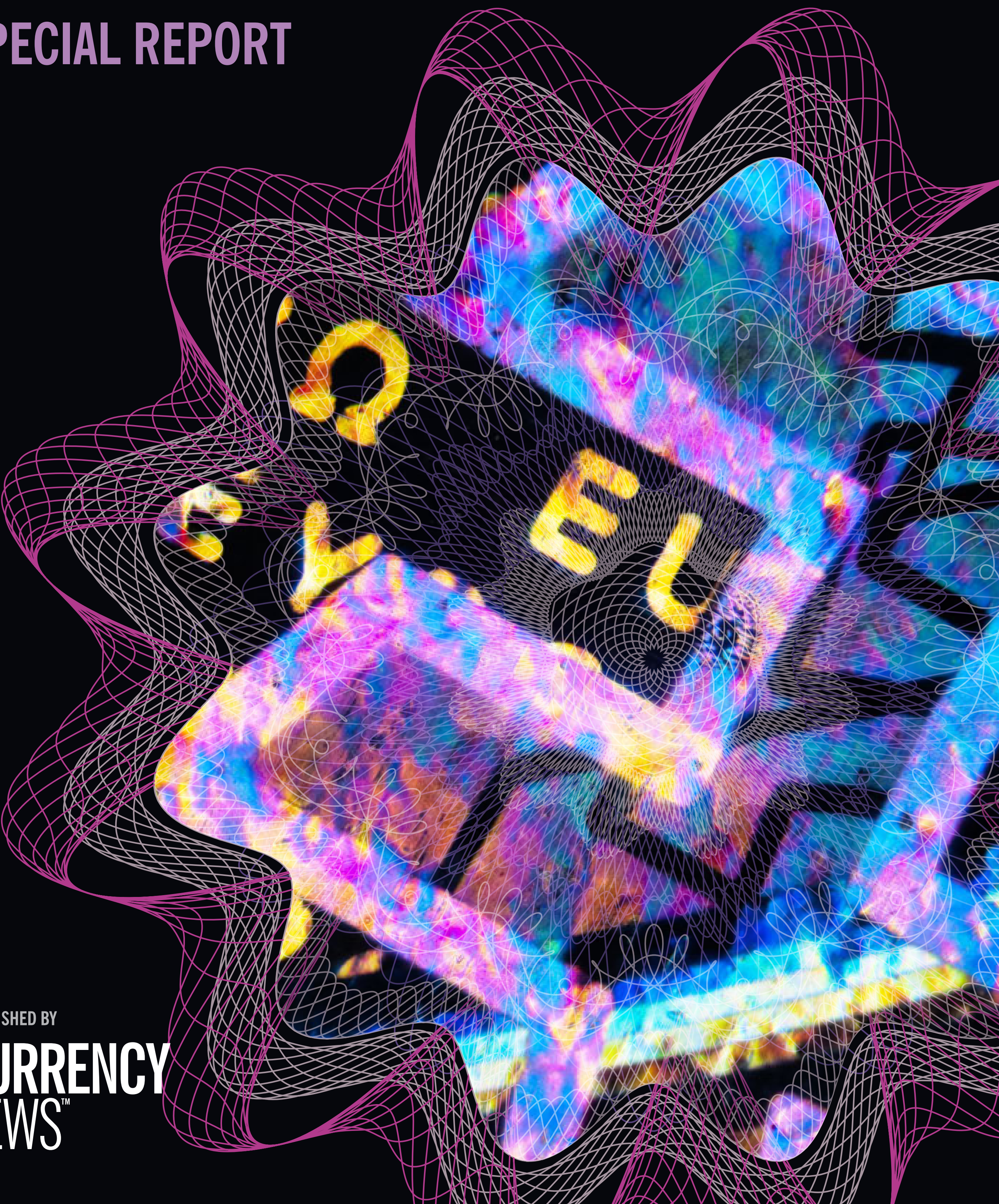
DIFFRACTIVE FEATURES ON BANKNOTES 2018

SPECIAL REPORT



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DIFFRACTIVE FEATURES ON BANKNOTES

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DIFFRACTIVE FEATURES ON BANKNOTES

2018

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www.ihma.org

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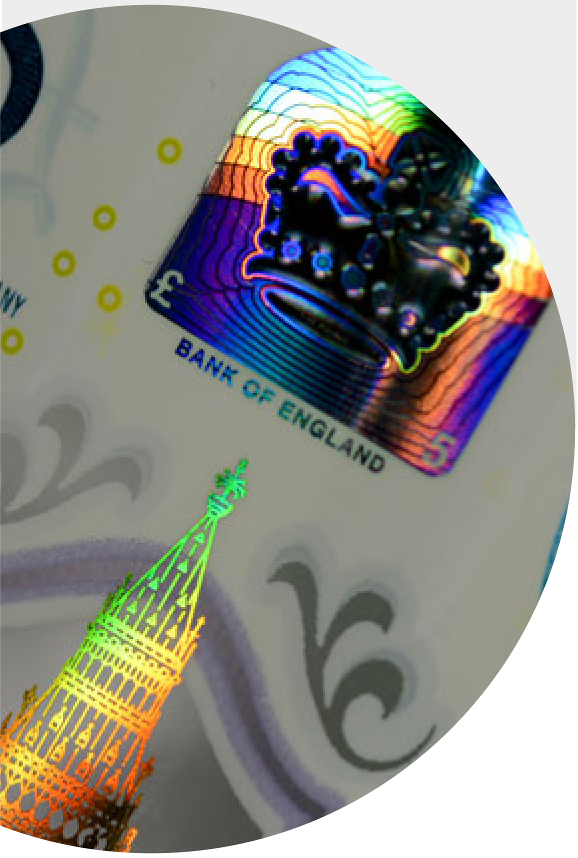
Introduction

This year marks the 30th anniversary of the use of DOVIDs on banknotes, so it seems fitting to publish this document to celebrate this important milestone and also to take a look at some of the developments that have occurred in this sector over the three decades.



Holograms, optically variable devices (OVDs), diffractive optically variable devices (DOVDs), diffractive foil features (DFF) or diffractive optically variable image devices (DOVIDs) are the variety of terms used to describe the security features that have become one of the most common, and successful, level 1 (overt) features on banknotes today. To most lay people they are collectively called holograms. However, for the purposes of this publication, we will refer to these features as DOVIDs as this most comprehensively captures the characteristics of these features.

Although primarily viewed as level 1 security features, DOVIDs on banknotes are unique in being able to provide multiple levels of security at any one time and can incorporate all levels of security within a single feature.

So What is a DOVID?

DOVID is a collective term that describes the family of features that includes holograms and other devices that exhibit a variety of complex iridescent images and patterns according to the viewing angle (ie. when they are tilted or rotated relative to the viewer), based on the diffraction of light.

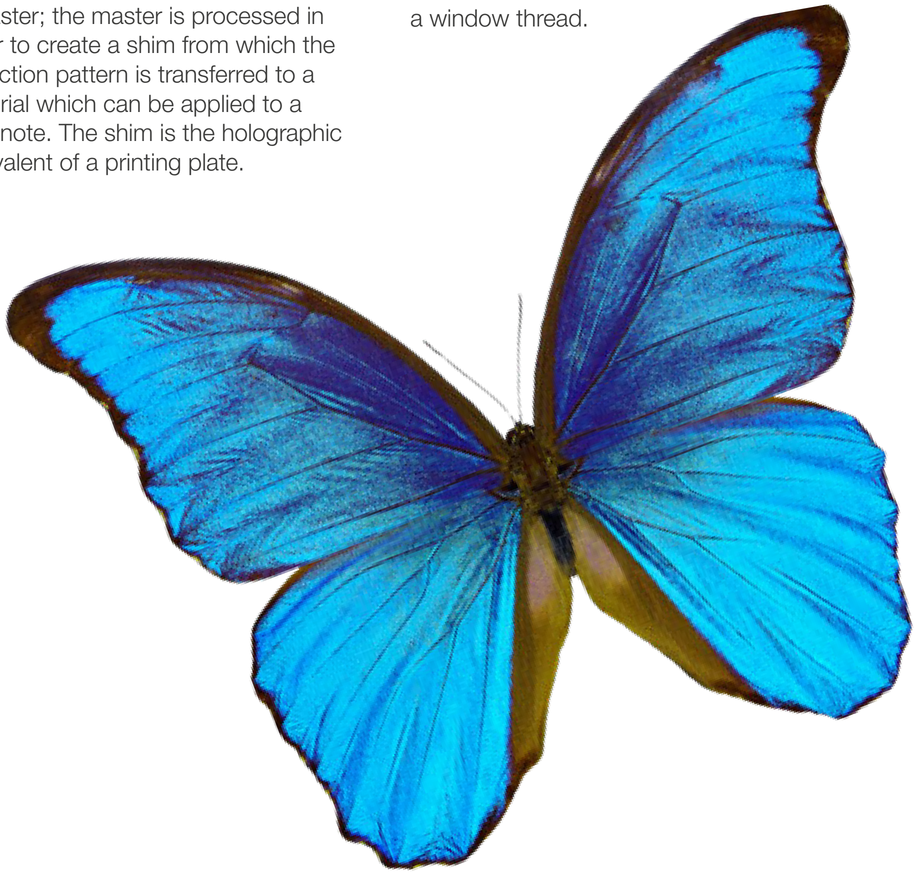
Holograms are a type of DOVID, but not all DOVIDs are holograms. Holograms (the word comes from the Greek words 'holos', meaning whole, and 'graphos', meaning image) are created through the interference of two laser beams to create what is called a diffraction pattern, but there are now methods to create diffraction patterns through directly etching them or blazing them using, for example, an electron beam (e-beam).

This process produces what is termed a master; the master is processed in order to create a shim from which the diffraction pattern is transferred to a material which can be applied to a banknote. The shim is the holographic equivalent of a printing plate.

Diffraction is the bending of light as it passes a boundary or obstruction (similar to sound travelling around the corner of a building). A *diffraction pattern* is a microscopic pattern of lines which interact with light waves at the quantum level to bend those light waves. Other examples of diffraction patterns are optical disks (CDs and DVDs), butterfly wings and peacock feathers.

This material is applied to banknotes in the form of a patch or stripe using a hot or cold stamping, transfer or roll-on process. We use the term *diffractive foil* feature to refer to such a material that, when applied to, or integrated within, a banknote, exhibits diffractive effects.

In addition to the transfer of *diffractive foil features* in the form of stripes or patches onto banknote substrates, DOVIDS can also be produced on a polymeric film that can be slit to create threads, usually 2-6 mm wide, which can be incorporated into a cotton-based substrate as a window thread.



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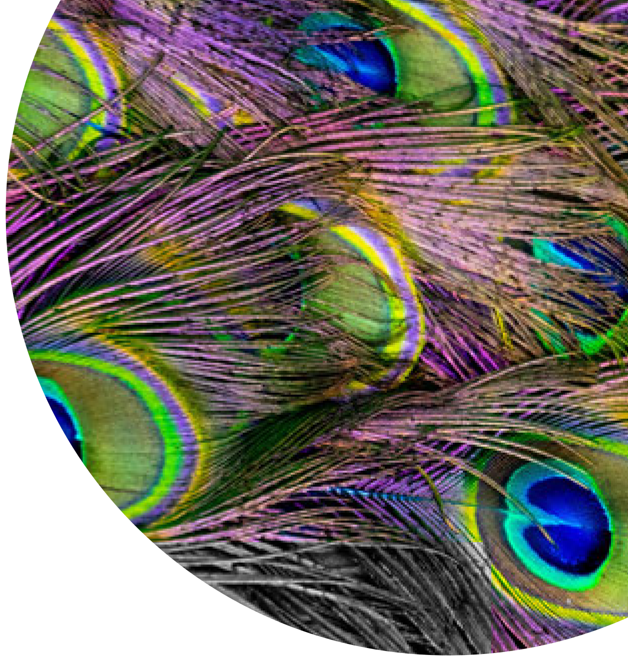
All three forms of DOVID – stripe, patch and thread – are successfully used in banknotes, as this report will show. The newest method of incorporating a DOVID is to form the diffraction pattern directly into a polymer banknote substrate, which removes the need to transfer it from a film carrier to the note.



The Rise and Rise of DOVIDs on Banknotes

A detailed description of the evolution of DOVIDs on banknotes is provided in the next section. But in advance of that, the first use of a DOVID for currency was in 1988, when the Reserve Bank of Australia issued a note commemorating Captain Cook's discovery of Botany Bay and the Austrian National Bank issued a new high denomination 500 schilling note.

Following this, progress was initially slow as many technical challenges, as well as the reluctance to accept DOVIDs as secure features, had to be overcome.

The next significant development, in 1992, was the issue by the Bank of Finland with a 2 mm wide DOVID security thread. This development was followed shortly afterwards by the first diffractive stripe, which appeared on Bulgarian banknotes. There were now three product options open for the use of DOVIDs on banknotes – patches and stripes from hot transfer foil and threads.

By 2000, around 49 banknote denominations featured DOVIDs as a prime level 1 security feature and by 2007 the number had grown to 176, helped by the use of DOVIDs on the new euro currency. By 2012 this had increased to 247 denominations.

At the end of 2017, 293 banknotes out of just over 1,000 current circulating denominations incorporated DOVIDs, of which 139 are stripes (47%), 112 (38%) are patches and 42 (15%) are threads. The logic for this distribution will be dealt with in a subsequent chapter.

We will also deal with the nuts and bolts of DOVIDs – how they are originated, manufactured and applied – along with who is supplying them, their attributes as a security feature, why they continue to be successful and what the future could hold.

This publication does not attempt to be a deeply technical or scientific document – its main purpose is to provide readers who have a non-technical background with a degree of familiarity with some of the history, technology, material science, terms, developments, latest products, market trends and other relevant factors that have led to this substantial use of DOVIDs as a banknote security feature. At times and for completeness we may also touch on other features and technologies that are neither foils nor diffractive.

Our hope is that this will help everyone involved in banknote design, production, issuance and security to put the use of such features into perspective and to help them approach the use of this important security feature as a vital tool in helping to prevent counterfeiting, gain public recognition and acceptance, and engender pride in banknotes.

Explanatory Notes

1. All figures given for DOVIDs in use are up to the end of 2017. Unless otherwise indicated, the figures are net (ie. if countries have dropped DOVIDs or changed format, these changes are reflected in the figures).
2. The report, and figures, relate to circulating banknotes only (ie. commemorative notes are not included).
3. The figures do not include the legacy currencies of the countries that use the euro, even though many of these included DOVIDs.
4. Where companies have changed names, the old name is used the first time and the new name thereafter, irrespective of when their names changed.
5. In some countries (Hong Kong, Macau, Northern Ireland and Scotland) there is more than one note issuing bank. For the purposes of this report, however, we are taking there to be one note issuing authority, irrespective of how many different versions of each denomination there are.

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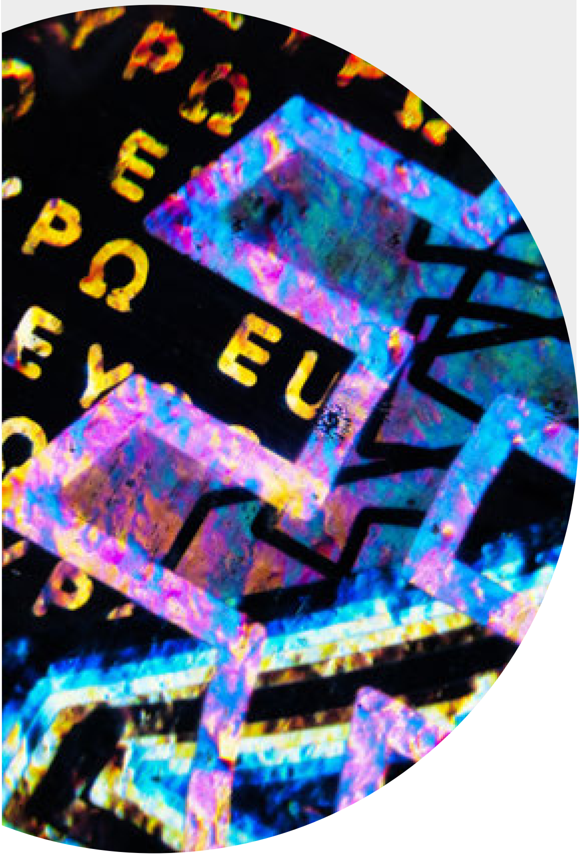
The Evolution of DOVIDs on Banknotes

In the beginning there was paper and ink. Thus began the modern history of the banknote and with it, banknote counterfeiting, leading to the introduction of a watermark in 1697 and, in 1945 an embedded security thread. The next major anti-counterfeiting feature was the introduction in 1984 of a window thread.



At Interpol's 6th International Conference on Currency Counterfeiting (Madrid, 1977), came the first reports of Japanese colour copiers being used to counterfeit currency notes.

A year later, Swiss banknote printer Orell Füssli and Landis & Gyr (now OVD Kinegram, a subsidiary of KURZ) presented a diffractive optical element on a coated paper substrate. This involved the use of a die incorporating a diffractive relief pattern and the use of a letterpress numbering machine (the *Numerota* from what was then De La Rue Giori and is now KBA-NotaSys). This approach was abandoned three years later in favour of the use of a transfer foil feature added to a paper substrate.

At the 7th Interpol conference (Lyon, 1987), SICPA announced that Thailand had taken the first steps to evaluate the use of its Optically Variable Ink (*OVI*™) on a banknote (the 60 baht). The first major adoption came when, in 1996, the USA decided to use OVI on the $100 bill.

1988 – the Breakthrough

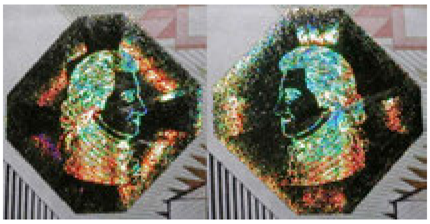
However, the challenge remained to create additional products to resist colour copying, and in 1988 the banknote world made a breakthrough. In that year, and at opposite ends of the world, two banknotes were issued that would signal a permanent change to banknote security.

In Austria, the high-value 5,000 schilling note appeared with an embossed foil patch of Mozart. The shim was produced by OVD Kinegram and the foil by KURZ, and was applied by a Gietz hot stamping machine.

In an even bigger departure from convention, and also applied using a Gietz machine, Australia issued a commemorative A$10 note made of biaxially orientated polypropylene (BOPP). This was the world's first polymer banknote, and displayed a computer-generated diffractive foil image of Captain Cook in a transparent window.

This feature was called *Catpix*™, a diffraction pattern created by blazing with an electron beam, developed by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) Division of Chemical Physics. The Catpix technology was developed to overcome degradation of the diffractive image resulting from flexing or crumpling of the banknote during its lifetime. In 1988 the Reserve Bank of Australia purchased the Catpix technology as part of the polymer banknote technology package.

The Austrian 5,000 schilling – one of the two first DOVIDs on banknotes in 1988.



The 5,000 schilling tilted to the left and the right to reveal different profiles of Mozart.

Although the Austrian schilling was subsequently replaced by the euro, and Australia suffered numerous technical problems (17.5 million A$10 notes were manufactured but the ones that went into circulation did not age well), the stage was set for a revolution in banknote security; banknotes with DOVIDs would proliferate as it became clear that the features could not be photocopied, scanned or printed, no matter how refined the equipment.

This is because a defining property of diffractive foil features is that the colour and imagery is strongly angular dependent – ie. optically variable. This means that, as the note/diffractive foil is handled, rainbow colours flash in front of the viewer. By comparison, a photocopy (static flatbed copy) of the foil appears lifeless, with no optically variable rainbow effect.

It is this varying rainbow pattern that most distinguished the Captain Cook image from anything that had been seen previously on a banknote. The development of a polymer substrate was merely a means to an end, that end being the ability to accept a game changing optically variable anti-counterfeit device.

Ironically, the polymeric substrate had greater staying power for Australia than the diffractive foil. This polymer substrate – called *Guardian*® – was made by Securency (now CCL Secure). The company has had significant success, with Guardian now being used by 24 countries on 80 denominations. The Reserve Bank of Australia discontinued the use of DOVIDs after this experiment until 2016.

Australia's commemorative A$10 – the world's first polymer banknote, and one of the world's first two banknotes with a DOVID.

Catpix diffractive Captain Cook foil patch.

Strictly speaking, the first DOVID on the Australian note wasn't a hologram (neither too was the *KINEGRAM*® on the Austrian schilling) because the diffractive fringes on the Australian note were totally computer-generated by CSIRO without any recourse to the phenomenon of interference. But to a wider, non-specialist audience, this is hair-splitting; hence the common use of 'hologram' to inaccurately refer to all of these iridescent foil features.

The Captain Cook image had no depth or parallax in any direction, but it did seem to flip from a positive to a negative image (although not in a consistent way). Indeed, its main visual features were that it resembled a portrait of Captain Cook and its metallic surface glistened with iridescent colours when caught in the light. That was enough to dramatically distinguish it from a photocopy.

Although this note was not primarily intended for circulation, the idea of using such features for circulation on currency caught the attention of the financial community and the idea slowly caught on.

The subsequent take-up of diffractive foils on banknotes was slow – the banknote community was cautious, the gestation period for any new banknote features was long and the technology for sophisticated foil features, large-scale production and application was in its infancy. Nevertheless, over the next three decades nearly 100 issuing authorities were to adopt the technology and apply it to just under 300 denominations.

Next Milestones

1993 saw the foundation of the International Hologram Manufacturers Association (IHMA) – which was set up to create a code of conduct for the rapidly-developing industry. The same year it launched the Hologram Image Register, a first-of-its kind initiative to maintain a record of security holograms produced by its members, and the so-called 'jewel' in its crown. The IHMA now comprises nearly 100 members and is the only part of the security features sector to have its own association.

The previous year, 1992, another milestone was accomplished with the first holographic thread, in the Finnish markkaa. At that time, however, threads could only be inserted into banknotes to a maximum width of 2 mm, which allowed little space for the diffractive effects to be viewed. The development of short-formers in the late 1990s enabled the integration of much wider threads, and hence provided a boost for the deployment of diffractive and other optically variable threads to widths of 6 mm and more.

Two years later, in 1994, came the first holographic stripe, *LEAD*® (Long-lasting Economical Anti-copy Device), on the Bulgarian leva, arguably a more important development since the majority of holograms are now applied as stripes.

1994 also saw Kuwait adopt holograms on three of its denominations (although, ironically, more than 20 years later, it was one of the first issuers to drop DOVIDs in favour of other overt features).

Since then, and in particular towards the end of the decade, there was a tremendous upsurge in the use of DOVIDs on banknotes.

This was prompted in part by the increasing use of digital scanners and photocopiers to counterfeit banknotes. It was also promoted by developments in foil production and application technology, which enabled high volumes of foil to be produced cost-effectively and applied at speeds commensurate with normal banknote printing production.

This was further supported by the introduction of machines to facilitate the application of foil to banknotes. KBA-NotaSys introduced the *OptiNota*™*H* sheet foil application machine, a joint development with KURZ, for printworks in 1997, while KURZ and Giesecke+Devrient developed web application machines. These enabled paper mills to supply sheeted paper with both threads and holograms, so that printers without their own DOVID application machine could produce banknotes incorporating holograms.

Another key development at that time was selective demetallisation, a highly sophisticated technique developed by KURZ in the mid-1990s which provided a quantum leap in hologram security (only a few companies have the requisite technology). Improved demetallisation techniques also, critically, facilitated the integration of the feature within the overall banknote design, thus making diffractive foil features more acceptable on aesthetic grounds to a traditionally conservative industry.

A €20 euro from the first euro series incorporating a demetallised DOVID stripe, and the €100 with a demetallised patch.

By 2000, DOVIDs – in the form of patches, threads and stripes – were being used on 49 circulating denominations from 27 issuing authorities.

Enter the Euro

Undoubtedly, the most significant driver in the widespread adoption of DOVIDs on banknotes was the first euro series, launched in 2002 and widely recognised as the successful culmination of a very thoroughly researched banknote, from concept to design, followed by a well-planned and executed production and distribution project.

The obvious presence and quality of DOVIDs on the euro proved that the technology had truly arrived. Every denomination included a DOVID, with stripes on the three lower denominations (€5, €10 and 20) and patches on the four higher denominations (€50, €100, €200 and €500). More than 13 billion notes were issued that year, by far the largest use for DOVIDs to date.

The choice of DOVIDS for the new series, their sophistication and their successful application to the banknotes at high speeds was a tremendous vote of confidence in the technology which encouraged other central banks to follow suit.

The DOVIDs used on the euro are much more complex than the Captain Cook feature from 1988. In addition to rainbow colours, these KINEGRAMS on the lower denominations and *Alphagrams*™ on the higher denominations, mastered by OVD Kinegram and Hologram Industries (now SURYS) respectively, contained dynamic imagery channelled to show different graphic designs at different angles.

Registered demetallised stripes on the entire banknote series issued by Turkey in 2008.

Such complexity presents challenges in describing and explaining the DOVIDs to specialist examiners and the general public. The European Central Bank (ECB) communicated the salient visual features through an extensive public education campaign using the strapline 'Look, Feel, Tilt', contributing to their success as a secure public feature, and the increasing complexity of imagery to provide high-security has continued unabated.

New STRAP Features

Up until this point, DOVIDs were being applied as patches or stripes, or integrated as threads. In 2003, a fourth type was introduced in the new note series issued by the Banque Centrale des États de l'Afrique de l'Ouest (BCEAO) – the central bank for the West African Monetary Union – namely a new diffractive version of Banque de France's *STRAP*® technology.

STRAP (Système de Transfert Réfléchissant Anti-Photocopie) is a discontinuous wide surface-applied reflective foil that was first applied to the French franc in 1993 and originally featured reflective metallised elements that turned black in colour copiers. The version used on the BCEAO banknotes incorporated holographic elements that changed their image and colour according to the viewing angle.

The BCEAO's 10,000 banknote incorporating STRAP supplied by KURZ.

Another milestone was reached in 2003, when research showed that DOVIDs were now being used on 105 circulating denominations from 47 issuing authorities.

Windows in Paper

The world's first paper banknote with an OVD aperture was introduced by Bulgaria, which issued a commemorative 20 leva banknote in 2004 with an innovative optically complex feature called *Varifeye*®, developed by Louisenthal.

The Bulgarian commemorative 20 leva banknote – the first paper banknote with an OVD aperture, or window.

This Varifeye feature involved the creation of a hole in the paper substrate. The hole was not cut out (as subsequent windows in banknotes were) but created during the process of cylinder-mould web paper formation, and a security stripe of film laminated over the aperture, running from top to bottom of the note.

The part of the film over the aperture contained a colour shift pattern using liquid crystal technology that provided different effects according to whether the note was viewed in reflected or transmitted light – switching from diagonal stripes to numerals. The stripe also included a diffractive feature, although not over the aperture.

The significance of this development was threefold.

First, it marked the advent of windows in paper banknotes, something that had previously been confined to polymer (more of which later).

Second, it was an early example of stripes combining different technologies – diffractive and others – which has subsequently become the norm for stripes on banknotes.

And third, the stripe was applied not as a continuous feature, but in register – again, something that has become the norm for stripes on banknotes.

Although diffractive foil features are viewed by reflection, they are actually transmission images rendered suitable for viewing on an opaque background (paper or printed polymer) by means of a reflective metallic coating, in this case aluminium. Without the metallic layer, the surface relief image is transparent and capable of showing its rainbow coloured imagery if held up to the light which is allowed to pass through it. It was only a matter of time, therefore, before their use in combination with windows in paper notes would catch on.

In 2005 China, which is the world's largest issuer of banknotes, modified its 1999 series with the inclusion of holographic threads.

Zero Tolerance Demetallisation

In 2006, KURZ (owners of OVD Kinegram since 1999), marked the 21st anniversary of the KINEGRAM with the introduction of the KINEGRAM *ZERO. ZERO®*, based on a new demetallisation process. The name was chosen to capture the key zero tolerance characteristic of the new process, meaning that the demetallisation is perfectly registered to the diffractive KINEGRAM image – a zero tolerance – compared to the typical tolerance of ±0.5 mm of alternative demetallisation processes.

KINEGRAM zero.zero in first order diffraction (left) and in transmission (right), showing the registration of the demetallised diffractive foil and transparent OVD window.

One of the main advantages of ZERO. ZERO is the clear delineation between the metallised and transparent areas of the KINEGRAM, enabling both its designers and the banknote's graphic designers to achieve a high level of integration between the two elements.

The first application for the KINEGRAM ZERO.ZERO was in the Central Bank of Turkey's new series introduced in 2008.

That same year, KURZ unveiled *KINEGRAM RECOLOR®*, a feature designed for transparent windows in banknotes which displays different images depending on the side of the note from which it is observed. On the front the viewer sees a usual metallised reflective, diffractive image, while the reverse view shows a patterned coloured foil also displaying the diffractive features. The feature uses selective demetallisation to highlight different parts of the images.

This feature subsequently led to the development of *KINEGRAM COLORS®* , which was used on the Bank of England £5 and £10 polymer banknotes in 2016 and 2017 respectively.

Windows Application

In 2007, KBA-NotaSys introduced *Opti-Windows®*, a module for its Opti-Nota H foil application system that enables printers to cut a window in a banknote and then apply a demetallised holographic stripe directly over this window in one pass and in perfect register at speeds of up to 10,000 sheets per hour.

Depth, Volume and Magic

2009 saw numerous developments in DOVID technology.

De La Rue, in a response to the development of *Motion®*, the micro-optical non-diffractive system developed in the US by Nanoventions and acquired by Crane, launched its *Depth Image™* hologram, which was adopted by the Clydesdale Bank that year. The feature is claimed to have visible depth, three-dimensionality, strong colour switching and contrast. The Clydesdale notes used patch holograms with a holographic depth of 8 mm.

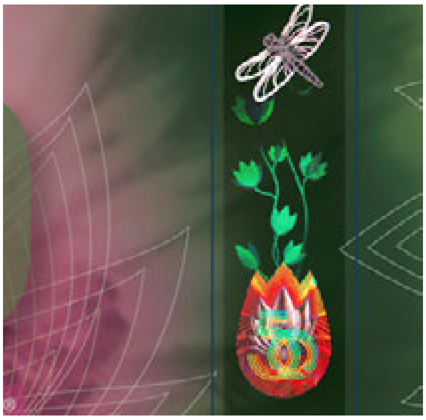
Depth Image was also later adapted for windowed threads and integrated into the Kazakhstan 5,000 Tenge denomination in 2011.

Also in 2009 was the development of volume holograms using photopolymer materials by KURZ for its modular banknote concept. The product was called *KINEGRAM VOLUME®* and it was originally developed as a thin laminate film prior to its subsequent development as a hot stamping foil.

This product was developed in response to a request from the Swiss National Bank (SNB) to develop a revolutionary security feature that went beyond what was being used for the euro.

Clydesdale £10 pound banknote incorporating De La Rue's Depth holographic patch.

HUECK FOLIEN's SIGNET foil applied in register to Cambodia's latest riel banknotes.



KINEGRAM VOLUME combined with KINEGRAM ZERO.ZERO from 2009.

The SNB requirements, which reveal the level of the challenge that KURZ accepted, were summarised as a volume hologram which was compatible with other foil technologies and other banknote features (eg. intaglio print); which was thin enough to use on banknotes; which could be applied using existing banknote production equipment; was durable, available in various colours and at a reasonable price.

This was a significant technical challenge, since to make the material thin enough to be useable on a banknote required a new approach to volume holography, given that the reason this is called a 'volume' hologram is that the interference fringes are recorded *within the depth* of the photosensitive material.

As KURZ noted at the time, there was no suitable holographic photopolymer available and no volume hologram production facility able to produce the numbers required for banknotes (hundreds of millions or more). It took three years for the company to develop an acceptable product.

However it took another five years for the first volume hologram to be used on a banknote and a further two years for the combined volume and demetallised stripe to appear on a circulating banknote.

In 2010, similar developments took place in Japan, with Dai Nippon Printing (DNP) introducing the first volume hologram windowed thread, although this was used on vouchers rather than banknotes. DNP also unveiled *SECUREIMAGE*™, a full colour volume (Lippmann) hologram stripe for banknotes.

Also in 2009, Louisenthal announced a further development of its Varifeye window product with the incorporation of a micro-optic see-through feature called *Magic*™, combined in a foil stripe with a diffractive feature. This product featured a year later in the Kazakhstan 1,000 tenge note commemorating Kazakhstan's presidency of the Organisation for Security and Cooperation in Europe (see page 33).

Registered Stripes and Improved Demetallisation

During this time technical advances in foil application machines also saw the introduction of registered diffractive foil stripes. This capability enabled the design within the foil stripes to be placed in exactly the same position on all banknotes in a denomination.

One of the first to adopt this was Turkey where their entire series incorporated registered demetallised stripes. This, as above, was the first commercial use of KINEGRAM ZERO.ZERO.

Another pioneer in this area was the Austrian foil and thread manufacturer HUECK FOLIEN, which offers a range of products based on diffractive, colourshift and nano-structured techniques.

DID patch on the Philippines 500 piso banknote. Top image: horizontal view of the banknote. Bottom image: banknote rotated 90°.

Diffractive Identification Devices

2010 saw the introduction of a *DID*® patch on the Philippines 1000 and 500 piso circulating banknotes. DID (Diffractive Identification Device) was produced by SURYS and is what is known as a zero order device (ZOD). ZOD devices have micro-structure relief profiles less than the wavelength of visible light and exhibit a clear colour switch when rotated through 90°.

The Canadian $20, 50 and 100 polymer banknotes incorporating a diffractive foil demetallised stripe.

The Return of DOVIDs in Polymer

Also in 2010, CCL Secure launched a diffractive feature called *Latitude*™, that required no separate hot stamping application of foil. Instead, the diffractive DOVID feature is incorporated into the polymer substrate during the manufacturing process and a layer of silver ink applied to provide the reflective layer. The diffractive design is not restricted to patch or stripe formats.

The first circulating banknote to feature Latitude was Nicaragua's 200 córdobas polymer note in 2015 (see page 36).

Latitude feature on the Nicaraguan 200 Córdobas polymer banknote.

And it brought the incorporation of DOVIDs into polymer full circle, the feature having been dropped after its first use on the commemorative A$10 back in 1988.

It was also the forerunner to a number of new series that were issued over the next five years on polymer, all incorporating DOVIDs, starting with Canada's new Frontier series in 2011. All the notes feature an almost full-length window with a demetallised diffractive foil feature (it was intended that the window should be full length but this proved to be too difficult for the existing registration systems in production).

Ironically, while it was the Catpix foil that was one of the catalysts for the development of polymer in the first place, the major marketing thrust for polymer notes following their launch in Australia had been their greater durability over conventional cotton-based banknotes.

But following a strategic policy change by CCL Secure to use security features from industry suppliers on their substrate, the potential to use polymer with highly secure features for high denomination banknotes became apparent.

Europa series €20 banknote incorporating KINEGRAM REVIEW portrait window technology.

In fact, the Bank of Canada indicated this as the main deciding factor to use polymer in preference to a cotton substrate.

Also worthy of mention in 2011 is both the Russian and Belorussian upgrades to their 5,000 and 200,000 ruble notes. Both upgraded notes incorporated a new thread feature called *Mobile* that utilises Fresnel lenses and the phenomenon of refraction (bending of waves, in this case light waves) rather than diffraction.

Mobile was developed by Computer Holography Centre and Krypten for the Russian printer and papermaker Goznak. Conveniently, the production processes for this feature exploit existing holographic technologies and equipment for mass reproduction.

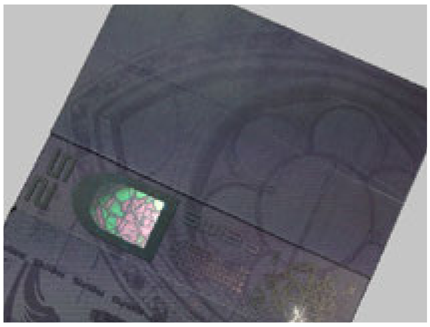
By 2012, the number of circulation denominations featuring DOVIDs had grown to 247 from 83 issuing authorities.

The New Europa Series

Around 2009, it became generally known that the second euro series (dubbed the Europa series) would retain DOVIDs but in an enhanced, more integrated form that was not possible for the first series due to the large number of suppliers and some printing works having machinery limitations.

After several delays, the new series begin rolling out with the new €5 in 2013, featuring a diffractive stripe as before but this time in register. The €10 followed, and then – in another breakthrough for the industry – the new €20 was issued in 2015 containing what the European Central Bank termed a 'portrait window'. This is a see-through diffractive feature that has different visible effects when viewed from the front, reverse and in transmission, as does the more recent new €50. Both notes use a *KINEGRAM REVIEW*® stripe developed by KURZ.

World's First Plasmogram



SURYS' Plasmogram window feature on a demonstration banknote.

Also in 2013, SURYS unveiled the *Plasmogram*™ as an optically variable device for use in the windows of secured documents such as banknotes and ID cards. What distinguishes this device is that it uses surface plasmons to create the image, making SURYS the first company to launch a commercial product which exploited this phenomenon.

The Plasmogram is intrinsically a device viewed in transmission because surface plasmons work in transmission mode. Hence its suitability for use in the windows of banknotes.

The underlying scientific principle of Plasmograms is, oddly, that which gives the colours in stained glass, as used for at least 800 years. Stained glass contains small metallic particles incorporated into the glass before it sets; the surface plasmon resonance (the quantum-level phenomenon of light waves travelling through metal at its surface) at the interface between these metal particles and the glass 'filters' the transmitted light so that only one wavelength is released.

In stained glass different colours are obtained by using different metals, different glass (thus changing the refractive index at the interface of the two) and different sized particles.

The same principle applies to plasmonic optically variable devices. Nano-sized metal particles are deposited onto a thin film substrate comprising nano-holes, so that the film becomes a light filter, allowing only the required wavelength through. By depositing different metals, each allowing through a different colour, images in light can be created.

Another development in 2013 was the launch by De La Rue of *Safeguard*®, its own polymer substrate. The significance of this was that there was now for the first time an alternative supplier for polymer, which has helped develop this market further, particularly as De La Rue is also a DOVID producer.

First volume stripe on a circulating banknote

The following year saw the world's first volume holographic stripe issued on a circulating banknote with the introduction of the 50 shekel by the Bank of Israel. This note featured the KINEGRAM VOLUME described earlier. This would be the first of the four newly-designed Israeli denominations to use the feature that produces fundamentally different visual effects than embossed holograms. The 200 shekel was introduced in 2015 and the 20 and 100 denominations in 2017.

The Bank of Israel 50 shekel banknote introduced in 2014 incorporating the world's first volume holographic stripe, and the 100 Shekel banknote, introduced in 2017.

The new 200 shekel displaying the KINEGRAM VOLUME stripe.

The New Zealand $5 banknote introduced in 2015 with a demetallised diffractive foil window patch.

In 2015, the Reserve Bank of New Zealand began to upgrade its polymer notes with a new series called the 'Brighter Money' series that – like the new Canadian Frontier series – incorporated demetallised DOVID window patches. (see page 35).

Enter 2016 with a Suite of Innovations

In 2016 SURYS introduced two new features – *DID Wave*™ and *DID Virtual*™ – on the new commemorative 20 zloty note, produced by Polish Security Printing Works (PWPW) (see page 36).

DID Wave incorporates colour permutation and animation motion effects, whilst DID Virtual incorporates colour permutation and surface relief 3D embossing effects. SURYS developed these features by incorporating the zero order DID technology with fresnel-type lenses.

In another first, the Swiss National Bank (SNB) launched its new banknote series (the ninth) with the issue of the new 50 Swiss franc note that incorporated a two colour KINEGRAM VOLUME foil stripe combined with a partially metallised KINEGRAM provided by KURZ.

To date, CHF 10, 20 and 50 notes have now been issued. The remaining notes in the series will also include this feature.

In the same year, KURZ unveiled another innovation – KINEGRAM COLORS, which was a development of its KINEGRAM RECOLOR technology and was a departure from conventional DOVIDS. These are normally available in one colour (mostly silver, sometimes gold). KURZ' development allowed for the incorporation of multiple colours in the foil in perfect register to the partial metallisation, and it received its debut that same year when, in September 2016, the Bank of England issued its new £5 polymer banknote with a KINEGRAM COLORS foil stripe. (see page 37).

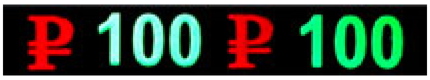
The front of the Bank of England's new £5 note, incorporating showing a KINEGRAM COLORS stripe in the window area.

The CHF 10, 20 and 50 banknotes printed on Landqart's Durasafe substrate and featuring the two colour KINEGRAM Volume stripe incorporating a partially metallised KINEGRAM. They also feature a diffractive thread within one of the windows from HUECK FOLIEN.

The polymer £10 followed in 2017 which also features KINEGRAM COLORS.

Virtually simultaneously in September 2016, on the other side of the world, the Reserve Bank of Australia launched its new polymer series, starting with the A$5 banknote, followed a year later by the new A$10, which feature a wide top-to-bottom stripe containing a DOVID.

Not to be outdone, the Russian company Krypten unveiled a suite of new thread innovations in 2016 that included two volume holographic threads: *3D-Gram-M*, available in green and red, and *3D-Gram-C* (C standing for colour), where the colours have been increased from two to three – green, red and blue.



An example of Krypten's 3D-Gram-C thread that can incorporate three colours.

More Innovation and Endorsements in 2017

Having enjoyed success with its *RollingStar®* micro-mirror technology incorporated into banknote threads, Louisenthal evolved its technology into an eye-catching transfer foil called *RollingStar® LEAD*.

The transfer foil combines holographic, micro-mirrors and colour shift technologies into a single product and it made its debut in the Armenian 500 dram commemorative note in 2017. (see page 38).

Louisenthal has long been an innovator of secure windows in paper banknotes and, even more recently, launched an enhanced feature called *varifeye® ColourChange*, which works in combination with the properties of the RollingStar LEAD transfer foil for translucent and transparent windows and also on its own as a patch.

Louisenthal's RollingStar LEAD feature incorporating Varifeye ColourChange and diffractive effects.

Australia's next generation banknote series featuring a clear DOVID stripe, which started in 2016 with the $5.

In another world first, in 2017, the National Bank of Kyrgyzstan issued a new 2,000 som commemorative paper banknote featuring KINEGRAM COLORS from KURZ applied for the first time as a patch. It comprised three distinct metal colours – gold, green and blue – taking the form of a traditional Kyrgyz yurt. In this instance, the distinction is in the variety of colours and not the combination of the feature with a window.

That same year, De La Rue introduced *TrueImage™*, a DOVID feature for polymer banknotes based on advanced plane (classical) holography that was a development of its Depth Image technology. The result is 3D photorealistic imagery with cinematographic animation effects which is ideal for polymer since the smooth surface does not disrupt the replay of the image sequence.

Resurgence of Patches

In another major endorsement of the use of DOVIDs, in 2017 the Reserve Bank of India sent out a Global Pre-Qualification Bid Notice (PQBN) for the supply of up to 8 billion foil patches per year. As the largest banknote issuer after China, this will increase the volumes of DOVIDs produced for banknotes each year exponentially.

As noted in the introduction of this report, as of the end of 2017, the number of banknotes with DOVIDs stood at 293. The DOVID has come a long way since its earliest application in the window of the A$10 and as a patch on the Austrian 500 schilling. From a simple patch format added, some would say, as an 'afterthought', the DOVID is now a fully-integrated security feature, applied in register with complex effects, more often than not combined with complementary optical features, and producing a whole new range of effects due to its combination in windows in paper as well as polymer banknotes.

The preponderance of threads versus patches versus stripes has changed over the years, with the use of diffractive threads declining markedly, and stripes overtaking patches. A clear trend in recent years, and one of the drivers for the ascendancy of the stripe, has been the combination of the window with DOVIDs.

In the case of paper, this has – until now – been confined to stripes. But in 2018, KURZ launched *KINEGRAM APL®*, which enables printers to create windows with DOVID features applied as patches.

With this latest development, patches are likely to make a resurgence. But whether as a stripe or a patch (or even, in some cases, still a thread), the opportunities for DOVIDs in banknotes going forward are stronger than ever.

The Kyrgyzstan 2,000 som commemorative note featuring KINEGRAM COLORS patch.

Examples of KINEGRAM APL, KURZ' latest innovation that enables the use of DOVID patches in conjunction with windows.

A TrueImage DOVID stripe from De La Rue.

The Evolution of DOVIDs on Banknotes – Timeline

1988

First use of DOVIDs on banknotes (Australian $10 and Austrian 500 schilling)

1992

First use of diffractive thread (Finland)

1993

Foundation of the IHMA

1994

First use of diffractive stripes (Bulgaria)

1997

Launch of OptiNota H

2000

DOVIDS in use on 49 circulating denominations

2002

Introduction of the euro, with DOVIDs on all seven denominations

2003

- Introduction of diffractive STRAP feature
- DOVIDS in use on 105 circulating denominations

2004

First paper banknotes with a window (Bulgaria)

2005

China modifies banknotes to include diffractive threads

2006

Kurz introduces KINEGRAM zero.zero

2007

KBA NotaSys launches OptiWindows

2009

- De La Rue introduces Depth Image
- KURZ unveils KINEGRAM Volume
- Louisenthal introduces Varifeye Magic

2010

- Dai Nippon unveils Lippman volume hologram for banknotes
- DID features debut on Philippines piso
- CCL Secure launches Latitude

2011

- Bank of Canada begins issue of all-polymer Frontier
- Russia and Belarus upgrade notes with Mobile threads

2012

DOVIDs in use on 247 circulating denominations

2013

- Launch of the first note in the second euro series, with a registered DOVID stripe
- SURYS unveils the Plasmogram
- De La Rue enters the polymer substrate market with Safeguard

2014

New Israeli shekels become the first notes to feature volume holograms

2015

- New Zealand introduces new polymer series with hologram windows
- The €50 is launched with a 'portrait window'

2016

- SURYS introduces DID Wave and DID Virtual
- Swiss National Bank begins roll-out of new series, with volume hologram
- New Bank of England £5 features KINEGRAM Colors
- Australia rolls out new series with a top-to-bottom window with DOVID
- Krypten unveils two volume holographic threads

2017

- De La Rue introduces TrueImage for polymer
- India specifies up to 8 billion DOVIDs for future banknote series
- DOVIDs now in use on 293 denominations

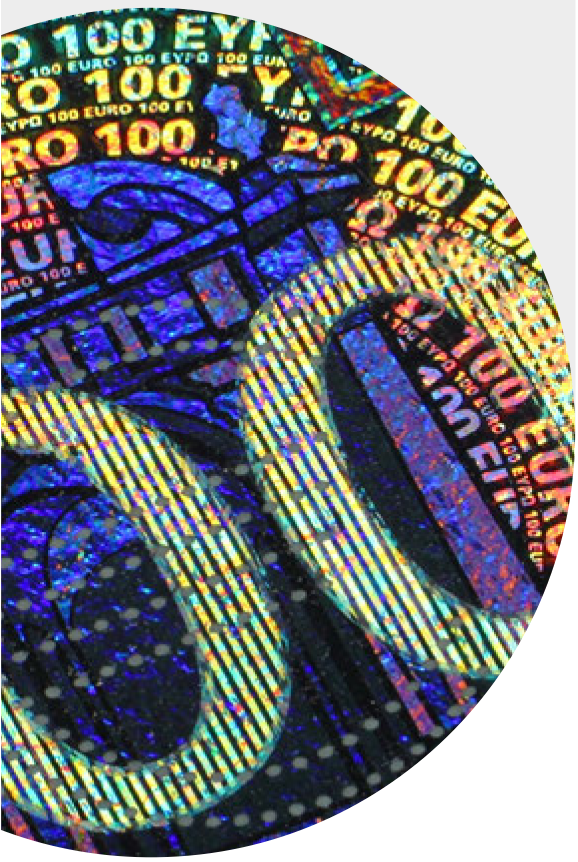
2018

- KURZ launches KINEGRAM APL for window patches
- Louisenthal launches Varifyeye ColourChange Patch

3

The Benefits of DOVIDs

Why have diffractive optically variable image devices (DOVIDs) become so prevalent on banknotes? The answer is simple: they add extra protection against fraudsters, and especially against digital photocopying, scanning and reproduction. They are also a feature that is highly recognised by the public.



The key characteristics of DOVIDs in terms of their ongoing success can be summarised as follows.

1. They are very difficult to counterfeit accurately, certainly at a quality that will pass inspection by an expert, and are also extremely difficult to simulate. Neither can they be copied, scanned or otherwise reproduced using digital printing equipment (at least with any of the diffractive or kinetic features that are so distinctive to DOVIDs).
2. Although primarily viewed as level 1 security features, DOVIDs on banknotes are unique in being able to provide multiple levels of security at any one time and can incorporate all levels of security required within a banknote in one feature.

   As such, they serve as a first-test security feature, revealing whether the note is suspect and should therefore be subject to more detailed examination. Further examination, moreover, is readily possible by specialists equipped with low-cost handheld tools.
3. DOVIDS cannot be easily removed from or replaced on a banknote. Also, the manufacturing and application process is now well-established, with the result that they are durable and last the life of the banknote.
4. While DOVIDs are stand alone features that work well on their own, nowadays they are increasingly integrated into, and form part of, the overall design and function of banknotes, creating a range of new creative opportunities for designers, and security opportunities for issuers.
5. They are obvious on the banknote – immediately attracting attention – and are easily recognisable by the public. Perception testing – the use of which is a growing trend in the banknote industry to inject some scientific rigour into the design of banknotes and features – has shown the DOVID is a highly recognised public security feature, second only to the watermark.

   For example, a study conducted by the Dutch National Bank (DNB) found that the watermark and the hologram received a much higher level of recall than other security features. The study also found that the public is able to retain the information provided by these two features for longer than for other security features.
6. DOVID manufacturers are self-policing and follow strict standards of conduct through their industry association (the only sector of security features suppliers to have an association). The International Hologram Manufacturers Association (IHMA), founded in 1993, has differentiated secure DOVIDs from other types of hologram used for packaging and brand protection.

   It has also set standards of practice regarding patents and copyright of DOVID images, and created and maintains the Hologram Image Register (HIR) for security DOVIDs, which is managed independently from the association, to prevent inadvertent copying of designs. Indeed, it has become normal in tenders for DOVID features for both IHMA membership and registration of the DOVID with the HIR to be qualifying criteria.
7. Although the membership of the IHMA suggests that there are a multitude of suppliers, in reality the equipment and knowledge required to create and manufacture DOVIDs to the level of image and material complexity required for banknotes remains available to only a very few organisations.

4

Origination Technologies

The process of creating DOVIDs for banknotes starts with design. DOVIDs can be made up of images captured from models, flat artwork, pictures and photographs, computer graphics, film footage, logos and text etc (a more detailed description of design and different examples is provided in Section 7).

The process of generating DOVID artwork is a complex and integrated process that typically utilises computer software tools.

Depending on the requirement and specification, DOVID computer-generated design artwork components are usually designed to appear in different layers such as for example, in the background or the foreground within the overall design.

In the case of the off-axis laser interferometry method (see later), the finished DOVID artwork is then separated into layers which are output from an image setter (high-resolution printer) onto a series of film transparencies for the origination process.

These films are then transferred to a series of glass artwork masks or plates. Each individual glass plate is then loaded into the off-axis laser interferometry mastering system and each individually recorded onto a recording plate (photosensitive film referred to as a *photoresist*) to create the multi-level master image.

In the case of using a real three-dimensional physical object to create the master image, for example from a model, then the above process of converting the artwork into film transparencies is not necessary. For other direct write origination techniques (see later) the DOVID artwork is directly written onto the photoresist to create the master image.

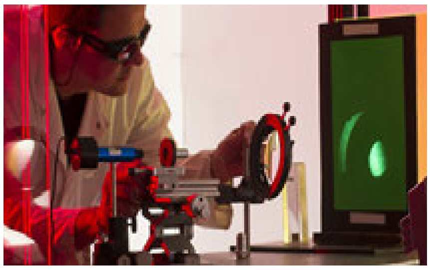
From Design to Origination

Origination is the process of converting artwork and creating the master image for the diffractive feature (or DOVID). This is the 'original' that can then be used in further processes for mass production and for use on banknotes.

Origination technologies play a crucial role in helping to protect banknotes because they are the stage that lays the foundation for most of the security features.

There are a number of techniques that can be used to originate diffractive foil features on banknotes. We will not attempt to cover all of these techniques in any great depth and detail, but instead aim to provide a brief overview of some of the main techniques that you are likely to encounter.

First, it is worth pointing out that most (but not all) of the diffractive foil features originated for today's banknotes can be described as *surface relief* (SR) structures that incorporate an embossed diffractive micro-structure.



Most SR structures are often referred to as rainbow holograms because all the colours that make up white light are observed – as in a rainbow.

However there are some exceptions such as the zero order *DID*™ (Diffractive Identification Device) feature produced by SURYS, the *KINEGRAM Volume*® feature produced by KURZ and the *SecureImage*® full colour Lippmann volume hologram produced by Dai Nippon Printing, none of which create rainbow image effects.

Origination Trends

Recent trends in origination have seen the continuing use of laser interference techniques, while alternatives such as electron beam lithography (e-beam) that have the ability to produce high-resolution features and other security effects too have also gained momentum. The result is the inclusion in the master and subsequent foils of numerous level 1 (overt), 2 (covert) and 3 (forensic) features.

And although not new, we have also seen the growth of combined origination methods and other technologies within banknote DOVIDs to improve security.

For example, in the latest Swiss series of banknotes, a volume holographic feature and a surface relief diffractive foil feature are combined into a single stripe.

More recently the Armenian 500 dram collectors' banknote incorporated a stripe feature produced by Louisenthal that combined diffractive optically variable effects with dynamic 3D effects, colour shifts and micro-mirror technology within a single foil.

We will now briefly discuss some of the main origination techniques used for banknote DOVIDs.

Off-Axis Laser Interferometry

This is the oldest and one of the most common techniques, and is sometimes referred to as off-axis laser 3D holography, the off-axis holography method or classical method.

The off-axis method is a technique where the laser beam is split into two beams: an *object* and a *reference* beam. The object beam illuminates the object/artwork and is scattered onto the photoresist.

The reference beam is directed onto the photoresist, from the same side but at a different angle (off-axis). The two beams meet and overlap at the photoresist, generating an interference pattern which, in essence, provides a three-dimensional holographic record of the object.

This recorded holographic image (or *H1* as it is sometimes referred to) can then be viewed in transmission by looking through it, with a laser beam or other monochromatic light source at the same wavelength as the recording laser, illuminating light from behind the master. (see Fig 1).

This off-axis technique was further enhanced to enable holograms to be viewed in ordinary white light in 1968 by Stephen Benton, a researcher at Polaroid. White-light transmission holograms are referred to as *rainbow holograms* because they split the white light (from a point-source behind the hologram) into its composite rainbow colours, so that when the viewer moves up and down relative to the hologram (or simply tilts it) they see the image in these rainbow colours. This work by Benton was another major milestone in the history of holography as it was the foundation that enabled mass production of holograms by embossing to emerge.

The off-axis white-light transmission holographic technique involves two recording steps:

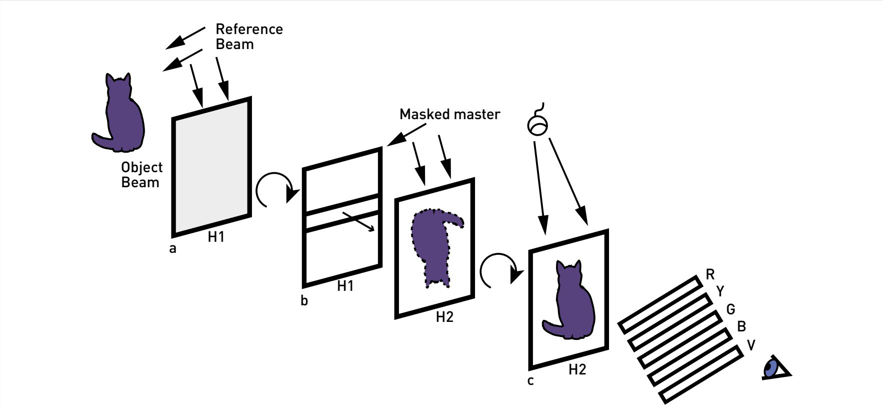


Fig 2: Schematic of H1, H2 ad white light view.

Step one – involves initially recording a master hologram, or H1, from an object using the conventional off-axis holographic technique, as described previously. The H1 plate is then masked to a horizontal narrow slit, like a letterbox.

Step two – is similar to step one and involves repositioning the now masked H1 recording plate as the object to project its interference pattern onto the plane of a photoresist plate known as the *H2*. By simultaneously allowing a second beam of light (the reference beam) to overlap with this image on the H2 plate a second interference pattern is generated which records a rainbow hologram of the projected image.

Another important milestone was Steve McGrew's introduction of 2D3D holography in 1982. Holograms made by the process described above are truly three-dimensional, in that the image has visible depth. The difficulty is that to reveal this image in focus requires a point source of light, such as the sun or a spotlight, but this is impractical for holograms which would be viewed in ambient light.

A 2D3D hologram has a very shallow image, barely any deeper than the surface plane of the hologram, which enables it to be seen in most ambient light (but not if it is very dull or dark).

This is achieved by the object for the hologram being a 2D graphic; by exposing more than one graphic on to a photoresist, or combining more than one 2D3D H1 on to the H2, striking multi-channel holograms can be originated, revealing a different image at a different viewing angle.

Initially a printed or hand-drawn picture, these days this graphic will be computer-designed and generated, allowing more complex finished holographic images. (see Fig 2).

There are alternatives to laser interferometry for the creation of the diffraction pattern that is at the heart of most DOVIDs. These largely involve different methods of directly writing the diffraction pattern into a master. This in turn means that any tool to write these lines must be very fine, so lasers and electron beams are the primary equipment used. Of course, the method of controlling these beams must also be highly sophisticated, to give minute adjustments of beam width, angle and intensity.

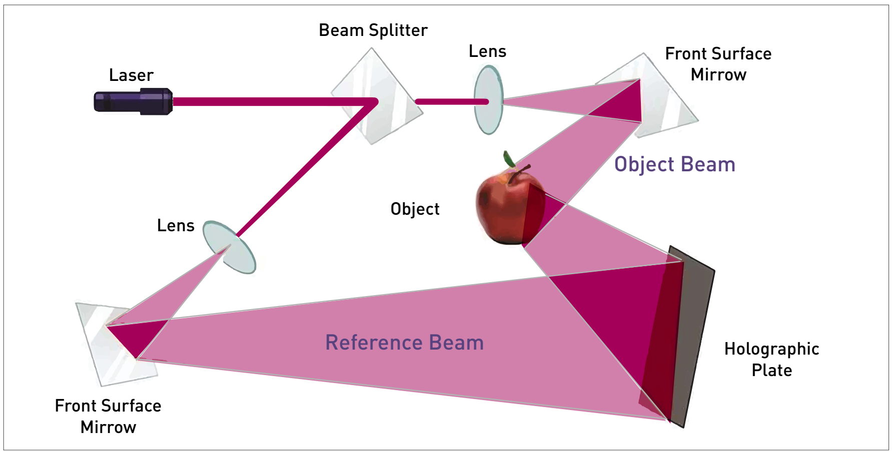


Fig 1: Schematic of off-axis laser interferometry.

Kinegram Technology

OVD Kinegram invented the KINEGRAM in the 1980s and subsequently trademarked the word, which derives from the Greek word 'kine', meaning movement.

The technique is maintained as a proprietary single site process. It is a high-resolution vector-based graphics system that writes the diffraction pattern into a photosensitive plate, in diffractive lines orientated in different directions.

Viewed with an electron microscope a KINEGRAM can be seen to comprise zones of diffractive surface relief lines (referred to as gratings). Each adjacent zone is configured with a slight incremental variation of the angular orientation of the relief structure. This produces the effect of the viewer's eyes being stimulated by different parts of the foil surface as it is moved, rotated or tilted.

Dot Matrix

The technique was introduced in 1988 by Toppan Printing and Frank Davis and was further pioneered by Applied Holographics (now Opsec) and Dimensional Arts (now DiArts).

The technique utilises computer-generated holographic images in which the image is comprised of an optically written array of diffractive microscopic dots or 'pixels'. Every dot is directly written onto the photoresist plate, by interfering laser beams to create an interference pattern in each dot. By controlling the angle between the laser beams, as well as the orientation of the beams and other variables, the interference pattern in each dot can be controlled to produce various colours and effects.

There are now several companies making and selling dot matrix origination systems, leading to a proliferation of the technology. On the basis of 'scarcity is security', and also due to the widespread use of dot matrix holograms in non-secure markets, this technology is not generally used for the origination of DOVIDs for banknotes.

Electron Beam Lithography (E-Beam)

Electron-beam lithography (e-beam) differs fundamentally from the previously described optical laser technologies because it uses an electron beam, rather than a laser beam.

E-beams can be accurately focused using electromagnetic lenses. No optical interference is used to record the diffractive structure and so the technique is therefore not restricted by the wavelength of the laser light. This enables e-beam originations to incorporate extremely small features within the origination.

The basic principle of e-beam lithography origination is fairly simple: the machine contains an electron beam source generated by a cathode (similar to those in vacuum tubes), a special electron photoresist plate and a highly-controlled x-y stage to enable precise, smooth, movement of the resist plate. The whole origination process is undertaken in a vacuum chamber where the e-beam writes onto the photoresist plate. This is sometimes referred to as a *direct write* process.

An example of the JEOL e-beam machine installed at Demax.

Historically the e-beam technique was used in the micro-electronics industry and is noted for its high resolution, typically 50-100 nm (0.05-0.1 microns), although higher resolutions are now achievable.

Modern e-beam lithography systems produced for example by JEOL can now achieve a line width resolution capability of 8-10 nm, allowing security features such as nano-text, micro-graphics and other features to be incorporated.

Electron-beam lithography systems are expensive (typically several million dollars, depending on the configuration) and very complex machines. The technology of the formation of surface relief diffractive structure is digital and relies on computers to generate or synthesise the micro-structure and is very knowledge-intensive.

Only a few companies have this equipment in-house. Others have established a relationship with a local university or research institute for the use of their e-beam equipment.

Electron-beam technology offers a wide range of features that are impossible to reproduce by means of optical hologram origination methods as the e-beam allows the shape/profile of the surface micro-relief to be controlled. The accurancy of micro-relief reproduction is of about 20 nm.

Volume Hologram Origination

Another DOVID feature that is now used on banknotes is volume holograms, also referred to as Lippmann holograms, Bragg holograms, volume reflection holograms or photopolymer holograms. All except the last are accurate descriptions of the optical characteristics of this type of hologram, while photopolymer is the material used to make banknote volume holograms.

Volume holograms use different origination and production processes to surface relief DOVIDs. The commercial development of volume holographic features for banknotes and other security documents is a considerable technical challenge that only a handful of companies have managed to achieve on an industrial scale. These companies include KURZ, Dai Nippon Printing, Krypten, SURYS and Du Pont Authentication (recently acquired by De La Rue).

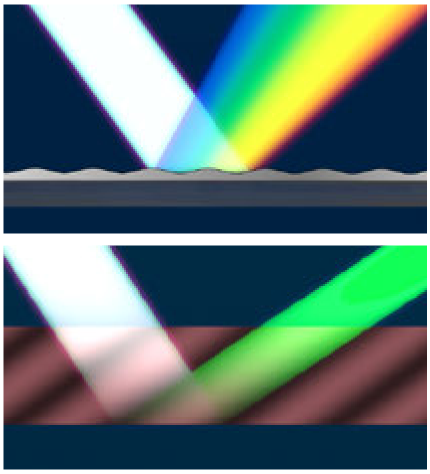


Fig 3: Examples of diffraction from a surface relief micro-structure showing rainbow colours (top) and a volume hologram diffractive feature showing a constant colour (bottom).

The volume hologram origination process uses the Denisyuk method (or a modification thereof), using lasers to record the holographic 'image' as interference planes, within a photosensitive material (in this case photopolymer), to a depth of tens of microns. The interference planes are parallel to the surface and result from a chemical and physical change within the photopolymer on exposure to the laser.

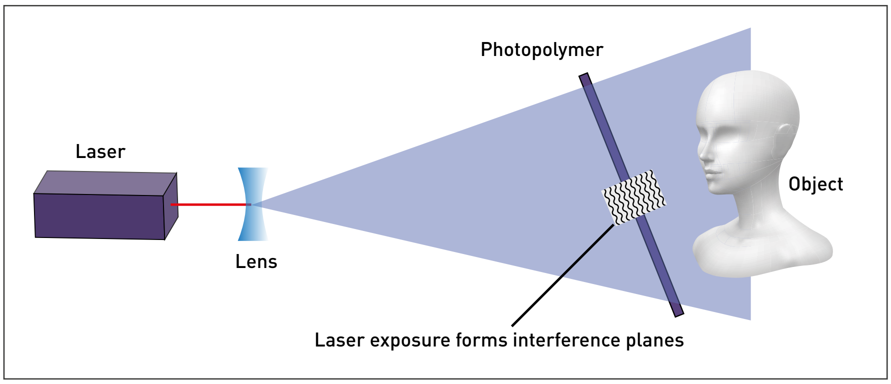


Fig 4: A simple schematic of the Denisyuk method.

The Denisyuk method, named after Russian physicist Yuri Denisyuk who invented the technique, uses a very simple set-up whereby the photosensitive recording material is placed in front of the object. The laser beam is expanded using a lens and is reflected from the object onto the photopolymer material from the reverse side (the object beam). Simultaneously, the reflected object beam meets the incoming laser beam (reference beam) at the photopolymer and the two beams create an interference pattern that is recorded within the photopolymer material.

Unlike rainbow holograms, volume holograms do not require any additional origination steps to enable them to be viewed using ordinary white light. When the hologram is illuminated using white light only, a single colour is seen as the photopolymer behaves, in effect, like a filter, reflecting only a selected wavelength of light by diffraction.

However, where more than one laser wavelength is used to record the hologram – for example red and green as observed in the diffractive foil feature on the latest Swiss series of banknotes – two colours (red and green) will be reflected and observed under ordinary white light.

Because the diffraction pattern is recorded through the depth of the photosensitive material it requires a relatively thick material – historically too thick to be used on a banknote (and also too expensive). The achievement of the companies now producing volume holograms for banknotes has been to develop a material thin enough for this purpose.

Volume holograms have also been expensive because each one requires a laser exposure to replicate the diffraction pattern from the production master. Again, the companies mentioned have managed to achieve mass production techniques that are both reliable and low-cost.

However, only KURZ has produced volume holograms on circulating banknotes, although other companies such as Dai Nippon Printing, Krypten, SURYS and Du Pont Authentication (recently acquired by De La Rue) also have volume hologram capability.

Other Origination Technologies

A number of other origination techniques also exist that although not widely used for DOVIDs on banknotes are worth mentioning.

Image Matrix

To the best of our knowledge, image matrix is not widely used to originate banknote DOVIDs, but the technology is more sophisticated than the dot matrix technique and has been successfully pioneered by Polish Holographic Systems with its *Kinemax* machine, New Light Industries and Geola.

Rather than using dots, the equipment writes computer-generated diffractive features composed of small rectangular pixels, (although pixels of any shape are possible), and other profiles and structures directly into the photoresist. The technique has recently been upgraded by Polish Holographic Systems with the addition of a second writing head enabling unique features and effects to be produced that were previously only obtainable using e-beam, at a faster speed.

Automated Origination

Swiss company DiARTS recently developed a proprietary origination technique and machine called the *Kinetic Light Machine* (KLM) that can be used to produce surface relief embossed diffractive foils. The technique does not use diffractive dots and directly writes 3D structures using a focused high-energy beam (not e-beam) into a proprietary photoresist plate.

The KLM technology is combined with an artificial intelligence robot called *ALICE* – which is the first automated robotic holographer that can write in 3D and has complete control over the origination process.

All variables are carefully controlled during the entire process, including temperature and humidity, whilst maintaining a clean room standard atmosphere throughout the entire process.

The operator loads an optically flat glass plate into the ALICE robot machine at one end and the robot will produce a finished originated master plate in a sealed and packed container without the need for any human intervention at the other end. A notification email can also be sent to the operator that the plate is ready for collection, if required.

Summary

For use on banknotes, it is important, no matter what origination technique(s) is/are selected, to ensure not only that the design is easy to understand, intuitive and durable for the general public, as the first line of defence, but also that the origination meets the following requirements:

1. It is bright, sharp and has a wide viewing angle;
2. It incorporates overt features that attract attention, are eye catching, and easy to authenticate;
3. It incorporates unique covert and forensic features;
4. It works in ‘dim’ lighting conditions;
5. It is aesthetically pleasing (although subjective) and is integrated into the banknote design with other features and is viewed as part of a security feature portfolio to authenticate and secure the banknote.

As previously mentioned, it is the origination stage that lays down the foundation of most of the DOVID’s security features. So it is vitally important that this process is optimised to help maximise the success of future processes.

DiARTS’ ALICE robotic origination system.

5

Manufacturing Processes

This section covers the production of surface relief foils. As already explained, volume holograms are fundamentally different. The generic process for their manufacture is covered at the end of this section.

To make foil DOVIDs suitable for use on banknotes following the origination process, which has recorded the diffraction pattern on a glass plate coated with photoresist, this fragile master has to be converted to a durable material suitable for use in mass production.

The photoresist is then developed to create the relief master, converting the photographic diffraction pattern to a micro-structure relief pattern from which a metal production master can be made.

From Photoresist to Shim

The initial process requires a thin layer of metal, usually silver, to be deposited onto the photoresist – now carrying a diffraction pattern as a micro-structure relief – to make it electrically conductive. This process can be undertaken by depositing silver either by spraying or vacuum deposition. This requires a skilled operator as the thickness and quality of the silver coating are crucial to the future process steps.

Growing shims in an electroforming tank.

To produce the first generation production master, sometimes referred to as the *mother shim*, the now electrically conductive silver-coated photoresist relief master is replicated in nickel by immersing it into an electroforming tank or bath where a layer of nickel is electrolytically deposited (grown) onto the photoresist to form the mother nickel shim to a desired thickness.

This process replicates the micro-relief structure in a reversed, or mirror image form.

Often, depending on the requirement, a step and repeat process is undertaken to replicate or gang up the diffractive image for mass production onto a 'plastic' carrier which is then made electrically conductive prior to electroforming. This is known as *recombining*.

The mother shim is then peeled off from the resist, destroying the micro-relief structure in the process.

This shim, which has a reversed image micro-structure (compared to the photoresist) is then placed back in the electroforming tank and another layer of nickel is deposited onto it.

This layer is then peeled off the mother shim and is referred to as the *daughter shim*, on which the micro-relief pattern is again mirror-imaged to revert it to the correct orientation.

The same process is used to produce *embossing* (or *casting*) manufacturing shims from the daughter shim. Many daughter shims can be made from a single mother shim, so by putting several daughter shims into electroforming tanks, several manufacturing shims can be produced at the same time.

Embossing

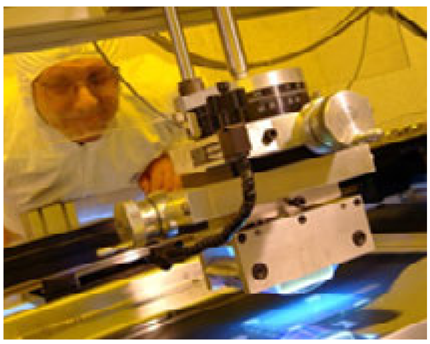
Embossing is the process whereby the diffractive surface relief micro-structure on the nickel shim(s) is transferred onto a relatively inexpensive thermoplastic film, often referred to as an embossing film.

For production, the shim or shims are mounted onto a rotary cylinder (the embossing cylinder) and pressed into a film or surface lacquer, using controlled heat and pressure and the use of a smooth compression or nip roller (backing roller).

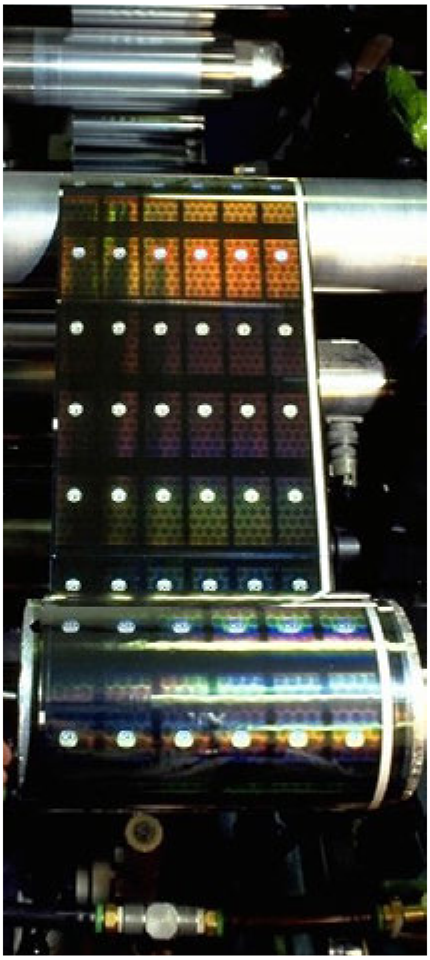
The relief pattern from the shim is pressed into the film or the surface lacquer. The film is then rapidly cooled or cured (see below) to harden and fix the pattern.

There are two types of embossing – hard and soft.

In hard embossing, the relief pattern is embossed into pre-metallised foil, requiring considerable heat and pressure, so it can be a relatively slow process. Hard embossing is a method used to produce diffractive foil features for credit cards.



Step and repeat (recombining) process.



A narrow web embosser.

Hard embossing was initially restricted to narrow web widths, typically 6-8 inches/15-20 cm, but up to 12 inches/30 cm wide. However, equipment embossing manufacturers including Diavy in Italy and Double R in the UK have introduced wide-web hard embossing with film widths of a metre or more. These are largely for the production of diffractive packaging film but can also be used for security DOVIDs.

Soft embossing involves the transfer of the relief pattern from the shim into a lacquer pre-coated on to the embossing film. Soft embossing uses comparatively lower pressure than hard embossing, which allows for the use of wide web materials (typically from 600 mm to 1.6 m wide). Several nickel shims can be used, mounted in register on the embossing cylinder. Or – because the process is gentler than hard embossing – a polymer blanket can be used. In this latter case the relief pattern is blazed into the material.

Soft embossing is generally used for the production of banknote DOVIDS.

More recently embossing equipment has been introduced that is capable of both hard or soft embossing, with appropriate adjustment of the key heat, pressure, dwell time and cooling settings.

UV Cast and Cure Embossing

There is also another method of manufacturing DOVIDs, which is referred to as UV *cast and cure* or simply UV *casting*. This uses a UV curable coating on a carrier film, which is exposed to UV light to fix the pattern from the shim either while in contact with the shim or immediately afterwards.

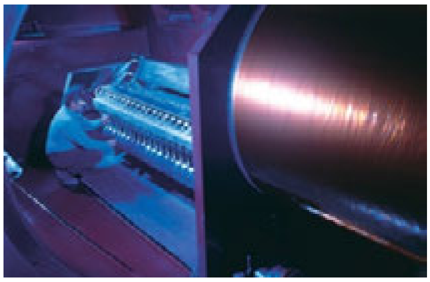
In this UV process, the UV-curable lacquer is in liquid form at the cylinder and flows completely into the diffractive micro-structure pattern of the shim, creating a near-perfect copy of the pattern on the shim.

This pattern is more durable than the previously described embossing methods, which are subject to distortion through heat and pressure. This is beneficial in the banknote production process as it is not degraded by the heat, either in the paper mill (drying process) or in its transfer to paper, which also uses heat and pressure.

Metallisation

These embossed or cast films now carry a DOVID which is viewable in transmission mode. This obviously is not suitable for DOVIDs which are placed on an opaque banknote substrate. The film is therefore metallised with a thin reflective layer, so that the DOVID can be seen in reflection mode. This layer is applied by vacuum deposition to a controlled thickness (in the nanometre range) onto the entire surface of the relief structure.

The most common metal used is aluminium, but copper or alloys are also used. It is also possible to use oxides, which are not reflective but instead return a narrow spectrum of light back to the viewer. These oxides allow the film to remain transparent at all except a narrow viewing angle, so they may be used on DOVIDs to be placed in banknote windows if the intention is to have a transmission-viewable DOVID.



Vacuum deposition metallisation.

Demetallisation

This is a highly sophisticated process which involves applying a coating of aluminium onto the embossed web at the metallisation stage and then selectively removing the aluminium.

A typical removal demetallisation process is the ‘resist and etch’ method, although there are other methods available. The resist and etch method involves printing a protective ink layer onto the aluminium, then dissolving away the unprotected aluminium (regions where there is no protective ink layer), usually with a caustic solution. The demetallised film is then dried.

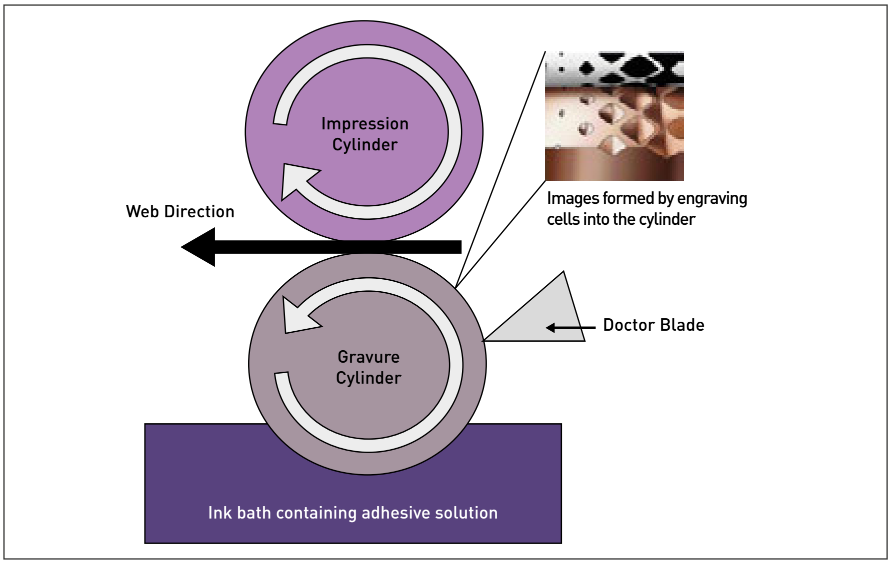
Over the last few years a number of companies have created highly sophisticated demetallisation processes that provide zero tolerance registration between the diffractive optically variable image and the demetallisation.

A combination hard/soft embossing system from Diavy.

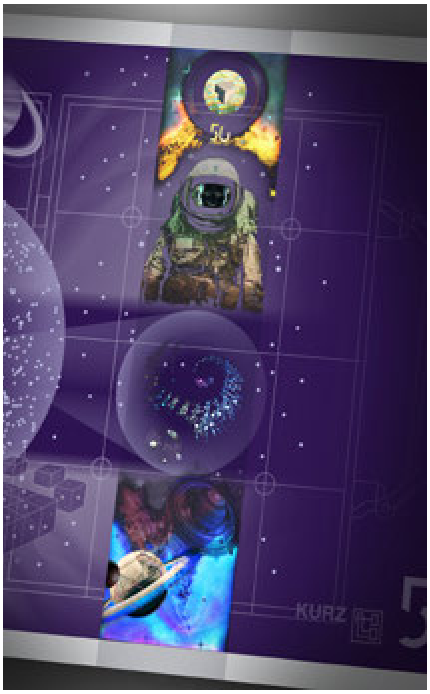
For example KURZ/OVD Kinegram has *zero.zero*®, Toppan has *Nano Edge* and Zhongchao Special Security Technology Co (ZSST – a division of China Banknote Printing and Minting), has *Nicety*™, which offers metallised lines down to 10 microns.

Other companies have also developed their own demetallisation processes, including Opsec Security's *Precision*™ and Fabriano's *Multilevel*™; SURYS, Louisenthal and De La Rue also have proprietary processes, as do other companies.

KURZ recently introduced *KINEGRAM HDM* (High-Definition Metallization), which delivers metallised lines down to 10 microns width to enable multitone greyscale images in the foil at almost photographic quality.



A schematic of the gravure process.



KURZ' new 'SPACE' demonstration note incorporating a KINEGRAM stripe demetallised using HDM technology.

Adhesive Coating

In order for the DOVID to be attached to the banknote, a durable adhesive coating is applied to the back of the film. In many instances more than one adhesive coating is applied and the gravure process is probably the most used technique to apply the coating(s).

The adhesive formulations are usually proprietary and are the result of extensive research and development and testing programmes. The combination of adhesive formulation(s) with the proprietary coatings on the film and the banknote application conditions all contribute to the viewability and durability of the final DOVID feature on the banknote.

Finishing

After adhesive coating, the rolls of diffractive foil features are normally inspected to remove defective material. Quality control inspection in fact is usually undertaken at each stage of the manufacturing process. Automated camera inspection equipment is often used for this, but it is also not unusual to have human inspection at critical stages (it is remarkable how effective the human visual perception system is at spotting variations in a moving film).

At this stage the material is then converted into the finished material for delivery to the papermaker or banknote printer. It will be rewound if required, then slit into its required finished banknote format such as stripes or patches. Stripes are normally wound onto bobbins, whereas patches are converted into reels.

If the format is a thread then further manufacturing processes, such as lamination and slitting, are then undertaken to convert the DOVID material into threads.

Volume Holograms

The replication of volume holograms requires a contact-copy process under laser illumination. This is because the mass-produced volume holograms replicate the diffraction pattern of the master in a photosensitive process *volume* (or thickness) of the material (as explained in the Origination section). This requires a laser of the same wavelength as that which was used to create the master – or wavelengths if the hologram has more than one colour.

In this process, the two holograms are brought into contact or very close proximity, in a way that ensures there is no dust or Newton's rings between them (Newton's rings are seen if two similar materials are pressed together with anything but a 100% uniform smoothness).

The manufacturing master will most likely be a single hologram or multi-up sheet, while the replication is on to a reel of photosensitive film (in the case of volume holograms for banknotes, a photopolymer film). Thus the transport mechanism is stepped, so that there is a period when the master and the copy are in static contact.

At this point the pair are exposed to the required laser or lasers. This may be a powerful laser with a spread beam which covers the holograms, but more likely the laser beam is kept to a minimum diameter, focused on the holograms and scanned line by line to copy the diffraction pattern from master to production copy.

Using photopolymer this is a dry process, requiring no chemical processing of the film. The polymer does require a black backing, however, to optimise the reflectivity of the material and thus the brightness and clarity of the image. So a thin black backing is either printed or laminated to the film, which is then slit to the required width for it to be applied to the banknotes.

The manufacturing process described here is a generic approach to mass-replicating volume holograms in a photopolymer material. It is possible that the few companies now making photopolymer volume or Lippmann holograms for banknotes have devised variations on this process, so this should not be taken as a categorical description of the way that banknote volume holograms are manufactured.

6

Application of DOVIDS on Banknotes

Following the manufacture of the diffractive surface relief foil, which is the most common form of DOVID feature, application onto the banknote substrate is the next step, normally undertaken by a process called hot foil stamping, sometimes referred to as hot stamping, foiling or foil application.

In principle, hot foil stamping is the process of using heat and pressure together with dwell time to permanently apply and transfer the metallic foil or DOVID foil feature assembly onto the selected banknote substrate.

However, before we move onto this topic we'll first take look at the structure of the foil.

Structure of Hot Stamping Foils for Banknotes

A diffractive hot stamping foil for banknotes principally consists of a carrier film (usually polyethylene terephthalate – PET), a release layer, a lacquer layer, an embossing lacquer layer carrying the diffractive image and a reflective layer (typically vacuum deposited aluminium), on top of which is an adhesive layer.

All of these layers have to be totally compatible with the application machine and the substrate for a perfect transfer of the diffractive multilayer foil assembly.

The release layer, which is ultra-thin and usually wax-based, is heat activated by the die (usually made of brass) on the application machine, allowing the other coatings and layers beneath it to separate from the PET carrier and adhere to the substrate by the adhesive layer, which is also heat activated. The PET carrier is removed during the process as waste.

Once on the banknote, working through from the top surface, the transferred diffractive image now comprises:

- Lacquer(s) that are uppermost on the banknote to protect the DOVID and improve its durability;
- The embossing (or UV) lacquer which retains the surface relief pattern of the diffractive image imparted from the nickel shim;
- The reflective metal layer (usually aluminium, but other metals or metal oxides might be used) which replays the light to give the image visibility;
- The adhesive layer, which is critical in forming a very strong bond with the substrate.

Unlike the foils commonly used in printing and packaging, diffractive foils for banknotes are highly specified and tuned. Special coatings ensure that stripes or patches can be applied faultlessly at high speeds on a variety of application machines, with strong adhesion to a variety of banknote substrates. The coatings must also provide resistance to abrasion and chemical attack and allow a clear and diffractive bright image to replay.

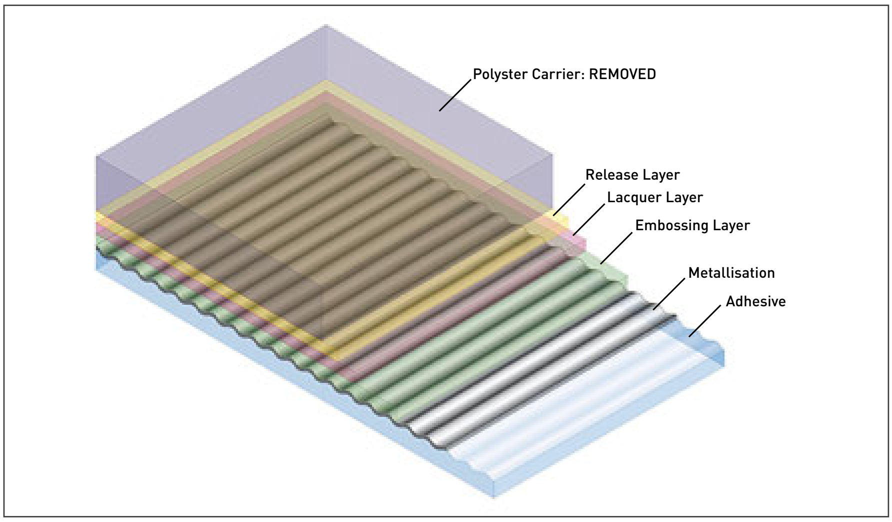
Invariably the foils have to be matched to both the application machine and the substrate to work perfectly. KURZ, which supplied most of the demetallised foil for the launch of the euro, claims to have supplied not one but 27 different foil formulations to meet the needs of the various printers, papers and application machines.

Substrate and Equipment Influence

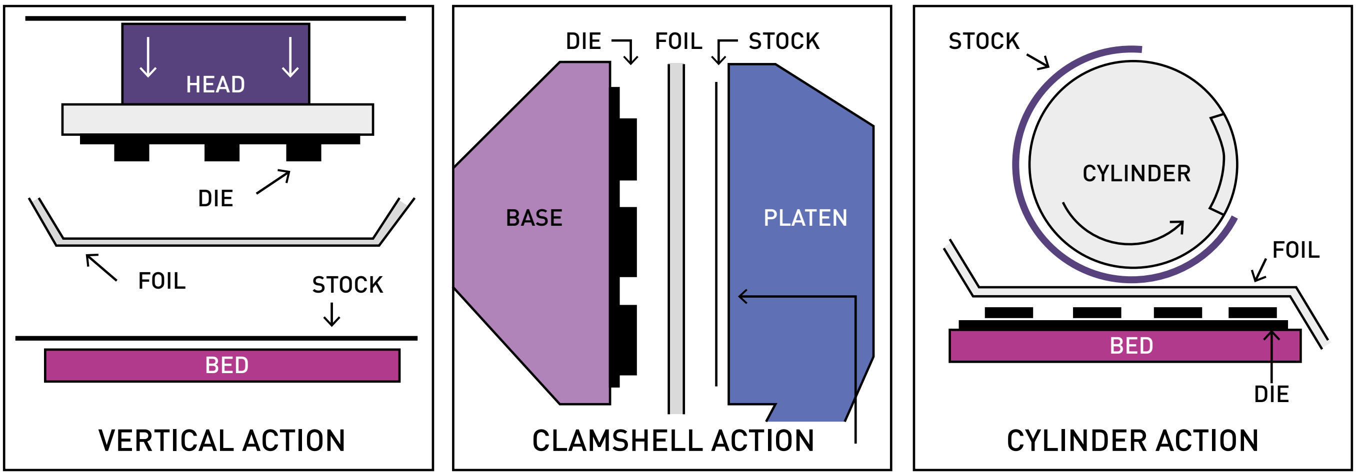
The banknote substrate manufacturer, substrate type and composition all have a major influence on the application success of the diffractive foil features, as can printing or coatings (for example to reduce soiling), and/or if the substrate has been printed and/or coated prior to foil application.

Often bespoke foil formulations and adhesive combinations are necessary as the 'one size fits all approach' does not work. For example, the adhesive system used on polymer banknotes is different from that used for paper substrates.

This process of development often requires application process optimisation and customer testing and approval.



A typical non-demetallised surface relief diffractive foil structure / hot stamping foil for a banknote.



Examples of different foil application mechanisms to apply diffractive foil features.

Patch or Stripe Application?

One choice is whether to apply a diffractive foil feature as a patch or a stripe. That decision rests on a number of factors – including the design itself (for example, whether the feature is being applied as an upgrade to an existing design – in which case a patch is probably more appropriate – or as part of a wholly new design), as well as the ability of the supplier to apply the foil.

A patch has to be applied to sheets,and can be stamped out in a number of different shapes (square, circular, elliptical, geometric etc), but a stripe can be applied reel-to-reel (web) at the end of the papermaking process or to sheets after the paper or polymer has been sheeted and sorted.

Waste is higher in reel-to-reel applications because perfectly applied foil can be rejected due to paper faults rather than foil defects. However, the foil design, price, flexibility, reliability and speed of the various application machines also have a major bearing on this choice.

The use of stripes also has the added benefit that they enable government or commercial printing works who do not have foil transfer machinery to buy sheeted banknote paper with pre-applied DOVIDs.

Development of Application Machinery

The foil application equipment originally available to banknote printers was initially confined to converted Heidelberg or Miller presses applying foil patches. These presses were slow and limited to small sheet sizes, but increasing demand led to manufacturers designing purpose-built machines for banknotes.

Initially the focus was on sheet-fed machinery for DOVID patch applications. For example, in 1988 application equipment supplied by Gietz was used to apply the first diffractive foil patch to the Austrian 5,000 schilling note and to the commemorative polymer Australian A$10 note. Later, Papierfabrik Louisenthal installed a reel-to-reel stripe applicator for the application of its holographic stripe feature.

This pioneering work and later improvements have led to DOVIDs now being applied in register at speeds as high as 500,000 per hour, matching the speed of the banknote printing process.

A number of companies supply industrial equipment to apply DOVIDs in volume onto banknotes. The main ones are BOBST, Diavy, Gietz, KBA-NotaSys, KURZ, Pasaban and Steuer. We will now take a look at the equipment provided by the some of these application equipment providers.

BOBST

Swiss print and packaging equipment company BOBST has developed a range of hot foil stamping equipment for application of diffractive foil features onto banknotes, including the *VISIONFOIL 104 H*.

This equipment has a maximum running speed of up to 7,500 sheets per hour, 12 individually-controlled heating zones and six foiling lines, allowing the application of small or relatively large diffractive foil features. Precision *Registron*® cameras are also used to ensure the diffractive foil feature is correctly placed onto every banknote.

Diavy

Diavy, based in Soliera in Northern Italy, is a producer of decorative films, security hologram products and surface relief production and application equipment.

For the application of holographic stripes onto banknotes, Diavy developed a multifunctional roll-to-roll MB machine series (*MB 26.8*). The machine is one of the foilers used for the production of the Europa series €20 banknotes.

Key advantages of the MB machine are that it can be tailored to individual customer requirements, achieves extremely low levels of waste, has a high degree of diffractive foil positional accuracy and has a speed of up to 150m/min.

The equipment can also generate windows in the banknote paper and apply foil stripes in register, all in one pass.

BOBST's Visionfoil 104H.

Gietz

Family-owned Gietz, based in Switzerland, is a leading provider of hot stamping machines, having pioneered and launched the world's first fully automatic hot foil stamping machine in 1957.

Since then, it has continued to supply, innovate and develop equipment for the application of both stripe and patch diffractive foil features for paper and polymer banknotes and for other documents and, as above, supplied the equipment for the application of the first DOVIDs on banknotes.

The latest application machine for the banknote industry is the *FSA 1060 Foil Commander NOTA* machine. This sheet-fed machine is designed to apply registered patch diffractive foil features and non-registered or sheet-registered stripes at speeds of up to 8,000 sheets per hour. The *SMART* register system compensates for inaccurate sheet cutting, in-feed errors as well as sheet distortion. It can run up to six foil feeds and comes with automated waste destruction. It is equipped with the patented *VACUFOIL* foil transportation system.

Other sheet-fed application equipment for banknotes includes the *FSA 870*, a more compact system for smaller sheets and five foil feeds.

In total Gietz has supplied more than 40 FSA Nota series machines exclusively for the banknote sector.

For the reel-to-reel application of diffractive foil stripes onto banknotes, Gietz has a range of machines including the *SECUR* series that has a maximum speed of 250m/min (depending on the specific machine).

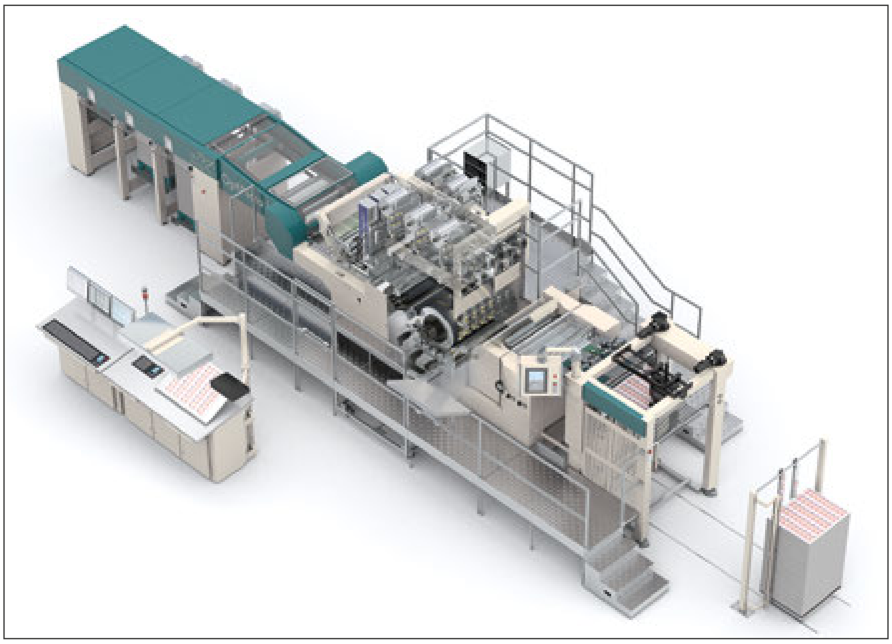
Gietz's FSA 1060 Foil Commander NOTA.

KBA -NotaSys

Swiss company KBA NotaSys introduced the rotary *OptiNota H* foil sheet-fed application equipment dedicated to the banknote industry in 1997.

The OptiNota H rotary press can apply both stripe and patch diffractive foil features at speeds of 8,000-10,000 sheets per hour to all banknote substrates (including polymer). This means that, for example with 50 banknotes to a sheet, it could apply the diffractive foil features at the rate of 500,000 banknotes per hour. The equipment is therefore most suited to printers with high volumes and long runs.

The OptiNota H is designed to waste minimum foil and paper. It operates using a non-stop rotary or cylinder process similar to a printing machine, and is able to achieve levels of speed and quality far in excess of commercial machines. And by achieving the same output as KBA-NotaSys' printing machines, it fits conveniently into the banknote line process.



The KBA-NotaSys OptiNota H rotary press.

An innovative feature of the OptiNota H is the stamping plate system, which puts an end to the use of stamping dies and complicated make-readies. A series of stamping plates are positioned across the entire cylinder, locked into place using a clamping system and then tensioned accordingly. In addition to reducing set-up time, it ensures a high degree of foil registration laterally and vertically across the sheet.

In 2007, KBA-NotaSys introduced a new module for the OptiNota H, which can be retrofitted to existing machines and is designed to produce banknotes with windows.

Opti-Windows™ is a one-pass technology enabling a window to be cut in the substrate followed by the application of a transparent or semi-transparent diffractive foil stripe over the window, in perfect register if required.

The module consists of a rotary die-cutting unit which cuts the windows in any shape required, the cut material being removed by vacuum. The sheet is then processed through the standard OptiNota H rotary foil application system where the diffractive foil stripe is applied and adhered to the substrate in register; there is no film carrier as in a hot stamping foil application.

Window size, shape and number can vary, and the diffractive foil stripes can range from simple transparent films to complex, high-precision versions.

An important feature of the module is its ability to achieve 'line-perfect registration' between the print, the window and the applied diffractive foil, resulting in tighter integration of the feature within the banknote's design.

KURZ

In addition to producing diffractive foils, KURZ also supplies hot stamping foil equipment to apply foil stripes on any paper-based substrate. For reel-to-reel systems, KURZ provides rotary foil application equipment – the *MHS* machine series – that normally operates at speeds up to 200 m/minute. KURZ pioneered the further technical advancement of reel-to-reel foil application for window features, and brought this technology to market in 2012 with the second euro series.

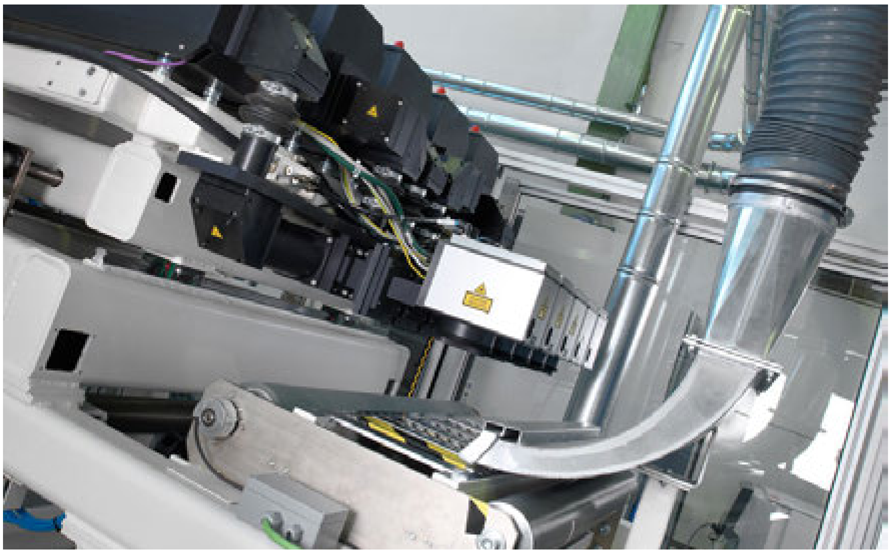
Using rotary punches or laser cutting, the MHS machines can generate windows in the banknote paper and apply foil stripes in register, all in one pass. Compared to laser solutions for creating banknote windows, the company states that mechanical punches have a more robust performance and can reach significantly higher real-life application speeds. In both varieties, the MHS equipment has been installed at many international banknote substrate producers.

Pasaban

Pasaban, based in Tolosa in Spain, was founded in 1928 and has a history of providing finishing equipment to the paper industry. In 2013 the company developed a laser punching system that allows virtually any window shape to be made on banknotes.

Pasaban was the first in the market to use a laser solution to create banknote windows. The system has several benefits, including reduced changeover downtimes, low maintenance costs together with high levels of repeatability and productivity compared to mechanical punching machines.

In 2014 Pasaban launched a reel-to-reel hot foil stamping machine for the application of stripes. The heat transfer stamping line works optimally with any qualified foil and any substrate, is capable of speeds of up to 200m/min and is available in various web widths.



Pasaban's laser punching equipment.

Steuer

Steuer, headquartered in Stuttgart, Germany, produced its first hot stamping machine in the mid-1980s. Then, in 1995, it launched a rotary hot foil stamping machine.

Steuer has a range of hot foil stamping machines that can be used to apply both diffractive foil stripes and patches. For example the *Foil-Jet FBR 104* (now upgraded to the *FBR 2020*) sheet-fed machine can apply diffractive foil features at a maximum speed of 12,000 sheets per hour.

More recently Steuer developed the sheet fed *RF106* and the reel-to-reel *Foil Web RR* series which has a maximum speed of 120m/min. The latter series is modular-based and utilises a new patented sleeve technology for the die and impression cylinder, thereby significantly reducing make-ready times. This system also incorporates infra-red heating.

Steuer's precision sleeve technology for the Foil Web RR series.

The KURZ rotary foiler MHS-840 for stripe application.

An example of the €20 stripe and laser punched laser portrait window.

7

The continuing confidence by central banks, printers and specifiers in DOVIDS as both as a security and as an aesthetic feature are a reflection of design and integration trends. This of course has been aided by the significant investment by DOVID producers in product development, enabling ever more creative iterations of DOVIDs to be created.

This section provides some examples of DOVID design. With a 30 year history of banknotes to cover, and over 300 denominations, it is hard to know where to start. We have focused, therefore, on recent examples only – attempting to provide a balance between substrates and formats.

We have also included a couple of commemorative notes since, although this report focuses only on circulating banknotes, many security features are 'tested' on commemorative notes first, and can be seen to their full advantage before making their way into circulating notes.

With a couple of exceptions, we have singled out DOVIDs not necessarily for the ingenuity of their diffractive features, but for their integration within the overall design. We have also selected a couple precisely because of their ingenuity.

There is also an element of personal preference – and the examples provided in this chapter are in no way an adverse reflection of all the other uses of DOVIDs that we simply do not have room for.

Design and Integration

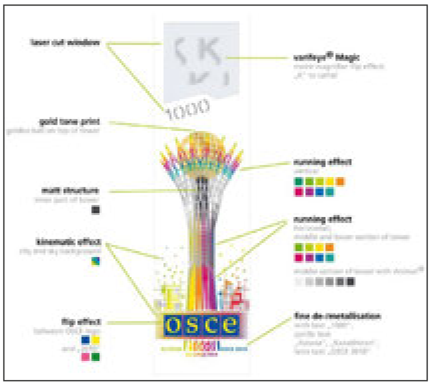
The design and incorporation of DOVIDs into banknotes as integrated, rather than standalone, features within the whole banknote design theme is a growing trend. Not only is this trend occurring for single banknote denominations but often for entire series of banknotes.

National Bank of Kazakhstan – 1,000 Tenge – 2010

In 2009, Louisenthal announced a further development of its *Varifeye*® window product with the incorporation of a micro-optic see-through feature called *Magic*™ combined within a diffractive foil stripe. This product featured on the Kazakhstan commemorative 1,000 tenge note in commemoration of Kazakhstan's Presidency, in 2010, of the OSCE (Organisation for Security and Cooperation in Europe).

The micro-optic lens image in the laser cut window interchanges between the image of a camel and the letter 'K' when tilted, whilst below this is incorporated a demetallised diffractive foil image of the Astana Baiterek monument and the text OSCE – which changes on tilting to 2010. The denomination is also incorporated at the base of the stripe.

The foil stripe design is fully integrated with the print features of the banknote, which incorporates iridescent ink exhibiting OSCE and the 1,000 denomination, a latent image, and a colour-shifting thread incorporating the text 2010 and OSCE.



Commemorative Kazakstan 1,000 tenge.

Russia – 5,000 and 2,000 Ruble – 2011 and 2017

In 2011 Russia upgraded its 5,000 ruble note to incorporate a thread feature developed by the Computer Holography Centre and Krypten for Goznak, called Mobile. The feature utilises Fresnel lenses and the phenomenon of refraction (bending of waves, in this case light waves) rather than diffraction.

The optically variable thread feature incorporating the denomination number, which appears to move on tilting, is integrated within the overall print design of the note and other features.

For example, the watermark incorporates the 5,000 denomination in electrotype whilst the denomination is clearly printed to be easily recognised. The micro-print and line patterning also includes the 5,000 denomination.

More recently, the 2,000 ruble note issued in 2017 was also upgraded to incorporate the Mobile thread. Like the 5,000 ruble, this too is fully integrated with the print and watermark security features.

5,000 ruble banknote incorporating Mobile thread and right: a close-up of the thread.

Reserve Bank of Fiji – New Series – 2012

The Reserve Bank of Fiji issued its new flora and fauna family of banknotes in 2013, celebrating the island's native plants and animals, some of which are believed to be extinct. The notes, in denominations of $5, $10, $20, $50 and $100, were printed by De La Rue, all on paper except for the $5, which was the world's first note to be produced on *Safeguard*®.

In addition to the new substrate, a range of new security features were incorporated. They included a diffractive patch on the $20 and diffractive stripes on the $50 and $100 notes.

The patch on the $20 displays an image of the Kacau ni Gau bird (the iconic Fiji petrel, which is the main design subject in the print), as well as the letters RBF, the Reserve Bank of Fiji logo and the denomination numeral, along with rainbow colours and the number 20 inside the hologram.

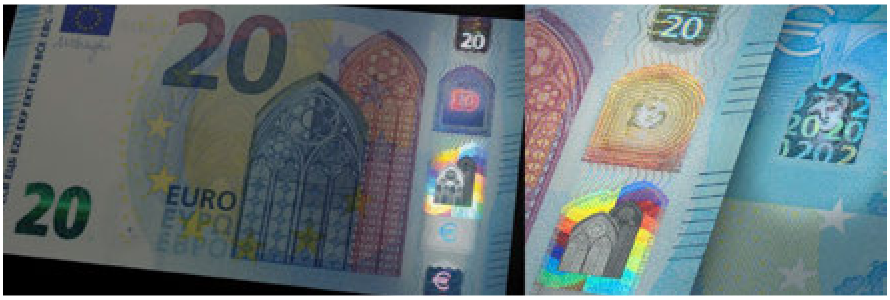
The front of the $50 and $100 feature De La Rue's *Dual Image*™ holographic stripe. The design elements include the Fijian coat of arms, the letters RBF, the Reserve Bank of Fiji logo, the denomination numeral RBF and various flora and fauna symbols. Again, rainbow colours are

Euro – Europa Series – 2013 and 2015

The second series of the euro banknotes – the Europa series – is being introduced gradually over several years, in ascending order. The first four banknotes in the new series, the €5, €10, €20 and €50, started circulating in 2013, 2014, 2015 and 2017 respectively. The final two notes in the series – the €100 and €200 – will be issued in 2019.

All of the banknotes have a common integrated design, with the portrait of the mythical goddess Europa used for both the watermark and the registered diffractive stripe.

But there is one key difference between the lowest two denominations and the €20 and €50 notes, in that the latter incorporate a 'portrait window' – namely, a window/DOVID combination which has different visible effects when viewed from the front and the back of the note, and in transmission. Although this is not the first window feature in a cotton substrate, it is the first with such a sophisticated DOVID and the first to be produced in such high volumes.



The portion of the stripe that covers the aperture in the paper is demetallised to form a transparent window, which reveals a portrait image of Europa on both sides of the note when held up to the light.

When viewed in normal light from the front and tilted, the portrait area displays clearly a '20' or '50' value in the centre with prominent, coloured, diffractive lines around it. When viewed from the reverse, the foil displays a number of different coloured '20s' or '50s'.

This feature is *KINEGRAM REVIEW*® foil from KURZ.

In all the notes, other elements of the stripe include the bridges that form the main printed image, the denomination numeral and the euro symbol. And in all the notes, the stripe is applied in register so that the diffractive elements are always in the same position.

Bank of Cape Verde – New Series – 2014

The Bank of Cape Verde issued a new series in 2014, completing this in 2015, with five denominations – four on paper and the lowest on *Safeguard*® polymer.

The new banknotes were very colourful and vibrant, following a Cape Verde design tradition, and used a wide colour palette to depict famous Cape Verdean artists from the worlds of literature and music, together with accompanying imagery of landscapes and musical instruments.

The principal security feature on the 200 escudos is a window containing an image of Henrique Teixeira de Sousa which mirrors his printed image. The other four notes feature a mould-made watermark, each the same as the intaglio portrait, along with an electrotype.

Other features include De La Rue's *Starchrome*® colour-changing security thread and holographic elements (a *Dual Image*™ patch for the 1,000 escudos and *Depth Image*™ stripe for the 5,000 escudos). In both of these, strong musical imagery corresponds perfectly with the printed design motifs.

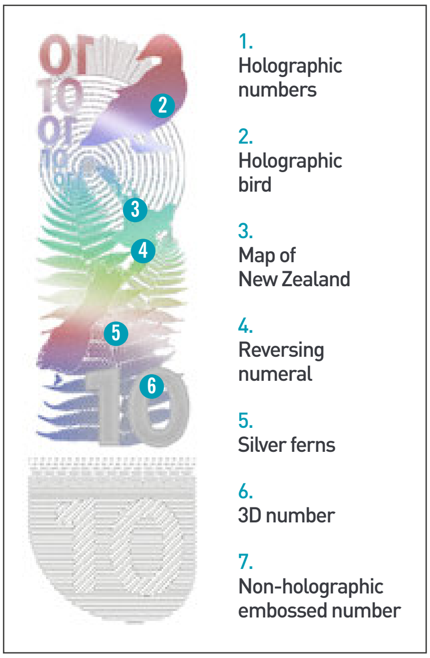
Reserve Bank of New Zealand – 'Brighter Money' Series – 2015

In 2015 the Reserve Bank of New Zealand began to upgrade its polymer notes with the 'Brighter Money' series, incorporating demetallised DOVID window patches supplied by KURZ.

Each of the five notes in the series include a diffractive design within the clear window. They feature the map of New Zealand and fern theme with a varying native bird feature on each denomination.

Microtext is also incorporated, together with an image flip, diffractive numbers, a 3D number effect and other security features.

Some of these diffractive foil design features are integrated within the print design of the banknotes so that the native bird is also printed in colour-changing optically variable ink, together with an embossed denomination number and a see-through 'puzzle number' which reveals the notes, denomination when viewed in transmission.



The demetallised diffractive patch window feature on the new $10.

Central Bank of Nicaragua – 200 Córdobas – 2015

The Nicaraguan 200 Córdobas Guardian polymer banknote featuring Latitude – as an image of a Guardabarranco bird. When tilted, the optically variable effect can be seen both on the front and back of the banknote.

In 2015 Nicaragua introduced the 200 Córdobas polymer banknote that incorporated *LATITUDE*™ – a holographic durable substrate-infused security feature produced by CCL Secure, making it the world's first polymer banknote with a substrate-integrated DOVID.

The diffractive holographic feature is incorporated into the substrate during the manufacturing process, requiring no separate purchase of holographic foil or its application by foil stamping processes.

The major advantage of this technology is the freedom of design it offers. It is not limited to a patch or stripe – hologram designs can be incorporated anywhere on the substrate and linked one to the other by another hologram if necessary.

The designs can be integrated in register with other polymer features, and can occupy multiple positions and large areas of the banknote, giving the public a dynamic, instant recognition feature.

In addition, it is not fully metallised and therefore not totally opaque, resulting in a different appearance from a conventional, bright, metallic, hot stamped diffractive hologram; in comparison, it has a distinct subtle metallic sheen and when held up to the light is partially transparent.

National Bank of Poland – Commemorative 20 Zloty – 2016

In 2016 SURYS introduced two new features – *DID Wave*™ and *DID Virtual*™ – to the new commemorative 20 zloty note, produced by Polish Security Printing Works (PWPW). The note was the first in the world to showcase' these two new DID features.

The DID Wave feature incorporates colour permutation and animation motion effects, whilst DID Virtual incorporates colour permutation and surface relief 3D embossing effects. SURYS developed these features by combining its zero order DID technology with Fresnel type lenses to produce new security effects.

The DID Wave and Virtual design elements are also integrated into the watermark, which shows an image of a deer and the denomination in electrotype (when viewed in transmission) as also observed in the DID features.

This is further enhanced with the print on the banknote, which exhibits the denomination and microtext denomination numerals.

Commemorative 20 zloty banknote featuring the DID Wave and DID Virtual.

The image of the DID feature that portrays a part of a relief of the Gniezno Cathedral doors.

Swiss National Bank – Series 9 – 2016

A further example of design integration is the launch of the ninth series of banknotes by the Swiss National Bank (SNB) with the issue of the new CHF 50 note in 2016 that incorporates a two colour *KINEGRAM VOLUME®* foil stripe combined with a partially metallised *KINEGRAM®*. This was followed in 2017 with the launch of the CHF 20 and CHF 10 notes that also incorporate the stripe feature, with different designs.

The new DOVID foil stripe for all three notes features the denomination numbers in two colours (red and green), appearing on four lines as the note is tilted from left to right. Tilting the note back and forth results in the numbers on the lines moving in opposite directions.

As an extra layer of complexity, and combined within the single stripe, appearing in silver, is a partially metallised KINEGRAM for all issued denominations that shows visible images of the map of Switzerland. In addition, on the CHF 50 note the KINEGRAM shows the Alps, the names of the main 4,000 m peaks in the Swiss Alps and the number 50.

The CHF 50 banknote printed on Landqart's Durasafe substrate and featuring the two-colour KINEGRAM VOLUME stripe incorporating partially metallised KINEGRAM.

On further tilting of the note backwards, the outline of Switzerland and the Swiss Alps appear in rainbow colours whilst little shining Swiss crosses become visible inside the number 50.

Partially metallised KINEGRAM silver features are also incorporated on the the CHF 10 and CHF 20.

Bank of England – New Polymer Series – 2016

In September 2016 the Bank of England unveiled its new £5 polymer banknote. The note was the first in the world to feature *KINEGRAM COLORS®* registered foil stripe provided by KURZ. This was followed a year later by the launch of the new £10 polymer banknote, which also incorporates a KINEGRAM COLORS registered stripe.

On the £5, the single foil stripe is in three sections and incorporates two different metallic colours (silver and gold) in perfect front to back register. The feature is applied over a clear window in the polymer substrate, making it visible from the front and the back of the note, where the colours green and silver are also used.

On the front of the note, a finely-detailed, bright metallic image of the Elizabeth Tower (Big Ben) is positioned inside the window. The tower is see-through via demetallisation, and appears in gold on the front of the note and silver on the back in perfect register.

Above the window, a silver area containing an image of the coronation crown in 3D can be seen, with multi-coloured rainbow colours distinctly moving up and down when the note is tilted.

Below the window, a second silver area shows an image flip between the words 'Five' and 'Pounds', together with a multi-coloured rainbow effect.

On the back of the note, behind the coronation crown that appears on the front, is a circular green foil block that appears in the shape of the maze at Blenheim Palace. The word BLENHEIM is spelt out in the segments of the maze.

The banknote print design also incorporates integrated design elements, including the denomination in clearly visible text, the denomination in microtext and in UV fluorescent ink, together with other features.

The polymer £10 that followed in 2017 uses copper, as well as silver and gold colours.

Reserve Bank of Malawi – 2,000 Kwacha – 2017

The Reserve Bank of Malawi, which issued a new series of notes and coins in 2012, supplemented these with a new high-denomination 2,000 kwacha in December 2016.

The lemon-coloured note is printed on cotton substrate and includes a portrait of freedom fighter the Reverend John Chilembwe (as do all the other notes in the series). This portrait is also used for the *Highlight* watermark and, in the form of a true colour hologram, on the foil stripe.

Other design motifs in both the print and the applied features include an African sunrise, the national flag, maps of the country and the great Lake Malawi (which are shown several times on the front and the reverse side in intaglio printing and in offset as a see-through-register), the national coat of arms and the Bank's logo, along with African patterns in traditional guilloches.

Several of these images and themes are incorporated into the *Truecolour LEAD* stripe from Louisenthal, which comprises a gold and aluminium foil with a number of striking features. They include the *Silkline*® 'running effect', a true colour hologram of John Chilembwe, *Animat*® pumping and 2D effects, microtext and demetallisation.

Central Bank of Armenia – Commemorative 500 Dram – 2017

In 2017 the Central Bank of Armenia issued a new 500 dram collectors banknote produced by Giesecke+Devrient Currency Technology and subsidiary Louisenthal, featuring the company's *RollingStar*® *LEAD* stripe and *Galaxy*® thread products. The note is the first in the world to feature the former.

The RollingStar LEAD stripe is shown within the reliquary (a shrine for holy relics) and colour shifts from gold to green on the left hand side of the note, whilst to the right of centre of the note is the Galaxy windowed thread.

The optical effects of the thread are synchronised with those of the LEAD stripe, displaying the same colour shift from gold to green and incorporating a striking 3D moving circles effect along with images of Noah's Ark and demetallised patterns of '500' and 'AMD'. The latter are viewed in transmission.

The gold/green colour shift effect is also synchronised in the *SPARK*® *Live* feature from SICPA, showing an image of the dove carrying the olive branch. Microtext features of the denomination and cathedral crosses together with other features are also incorporated.

Although the LEAD stripe is a feature based on micro-mirrors, integrated within the stripe and appearing above and below the reliquary are delicate holographic effects, with the whole surrounded by a window frame printed in intaglio.

Left: the 500 dram commemorative banknote incorporating RollingStar LEAD stripe. Above: the reliquary (shrine for holy relics) colour shifts from gold to green on tilting.

8

Trends in DOVIDs on Banknotes

As outlined in the section on Evolution, 1988 was a watershed year for DOVIDs – being the year that saw its launch on two banknotes on opposite sides of the world.

The growth thereafter was slow – another six years were to pass before a holographic thread made its debut in Finland, and eight years before it was used on Kuwait's banknotes and as a stripe for the Bulgarian lev.

The banknote industry is cautious and new features can have a long gestation time, particularly as the price of getting it wrong – in terms of a feature that either doesn't work or causes problems in production or circulation – is high.

During the 1990s there was nevertheless a steady increase, and by 2000, 49 denominations from 27 issuers featured DOVIDs.

The real shot in the arm for DOVIDS came with the launch of the euro. This was launched in 2002, but the preparation and production started in the late 1990s, at which time it was known that all denominations would feature a DOVID.

Not only was this a ringing endorsement for the technology, but the suppliers – printers, papermakers and DOVID producers themselves – had all invested heavily in technology and capacity to produce the 14 billion or so banknotes required for the launch. They therefore had the means – and also, as became apparent following the launch – the incentive since, in the immediate years following the launch, volumes fell dramatically, resulting in huge over-capacity.

By 2003, DOVIDS were being used on 105 denominations from 47 issuing authorities. Four years later, the number had jumped to 176 denominations from 69 authorities (a 67% increase).

For the rest of the decade, these numbers continued to climb but more slowly. By 2012, the corresponding figures were 247 denominations from 83 issuers (a more modest 40% increase).

By the end of 2017, the number of denominations had increased by 20% to 293 from 92 issuers.

During this period, and the latter half of the last decade in particular, a number of other optically variable technologies were making their debut – notably *MOTION®* from Crane and *SPARK®* from SICPA, along with a host of new colour-shifting effects.

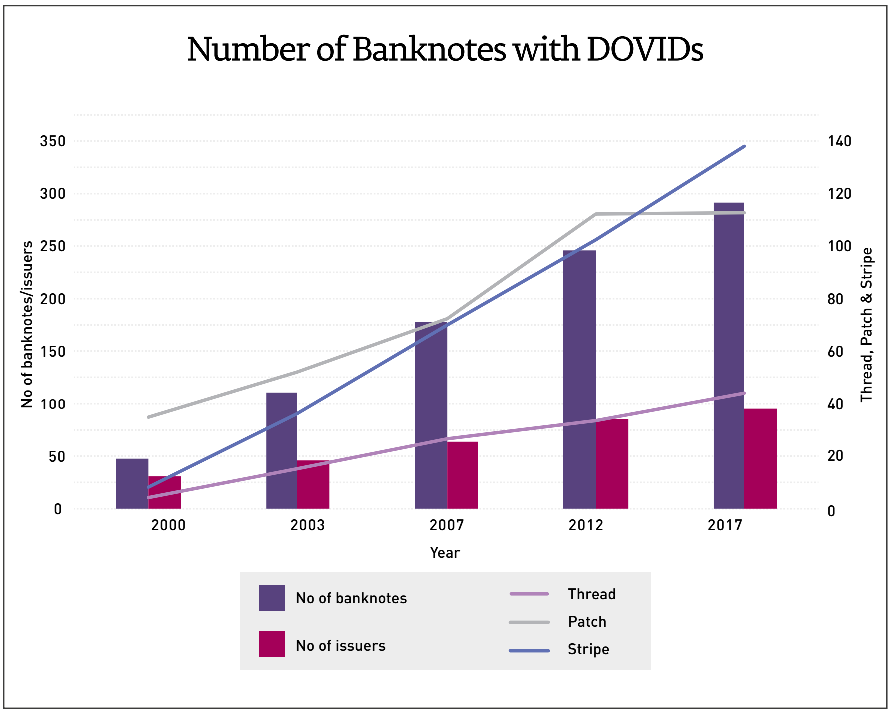
Would these end up displacing DOVIDs? And is the DOVID running out of steam?

Far from it. One of the factors in the success of the DOVID industry is its ability to innovate and reinvent itself. It continuing growth in the face of a panoply of alternatives has been the result primarily of three developments.

DOVIDS on Polymer

First was the deployment of DOVIDs on polymer. As we have already covered, polymer was developed first and foremost to provide a smooth carrier for diffractive features.

But then it was dropped, CCL Secure focusing instead on the durability of the substrate. And so it remained for nearly two decades, until a change of strategy saw the company refocus on the security benefits of polymer.



What it had at its disposal, which was for a long time available only in polymer, was the window. The presence of this is a security feature in its own right. But it also serves as a platform for numerous effects that can be seen on either side of the banknotes, and in transmission as well as reflected light.

CCL Secure's launch of *Latitude*® in 2010 was a significant development, but the catalyst was the invitation to industry suppliers to supply their products or develop new ones for their polymer notes.

The subsequent use of KURZ's DOVIDs for Canada was the first in which the security of the polymer notes had been a critical determinant in the decision by a central bank to use polymer, and for all its denominations. New Zealand, Australia and the Bank of England all followed suit, greatly enhancing the potential of polymer as a substrate; it was a tipping point.

Windows in Paper

Second was the use of windows in paper. For years, papermakers had argued that polymer notes could not offer the same security as paper, mainly because the intaglio is not so clearly defined and polymer cannot contain a watermark (still the most recognised feature by the public, even to this day).

But what polymer could offer instead was the window, and the papermakers identified this fairly early on. The technical barriers, however, were considerable.

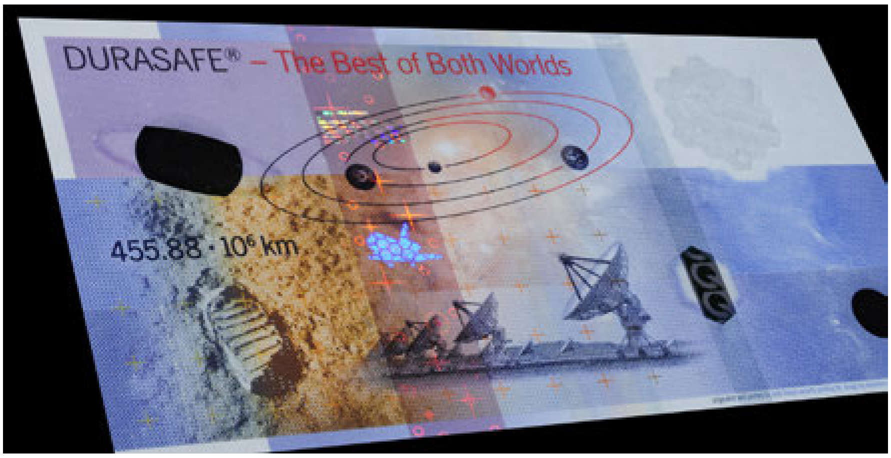
Louisenthal broke the mould in 2004 with *Varifeye*®, the combined aperture created during the papermaking process with an overlay in the form of a stripe. In 2007, KBA-NotaSys launched a new module for its *OptiNota H*, which both cuts a hole in the paper and applies the stripe in one pass.

Composite Substrates

Third, and running in tandem with both of these, was the development of composite substrates – a combination of paper and polymer – offering both durability and security.

Landqart was the first in 2009 with *Durasafe*®, comprising an inner polymer core bound either side by paper, with the polymer fusing with the paper. This enabled multiple windows – clear and semi-transparent – to be created.

This was followed shortly afterwards by Louisenthal with *Hybrid*™, which is the other way around – in that it comprises a paper core laminated with polymer. Windows can also be created in Hybrid.



Durasafe an inner polymer core bound either side by paper.

In all cases, the window – whether in polymer, paper, or composites – provides a whole new series of opportunities for different optically variable effects.

The potential both of polymer and of windows was duly noted in the industry and the DOVID community rose to the challenge of providing innovative effects which will, in all likelihood, provide the impetus for further DOVID developments for banknotes.

Paper or Polymer or Composite

The choice of substrate is no longer a determining factor in the use or otherwise of DOVIDs.

Polymer still accounts for a very small percentage of the overall substrate market (around 5%). Its growth has – and will continue to be – assisted by the arrival of De La Rue with its own version, *Safeguard*® (and its own suite of DOVID features for polymer). Others, too, are developing polymer substrates, notably the Russian printer and papermaker Goznak (which issued a 100 ruble polymer note to commemorate the 2018 FIFA World Cup).

There were no DOVIDS on polymer notes up until 2011. But the figures have climbed since and there is no indication that this will diminish.

Composite papers made their advent in 2009 with Durasafe, and then Hybrid. Other manufacturers are working on composite substrates too.

And cotton – which continues to be the banknote substrate of choice, accounting for over 90% of the market – whether 100%, a mixture of cellulose fibres, varnished or strengthened – was always suitable for DOVIDs, with the advantage that it (along with composites) can include a watermark, security thread and other integral substrate-borne features.

The issue of which substrate, therefore, has now become academic – DOVIDS are suitable for all.

Thread, Patch or Stripe

The choice of whether to use a thread, patch or stripe (or even, in a couple of cases, more than one format) is determined by a number of factors.

They include the design concept itself and which option fits best within that, whether the note is an upgrade or a redesign, security and cost factors, and whether the papermaker and/or printer has the necessary integration and application equipment.

Patches, for example, are normally applied at the printworks prior to intaglio printing, on equipment ranging in cost from several hundreds of thousands to millions of dollars. For those printworks without the volumes, will or finance to fund such an investment, the alternative is the application of the DOVID by the substrate maker, normally as a stripe, or integration as a thread, but sometimes as a patch as well.

Several denominations have switched from patch to stripe, as with this example of the Kyrgyzstan 1,000 som.

The cost of DOVIDS on a banknote depends on a number of variables, not least the area of the DOVID and the application processes used. Stripes have a significantly greater area in general than patches so generally would cost more than a patch, but they can be very efficiently applied in the paper mill. However, if the reject rate of the paper at sheeting is high due to faults (pin holes, thread breaks, marks etc) then the DOVID is also wasted, decreasing the DOVID yield.

If a patch is applied to sheets, whether prior to or after offset printing, any waste from faulty paper will be avoided, but more foil will be used as there is surplus foil surrounding each patch. In the printing works, DOVIDS can be applied first before the sheets are printed or after offset, but they are rarely applied after intaglio since this is designed to overlap the DOVID in order to increase the integration of the DOVID and hence security of the banknote.

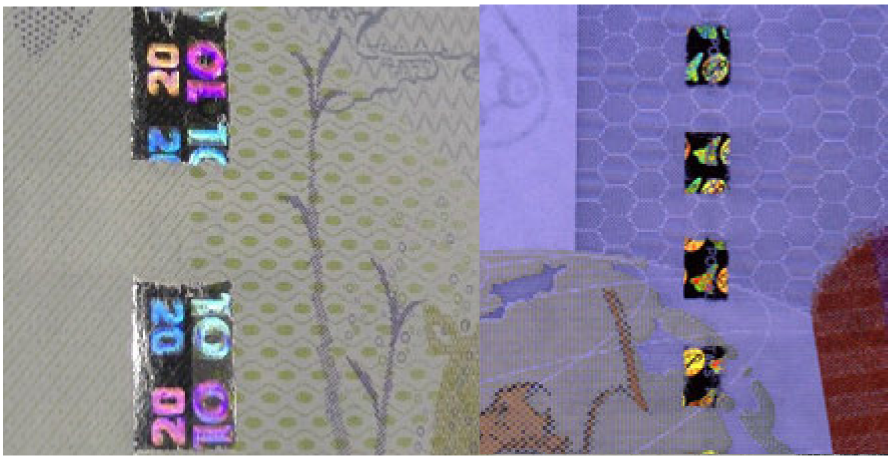
Thus the net yield of the DOVID and hence the net cost per finished note depends on a considerable number of factors and the choice of patch or stripe is not so much one of cost but more one of design and security.

In terms of design, patches – generally speaking – can be more easily integrated into a note's design, particularly when used in combination with intaglio printing. They are subtler and, when demetallised (as all DOVIDs for banknotes now are), can appear to morph into the print and vice versa.

This is particularly useful for designers and issuers who don't want any one particular feature to dominate (DOVIDs can have a tendency to do that).

Patches are also useful for banknote upgrades as they do not tend to impact on the overall design in the way the stripes do. That said, there has been a noticeable shift away from patches and towards stripes which, by 2017, comprised 47% of DOVIDs on banknotes, compared with 38% for patches. Interestingly, over the five year period from 2012, DOVIDS were adopted on a further 25 patches. But the same number dropped them – either because of a switch to a stripe (in 11 cases) but also because a number of central banks dropped the DOVID altogether in favour of other features.

Until very recently, patches could not be used over window features. Recent developments by both KURZ with *KINEGRAM APL* and Louisenthal with *Varifeye*® ColourChange Patch will change that.



Examples of holographic threads in paper from Zhongchao Special Security Technology (left) and De La Rue (right).

Stripes, by contrast, take up more real estate and tend to be more prominent.

They are also more versatile – because of their larger area (typically 8-10 mm wide and running the full length of the note), they provide an ideal platform for the combination of different optical effects – not just diffractive – in one feature. They are also the means by which diffractive features are imparted to banknotes with windows.

Holographic threads are inserted at the papermaking stage and are markedly cheaper than either patches or stripes, mainly because far less DOVID material is used.

So threads score highly on a cost/benefit ratio. They are also well-suited for banknotes that are being upgraded, rather than redesigned, as their effect on the overall design is minimal (particularly if they are replacing an existing thread).

The downside is the lack of real estate. Despite the increased width of windowed threads afforded by the development of short-forming technology, such threads are generally restricted to 4-6 mm wide, which is not optimal for the visual benefits of DOVIDs.

Added to this, several of the papermakers and printers – who also make their own threads – have brought out alternative optically variable threads with simple effects of animation or colour shift or both (for example Crane with *MOTION*® and *MOTION Rapid*, De La Rue with *StarChrome*® and now *Kinetic StarChrome*, Louisenthal with *RollingStar*® and *Galaxy*®*, and Fabriano with VISTA*™*, among others)*.

The optically variable thread market is, as a result, pretty crowded, and the presence of simple, easy to see and authenticate alternatives largely account for the reduction in the number of more traditional (holographic) DOVID threads in banknotes.

So the trend has been only small increases in diffractive threads, and a clear shift towards stripes at the expense of patches. But with the ability to apply patches to windows in paper notes now available, we can expect to see patches making something of a comeback.

Geographic Trends

There are few discernible trends in terms of geography, and those that do exist are determined largely by historical factors.

Oceania, for example, has traditionally been a polymer stronghold, due to the proximity and links with Australia, the home of *Guardian*®. And so, until the Australia and New Zealand series were launched, few others in the region had or have DOVIDS on their notes. On the other hand, DOVIDs are still relatively rare on banknotes in Latin America.

The US, one of the largest banknote issuers, does not use DOVIDs, and shows no sign of doing so. But its neighbour Canada does.

Europe is dominated by the euro. Other countries in Europe – which are either part of the EU but not the Eurozone, or adjacent to the EU – have also adopted DOVIDs in order to ensure their notes have the same level of security and, in some cases, to mirror many of the features of the euro pending such time as they adopt this as their currency.

Another factor pertains to influence arising from historical, even colonial, ties. Russia, for example, has strong links to CIS countries and parts of the Middle East. The UK is active in parts of what was the British Empire, notably in Africa. As is Germany.

Both countries are the only two with commercial banknote printers that also produce DOVIDs (ie. De La Rue and Giesecke+Devrient), so it follows that they will be more proactive in promoting DOVID technologies than other printers.

China is the largest user of DOVIDs in banknotes, simply by virtue of it being the largest issuer of banknotes, and threads feature in most of them. Whether it will upgrade or replace these remains to be seen, but it has ability to do so via Zhongchao Special Security Technology, a subsidiary of China Banknote Printing and Minting (CBPM), which has developed some interesting new DOVID features in recent years.

What is likely in the medium term is that China will become more active on the international market. It has all the requisite production capability and technology (including DOVID production), not to mention capacity. Demand for banknotes in China has fallen dramatically in recent years, due to the popularity of cashless payments, potentially leaving CBPM with up to 50% surplus capacity. It has already indicated its ambitions to produce banknotes for other countries, and is likely to focus on those – mainly in Africa, parts of Asia and Latin America – that do not have their own printworks.

And then there is India, another major issuer of banknotes in volume terms. It has issued an RFP (Request for Proposals) suggesting the use of up to eight billion patches.

India has a vibrant DOVID community but, to date, this has not been active in the banknote industry. The Indian government's 'Made in India' policy has made it clear that Indian manufacturers will be the preferred suppliers.

Those particular regional circumstances apart, DOVIDs are used on banknotes around the world, with little particular geographic preference or predominance – which is perhaps not surprising.

The substrates and circulation conditions of banknotes may vary from country to country and region to region depending on climate, conditions of use, levels of automation etc.

But the core requirements of security and aesthetic design in order to engage the public are universal – regardless of size, economic development or location.

So it follows that DOVIDS are as necessary in a large well-developed country as they are in a small and/or less developed one.

The Alternatives

While 92 issuing authorities issue one or more denominations with DOVIDs on them, that still leaves nearly the same number again that don't.

These include 10 issuing authorities that have dropped DOVIDs altogether in favour of other security features – as well as a number of others that have replaced DOVIDs on some of their denominations.

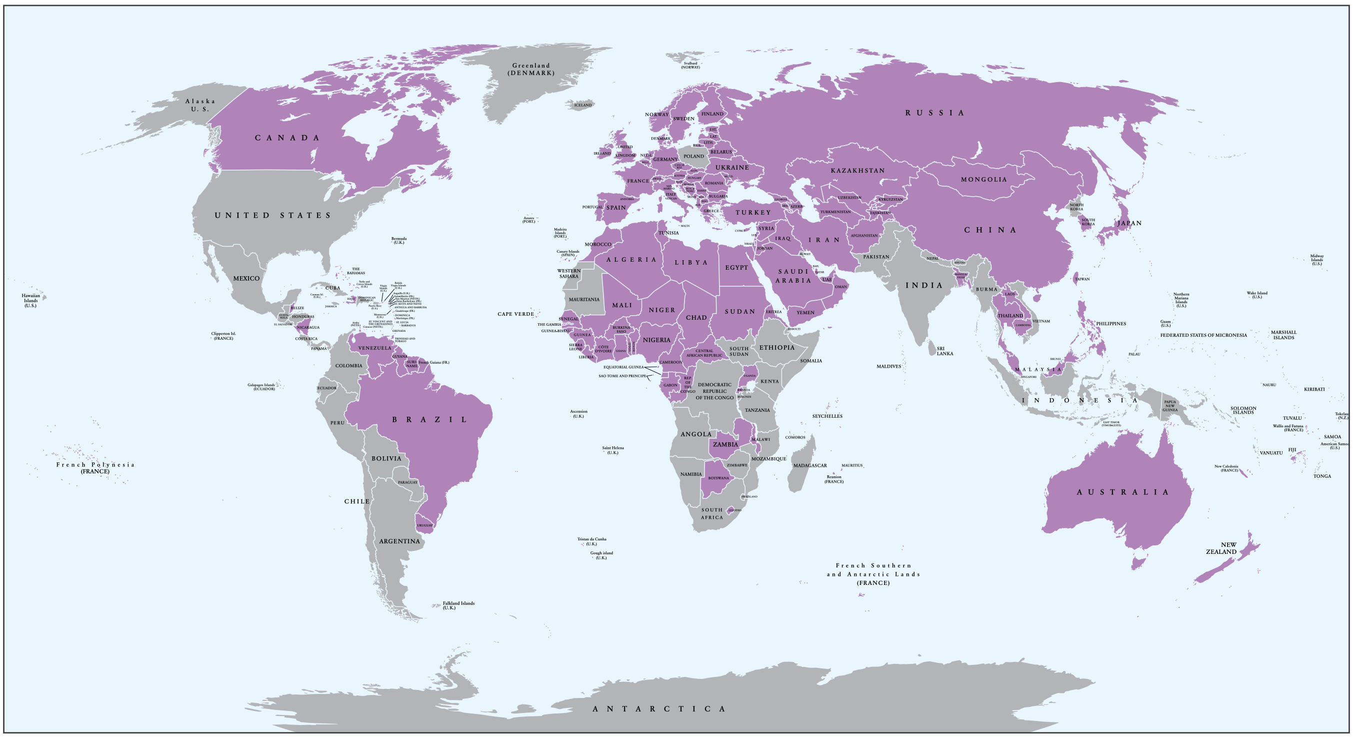
In total, the number of denominations that used to feature DOVIDs, but now don't, is 45.

So the trajectory of DOVIDs on banknote has not been one long upward curve. If it had been, there would be 104 issuers using DOVIDs on their banknotes, and 340 denominations with DOVIDs on them, as opposed to 292.

Of the number of denominations that dropped out, 20 were between 2005 and 2012, and 25 between 2013 and 2017, with nine alone in the last year. In all the recent examples, they have been replaced by other features detailed in this report.

For an industry that has been supplying DOVIDs for banknotes for 30 years, this is a remarkably low attrition rate. Competition is a fact of life and, given the ever-short design life of banknotes, coupled with increasing expectations for new designs and novel features, this it to be expected.

Whether or not the last year alone is the start of a trend away from DOVIDs remains to be seen. But given the ongoing developments in the industry, and in particular the opportunities now presented by window features (for which DOVIDs are better suited than some other level 1 features), it is unlikely.



Countries of the world (in purple) that have DOVIDs on their banknotes.

9

The Future for DOVIDS on Banknotes

The key question currently is what is the future for banknotes given the advent and advance of new methods of payment.

Digital copying and printing technology required the banknote sector to develop new security features. Now, digital technology applied to alternative methods of payment could end up being responsible for the demise of cash.

There is, however, inconsistency in the trend to less cash around the world and, so far, there are only a very few countries where banknote volumes are actually declining. Everywhere else, the average annual growth rate in terms of banknote volumes is around 5%, and in Sweden, one of the first countries to state it was aiming to be cashless, there are very public second thoughts. The anonymity, speed and durability of cash (it is not affected by power cuts or software glitches) continues to appeal.

Assuming banknotes still have a long life in front of them, the question arises – will the DOVID continue to play such a prominent role?

Currently DOVIDs are more than holding their own as a major security feature and are used on a combination of high and low denomination banknotes.

Furthermore, the public recognises DOVIDs as a high security feature for banknotes – they have been shown in various research programmes to create a feel-good factor and are the most recognised feature after the watermark.

Added to these positive factors is the very high quality of both the imagery and security provided by modern DOVIDs, and the R&D that is being invested in creating yet more.

As yet, there is nothing on the horizon looking to make a major impact in the market. But there have been two significant developments in the last decade that are giving DOVIDs a run for their money.

First is *MOTION*® from Crane Currency – first introduced as a thread in 2004. This feature, based on micro-optics, displays unique kinetic effects and it certainly did impact DOVIDs as well as other security features, particularly threads. What it has also done, however, is generate development in features based on micro-optics from other suppliers too, that are now being used for banknotes in conjunction with DOVIDs.

Second is more complex colour shifting effects, combined with movement.

As explained in the introduction, optically variable ink (*OVI*®) made its debut on a banknote a year earlier (1987) than the introduction of DOVIDs.

There was a step change in around 2007 with the development of optically variable magnetic ink (*OVMI*™), enabling such features to display movement as well as colour change through the orientation of the particles within the ink. This feature is known as *SPARK*® and has since been enhanced to *SPARK*® *Live*™.

As well as SPARK, which is applied as a patch direct to the banknote surface, colour shifting threads have become more sophisticated and popular, in some cases at the expense of diffractive threads.

While most provide a straightforward and easily-recognisable colour change, there have also been developments that combine the colour shift with movement, as in the case of *RollingStar*®, which uses micro-mirrors, from Louisenthal. Originally developed as a thread, the technology is now being used for stripes (and, shortly, patches), sometimes in conjunction with diffractive features.

Other features which combine colour shift and movement within threads include De La Rue's *Kinetic StarChrome*® and Zhongchao Special Security Technology's *ColorDance-Shift*™ (in the latter case, the movement is caused by diffraction).

There is no doubt that some of these technologies have been introduced at the expense of DOVIDs. But they also present an opportunity, with diffractive features sitting alongside colour shifting and micro-optics features within stripes, and the effects synchronising with colour shift threads and SPARK.

What are viewed as competing technologies have the potential, in other words, to be increasingly complementary.

A notable trend of the last few years is the improved integration of the design and the materials of DOVIDs with the graphics and the substrate of the banknote. This has been facilitated by the improved resolution and registration tolerances of demetallisation, as well as the constant development of new origination and manufacturing processes for DOVIDs.

This trend is likely to continue, and the more the DOVID is banknote-integrated in this way, the more likely DOVIDs are likely to remain a feature of those banknotes.

Where the technology takes us next remains to be seen. We certainly see this level of optical and material development continuing and the use of combinational origination technologies – DOVID manufacturers have proven their ability to invent and innovate – but perhaps there is also another watershed or step-change factor under development. Of course, such an innovation would be kept under wraps until it is launched, but they do seem to come along every 10 years or so. Who knows what might be introduced in the next few years? We can safely predict evolutionary development but not such a step-change innovation.

But, so long as banknotes continue to be widely used as a means of payment and storage of value, and so long as banknotes remain a target for counterfeiters, and so long as the main suppliers continue to innovate for enhanced effects and integration with other features and with the banknote itself – then we can safely assume that DOVIDs have a bright future.

To sum up this future, we use the words of De La Rue – one of the first companies to develop and produce secure DOVIDs – who state:

"(DOVIDs) are widely known and understood by the general public and are proven solutions on banknotes."

"They are visually striking, which means they catch the eye of the user and encourage closer inspection."

"Their effects are easy to understand and intuitive to view, making the hologram a highly suitable security feature for the public to use to authenticate their notes."

"The complex science required to make a (DOVID) is a significant barrier for counterfeiters and is the reason why many issuing authorities use them."

With which statement we wholeheartedly agree.

Appendix

HUECK FOLIEN

Expect More.

The Highest Security:

trilumic®

TRILUMIC®

- new complex level 2 UV fluore-scence element
- multi halftone colour impression based on RGB reproduction system
- complex to counterfeit

This complex security feature is placed registered on the holographic stripe and is hidden under daylight. Under UV light source it is showing an extremely brilliant true colours half tone image which cannot be realized on paper surface but on foil. The special technology of the feature in combination with the demetallized area of a holographic stripe ensures attractiveness for the public, interesting opportunities for the banknote designers and a significant barrier for counterfeiters. TRILUMIC® is a trademark resulting from a cooperation between HUECK FOLIEN and Banque de France.

Creating Unmistakable Identity. **hueck-folien.com**

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Appendix I: Glossary of Terms

Achromatic

An optical system free from dispersion or used to describe a colourless (grey tone monochrome) holographic image.

Alphagram

Alphagram™ is an origination technology based on the interferential micro-lithography technique invented by SURYS. This technology is used to produce very bright, animated high-resolution diffractive images with no pixelisation. It integrates unique optical effects – morphing, switching from positive to negative, achromatic elements and wide animations.

2D/3D holograms

Holographic images in which depth is indicated by a series of two-dimensional planes are known as 2D/3D holograms. True 3D holographic images are of models or objects which, in themselves, occupy volume in space. The artwork for 2D/3D holograms is easy to produce because each layer is printed onto a two-dimensional sheet. Stacking these sheets and making a hologram of the stack produces a parallax effect which the eye perceives as image depth. A key advantage is that 2D/3D holograms do not require a point-source illuminator so can be viewed in ambient light.

Beamsplitter

An optical device that divides a beam of light into two beams.

Blazed grating

A diffraction grating which has a sawtooth profile structure.

Bragg diffraction

The diffractive principle where a layered stack of parallel reflecting surfaces of alternate higher and lower refractive index will reflect a beam of light, but only when the reflected wavefronts are of an appropriate wavelength and orientation to produce constructive interference.

Bragg hologram

Any hologram in which the Bragg condition is preferential to the grating condition in forming the image; a volume hologram.

Casting

A method of embossing whereby a film of soft resin is applied to a nickel shim then exposed to ultraviolet light, causing the resin to harden by cross-linking. The resin film can then be removed (normally by moving the base film carrier) and retains a faithful copy of the surface relief image that was present on the shim. This method of transferring an image from a nickel shim onto a plastic film results in a bright image and causes very little wear to the shim.

Classical hologram

A classical hologram is usually made using a 3D object, often a model. A laser beam is split in two and part is diverted onto the object, reflected off it then allowed to combine (or interfere) with the other part of the beam known as the reference beam. The classic hologram is a recording of the interference pattern. A well known example of such an image is the small dove used by Visa on its credit cards.

Coherence

The degree to which photons in a beam of light are in phase.

Computer-generated hologram

A hologram made from a 3D computer model.

Demetallisation

A process in which metal, usually aluminium, is deposited onto the DOVID and then selectively removed. The removal is achieved by either first printing a protective resin onto the metallic layer then dissolving away the unprotected metal, or ablating the metal with a laser beam. Other demetallisation methods are also available.

Diffraction

A phenomenon whereby light waves are bent as a result of passing through small apertures or passing by small objects or lines whose dimensions are comparable to the wavelength of light. Of particular interest are gratings (a pattern of such lines – see definition below) with line spacings close to the wavelength of light, because these have the ability to bend light of different wavelengths by different amounts. Hence, they produce a prismatic effect of splitting white light into the colours of the rainbow.

Diffractive Identification Device

DID® is a zero order device (see zero order device definition) DOVID produced by SURYS. These devices efficiently reflect narrow wavebands. For example, a red to green colour shift is observed whilst performing a 90° in plane rotation of the image, enabling easy examination.

Diffractive Optically Variable Image Device (DOVID)

A generic term, which comprises all security devices that are based on the diffraction of light by fine gratings. The different DOVIDs differ in their image resolution, brightness, and their animation capabilities. Examples of DOVIDS include holograms which by definition display three-dimensional images and other devices known by their tradenames such as KINEGRAM®, DID®, Dot-Matrix-Hologram, Exelgram®, Movigram®, Pixelgram® and Stereogram®.

Dot matrix

A surface relief hologram built up from an array of tiny diffractive gratings arranged at certain angles. The 'dots' are a point at which two microscopic beams of laser light meet at an angle and produce an interference pattern. In a dot matrix machine, a mechanical arrangement moves this point of light in a matrix pattern relative to a photosensitive plate. According to the final image required, the angle at which each dot is exposed into the matrix is determined by mathematical calculation. It is thus possible to construct fully synthetic images of objects that never existed in real life.

E-beam (electron beam lithography)

An alternative means of creating a holographic image, dispensing with the traditional method of creating an interference pattern by interfering two laser beams and instead 'writing' the individual interference fringes using a fine beam of electrons in a vacuum chamber. The challenge here is to calculate the exact position of each fringe according to where it would have resulted if a reference beam had interacted with an object beam. If the correct software is available, this method of origination is the most versatile as it is capable of producing the same results as any other origination technique and any combination of them.

Efficiency

In holography, this refers to the brightness of an image. It is the ratio of diffracted to incident light intensity.

Electroforming

The process of converting a holographic image (micro-structure) from photoresist or plastic to metal (nickel). See Shim definition.

Embossing

Embossing is the process whereby a surface relief micro-structure on a nickel shim is transferred to a relatively inexpensive plastic film or thermoplastic coated plastic film. The shim or shims are mounted onto a cylinder and pressed into a thermoplastic film with heat and pressure. If the film is a tough plastic such as polyester, or is coated with a thin layer of metal to make it reflective, the process is called hard embossing and the lifetime of the embossing shim is relatively short. In such a process, the image may be exhausted from the shim after only a few hundred metres of embossing. For this reason, the plastic film is usually coated with a softer layer which deforms more easily under heat and pressure. This is called soft embossing and many thousands of metres can be produced before the embossing shims need to be replaced.

Grating

A grating is a series of parallel lines having a spacing comparable with the wavelength of light. Such an array of lines has the ability to split white light into a rainbow because the different wavelengths are bent, or diffracted, by different amounts. Such gratings were originally produced by using a diamond to rule closely spaced lines onto glass, but they are now more often produced by optical interference.

Exelgram

Exelgram® is a track-orientated DOVID security feature originated by e-beam lithography produced by CSIRO. The Exelgram is composed of diffractive tracks that can vary in frequency and angle.

Hologram

The term 'hologram' is derived from two Greek words 'holos' meaning whole or complete and 'graphos' meaning an image. The term therefore describes a recorded image which is complete, in that it shows the whole volumetric space of the object or image, as opposed to a conventional picture, painting or photograph which displays an object from a single viewpoint.

Hot stamping foil

Sometimes abbreviated to HSF, this is a thin material which is applied to paper or other substrates through a combination of heat and pressure. HSF can be used to support diffractive images which can be transferred, using heat and pressure, onto another substrate such as paper or plastic. The layers containing the image are extremely thin, typically 5-6 microns. Therefore they need to be supported on a thicker material such as 19 micron thick polyester. The action of stamping the foil with a heated die causes a 'release' layer between the hologram and the polyester support to melt while simultaneously softening an adhesive 'size' coating. These combined effects allow the DOVID to transfer from the polyester support and adhere, irreversibly, to its new location.

HRI, or High Refractive Index

In situations where a transparent hologram is required, instead of coating the diffractive image with a metallic film, a transparent coating is made using a material with HRI. If transparency is achieved by simply not coating with metal, the image will disappear with handling or when an adhesive is applied because the microscopic ridges and grooves fill with the adhesive or body oils, so that there is no diffraction and no DOVID. The HRI materials used in this process are oxides (eg. titanium dioxide) or sulphides (eg. zinc sulphide).

Interference

A phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude. Interference usually refers to the interaction of waves that are coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency.

KINEGRAM

The KINEGRAM® is a vector-based computer-generated DOVID by KURZ and its subsidary OVD Kinegram that is manufactured by proprietary lithographic techniques capable of producing multiple high-resolution images. It contains special types of computer-generated diffractive optical elements. These can be designed in different ways to exhibit kinematic, colour-changing, contrast reversal, rotational, expansion and other special effects. The technique allows the generation of blazed gratings (see blazed grating)

Kinetic

An adjective whose roots lie in the Greek word 'kinesis' indicate motion. A diffractive image which displays movement of form or colour is said to be kinetic. Often, such images are patterns rather than objects. The patterns can be made up of fine lines or graphic elements and appear to scintillate when moved. OVD Kinegram found a particularly effective way of producing such designs, and called them 'kinegrams'.

Laser

Derived from the word 'light amplification by stimulated emission of radiation'. A device that produces coherent light by stimulated emission of radiation.

Micro-structure

Micro-structure is the very small scale structure of a prepared surface of a material as revealed by a microscope above 25× magnification. Diffractive micro-structures comprise micro-protrusions or micro-grooves or a combination thereof that are capable of diffracting light waves.

Moviegram

Moviegram® is a type of digital hologram made from flat artwork sequences that display a kinematic effect.

Multi-channel

A diffractive image in which different, usually unrelated images appear at different viewing angles. The most usual, and easiest to make, is for the images to flip from one to another as the DOVID is tilted from side to side. The most difficult is for the image to change as the hologram is rotated.

Object beam

This is the diffractive beam that is reflected from an object and incident on a sensitive material, usually a photosensitive material. It also refers to the beam that is transmitted and diffracted by a holographic plate (H1) which is the 'object' from which a copy (H2) is made.

Parallax

The phenomenon in an image which allows depth to be judged from the movement of near image elements relative to more distant ones. Traditional embossed DOVIDs only display parallax from side to side, but the lack of vertical parallax is rarely noticed.

Photopolymer holograms

Holograms produced from photopolymer materials. The latter are materials that polymerise (the cross-linking of molecules) under the action of light energy and thus change their refractive index, and are used to record volume reflection holograms (see volume holograms) or Lippmann holograms.

Photoresist

a substance that becomes insoluble (negative) or soluble (positive) under the action of light. A surface grating image is produced which is the first stage in the making of an embossed DOVID.

Pixelgram

Pixelgram® is a pixel-orientated DOVID security feature originated by e-beam lithography produced by CSIRO. The Pixelgram is composed of a diffractive matrix of regular fine rectangular pixels. The grating structure consists of lines that vary in frequency and angle.

Rainbow

A rainbow is the visual result of splitting white light into its constituent colours according to wavelength. The order of the colours is red, orange, yellow, green, blue, indigo, violet – with red having the longest wavelength and violet the shortest. The natural phenomenon is caused by the prismatic effect of raindrops in the sky but it can also be caused by diffractive gratings with a spatial frequency approaching the wavelength of light.

Rainbow hologram

Also sometimes referred to as a white light transmission hologram or a Benton hologram after the inventor Steve Benton. This can be considered a slit transfer hologram during which the image formed on the H1 photoresist is used as the object for the final H2 hologram in which the vertical parallax is eliminated, so that a change in viewing angle in the vertical direction changes only the hue of the image and not the perspective.

Recombination

This is a 'step and repeat' process whereby a single diffractive image is laid out in rows and columns in preparation for shim production. It can either be carried out mechanically or optically. In the mechanical process, the single image is made into a stamper which is impressed at pre-determined intervals, into a plastic sheet. If done optically, the single image is exposed in a predetermined pattern onto a (glass) plate coated with a photoresist.

Reference beam

The unmodulated beam which, when directed at the photoresist forms a stationary interference pattern with the object beam.

Reflection hologram

See volume hologram. These are viewed by the reflection of white light. The diffractive planes within the depth of the recording material have a spacing which corresponds only to a single wavelength of light. This wavelength, usually green or yellow, is reflected back and reconstructs the image, the other colours being transmitted and absorbed by a black backing placed behind the hologram.

Shim

A 'shim' is a thin plate of metal, usually nickel, which is attached to a cylinder in preparation for the embossing process. The shim is produced by an electro-deposition process whereby the plate with the recombined images is immersed into a galvanic tank and nickel is caused to accumulate on its surface. This metal plate is usually referred to as the 'master' or 'mother' shim. It is usually used to prepare 'daughter' shims which are used for the mechanical embossing process.

Stereogram

This is a hologram prepared using the sequential images from a piece of movie footage. Each frame of the movie is converted into a vertical slit image and stacked against another slit image of the adjacent frame. The result is a hologram which, when the viewing angle changes from side to side (usually), the same image motion as the movie footage is seen as the frames are seen one after another. The technique usually employs around 100 movie frames equivalent to only a few seconds of action.

Surface relief hologram

A surface relief hologram is one in which all the details of the image are recorded as an interference pattern in relief on the surface of some material. It can be compared to the ripples on water frozen in time, except that the ripples are the interference patterns arising when two laser light beams interfere with each other, and the ripples are tiny, with a frequency close to the wavelength of light. The value of such surface relief holograms is that they can be mass-replicated by mechanical transfer from a master image to inexpensive plastic.

Transmission hologram

A transmission hologram is one that can be seen by light passing through the material containing the holographic image. Ironically, all metallised, embossed holograms are transmission holograms but are conveniently seen by reflected light because the incident light passes through the diffractive grating and is reflected back by the mirror coated on the reverse side (usually aluminium). In the process, the incident white light is split into all the colours of the rainbow causing different aspects of the image to be seen in different colours when viewed at different angles. For this reason, such holograms are also referred to as 'rainbow' holograms.

Viewing angle

This is the angle at the surface of a DOVID which defines the limits of the space relative to the DOVID in which an image can be observed with acceptable visual performance.

Volume hologram

A volume hologram, otherwise known as a Bragg interference hologram, and also known as a Lippmann hologram (both named after the inventing scientists) is formed as a result of changes in refractive index throughout the depth of a coating of material. The materials used to create such holograms are traditionally silver halide film or dichromated gelatine (DCG). In recent years, these materials have been joined by synthetic photopolymers (which have largely replaced DCG). Volume holograms must necessarily be reproduced by optical exposure followed by some form of processing. These replication methods are less convenient than the traditional embossing of surface relief holograms but the great advantage is the gain in image quality. Such holograms display both vertical and horizontal parallax, creating a greater sense of realism.

Zero order device

Often abbreviated to ZOD, these devices comprise gratings less than the wavelength of visible light (below 400 nanometres). These devices can be produced by embossing and display unique colour effects which are dependent on the plane of rotation of the device.

The authors would like to acknowledge the following contributors for the compilation of the glossary.

SURYS website: **www.surys.com**

International Hologram Manufacturers Association Website: **www.ihma.org**

Practical Holography, Fourth Edition, Graham Saxby, Stanislovas Zacharovas, CRC Press, 2015

LATITUDE™

GUARDIAN™

A diffractive optically variable device (DOVD) integrated into the transparent window area of CCL Secure's Guardian™ polymer substrate.

Latitude™ is not restricted to a conventional applied patch or stripe format, allowing complete design freedom. This easy to recognise Level 1 security feature can be validated in both reflection and transmission, enhancing the security on both sides of the banknote.

www.cclsecure.com

Winner of Excellence in Holography Award - Best Applied Security Product 2017 by IHMA.

CCL

Appendix II: Issuing Authorities and Denominations with DOVIDs

Country	Currency	Denomination(s)	Method	First Year of Issue*	Discontinued
Afghanistan	Afghani	500 1,000	Stripe Stripe	2002 2002	
Albania	Lek	2,000 5,000	Patch Patch	2008 1999	
Algeria	Dinar	500 1,000 2,000	Stripe Stripe Stripe	2000 1999 2011	
Armenia	Dram	1,000 5,000 10,000 20,000 100,000	Stripe Patch; Stripe Stripe Patch; Stripe Stripe	2011 2003; 2012 2003 1999; 2007 2009	
Australia	Dollar	5 10	Stripe Stripe	2016 2017	
Azerbaijan	Manat	10; 20; 50; 100	Patch	2006	
Bahamas	Dollar	100	Patch	2000	
Bahrain	Dinar	5; 10; 20	Patch	2008	2016
Bangladesh	Taka	50 100 500 1,000	Thread Thread Thread Thread	2003 2001 2002 2008	
Barbados	Dollar	50; 100	Patch	2013	
Belize	Dollar	100	Patch	1997	
Botswana	Pula	50; 100; 200	Stripe	2009	
Brazil	Real	20 50; 100	Stripe Patch	2002 2010	2010
Bulgaria	New Lev	2; 5; 20; 50 10 100	Stripe Stripe Stripe	1999 2008 2003	
Cambodia	Riel	10,000 20,000 50,000 100,000	Stripe Stripe Patch; Stripe Thread	2015 2008 2001; 2014 1995	
Canada	Dollar	5 10 20; 50; 100	Stripe Stripe Stripe	2006 2005 2004	
Cape Verde	Escudo	1,000 2,000 5,000	Patch Patch; Stripe Patch; Stripe	2007 1999; 2014 2000; 2015	

Country	Currency	Denomination(s)	Method	First Year of Issue*	Discontinued
Cayman Islands	Dollar	25; 50; 100	Stripe	2011	
Central African States	CFA Franc	5,000; 10,000	Stripe	2003	
China	Yuan	5 10 20; 50; 100	Thread Thread Thread	2002 2001 2005	
Comoros	Franc	5,000; 10,000	Stripe	2006	
Congo, Dem Republic of	Congolese Franc	10,000; 20,000	Patch	2012	
Croatia	Kuna	50; 100 200	Stripe Patch	2002 2002	
Denmark	Krone	50 100; 200 500 1,000	Patch Patch Patch Patch	2009 2010 2011 2004	
Egypt	Pound	20; 50 100 200	Thread Thread Thread	2001 2000 2007	 2016 2016
England	Pound	5 10 20	Stripe Patch; Stripe Stripe	2016 2000; 2017 2007	
Eritrea	Nakfa	5; 10; 20 ,50 100	Stripe Stripe	2015 2011	
European Union	Euro	5; 10; 20 50 100; 200; 500	Stripe Patch; Stripe Patch	2002 2002; 2017 2002	
Faroe Islands* **	Krona	500 1,000	Patch Patch	2004 2005	2011 2011
Fiji	Dollar	20 50; 100	Patch Stripe	2013 2013	
French Overseas Territories	CFP Franc	5,000; 10,000	Patch	2014	
Gambia	Dalasi	100 200	Patch Patch	2010 2015	
Georgia	Lari	5 20 50; 100 200	Stripe Stripe Patch; Stripe Stripe	2017 2016 2004; 2011 2007	
Ghana	Cedi	10; 20	Patch	2007	
Guatemala* **	Quetzal	100	Stripe	2002	2017
Guinea	Franc	10,000	Patch	2012	
Guyana	Dollar	500; 1,000 5,000	Patch; Stripe Stripe	2000; 2011 2013	
Haiti	Gourde	20 25; 50; 100; 250; 500 1,000	Stripe Stripe Patch	2002 2004 2004	

Country	Currency	Denomination(s)	Method	First Year of Issue*	Discontinued
Hong Kong**	Dollar	20 50 100; 500 1,000	Thread Thread Thread Thread	2003 2004 2003 2003	
Hungary	Forint	1,000 2,000; 5,000 10,000 20,000	Stripe Stripe Stripe Stripe	2006 2017 1997 2001	
Iran	Rial	50,000	Thread	2007	
Iraq	Dinar	10,000; 25,000 50,000	Stripe Stripe	2014 2015	
Israel	New Shekel	20; 100 50 200	Stripe Stripe Stripe	2017 2014 2015	
Japan	Yen	5,000; 10,000	Patch	2004	
Jersey	Pound	10; 20; 50	Patch	2010	
Jordan	Dinar	20; 50	Patch	2003	
Kuwait***	Dinar	5; 10; 20	Patch	1994	
Kazakstan	Tenge	1,000 2,000 5,000	Thread Stripe Stripe & Thread	2006 2013 2011	2014
Korea (South)	Won	1,000 5,000 10,000 50,000	Thread Patch Patch Stripe	2007 2006 2007 2009	
Kyrgyzstan	Som	100 200 500; 1,000	Stripe Stripe Patch, Stripe	2014 2010 2000; 2010	
Laos	Kip	100,000	Thread	2010	
Lebanon	Livre	5,000; 10,000 20,000; 50,000 100,000	Thread Stripe Stripe	2005 2005 2011	2012 2012
Lesotho	Loti	50; 100	Patch	2011	
Libya	Dinar	1 5 10 20; 50	Thread Stripe Patch; Stripe Stripe	2013 2015 2004; 2015 2013	
Macau**	Pataca	1,000	Thread	2005	
Macedonia	Denari	1,000	Patch	2003	
Madagascar***	Ariary	5,000; 10,000	Stripe	2003	2017
Malawi	Kwacha	200; 500; 1,000 2,000	Stripe Stripe	2012 2016	
Malaysia	Ringgit	10 50 100	Stripe Stripe Stripe	2003 2009 1998	2012 2012

Country	Currency	Denomination(s)	Method	First Year of Issue*	Discontinued
Mauritania***	Ouguiya	500; 1,000; 2,000 5,000	Patch Patch	2004 2010	2017 2017
Mauritius	Rupee	200; 500; 1,000 2,000	Patch Patch	2011 1999	
Mongolia	Tugruk	10,000 20,000	Patch Stripe	2002 2006	
Mozambique***	Metical	200; 500	Patch	2006	2012
New Zealand	Dollar	5; 10 20; 50; 100	Patch Patch	2015 2016	
Nicaragua	Córdoba	200	Patch	2015	
Nigeria	Naira	100 200 500 1,000	Thread Thread Thread Patch & Thread	1999 2000 2001 2005	
Northern Ireland**	Pound	10 20 50 100	Patch Patch Patch Patch	2013 2007 1994 1994	
Norway	Krone	100 200 500 1,000	Stripe Stripe Stripe Stripe	2003 2002 1999 2001	2017 2017
Oman	Rial	5; 10; 20; 50	Stripe	2000	
Paraguay***	Guarani	100,000	Patch	1998	2005
Philippines	Piso	500; 1,000	Patch	2010	
Poland	Zloty	200	Patch	1995	2016
Qatar	Riyal	50 100; 500	Stripe Patch	2003 2007	
Russia	Ruble	1,000 2,000 500; 5,000	Thread Thread Thread	2010 2017 2011	
Rwanda	Franc	1,000 2,000 5,000	Stripe Stripe; Thread Stripe; Thread	2004 2007; 2015 2004; 2015	2015
Sao Tome & Principe	Dobra	100; 200	Patch	2017	
Saudi Arabia	Riyal	50; 100; 500	Stripe	2007	
Scotland**	Pound	10 20 50 100	Patch Patch Patch Stripe; Patch	2009 2007 2005 2007; 2009	
Serbia	New Dinar	200 500 1,000; 5,000 2,000	Patch Patch Patch Patch	2005 2004 2003 2011	

Country	Currency	Denomination(s)	Method	First Year of Issue*	Discontinued
Seychelles	Rupee	25 50; 100; 500	Patch Patch	2016 2011	
Sierra Leone	Leone	5,000; 10,000	Patch	2010	
Singapore	Dollar	2; 5; 10; 50; 100; 1,000; 10,000	Patch Patch	1999	2005
Solomon Islands***	Dollar	50; 100	Patch	2006	2013
Sudan	Pound	10; 20; 50	Stripe	2011	
Suriname	Dollar	5; 10; 20; 50; 100	Stripe	2010	
Swaziland***	Lilangeni	50 100; 200	Stripe Stripe	1995 1996	2010 2010
Switzerland	Franc	10 20 50 200 100; 1,000	Patch; Stripe Patch; Stripe Patch; Stripe Patch Patch	1997; 2017 1996; 2017 1995; 2016 1997 1998	
Syria	Pound	500 1,000 2,000	Thread Thread Thread	2014 2015 2017	
Taiwan	New Taiwan Dollar	500; 1,000 2,000	Stripe Patch	2001 2002	
Tajikistan	Somoni	5; 10 20; 50; 100 200; 500	Stripe Stripe Stripe	2012 2000 2010	
Tanzania***	Shilling	1,000; 2,000; 5,000; 10,000	Stripe	2003	2011
Thailand	Baht	100 500 1,000	Stripe Stripe Stripe	2004 2012 2005	
Trinidad & Tobago	Dollar	50 100	Patch Patch	2012 2006	2015
Tunisia	Dinar	5 10 20; 50	Stripe Stripe Patch	2008 2013 2011	2017
Turkey	Lira	5; 10; 20; 50; 100; 200	Stripe	2009	
Turkmenistan	Manat	50; 100 500	Patch; Stripe Patch	2009; 2014 2005	2009
Uganda	Shilling	10,000; 20,000; 50,000	Stripe	2010	
United Arab Emirates	Dirham	200 500; 1,000	Stripe Stripe	2004 1995	
Uruguay	Peso	500 2,000	Thread Stripe; Thread	2014 2003; 2016	
Uzbekistan	Som	5,000	Thread	2013	

Country	Currency	Denomination(s)	Method	First Year of Issue*	Discontinued
Venezuela	Bolívar	100,000	Thread	2016	
West African States	CFA Franc	5,000; 10,000	Stripe	2003	
Yemen	Rial	250 500 1,000	Thread Stripe; Thread Stripe; Thread	2009 2001; 2017 1998; 2009	
Zambia	Kwacha	10; 20; 50; 100	Stripe	2013	

* The First Year of Issue relates to the year the DOVID was introduced. In many cases, there will have been subsequent upgrades (to the note and the DOVID) but the dates of these have not been included, unless there has been a change of format (eg. if a patch has been replaced by a stripe, or a stripe by a thread).

** For countries with more than one note – issuing bank (Hong Kong, Macau, Scotland and Northern Ireland), there are multiple variations of the same notes. But for the purposes of this report, they are all being treated as one currency.

*** No longer in use on any denomination

⊗ Date discontinued

DIFFRACTIVE FEATURES ON BANKNOTES

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