Audio Pixels Holdings Ltd (ASX:AKP)

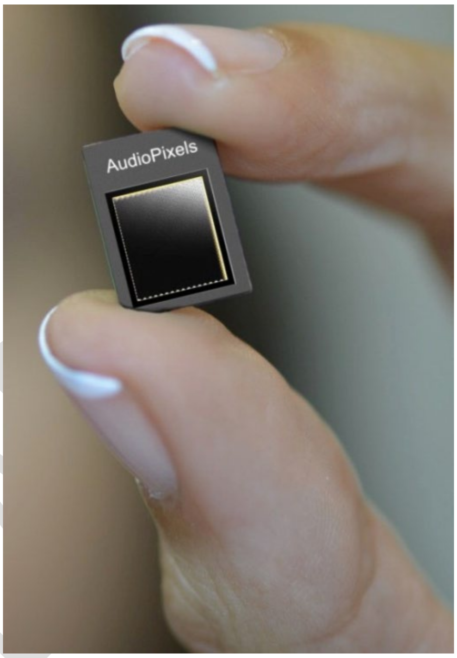
Listed shares: *28.3 million*
Share price: *$17.71 as at 23 June 2020*
Market cap: *$501m*

About to take the world by storm

- The company has been working for many years on the development of a disruptive technological platform that will forever change consumer markets' perception and expectations of loudspeakers.
- The platform is based on Digital Sound Reconstruction theories made possible with a proprietary MEMS-based transducer and a control ASIC driven by sophisticated algorithms.
- When compared with traditional analogue speakers, the platform enables the creation of products with a number of advantages; paramount among them is the vastly superior sound quality offered in far more appealing form factors.
- The speakers are expected to be made available to prospective customers for testing in coming months, perhaps in the 3rd or 4th quarter of this year.
- The who's who of the consumer electronics world has been beating down the doors in their eagerness to test the product. There should be no problem selling the units; the constraints might have far more to do with supplying demand in the company's initial years of product introduction.
- It is thought that the market potential exceeds 8 billion chips annually. Initial sales are anticipated to be directed at premium market applications, in verticals such as smart-TVs, smart-speakers, smartphones and (after re-tooling) luxury vehicles. Other markets would include computers, home speakers and indeed any loudspeaker application that might benefit from superior sound offered in a far more power efficient, aesthetically appealing form factor.
- In my analysis, for illustrative purposes I allow for a gross profit margin of $5 per unit, which would translate to annual net profit eventually rising to many billion dollars.
- Investors have seen deadlines come and go over the years and so may be a little jaundiced, and that might explain why the shares are half their 2016 high of $35 despite the technology having since been significantly advanced to commerciality.
- It would not surprise to see a bid for the company emerge over the next year but it would have to be at a high price to win over the major shareholders, being the directors and management and their acquaintances, who have held tight for many years.
- AKP could be a ten-bagger within a relatively short space of time, all going well.

The business

Figure 1: The Audio Pixels speaker chip



What it does

Since its formation in 2006 and from its laboratory in Israel, AKP's wholly owned subsidiary Audio Pixels Ltd has developed technology for reproducing sound using micro-electromechanical structures (MEMS), enabling the production of a new generation of tiny speakers that far exceed the performance of similarly sized conventional analogue speakers. The chip will replace conventional speaker driver(s), the enclosure or acoustic chamber, as well as the electronic circuitry associated with converting and amplifying the digital signal feed to analogue.

Technology

An Audio Pixels speaker chip contains a MEMS die[1] and an application-specific integrated circuit (ASIC). These items are assembled and enclosed in a protective package some 12mm by 15mm in size. The front side of the chip is protected by a acoustically transparent thin film that allows sound to emanate from the chip while protecting the transducer from environmental contamination.

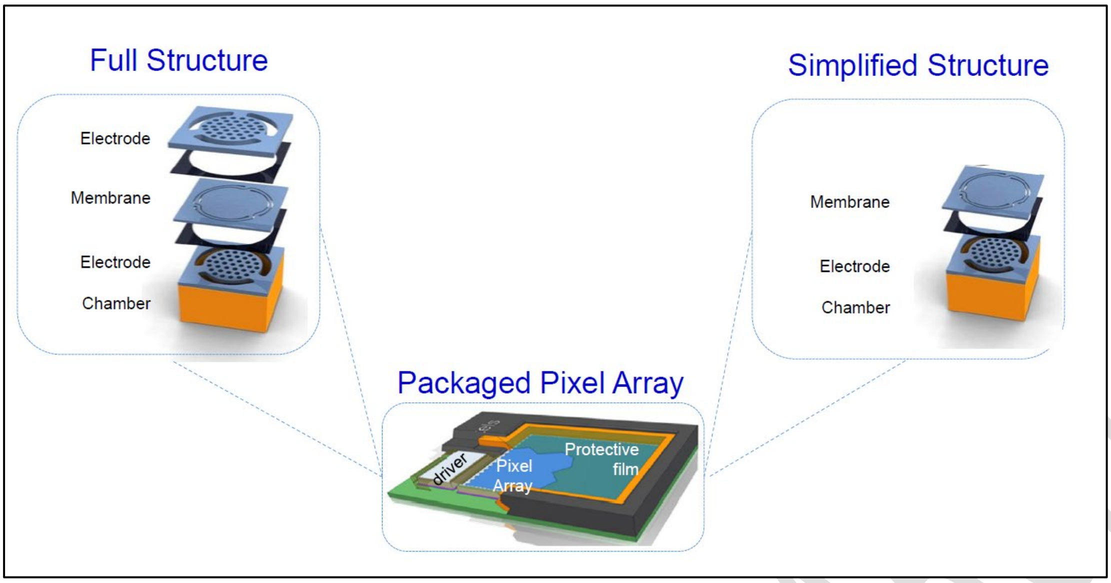
The die contains a square array of 1024 identical pixels[2]. Each pixel is some 150µm in diameter and contains a moving element sandwiched between two electrodes (actually AKP can also derive excellent sound without the top electrode as noted elsewhere in this report). The primary drive mechanism used in the device is electrostatic force. To induce the required amplitude, higher voltages are required than is customary in most other MEMS devices and these voltages are generated by the integrated ASIC.

Digital sound reconstruction is achieved by digitalised sound waves hitting the algorithmic 'engine', thus actuating the pixels in a certain pattern to regenerate those same sound waves.

[1] The term 'die' is interchangeable with the term 'chip', although the completed package is also called a chip, so it is a bit confusing.

[2] Strictly speaking a pixel (short for 'picture element') is a tiny square of colour. Lots of these pixels together can form a digital picture. The process of digitalisation takes an image and turns it into a set of pixels, which can then be transmitted any distance and converted back into a picture. AKP have adopted this term because their pixels are a tiny 'square' of sound.

Figure 2: Diagram of pixels (full and simplified structures) and chip



Source: Audio Pixels presentation 25 May 2020

So that is a brief description of the speakers. But the physics that is involved, the materials and details of manufacture and almost everything else to do with the technology, is extraordinarily complex and I am not going to go into detail, firstly because much of it is way beyond my comprehension, and secondly to protect their IP, the company does not want certain details published.

That said, I attempt below to briefly describe the manufacturing process, in order to put into context the challenges that have arisen and been overcome, as well as the steps still to be taken.

The manufacturing process

MEMS fabrication

The first step in the fabrication process begins with thin pure silicon[3] wafers. These raw wafers are used as the substrate upon which a number of layers are patterned, deposited, annealed, etched, cleaned and polished. Many of the means, methods and process tools used in MEMS originated from integrated circuit (IC) fabrication. The key difference between and IC and MEMS is that MEMS typically involves moving structures. This is made possible by depositing sacrificial materials within the structure that eventually gets removed in a process called "release". The finished wafer most often contains a 3-dimensional structure, allowing one or more parts of the MEMS to move.

In the case of Audio Pixels wafers, which to date have been 150mm in diameter[4], certain layers are patterned to contain tens of thousands of individual sound-emitting pixels arranged into roughly 8mm square arrays of 1024 elements (pixels). At some point in the

[3] Silicon is a semi-conductor.
[4] Commercial production is likely to be based on 200mm wafers.

process the wafers are overturned so as to fabricate a cavity that serves as an acoustic chamber for each individual pixel. The final step in the fabrication process is to remove the sacrificial layers, freeing up the membrane to move upon actuation.

Throughout the entire fabrication processes tests are carried out to determine that everything is on track regarding tolerances, performances, etc.

Assembling and packaging

The wafers are manufactured by third party silicon foundries or fabrication plants (fabs) and delivered to other third-party vendors, some of which are responsible for the assembly and packaging of the chips.

First, wafers are diced; that is, cut and singulated into individual dies.

Following dicing, wires are bonded to metal pads on the chips and to a substrate, creating both the external and the internal electrical connections required between the MEMS and the ASIC, and the outside world.

Finally the components are assembled together and encapsulated within a protective coating, to become the completed ‘chip’.

Every step of the way tests are conducted as to ensure quality, reliability and functionality. Chips that fail testing might be discarded impacting the yield, which is a key factor in determining cost.

Summary

By the way this system of wafer fabrication, die production, and chip assembly and packaging is common in the business although of course the Audio Pixels structure and processes have many unique features. The entire process is conducted under very strict cleanroom conditions.

Competitive advantages

The AP speaker is not only radically smaller and lighter than traditional analogue speakers; it offers far better acoustic performance – clearer sounding, less distorted, more accurate sound reproduction, while consuming far less power. There are significant other advantages, some of which are listed below:

- Wider frequency range including much lower frequencies.
- Immeasurable distortion.
- A fraction of the power consumption.
- Greater design flexibility.
- No requirement for damping due to there being no oscillation.
- Much less vibration.
- Ability to direct sound.
- No digital to analogue (D2A) conversion.
- No signal amplification required.
- No acoustic cavity or chamber required.
- Automated assembly compatible.
- Same chip for all applications.

The AP speakers offer unprecedented flexibility. In sharp contrast to conventional speaker technologies where the types and number of drivers, as well as the enclosure and its electronics all must be customized and endlessly fine-tuned to specific applications; Audio Pixels offers a single chip design that is modular and perfectly predicable and linear. Given that the total number of "pixels" is the only factor determining quality, frequency and sound volume, manufacturers and device designers need only to determine the target acoustic performance and select the appropriate number of speaker chips, which are serialized using a single controller.

The homogeneous construction of the chips simplifies and reduces the cost and complexity of customer design, integration, assembly and product inventory. It also permits Audio Pixels to optimize its pixels, the array, the fabrication and test processes.

The advantages the AP chip brings to directional sound are also interesting. The same speaker can be used as an omni-directional sound source (much like conventional speakers), or a unidirectional source (a narrow beam of sound is projected in one directions, and almost no sound is projected in any other direction), or a multi-directional source projecting several sound beams (each may carry different audio, such as sound level or language), in several different directions. The applications leveraging control of sound directionality are limitless.

The versatile modular approach to sound reproduction enables Audio Pixels to address untold markets with a single product; from hearables to complete home sound systems and everything in between.

Some key market segments for Audio Pixels speakers.

Cell phones

The micro analogue speakers used in cell phones have roughly the same surface area of the Audio Pixels speakers (albeit they are oval or circular rather than rectangular). They vary from 5mm to 8mm in thickness, including the speaker itself (2-4mm) and the roughly 3 cubic centimetre air cavity required to facilitate the sound. The smaller the air cavity, the worse the sound quality, so there has to be a trade-off between sound quality and phone thickness. Stereo is achieved by having two speakers, and generally there is a third near where one places one's ear.

The Audio Pixels speakers are less than 2mm in thickness including the air cavity, so phones can become much thinner and lighter. But by far the biggest advantage will be the dramatic improvement in sound quality. Also there will be lower power consumption (which is important for battery life), less vibration particularly at high volumes, and a whole range of other advantages.

Television Displays

As the display industry continues its transition from LCD to OLED and QLED, the space required for sound let alone quality sound is increasingly at a premium. More and more manufacturers have had to diminish the appeal of their ultra-thin display by adding bulk to the television base to accommodate sound. Some have taken a more radical approach of removing embedded sound from their displays, offering external sound solutions (such as sound-bars and wireless loudspeakers).

Audio Pixels technology will allow vendors to bring superior sound quality back to, or into television. Premium TVs could contain up to 32 AP chips to achieve a targeted decibel level, or even 64 chips if directional sound is desired.

Vehicles

Vehicles typically have at between six and 10 analogue speakers. Generally there is one in each door, each weighing several kg taking into account the various components, with others in the front and rear. The replacement suite of Audio Pixels speakers (there would be a number of them to replace each analogue speaker) would weigh perhaps a couple of hundred grams in total. This becomes important with the strong focus on reducing weight within the industry. Not to mention the far superior sound and the ability to locate the speakers closer to the listener for an improved navigation and infotainment experience. And directional sound would provide additional appeal.

Competitive technologies

There are no other companies known to be working on producing a true digital loudspeaker. Audio Pixels currently has the whole field to itself, and its technology is comprehensively patented. Put simply the barriers to entry are extreme; outside of AKP's strong patent position, a competitor would require considerable multidisciplinary expertise in MEMS design and fabrication, physics, materials, microfluidics, aerodynamics, chip packaging, electronics, and signal processing.

There are a number of companies working on MEMS technologies relating to sound but most are engaged in improving microphones, and MEMS technology of course now dominates that industry. Those few that are involved with loudspeakers, such as USound GmbH and Arioso Systems GmbH, are all looking to improve and/or miniaturise analogue speakers using MEMS fabrication techniques.

Status

The development of the technology has taken many years and many tens of millions of dollars. I have been following the story from almost the beginning and every year it seemed success was within reach, only to slip away because of some new challenge that had emerged. The company is pioneering extraordinarily complex technology so in hindsight I guess delays are no surprise. But the important thing is that each year, progress has been made. And today, I am more convinced than ever that AKP is on the cusp of success.

During 2018 a number of breakthroughs were made, the main one being resolution of the stiction[5] and charge trapping issues that had bedevilled the company for two years. Standard methods of resolving such problems did not work because of the higher voltages used in the Audio Pixels devices. But finally a solution devised by Audio Pixels worked.

Another breakthrough was the 'accidental' invention of a simplified structure. In order to be able to rapidly change the process parameters that were needed to solve the voltage/stiction problem without having to produce the full device through to completion, which takes time and of course more expense, simplified chips with just one electrode were used (whereas the full structure has two electrodes). During 2018 the company was curious to try out their pressure generating mechanisms on one such simplified structure and to their surprise the device produced significant sound pressure. Expanding on this finding, specific wafers and algorithms were designed and fabricated to further explore the characteristics of this design. The resultant wafers provided exceptional performance even to below 100Hz[6].

[5] Stiction is the unintended adhesion due to surface tension of microstructural structures with a large surface area to volume ratio, such as is the case with MEMS devices, thus preventing easy movement of elements. This can happen during fabrication, for example after removing a sacrificial layer with wet etching, or during the application of an electrostatic load.

[6] By comparison the best similar-sized analogue speakers have a lower limit of some 800Hz or 3 octaves above.

So two versions of the speakers are now being advanced simultaneously, one with the full structure and one with the simplified structure. The full version is more complex and expensive to produce but can produce much louder sound than the simplified structure which is particularly good at reproducing lower frequencies. It is thought that each version will have applications in the different markets.

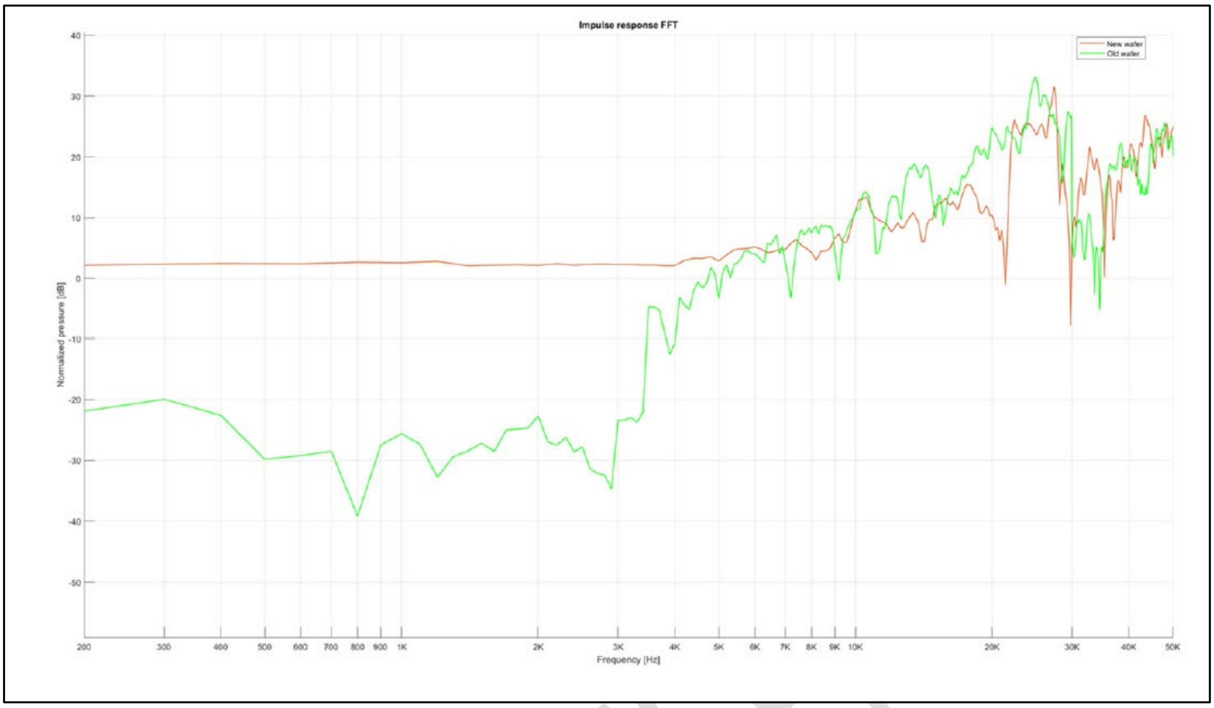
The [presentation] at the AGM held on Tuesday 26 May 2020 given by Danny Lewin and Yuval Cohen provided a summary of the technology and an analysis of the problems that emerged during 2019 and 2020 to-date, and how they were overcome.

- It proved unusually difficult to protect the front side of the wafers during backside processing. As was discovered in May 2019, this process step had a tendency to break, damage and scratch some of the delicate structures on the top of the wafer. By August the company had invented a new protection scheme which proved highly effective, enabling the company to shift focus to acoustic output.
- In August acoustic characterisation revealed lower performance than expected. The presence of disruptive waves was discovered and ultimately traced to subtle deviation from manufacturing tolerances that were only detectable when the adverse effects of the electrostatic actuation were overcome. Minor changes were introduced into the MEMS manufacturing process and hundreds of variants were tested. Ultimately one process variation resolved the problem. Fabrication of the new wafers commenced in December and they were delivered in April 2020. Testing showed a dramatic improvement in sound quality; the sound from a simplified chip was played at the recent AGM and (to my untrained ear) the quality was brilliant[7].
- However, unwanted residue was detected on the electrodes and this is currently the subject of ongoing investigation and rework. It is thought that this problem can be eliminated with minor process modifications and/or access to newer fab machines so it is of little concern to the company.
- Meanwhile work on the metal module commenced in November. During development of the chip no metallisation was required; instead wafers were tested by touching bare silicon using a probe card[8]. But in the final product connections to the die must use permanent wire bonding. For this purpose, metal pads must be deposited onto the MEMS chip and in the event, the initial release process proved incompatible with the metal pads and new release processes and tools were required. A solution was found by February.

[7] And the sound was heard through analogue speakers in my headphones. To hear true digital sound one had to be in the cleanroom and by all accounts the quality was phenomenal!

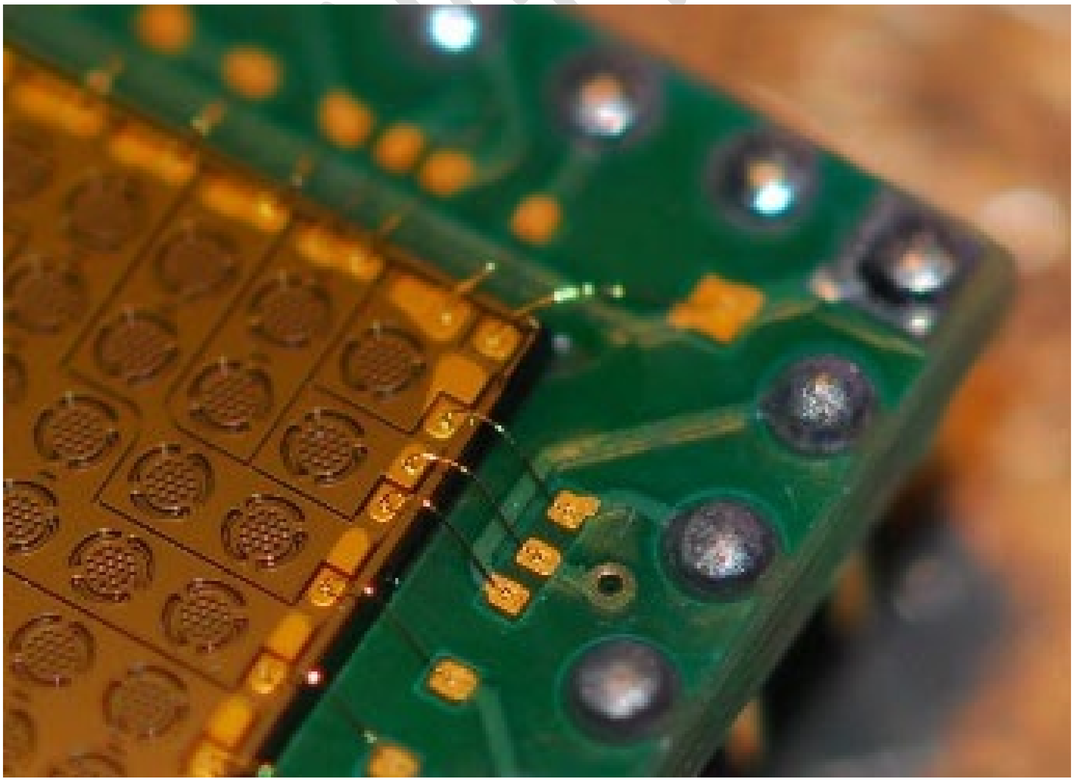
[8] A probe card is a temporary interface between an electronic test system and a wafer. It consists of a printed circuit board and some form of contact elements that can be aligned to points on the wafer. This is done for testing purposes during the development process, prior to the wafer being diced into chips.

Figure 3: Frequency response of April 2020 chip vs August 2019 chip



Source: Company presentation May 2020. I apologise for the font size of the text within the slide. So to explain, the red line is the frequency response of the chip produced in May 2020, the green line is that of the earlier chip. The vertical axis shows the normalised sound pressure from minus 60 dB to plus 40 dB (noting that a negative dB reading is inaudible). The horizontal axis shows the frequency on a log scale from 100 Hz to 50 kHz.

Figure 4: Magnified image of part of a chip showing the metal pads and wires

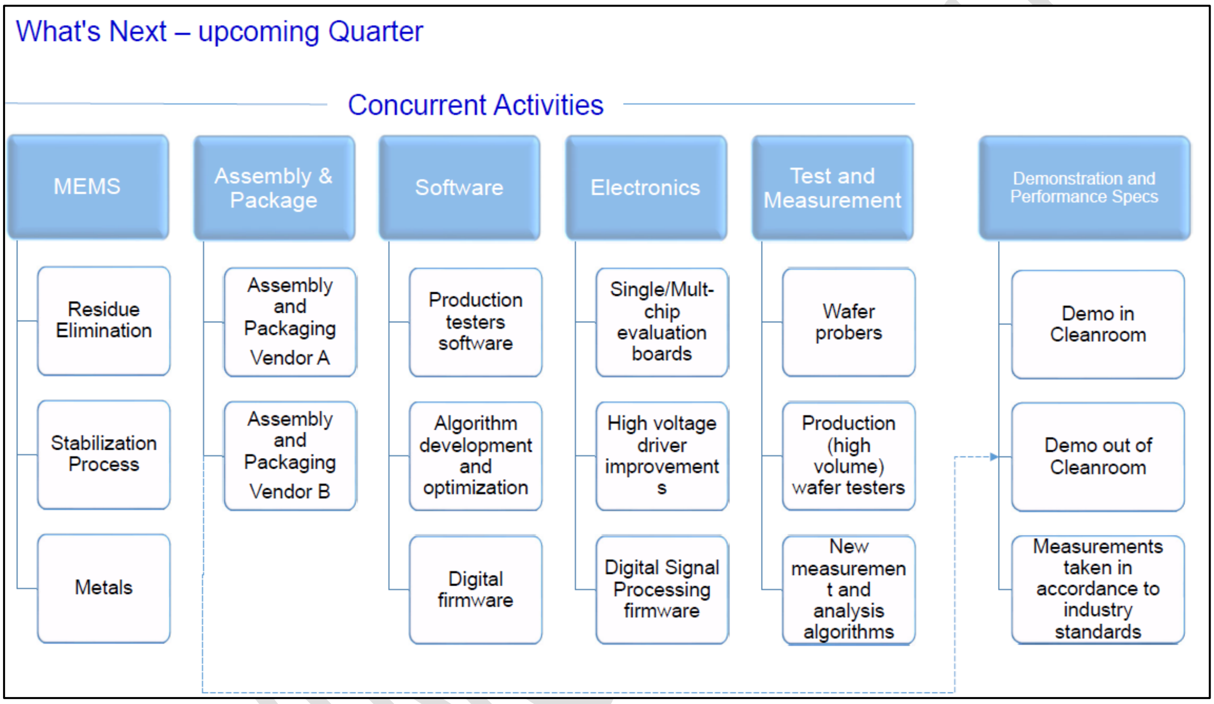


Source: Audio Pixels presentation May 2020.

Next steps

During the upcoming September quarter a number of concurrent activities will be undertaken to complete the road to commercialisation, as shown in one of the slides presented at the AGM (Figure 5). Timing to work through all this is difficult to determine, partly because of the coronavirus lockdown, but reading between the lines there is a small chance it could all be completed by the end of the September quarter or failing that, there is a much better chance it could be completed by the end of the year.

Figure 5: Activities to complete the process of commercialisation



Source: Audio Pixels presentation 26 May 2020.

In more detail:

- The activities to do with MEMS have essentially been completed. New wafers are expected in the next week or two and these should be free of residue.
- Assembly and packaging has to be completed before a demonstration of the speakers can be conducted outside of the cleanroom. Research on this aspect has been carried out for the past four years because there are a number of elements in the Audio Pixels design that are unique, the main one being the need for the front of the chip not to be encased in a resin as is typically the case, but to be protected by a thin film of a special material that not only allows sound waves through but also tough and strong enough to prevent damage, dust contamination and moisture egress.
- A solution was found but this has not yet been applied to a fully operational chip because they were not available at the time. So that work is being done by a couple of vendors in Germany albeit the coronavirus has delayed things to an extent. The

company is confident that the system will work well on a fully operational chip but nothing is guaranteed.

- Again, because the fully functional MEMS have not been available except in recent months, the algorithms that had been developed in the past have to be tweaked to take into account actual performance of the chips as opposed to the performance that had been assumed previously.
- Testing and measurement will of course be conducted throughout the process. The company must test packaged chips outside the "noisy" cleanroom in an acoustically appropriate environment as to ensure the accuracy of performance specifications prior to publication.
- Demonstration of the speakers out of the cleanroom must be made possible so that potential customers can familiarise themselves with the devices and test them at length. Assembly and packaging of the chips must be achieved for this to occur.

Market potential

The global market for Audio Pixels speaker chips is thought to be over 8 billion units.

- Cell phone sales are about 2.1 billion units annually, which would account for up to 4 billion AP speakers.
- Vehicles sales are about 70 million annually. Each vehicle contains an average of six analogue speakers and each of those speakers could be replaced by 6-12 AP speakers. The vehicular market could therefore approximate 2.5 to 5.0 billion AP speakers.
- Smart TV sales are about 200 million sets annually but units with premium sound, which would require a lot more speaker chip per set, would be considerably less than that. The market might require up to 2 billion speaker chips.
- Computers, laptops, tablets and smart speakers are among other markets of interest.

Ramp up of sales

There is no question that once the chips are commercially available, electronics companies and manufacturers of consumer products will want to move quickly to incorporate them into their products. The limiting factor in the initial two or three years will probably be production capacity rather than market demand, because massive new fab capacity will required[9].

[9].In 2019 worldwide installed capacity for MEMS fabs was probably about 1.5 million 200mm wafer equivalents per month. If the entire industry suddenly switched to producing Audio Pixels chips and allowing for say 250 chips per wafer*, some 4.5 billion of these chips could be produced.
*The area of a 200mm wafer is around 31,400 mm^2, while the area of a chip is 100mm^2. Divide one by the other and you get 314 chips per wafer before taking into account the yield of workable chips.

The other limiting factor will be the need to completely redesign some consumer products and then retool in order to incorporate the Audio Pixel speakers. That will probably include cell phones and vehicles. It might be that products to incorporate the devices early might be smart speakers, TVs, computers, laptops and tablets, rather than vehicles and cell phones. And no doubt manufacturers of luxury vehicles will embrace the speakers before they become more widely adopted in the vehicle industry.

I have assumed that potential customers will be provided chips for testing purposes by the end of 2020 but that it won't be until 2022 that first sales are made. Beyond that, it might take 10 or15 years to saturate the market.

Potential profitability

At a guess, each microchip might cost in the region of $5 plus or minus 25% to produce at scale. The cost will be considerably higher in the initial years before production ramps up to higher levels, partly because yields of workable chips would be lower. And chips with one electrode will be lower cost than those with two.

The sale price will depend on the application but it would seem reasonable to assume much higher prices initially, to markets that will accept higher prices, then a decrease over time as production ramps up and costs decline accordingly.

The gross margin per unit could be more consistent than price or cost. I would have thought that a gross profit margin of 50% or $5 per speaker chip would be reasonable at scale (i.e. in the longer term). In earlier years of production when costs are high but prices much higher, the gross margin per unit might be lower in percentage terms but higher in dollar terms (e.g. price $30, cost $20, margin 33% or $10 per unit).

I have prepared an annual profile of a possible earnings scenario to 25% market penetration by 2030, for illustrative purposes only. Refer to Figure 6. As you can see, the numbers get quite large. Please bear in mind these are not earnings forecasts, just one scenario of many. And I have ignored interest income and expense.

Figure 6: Illustrative annual profit scenario ($m unless otherwise indicated)

Yrs to 31 Dec	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Units mill		1	5	25	100	300	600	1,000	1,500	2,000
Margin $/unit		10	8.00	6.00	5.00	5.00	5.00	5.00	5.00	5.00
Gross profit	0	10	40	150	500	1500	3000	5000	7500	10000
Sales/ mkting	-2	-5	-10	-20	-25	-30	-35	-40	-45	-50
R&D	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15
Admin	-3	-5	-8	-10	-15	-20	-25	-30	-35	-40
Depn/amortn	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Pretax profit	-12	-8	13	110	449	1438	2927	4916	7405	9894
Income tax	-	-	-	-21	-135	-431	-878	-1475	-2222	-2968
NPAT	-12	-8	13	89	314	1007	2049	3441	5184	6926

Source: My estimates

I allow for a fair whack in R&D expense because there will certainly be improvements made to the speakers over time, plus there is very likely to be new products derived from the technology to develop markets other than loudspeakers (for example, in the ultrasonic spectrum).

Funding

An equity capital raise is likely to take place before the end of this year. The cash position at 31 March was $4.3m while quarterly outlays are some $1.5m. But the company could raise more than is needed for cash flow purposes in order to place itself in a strong financial position prior to completing negotiations with potential customers and/or acquirers. So perhaps a raise of $10-20m could be approved by the board.

If the company decides to build and operate its own assembly and packaging plant to reduce unit costs and further strengthen its negotiating position, then that would require considerable additional funding.

In addition, AKP will probably have to contribute funding for the acquisition of equipment for fabrication plants, whether it be a new production line in an existing factory or in a new factory, in order to provide sufficient incentive to fabs to dedicate capacity to the Audio Pixel speakers. That might require tens of millions of dollars.

Strategy

There are three main approaches that AKP could take:

- continue as a standalone business, or
- licence the technology; or
- sell the company to the highest bidder.

If the price offered is high enough, I have a feeling that sale of the company would be preferred. The shares would eventually be worth a lot more as a standalone business but to receive cash upfront from selling the company certainly has its attractions.

Valuation

The figures in Figure 6 suggest that any valuation would be multiples of the current price. Five to ten billion dollars would not be out of the question.

Corporate

Brief history

The main operating subsidiary Audio Pixels Ltd domiciled in Israel was acquired in January 2011[10] by ASX-listed Global Properties Ltd (GPB) and the latter subsequently changed its name to Audio Pixels Holdings Ltd (AKP). Global Properties' only asset prior to the acquisition was a commercial property at 360 Pacific Highway, Crows Nest, Sydney, and this was eventually sold to unrelated parties in 2014 for a $1.48m cash consideration.

The consideration for the acquisition of Audio Pixels Ltd was $1.09m cash, 4.9 million shares and 1.1 million 38¢ options.

Directors and management

The three directors of the holding company reside in Sydney. They are Fred Bart chairman and chief executive officer, Cheryl Bart AO non-executive director (his wife) and Ian Dennis non-executive director, who is also company secretary.

Fred Bart and Ian Dennis have been directors since September 2000 while Cheryl Bart became a director in November 2001. There have never been any other directors of the company since that time.

Fred Bart is a well-known businessman involved in textiles, manufacturing, property and finance, including the Sleeping Giant bedding chain. He is also chairman of the successful ASX-listed aerospace company Electro Optics Systems Holdings Ltd (EOS, price $5.67, mkt cap $828m) and is a non-executive director of ASX-listed memory semi-conductor company Weebit Nano Ltd (WBT, price 38¢, mkt cap $28m). He has a small shareholding in WBT with 400,000 shares but is a substantial shareholder of EOS with 5.6 million shares. Another ASX-listed company in which he has a shareholding is biotech Noxopharm (NOX, price 20¢, mkt cap $43m). He is also a director of Immunovative Therapies Limited, a private Israeli company involved in the development of cancer vaccines. Some in the press have belittled him as a "rag trade millionaire" and I have seen past reference to him having been "a professional poker player" but I admire his business skills and sheer tenacity.

Cheryl Bart AO is a lawyer by background and now a professional company director. She is a director of ASX-listed SG Fleet Australia Ltd (SGF, price $1,735, mkt cap $455m) and a number of prestigious unlisted companies and non-profit organisations. She was on the board of the Australian Broadcasting Commission from 2010 to 2015. And she is also a well-known mountaineer and polar adventurer. That is an admirable background.

Ian Dennis is a chartered accountant. He is a director of Electro Optics Systems Holdings Ltd.

[10] Actually AKP acquired 54.1% in September 2010 for $1m cash then acquired the balance in January 2011.

The management team is based in Israel, where they are employed by subsidiary Audio Pixels Ltd. Key executives are company founders Danny Lewin chief executive officer and Yuval Cohen chief technical officer (actually Yuval moved to Sydney in 2017). These two, along with Shay Kaplan previously chief scientist, have been associated with Audio Pixels Ltd since they started the company in 2006.

Shareholders

The Bart group owns 5.8m or 20.6% of the shares under the names of Fred Bart, Landed Investments (NZ) Ltd and other entities. The shares have been held for very many years, well before the Audio Pixels Ltd acquisition in 2011. In fact over the years the Bart Group has increased its holding by 0.5 million shares through converting convertible notes to shares, through participating in placements (0.2m shares at $5.00 in March 2013) and through some on-market purchases[11]. I should add that Cheryl Bart has a direct holding of 0.5 million shares and for some reason this is not counted within the shares held by the Bart Group.

The only other substantial shareholder with 1.9 million or 6.8% of the shares is Link Traders (Aust) Pty Ltd associated with Laurence Freedman AO, who like a number of other long term shareholders is a close acquaintance of Bart's. In 2011 the Link Group appeared on the list of top 20 shareholders for the first time with 0.4 million shares and it has increased the holding a little each year and by somewhat more (0.6 million shares) in 2018. It is probably still soaking up stock.

Danny Lewin and Yuval Cohen each owned 1.4 million shares or 4.9% as at 31 December 2019. These shares are held on their behalf by Israeli investment house Altshuler Shacham Trusts Ltd, which in total holds 3.1m or 10.8% of the shares on behalf of the vendors[12] of Audio Pixels Ltd.

Of the original vendors, Yuval Cohen received 1.4 million shares and 0.5 million options, Daniel Lewin received 1.4 million shares and 0.3 million options and Shay Kaplan (previously chief scientist but he retired in June 2018) received 0.7 million shares and 0.1 million options. The options were converted to shares at 38¢ upon expiry in 2013 and from then until 2019 Yuval held 1.9 million shares and Daniel held 1.7 million shares. As a precondition associated with an early funding round, in 2018 Yuval and Danny (and Shay too) had to relinquish their options-derived shares at a nominal profit, reducing them to their original holding of 1.4 million shares.

Ian Dennis and associated parties held 320,000 shares as at 31 December 2019. As in the case of the other large shareholders, these have been held for many years. I note that in

[11] The latest being 38,482 shares purchased at $12.82 in September 2019.
[12] In 2011 the vendors received 4.9 million shares and 1.1 million options but sold down over the years.

2011 Ian Dennis held 520,000 shares, increasing to 570,000 in 2014, and falling to the present level in 2017.

Capital structure

The company placed 2.15 million shares at $2 in October 2010 to fund the acquisition and future activities of Audio Pixels Ltd. On 31 January 2011 following the acquisition the company's equity capital consisted of 23.3 million shares.

Since then some 5 million shares have been issued, including the following capital raisings:

- December 2012, a placement of 1.1 million shares at $5.00.
- March 2013, a placement of 0.2 million shares at $5.00 to Fred Bart[13].
- March 2013, the 1.1 million vendor options were exercised at 38¢.
- March 2016, a placement of 1.0 million shares at $6.60.
- December 2018, a placement of 0.8 million shares at $13.00.

In addition, over the years Fred Bart has provided funding in the form of convertible notes and these have now all been converted to shares.

Financial

In the year ended 31 December 2019 the company made a loss of $6.2m compared with a loss of $4.5m in the previous year. Biggest cost was R&D of $4.8m.

Figure 7: Historical profit ($000)

Years to 31 December	2016	2017	2018	2019
Revenue				
Interest received	104	66	87	151
Recharge income	-	-	-	122
Total	104	66	87	273
Costs				
Administrative expenses	-1,108	-751	-916	-1,041
Amortisation	-81	-80	-79	-85
Depreciation	-74	-80	-71	-406
Directors fees and super	-149	-149	-149	-149
Exchange gains/(losses)	351	-1,768	2,724	15
Interest expense	-420	-593	-1,512	-30
Fair value movement of derivative liability	-512	-158	-940	-
Gain/(loss) on amendment of conv note terms	-223	286	-525	-
Marketing	-21	-17	-4	-1
Research and development	-2,922	-2,672	-3,134	-4,809
Total	-5,158	-5,981	-4,607	-6,504
Profit				

[13] This was on the same terms as the earlier placement but was delayed in order to obtain shareholder approval.

(Loss) before income tax	-5,055	-5,915	-4,520	-6,232
Income tax benefit	-	-	-	-
NPAT	-5,055	-5,915	-4,520	-6,232

Source: Company reports

At the end of the year accumulated losses totalled $34.2m, virtually all of which was accumulated post January 2011 when the acquisition of Audio Pixels was made. Cash at 31 December 2019 was $5.8m and there was no debt.

During the quarter ended 31 March 2020 there was a cash deficit of $1.5m from operations and hardly any other cash flow items, leaving the company with a cash position of $4.3m.

APPENDIX: BACKGROUND BRIEFING ON SPEAKERS

How speakers work

In technical terms a loudspeaker is an electroacoustic transducer; a device which converts an electrical audio signal into a corresponding sound.

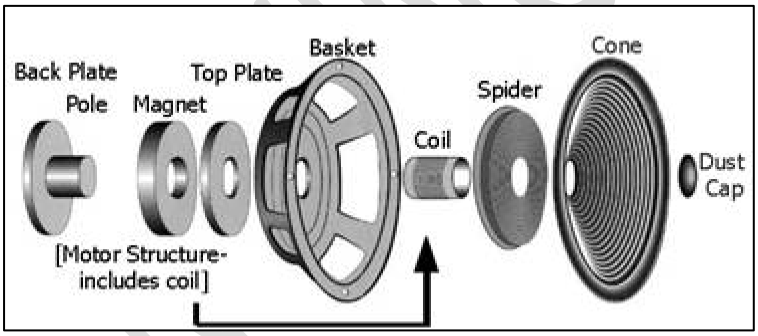
Sound moves in pressure waves. When air particles are compressed and rarefied fast enough, we hear it as sound. The faster the air pressure changes, the higher the "frequency" of the sound we hear. When a speaker cone or diaphragm moves back and forth it pushes on air particles which changes the air pressure and creates sound waves. Speakers work by converting electrical energy into mechanical energy (motion). The mechanical energy compresses air and converts the motion into sound energy or sound pressure level (SPL).

Analogue speakers

Many parts

In an analogue speaker there are many parts, comprising: the cone and dust cap (the parts that move air and produce sound); the spider and the surround (also called the suspension, these are the parts that hold the cone in place while still allowing it to move); the magnet and voice coil (the parts that interact to convert electric energy into motion); the basket, the pole and top plate; and finally the frame that mounts everything together.

Figure 8:Parts of an analogue speaker



Source: Nevi Sonics

When an electric current is sent through a coil of wire, it induces a magnetic field. In speakers, a current is sent through the voice coil which produces an electric field that interacts with the magnetic field of the permanent magnet attached to the speaker. Like charges repel each other and different charges attract. As an audio signal is sent through the voice coil and the musical waveform moves up and down, the voice coil is attracted and repelled by the permanent magnet. This makes the cone that the voice coil is attached to move back and forth. The back and forth motion creates pressure waves in the air that we perceive as sound.

Analogue speakers are typically housed in a speaker enclosure or speaker cabinet which is often a rectangular square box made of several forms of wood, or sometimes plastic. The enclosure's materials and design play an important role in the quality of the sound.

An audio power amplifier (or power amp) is an electronic amplifier that amplifies low-power electronic audio signals such as the signal from radio receiver or electric guitar pickup to a level that is high enough for driving loudspeakers or headphones. Audio power amplifiers are found in all manner of sound systems including sound reinforcement, public address and home audio systems and musical instrument amplifiers like guitar amplifiers. It is the final electronic stage in a typical audio playback chain before the signal is sent to the loudspeakers.

Other than Audio Pixels speakers, modern speakers marketed as 'digital' are always analogue speakers, in most cases driven by an analogue amplifier. The widespread use of the term 'digital' with speakers is a marketing ploy intended to claim better suitability with 'digital' source material (e.g., MP3 recordings), or impute 'higher technology' than some other speaker, and perhaps higher price. If pressed, manufacturers may claim the term means the product is 'ready' for input from digital players; this is true of essentially all speaker systems.

Speaker performance

The ultimate test of fidelity for a speaker is how similar the waveform in the air (the pressure wave) is to the electronic signal (the sound recording) that was sent into the amplifier. If every frequency is accurately reproduced to the listener without adding or removing any information it’s probably a superb speaker.

There are several factors that determine how accurate the listening experience will be including the frequency response, the amount of distortion, and the directionality (dispersion) of the speaker.

Frequency response

Frequency response is how loud the output of a speaker will be at different frequencies.

A typical test for frequency response sends out a sweep of frequencies from the bass to the mids, and up to the treble range to see if the sound from the speaker is the same in all these areas. The ideal frequency response for a speaker is very flat. This means the speaker would be the same level at low frequency as it is in the mids or highs.

The goal of a flat frequency response is to ensure that the people listening to your music experience it the way you intended it. If your track is well mastered and sounds good on speakers with a flat response, you can be sure that it will sound its best on any playback system.

Many analogue speakers are not flat. Some do not have enough treble or enough bass, or they have peaks or dips in their frequency response where certain frequency ranges are over emphasized or hidden or masked. If this happens some instruments may be louder or softer than you intended them to be and the mix you worked so hard on will not be properly represented.

For high frequencies, speakers must move very quickly. For low frequencies, speakers must push a lot of air. This is why tweeters (high-frequency drivers) are typically small domes and woofers (low frequency drivers) are usually large cones.

Humans can hear 10 octaves (20hz-20kHz); that is a very wide range (for comparison, we can only see less than one octave of light). It is a lot to ask for an analogue speaker to reproduce such a wide range accurately and it often takes 2 (woofer + tweeter), 3 (woofer +mid-range+ tweeter), 4 (sub +woofer +mid-range + tweeter) drivers to produce this wide range well. The downside though is that there is distortion of sound (termed 'crossover') where the driver ranges overlap.

Other comments

Analogue speakers are one of the least efficient technologies that we still use today because less than 1% of the power that goes into a speaker gets converted into sound, with the remainder converted into heat. Traditional speakers are actually less efficient than incandescent lightbulbs, which are pretty much outlawed at this point.

Digital speakers

The missing link

Digital speakers or Digital Sound Reconstruction (DSR) systems are a form of loudspeaker technology not to be confused with modern digital formats and processing. It is digital to digital, not digital to analogue. Despite 140 years of development in sound technology, the loudspeaker transducer remains the only analogue component in a world dominated by digital media and electronics. The introduction of a digital transducer would complete the missing link in the digital chain alleviating many of the inadequacies associated with traditional analogue speakers. Digital Sound Reconstruction offers a path to the digital transformation of the loudspeaker.

How they work

Traditional sound reconstruction techniques use one or more analogue speaker diaphragms with motions that are proportional to the sound being created. Louder sound is generated by greater motion of the diaphragm and different frequencies are produced by time-varying diaphragm motion.

But with DSR the desired sound waveform is generated from the superpositioning or summation of discrete pulses of acoustic energy that are produced by an array of speakers or speaklets (Audio Pixels calls them call them “pixels”). Each pulse contributes a small portion to the overall sound being reproduced, so unlike analogue speakers, DSR pixels do not require a large dynamic range. Instead, louder sound is generated from a greater number of pixels emitting pulses, and different frequencies are produced by time-varying the number of (pixels emitting) pulses.

The number of pixels in the array and the sampling rate (frequency at which the number of pulsed pixels are updated), determine the resolution of the resulting waveform. Since the human ear inherently has the characteristics of a low-pass filter, the listener hears an acoustically smoother signal identical to the original analogue signal.

A digital transducer array is required to implement true, direct digital reconstruction of sound. At any given time a binary digital signal is represented by one digit (or ‘bit’) either a ‘1’ or ‘0’. Switches in voltage are driven by these binary signals, from on to off. A value of “1” causes an audio driver to be driven to full amplitude, a value of “0” causes it to be off. This allows for high efficiency, dissipating no power as heat at any time.

Some considerations

There are many considerations that are essential to digitally reconstruct sound using an array of transducers or pixels, among them:

- The acoustic response of a single transducer must be fast. This includes the time it takes for the transducer to move and generate the impulse as well as the time it takes for the impulse to decay.
- The acoustic response must be repeatable and uniform over time and across all pixels in the array. Variations in uniformity will introduce errors into the digital conversion.
- The resulting acoustic energy from those pixels must add linearity[14], as without linearity, the summation of acoustic energy cannot be predicted and therefore it is impossible to calculate the timing and quantity of pixels that need to transition at any given moment.

[14] An audio system is called linear if it has two properties: homogeneity and additivity.
Homogeneity requires the output level to be proportional to the input level. For example, if we amplify the input by 6dB, the output also increases by 6dB; and If we half the input, the system also halves its output. From a practical point of view, it means that a linear system is generally independent of level; the effect remains exactly the same for both small and large signals.
Additivity (also called “Superposition”) demands that the response caused by two or more sources is the sum of the responses that would have been caused by each source individually. This guarantees that no interaction appears between the different sources. Due to this property, linear processes can be separated, reordered and combined at a later point, while maintaining exactly the same results.

Disclaimer

This analysis is cursory in nature and is not intended to be relied upon by third parties, who should make their own enquiries. The report does not contain investment advice.

Any views expressed in this report are purely my own unless otherwise indicated.

Disclosure

I have not received any remuneration from any person for this report.
Associated entities own 20,000 shares in AKP at the time of writing.

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