# Ultrasonic Imaging Parameters

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# Blood velocity

| | Circuit | Method | Apparatus | System | Process |
|---|---|---|---|---|---|
| amount | * (1) | ********** *** (10) | ******** (7) | ***** (5) | ***** (5) |

| | |
|---|---|
| Estimation velocity algorithm | 2 |
| Estimation velocity spectrum | 3 |
| flow estimation and measurement | 4 |
| Non-stationary flow estimation | 1 |

S. K. Alam and K. J. Parker,"The butterfly search technique for estimation of blood velocity," Ultras. in Med. Biol.vol. 21, pp. 657-670, 1995.

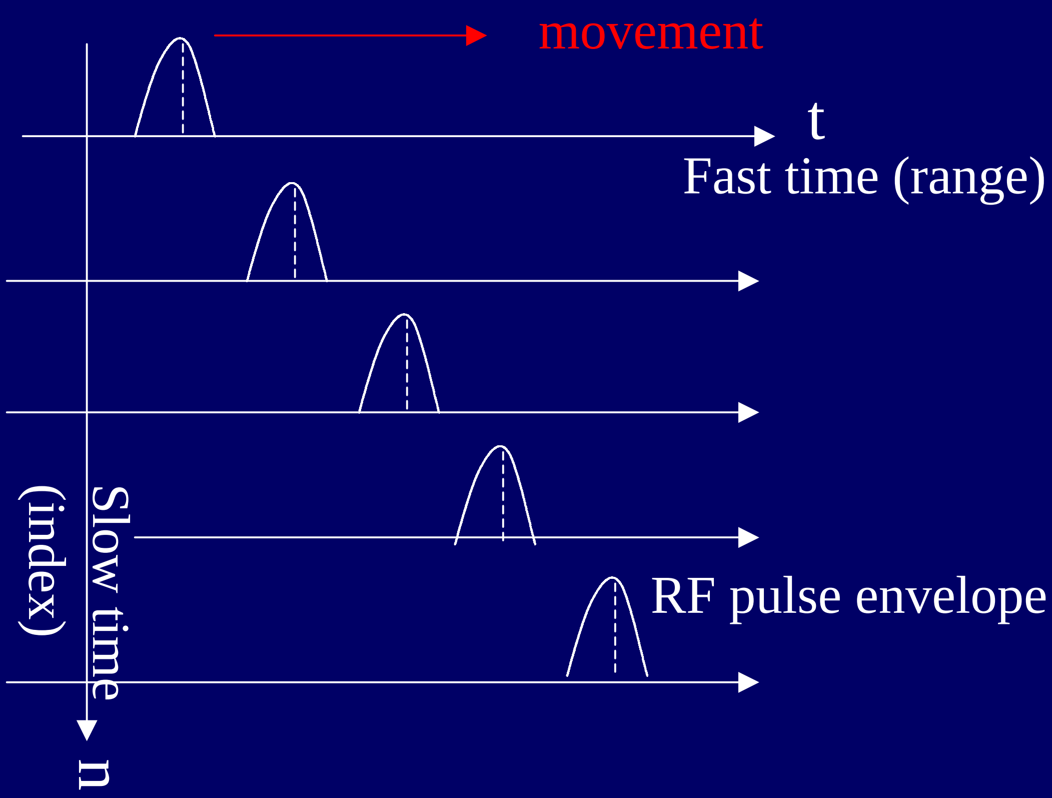
# Evaluation of estimation techniques

- Computational complexity
- SNR
  - Blood backscatter is weak
  - The estimation technique must perform well in noisy situations.
- The number of successive scan lines
  - This relates to the color flow imaging rate

# The butterfly search technique

- Can overcome the tradeoff criterion between image resolution and velocity resolution.
- Combines some of the best features of time domain and Doppler methods.
- Is reliable in hardware without exensive correlation calculations.

# The envelope of echoes from a single reflector

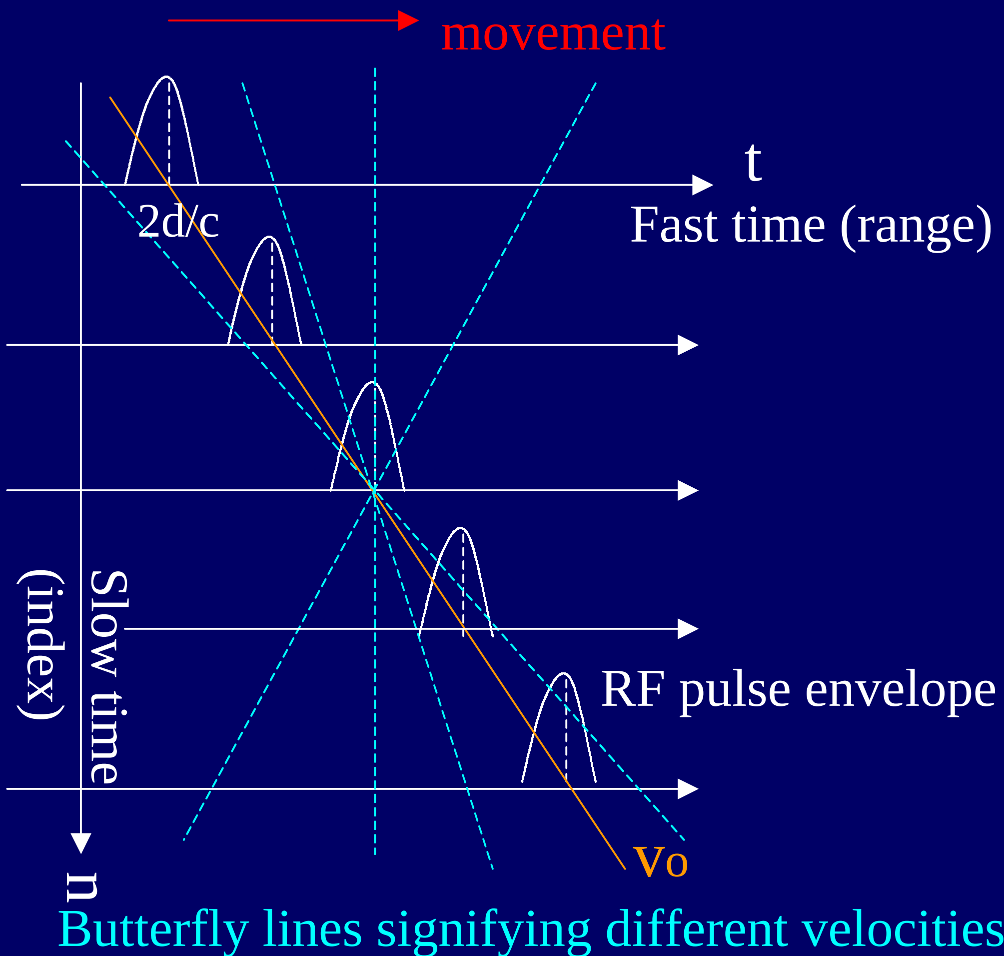



Movement of envelope on the time frame with the movement of the scatter

# RF or envelope search
# -- a time domain technique

If the trajectory matches the scatter movement, all the data samples would have the same value and their variance will be zero.

Noise
⇨variance is minimum



the envelope $e(n,t)$ for the $n$th RF A-line

$$e(n,t) = Ar(t - 2\frac{d}{c} + 2n\frac{v_0}{c}T) \qquad n = 0,1,2,....,N-1.$$

$r(t)$ : the envelope of the transmitted pulse

To sample $e(n,t)$ at its maximum value

$$(t - 2\frac{d}{c} + 2n\frac{v_0}{c}T) = 0 \qquad \because r() \text{ maximizes at } t = 0$$

In the discrete time form

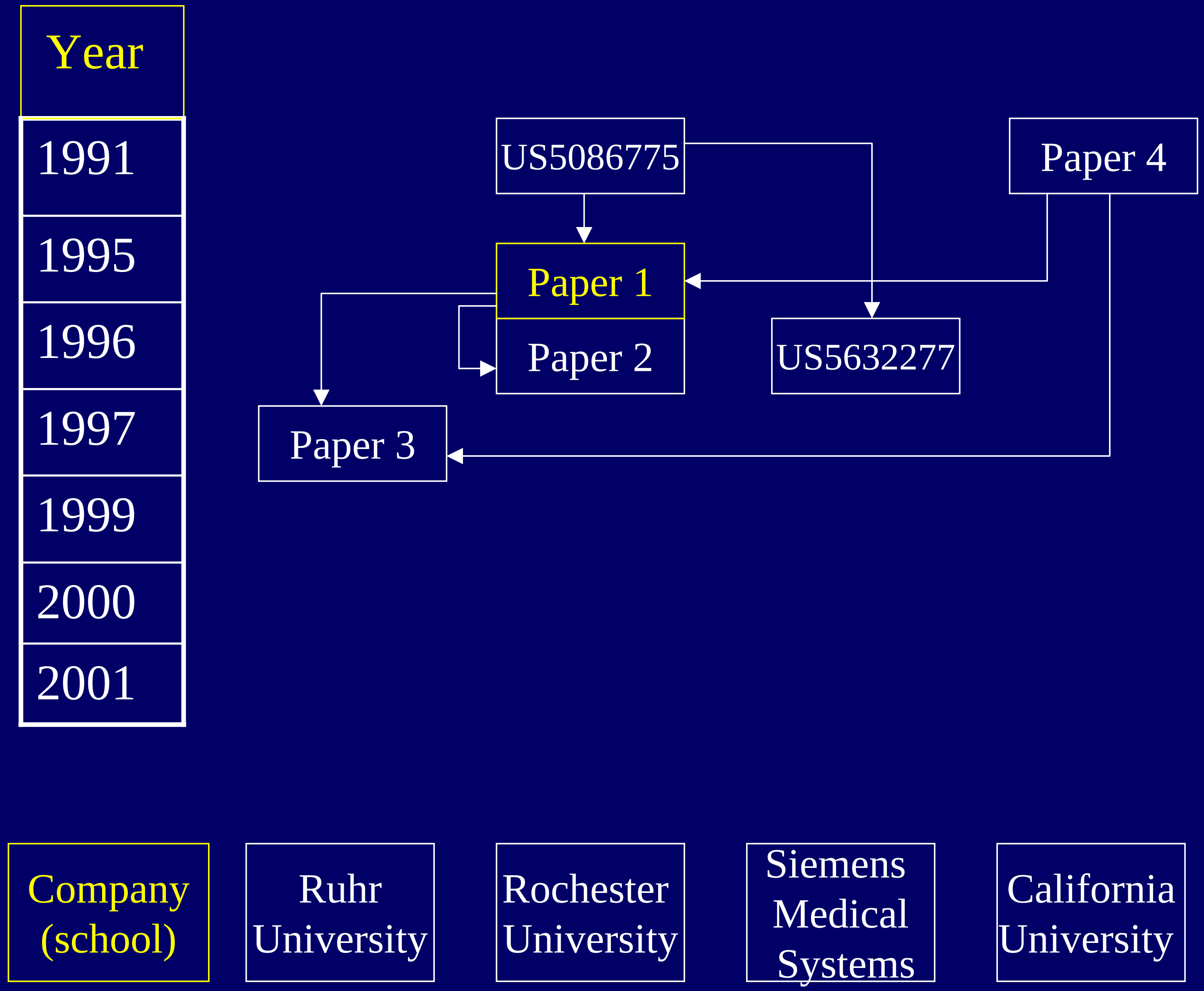
$$(\frac{i}{f_f} - 2\frac{d}{c} + 2n\frac{v_0}{c}T) = 0 \qquad i : \text{integer}$$

After interpolation

$$e_{Bv}[n] = e(n,t)\delta(t - 2\frac{d}{c} + 2n\frac{v}{c}T)$$

The estimated velocity

$$\hat{v} = \min\{\text{var}(e_{Bv}[n])\}$$


Year
1991
1995
1996
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US5086775
Paper 4
Paper 1
Paper 2
US5632277
Paper 3
Company (school)
Ruhr University
Rochester University
Siemens Medical Systems
California University

# Nonlinear ultrasonic imaging

| | Circuit | Method | Apparatus | System | Process |
|---|---|---|---|---|---|
| amount | **** (4) | ********** ** (10) | ******* (6) | *** (3) | **** (4) |

| | |
|---|---|
| reducing the amount of computation | 4 |
| Designing an array transducer | 2 |
| Higher order harmonic | 1 |
| Pulse inversion | 3 |

B. H. H. and R. Y. C., "Ultrasound Imaging With Higher-Order Nonlinearities" , US patent 6063033, May 16, 2000.

# Introduction

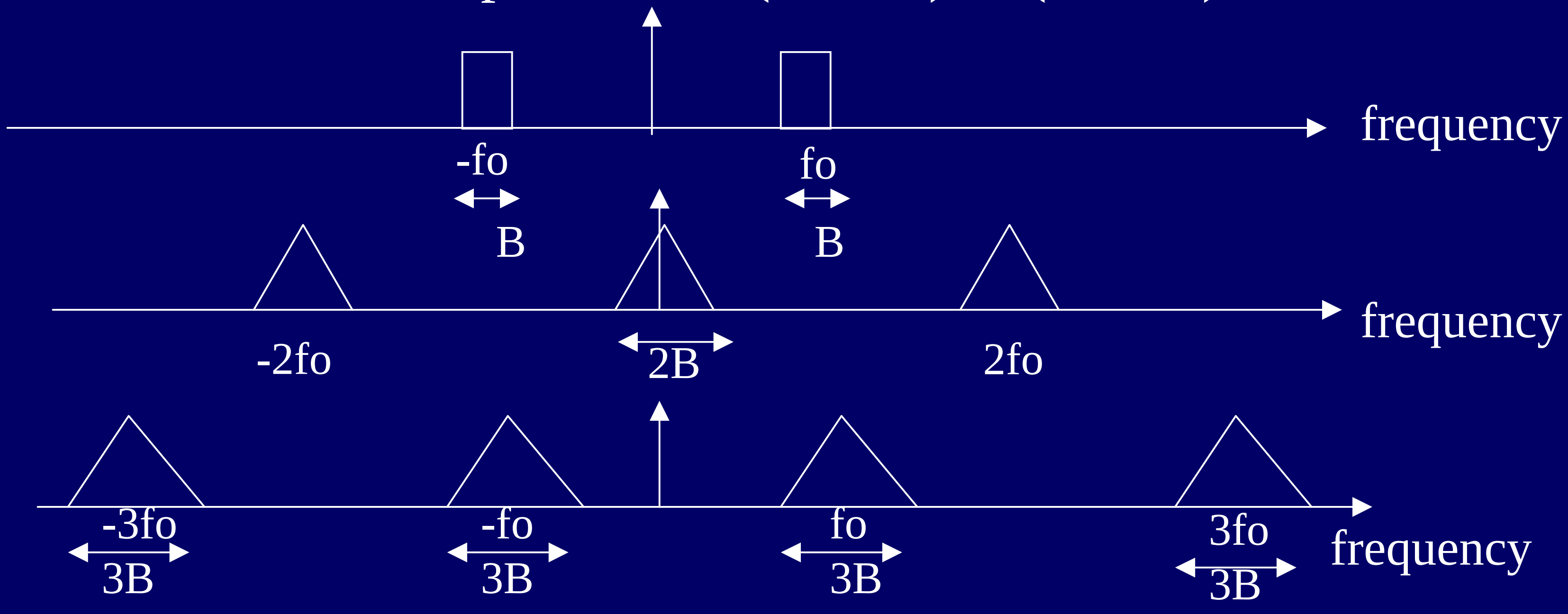
- Fundamental and harmonic signal components
  - Direct echoes of the transmitted pulse
  - Generated in a nonlinear medium

    ex. tissue
- Second harmonic
  - Worse SNR compared with fundamental
  - Improve image quality (Clutter rejection )
- Higher harmonic
  - SNR ???

# Separate the second harmonic from the fundamental frequency

- Bandpass filter
  - A transmitted signal centered at fo
  - The receive filter is centered at 2fo
  - Challenge : bandwidth requirement

    passband : (fo-B/2) to (2fo+B)



# Method to extract the higher order nonlinear components

Model the nonlinear echo signal
polynomial expansion of some basis waveform

↓

Solve the coefficient of this model
(least squares inversion)

Transmit signal $p_i(t) = b_i\, p_o(t)$   $i = 1 \ldots I$

$b_i$ : the same waveform with different complex amplitude

$$s(t) = \sum_{n=1}^{N} a_n b_i^n q^n(t) \quad i = 1 \ldots I$$

$$\Rightarrow s(t) = \begin{bmatrix} b_1 & b_1^2 & \cdots & b_1^N \\ b_2 & b_2^2 & \cdots & b_2^N \\ \vdots & \vdots & \ddots & \vdots \\ b_I & b_I^2 & \cdots & b_I^N \end{bmatrix} \begin{bmatrix} a_1 q \\ a_2 q^2 \\ \vdots \\ a_3 q^3 \end{bmatrix}$$

received echo signals    complex excitation (B)    harmonic components

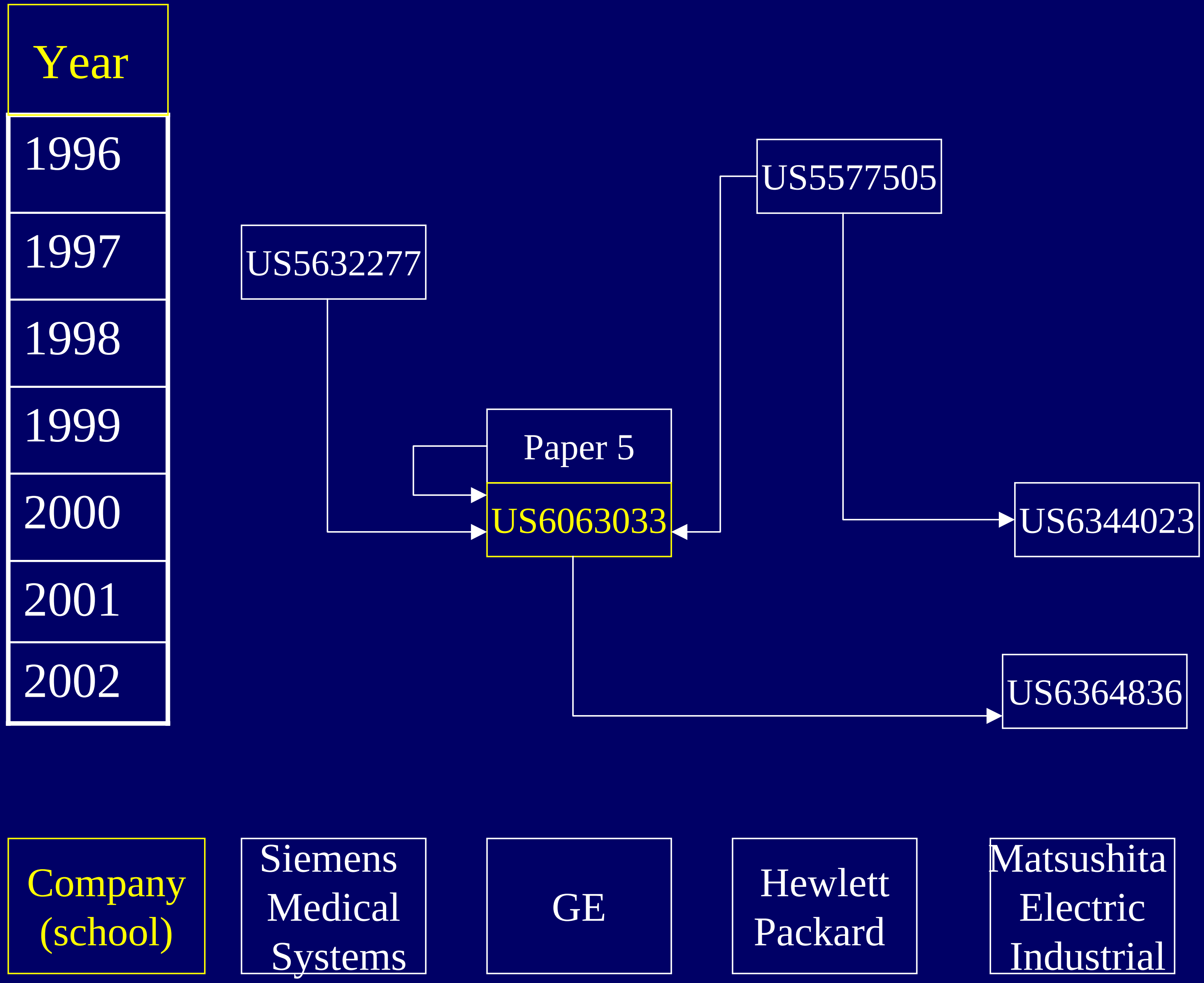
estimated harmonic components : $(\mathbf{B}^T\mathbf{B})^{-1}\mathrm{B}^T\mathbf{s}(t)$

# System Nonlinearities

- Odd order system nonlinearities of circuit
  - Voltage symmetric pulser and amplifier
- To cancel the system nonlinearities
  - by subtracting the linear echo

$$(B^T B)^{-1} B^T = D = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & d_{32} & d_{33} & d_{34} \\ d_{41} & d_{42} & d_{43} & d_{44} \end{bmatrix}$$

$$\Rightarrow D_{correction} = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} - cd_{11} & d_{32} - cd_{12} & d_{33} - cd_{13} & d_{34} - cd_{14} \\ d_{41} & d_{42} & d_{43} & d_{44} \end{bmatrix}$$


Year
1996
1997
1998
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2000
2001
2002
US5577505
US5632277
Paper 5
US6063033
US6344023
US6364836
Company (school)
Siemens Medical Systems
GE
Hewlett Packard
Matsushita Electric Industrial

# Elastic modulus

- Elastic constant
  - Young's modulus, shear modulus, bulk modulus
- Young's modulus

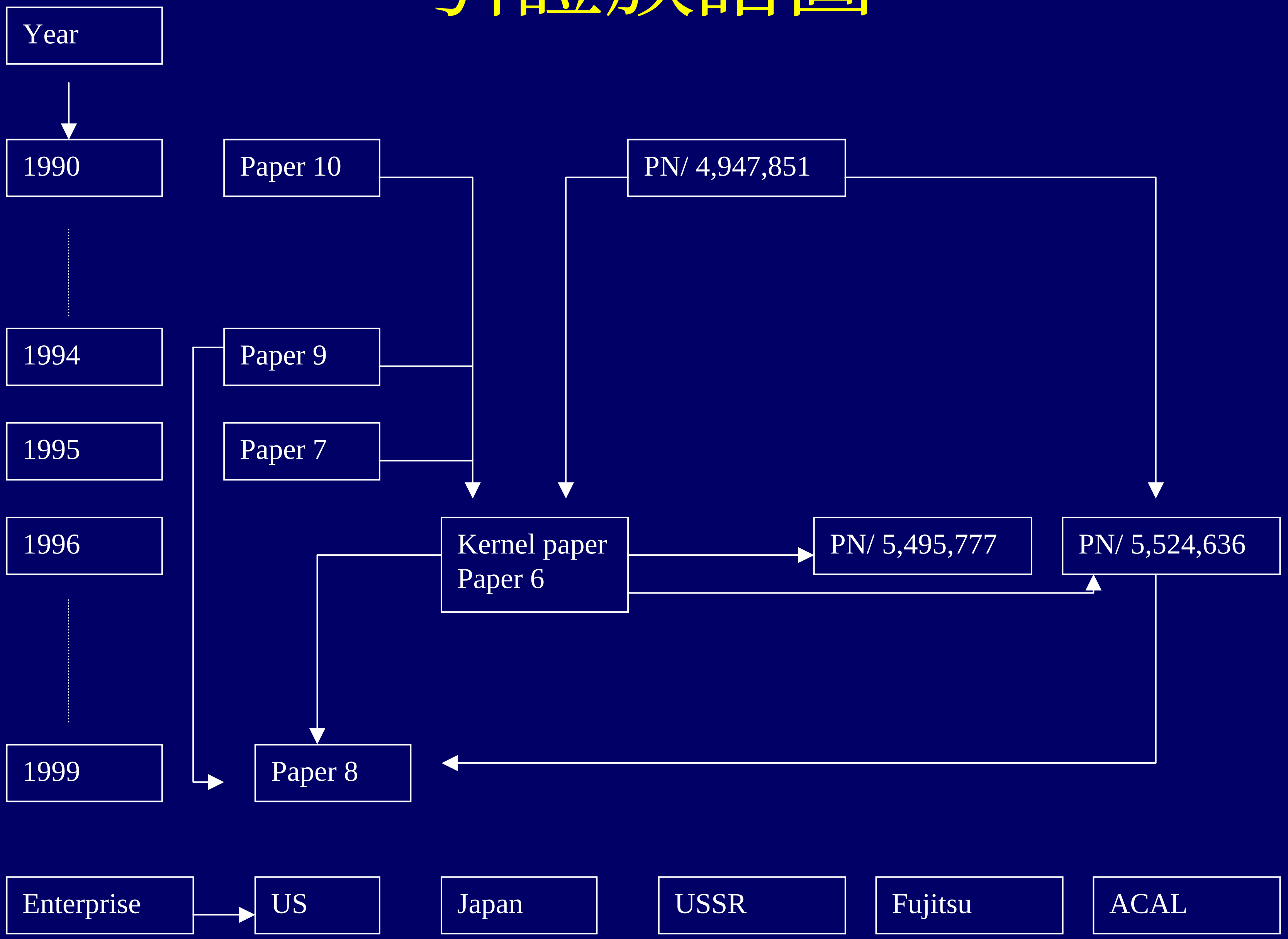
$$E = \mu \frac{3\lambda + 2\mu}{\lambda + \mu}$$

- For soft tissue $E = 3\mu$

# 標的分析統計表

| | Device | Circuit | Method | Apparatus | System | Process | Total |
|---|---|---|---|---|---|---|---|
| Elastic modulus | 2 | 0 | 16 | 6 | 0 | 3 | 15 |
| Total amount | 2 | 0 | 16 | 6 | 0 | 3 | |

# 引證族譜圖



Year
1990
1994
1995
1996
1999
Paper 10
Paper 9
Paper 7
PN/ 4,947,851
Kernel paper
Paper 6
PN/ 5,495,777
PN/ 5,524,636
Paper 8
Enterprise
US
Japan
USSR
Fujitsu
ACAL

# Reconstruct elastic modulus [1]

- Elasticity imaging
  - Measurement of tissue displacement using speckle tracking algorithm
  - Measurement of strain tensor component
  - Spatial distribution of the elastic modulus using strain images

# Cont'd

Constitutive equation $\sigma_{ij} = p\delta_{ij} + 2\mu\varepsilon_{ij} \qquad i, j = 1,2,3$

Static equilibrium equation $\sum_{j=1}^{3} \frac{\partial \sigma_{ij}}{\partial x_j} = 0 \qquad i = 1,2,3$

$$\begin{cases} \frac{\partial}{\partial x}(2\mu(2\varepsilon_{xx} + \varepsilon_{yy})) + \frac{\partial}{\partial y}(2\mu\varepsilon_{xx}) = 0 \\ \frac{\partial}{\partial x}(2\mu\varepsilon_{xy}) + \frac{\partial}{\partial y}(2\mu((\varepsilon_{xx} + 2\varepsilon_{yy}))) = 0 \end{cases}$$

# Cont'd

Relation of two RF images envelop intensity
$f_2(x, y)=(1-k) \cdot f_1(x-u_x, y-u_y)$

↓ Taylor expansion

$(f_2-f_1)+u_x f_x+u_y f_u+kf_1=0$

↓ The least squares estimation

Minimize $J = \iint_G (f_t + u_x f_x + u_y f_y + kf_1)^2 \, dxdy$

↓

Estimate 2-D displacement($u_x$, $u_y$ ) distribution

↓ Spatial derivative

Strain tensor

Static equilibrium eq：

$$\frac{\partial}{\partial x}(2\mu(2\varepsilon_{xx}+\varepsilon_{yy}))+\frac{\partial}{\partial y}(2\mu\varepsilon_{xx})=0$$

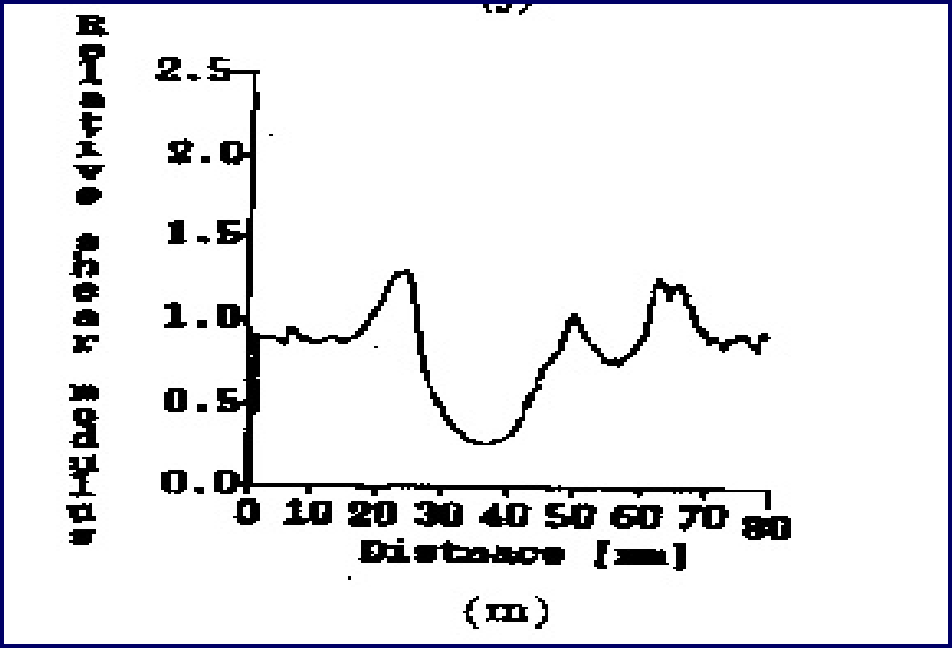
$$\frac{\partial}{\partial x}(2\mu\varepsilon_{xy})+\frac{\partial}{\partial y}(2\mu((\varepsilon_{xx}+2\varepsilon_{yy})))=0$$

↓ Finite element method

Shear modulus

# Implement

- Make a gel-based phantom
- Select ROI
- Spatio-temporal derivative method



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- Paper 6: Yasuo Yamashita, Misuhiro Kubota,“Tissue elasticity reconstruction based on ultrasonic strain measurements,” IEEE ultrasonic symposium, 1996.
- Paper 7: A. R. Skovoroda, S.Y. Emelianov, and M. O’Donnell, “Tissue elasticity reconstruction based on ultrasonic displacement and strain images,” IEEE Trans. Ultrason., Ferroelect, Freq. Contr., vol.42, pp. 747-765, July 1995.
- Paper 8: A. R. Skovoroda, Mark A. Lubinski, S.Y. Emelianov, and M. O’Donnell, “Reconstructive elasticity imaging for large deformations,” IEEE Trans. Ultrason., Ferroelect, Freq. Contr., vol.46, No. 3, May 1999.
- Paper 9: A. R. Skovoroda, S.Y. Emelianov, Mark A. Lubinski, A. P. Sarvazyan and M. O’Donnell, “Theoretical analysis and verification of ultrasound displacement and strain imaging,” IEEE Trans. Ultrason., Ferroelect, Freq. Contr., vol.41, pp. 302-313, May 1994.
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