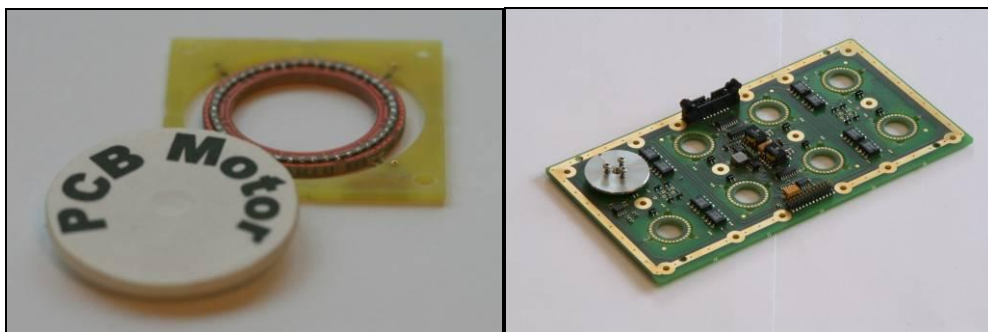




Engineer's Guide for Building applications with the PCBMotor

Design your own original application and earn royalties for the life of the product



Piezo motors mounted directly on PCB

Revolutionizing applications that require electronic motion

Driving new design & reducing cost

PCBMOTOR.COM



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Executive Summary

Today's challenge is to make electronic applications smaller and cheaper. PCBMotor builds accurate and powerful motors *directly onto* the PCB itself. In addition to a world of new design opportunities, you can significantly reduce the size and cost of your application with this technology.

Are these challenges relevant to you?

- Do you have an electronic application that requires movement?
- Would you like to integrate several motors directly onto a single printed circuit board?
- Do you need precise control of a lens, valve, laser, mirror, pointer or the like?
- Do you need a step size all the way down to 2 micron for your system?
- Would you like to reduce the height of your application or otherwise improve the look-and-feel of your product?

A PCBMotor will help you reach your goals innovatively and profitably.

Get a competitive advantage and increase your profit margin:

- Make your application smaller by integrating motion and all electronics into one printed circuit board.
- Reduce your bill of materials – PCBMotor's direct drive eliminates gears.
- Innovate using the unique and ultra slim form factor of the PCBMotor.
- Since the piezo components for the PCBMotor are SMD-mounted directly on the PCB, you further reduce your bill of materials by eliminating screws, wires, connectors and manual assembly.

Design your own original application – and earn royalties for the life of the product.

What to do next

PCBMotor offers a **30-minute Consulting Assessment** to help you utilize the benefits of the PCBMotor in your application. We conduct this over the telephone with you, your top engineers and Mr. Eivind Johansen, our Chief Technology Officer (CTO) and former Intel Fellow.

Please be assured that this consultation is not a thinly disguised sales presentation. It consists of the best intelligence Mr. Johansen can supply in the allotted time. The Consulting Assessment is free, but be advised that there is a strict 30 minute time limit.

In addition to the 30-minute Consulting Assessment, we've developed several options to help people with different levels of expertise and different application requirements. They include:

- Evaluation Kit
- Test Kit
- Development Box
- Design Starter Kit
- All-In-One Package

Please refer to the **Getting Started** section at the end of this document to find out which of these options best fits your needs.

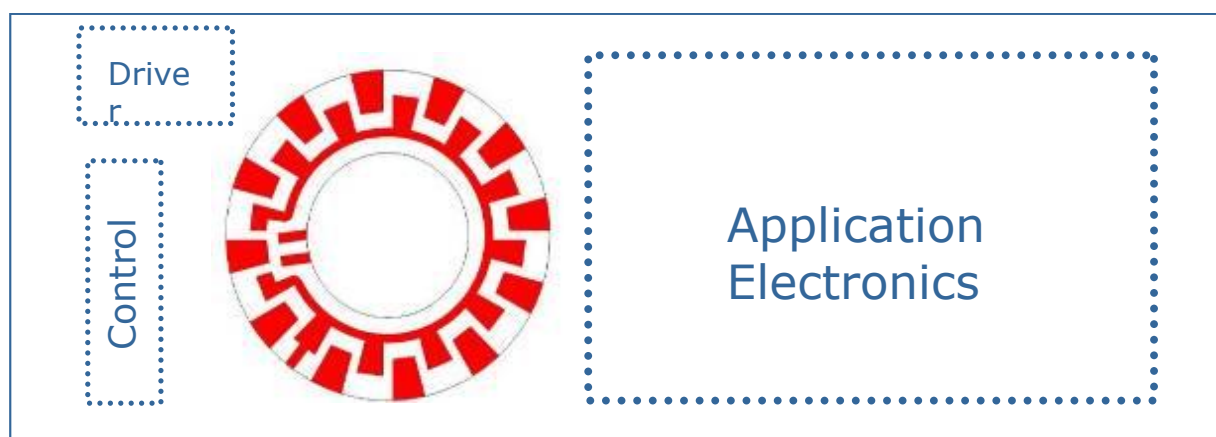


Technical Details

The block diagram below shows a Printed Circuit Board (PCB) that contains a stator, driver electronics and application electronics all on the same PCB.

The PCBMotor system consists of the following:

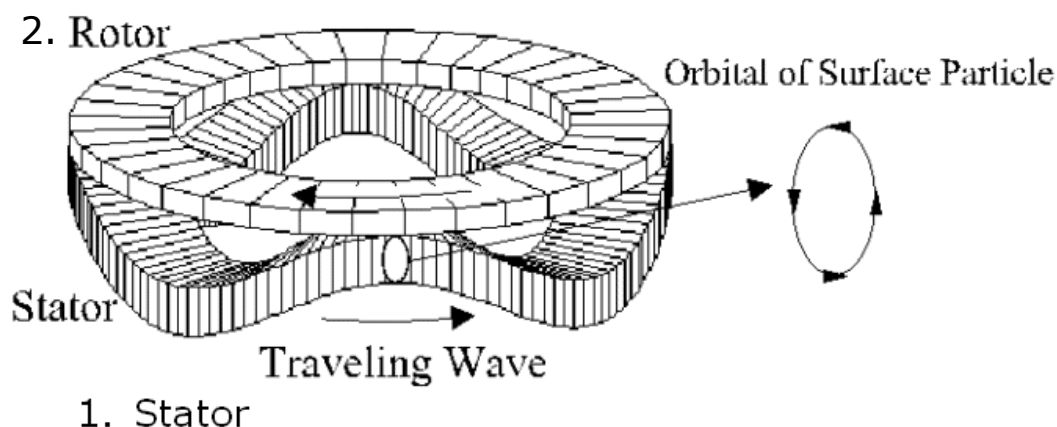
- PCB mounted with piezo components acts as stator/resonator (Patented)
- Application specific rotor mounted on top of the stator
- Control driver can be integrated on the same PCB as the stator (see below)



The PCBMotor uses the travelling wave principle to create the motion in the stator.

How it works:

1. The stator, milled out of the PCB itself, holds the actuators (the piezo components) and electrical connecting circuit. The PCB can also hold the driver.
2. The application rotor, pressed onto the surface of the stator, delivers the mechanical output. A travelling wave is generated over the stator surface, acting as a flexible ring to produce elliptical motion on the rotor interface. The elliptical motion of the contact surface propels the rotor and the connected drive-shaft.



Figure

1



Elements of the Stator

Printed Circuit Board

The PCB used for a PCBMotor is made of standard FR4 material and can be from one layer to multiple layers depending on the application's requirements. Manufacturing processes are well known and most PCB manufacturers can deliver to the designated specifications.

Piezo Ceramics – commercially used since World War II

If you've never heard of piezo, you might think it is something very new and exotic. But in fact piezo ceramics has been known for decades; they were actually invented during World War II. The most interesting characteristic of a piezo ceramic component is that it acts as a capacitor, transforming electrical energy into mechanical energy - expanding in one dimension and contracting in another.

Today, piezo ceramics are used in many shapes and forms and in many applications: cars, cell phones, sonars, PCs, PDAs, positioning applications, cameras, medical, audio and countless others. In other words, piezo ceramics are mainstream components.

Mechanical characteristics

The PCBMotor uses the travelling wave principle to create the motion in the stator. **Figure 2** illustrates a mode shape for a 3 wave stator - 20mm FR4 stator with 24 piezo elements on each side.

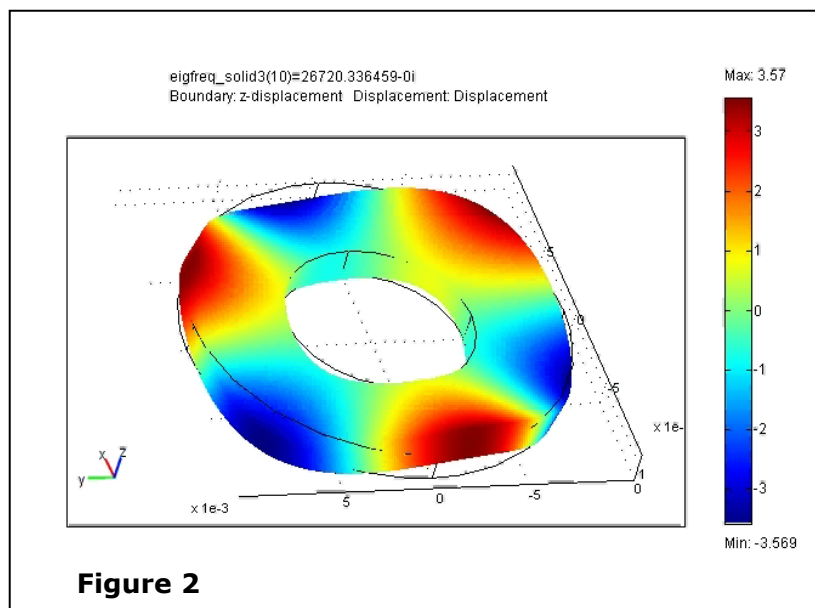


Figure 2

To put it simply, the motor is driven by resonance from the mechanical system. The resonance of the mechanical system is determined by the stiffness of the PCB material, diameter, thickness of the PCB and the size and location of piezo components mounted onto the PCB. The resonance frequency generated from the driver circuit is a 2-phase drive current applied to the 1x1 mm ceramic piezo components mounted on the PCB.

Electrical characteristics of piezo components used in the PCBMotor

The performance of the motor (i.e. speed & stall momentum) is closely related to the total DC current supplied to the output stage transformers so the optimum frequency can be determined by measuring the current as a function of frequency.



Figure 3 compares the current measurement for two ordinary 330pF capacitors (one for each phase) with a free stator (also approx 330pF). The current measurement for the two capacitors shows the expected minimum at the electrical resonance of the output stage, while the stator with the piezo elements has a peak at the same frequency. This behavior is due to the *mechanical* resonance of the stator with piezo elements. The peak represents the quality of the mechanical resonance.

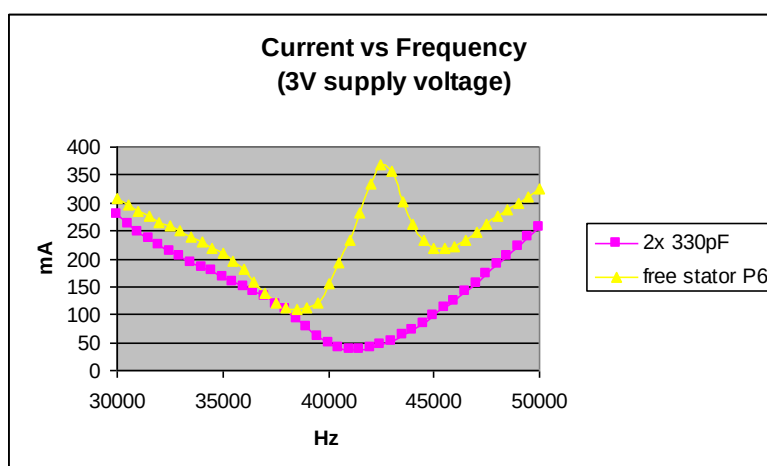


Figure 3

The curves illustrate a power efficiency of approx 85% in the driver alone, as the 2x330pF current shows the loss involved in driving the stator. Since the mechanical resonance is slightly dependent on temperature while the electrical parameters are stable, the efficiency will be lower at the ends of the temperature range. Please note that the overall efficiency, i.e. from electrical input to power on the shaft of the motor, is in the range of 5-10%.



High resolution positioning

The PCBMotor can achieve very high resolution when the motor is turned on in micro steps down to a width of 0.1msec each. The motor is operating at a frequency of 40kHz and needs at least a few cycles of 25usec (40kHz) per micro step, hence the limit of 100usec.

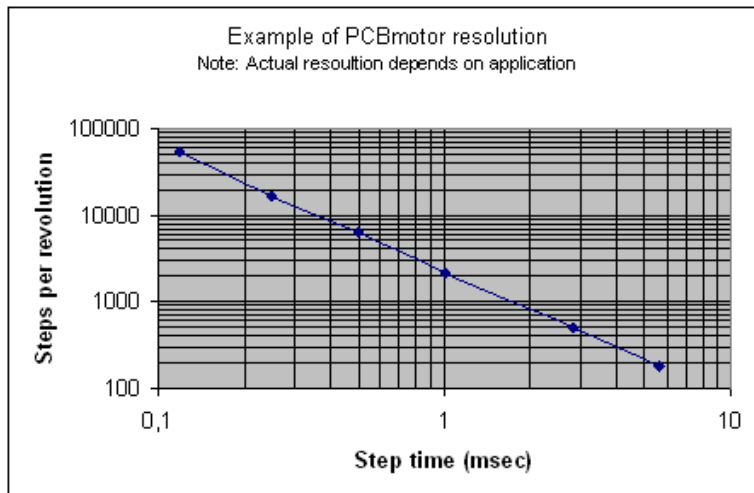


Figure 4

Please note:

- An Evaluation Kit with a tracking controller and a potentiometer as position sensor was used in the experiment.
- The experiment was conducted with a very light rotor. A larger rotor mass will make the steps smaller resulting in more steps per revolution,
- Each micro step was followed by a pause of 30msec to measure the position.
- Audible noise is associated with the micro stepping. Each step is heard as a small click.

Motor reliability and lifetime has not yet been investigated with extended use of micro stepping.

Stator Manufacturing

Stators are manufactured using standard methods from the electronics industry. The piezo components are just another set of electronic components added to your library in the layout tool. Your usual vendor of PCBs is simply doing some additional milling for the stator ring. That's all that is needed for a final stator PCB.

Surface Mounting (SMD) of the piezo components is also a standard process. For small to low volume series, the piezo components are supplied as tape and reels which fit standard Pick & Place machinery. This is a flexible and efficient solution for changes in the supply chain.

For high volume applications we recommend using piezo components in bulk, diced in the right dimensions. Dedicated sorting and feeding equipment can be mounted on the specific production line.



In summary:

- Standard production methods from the electronics industry are used to build a PCBMotor.
- Piezo ceramics are mounted as SMD components.
- Pick & Place machine with a rotary head can mount a PCBMotor in just seconds
- "Landing bridges" connect the stator to the driver.

Full details and specifications are included in the Design Starter Kit.

Control Driver Electronics

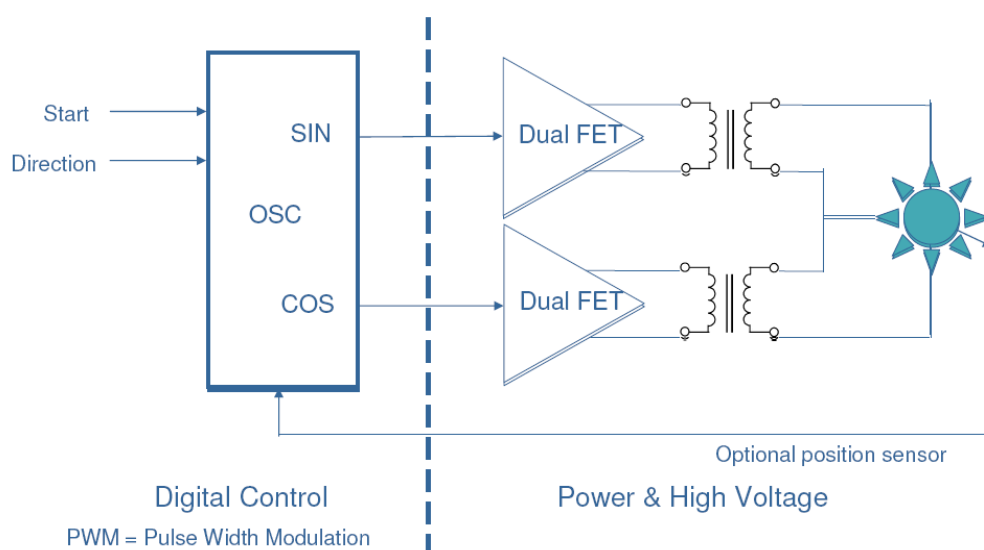


Figure 5

The motor is resonating at approximately 40kHz and is supplied with a 5V power supply. It generates a two-phase sinusoidal wave that is stepped up through two transformers to a drive voltage of 100-200Vrms.

The V_s supply for the transformer can be decreased to approximately 3V to slow the motor down. However, when the rotor is mounted on the stator, a minimum drive voltage is required to overcome the static friction between rotor and stator and start the motor turning.

There is a 90 degree angle difference between the phases. Since the resonance is slightly dependent on the temperature of the PCB, the driver frequency control should take this into account. One solution is to measure the DC supply current to the motor driver. The motor resonance frequency is primarily determined by the mechanical constants of the PCB-material and it is necessary to compensate for the change in resonance frequency for the best performance over the entire temperature range. For continuous operation, the new tracking feature in Version 4 of our Development Box is an effective way of setting the optimum frequency to compensate for the motor's self-heating. The frequency tracking feature can be easily implemented in your own microcontroller. The source code is delivered as part of the Development Box.

Our new Tracking Evaluation Kit is a uController based extension to our standard driver. The controller adjusts the frequency for maximum current which gives optimum performance in the motor regardless of temperature and voltage. When power is applied the controller turns on the motor and makes an initial frequency sweep to find/store the resonance frequency. The motor is then stopped. The next time the motor is started manually, the stored frequency is used and optimized while the motor is running. When stopped, the last frequency is stored.

[illegible]

The red curve in the chart shows the current consumption of the motor. When the motor is started, the controller will follow the Sw1a-Sw1b arrows until the maximum current is found. Then tracking will start and follow the resonance frequency versus changes in temperature and voltage. By properly setting the parameters, the Sw1a-b process takes a fraction of a second. In practice, it operates as a "soft" start of the movement.

The rotor

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Key features

Here are a few of the valuable benefits you get from a PCBMotor:

- Lower height results in much slimmer designs than traditional motors allow.
- Very fast movement is possible – starts and stops in fractions of milliseconds - without gear slippage.
- A PCBMotor is not limited to a fixed number of steps. The motor can start in less than 0.4ms and stop in less than 0.1ms. This can translate to steps size down to 2 microns, or equal to a resolution of 50,000 steps for an 30mm PCBMotor.
- With a position sensor, a PCBMotor can achieve extremely precise movement.
- Motor position can be maintained when the power is turned off due to the high holding torque of a PCBMotor. However, the friction *can* be overcome so the motor can be turned by force. But unlike a conventional motor solution there is no damage to a gear box. You can think of the PCB Motor as a clutch that is able to turn by itself.
- The ring shape of the motor can also be very useful. For instance, you can place a lens in the centre of the motor and turn the motor to focus the lens.

Motor sizes, speed and output power

The diameter of the motor can vary. The standard range is from 15 to 61 mm.

- A powerful motor requires a large diameter, because more piezos generate more power. However, with longer distance to travel, speed goes down.
- High speed can be obtained with a smaller diameter.
- High power and high speed can be achieved in the same motor by mounting piezos on both sides of the stator.



Solutions

The size of your application's stator depends on your requirements for speed, torque and output power. **Figure 7** gives a quick overview of some selected diameters:

Outer Diameter mm	Inner Diameter mm	# PZ / side	Free Speed Rev/sec	Stall Torque Nmm 1)	Stall Torque Nmm 2)	Max Power mW 1)	Max Power mW 2)	
10	4	16	3,1	1	2	10	20	Extended
15	9	24	2,1	2	5	15	30	Standard
20	14	32	1,6	4	8	20	40	
25	19	40	1,3	6	13	25	50	
31	24	48	1,0	9	18	30	60	
36	29	56	0,9	12	25	35	70	
41	34	64	0,8	16	33	40	80	
46	39	72	0,7	21	41	45	90	
51	44	80	0,6	25	51	50	100	
56	49	88	0,6	31	62	55	110	
61	54	96	0,5	37	73	60	120	
66	59	104	0,5	43	86	65	130	Extended
71	64	112	0,4	50	100	70	140	
76	69	120	0,4	57	115	75	150	
81	74	128	0,4	65	130	80	160	
87	80	136	0,4	74	147	85	170	
92	85	144	0,3	82	165	90	180	
1) = Single side mounted Torque & Power can be higher with audible noise 2) = Double side mounted Voltage stepped up to 200 V in driver electronics								

Figure 7

PCBMotor can design and manufacture complete PCBMotors containing the stator, driver and positions sensor that fit your application.

Alternatively, we can provide training that will enable you to design and build your own PCBMotor. We provide the control driver schematic free of charge, enabling you to build this yourself, as well.



Getting Started

We want to help you as much as possible so we've developed several different ways to get you started. Pick the option that best suits your application's requirements and your level of expertise:

If you would like to discuss the potential benefits of a PCBMotor in your application, we offer a **30-minute Consulting Assessment**. This is conducted over the telephone with you, your top engineers and Mr. Eivind Johansen, our Chief Technology Officer (CTO) and former Intel Fellow. Please be assured that this consultation is not a thinly disguised sales presentation. It consists of the best intelligence Mr. Johansen can supply in the allotted time. The Consulting Assessment is free, but be advised that there is a strict 30 minute time limit. To schedule your own Consulting Assessment, please call Henrik Staehr-Olsen at +45 70 28 32 10, or email hso@pcbmotor.com.

We recommend our [Evaluation Kit](#) to fast-track your development effort. This enables a quick path to explore the possibilities of the PCBMotor in your specific application. You can easily alter the Evaluation Kit to fit your purposes, making it an ideal place to start. The Evaluation Kit is ready-to-use with stator, rotor, driver and power supply enabling you to make a first mock-up of your application with a PCBMotor.

You could also use our lab [Test Kit](#). This kit contains a stator, rotor and driver. All you need to supply is the driver with 5V DC. You can download a free control software program which includes the features for start, stop and direction. And this control software can also be used for the Evaluation Kit.

If you have an ongoing development project or want to further accelerate development, you could benefit from the [Development Box](#). The box includes extensive software features such as the frequency tracker option, settings for frequency, sweep and tracking and advanced drive schedule options for start, stop, direction, and pause.

You can also go directly to designing your own PCBMotor. The [Design Starter Kit](#) will take you safely through the initial design phase. This kit provides a comprehensive set of guidelines to fast track your development process and avoid the most common pitfalls.

Try our [All-In-One package](#) with a 12-month money back guarantee. This package bundles the Development Box, Design Starter Kit and a prototype delivery. We mount the piezo components on your stator PCBs - up to 8 or 800 piezos, whatever comes first. Plus you'll receive four 30-minute Consulting Assessments, valued at €400. We're confident you'll be satisfied. In fact, we'll give you your money back if we fail to provide a working stator within 12 months, provided your PCB layout is made in accordance with the Design Guidelines.

We have a passion for sharing our experience. Contact us to find out how we can help *you* get started with a PCB Motor!

Thank you for your interest in PCBMotor.

Henrik Staehr-Olsen, CEO
hso@pcbmotor.com



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