MEMS Optical Scanner "ECO SCAN"
Application Notes
Design Edition

Ver.0

Visionary Business Center

Micro Electro Mechanical Systems Promotion Dept

The Nippon Signal Co., Ltd.

A-LG9646A-001

Precautions

Caution

- Since ECO SCAN uses strong magnets, there are the following risks:
  - Moving a magnetic material close to the mirror part may cause damage or affect its performance characteristics.
- Since the moving plate is exposed, there are the following risks:
  - The moving plate may be damaged if it is hit by fingers or tweezers, or strongly blown by air.
- Since ECO SCAN is a precision optical component, there are the following risks:
  - Using it outside the scope of specifications may cause malfunction or failure.
  - During transportation and handling, the mirror part may be damaged if it is dropped or hit.
  - Disassembly or alteration may cause abnormal motion, failure, and damage.
- Applying a torsional force to ECO SCAN may break away attached parts.
- Touching the drive unit while ECO SCAN is turned on may cause abnormal heat, burning, and damage.
- Installation, maintenance, and troubleshooting while ECO SCAN is turned on may cause damage.
- Wrong connection may cause unexpected malfunction, heat, and fire. See the circuit diagram and connect ECO SCAN properly.

Preface

This document summarizes the features of MEMS optical scanner "Eco Scan" and considerations in design terms. Please understand the features before using Eco Scan.
We also support custom designing of Eco Scan. Use this document to consider various features.

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1. Operation Principles and Features

Eco Scan is an electromagnetic drive MEMS*1) optical scanner. Figure 1 describes the product configuration. This scanner is configured by aligning permanent magnets around the monocrystal silicon substrate that forms the moving plate (with the mirror and drive coil on its surface), beams, and supporting section. When the electric current (*i*) flows through the drive coil formed on the periphery of the moving plate, running torque (*F*; Lorentz force) is generated by the interaction with the magnetic field of the permanent magnets. As a result, the moving plate can tilt to the position balanced with the righting moment of the beams. Since the Lorentz force is proportional to the current, by changing the current value, the moving plate can tilt freely. That is, the optical scanning angle (hereinafter "deflection angle") can be changed freely within the scope of rating.

Table 1 describes MEMS optical scanner's general drive systems and their features. Eco Scan's electromagnetic drive system suits "large mirror drive" and "dissonance drive" that need large driving power.

Figure 1 describes one-dimensional type, but we provide two-dimensional type as well.

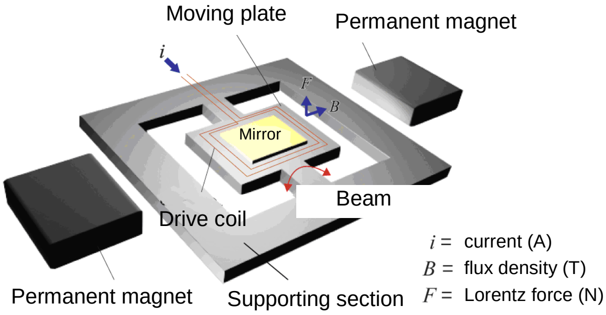


Figure 1. Production configuration of Eco Scan

*1) Abbreviation for Micro Electro Mechanical Systems. Fine processing technology that comes from semiconductor manufacturing. It is used to integrate micro electrical and mechanical elements into a silicon or glass substrate of a sensor, actuator, and other devices.

Table 1. Drive systems and features of MEMS optical scanner

Drive system	Electromagnetic	Electrostatic	Piezoelectric (thin film type)
Merits	- Low driving voltage (5 V or less) - Large driving power →Supportive of large mirrors and dissonance drive	- Small numbers of parts - Consistent with LSI processes - Easy to control the mirror arch	- Small numbers of parts - Easy to control the mirror arch - Highly efficient forming technology of piezoelectric thin film has been established.
Demerits	- Large number of parts (magnets, yokes, etc.) - Characteristics degradation due to the use beyond the storage temperature (decrease of flux density due to high temperature) - Difficult to control the mirror arch (Film stress of the drive coil affects the mirror arch.)	- High driving voltage (50 V or less) - Small driving power →Not supportive of large mirrors and dissonance drive - The comb electrode limits the amplitude. →Difficult to control the amplitude →Not supportive of large mirrors and large amplitude	- High driving voltage (50 V or less) - Small driving power →Not supportive of a large mirror and dissonance drive (a large drive unit is needed to support them.)
Manufacturers in use	- Nippon Signal - Micro Vision - Hamamatsu Photonics: under development	- Opus - STMicroelectronics (bTendo) - Panasonic: under development	- Konica Minolta: under development - Stanley: under development

2. Considerations on Designing

2.1 Mirror Size, Deflection Angle, Resonant Frequency

Commercially available MEMS devices (pressure sensor, acceleration sensor, gyro sensor, etc.) are designed to be used within the minimum range of mechanical strength of silicon. For the MEMS optical scanner, on the other hand, since the silicon beams (aluminum beams for DMD) are highly twisted to operate the moving plate and large stress is generated, it is normally used around the limit of the mechanical strength of silicon. The MEMS optical scanner's main characteristics are the "mirror size (moving plate size)", "deflection angle", and "resonant frequency", and these characteristics each determine the stress applied to the beams, and thus are in a trade-off relation (see Figure 2).

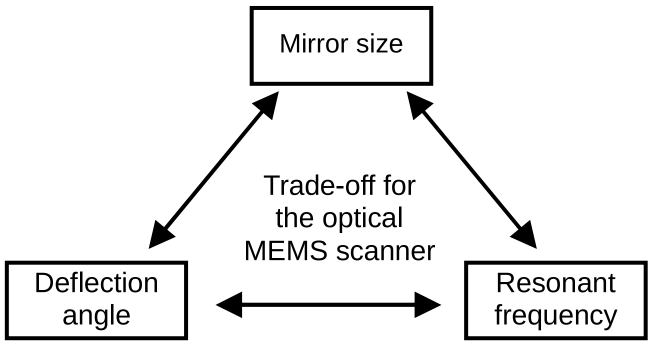
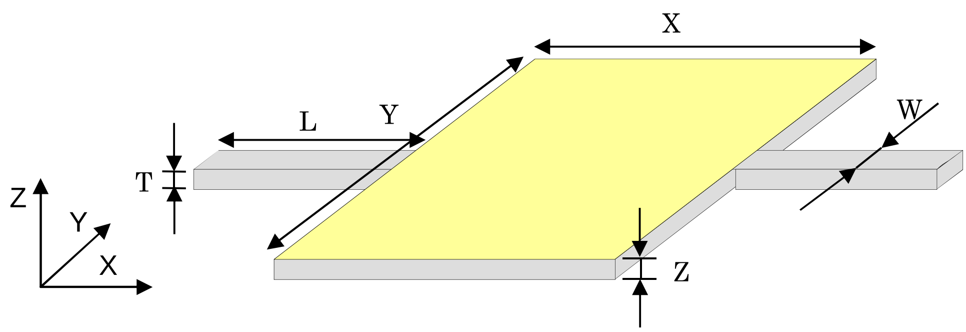


Figure 2. Trade off in mechanical strengths of MEMS optical scanner main characteristics

Eco Scan is designed based on vibration engineering and material mechanics considering the above trade-off relation. Figure 3 describes design parameters for Eco Scan. This section describes in detail the impact on the characteristics of these parameters with the help of equations. For Eco Scan, the mirror thickness (*Z*) and the beam thickness (*T*) are the same (Z=T) for production purposes.



X: Horizontal dimension of the mirror, *Y*: Vertical dimension of the mirror, *Z*: Structural thickness
W: Beam width, *L*: Beam length, *T*: Beam thickness

Figure 3. Eco Scan parameter definitions

(Beam twist) resonant frequency (f_0) and moment of inertia (J) are expressed by the following equations:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{J}} \qquad \cdots\cdots\cdots(1)$$

$$J = \frac{X \cdot Y \cdot Z \cdot \rho_{Si} \cdot (Y^2 + Z^2)}{12} \qquad \cdots\cdots\cdots(2)$$

k: Spring constant, ρ_{Si}: Silicon density

The torque (M_t) is expressed for the deflection angle (θ) and Lorentz force (F) by the following equation:

$$M_t = k \cdot \theta \qquad \cdots\cdots\cdots(3)$$

$$M_t \fallingdotseq \frac{Y}{2} \cdot \mathrm{F} \qquad \cdots\cdots\cdots(4)$$

Substitute the Lorentz force expressed in (5) into the equation (4).

$$F \fallingdotseq n \cdot X \cdot I \cdot B_y \qquad \cdots\cdots\cdots(5)$$

$$M_t \fallingdotseq \frac{Y}{2} \cdot n \cdot X \cdot I \cdot B_y \qquad \cdots\cdots\cdots(6)$$

n: Driving coil winding number, *I*: Impressed current, B_y: Magnetic field intensity orthogonal to the current that flows on the coil

(θ) can be solved by solving (*k)* in the equation (1), and substitute it with the equation (4) in the equation (3) as follows:

$$\boxed{\theta \fallingdotseq \frac{3}{2} \cdot \frac{1}{{f_0}^2} \cdot \frac{n \cdot I \cdot B_y}{Z \cdot \rho_{si} \cdot \pi^2 (Y^2 + Z^2)}} \qquad \cdots\cdots\cdots(7)$$

The above equation indicates the quantitative relation between three major characteristics (the mirror size (moving plate size): *Z*, *Y*, deflection angle: θ, resonant frequency: f_0).

2.2 Power consumption

Since Eco Scan has the electromagnetic drive system, power consumption needs to be considered. Power consumption may lead to heat in the drive coil, degradation of metal material forming the coil, and variation of characteristics. As shown in the equation (8), power consumption relates to the above three major characteristics, and therefore it should be balanced with them.

The power consumption (*P*) and the drive coil resistance (*R*) are expressed in the following equation:

$$\mathrm{P} = I^2 \cdot R \qquad \cdots\cdots\cdots(8)$$

$$\mathrm{R} \fallingdotseq \frac{R_{\mathrm{coil}} \cdot n \cdot X}{l_w \cdot l_z} \qquad \cdots\cdots\cdots(9)$$

R_{coil}: Resistance rate of the drive coil material, l_{w}: Line with of the drive coil, l_{z}: Thickness of the drive coil

Solve (*I*) in the equation (7), and substitute it with the equation (9) in the equation (8) to make the following equation:

$$\boxed{P \fallingdotseq \frac{4}{9} \cdot \theta^2 \cdot {f_0}^4 \cdot \frac{Z^2 \cdot X \cdot R_{coil} \cdot {\rho_{\mathrm{si}}}^2 \cdot \pi^4 \cdot (Y^2 + Z^2)^2}{n \cdot {B_y}^2 \cdot l_w \cdot l_z}} \qquad \cdots\cdots\cdots(10)$$

The above equation indicates the quantitative relation between the power consumption and the above three major characteristics.

2.3 Mirror Arch

The mirror and drive coil is equipped on the moving plate of Eco Scan. Although they are on the same surface, the mirror and the drive coil are normally formed on different sides each other to ensure a large size mirror.

Film stress of the metallic film used for the mirror and drive coil creates an arch of the mirror (moving plate). The radius of curvature (*r*) of the arch is expressed by a general equation below.

$$r = \frac{E_{\mathrm{Si}} \cdot Z^2}{6(1 - \nu_{\mathrm{Si}})\sigma d} \qquad \cdots\cdots\cdots(11)$$

E_{Si}: Young's modulus of silicon, ν_{Si}: Poisson's ratio of silicon、σ: Film stress of the metallic film, *d:* Thickness of metallic film

The equation (11) indicates that the mirror arch can be suppressed by thickening the moving plate thickness (*Z*) or thinning the metallic plate thickness (*d*) or decreasing the stress (σ) of the metallic film.

The film stress of the metallic film is determined under the production process condition, and therefore changing it is not easy. On the other hand, the moving plate thickness (*Z*) and the metallic film thickness (*d*) are determined by the four elements "mirror size", "deflection angle", "resonant frequency", and "power consumption", and thus a trade-off between them must be considered.

3. Mirror (Material and Reflectance)

For Eco Scan, metallic film is created to form a mirror on the moving plate (polished surface of the silicon). Figure 4 describes the wavelength dependability of reflectance of various metals. Al (aluminum) or Ag (silver) is used for visible light (400 to 700 nm), e.g. display unit, and Au (gold) is used for near infrared light (800 to 1000 nm), e.g. distance sensor. Although Ag has higher reflectance throughout the range of visible light and lower durability than Al, we provide durable Ag film by combining it with surface protection film.

We also support dielectric multilayer mirrors that have high reflectance with a specific wavelength. However, we do not recommend it because the film stress of each layer is added up, and the arch or the mirror is large and difficult to control.

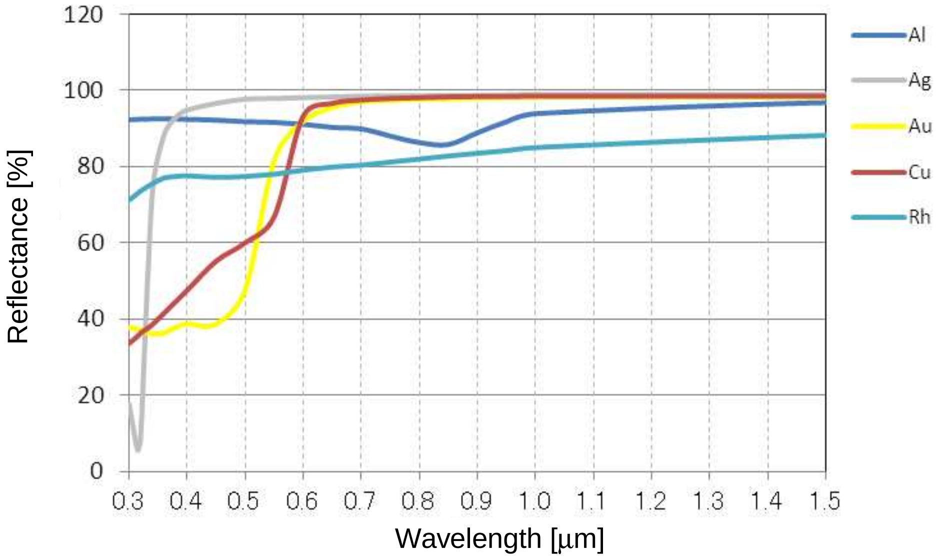


Figure 4. Material and reflectance of the mirror (excerpt from Chronological Scientific Tables 2006)

4. Monitoring Amplitude

To control vibration of Eco Scan, the amplitude needs to be monitored. To do this, the following three methods are available: (1) the counter electromotive force, (2) piezo signal, and (3) optical sensor. Table 2 summarizes their principles and features. For details, see the accompanying document (control edition).

To support (1) the counter electromotive force method, a detection coil is newly installed, which is totally separated from the drive coil. For (2) the piezo signal method, piezoresistive elements (to convert the stress on the beam into an electric signal) are equipped on the monocrystal silicon substrate. For (3) the optical sensor method, the customer shall prepare the external light source and detecting element for Eco Scan. Use a method that meets your requirements.

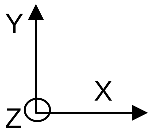
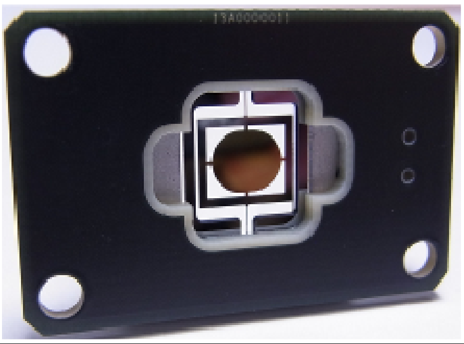
Table 2. Mirror position detection methods and their feature

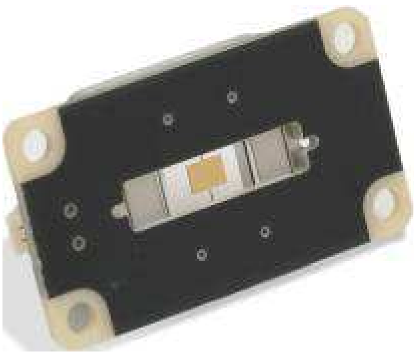
Detection method	Counter electromotive force	Piezo signal	Light sensor
Principles	• Detect a counter electromotive force generated on the coil oscillating in the magnetic field.	• Use the variation of piezoresistive element resistance value to electrically detect the stress generated by oscillation.	• Detect the deflection angle by the elapsed time of reflected light that is detected by the light sensor.
Merits	• No drive circuit for detection is necessary, enabling lower power consumption. • Temperature characteristics are good since the temperature dependability is of magnetic field.	• Less noise of detection signals • Actual movement of Eco Scan can be detected.	• High-precision detection is possible • Temperature dependability is small.
Demerits	• Actual movement of Eco Scan cannot be detected because a time derivative of the mirror position is output. • Large noise of detection signals	• The drive circuit of piezoresistive element is necessary. • Temperature control is difficult because there are multiple factors of temperature dependability.	• External detecting element needs to be installed. • Actual movement of Eco Scan cannot be detected because consecutive detection of mirror position is not possible.

5. Product Examples

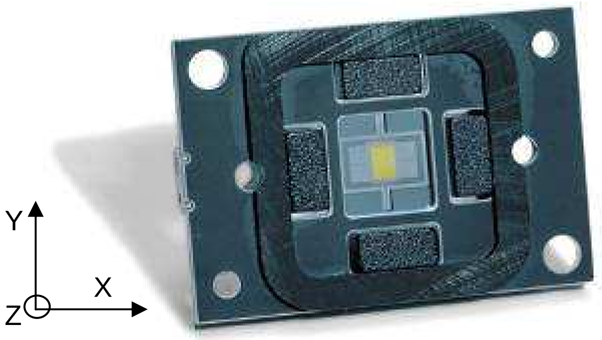
This section shows main Eco Scan products. Each characteristic value is not exact.

■ One dimensional type

ESS112		ESS115	
 			
Effective mirror size (X × Y)	ϕ3 mm	Effective mirror size (X × Y)	5.5 × 4.5 mm ellipse
Dimensions (X × Y × Z)	30 × 21.5 × 4.6 mm	Dimensions (X × Y × Z)	37 × 24 × 5.6 mm
Optical deflection angle	±20 degrees	Optical deflection angle	±30 degrees
Resonant frequency	2260 Hz	Resonant frequency	560 Hz
Detection monitor	None	Detection monitor	None
Notes	Standard product	Notes	Improvement on the arch (with the mirror and coil uncoupled) Standard product

ESS120		ESS140	
			
Effective mirror size (X × Y)	4 × 3 mm	Effective mirror size (X × Y)	ϕ1.5 mm
Dimensions (X × Y × Z)	41.6 × 23.5 × 5.6 mm	Dimensions (X × Y × Z)	7.2 × 8.8 × 5.6 (except a lead frame)
Optical deflection angle	±30 degrees	Optical deflection angle	±12 degrees
Resonant frequency	3250 Hz	Resonant frequency	950 Hz (dissonance drive available)
Detection monitor	None	Detection monitor	Piezo signal
Notes	-	Notes	Improvement on the arch (mirror pasting type) Dissonance drive (DC) type

■Two dimensional type

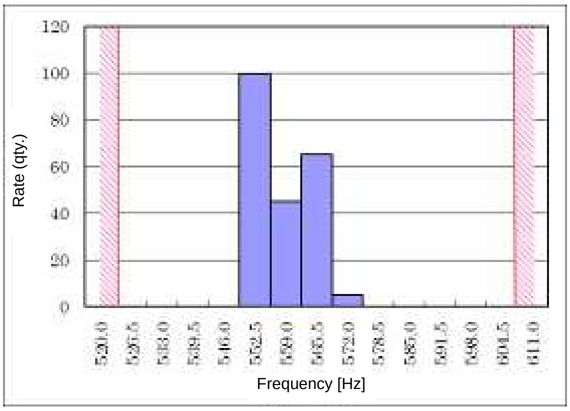
ESS212		ESS229	
			
Effective mirror size (X × Y)	3 × 4 mm	Effective mirror size (X × Y)	Special (8.8 × 5 mm)
Dimensions (X × Y × Z)	50 × 35 × 9	Dimensions (X × Y × Z)	36.6 × 31.6 × 7.8
Optical deflection angle	Outer axis ±30 degrees Inner axis ±30 degrees	Optical deflection angle	Outer axis ±30 degrees Inner axis ±25 degrees
Resonant frequency	Outer axis 450 Hz Inner axis 1570 Hz	Resonant frequency	Outer axis 420 Hz Inner axis 1410 Hz
Detection monitor	None	Detection monitor	Counter electromotive force
Notes	Standard product	Notes	Standard product

ESS235		ESS238	
Under development			
Effective mirror size (X × Y)	ϕ1.1 mm	Effective mirror size (X × Y)	3 × 3 mm
Dimensions (X × Y × Z)	6 × 12 × 7.5	Dimensions (X × Y × Z)	47 × 34.5 × 10.6
Optical deflection angle	Outer axis ±14 degrees Inner axis ±28 degrees	Optical deflection angle	Outer axis ±6 degrees Inner axis ±8.5 degrees
Resonant frequency	Outer axis 760 Hz (dissonance drive) Inner axis 28500 Hz	Resonant frequency	Outer axis 330 Hz (dissonance drive) Inner axis 1720 Hz
Detection monitor	Piezo signal	Detection monitor	Piezo signal
Notes	Superimpose drive type	Notes	Superimpose drive type

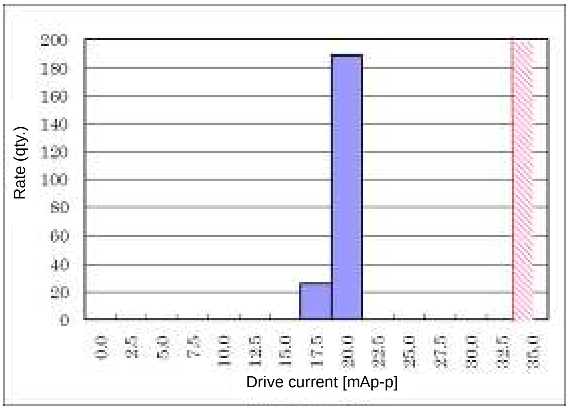
6. Characteristics Example

The characteristics of standard ESS115 are given below as an example.

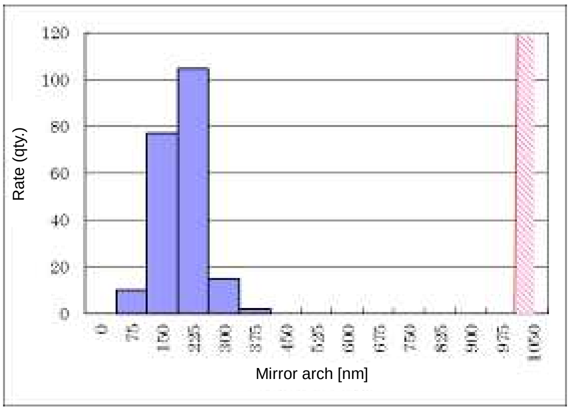
■ Resonant frequency



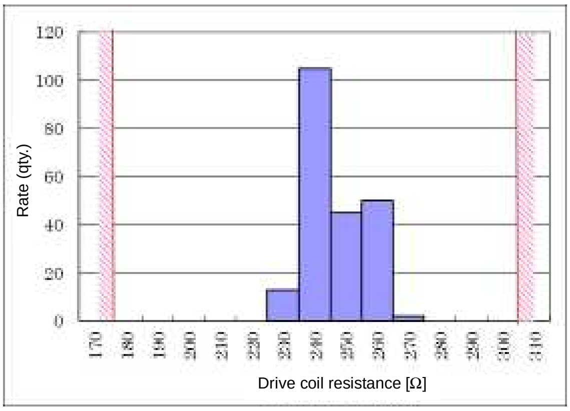
■ Current value (optical deflection angle ±30 degrees {rated amplitude})



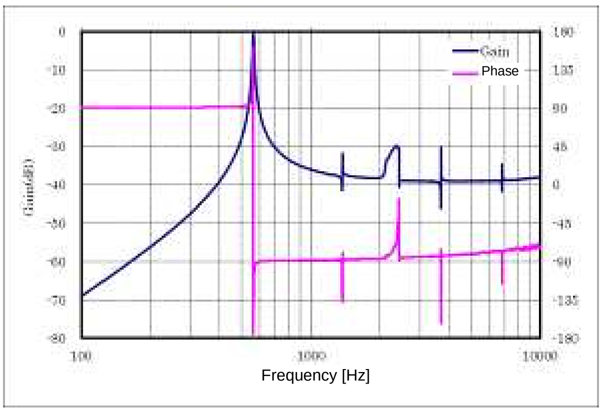
■ Mirror arch



■ Drive coil resistance



■ Board wiring diagram (reference)



お問い合わせは

日本信号株式会社
ビジョナリービジネスセンター
MEMS 事業推進部

〒100-6513
東京都千代田区丸の内 1-5-1　新丸の内ビルディング 13 階
TEL:03-3217-7167　FAX:03-3217-7377
URL　: http://ecoscan.jp

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