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MEASUREMENT SPECIALTIES

Piezo Film Sensors

Technical Manual

Internet Version

Part 18 of 18

Appendix C – Discussion of Ultrasonic Ink Level Sensing

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Q: What is MSI's concept for detecting low ink level?

A: Right now, ink level in an ink-jet print cartridge can be measured using resistance (if the ink is partially conductive), or can be estimated by simply counting the number of droplets ejected. There are situations where neither approach will work – when the ink does not contain carbon, or where the cartridge is replaceable separately from the print head. MSI has based their approach on other work involving high-frequency ultrasound, and propose a kind of ultrasonic switch for each chamber of the cartridge. This "switch" would be a small patch of piezoelectric polymer, stuck onto the outside of the cartridge, which can send and receive an ultrasonic pulse into the wall. If the ink level is above the point where the patch is located, then most of the ultrasonic signal will travel on into the ink, and only a weak echo returns to the sensor. If the ink level is below the patch, then most of the signal returns, and the echo is strong. A simple voltage threshold is used to detect which condition exists.

Q: Sounds easy. What's the catch?

A: The basic principle is pretty straightforward, and has been demonstrated in the lab using electronics based on readily available discrete components. We know it has to be a low-cost solution, both for the sensor and the associated electronics. The integration of the electronics into an ASIC should be quite practical. The operating frequency of the device is high (about 20 MHZ) and we need some gain (+40 dB seems likely) – but the development of mobile phones and high capacity hard disk drives has made this requirement seem quite realistic. Our biggest challenge is, quite simply, fixing the sensor onto the wall. If we don't achieve good consistency in this area, the sensor would not be reliable. It is unlikely that MSI will be doing this part of the assembly, so we need to work together to make sure that the process works.

Q: What about multiple chambers in a single cartridge? I'm interested in monitoring color cartridges.

A: Obviously, we could arrange separate sensors for each chamber. With our piezo film technology, this is easy since we can form independent patterns on a single piece of film. So an arrangement with three active signal electrodes, and a common ground, would work well – but this would require four contacts, and some mutiplexing on the receiver amplifier input.

At this point, we began to think of ways to combine three sensors (for example) into a single, extended one, to simplify the interconnection and the associated electronics.

The obvious possibility is to treat the three separate walls as if they were one, allowing the three echoes to "add up" on arrival. If any one out of the three echoes were to increase in amplitude (as the ink level fell below the sensing point), we could detect this and flag the condition. This sounds fine until we consider the influence of tolerances on the echo amplitude. The basic piezoelectric coefficients of our material don't vary much along the length of a roll of film, but we would need to consider roll to roll variation, temperature influence on sensitivity, adhesive bonding variations, adhesive property temperature variations, wall tolerances on thickness and parallelism, and the variation of these with temperature.

Q: It's beginning to sound "risky". What is the basic signal/noise ratio?

A: Typically around +10 dB amplitude change, from ink to air on the inside of the wall. The precise value depends on the wall material, and slightly on the ink composition. But if we allow ± 3 dB on the starting level to cover all tolerance ranges, then add up three return echoes, we don't think we would have a very good "switch"!

That's why we exploited another concept we originally developed for a different kind of liquid level sensor – creating different path lengths for the ultrasonic signal for each chamber. This would simply be done by arranging fractional differences in the wall thickness of each chamber. This separates the three returning echoes so they arrive one after another, with approximately equal amplitude. We still have a tolerance associated with the amplitudes, but they don't add, and a single threshold should suffice to detect any one out of the three going "dry". The same principle applies for any number of chambers (within reason!).

Q: How much thickness change is required for each chamber?

A: Difficult to say, before we optimize many of the variables, but 0.2 to 0.5 Mr. & Mrs. steps look practical right now. So 1.0, 1.5 and 2.0 Mr. & Mrs. walls would certainly work – if necessary, the imbalance in internal volume could be made up by adding or subtracting material elsewhere in the chamber. The step size could be smaller, if we push for "perfect" ultrasonic waveform and possibly higher frequency.

Q: My cartridges have sponges inside. Will this affect the performance?

A: We believe not. It seems so far that a dry sponge looks just like air, and a wet sponge just like ink. It really is quite difficult to get good ultrasonic coupling at 20 MHZ frequency, and the dry sponge simply lying in contact with the wall does not, as far as we can tell, absorb any of the ultrasonic energy at the interface. Even pushing a solid, flat block of polymer against the inside wall doesn't affect the signal unless a significant amount of force is applied, or liquid is allowed to penetrate into the gap.

Q: It sounds like the fixing of the sensor onto the wall is going to be quite a challenge!

A: The ideal case would be a very thin layer of liquid adhesive, which then cured to reach a hard state – epoxy works great! But we appreciate that a liquid process may not prove acceptable in production. We may be able to procure an off-the-shelf "transfer adhesive" (in tape form) which we can laminate to our film during our production cycle. Alternatively, we may need to enter into a dialog with a tape converter who could develop and apply a coating (with release liner) onto our film.

We envisage supplying reels of self-adhesive "labels", kiss-cut to allow easy application onto cartridges.

Q: I understand the principle of the sensor. Now, how do we connect to this "label"?

A: We're working on this! One possibility is lightly-sprung contacts, which would be brought into contact only when the cartridge is at rest. Our electrode surface will be either sputtered metallization (around 500 Å thick) or printed silver ink (about 7 μm), so we don't think a wiping contact would be appropriate. Another possibility is capacitive coupling, if we can arrange some reasonable area of electrode surface (for both signal and ground tracks) to come into proximity with a similar arrangement fixed to the printer. There would be further signal losses, and probably additional tolerance variations, if this method were adopted. This is partly a cost issue – if we add too much area to the sensor just for capacitive coupling, the cost of this inactive area may jeopardize the economics of the whole solution.

The connection scheme also has to take into account the physical layout and practicalities of the printer itself. We can't design the solution in a vacuum – we need input from both the mechanical and electronic design teams responsible for the printer.

Q: Where should the interface electronics be located? Can I integrate these into an ASIC on the main pcb?

A: We think so. The sensor will be designed to have as low an impedance as practical at the operating frequency – ideally 50 ohms. Although we have, in theory, a small "antenna" connected to the gain stage, in practice we don't see noise pick-up as being a major problem. Shielded cable, or "gnd-sig-gnd" coplanar wiring would be preferred for carrying the signals over any significant distance within the printer. Our measurement process should only take a few microseconds, so it is possible that a "quiet time" (as far as intentional digital or control activity is concerned) could be selected to make the measurement. Noise radiation and immunity would need to be considered and reviewed throughout the design process.

Q: What control do I have over the "switching point"?

A: The placement of the sensor, of course, dictates the basic depth of ink where the "switch" will change state. Ideally, the active electrode area would be a narrow horizontal line. In practice, we prefer to use a rectangular element to increase the capacitance of the sensor (which allows better matching to practical electronics). The "switching point" will nominally occur at the vertical midpoint of the sensor. A "height" in the region of 5 to 10 Mr. & Mrs. appears likely for the overall "label", so the lowest sensing depth may be 2.5 to 5.0 Mr. & Mrs. Temperature effects may vary the apparent location of this switching point, but worst-case uncertainty would be determined by the active electrode height.

Q: What factors would MSI wish to influence in my cartridge design?

A: The base material has an influence on the effectiveness of the solution. Some polymers (such as Nylon and acetyl) have high attenuation in the ultrasonic region. A close match of acoustic impedance (speed of sound x density) to the ink would be preferred. Given several choices, we would evaluate and select the most favorable.

The wall thickness(es) have already been discussed, but it is also important to have the best possible parallelism at the sensing area. We appreciate that a finite draw angle is required for the moulding process, but if this can be minimized in the region of interest, then it makes our job much easier.

Smooth surfaces (outside and inside) work best – a spark-eroded on the outside surface would make ultrasonic coupling extremely difficult.

Q: I'm interested. How do we proceed?

A: We would split up the development effort into phases. Before commencing, we would seek to establish performance and economic targets for the solution, including timescales for the various stages of effort.

As a guideline, MSI would propose the following:

In Phase 1, MSI would build and supply concept demonstration units based on available cartridge samples, using discrete electronics. These units would not be qualified for temperature dependence or noise immunity, nor would the transducers or electronics be optimized, but they would serve as a discussion point when considering future effort. Basic performance would be documented in the form of a brief engineering report, together with candidate interconnection schemes and their characteristics.

Phase 2 would involve investigations into candidate adhesive systems and processing, study of temperature and other environmental effects on transducer performance, preparation of budgetary estimates for production equipment design and procurement, budgetary estimates of unit cost in production volumes. A series of prototype transducers would be supplied for customer evaluation and qualification.

A separate (perhaps parallel) effort may be required to qualify the selected interconnection scheme. This is highly dependent upon specific details of the printer design, and it is possible that this effort may best be performed by the printer manufacturer.

Phase 3 would lead towards product launch, including the design and procurement of production tooling.