Establishing technical specifications for New Zealand's new 10 cent, 20 cent and 50 cent coins

by Don Oliver

This article explains the analytical process through which the Reserve Bank established technical specifications for New Zealand's recently issued silver- and copper-coloured coins. The new coins are smaller and are constructed using metal plating rather than solid alloy. Both these innovations reduced the cost of manufacturing New Zealand's coins, but also required extensive testing and analysis to meet the needs of the vending machine industry and the general public. In particular, the Reserve Bank needed to be satisfied that the coins could work reliably in vending machines, yet also be hard to fake. The coins also had to withstand the wear they would be likely to receive in circulation.

1 Introduction

In late 2004, the Reserve Bank sought public submissions on a proposal to reduce the size of New Zealand's 10 cent, 20 cent and 50 cent coins (commonly called 'silver' coins) and to change their construction from solid alloy to metal plating. Surveys had shown that the general public and retailers tended to favour smaller, lighter coins. Compared to the international trend, the then-present New Zealand silver-coloured coins were large, with the 50 cent piece being above the internationally recommended maximum diameter of 30mm. Also, the cost of the solid-alloy coins' metal content was rising, leading us to consider the plated coin option.

During the public consultation and tender process, submissions from the vending machine industry and from coin mints raised concerns about both the durability and the functionality of plated coin. If the proposed coins were to deteriorate in circulation, or the coins could not be used in vending machines, the public would be most unlikely to view them favourably. This would clearly be an unacceptable outcome.

The Reserve Bank therefore needed firm evidence that plated coin was a workable option. Analytical work indicated that plated coin could work as long as certain rules were followed relating to the coins' durability and to their Electro Magnetic Signature (EMS), which combines the inductance and conductance properties of the metals making up the coin. The final specifications for the coins were confirmed after extensive testing in vending machines, using EMS tolerances as tight as current plating technology allows.

The rest of this article explains these aspects of the specification process in more detail. Section 2 discusses the submission process and how the technical problems to be overcome were identified. Section 3 sets out the different elements of the specification, focusing on the role of the EMS. Section 4 explains how the specification options were narrowed down to a final choice. Section 5 concludes.

2 Why review the 'silver' coins?

The Reserve Bank's main motivation for the review was to introduce smaller coins that would be more convenient for the general public and for cash-handling businesses. We also needed to reduce the cost of manufacturing the coins to keep it below the coins' face value. The difference in value is called 'seigniorage'. In some countries, the value of coins' metal content exceeds their face value ('negative seigniorage'), and the public consequently keeps them for resale to scrap metal dealers. Although this situation had not arisen in New Zealand at the time of the review in 2004, we were coming very close for some coins, due to the increase in prices of the metals on world markets.

Consultation with other mints and central banks suggested that plated coin, instead of solid alloy as in the existing coins, would be one approach to reducing the manufacturing cost, as plated coin does not require as much high-cost metal.

Box 1

Metal plating options

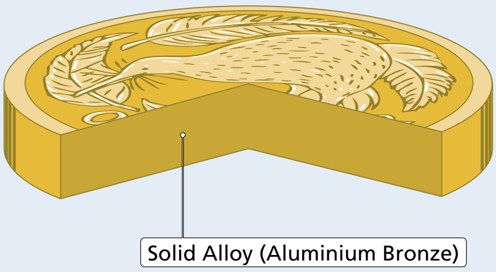
This box briefly explains the broad options the Reserve Bank considered for the new plated coins, compared to their alloy predecessors.

Alloy

The old 'silver' coins were made of a 75% copper, 25% nickel alloy; and the current one and two dollar coins are made of an aluminium-bronze alloy, illustrated right.

$1 AND $2 COINS

Not to scale

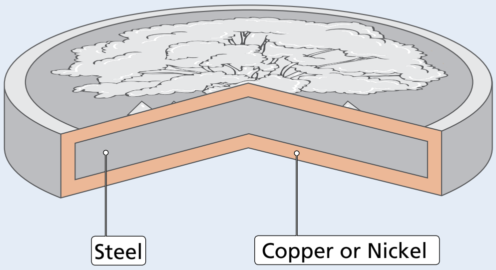


Mono-plated

A low-cost metal core is electroplated with another metal. In the Reserve Bank's tender we specified either copper or nickel over an iron core. This was not adopted for New Zealand.

MONO-PLATED

Not used in New Zealand, indicative coin only.
Not to scale

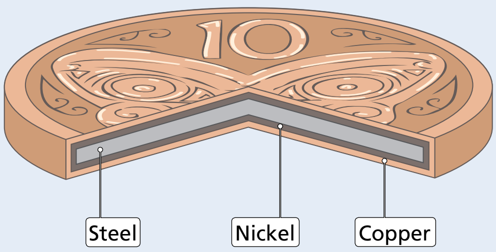


Bi-plated

A low-cost metal core is electroplated with two layers of different metals. We specified nickel over copper, or copper over nickel, over an iron core. The 10 cent piece uses this method, illustrated right.

10c PIECE | BI-PLATED

Not to scale



Tri-plated

A low-cost metal core is electroplated with three layers of different metals. Although the extra level of plating was not strictly necessary to achieve the Reserve Bank's objective of exploiting plating technology to reduce cost, one of the tendering mints offered an electroplating process that does not rely on the use of cyanide, and hence would be more environmentally friendly, while still being cost-competitive. If a copper layer is used in this process, then a thin layer of nickel is required between the iron core and copper plating to ensure that the copper adheres to the iron core. The result would then be nickel over copper over nickel, over an iron core. The 20 and 50 cent pieces use this method, illiustrated right.

20c AND 50c PIECES | TRI-PLATED

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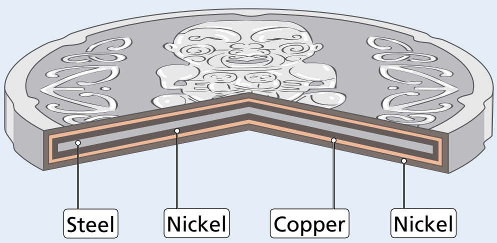


In late 2004, the Reserve Bank asked for public submissions on a proposal to replace the then-present solid alloy coins with nickel- and copper-plated coins, and to remove the five cent piece.[1] Box 1 shows these options. Then, in early 2005, the Reserve Bank sought tenders for the supply of new nickel-plated coins, and announced the removal of the five cent piece.

Some submissions during the public consultation and tendering process pointed to a tendency for defects in plated coins in countries that had issued them. In particular, submissions from some mints raised concerns about the durability of coins, noting instances where the outer layer of nickel had failed and exposed the layer below. Most of the vending machine industry's submissions related to problems in distinguishing genuine coins from 'slugs' (an industry term for false coins) and from genuine coins of different value. The problem here was the proposed core of iron, which is a metal that is commonly available. This had allowed common metal washers or similar items (slugs) to be accepted by vending machines in some countries.

The Reserve Bank conducted extensive investigative work on these issues, given their apparent seriousness. It had been over 37 years since the decimalisation of New Zealand's notes and coin, so a technical team had to be assembled comprising an electronics expert, a metallurgist who would assess the electroplating technology, and a specialist in sensor technologies who would assess the vending machine industry's needs. This team conducted in-depth consultations with vending machine manufacturers and mints to assess whether plating technology could work acceptably, and what the necessary specifications would be.

3 Elements of the specification and the role of the electromagnetic signature

Prior to seeking submissions on the proposal, the Reserve Bank had already decided that the 20 cent and 50 cent coins would have an outer layer of nickel, and the 10 cent coin would have an outer layer of copper, to produce the silver and copper colours respectively. Based on this composition, the tenders confirmed that plated coin would be less costly than alloy coins, but as noted above, the issues raised in the submissions and tenders meant that the team had to satisfy itself that plated coin would satisfy both durability and vending machine requirements.

Durability

Nickel was in the then-present coins, and these had been in circulation for 38 years so they could be used as a reference for wear over the life of the coin. The Reserve Bank's target was to achieve a 25-year life. Various coins that had been in circulation up to the 25-year period were tested to measure the wear pattern. This wear was then compared to the wear on test versions of the new coins.

Sample coins of nickel-plated steel were tested using three methods, all involving tumbling in a barrel:

(1) with soft cloth to simulate wear in people's pockets;

(2) with other coins to simulate what they would experience during normal circulation in cash-handling, cash tills and coin vending machines; and

(3) with other coins and an added abrasive to simulate 'extreme' wear.

New alloy coins were included in initial tests to determine the barrel time required to produce an appearance comparable to the existing worn coins. Then the nickel-plated steel coins were run for the same length of time.

In the worst case, the wear on the nickel-plated steel coins came to 5 microns over a simulated 25-year period. To be on the safe side, the Reserve Bank decided on a specification of 10 microns of nickel. The manufacturing tolerance was +/- 3 microns, producing a minimum thickness of 7 microns. This would give coins an expected life well in excess of the 25-year target.

The specification for the 10 cent coin's copper-plated outer layer is 30 microns. The 10 cent coin, being the lowest-value coin, has a historically shorter circulating life than the other two coins. Although copper is a softer metal than nickel and will wear faster in circulation, this thickness would be sufficient to give the coin the required life.

[1] **Boaden (2008) reviews the experience of removing the five cent piece from circulation.**

The vending machine industry's requirements

Our investigations indicated that plated coins could work in vending machines, as long as certain rules were followed. These related to the coins' physical sizes, and to the differences between their EMS relative both to commonly available metals and to each other. The major part of our investigations focused on these aspects, due to the critical importance of the public being able to use the new coins in vending machines.

Choosing the size of the new coins was relatively straightforward. Thickness and diameter are two size properties of coins that the vending machine industry uses to identify and separate coins. The larger the difference between coins along these dimensions, the more likely they are to be distinguished. However, size properties, without additional EMS checks, provide only a low comfort level for authentication, with risks of fraud from other materials of the same size. This is especially the case given the reduction in the internationally conventional size of coins, because of cost benefits and convenience of use.

Consultations with the vending machine industry indicated that thickness was not as important as diameter, though the industry did not want any new coins to exceed the thickness of New Zealand's present one dollar coin, which is the thickest we have at 2.74mm. Thicknesses with a given diameter give the coins their weight, and the heavier the coin the easier it is for the industry to process. The industry preferred a diameter difference between the new coins of 2mm. To maximise the difference in diameters, the existing one and two dollar coins had to be included, which limited the diameters available. The industry recommended a range of 19mm to 30mm from smallest to largest coin. This restricted the Reserve Bank to offering a minimum 1.25mm diameter difference between each coin. Although this was not the preferred difference, the industry accepted that it was workable.

The role of the electromagnetic signature

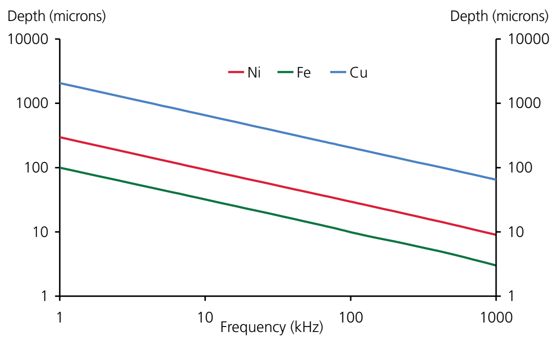
The vending machine industry's submissions raised issues regarding the proposed materials in the new coin and difficulties encountered with identifying and authenticating plated coin when it had been introduced into other countries. There was concern about inconsistent EMS on those coins, which forced vending machines to have a wider EMS 'acceptance window' for each coin than they were comfortable with, because of the increased risks of mix-ups with other coins and with objects of similar size but different material. As a result of this concern, the mint's quality-assurance processes and keeping manufacturing tolerances to a minimum would be an important objective.

Consultations established that vending machines typically use the 'Skin Effect' of an oscillating electromagnetic field to check and authenticate coins. The field is generated by a coil that is supplied with AC power and wound around a soft iron core. The EMS of the coin is measured through its effect on the voltage or current in the coil, and reflects the inductive and conductive properties of the target material (see Box 2 for more details).[2]

Skin Effect refers to the effect of the frequency of oscillation on the depth of penetration of the electromagnetic field into the material. As the frequency increases, the depth of penetration decreases. Depth of penetration also varies with the material. Figure 1 shows the difference between the three metals involved in the proposed plated coins.

The frequency of oscillation enables the vending machine to select what part of the coin it checks. Some machines have sensors on both sides of a coin to compensate for an off-centre coin. In the case of plated coins, the Skin Effect would have to be used to measure the EMS at a particular depth in

Figure 1
Electromagnetic penetration by frequency



[2] Some machines include the induced eddy currents in their sensing, which are also affected by conductivity and inductance.

Box 2

Conductance and inductance

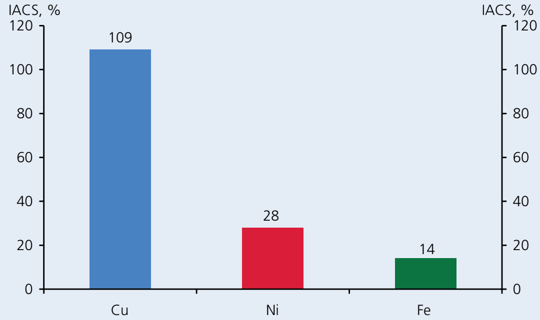
This box explains the properties of conductivity and inductance, which together define a material's electromagnetic signal.

Conductivity is a material's ability to pass an electrical current, normally expressed in terms of the International Annealed Copper Standard (IACS), which compares any material to copper (which is given a figure of 100%). Inductance is the effect a material has on a changing magnetic field (usually created by an electrical coil supplied with oscillating voltage), which induces eddy currents within the material. The eddy currents produce an opposing magnetic field, which would be equal in strength to the inducing field if there were no losses. The losses characterise different materials and are measured in various ways. The two most important ones used in the vending machine industry exploit the resistivity and permeability of the material.

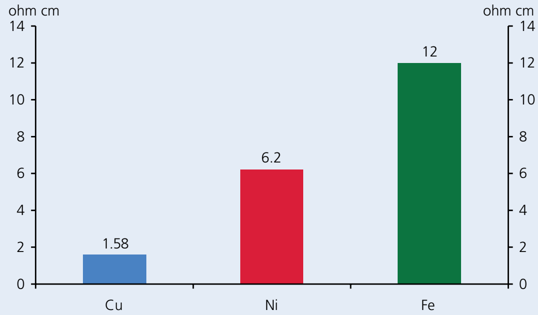
Different countries specify, by a range of different methods, conductivity or inductance (or both) for their coins, to ensure that the vending industry has a consistent product. Consultations with vending machine manufacturers indicated that they tended to use various combinations of conductivity and inductance.

The three metals involved in the Reserve Bank's tender were copper (Cu), nickel (Ni), and iron (Fe). All have different inductance and conductance properties and produce a different EMS. This is shown in the charts below. Inductance is shown using resistivity and permeability, as these are the two most common properties of inductance utilized by the vending industry.

Conductivity (IACS)

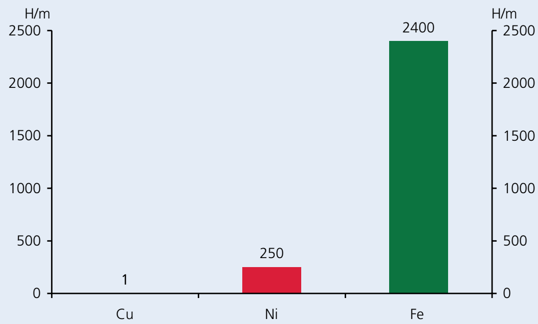


Resistivity (ohm cm)



Permeability (H/m)

(A property of magnetism)



The target area of 30 to 50 microns of depth corresponds to the normal approximate thickness of plating. The issue then became one of choice of nickel and copper plate layer thicknesses to achieve sufficient separation of the EMS of genuine coins from each other and from slugs.

As shown below, nickel does not have exactly the same EMS as iron, but is much closer to iron than copper, so there would need to be much more nickel than copper to shift a nickel-plated coin's EMS away from an iron slug. Consultations suggested that at least 40 microns of nickel would be required. 40 microns of nickel would make the coin very expensive to produce (nickel is the most costly of the three metals). Electroplating costs would also be higher with plating of this thickness.

Copper, on the other hand, has both conductive and inductive properties very different to iron. Since we had wanted a silver colour for the 20 cent and 50 cent coins, and a copper colour for the 10 cent coins, we needed nickel on the outer layer of the 20 and 50 cent pieces, and copper on the outer layer of the 10 cent coin.

(continued)

The problem then became how to minimise the amount of nickel for cost reasons, and to introduce copper for EMS reasons. As explained earlier, wear tests indicated that at least 10 microns of nickel would be required to give the coins a 25-year life. That left the choice of how much copper under the nickel would be required to produce an EMS that vending machines could use with reasonable levels of security. We could find no information on this topic, so we decided that the winning mint would be required to make test coins with a nickel outer layer and different thicknesses of copper under it, to see how they would influence the EMS.

the coin. The issue here was that the plated coin core would be made of iron, which is a very commonly available material and thus would open up risks of fraud from steel washers and the like. This made it essential that the Skin Effect was exploited to avoid the iron layer in the plated coins, and increase the reliability of sensing and rejecting slugs.

Our consultations suggested that the most common frequency used by vending machines was 120 kHz, which tends to make the Signature more sensitive to the first 30 to 50 microns – though as noted this would depend to some degree on the metal presented to the Signature, which in the case of plated coins would be metals with different characteristics. Frequencies below 120 kHz tend to penetrate into the core and become less sensitive to the plating materials, whereas frequencies around 500 kHz and above become too sensitive to the surface shape of the coin, which would necessitate a widened acceptance window and associated reduced security.

As a result of these findings, the specification was narrowed to designs of coins that would be usable at frequencies around 120 KHz.

4 Bi-plating or tri-plating, and checking the results

The choice remained over whether the coins should be bi-plated or tri-plated. The nickel-plated coins needed to be at least bi-plated so that copper could be present for EMS reasons. Mint technology we investigated offered both bi- or tri-plating. The final selection of tri-plating was based on comparing the tenders of the mints on cost, quality control and environmental considerations – one mint offered a production process that did not rely on cyanide. Although the non-cyanide process meant that the silver-coloured coins would be tri-plated, we were satisfied that bi-plating could also be used in the future while duplicating the EMS signature. So, the result was that the 10 cent piece would be bi-plated with a copper outside layer, and the 20 and 50 cent pieces would be tri-plated with a nickel outer layer.

Prior to our finalisation of the specification for the plating thickness, the winning mint manufactured some test coins of all intended designs, with copper of varying thickness. These were then sent to a vending machine manufacturer to check which combination would enable separation by the vending machines from each other and from slugs. This manufacturer had expressed difficulty with identifying plated coin in the past.

These tests clearly indicated which specification of the copper layer gave the best separation of EMS. The final specification was now completed.

As noted, keeping manufacturing tolerances to a minimum was identified as one of the areas where the vending machine industry had experienced difficulties in the past. The winning mint's quality assurance procedures thus needed to demonstrate tight control of manufacturing tolerances at each step, with minimum variation in core and plating layer thickness to ensure the variation of the EMS would be minimised. We thus required that the mint produce a volume of coins so that their EMS could be checked.

A coin-sorting machine manufactured by Scan Coin was able to process the volume of coin required, and check their EMS. For future production, a master set of coins of each denomination was created. Scan Coin's machines are calibrated to these master coins. This ensures that the machines are checking to known reference coins, preventing any variation of the EMS in future production runs.

5 Conclusions

The information collected by the Reserve Bank's team of technical experts in the process of establishing the new coin specification places us at the forefront in plated coin technology. Through this process we were able to reduce the cost of manufacturing New Zealand's coins, while also ensuring that we use the best of available technology to produce coins that satisfy the most demanding needs of vending machine manufacturers and the general public.

The Reserve Bank acknowledges and greatly appreciates the co-operation, assistance and support of the vending machine companies, mints and Scan Coin consulted in the course of our work introducing the new 'silver' coins. Much of the detailed information provided to us is commercially sensitive and not otherwise available. It has not been disclosed here. The individuals consulted were very open and informative, allowing the Reserve Bank to assess thoroughly the different coin technology options available and how they could work satisfactorily in practice. Their assistance has created benefits for all users of coins.