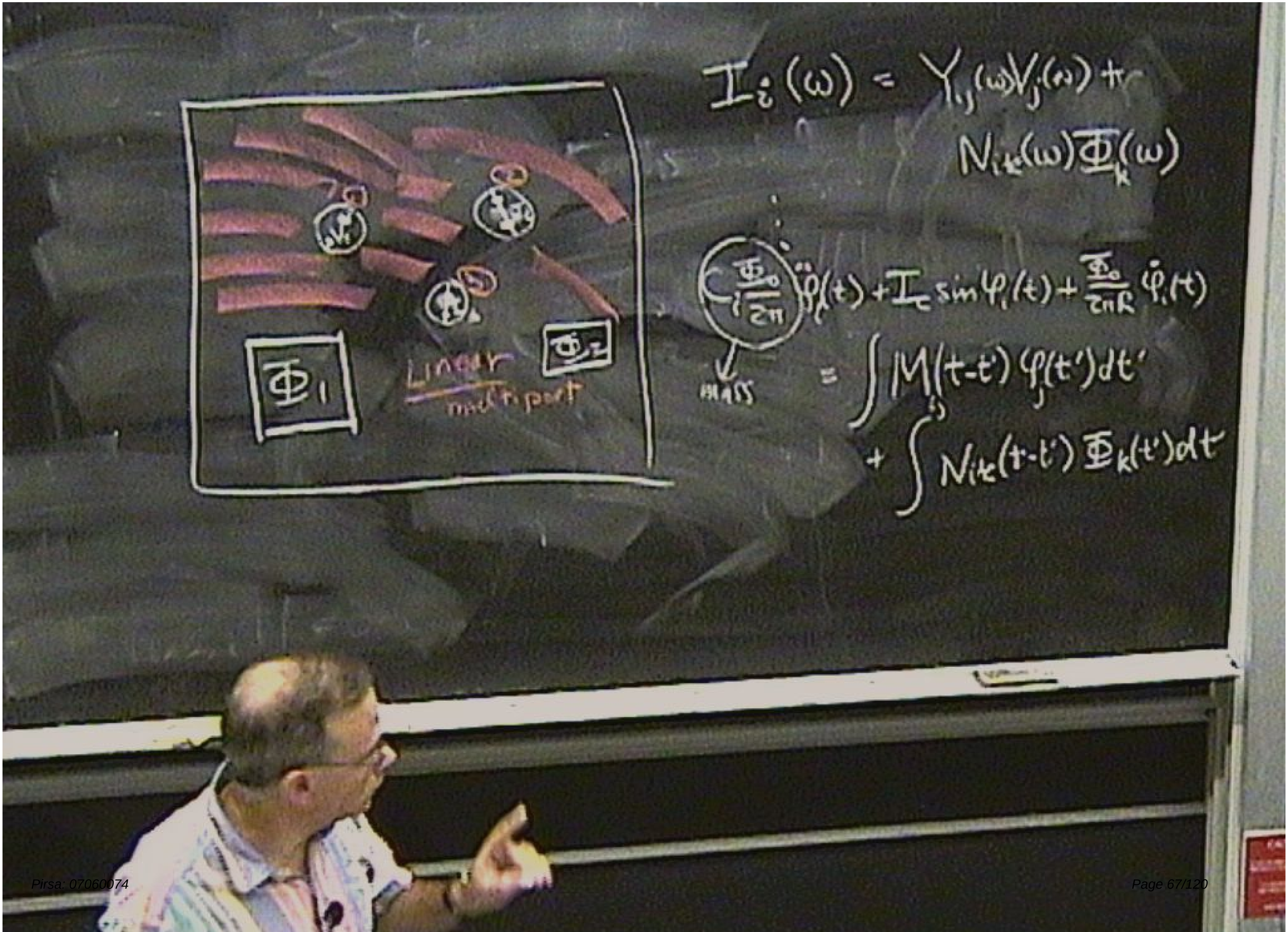
$$C\frac{\Phi_0}{2\pi}\ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}_i(t)$$

$$= \int M_{ij}(t-t')\,\varphi_j(t')\,dt' + \int N_{ik}(t-t')\,\Phi_k(t')\,dt$$

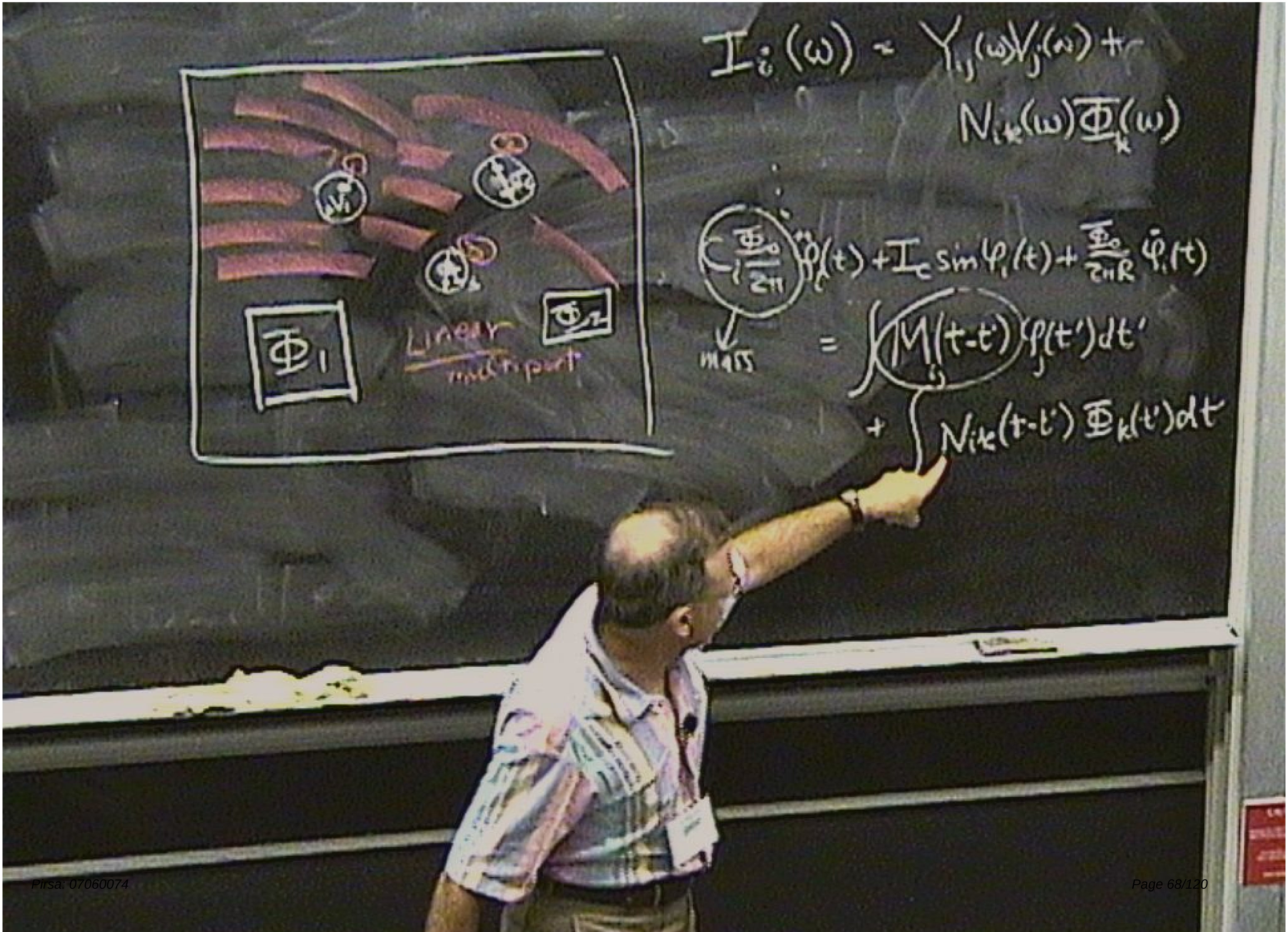

Linear
mass

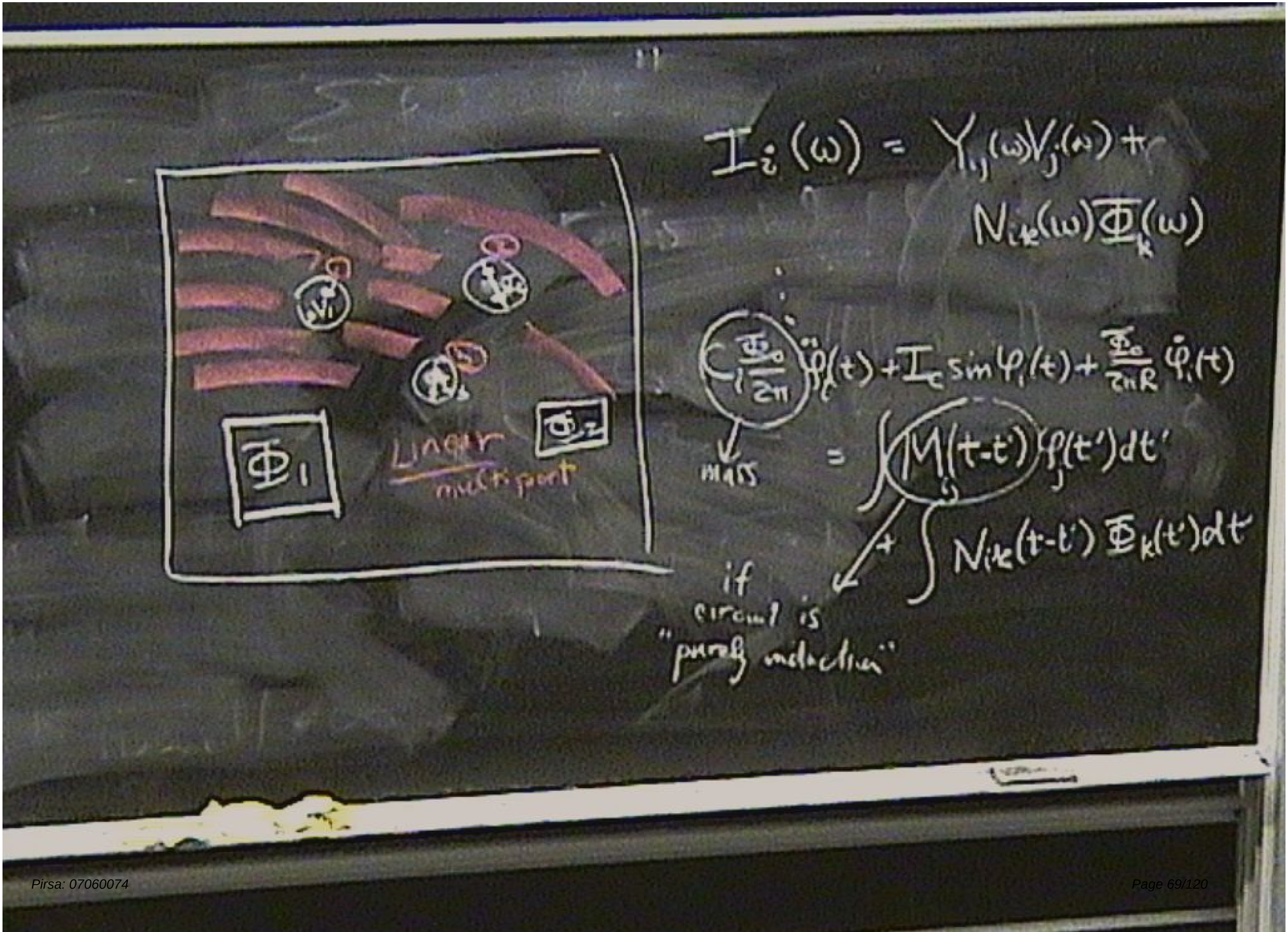


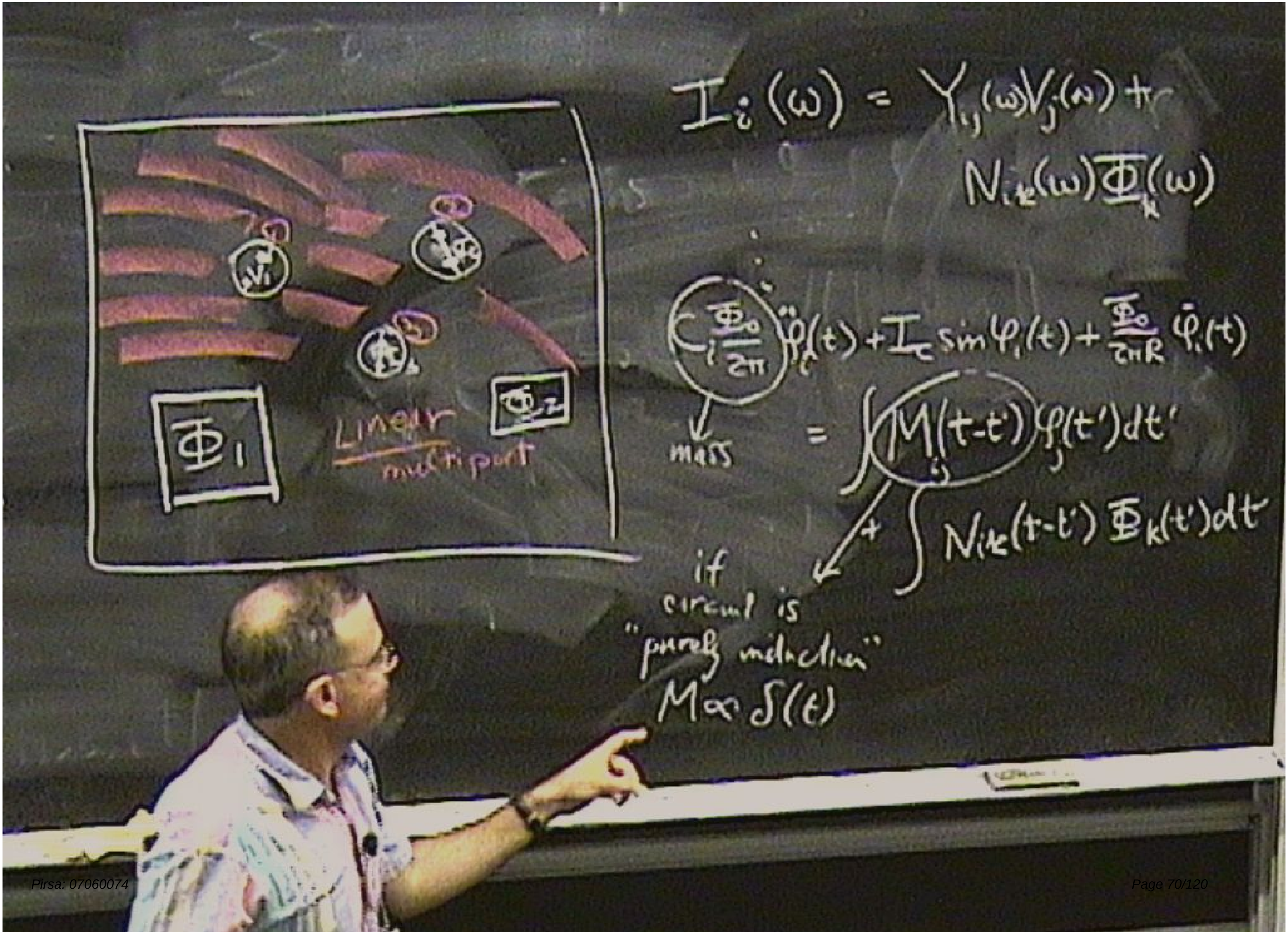
Linear
multiport
mass



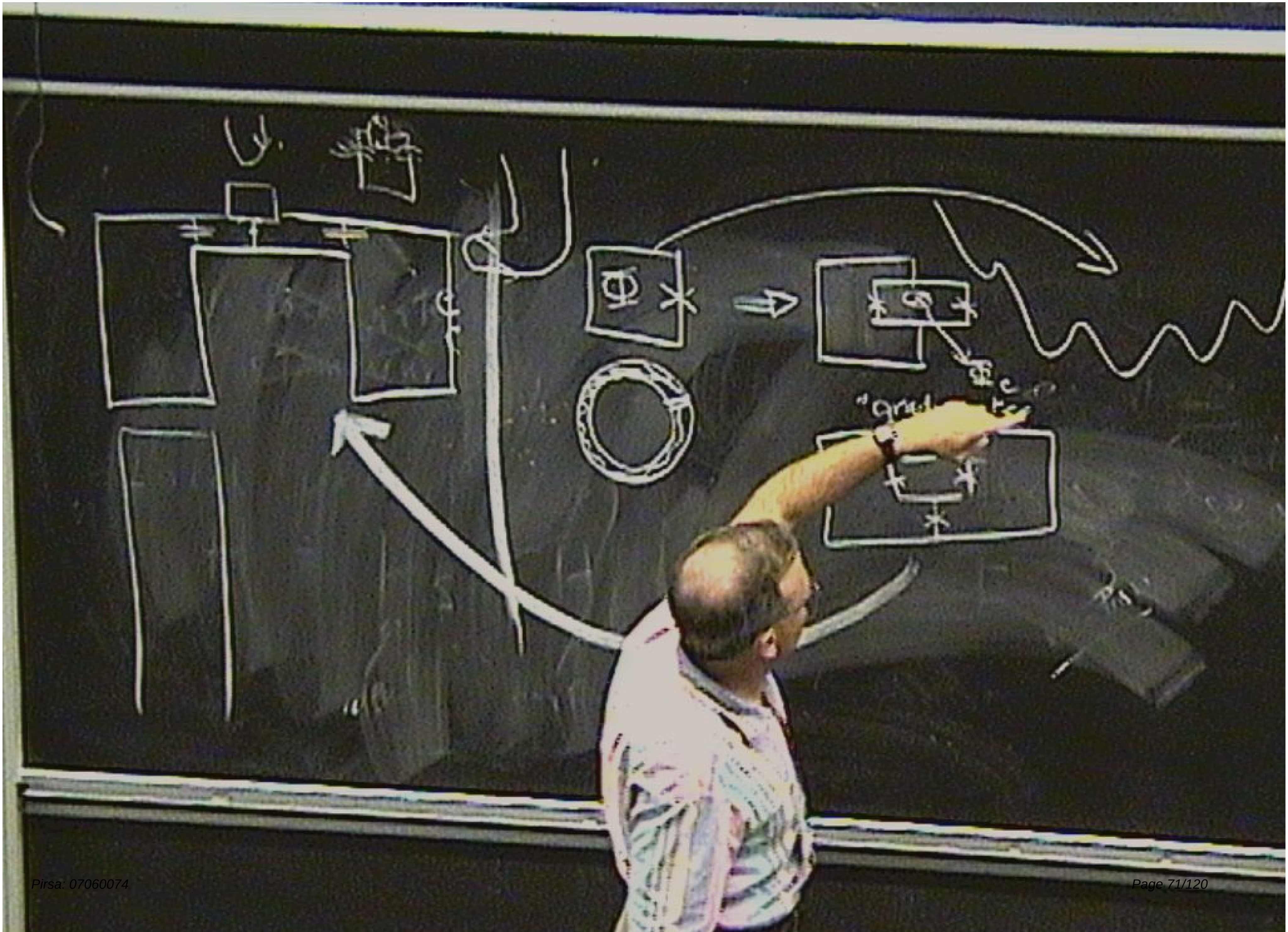
I_i(ω) = Y_ij(ω)V_j(ω) +
N_ik(ω)Φ_k(ω)
Φ_1
Φ_2
Linear
multiport
MASS
C (Φ_0/2π) φ̈_i(t) + I_c sin φ_i(t) + (Φ_0/2πR) φ̇_i(t)
= ∫ M_ij(t-t') φ_j(t') dt'
+ ∫ N_ik(t-t') Φ_k(t') dt'

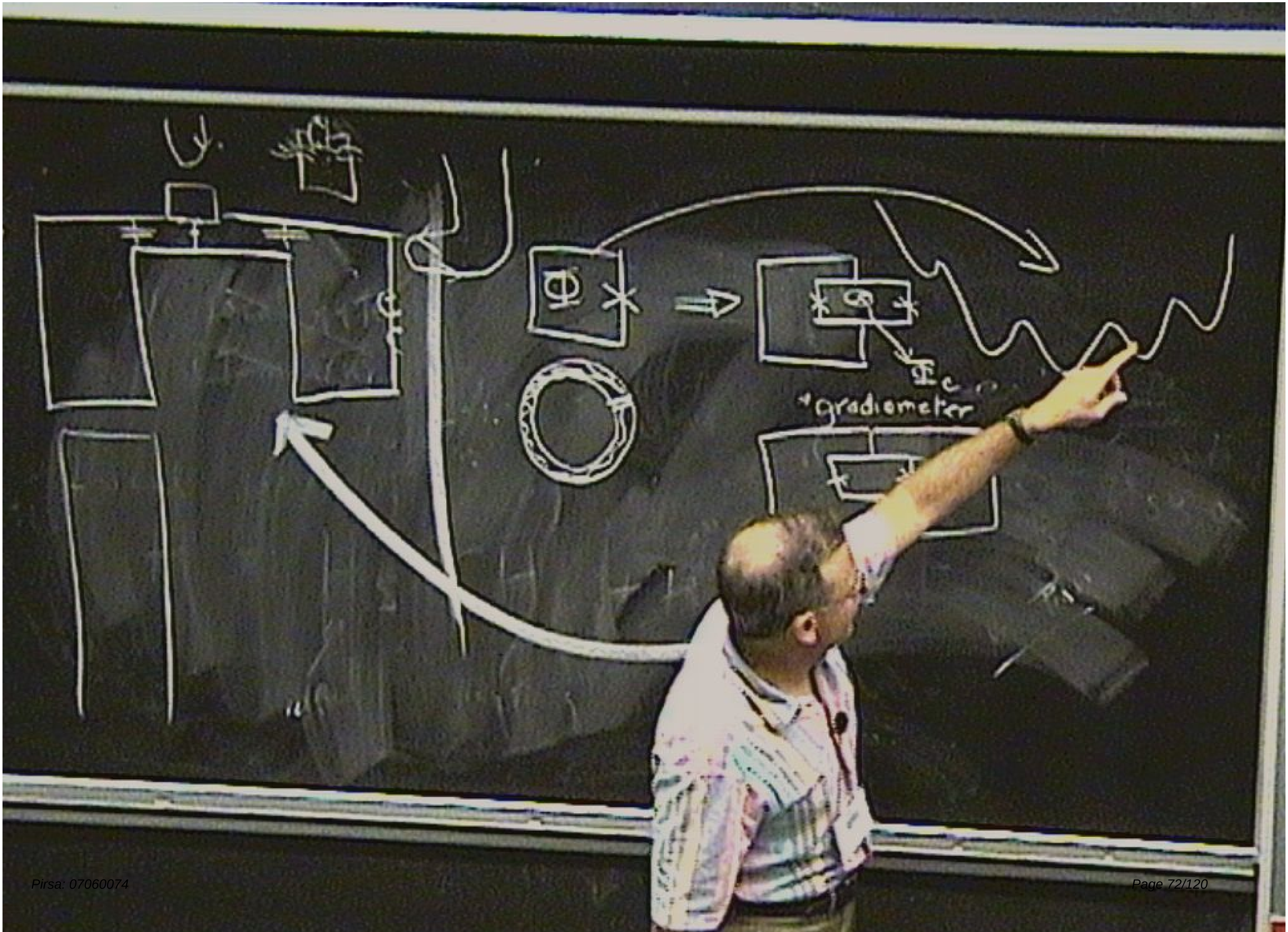

Linear multiport
mass


$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) +$
$N_{ik}(\omega)\Phi_k(\omega)$
$\frac{\Phi_0}{2\pi} C \ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}_i(t)$
mass
$= \int M_{ij}(t-t')\varphi_j(t')dt'$
$+ \int N_{ik}(t-t')\Phi_k(t')dt'$
if circuit is "purely inductive"
Linear multiport
Φ_1
Φ_2

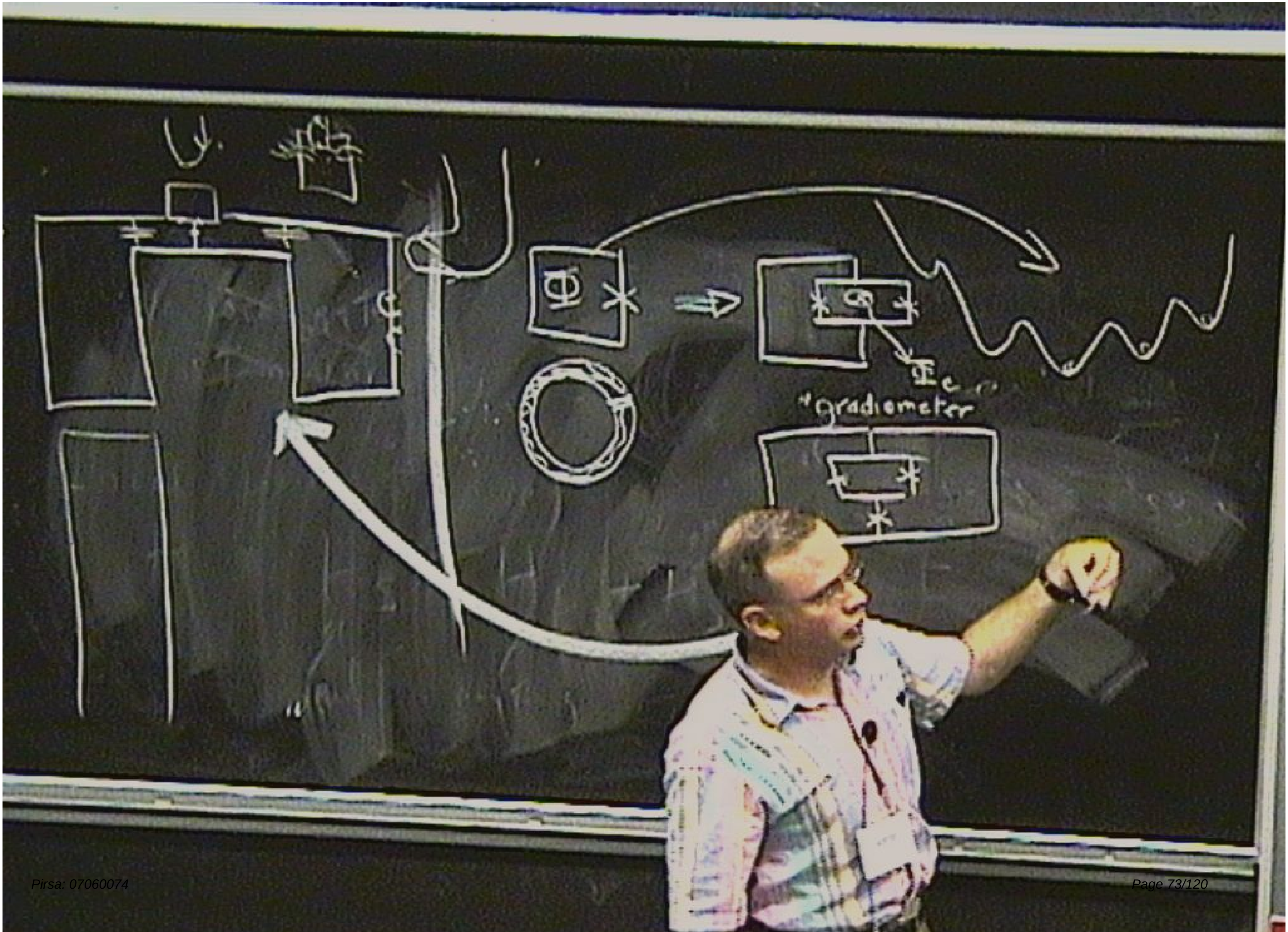


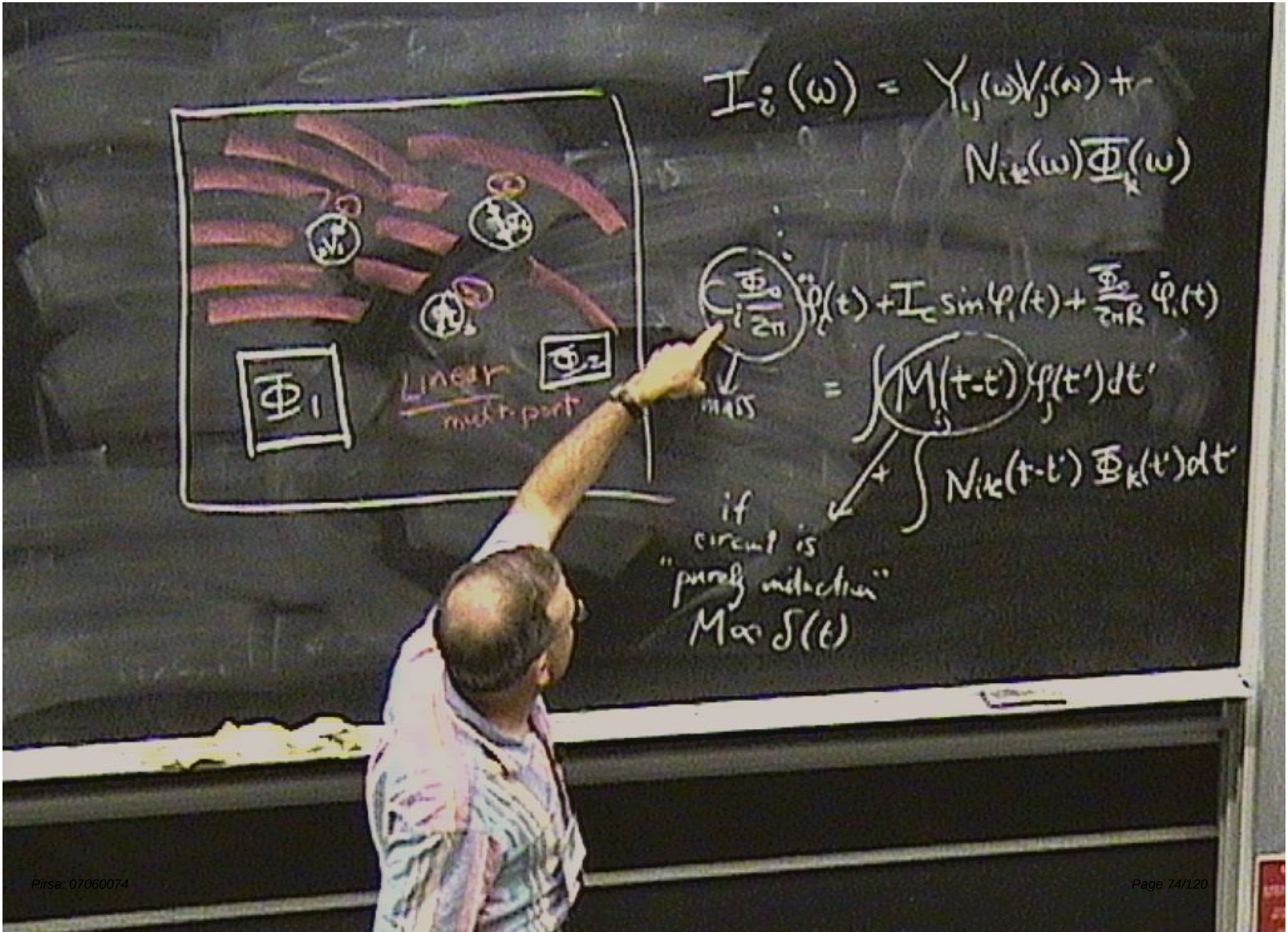
$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$
$C_i \frac{\Phi_0}{2\pi}\ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}_i(t) = \int M_{ij}(t-t')\varphi_j(t')dt' + \int N_{ik}(t-t')\Phi_k(t')dt'$
mass
if circuit is "purely inductive" $M \propto \delta(t)$
Φ_1
Φ_2
Linear multiport



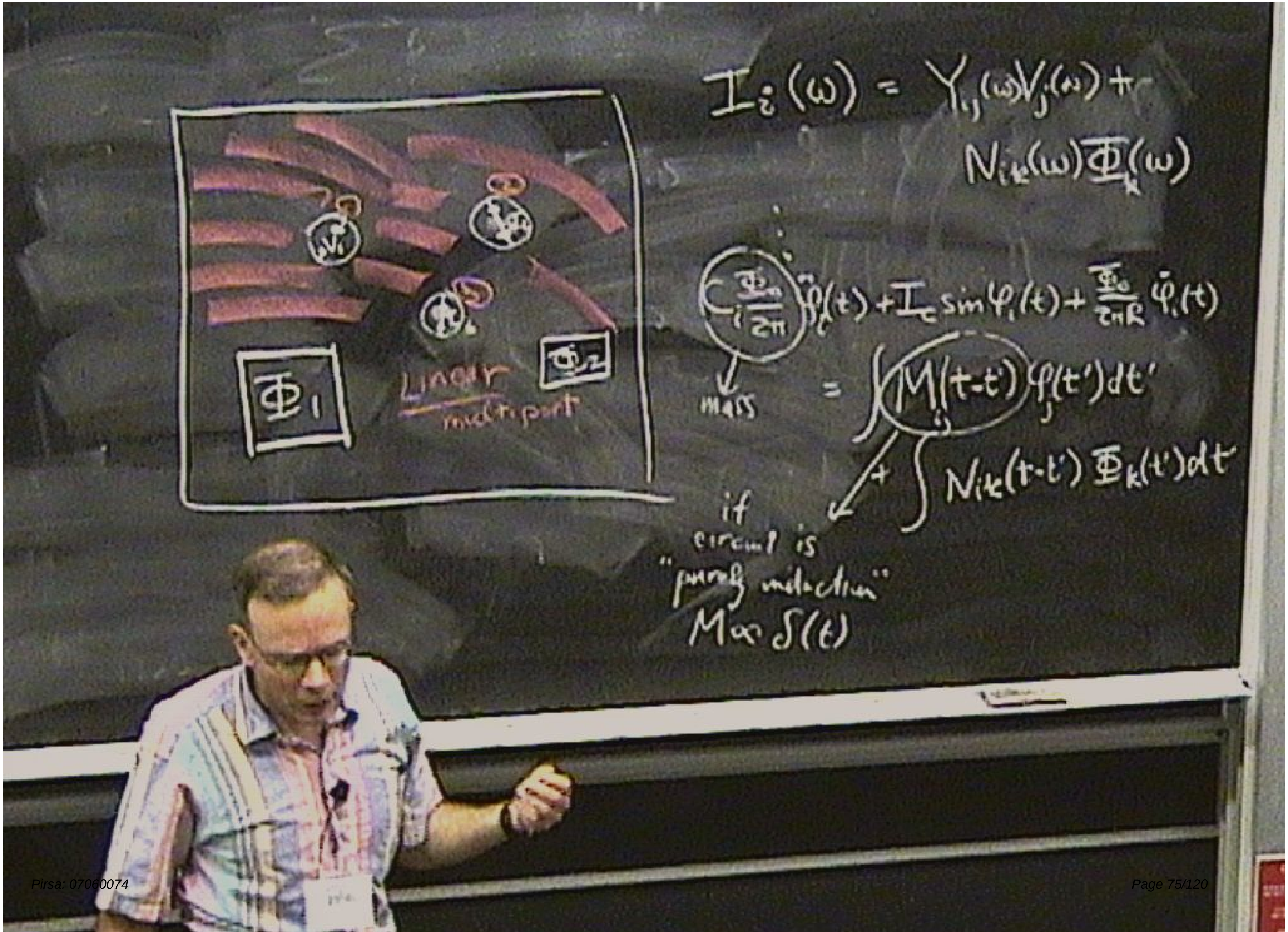


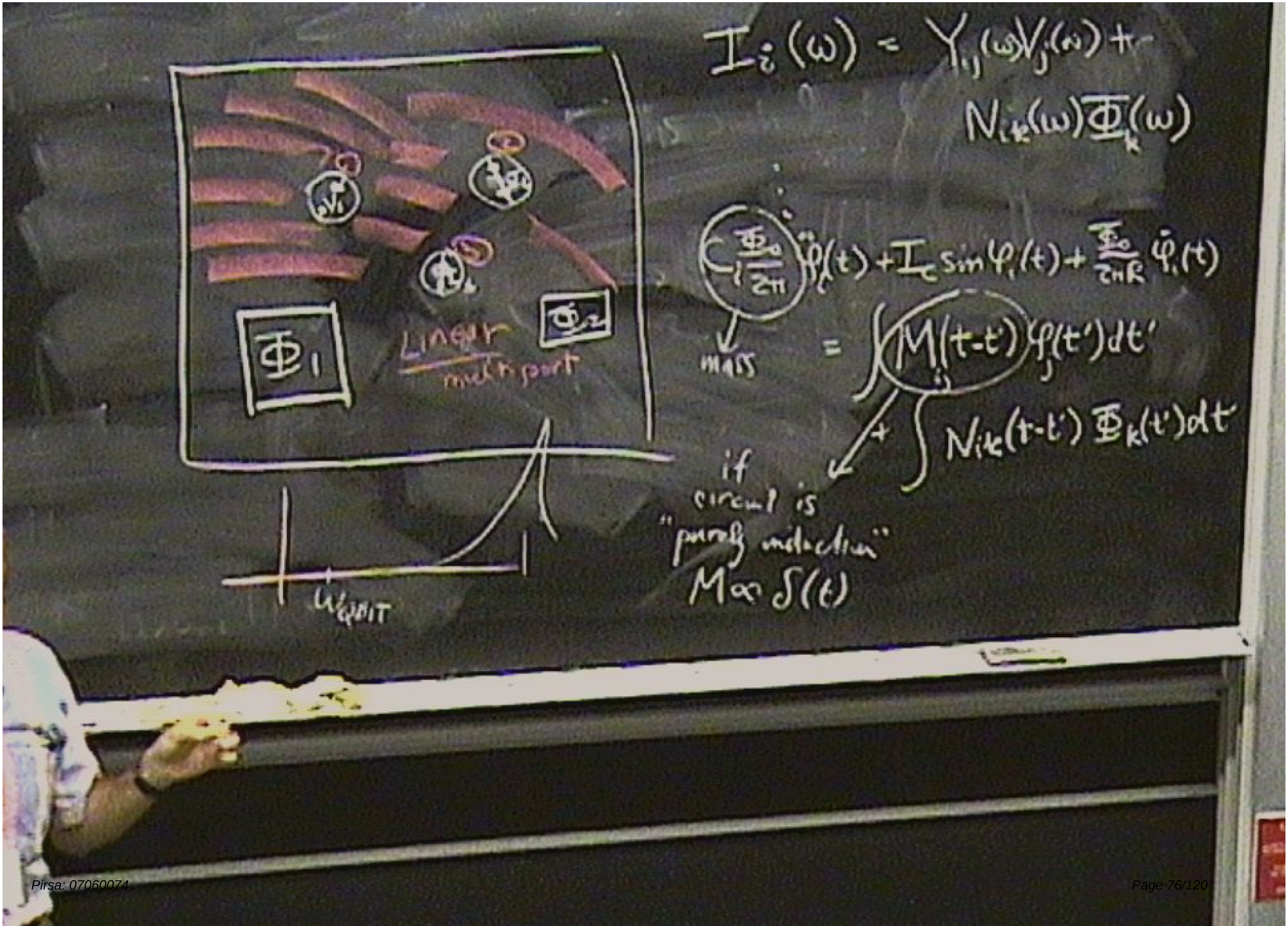
gradiometer

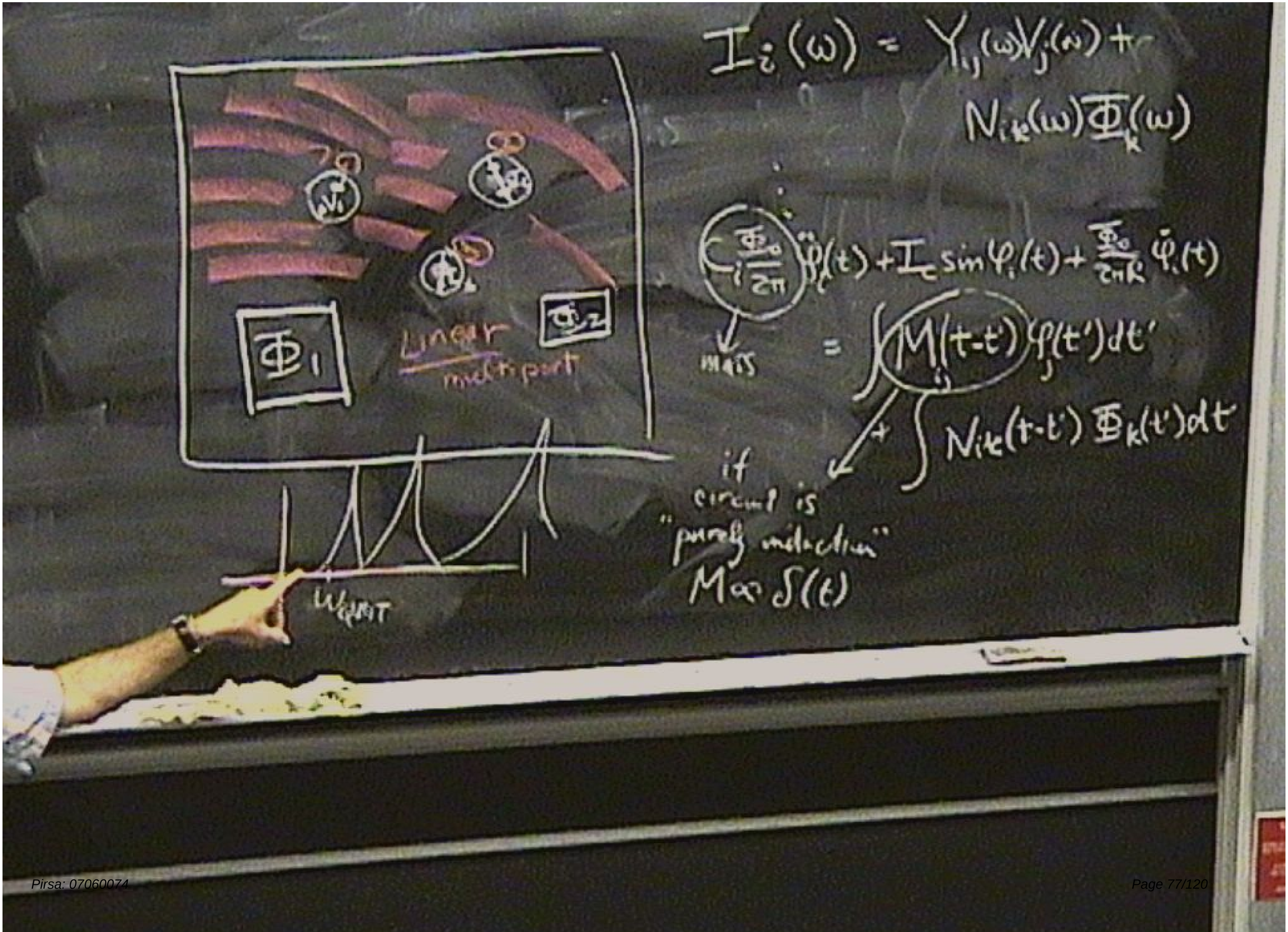

gradiometer

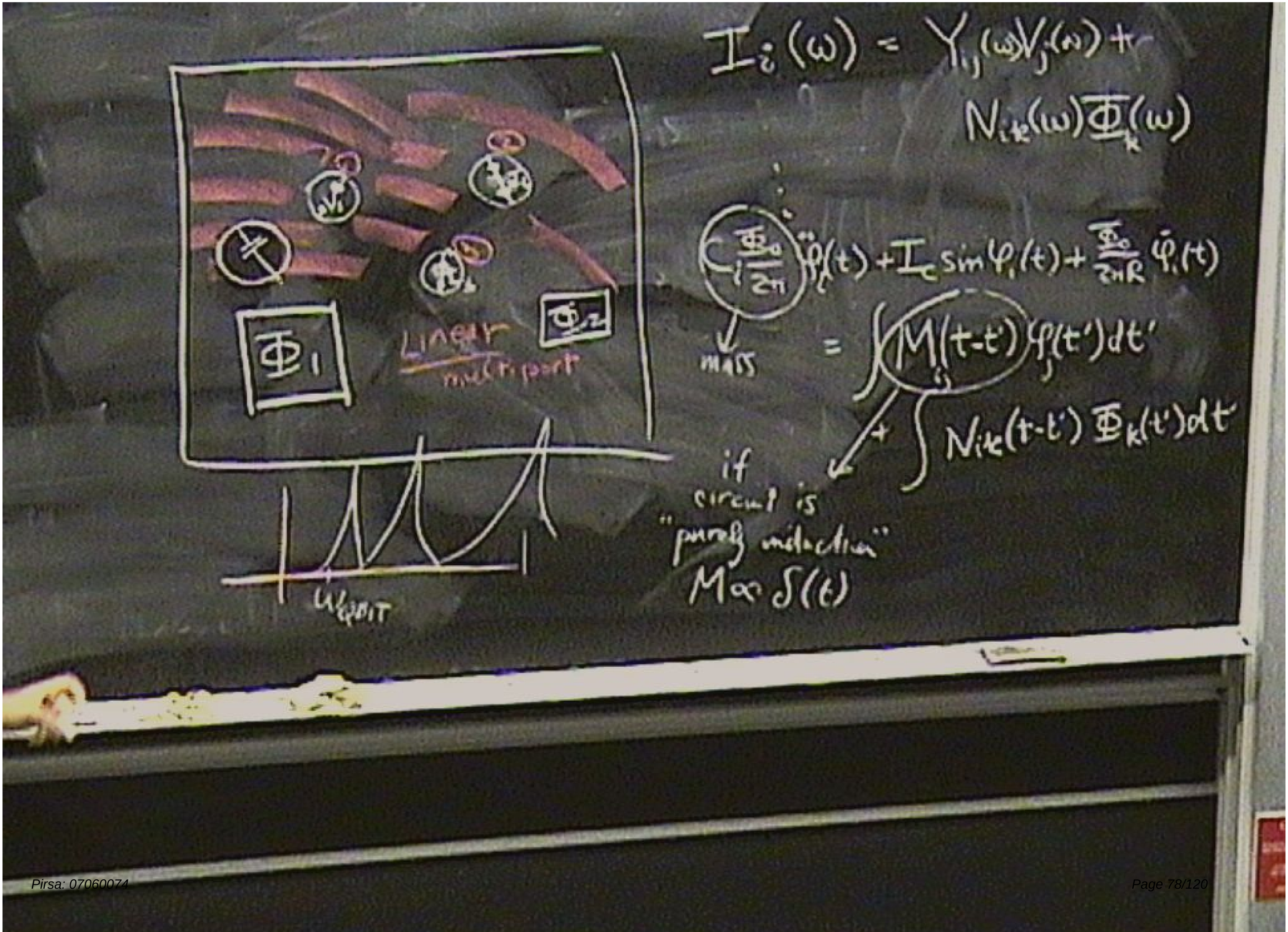


I_i(ω) = Y_ij(ω)V_j(ω) +
N_ik(ω)Φ_k(ω)
Φ_1
Φ_2
Linear
multi-port
mass
if
circuit is
"purely inductive"
M ∝ δ(t)

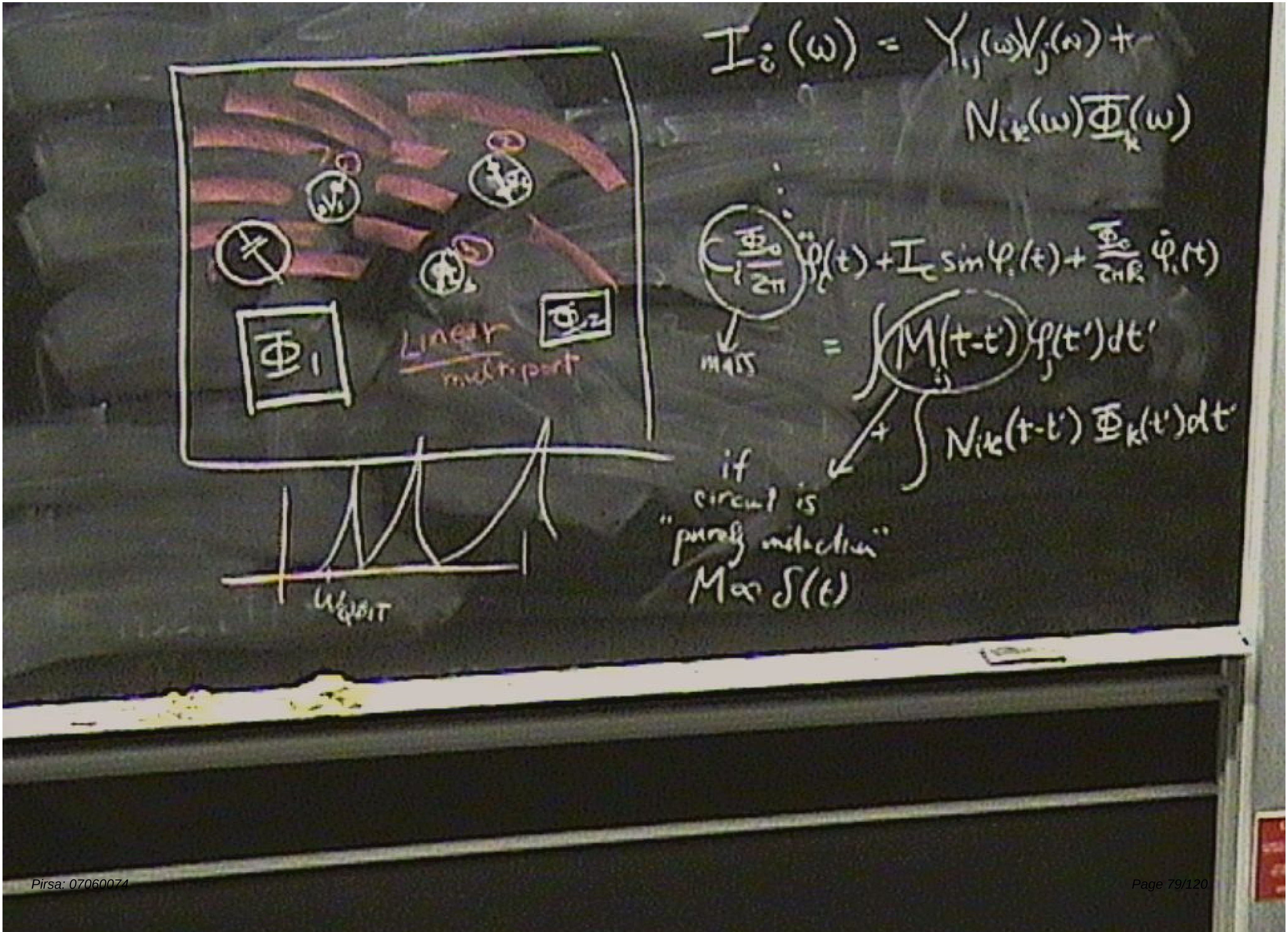

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$
$C_i \frac{\Phi_0}{2\pi}\ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}_i(t) = \int M_{ij}(t-t')\varphi_j(t')dt' + \int N_{ik}(t-t')\Phi_k(t')dt'$
mass
if circuit is "purely inductive"
$M \propto \delta(t)$
Linear multiport
Φ_1
Φ_2

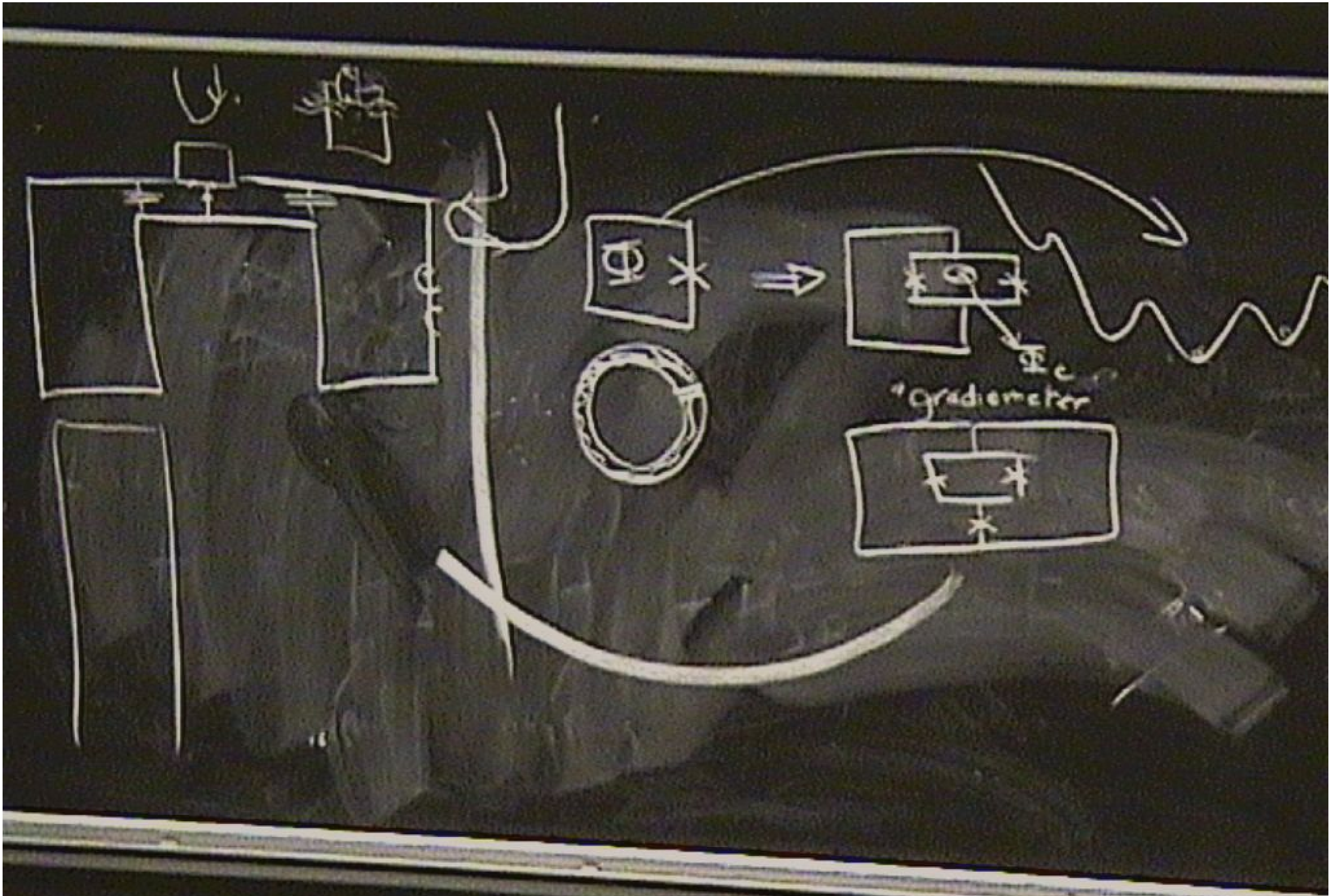

$I_i(\omega) = Y_{ij}(\omega) V_j(\omega) + N_{ik}(\omega) \Phi_k(\omega)$
Φ_1
Φ_2
Linear
multi port
ω_{QBIT}
$C \frac{\Phi_0}{2\pi} \ddot{\varphi}_i(t) + I_c \sin \varphi_i(t) + \frac{\Phi_0}{2\pi R} \dot{\varphi}_i(t)$
mass
$= \int M_{ij}(t-t') \varphi_j(t') dt' + \int N_{ik}(t-t') \Phi_k(t') dt'$
if circuit is "purely inductive"
$M \propto \delta(t)$

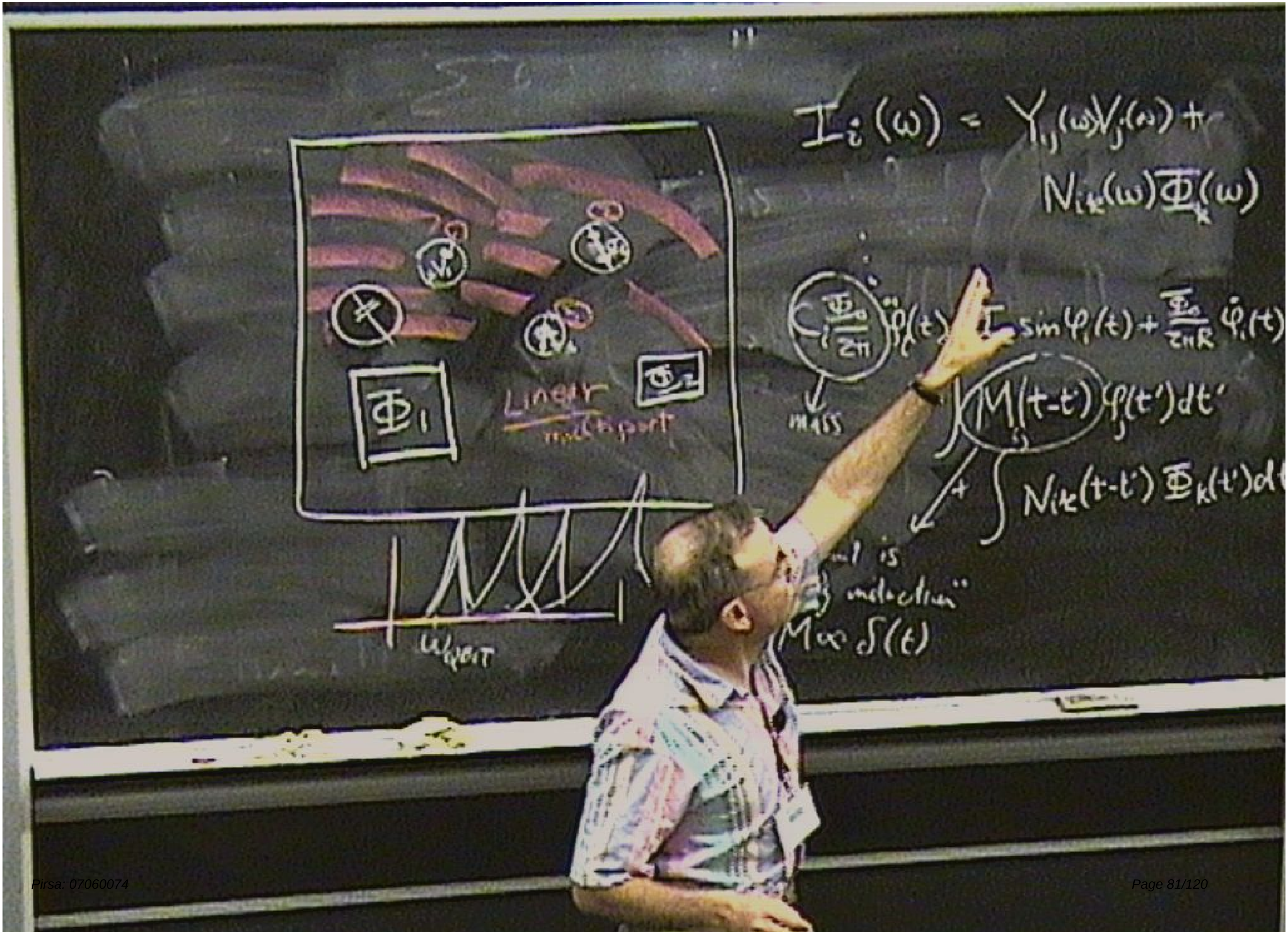

Linear
multi-port
mass
if
circuit is
"purely inductive"
M ∝ δ(t)



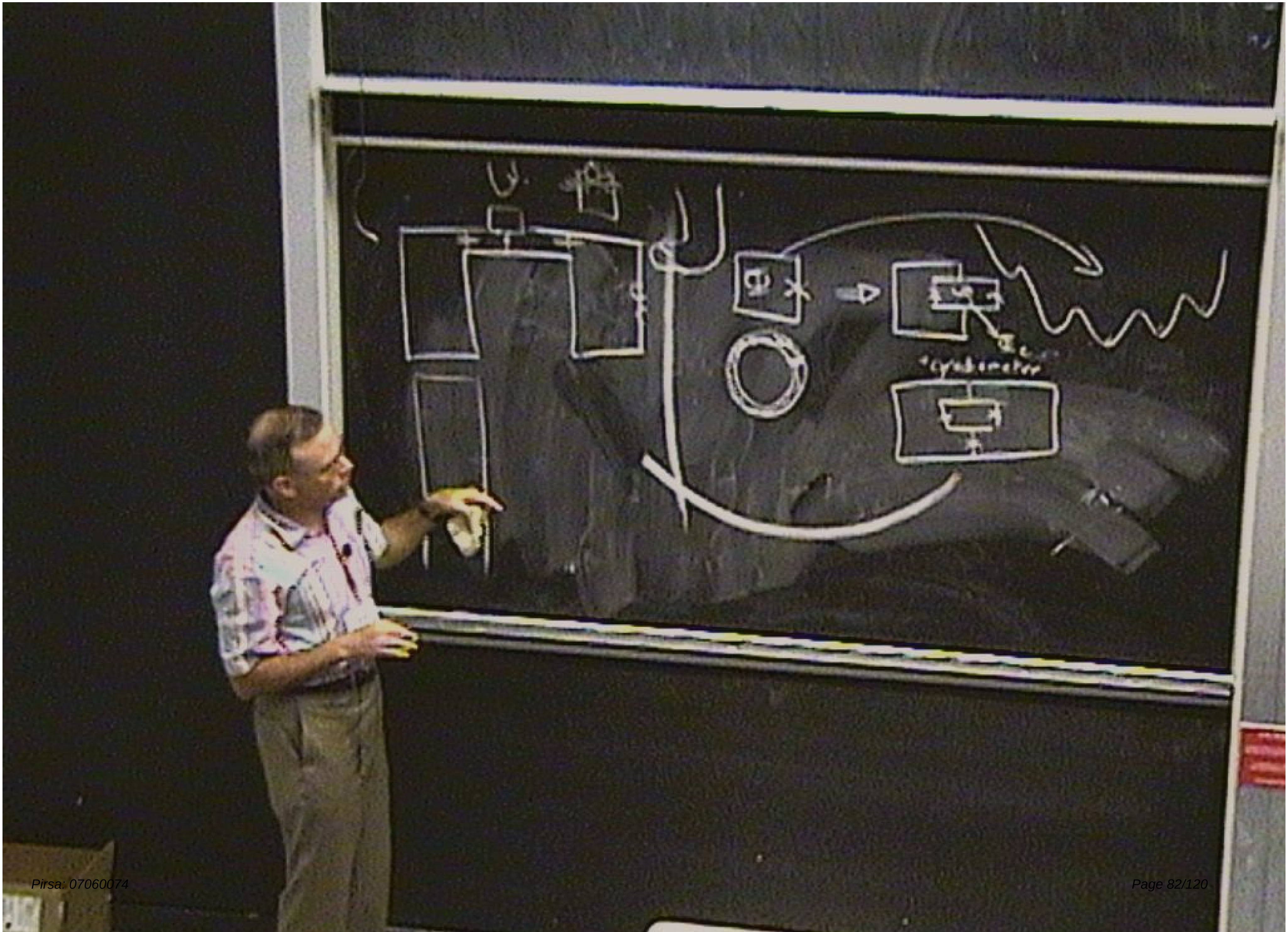
I_i(ω) = Y_ij(ω)V_j(ω) +
N_ik(ω)Φ_k(ω)
C Φ_0/2π φ̈_i(t) + I_c sin φ_i(t) + Φ_0/2πR φ̇_i(t)
mass
= ∫ M_ij(t-t') φ_j(t') dt'
+ ∫ N_ik(t-t') Φ_k(t') dt'
if
circuit is
"purely inductive"
M ∝ δ(t)
Φ_1
Φ_2
Linear
multiport
ω_QUBIT

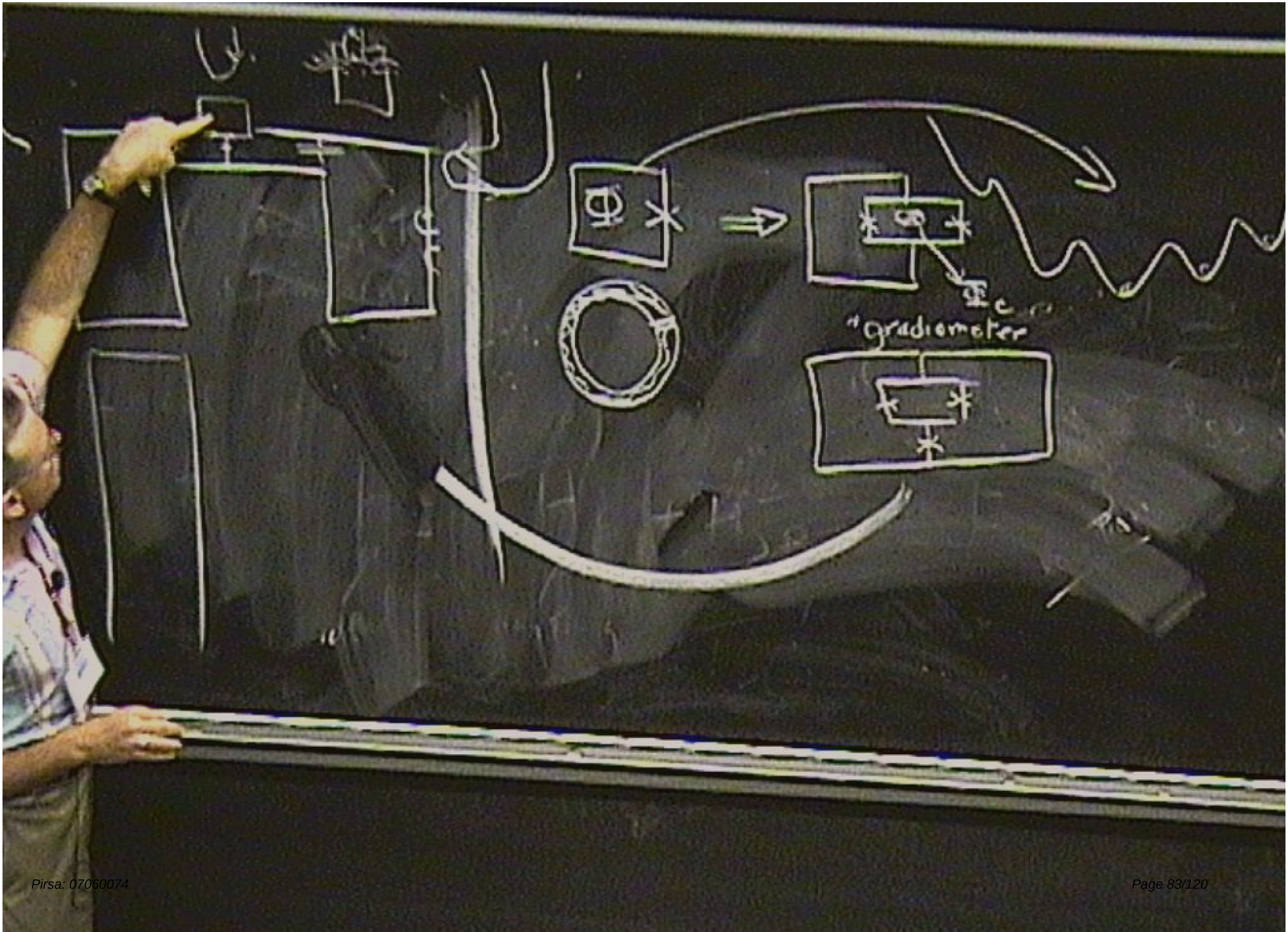

$I_i(\omega) = Y_{ij}(\omega)V_j(\omega) + N_{ik}(\omega)\Phi_k(\omega)$
$C\left(\frac{\Phi_0}{2\pi}\right)\ddot{\varphi}_i(t) + I_c \sin\varphi_i(t) + \frac{\Phi_0}{2\pi R}\dot{\varphi}_i(t) = \int M(t-t')\varphi_j(t')dt' + \int N_{ik}(t-t')\Phi_k(t')dt'$
mass
Linear multiport
Φ_1
Φ_2
ω_{QUBIT}
if circuit is "purely inductive"
$M \propto \delta(t)$

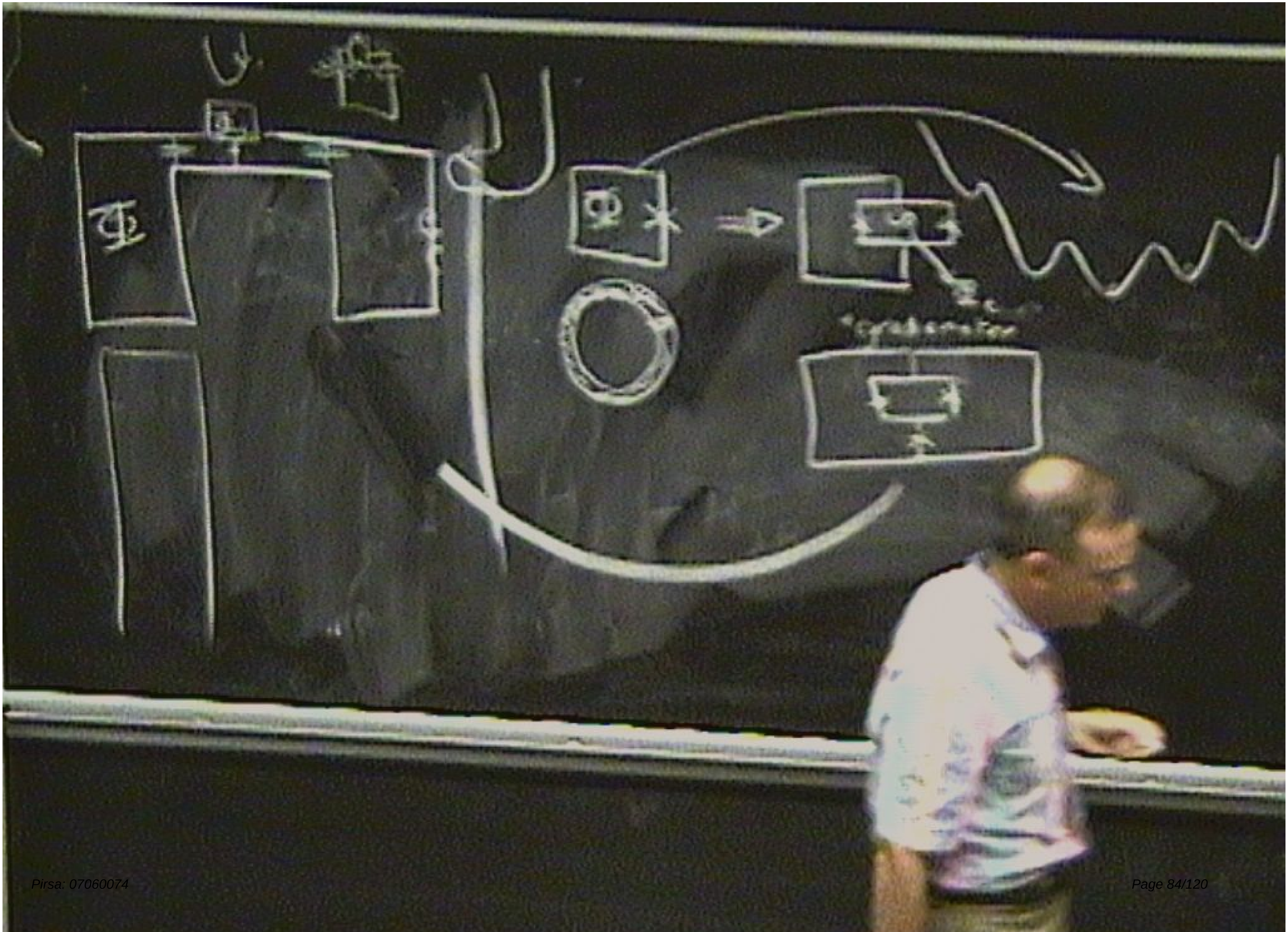

"gradiometer"

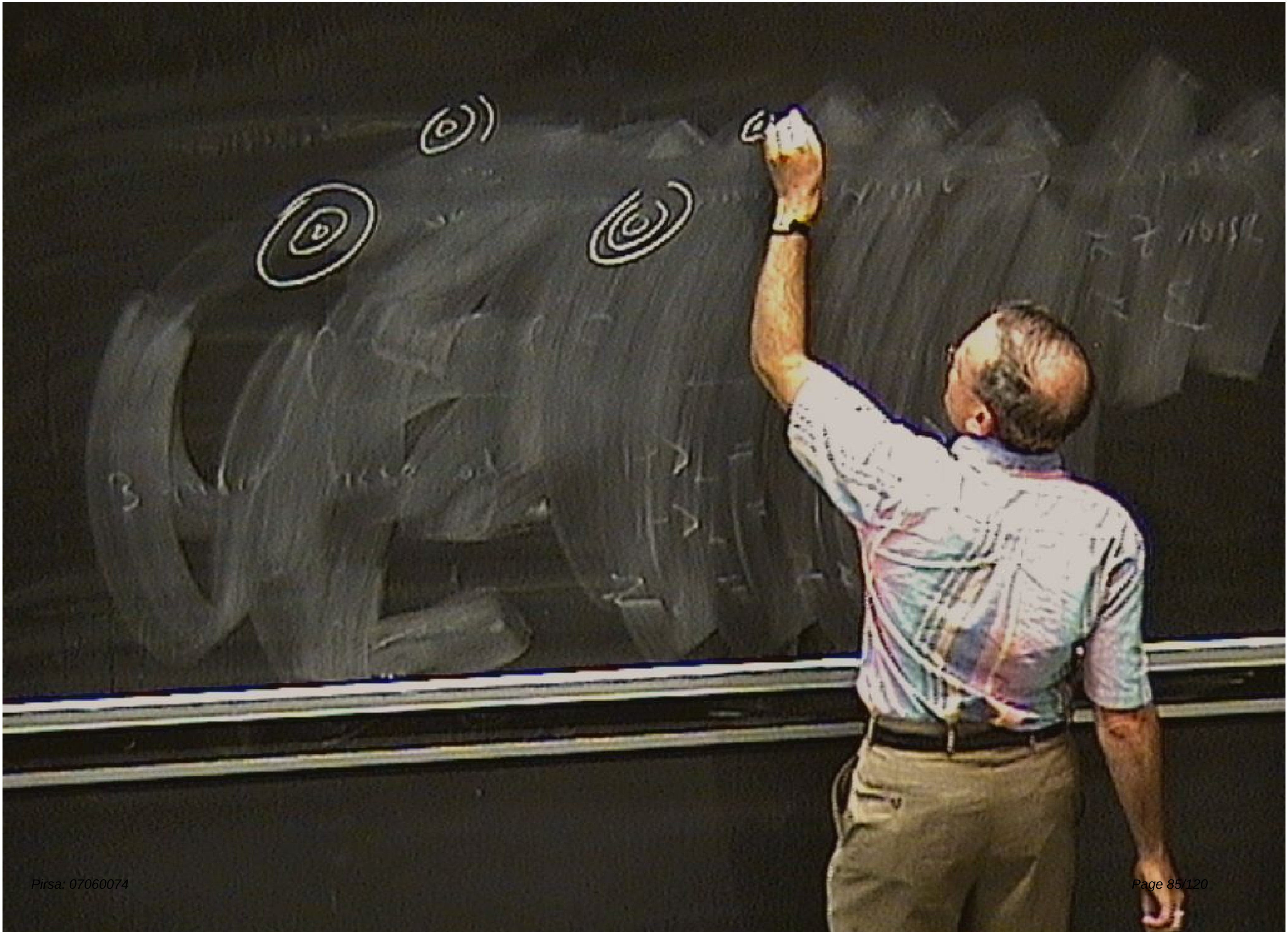


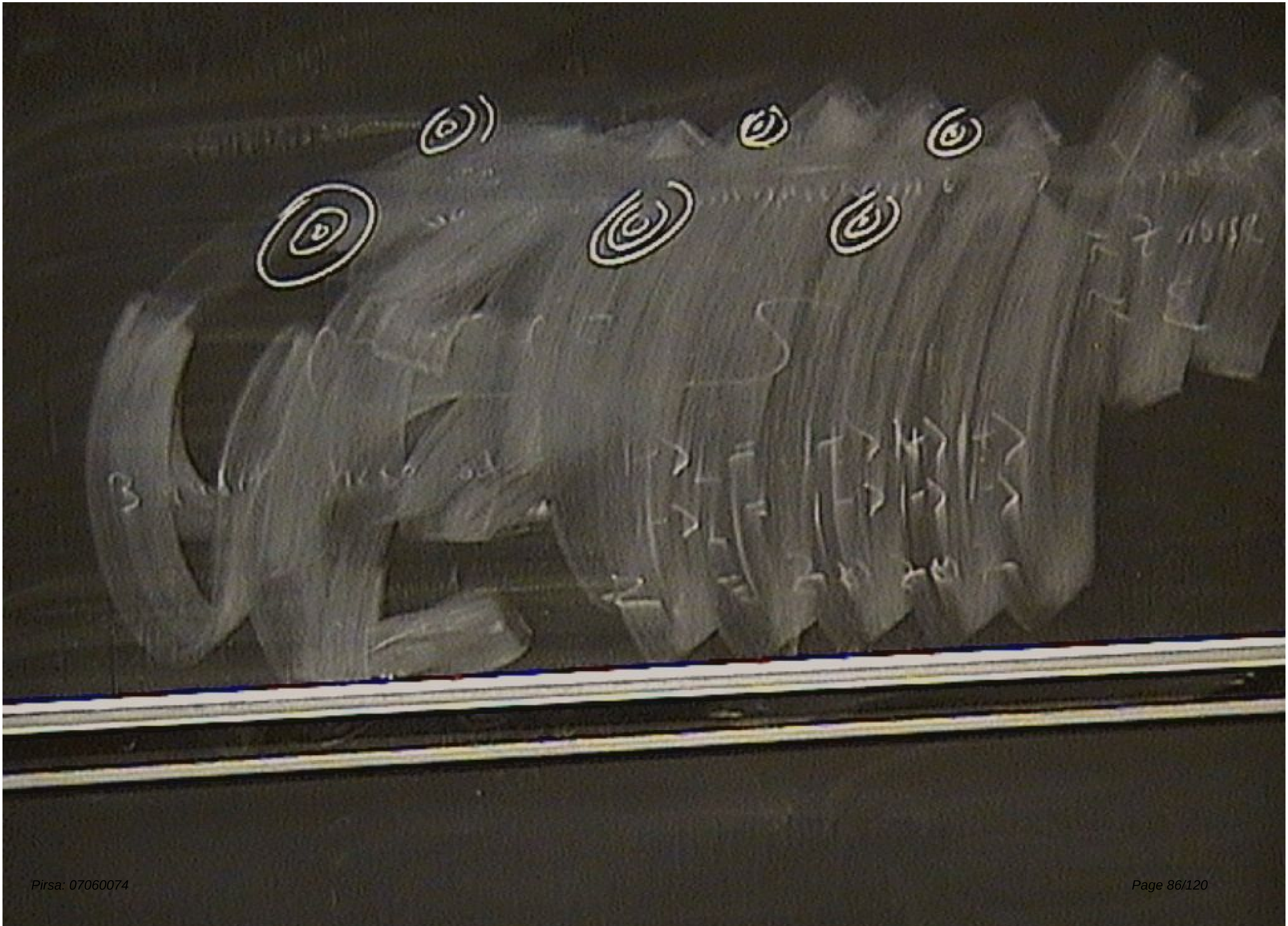
I_i(ω) = Y_ij(ω)V_j(ω) + N_ik(ω)Φ_k(ω)
Φ_1
Φ_2
Linear
mass
ω_QBIT
M ∝ δ(t)

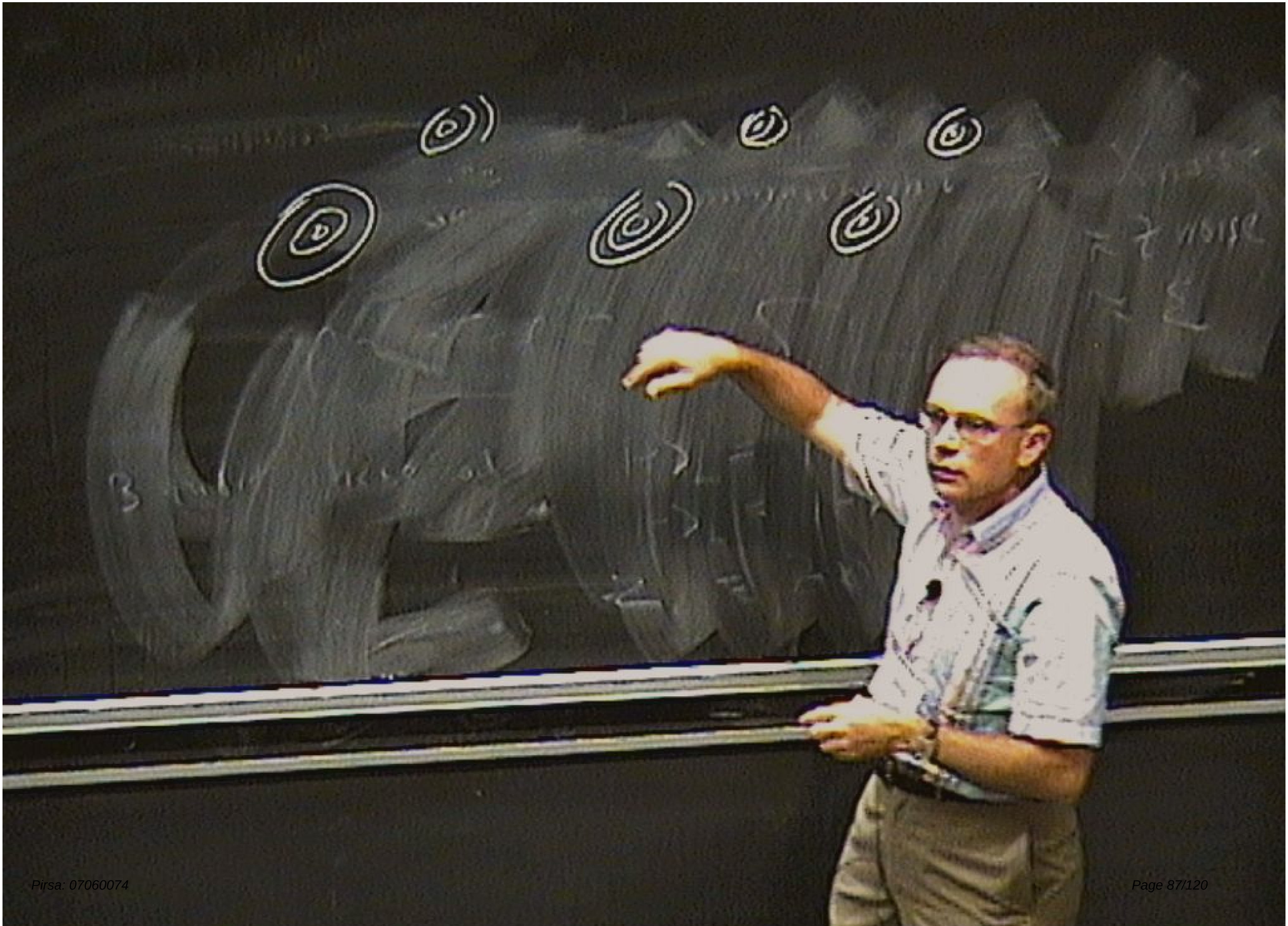


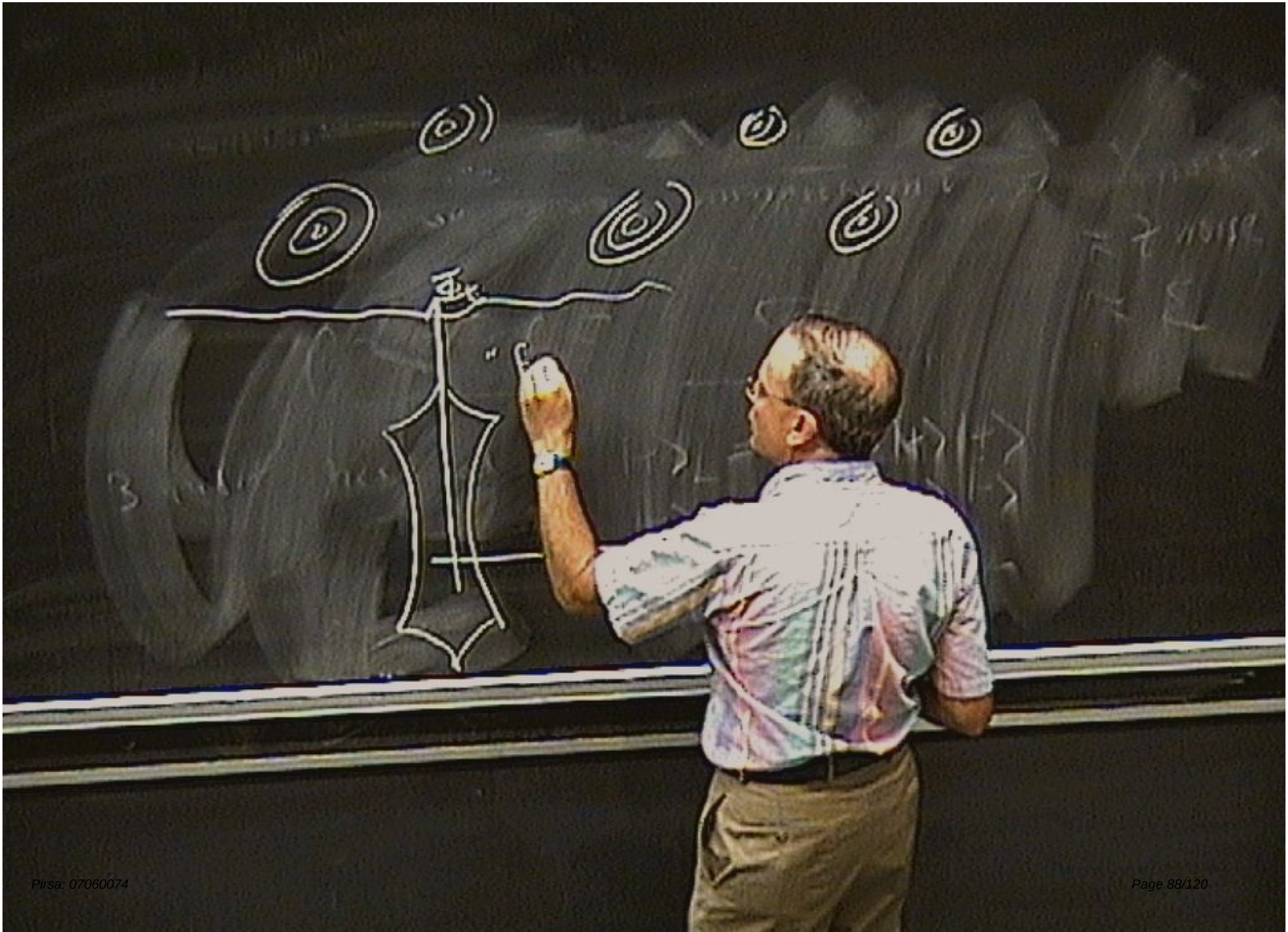

"gradiometer"

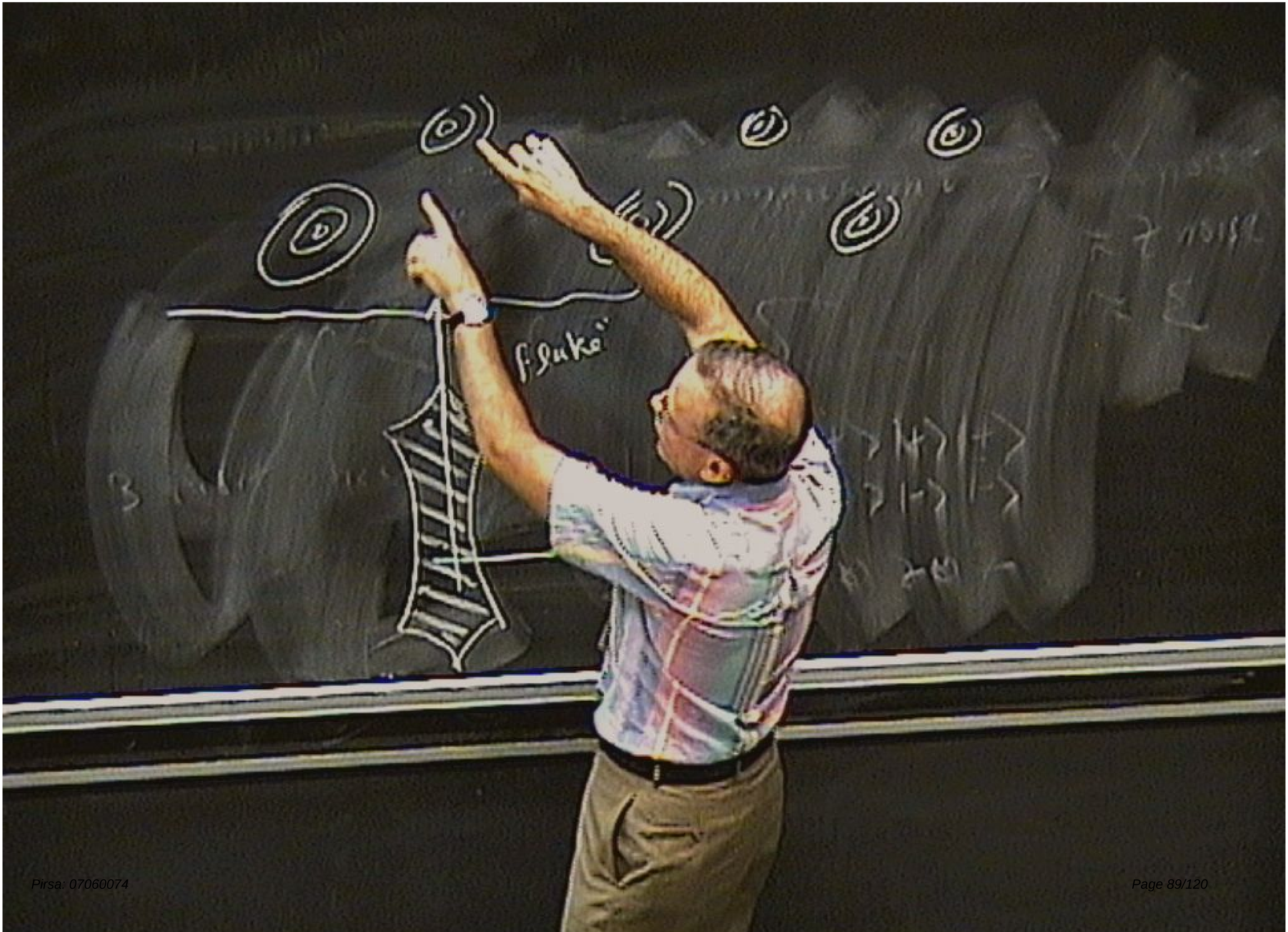


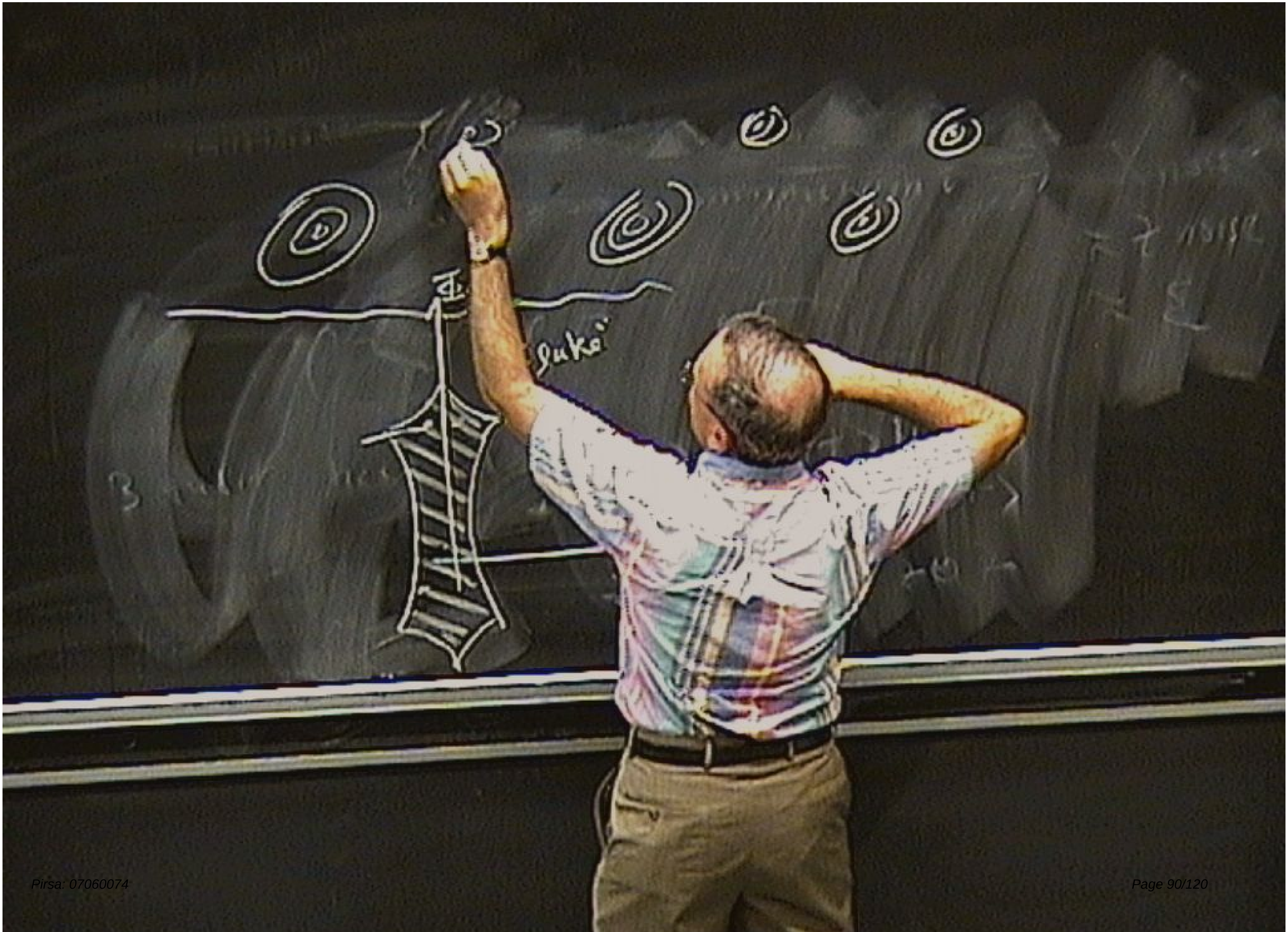


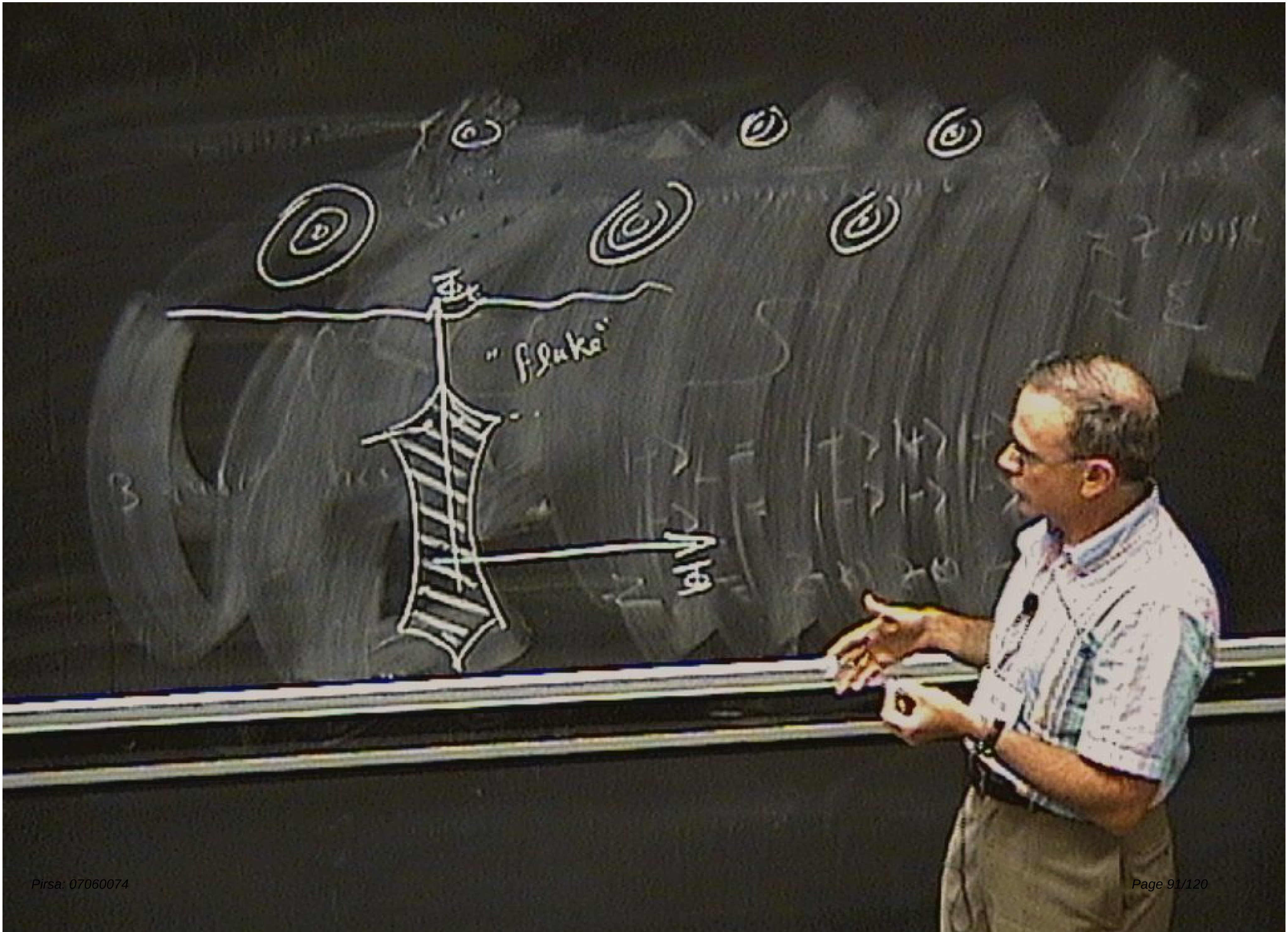


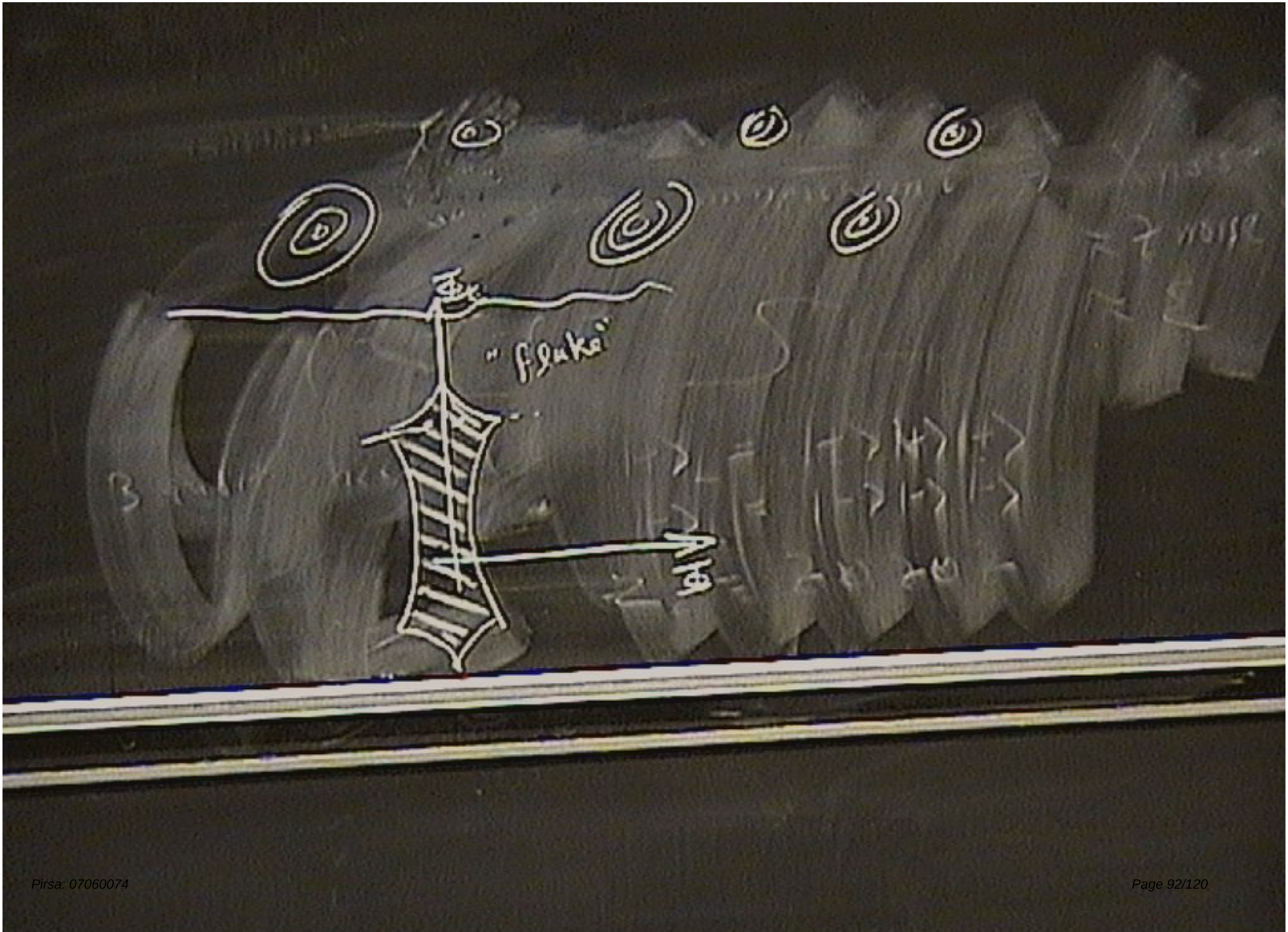


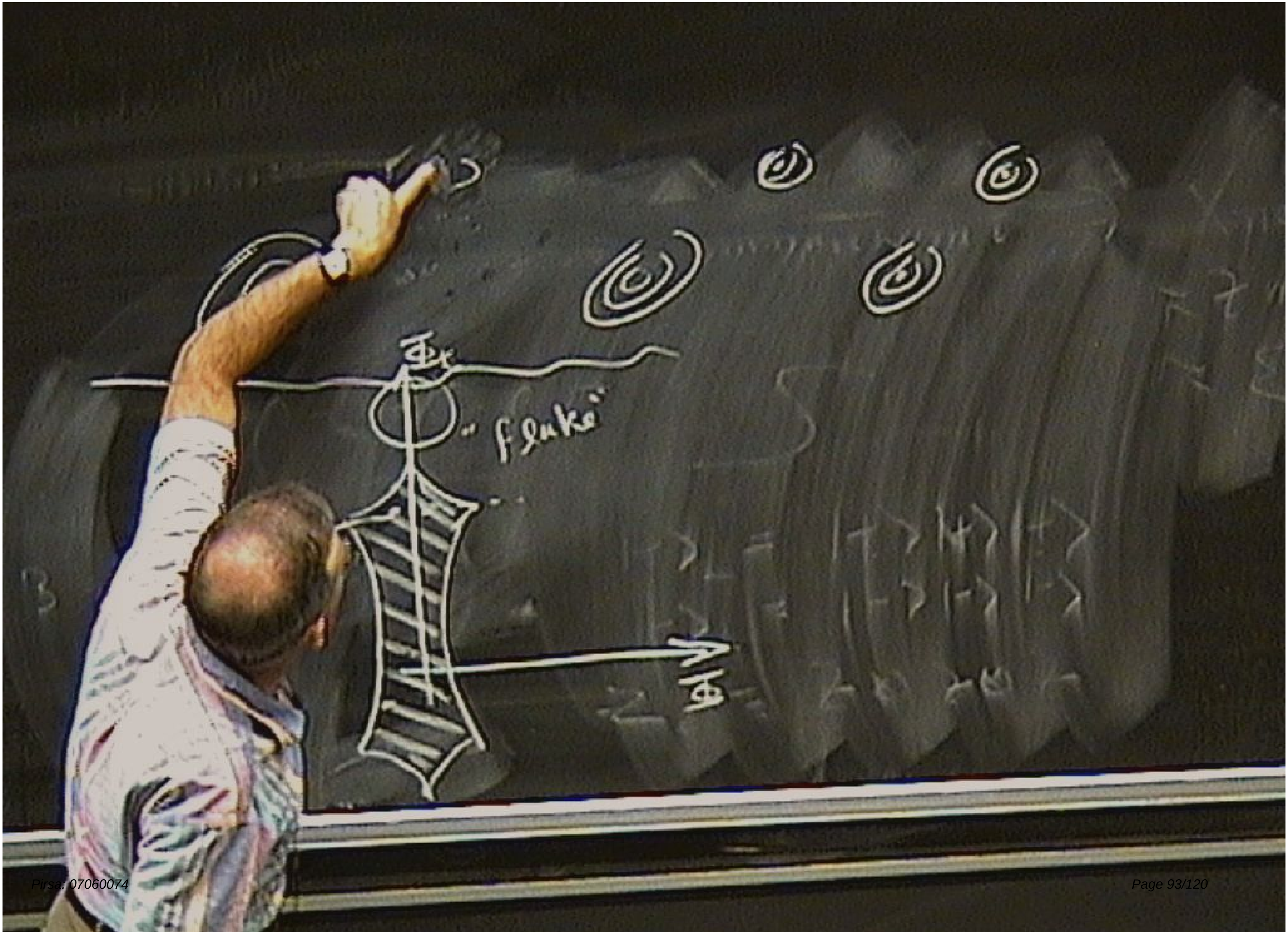


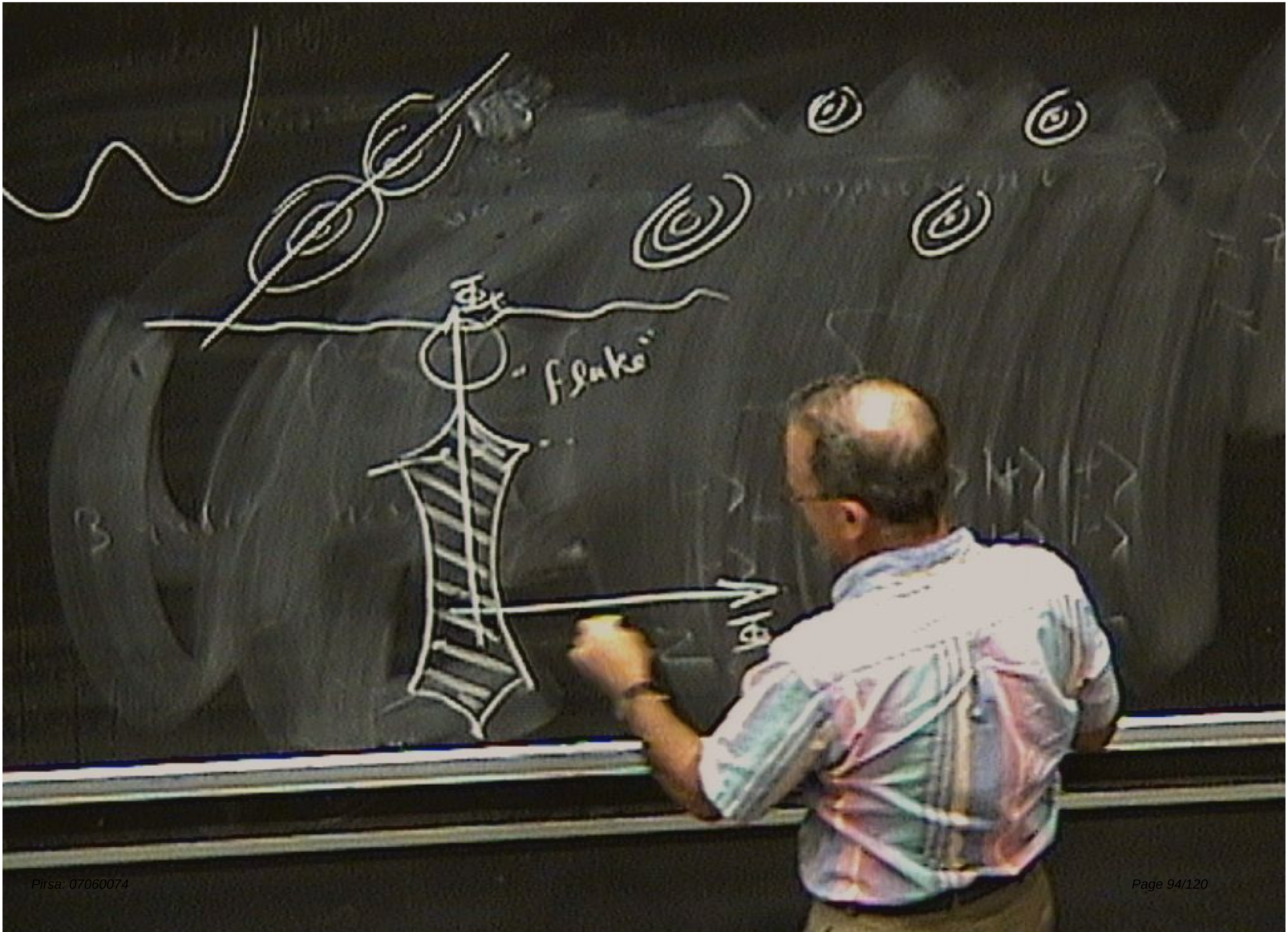

"fluke"

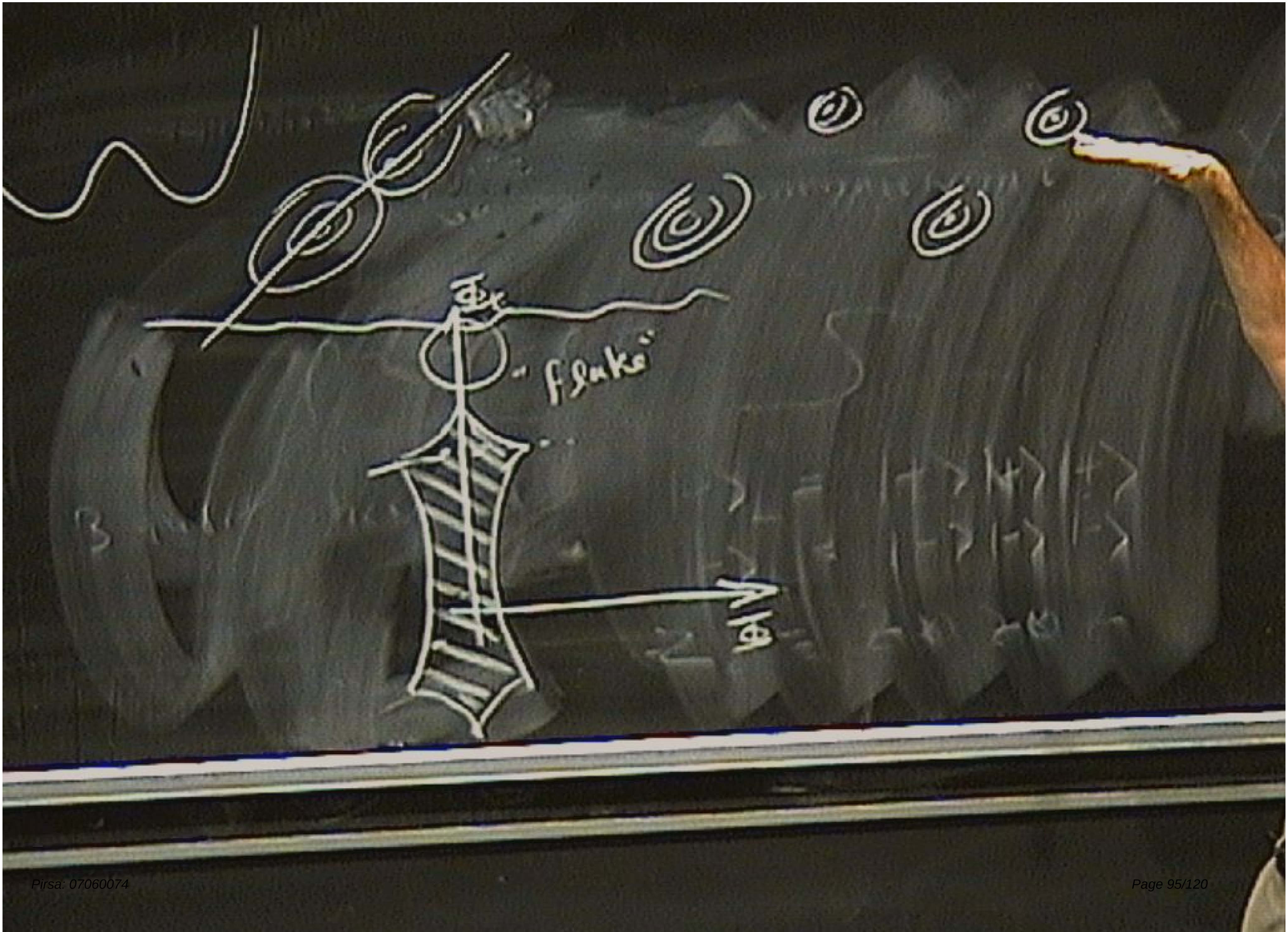


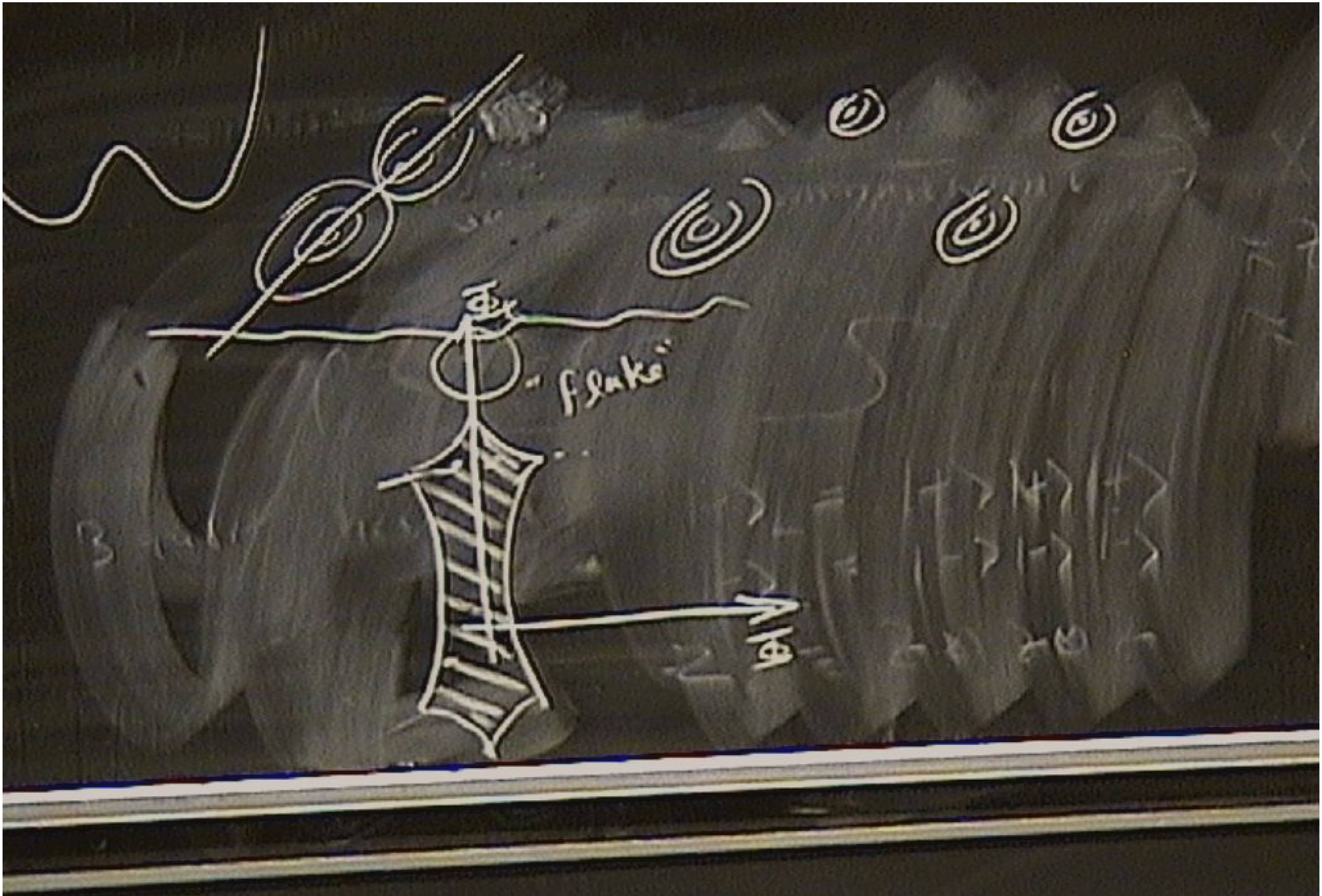

"fluke"

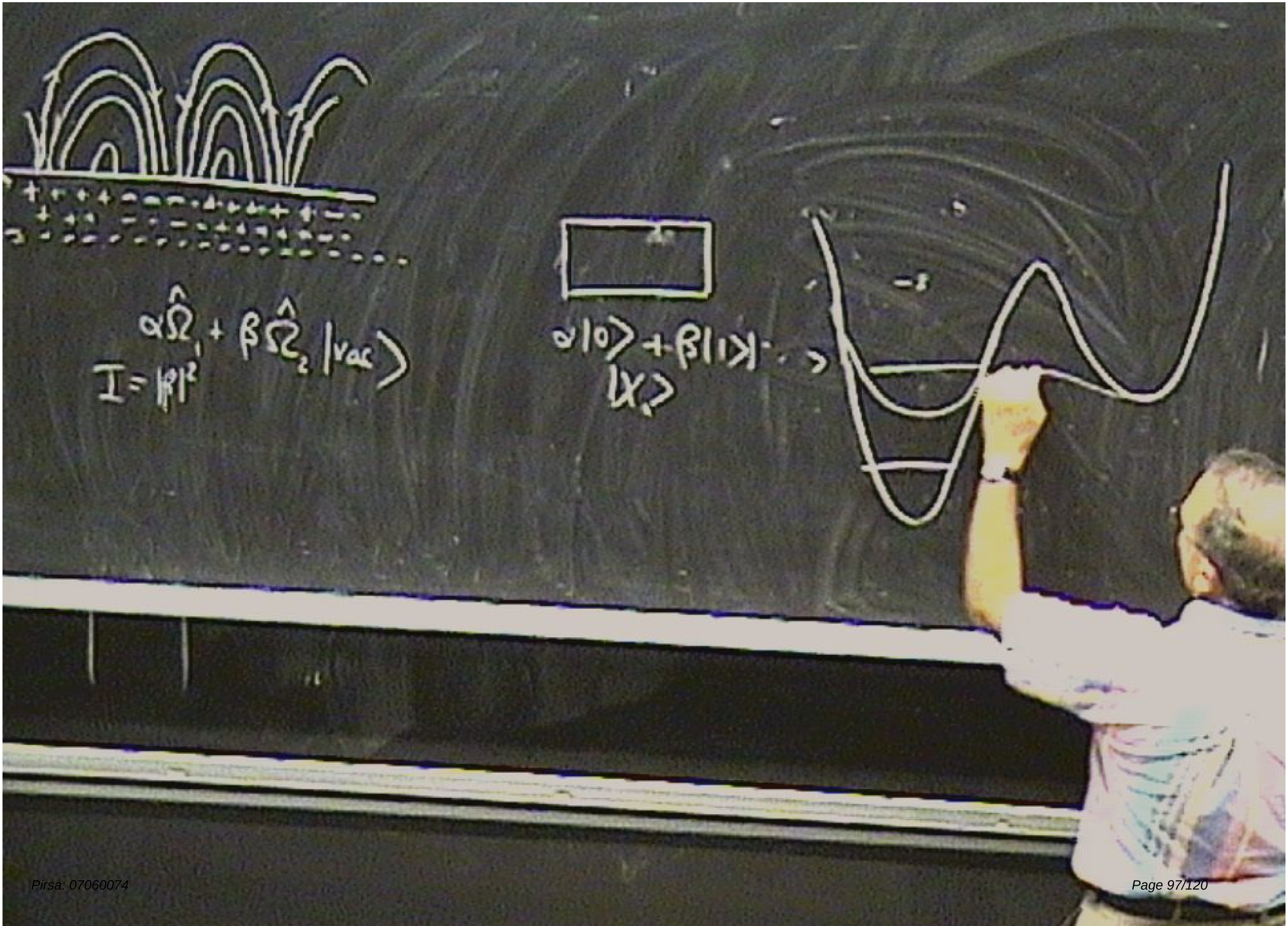

"flake"
noise

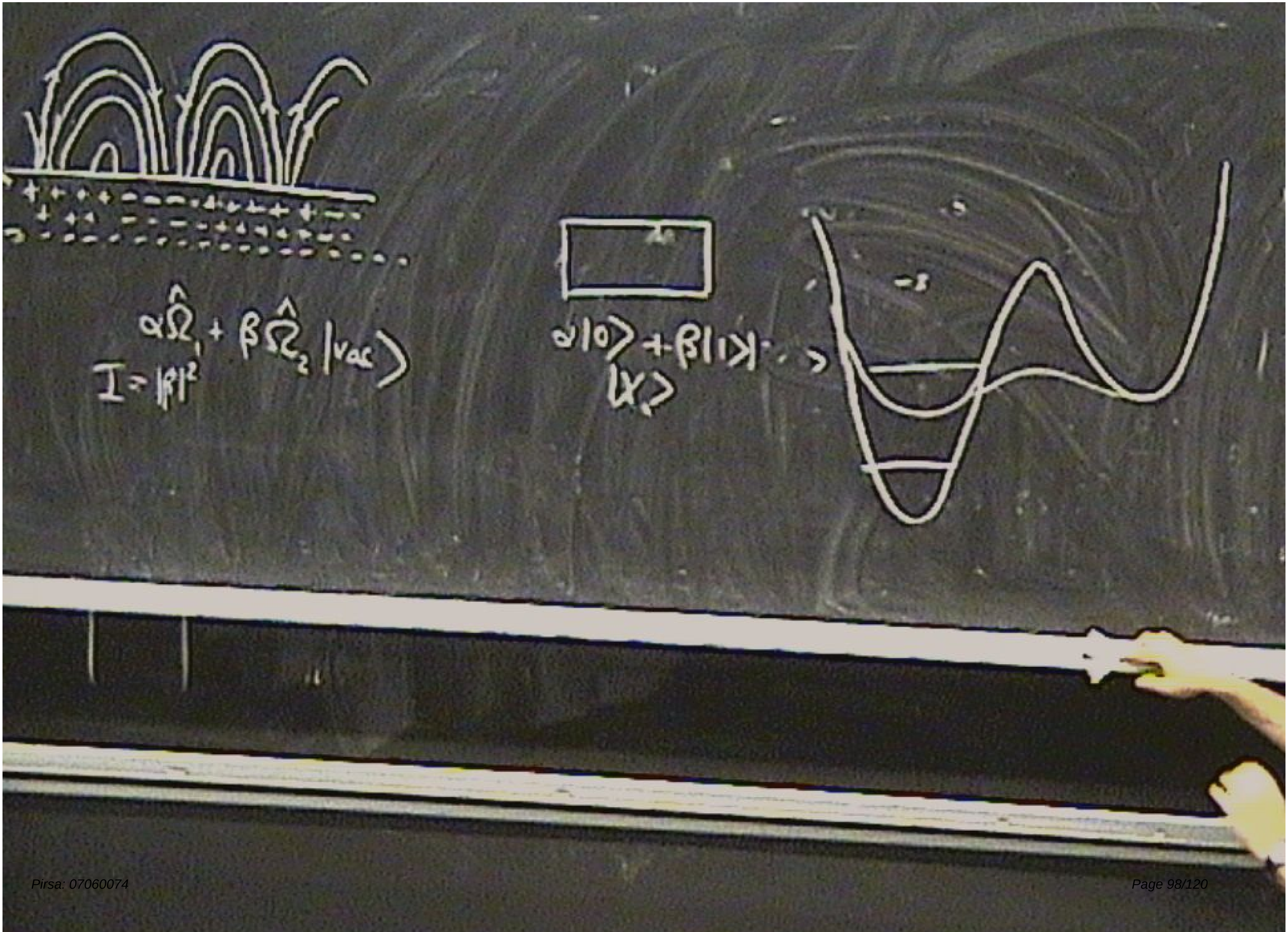

"fluke"

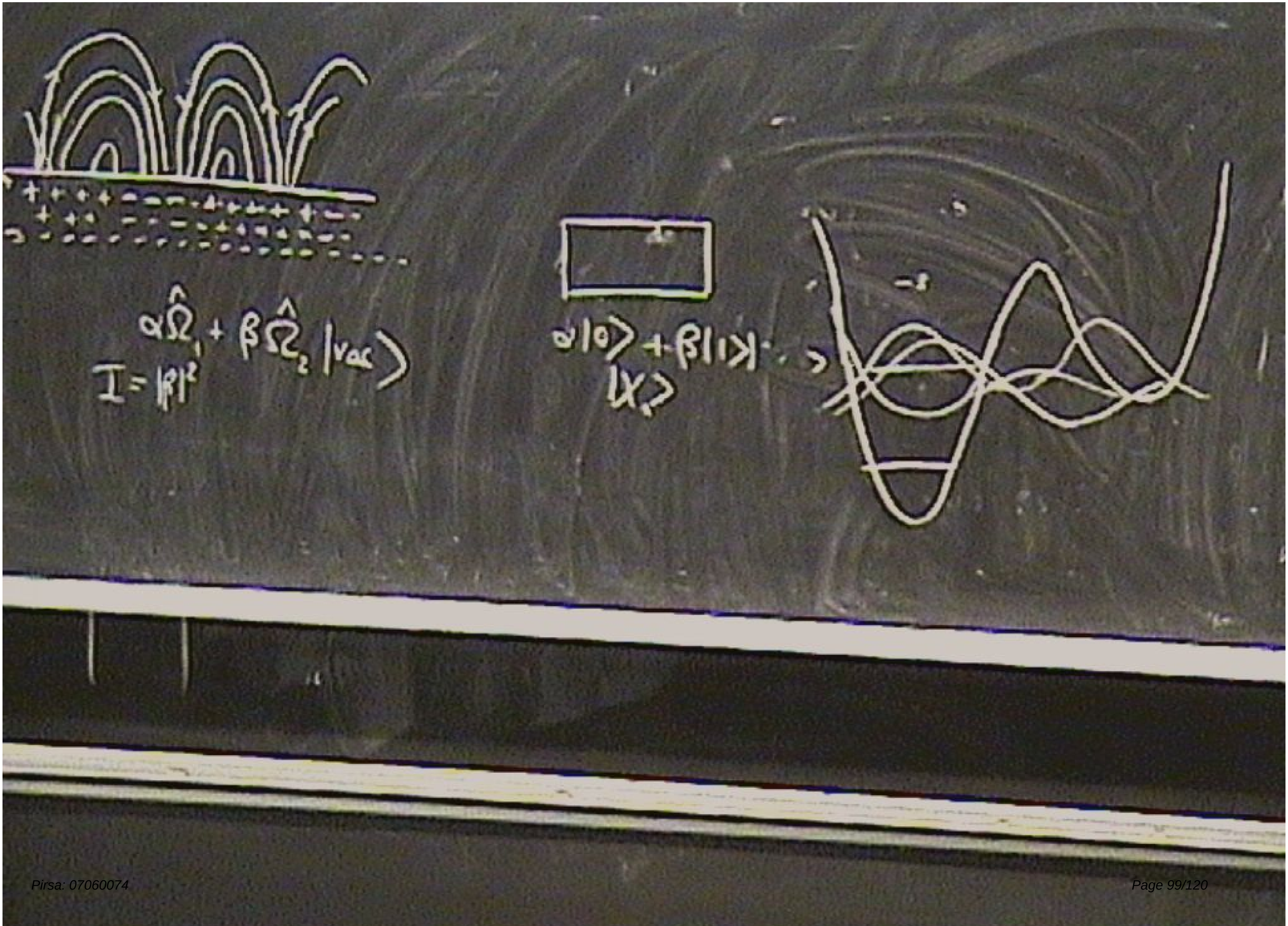

"fluke"

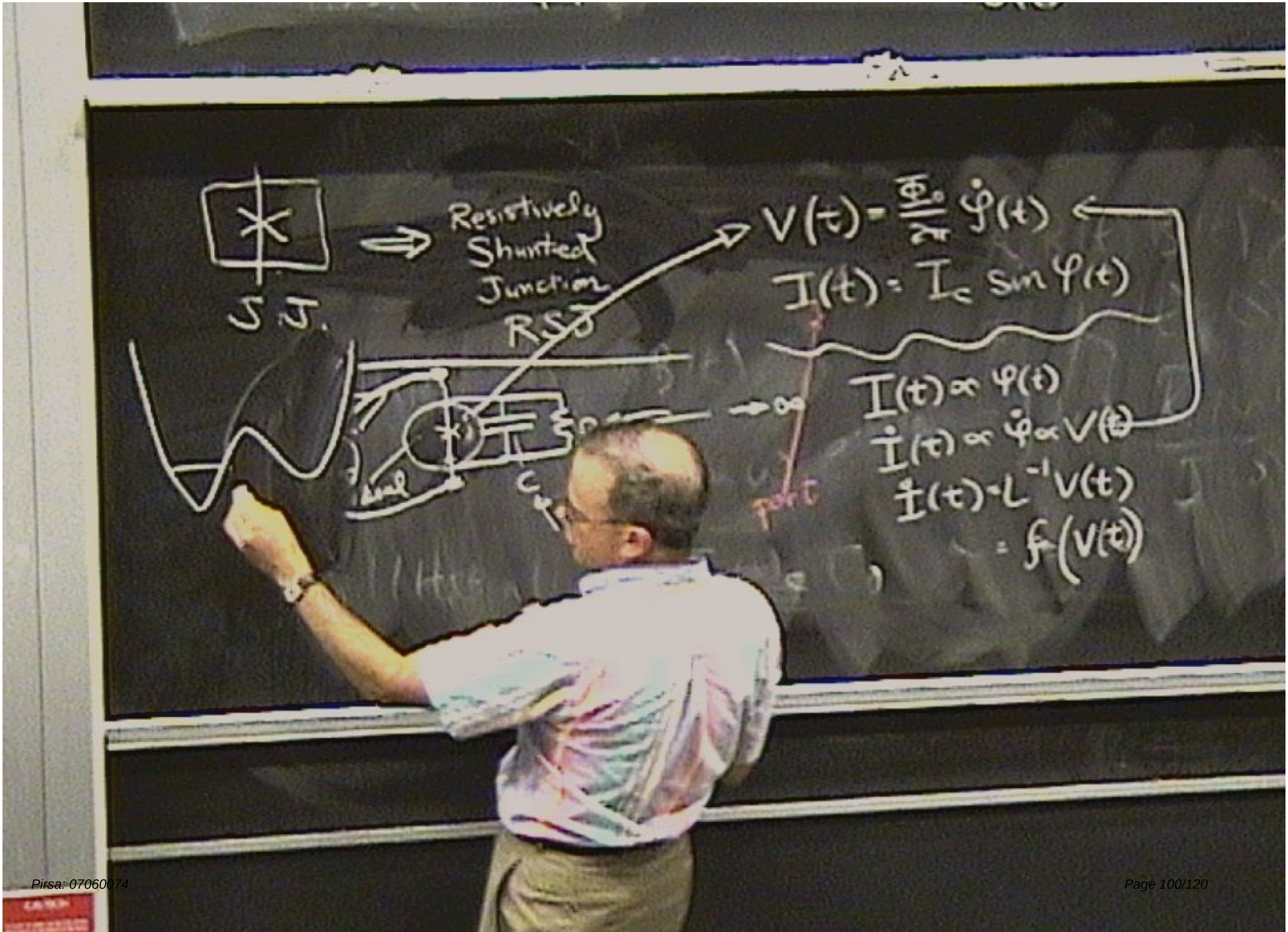

"fluke"

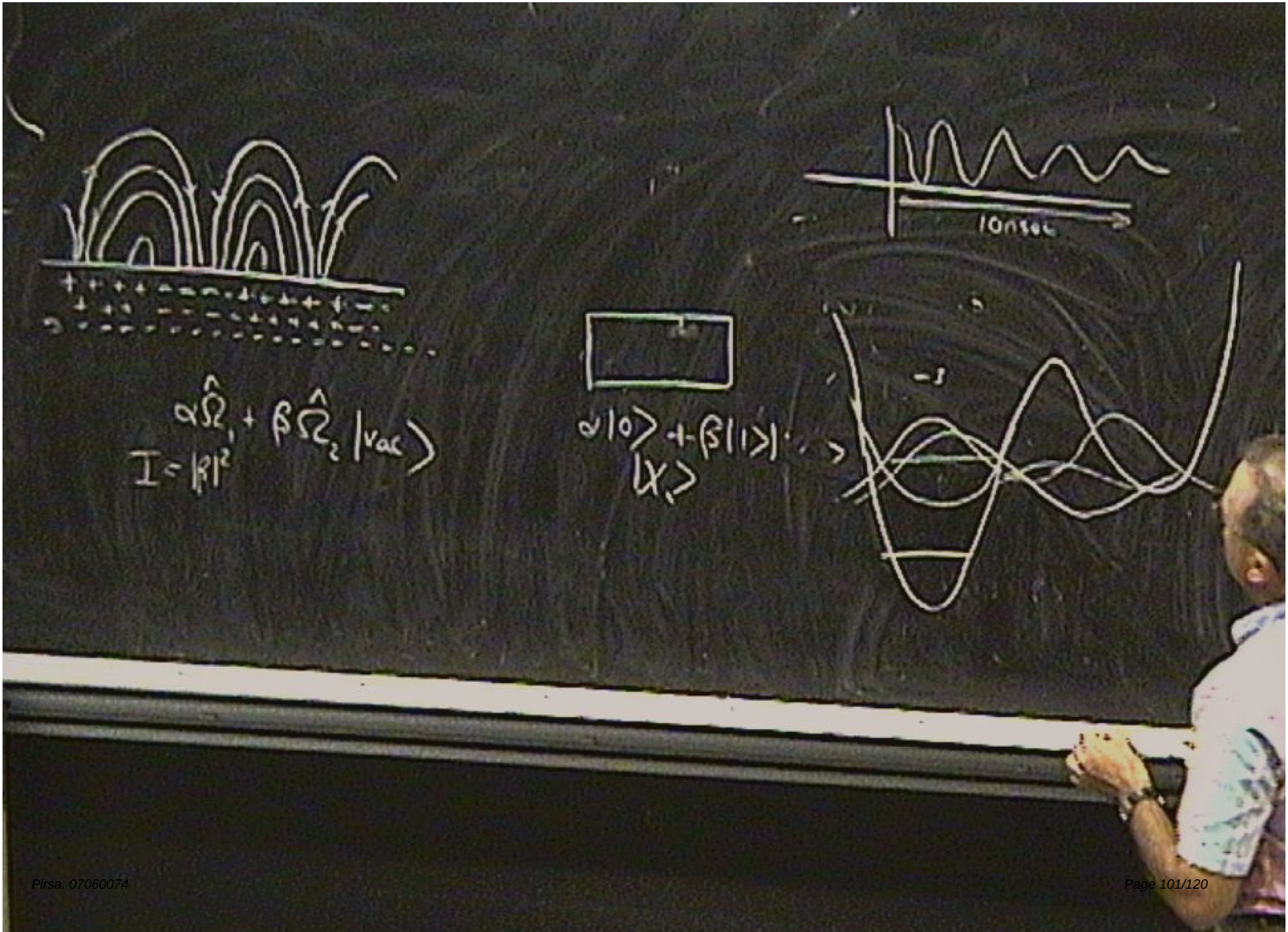

"flake"


$\alpha\hat{\Omega}_1 + \beta\hat{\Omega}_2 |vac\rangle$
$I = |\beta|^2$
$\alpha|0\rangle + \beta|1\rangle$
$|\chi_c\rangle$

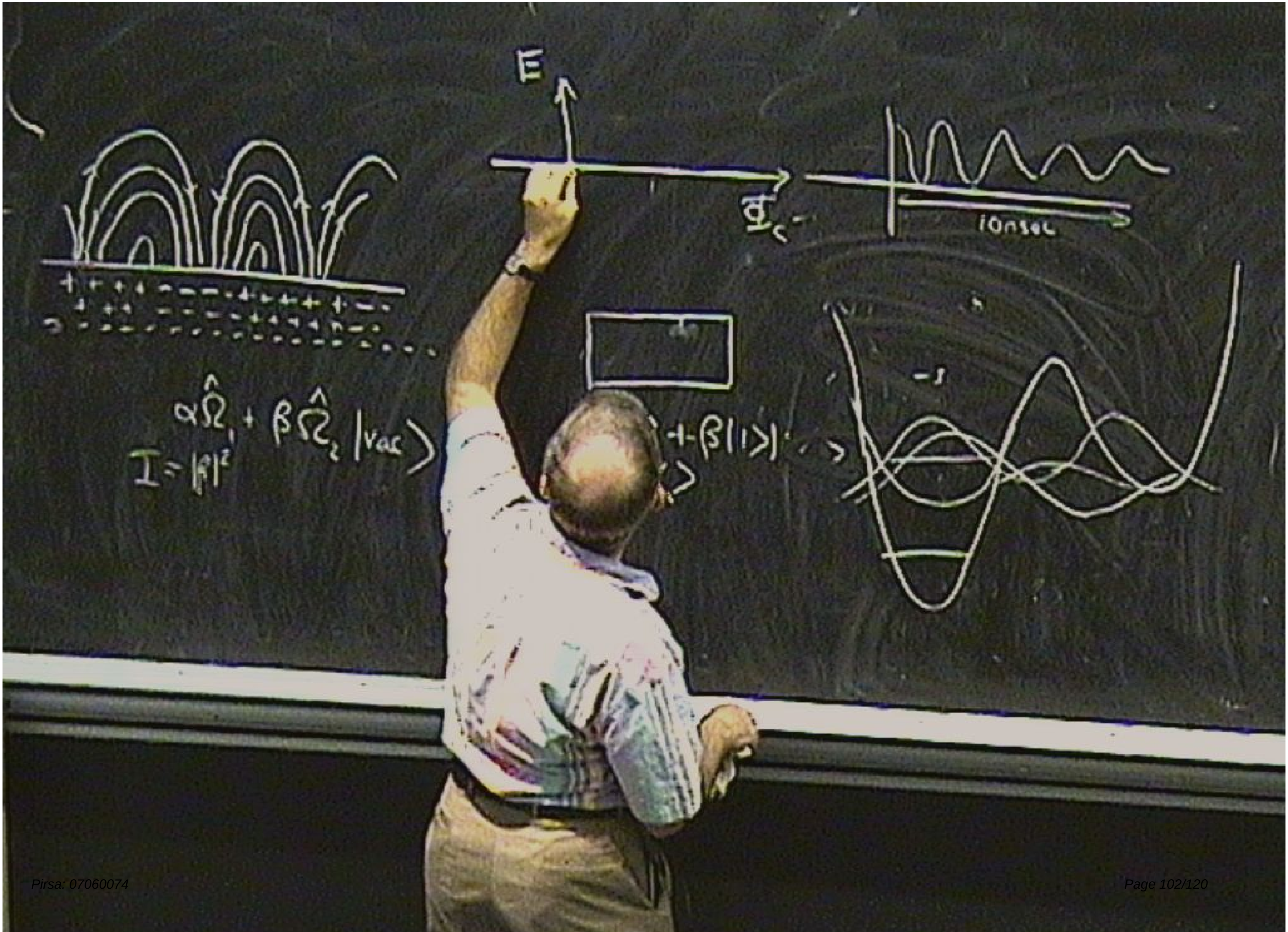

α Ω̂1 + β Ω̂2 |vac⟩
I = |β|2
α|0⟩ + β|1⟩ ...
|χ⟩

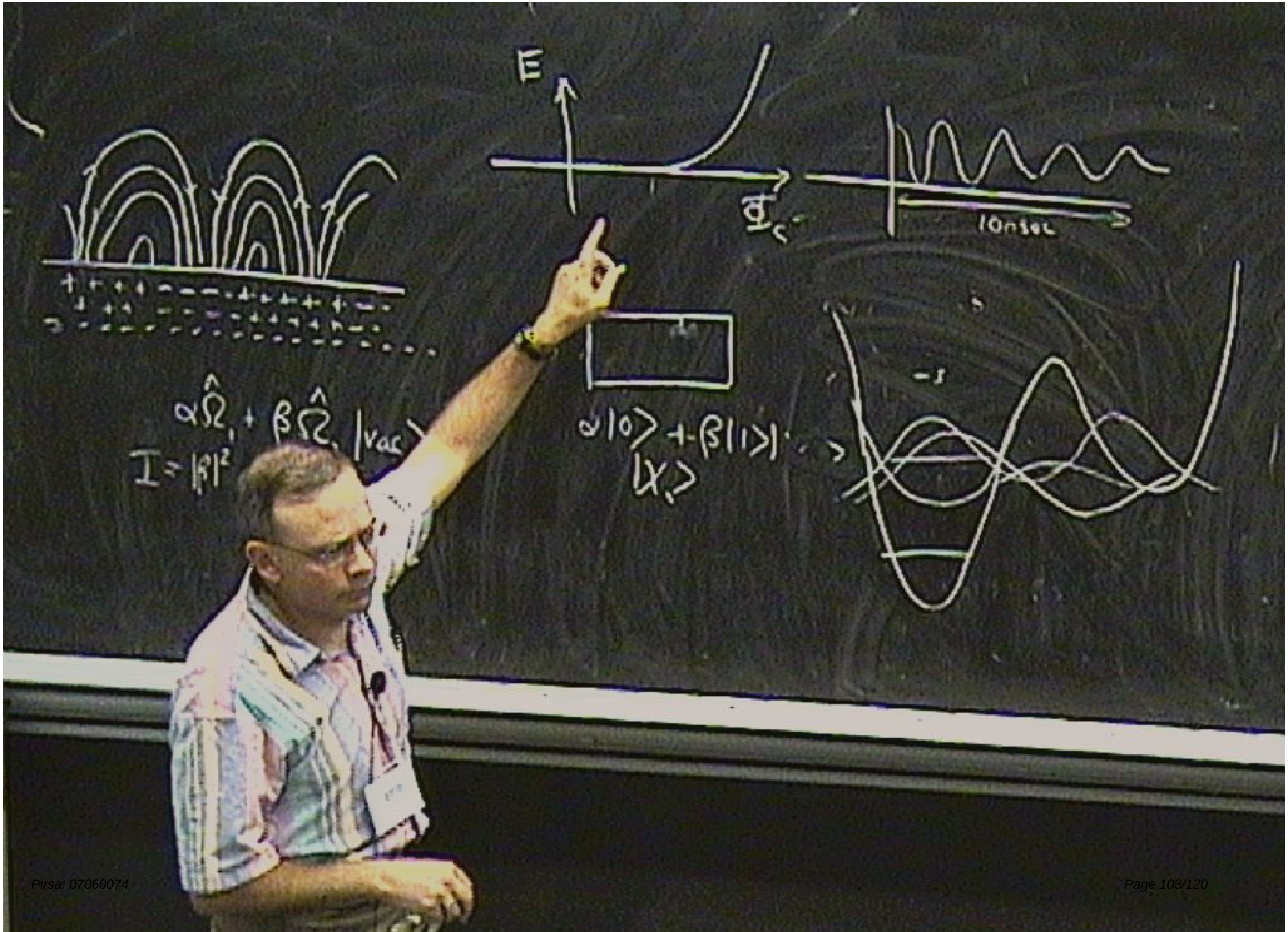

αΩ̂₁ + βΩ̂₂ |vac⟩
I = |β|²
α|0⟩ + β|1⟩
|χᵢ⟩

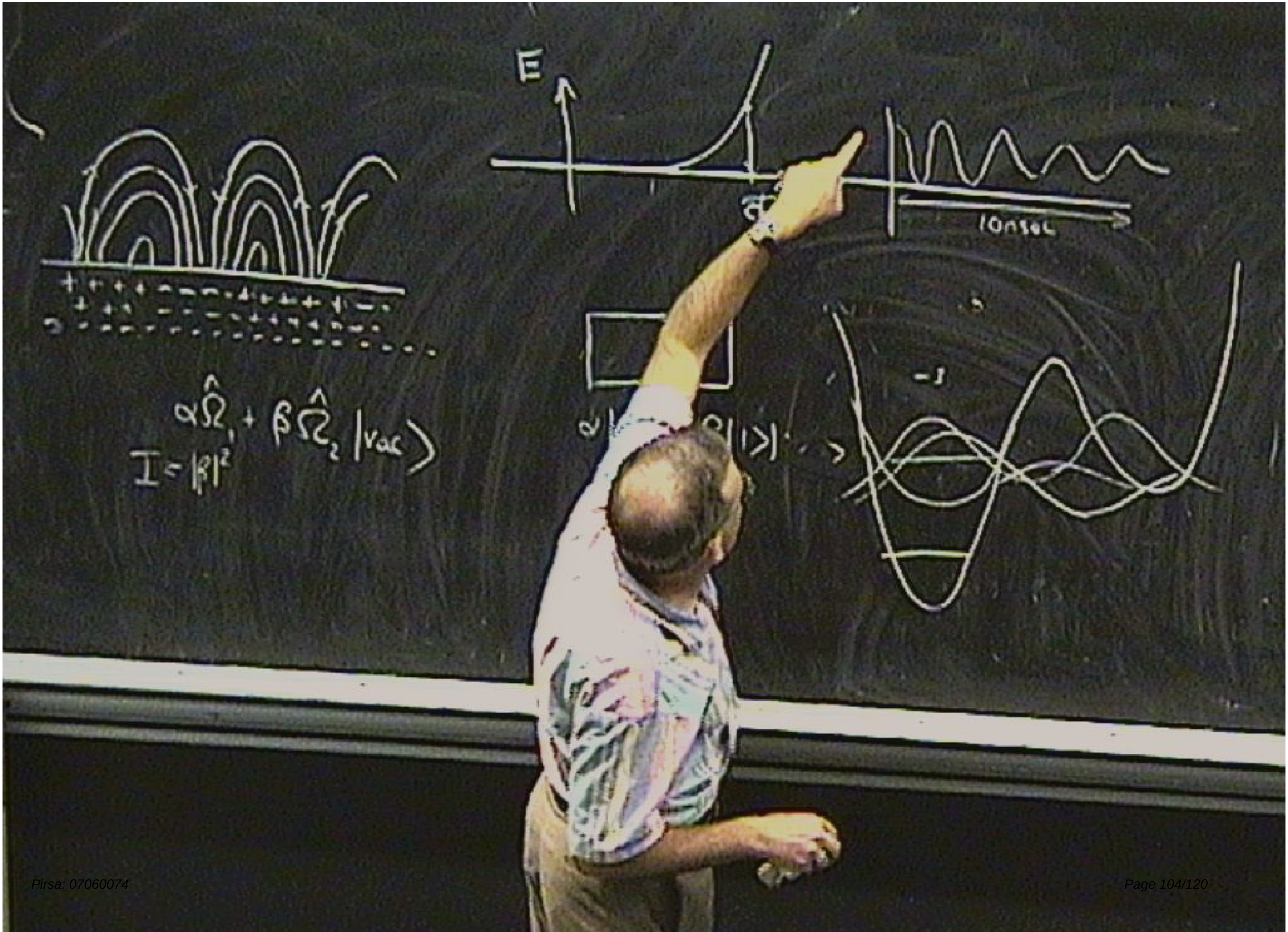

J.J.
Resistively
Shunted
Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
= f(V(t))

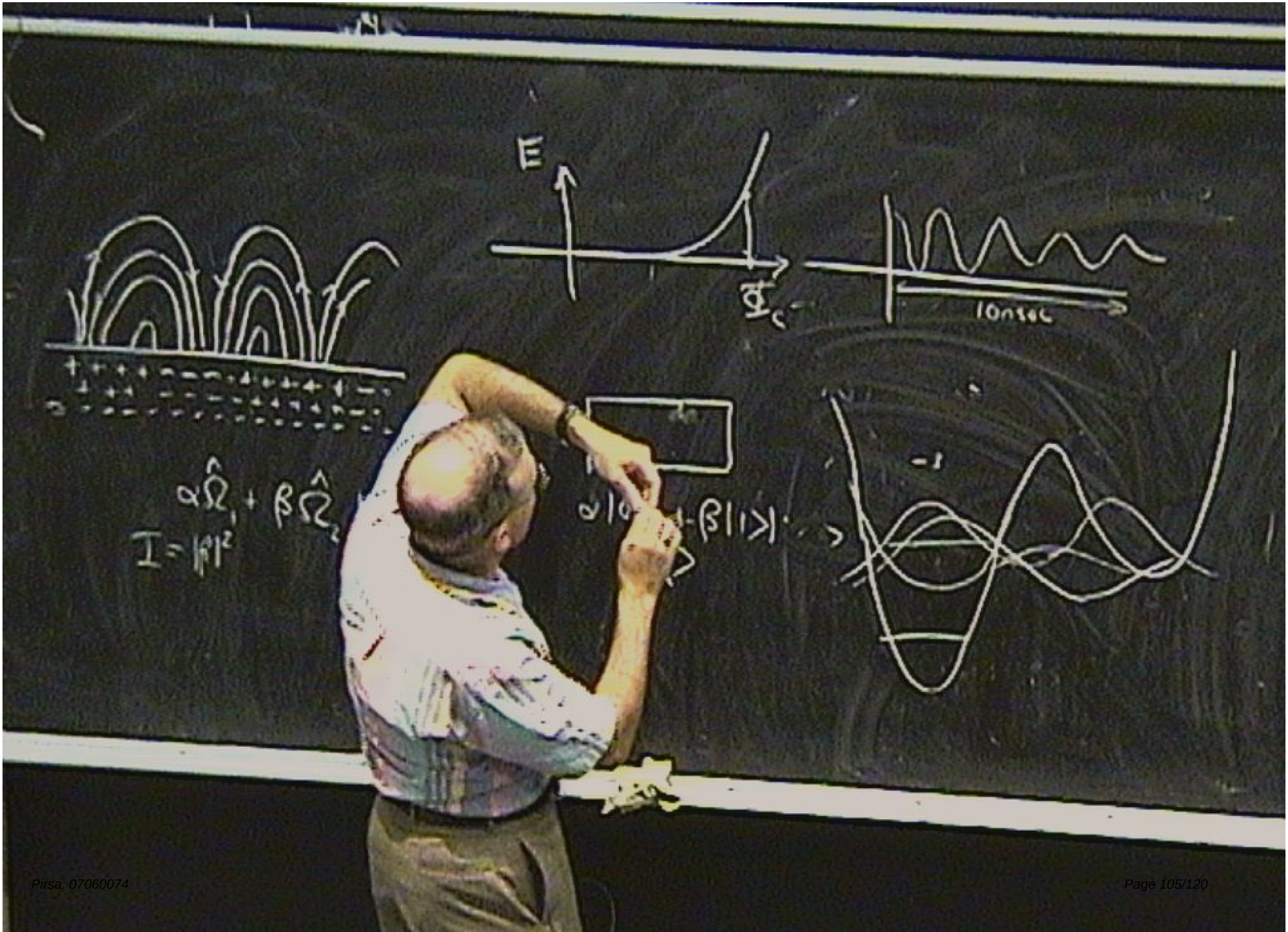


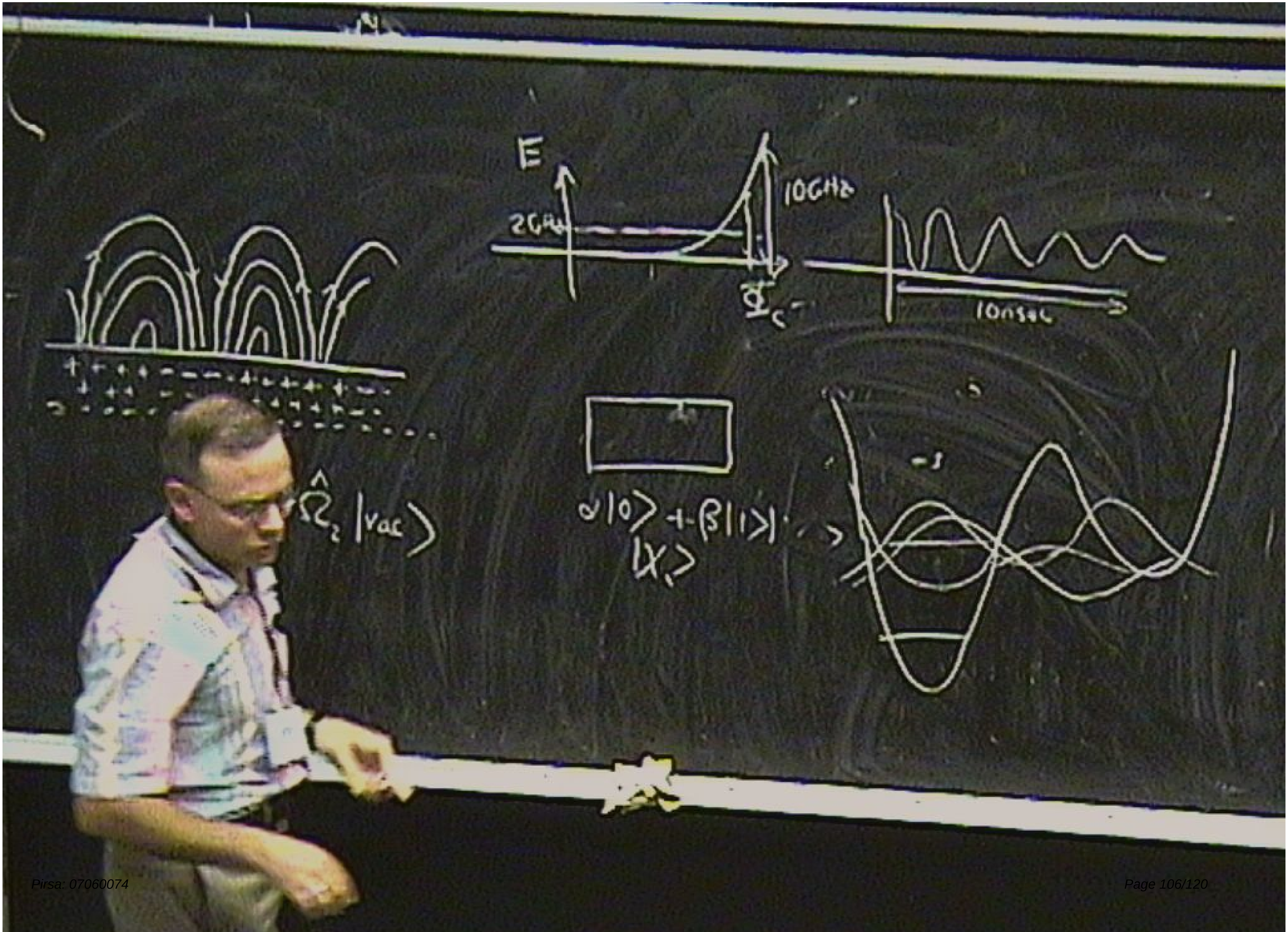
10nsec
$\alpha\hat{\Omega}_1 + \beta\hat{\Omega}_2 |vac\rangle$
$I = |\beta|^2$
$\alpha|0\rangle + \beta|1\rangle$
$|\chi_1\rangle$

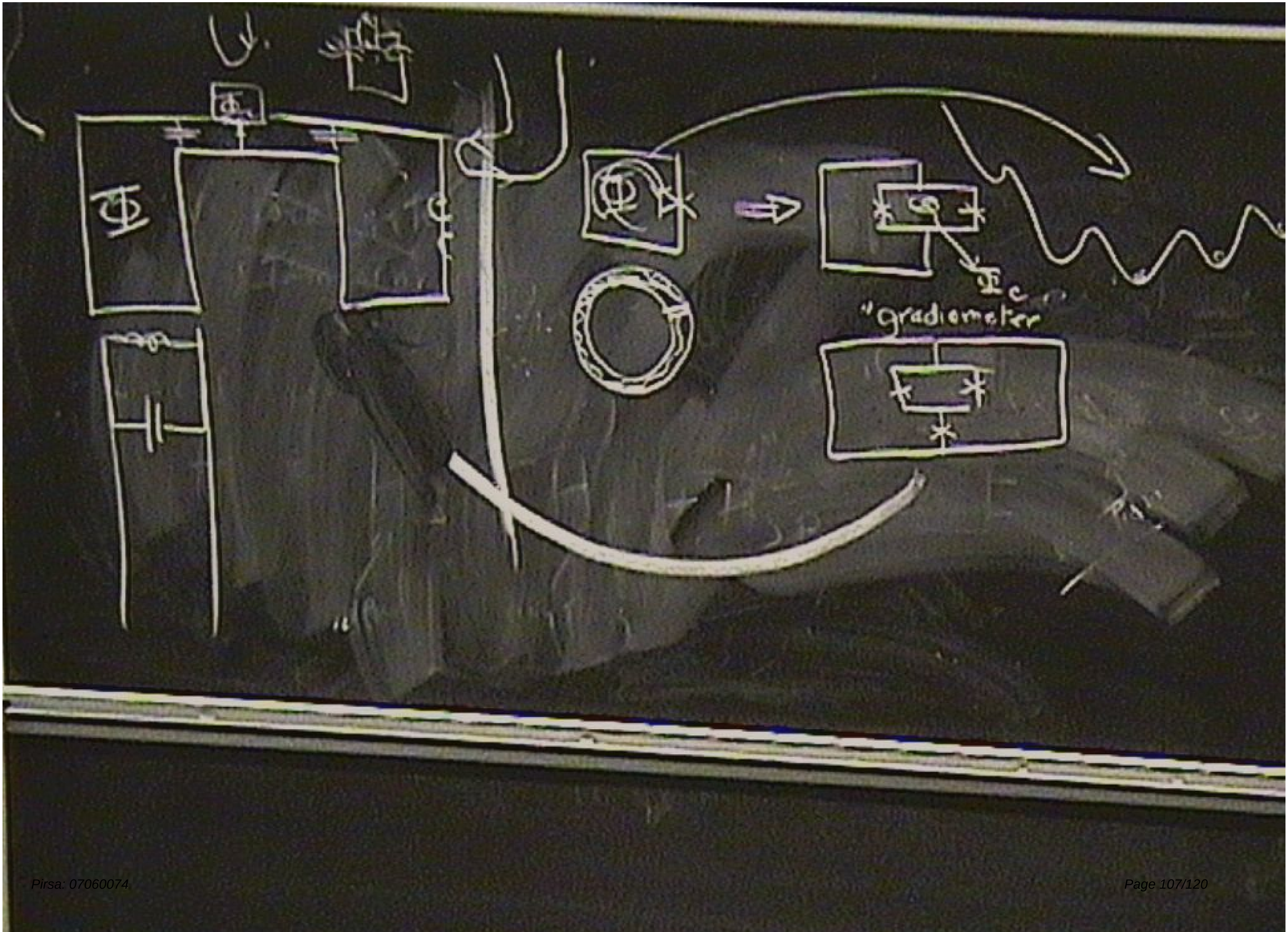

E
10nsec
I = |β|²

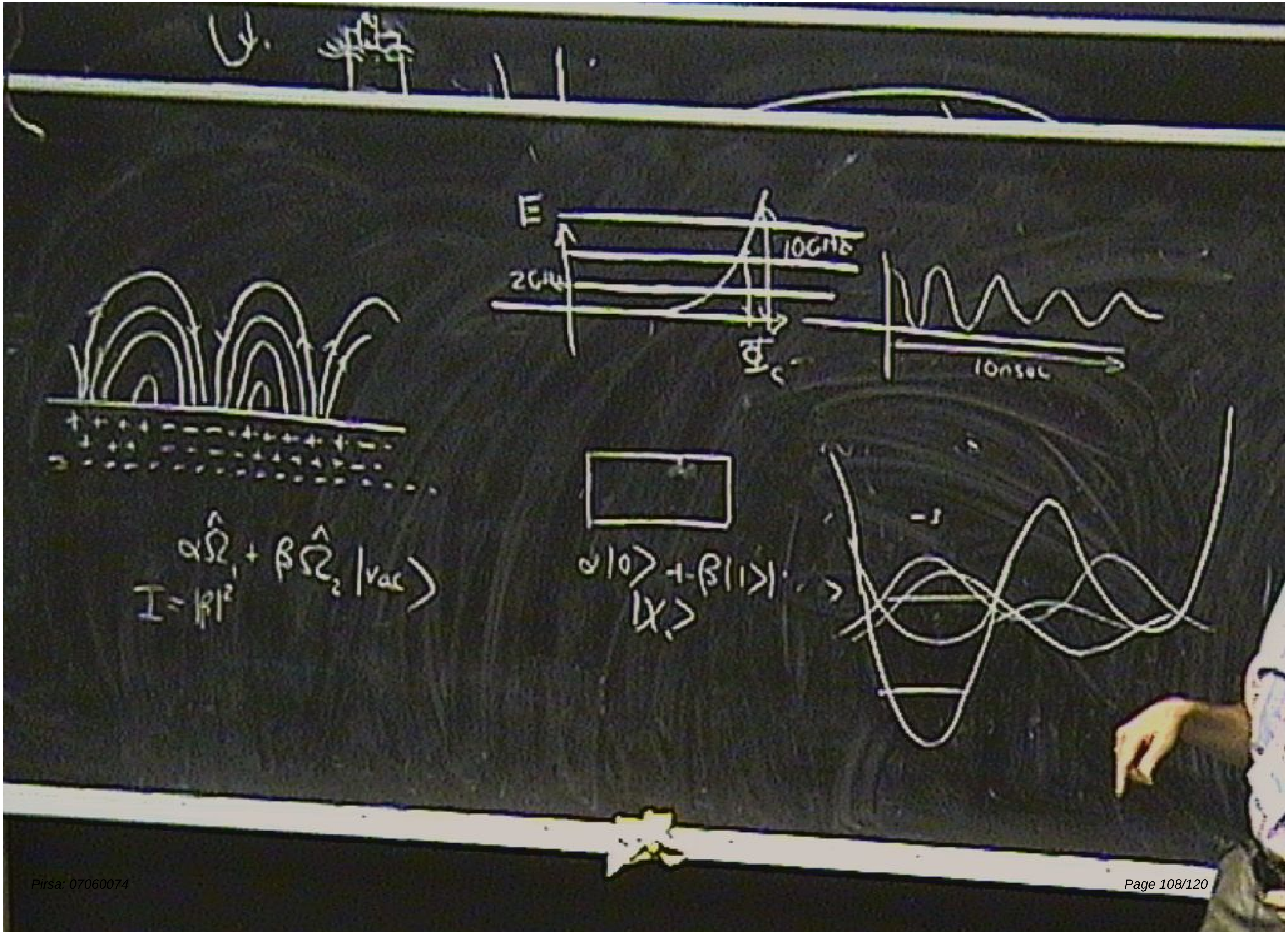

E
10nsec
α|0> + β|1>
|χ>
I = |β|²

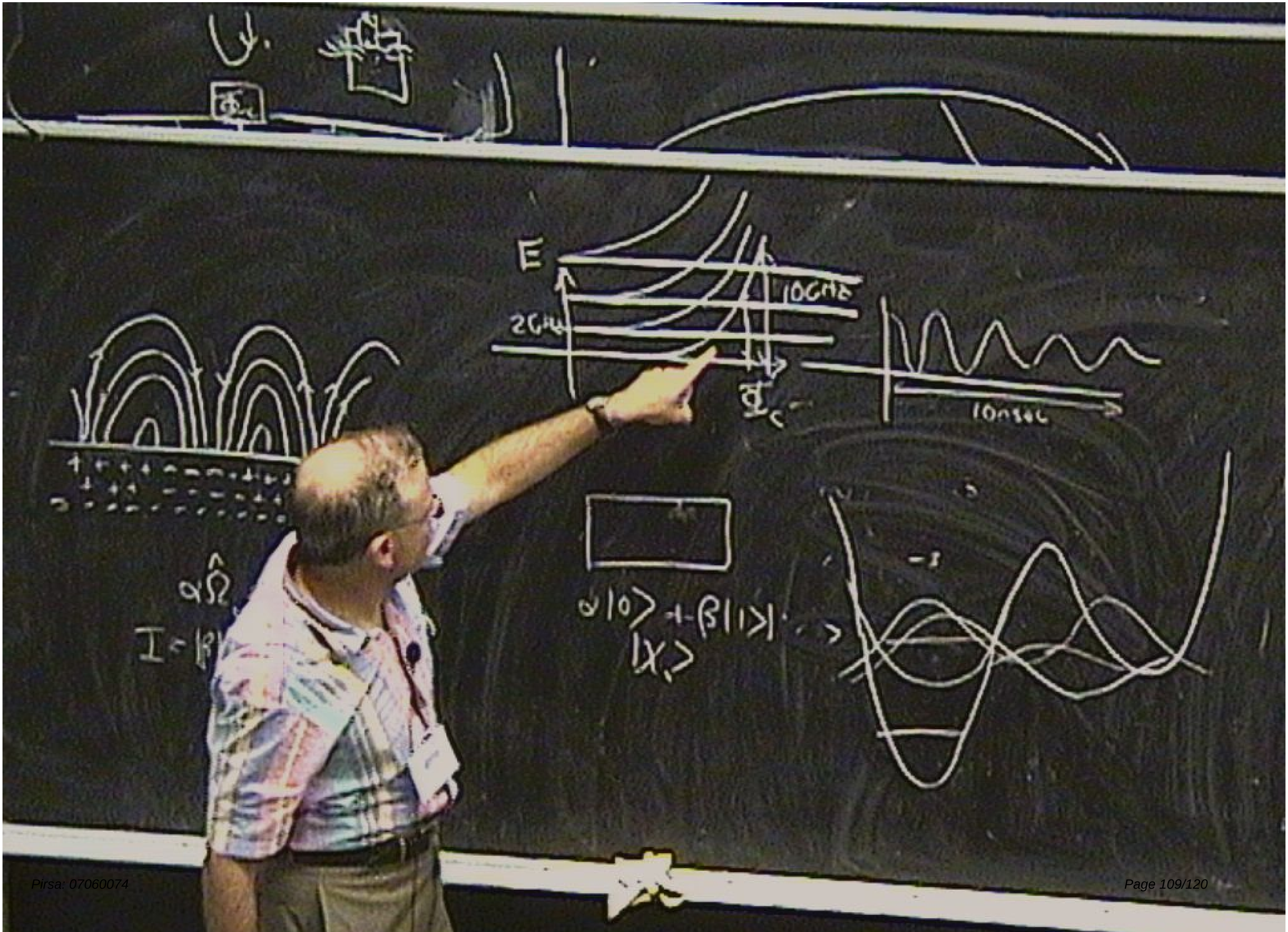

E
Ionsec
$\alpha\hat{\Omega}_1 + \beta\hat{\Omega}_2 |vac\rangle$
$I = |\beta|^2$

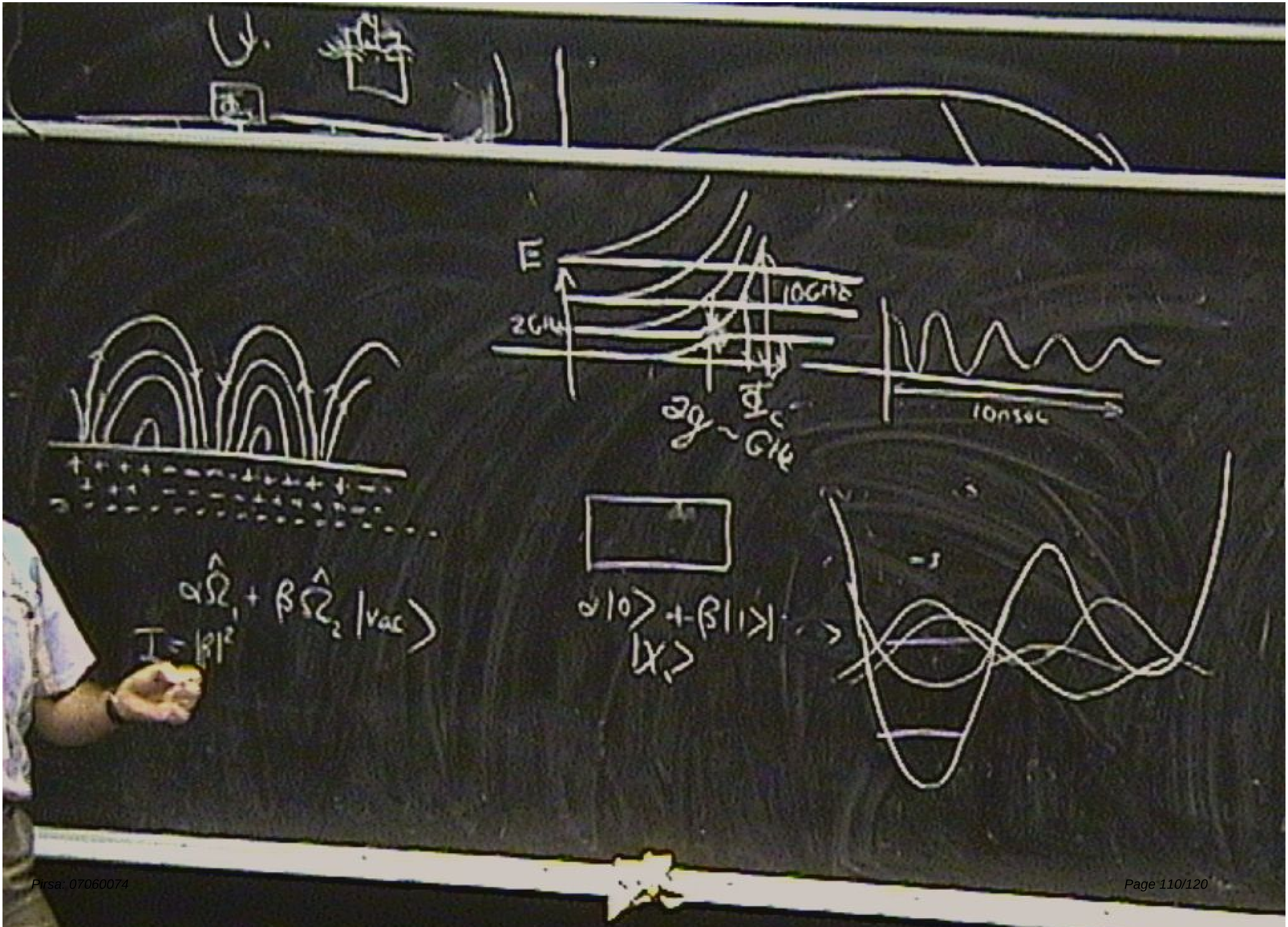

E
10nsec

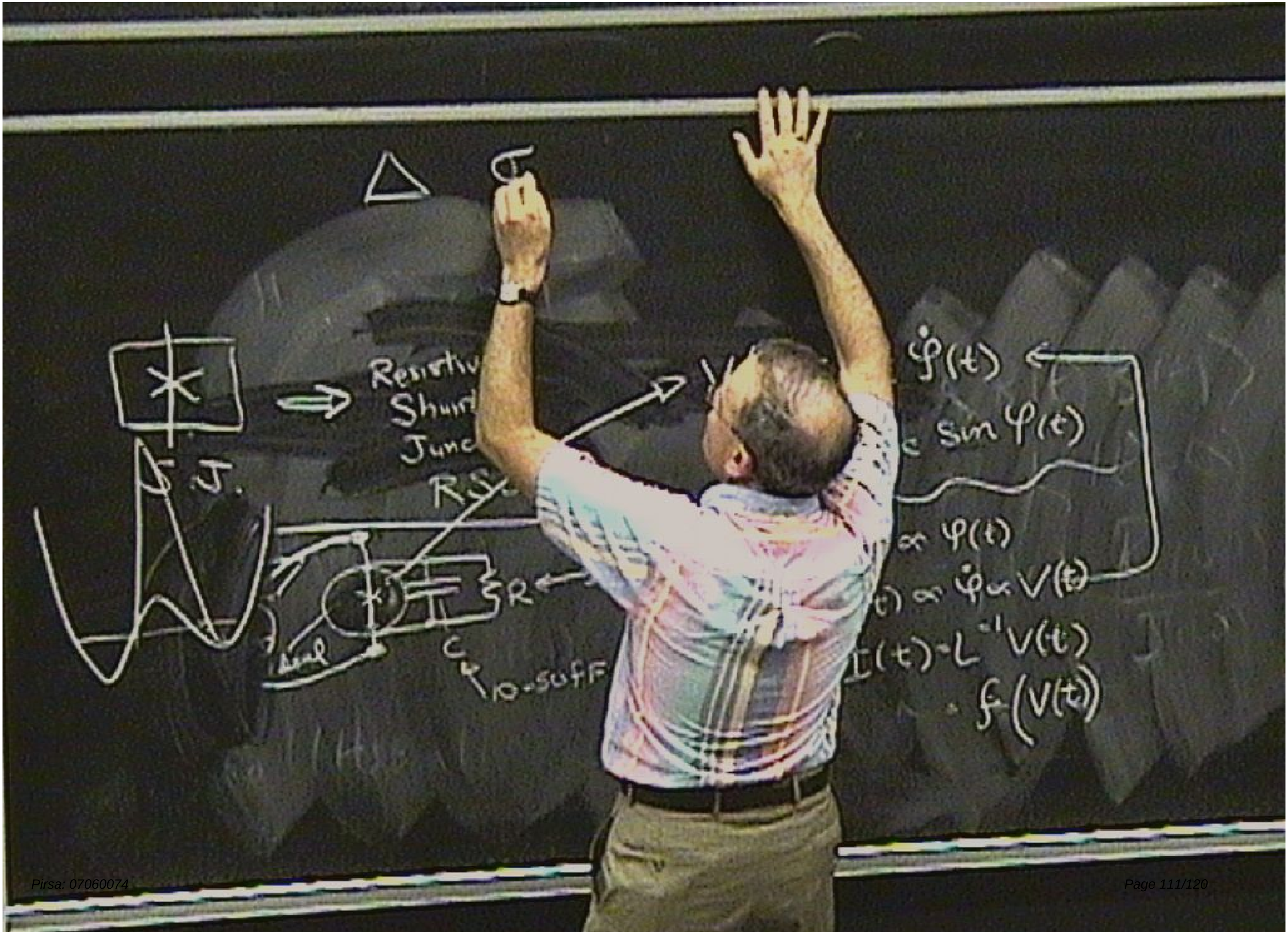

E
2GHz
10GHz
10nsec
α|0> + β|1>

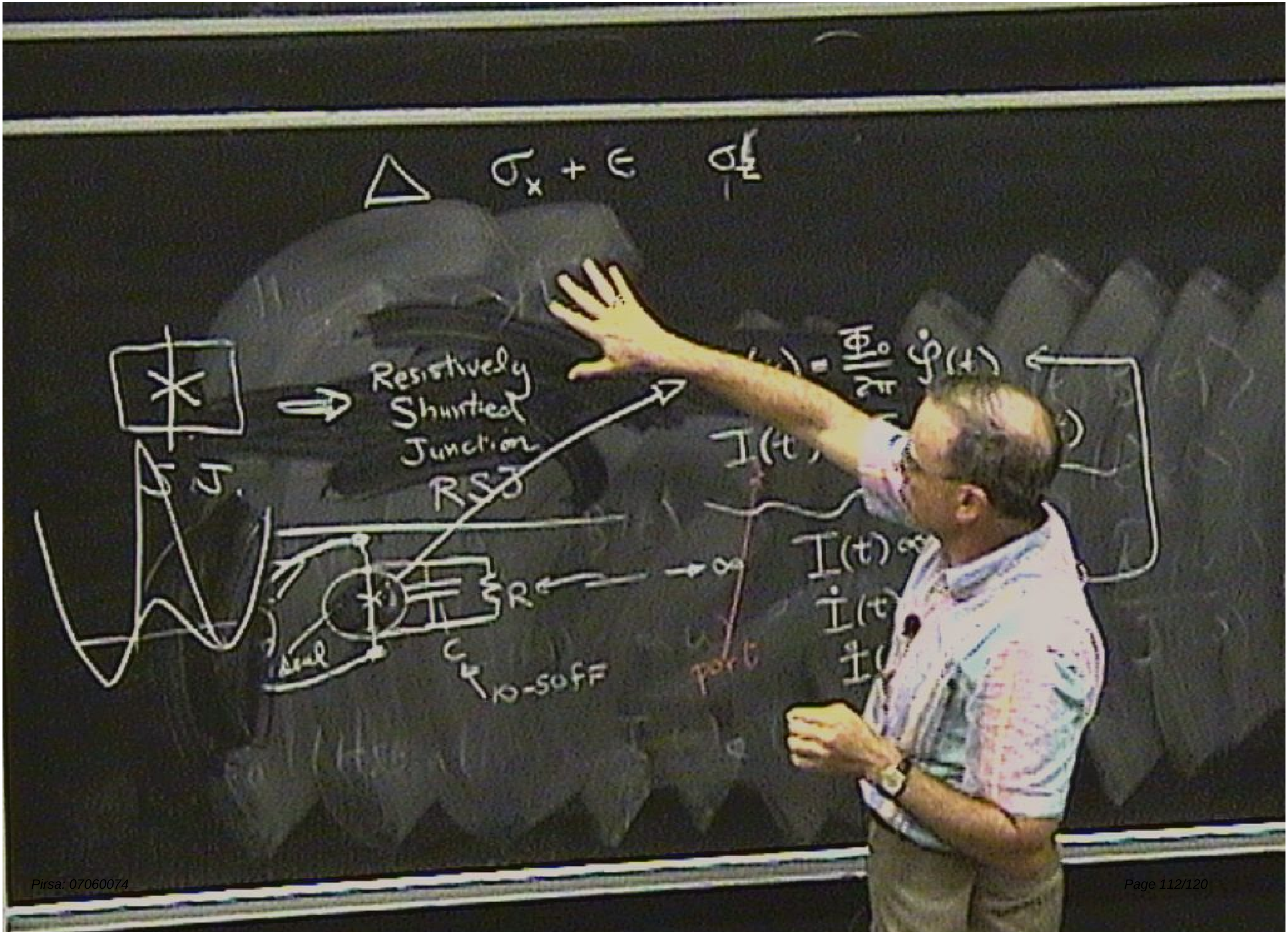

"gradiometer"


E
10GHz
2GHz
10nsec
$\alpha\hat{\Omega}_1 + \beta\hat{\Omega}_2 |vac\rangle$
$I = |\beta|^2$
$\alpha|0\rangle + \beta|1\rangle$
$|\chi\rangle$

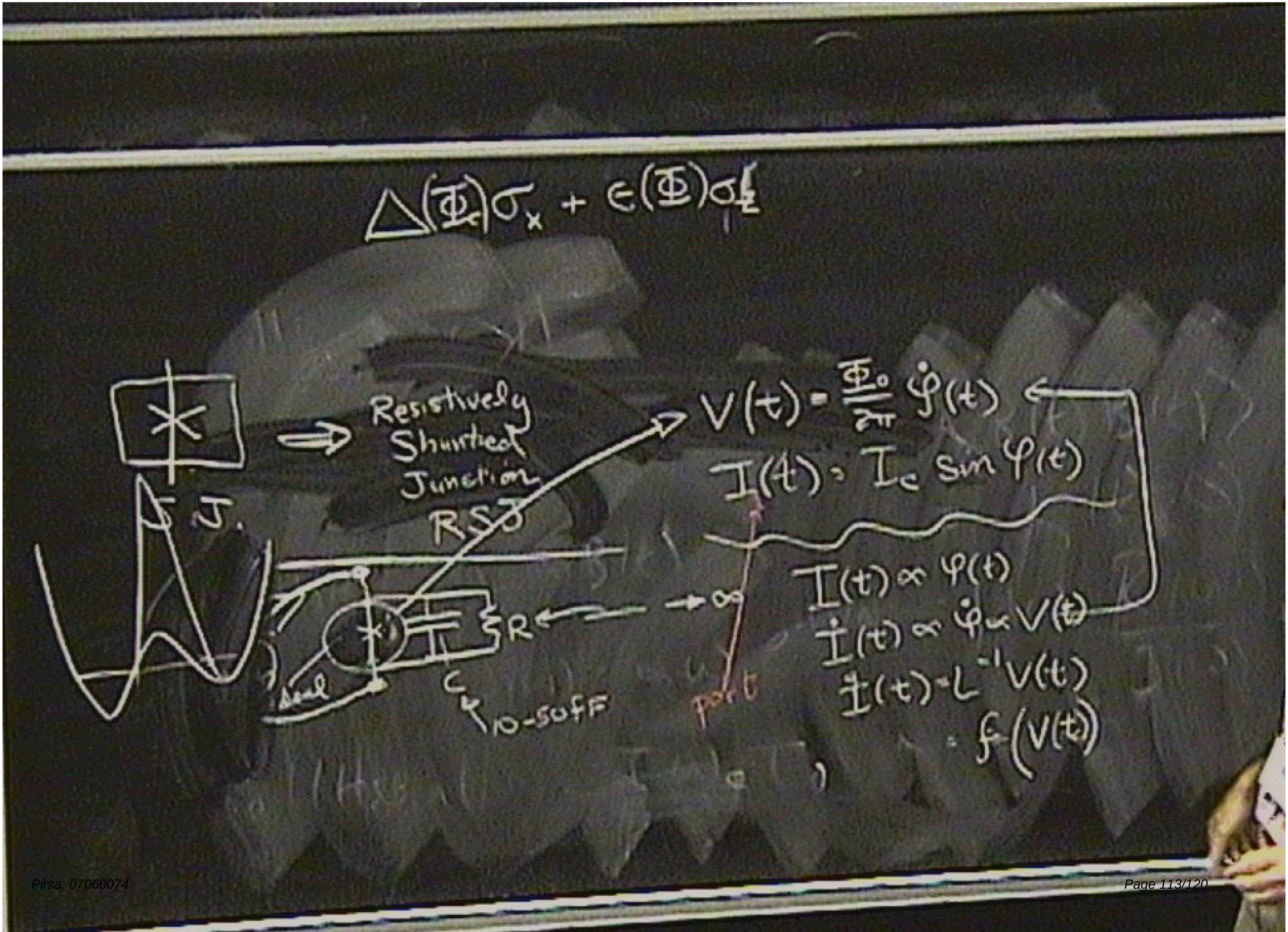

E
10GHz
2GHz
10nsec

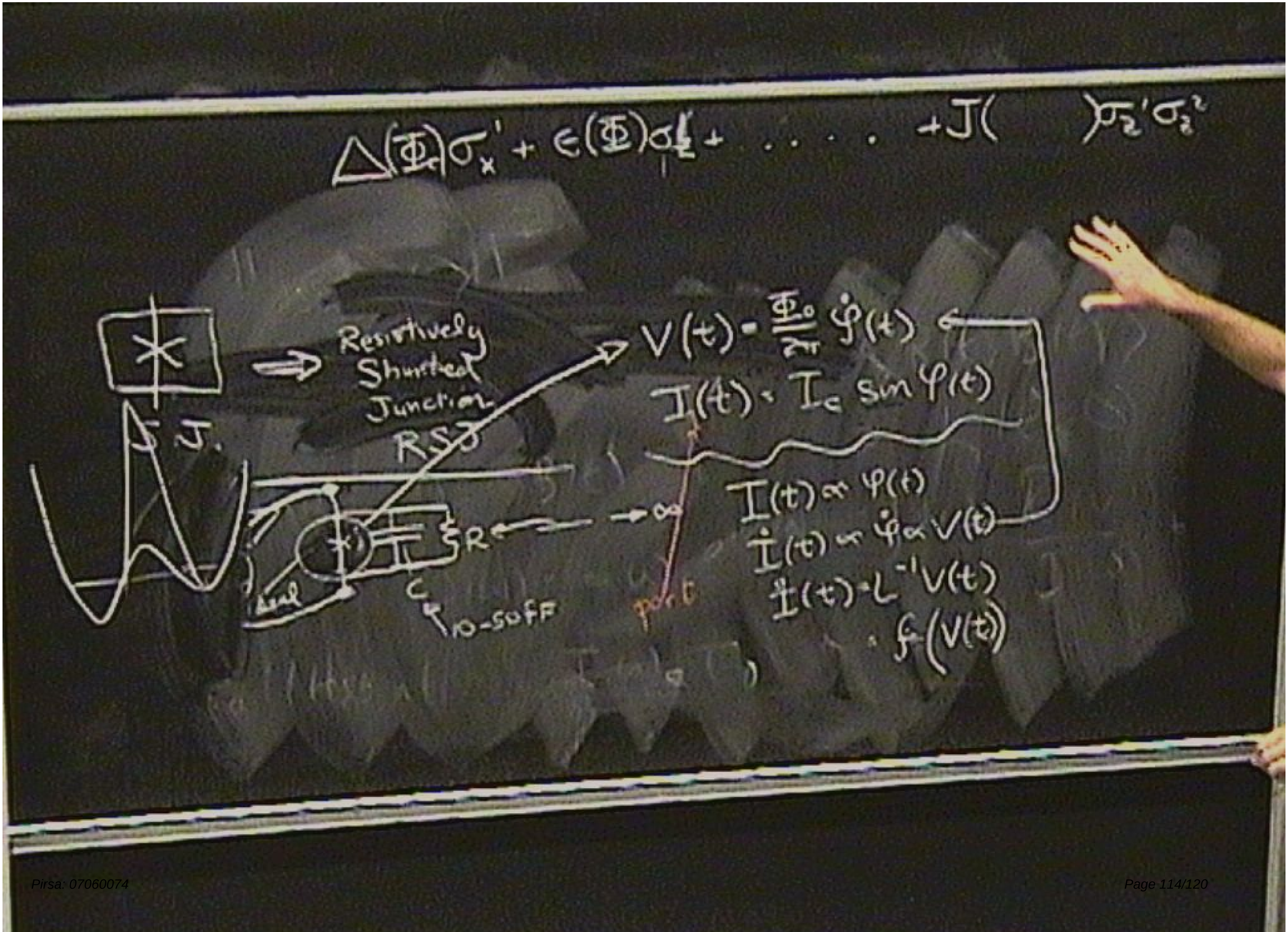

E
2GHz
10GHz
10nsec
I = |β|²
α|0> + β|1>
|χ_c>

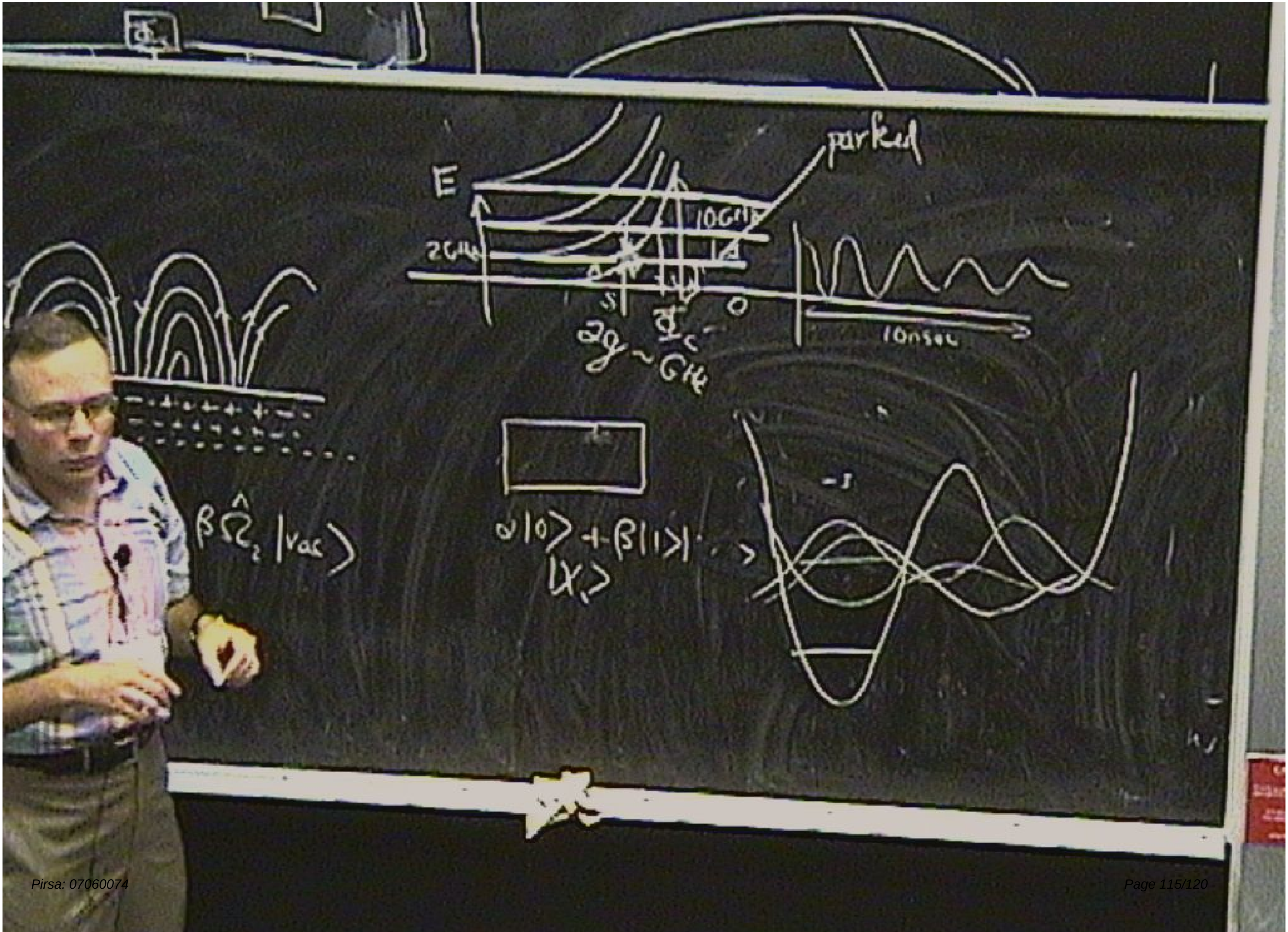

Δ
Resistiv
Shunt
Junc
R.S.
S.J.
R
C
φ̇(t)
sin φ(t)
∝ φ(t)
∝ φ̇ ∝ V(t)
I(t) = L⁻¹ V(t)
= f(V(t))

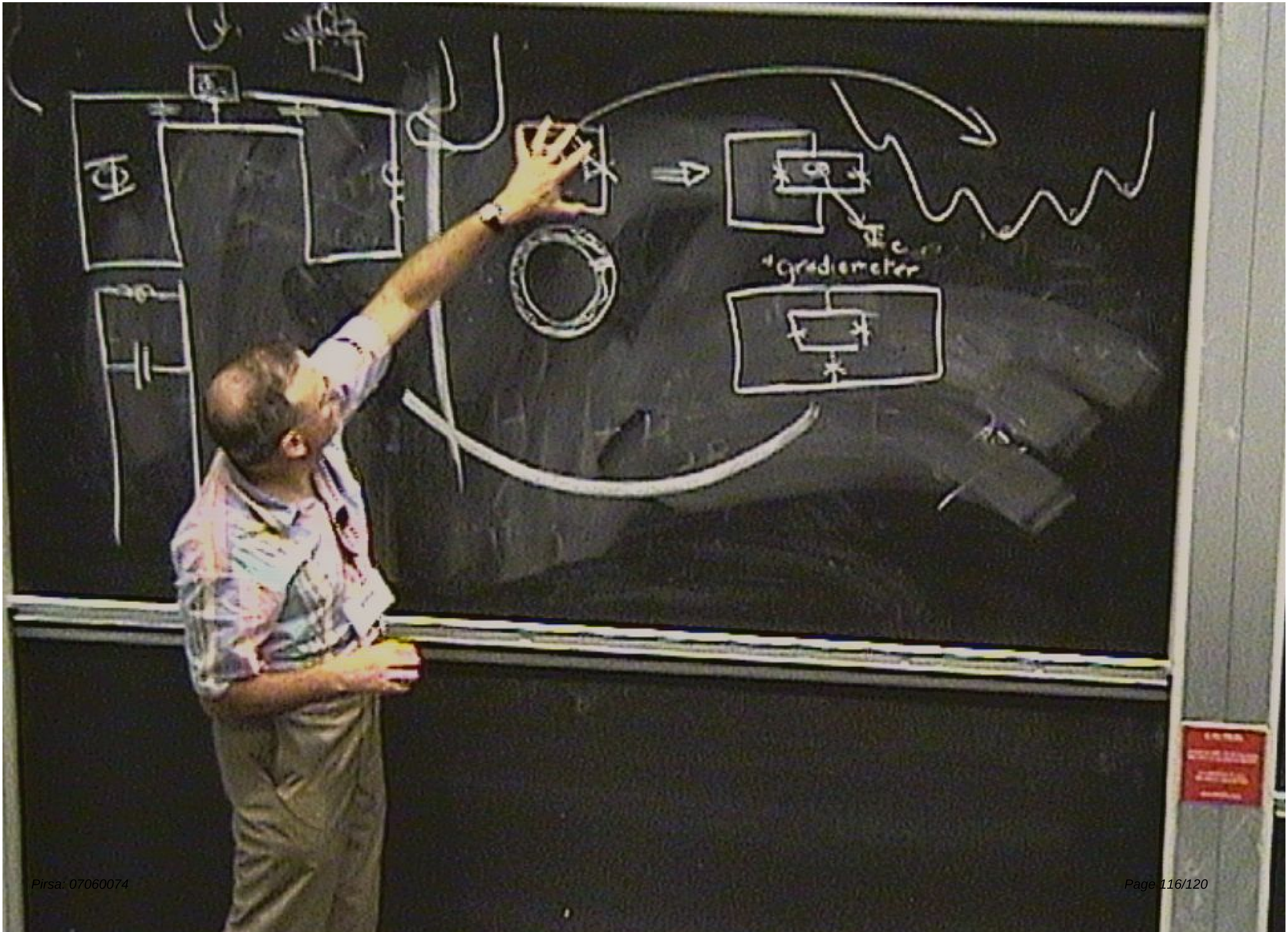


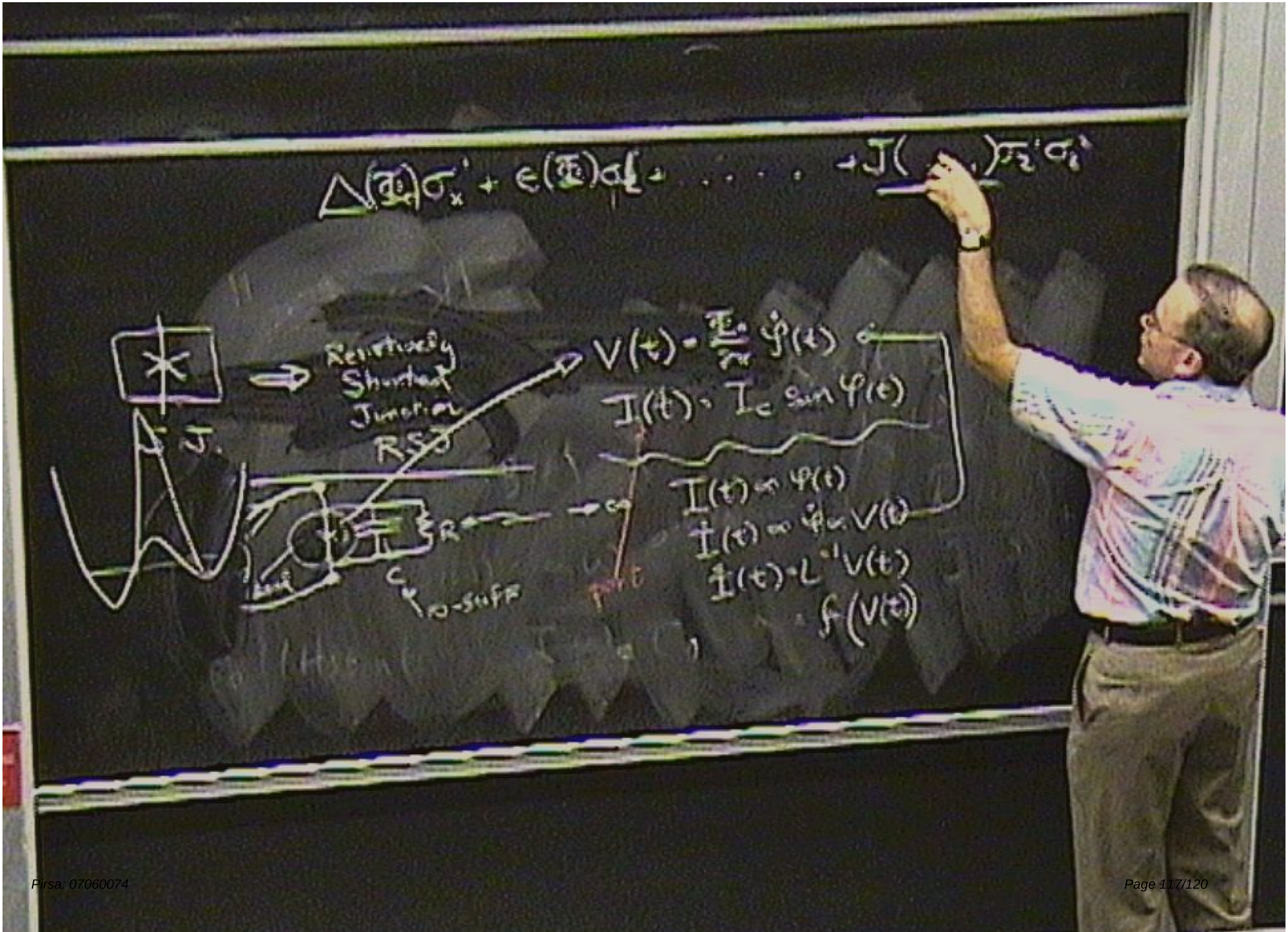
Resistively
Shunted
Junction
RSJ
J.J.
R
C
port
10-50fF

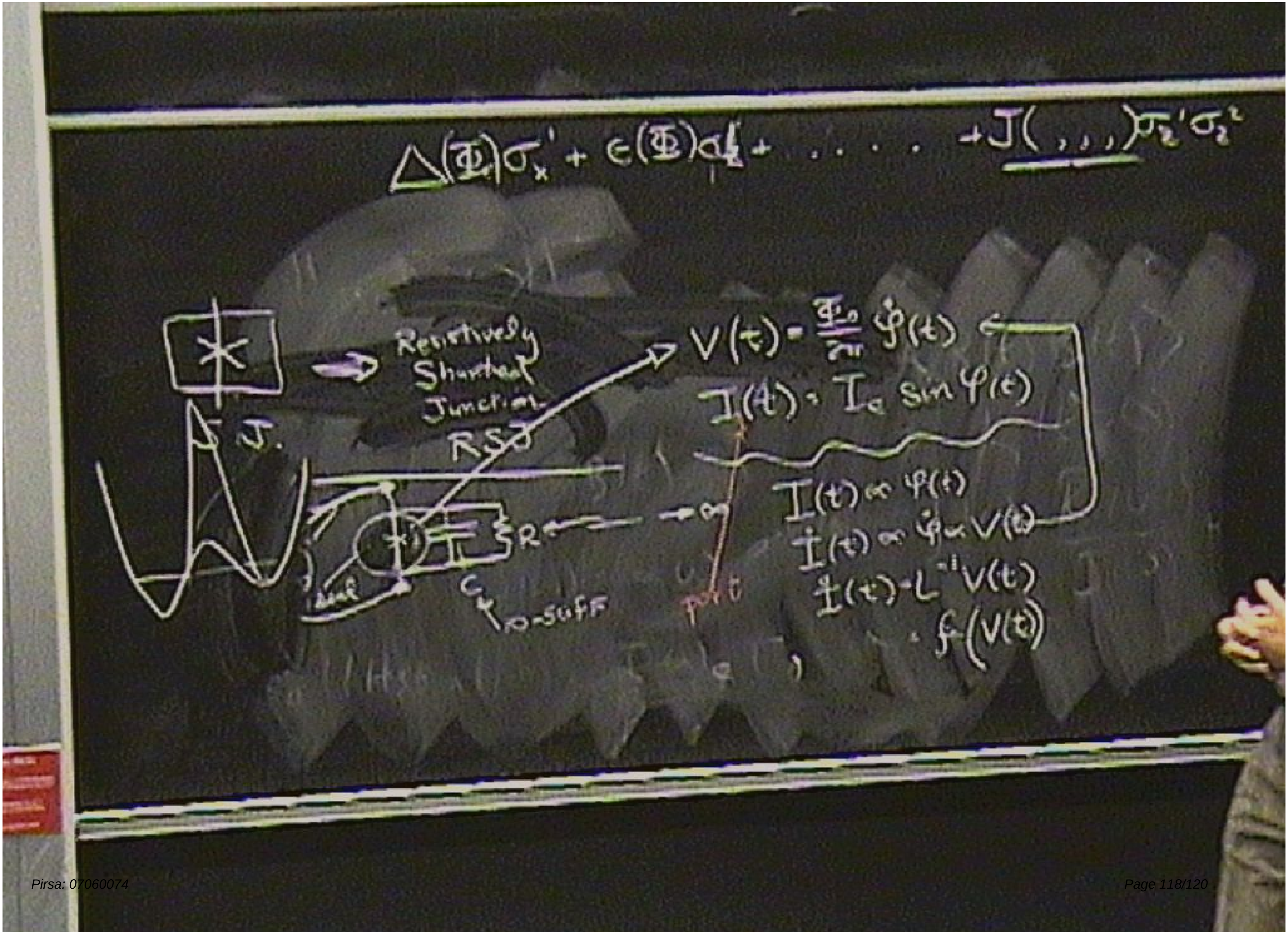

Δ(Φ)σx + ε(Φ)σz
Resistively
Shunted
Junction
RSJ
V(t) = Φ0/2π φ̇(t)
I(t) = Ic sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹V(t)
= f(V(t))
R
C
10-50fF
∞


Resistively
Shunted
Junction
RSJ
S.J.
R
C
10-50fF
V(t) = Φ0/2π φ̇(t)
I(t) = Ic sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹V(t)
= f(V(t))

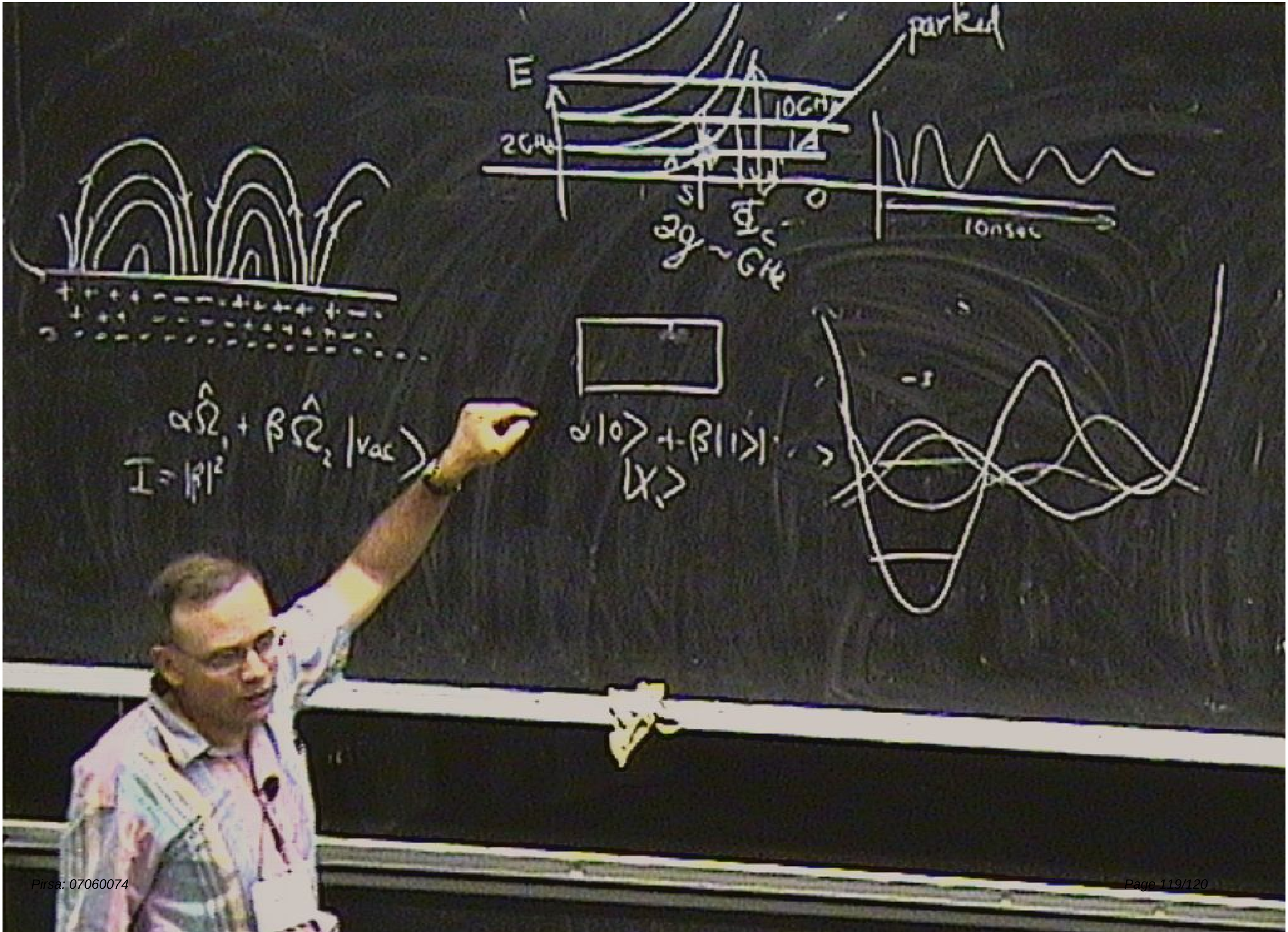

E
parked
10GHz
2GHz
10nsec
2g ~ GHz
β Ω̂₂ |vac⟩
α|0⟩ + β|1⟩
|χ⟩

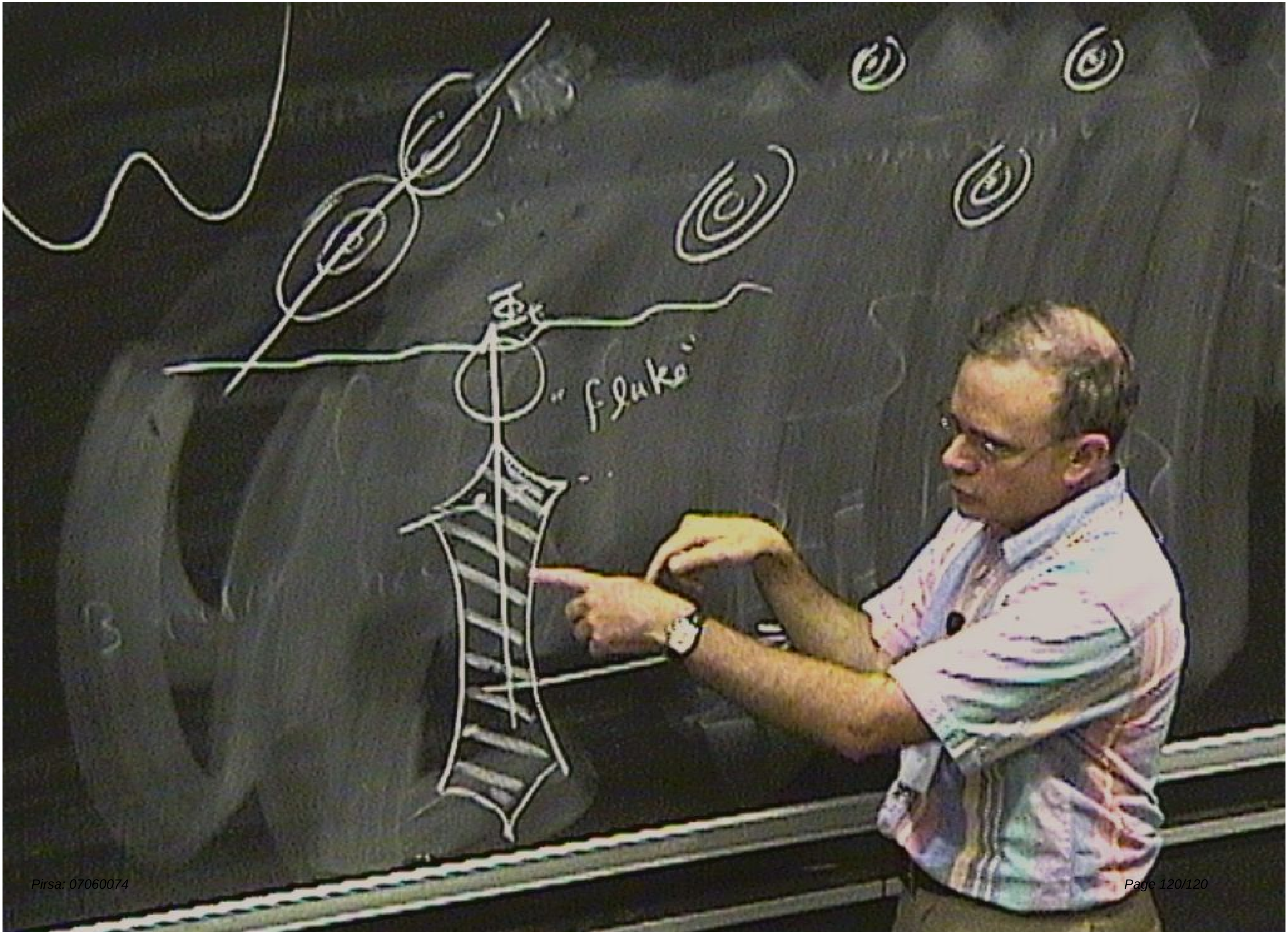

gradiometer


Resistively Shunted Junction RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹ V(t)
f(V(t))



Resistively
Shunted
Junction
RSJ
V(t) = Φ₀/2π φ̇(t)
I(t) = I_c sin φ(t)
I(t) ∝ φ(t)
İ(t) ∝ φ̇ ∝ V(t)
İ(t) = L⁻¹V(t)
= f(V(t))
R


parked
E
10GHz
2GHz
10nsec
$2g \sim$ GHz
$\alpha\hat{\Omega}_1 + \beta\hat{\Omega}_2 |vac\rangle$
$I = |\beta|^2$
$\alpha|0\rangle + \beta|1\rangle$


"fluke"