The Comprehensive PBR Guide by Allegorithmic - vol. 2

Light and Matter : Practical guidelines for creating PBR textures

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Light and Matter

Practical guidelines for creating PBR textures

Physically Based Rendering (PBR) can be thought of as more of a methodology than a hard standard. There are specific principles and guidelines, but not a true standard and thus there can be different implementations. These differences can typically be found in the map types used i.e. the workflow, the BRDF and how data values for roughness/glossiness could be remapped for customized implementations. There are even implementations that change the map names, but the underlying usage is still the same.

In this guide we will discuss the two most common workflows, which are metal/roughness and specular/glossiness as shown in figure 01. The Substance toolset for authoring PBR maps, which is comprised of Substance Designer, Substance Painter and Bitmap2Material 3, support both workflows. The Substance PBR shaders for metal/roughness and specular/glossiness use GGX BRDF and do not utilize any value remapping for roughness/glossiness. However, if any custom remapping is needed, this can easily be implemented in the Substance material. Furthermore, custom shaders are supported in the Substance toolset, which means you can adapt Substance to any customized pipeline.

It's important to state that while both workflows each have pros and cons in their implementation, one workflow is not particularly better than the other. What is truly important is that you understand the core principles behind PBR. It's the concepts and guidelines that make the PBR maps you author accurate and not the workflow itself. The workflows represent the same data, but they implement the data in different ways.

In Volume One of "The Comprehensive PBR Guide," we defined PBR from a technical and theoretical standpoint. In this 2nd Volume, we will discuss the practical application of authoring PBR textures and provide a set of guidelines that are based on the foundations established in Volume One. We will begin by redefining PBR from an artistic perspective. From there, we will discuss the metal/roughness workflow to address the principles and guidelines. We will then follow up with the specular/glossiness workflow and only detail the differences in the authoring methods. Therefore, it is best to read through both workflows to get a full idea of the overall guidelines for authoring PBR textures.

Figure 01

What is PBR?

Physically Based Rendering (PBR) is a method of shading and rendering that provides a more accurate representation of how light interacts with surfaces. It can be referred to as Physically Based Rendering (PBR) or Physically Based Shading (PBS). Depending on what aspect of the pipeline is being discussed, PBS is usually specific to shading concepts and PBR specific to rendering and lighting. However, both terms describe on a whole, the process of representing assets from a physically accurate standpoint.

What are the benefits?

We can view the benefits of PBR from an artistic and production efficiency mindset, which are as follows.

1. It can be easier to create realistic assets as it removes the guesswork of authoring surface attributes such as specularity since the methodology and algorithms are based on physically accurate formulas.
2. Assets will look accurate in all lighting conditions.
3. Provides a workflow for creating consistent artwork, even between different artists.

What does it mean for the artist?

We as artists need to think differently about the maps that describe the attributes of a surface. There are new map types with rules and guidelines to follow.

We need to throw out the concepts of diffuse and specular maps from traditional rendering workflows. These maps only served as workarounds so to speak for approximating light interaction with materials. Advances in computer hardware and rendering allow us to now more closely simulate the physics of light.

In PBR, the shader handles the heavy physics lifting through Energy Conservation and BRDF, while we as artists create maps that are guided by physics principles. It takes out the guesswork of material values and allows us, as artists, to spend more time in the creative aspects of texturing. While it is important to adhere to guidelines and author maps correctly, it doesn't mean that we now have to disregard our artist intuition. In fact, it’s the artistic perspective that truly brings character to a material, revealing its story through carefully crafted detail and expression. It’s important not too get overly caught up in the physics. Just because we are working in a more physically accurate environment, it doesn't mean that we can't do stylized art as well. For example, Disney's physically based reflectance model was designed to be a "principled" approach meaning that it was geared more towards art direction rather than a strictly physical model. So we should know the principles and utilize the guidelines, but not be slaves to them.

We as artists need to think differently about the maps that describe the attributes of a surface. There are new map types with rules and guidelines to follow.

Metal/Roughness Workflow

The metal/roughness workflow is defined through a set of channels, which are fed as textures to a sampler in the PBR shader. The maps specific to the metal/roughness workflow are base color, metallic and roughness as shown in figure 02 and we will discuss each of these map types in the sub-sections below. The PBR shader will also utilize ambient occlusion, normal and possibly height for parallax mapping as shown in figure 03. These map types are common to both workflows and will be discussed in the "Maps common to both workflows" section.

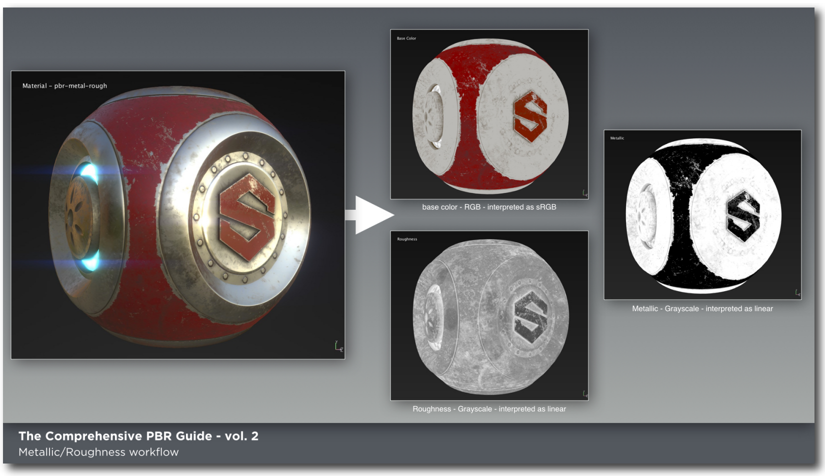


Figure 02

In the metal/roughness workflow, the reflectance value for metals are placed in the base color map along with the reflected color for dielectrics and the reflection at grazing angles is handled by the BRDF. A metallic map is utilized, which works like a mask to differentiate metal and dielectric data found in the base color map. The dielectric F0 values are not authored by hand as the shader handles them. When the shader sees black in the metal map, it treats that corresponding area in the base color map as dielectric and uses a 4% (0.04) reflectance value as shown in figure 04. As we discussed in Volume One, the 4% value covers most common dielectric materials. It's important to note that all values, such as dielectric F0, metal reflectance and brightness ranges for albedo color, are derived from actual measured data. As we look at each map type, guidelines will be discussed, which are based on measured data.

In Volume One, we discussed the notion of energy conservation where the light reflected off the surface will never be more intense than it was before it hit the surface. In terms of implementation, the shader typically handles the control of energy conservation, which is the case with Substance. With the metal/roughness workflow it is not possible to break the law of energy conservation. The diffuse (reflected color) and specular balance are controlled through the metallic mask, which means you can't create a situation where the diffuse and specular can combine to reflect/refract more light than is initially received.

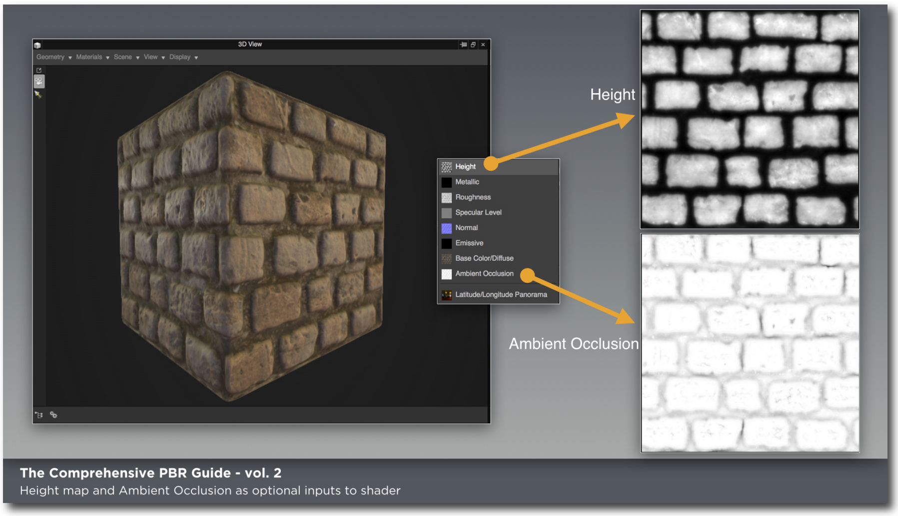


Figure 03

The reflectance value for metals are placed in the base color map along with the reflected color for dielectrics

Figure 04

Dielectric F0

The F0 for common dielectric materials is typically set to 0.04 (linear) 4% reflective. In the metal/ roughness workflow, this value is hardcoded in the shader at this 4% value.

Some metal/roughness implementations such as those found in the Substance toolset and Unreal Engine 4 have a specular control, which allows the artist to change the constant F0 value for dielectrics. In Substance, this output is labeled as "specularLevel" and is supplied by a texture sampler in the metal/ roughness PBR shader. It represents the range of 0.0 - 0.08 as shown in figure 05. This range is remapped in the shader to 0.0-1.0 where 0.5 represents 4% reflective

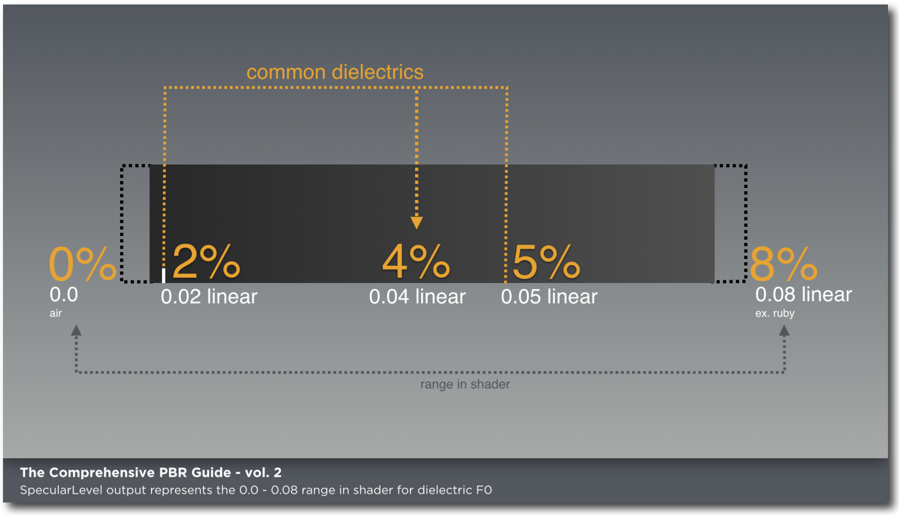


Figure 05 *Conversions from sRGB to linear were done using the gamma 2.2 approximation. See linear space rendering in Vol.1 for more details.*

If you need to manually set the F0 for a dielectric, you can do so using the "specularLevel" output in the Substance graph within Substance Designer as shown in figure 06. We will discuss F0 for dielectrics in depth in the specular/ glossiness workflow as you have full control over F0 in the specular workflow.

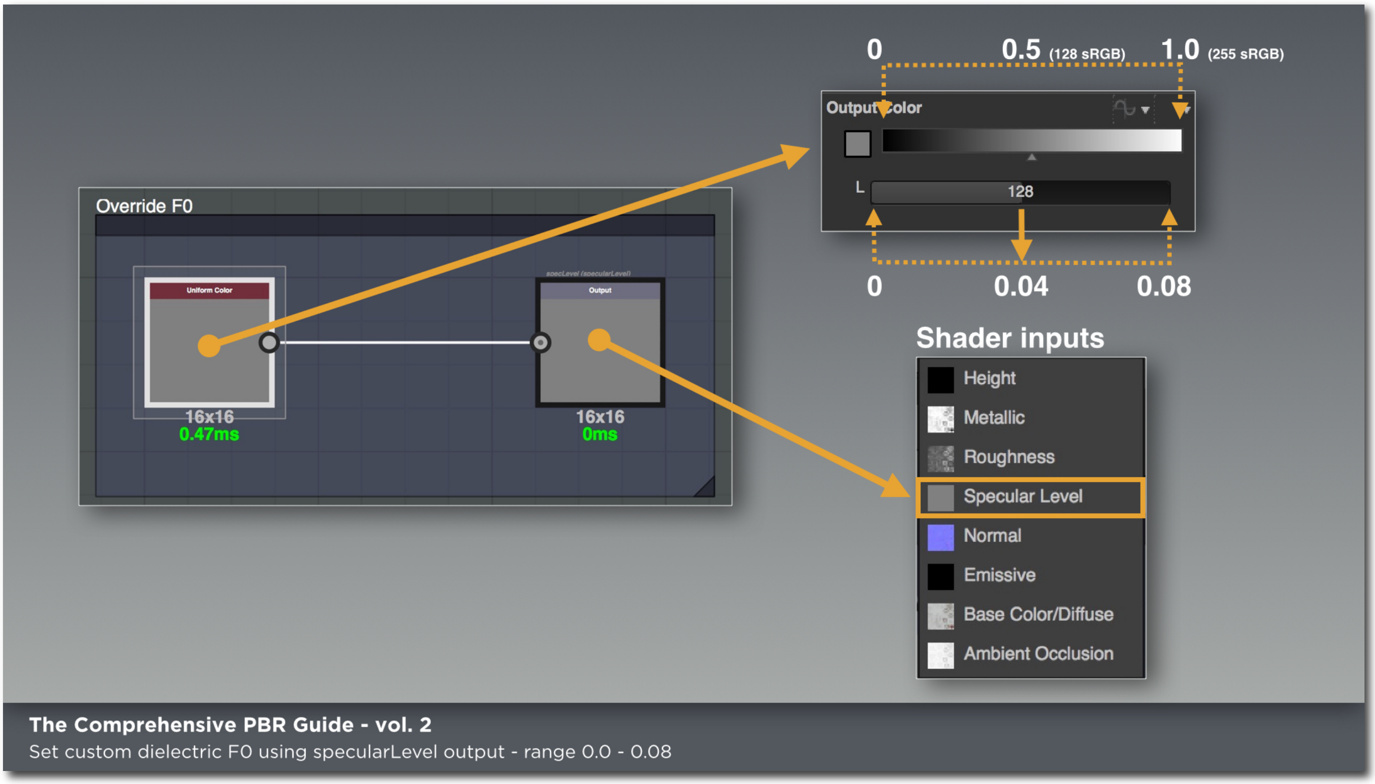


Figure 06

Base Color (RGB - sRGB)

The base color map is an RGB map that can contain 2 types of data: reflected color for dielectrics and reflectance values for metals as shown in figure 07. The color that represents dielectrics represents reflected wavelengths as discussed in Volume One. The reflectance values are present if an area is denoted as metal in the metallic map.

Creation Guidelines

The base color map can be thought of as somewhat flat in tonality i.e. lower contrast than a traditional diffuse map. You don't want to have values too bright or too dark. Objects are actually much lighter in terms of tone than we may remember them in our minds. We can visualize this range in terms of the darkest substance being coal and the brightest being fresh white snow. For example, coal is dark, but it is not 0.0 black. The color values we choose need to stay within a brightness range. In regards to brightness ranges, I am mostly referring to dielectric reflected color. In figure 08, you can see an example where the dirt value has fallen below the correct brightness range. For dark values, you should not go under 30 - 50 sRGB. The range for dark values could be more tolerant at 30 sRGB and stricter at 50 sRGB. For bright colors, you should not have any values that go above 240 sRGB.

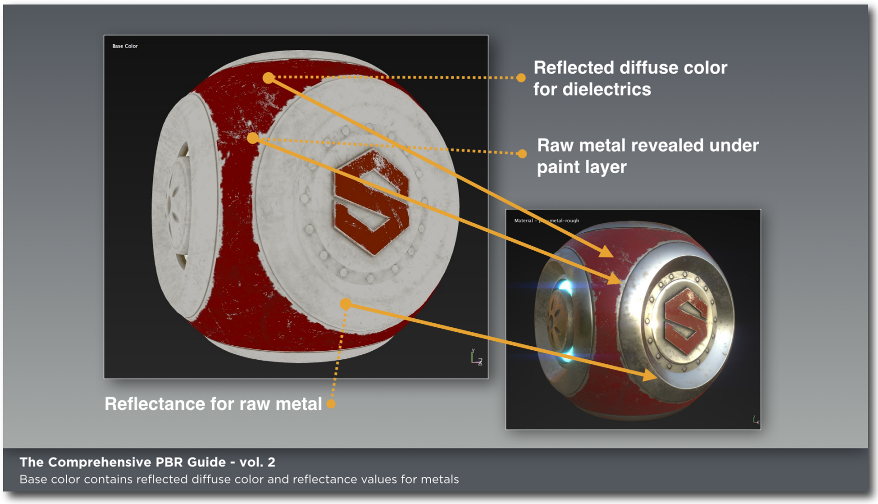


Figure 07

We stated that the base color contains data for reflected light in terms of dielectric materials and thus it should be devoid of lighting information such as ambient occlusion. There can be exceptions for adding micro-occlusion in cases where the shader would not be able to represent this level of detail with only an ambient occlusion channel as shown in figure 09. However, if micro-occlusion is added to the map, it still needs to be governed by the brightness ranges.

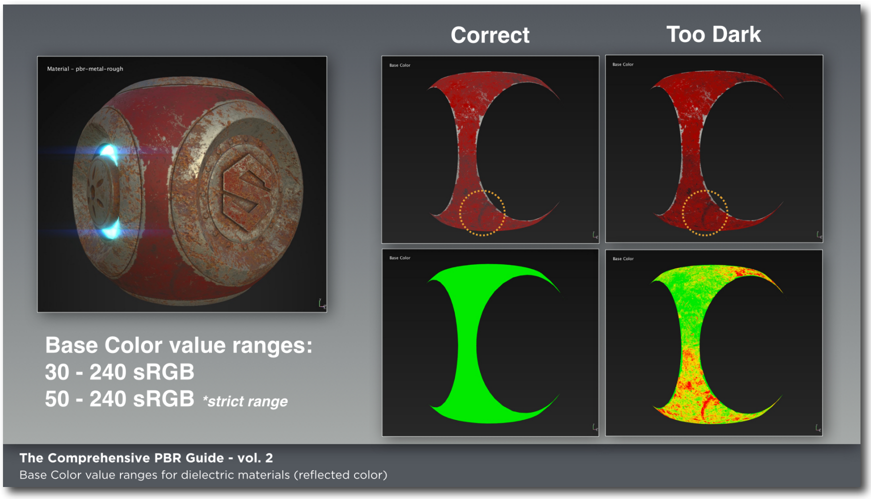


Figure 08

The values in the map that indicate the reflectance values for metals should be obtained from real-world measured values. These values are going to be around 70-100% specular, which we can map to an sRGB range of 180-255. In the Substance PBR Utilities section, we will discuss tools that provide preset F0 values for common materials. Also, the metal/roughness charts provided by Sébastien Lagarde are great resources as well.

http://seblagarde.wordpress.com/2014/04/14/dontnod-physically-based-rendering-chart-for-unreal-engine-4/

Figure 09

Values that indicate the reflectance values for metals should be obtained from real-world measured values

1. Color represents albedo for non-metal materials and reflectance values for metals.
2. Base color should be devoid of lighting information with the exception of micro-occlusion.
3. Dark values should not go below 30 sRGB (tolerant range) - 50 sRGB (strict range).
4. Bright values should not go above 240 sRGB.
5. Reflectance for raw metal is going to be high in the range of 70-100% specular, which we can map to 180-255 sRGB.

As you will read in the Metallic section below, the base color also can contain metal reflectance values. If dirt or oxidation is added to the base color, then this will cause the metal reflectance value to be lowered to a range that should not be considered as raw metal. The addition of dirt or oxidation must also be accounted for in the metallic map. The metallic map value must then also be lowered in these areas to denote it is no longer being considered as raw metal. For example, in figure 10 you can see that rusted metal is treated as dielectric and set to black in the metallic map.

The metallic map operates similarly to a mask as it tells the shader how it should interpret data found in the base color.

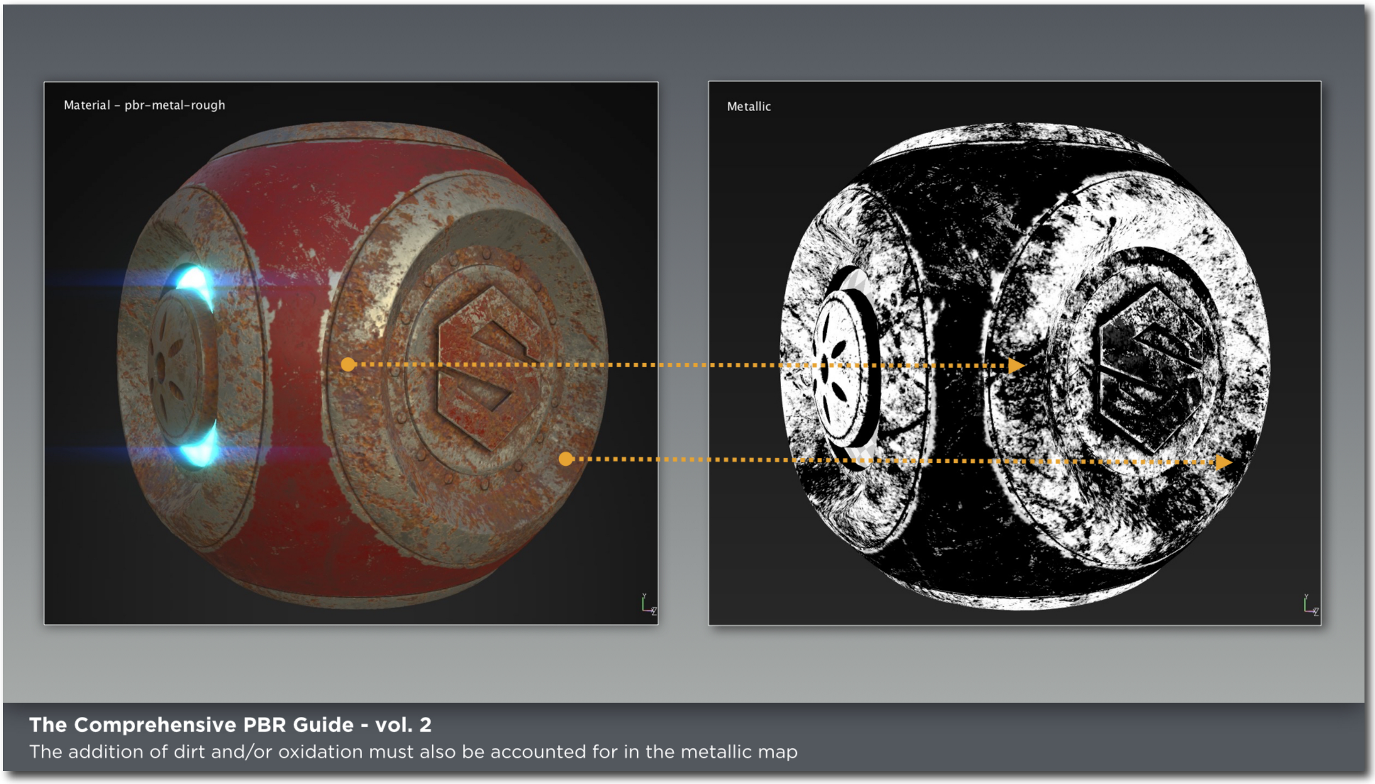


Figure 10

Metallic (Grayscale - Linear)

The metallic map is used to define which areas of a material denote raw metal. The metallic map is a grayscale map. It operates similarly to a mask as it tells the shader how it should interpret data found in the base color. The data in the metallic map doesn't contain real-world data that is directly used as material value. It simply describes to the shader which areas in the base color should be interpreted as reflected color (dielectric) and which areas denote metal reflectance values. In the metallic map, 0.0 (black - 0 sRGB) represents non-metal and 1.0 (white - 255 sRGB) represents raw metal. In terms of defining raw metal and non-metal, this metallic map is often binary i.e. black or white, metal or non-metal. In practice, when the shader looks at the metal map and sees white, it then checks the corresponding areas in the base color map to get the reflectance values for the metal as shown in figure 11.

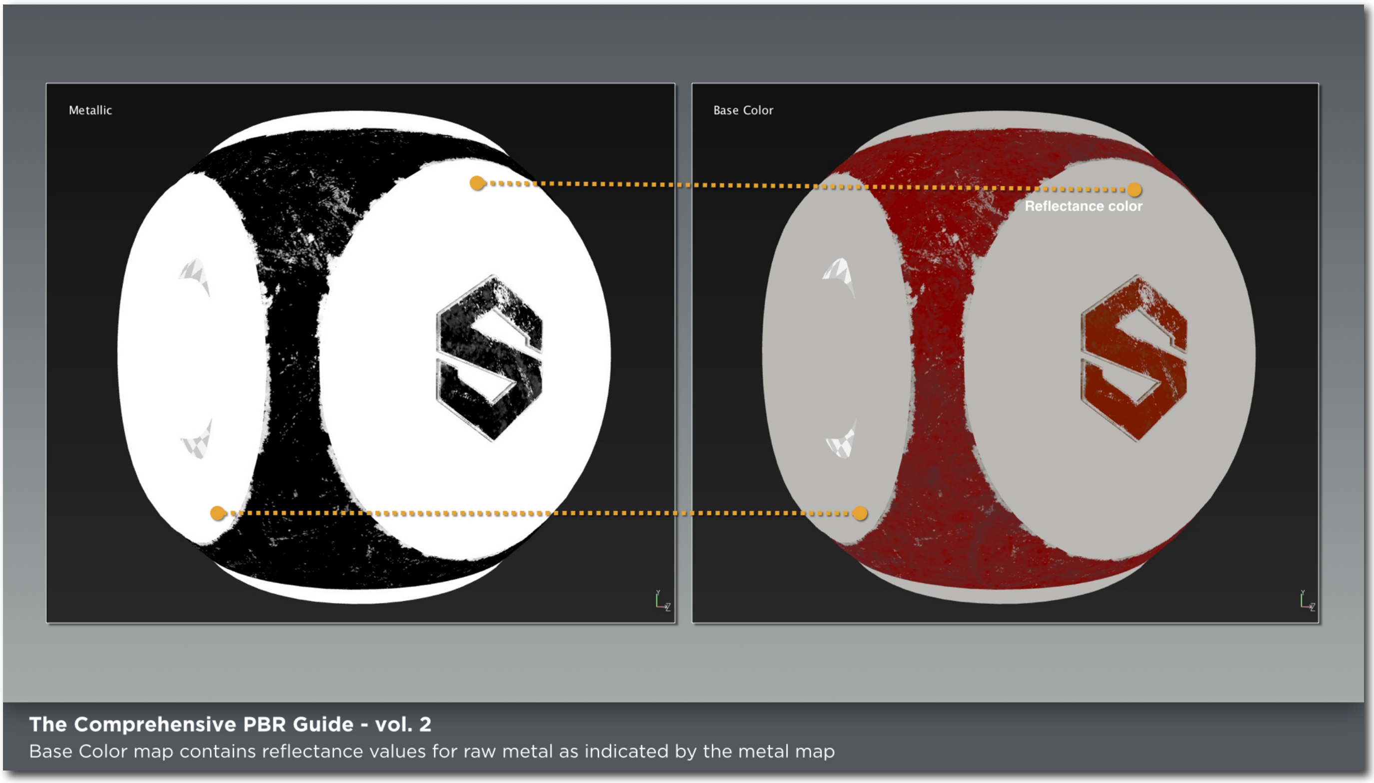


Figure 11

Creation Guidelines

Metal surfaces have two important aspects as it relates to texturing, which are that their reflectance values are going to be high in the range of 70-100% specular and some metals can be corroded. We will look at these two aspects individually as we discuss the creation guidelines.

For metal areas that fall in this range, they will need to have a reflectance range of 70-100% reflective

Raw Metal

The metal map is to be authored as 0 or 1, metal or not, and is used to define a raw, polished metal state. As a general guide, the grayscale range for raw metal will be defined as 235 – 255 sRGB in the metal map. For metal areas that fall in this range, they will need to have a reflectance range of 70-100% reflective in the base color map which we can map to 180-255 sRGB as shown in figure 12. Again, these values are based on real-world measured data.

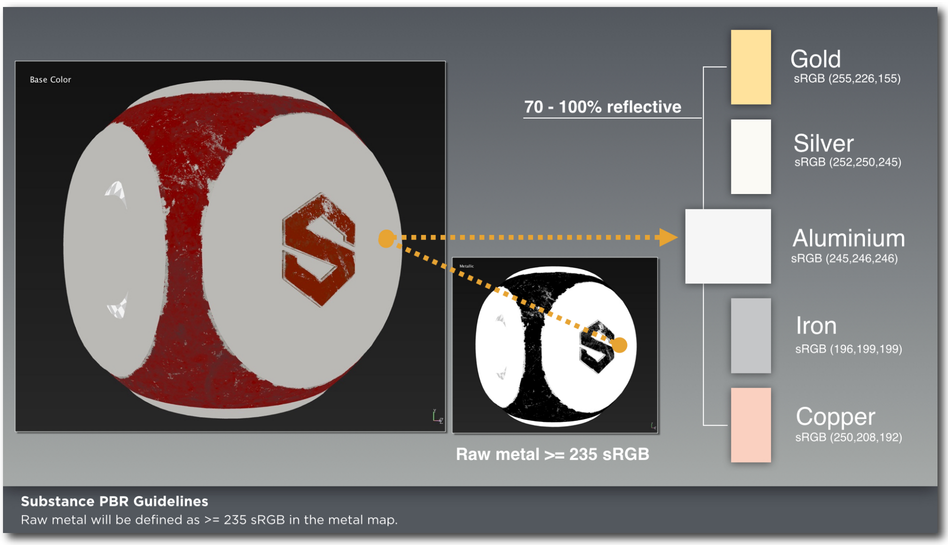


Figure 12

Corroded or dielectric layer

When weathering a surface, the metal may need to be regarded as oxidized or compensate for other environmental aspects such as dirt and grime layers. Metal that is oxidized needs to be treated as dielectric e.g. rusted metal. The same is true for metal that has been painted. For example, if you look at painted metal where portions of the paint have scratched or chipped away, the metal exposed is the "raw" metal (white in the metallic map) and the paint is a dielectric layer (black in the metallic map) as shown in figure 13.

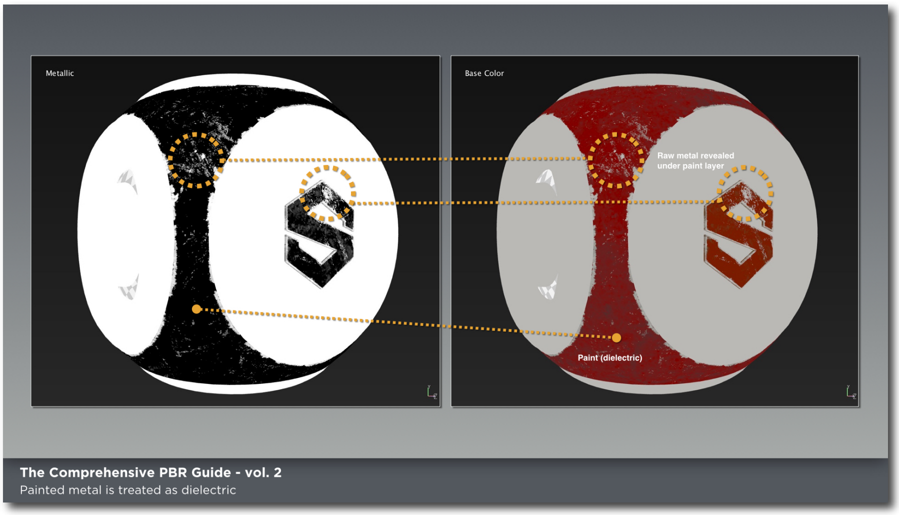


Figure 13

The metallic map can represent a blended state between metal and non-metal that is represented by transitional gray values in the map. The key is that if the metallic map has gray values lower than 235 sRGB, then you would need to lower the "raw" metal reflectance value in the base color. For example, think of a dirt layer that partially obscures portions of raw metal as shown in figure 14. The dirt is dielectric and if you were to leave the metallic map at full white, then it would treat these dirt areas in the base color as the reflectance value for metal. The dirt color value is much lower than the value needed in order to represent the 70-100% reflectance for polished metals. By lowering the metallic map value in areas represented by the dirt, you create the appropriate blend between the dielectric and metal reflectance values.

The opacity of the dirt layer can indicate how much to lower the reflectance value in the base color. There are no hard-and-fast rules here. What you are doing is moving from a high-reflectance surface (conductive) to a lower reflectance surface (dielectric). However the degree in which this transition is taking place may vary.

The Substance toolset allows you to easily work with weathering effects and control how the effect will propagate to the channels through multi-channel support. Substance Designer and Substance Painter allow you to change parameters on a Substance effect, which will automatically adjust the channels that are controlled by the Substance effect. For example, in Substance Designer, you can use a Material Color Blend node to apply an effect such as dirt across multiple channels. On the Material Color Blend, you can control the dirt layer's effect on metal by adjusting the metallic value slider as shown in figure 15.

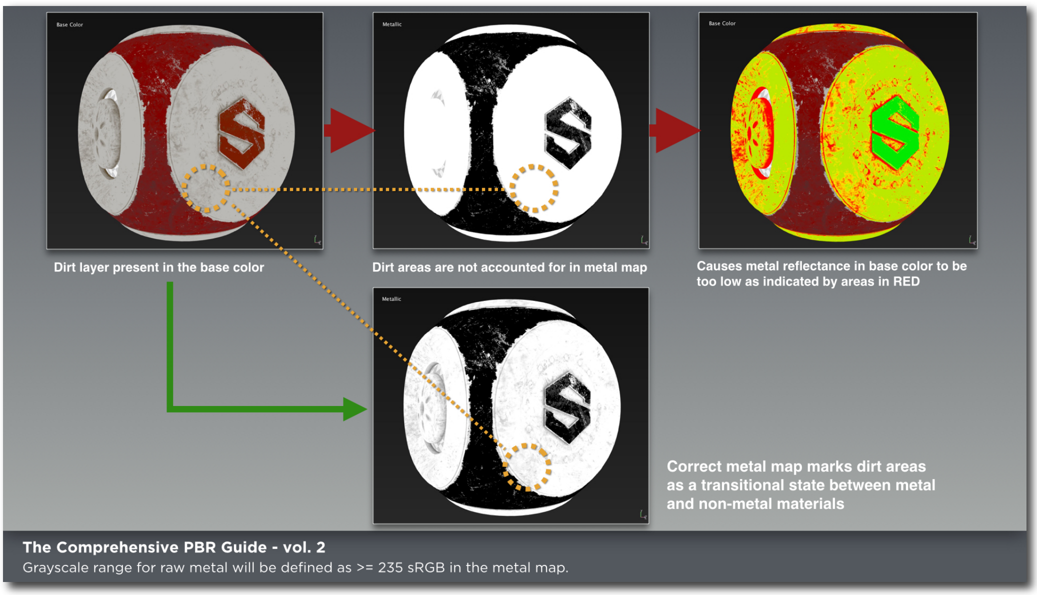
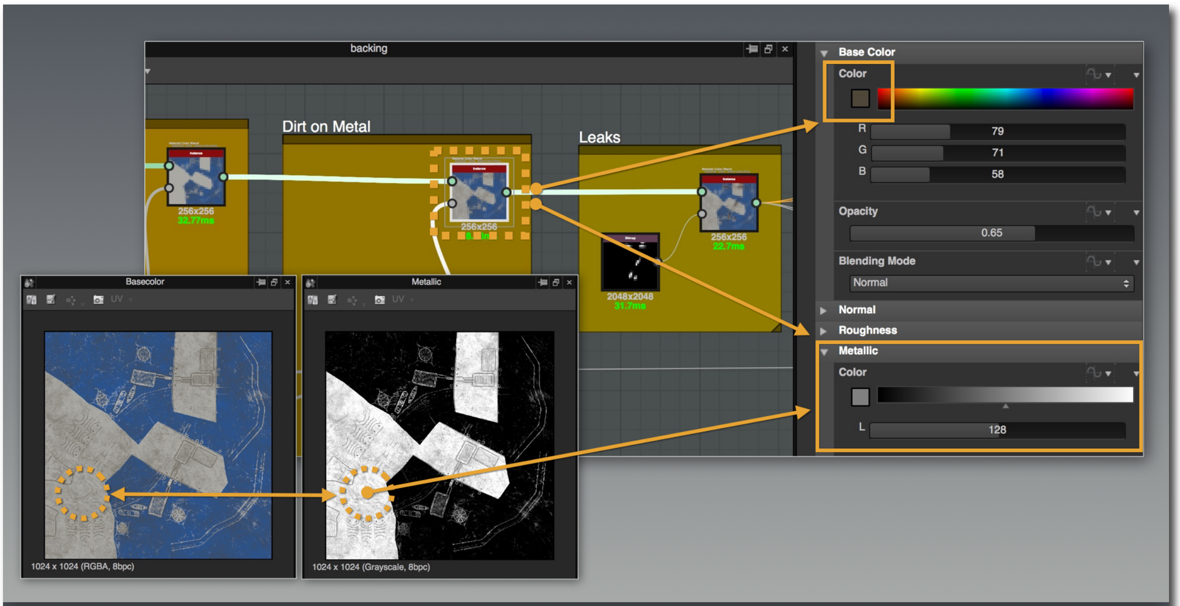


Figure 14

Metal that is oxidized needs to be treated as dielectric e.g. rusted metal. The same is true for metal that has been painted



The Comprehensive PBR Guide - vol. 2
Material Color Blend - Lower metallic value indicates thin dirt layer (transitional state between dirt and metal)

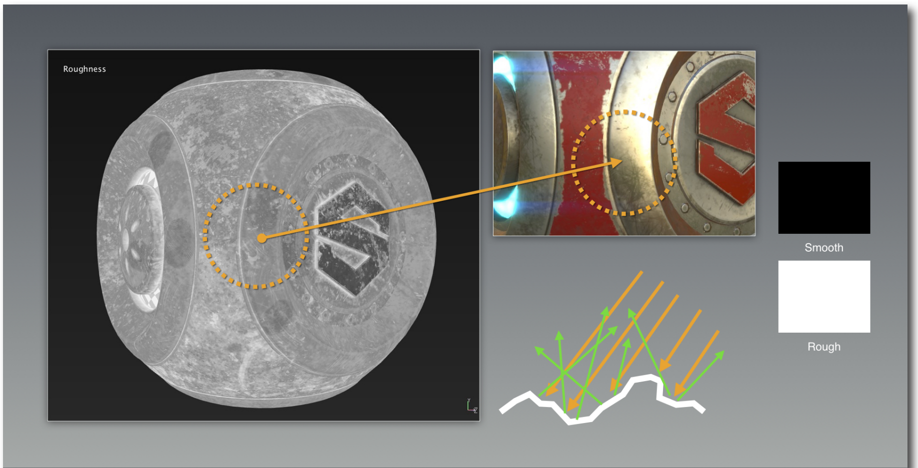
Figure 15

1. Black (0.0) is non-metal and white (1.0) is metal. There can be transitional grayscale values to account for oxidation or dirt.

2. If metal map has values lower than 235 sRGB, then the reflectance value needs to be lowered in the base color map.

Roughness (Grayscale - Linear)

The roughness map describes the surface irregularities that cause light diffusion as shown in figure 16. As discussed in Volume One, the reflected direction will vary randomly based on the surface roughness. This changes light direction, but the light intensity remains constant. Rougher surfaces will have larger and dimmer looking highlights. Smoother surfaces will keep specular reflections focused, which can appear to look brighter or more intense even though the same total amount of light is reflected.



The Comprehensive PBR Guide - vol. 2
The roughness map describes the surface irregularities that cause light diffusion

Figure 16

In this map, black (0.0) represents a smooth surface and white (1.0) represents a rough surface. The roughness map is the most creative map as it allows the artist to visually define the character of a surface. In essence, it allows you to creatively tell a story about the condition of a surface. What is its environment? Has it been handled with care or disregard? Has it been exposed to the elements? The condition of a surface tells a lot about the environment it is in and thus further relates to the overall design of the assets and worlds you are trying to create.

With roughness, there isn't really a right or wrong. The artist has full creative control. A good place to start with roughness is the normal map. The normal map will often contain key surface details that should also be represented in the roughness map as well.

Creation Guidelines

1. Be creative and tell a visual story about the surface.

Resolution and Texel Density

A byproduct of using the metal/roughness workflow is that it can produce a white edge artifact as shown in figure 17. We are discussing the metallic workflow, but this issue also appears with the specular/glossiness workflow as well. However, it is not nearly as visible because the effect is reversed i.e. there is a black fringe instead of white as shown in figure 18.

This fringe is apparent in the transitional areas between materials where it goes from a dielectric to a very bright metal due to texture interpolation as shown in figure 19. With metal/roughness, the base color contains a brighter value for the metal reflectance that is interpolated with the non-metal diffuse color, which produces the white edge. With specular/glossiness, the diffuse map contains black since raw metal has no diffuse color. The black value is interpolated with the non-metal diffuse color, which in turn, produces a black fringe.

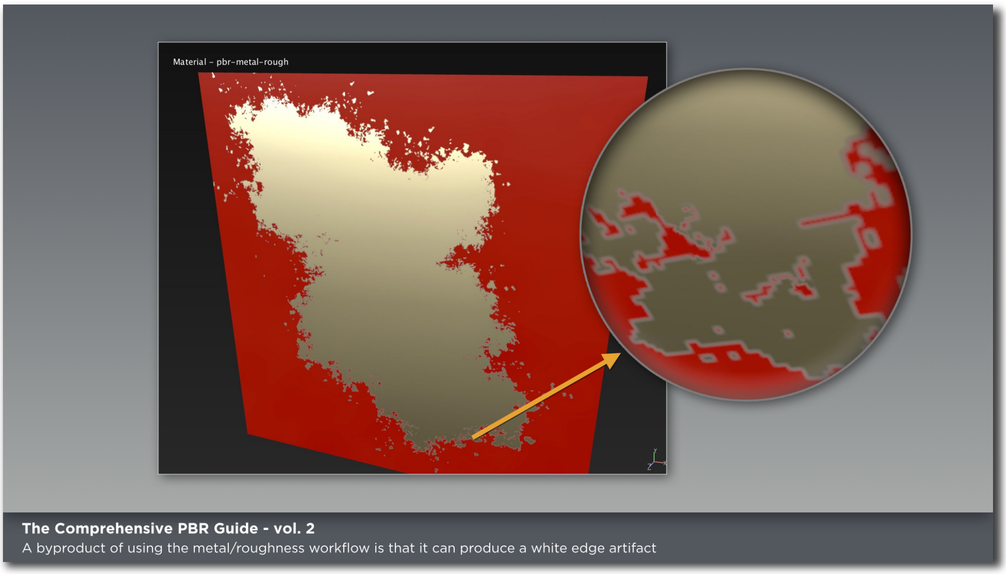


Figure 17

The document resolution and texel density have a direct impact on the visibility of edge artifacts. For example, if you use a hard edge brush to create the transitional areas between metal and non-metal, a low document resolution will still soften the edge and thus exacerbate the artifact. This low-resolution issue is also caused by UVs that are not scaled to provide an adequate texel density based on the document resolution. Providing a good texel density for UVs is the best method for minimizing any edge artifacts shown in figure 20. In figure 20, both texture sets are using the same 2048 pixel resolution. However, the image on the right shows a poor UV layout with a low texel density.

The document resolution and texel density have a direct impact on the visibility of edge artifacts

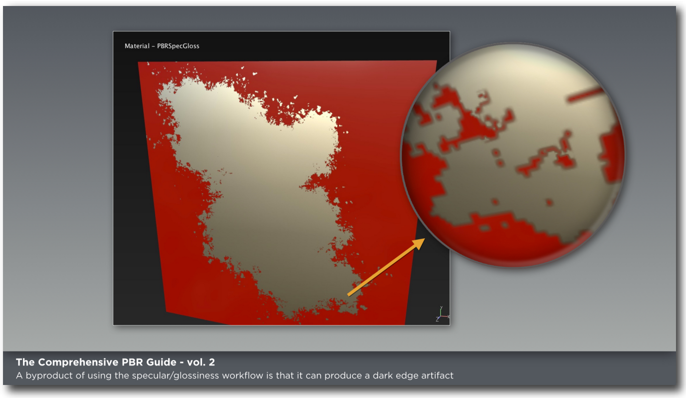


Figure 18

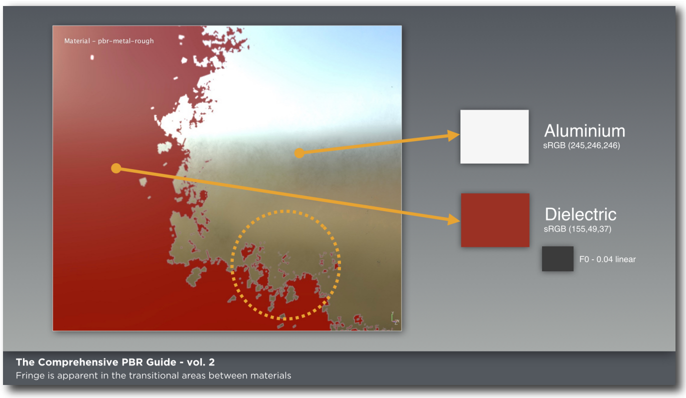


Figure 19

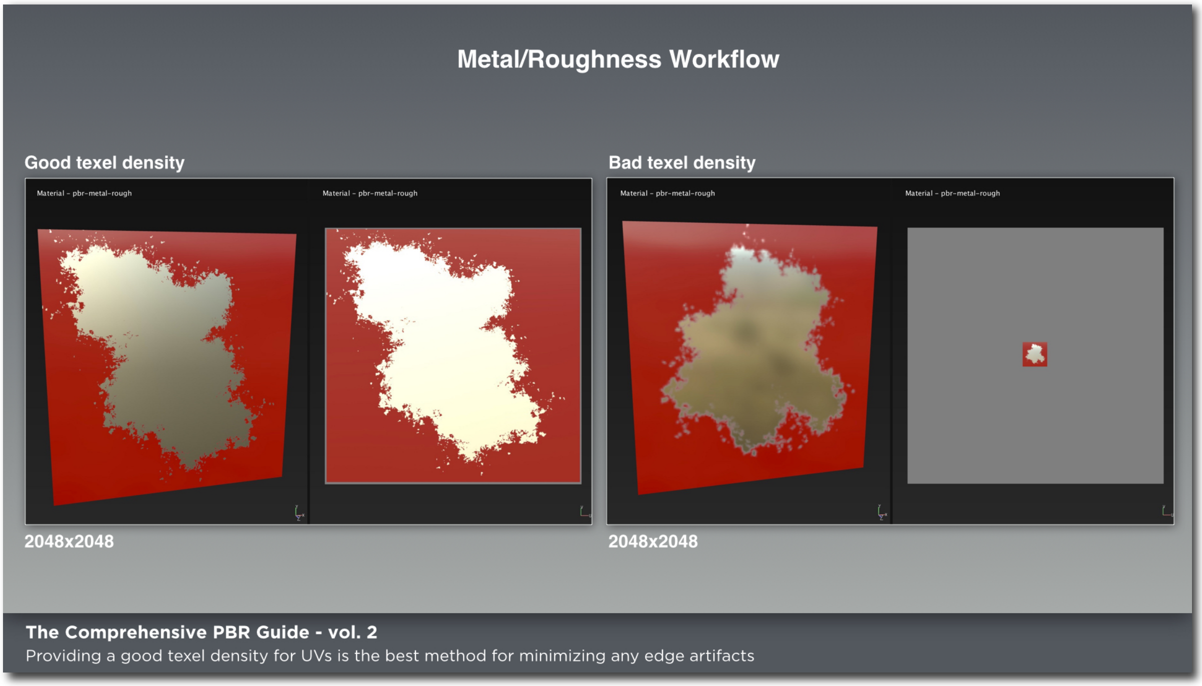


Figure 20

Creation Guidelines

1. Texel density and resolution impact the white edge that can appear in the metal/roughness workflow. Be sure that your UVs provide an adequate density to match the document resolution to minimize artifacts.

Pros and Cons of the Metal/Roughness Workflow

Pros

1. Can be easier to author and less prone to errors caused by supplying incorrect dielectric F0 data.

2. Uses less texture memory, as metallic and roughness are both grayscale maps.

3. Seems to be a more widely adopted workflow.

Cons

1. No control over F0 for dielectrics in map creation. However, most implementations have a specular control to override the base 4% value.

2. Edge artifacts are more noticeable especially at lower resolutions.

Specular/Glossiness Workflow

Just as with metal/roughness, the specular/glossiness workflow is defined through a set of maps, which are fed as textures to a sampler in the PBR shader. The maps specific to the specular/glossiness workflow are diffuse, specular and glossiness as shown in figure 21. Although the specular/glossiness workflow uses more familiar names such as diffuse and specular, it is important to make the distinction that these maps are not the same as their traditional counterparts. Substance uses the term diffuse, but some implementations may refer to diffuse as albedo. The PBR shader will also utilize ambient occlusion, normal and possibly height for parallax mapping, which as mentioned earlier, will be discussed in the "Maps common to both workflows" section.

In this workflow, the reflectance values for metal and F0 for non-metal materials are placed in the specular map. With the specular/glossiness workflow, you have 2 RGB maps: one for diffuse color (albedo) and another for reflectance values (specular). With the specular map, you have control over the F0 for dielectric materials within the map itself.

As we stated in the metal/roughness workflow, the PBR shaders in Substance handle energy conservation. This becomes even more important in the specular/glossiness workflow as the specular map provides full control over the dielectric F0, which means the map is more susceptible to contain incorrect values. For example, a white (1.0) diffuse and a white (1.0) specular value can combine to reflect/refract more light than was initially received, which in turn breaks the law of conservation. This means that when authoring the textures, you wouldn't see the actual result corresponding to the texture data.

As you will see, the data that the maps are representing is the same as in the metal/roughness workflow. We will follow the same guidelines, however, the difference will be in how the maps are authored. The data will be placed in different maps, but we will follow the same principles. As stated earlier, all values, such as dielectric F0, metal reflectance and brightness ranges for albedo color, are derived from actual measured data. As we look at each map type, guidelines will be discussed, which are based on measured data. In this section, I will not repeat the exact information as it was covered in the metal/roughness section. Instead, I will focus on the differences and where distinctions need to be made for the specular/glossiness workflow.

Figure 21

Diffuse (RGB - sRGB)

Just as with the base color map from the metal/roughness workflow, the diffuse map contains albedo color. However, it doesn't contain any reflectance values.

Creation Guidelines

The diffuse map is only albedo color. The areas that indicate raw metal will be black (0.0) because metal doesn't have a diffuse color as shown in figure 22. In the case where oxidation has occurred, the metal area would contain color, as it's no longer treated as raw metal. The same is true for dirt or other effects that create a dielectric layer over the raw metal.

The guidelines for the diffuse map in terms of tonality are the same as the base color map. However, the exception is that if raw metal is present, then a value of 0.0 (black) is allowed and it is not governed by the guidelines for the darkness ranges.

1. Color represents albedo for non-metal materials and black (0.0) for raw metal.
2. Base color should be devoid of lighting information with the exception of micro-occlusion.
3. Dark values should not go below 30 sRGB (tolerant range) - 50 sRGB (strict range) except black for raw metal.
4. Bright values should not go above 240 sRGB.

Figure 22

Specular (RGB- sRGB)

The specular map defines the reflectance values for metal and the F0 for non-metal as shown in figure 23. This RGB map allows for different values for dielectric materials to be authored in the map. This is different from the metal/ roughness workflow where dielectrics are hard-coded at 4% reflectivity and can be modified only through the specularLevel channel. Just as we covered with the metal/roughness workflow, the F0 data should be derived from real-world measured values. The F0 for dielectrics will be a grayscale value and the metal reflectance can be colored as some metals absorb light at different wavelength.

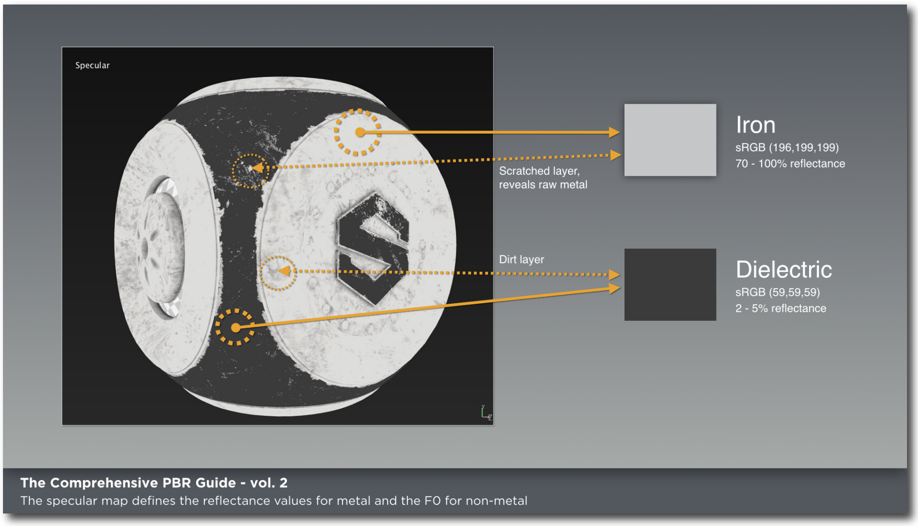


Figure 23

The specular map allows for different values for dielectric materials to be authored in the map

Creation Guidelines

Since the specular map contains the F0 value for both metals and non-metals, we will break the map into a separate category for each material type.

Raw Metal

The F0 value should be based on real-world data. Just as we covered in the metallic map, the reflectance for raw metal will need to be lowered if there is oxidation or some layer that indicates non-metal. In the case of the specular/ glossiness workflow, dirt or oxidation will raise the diffuse color for raw metal in the diffuse map and lower the reflectance value in the specular map as shown in figure 24. (IMAGE) Also shown in figure 24 is an example of a dirt layer on raw metal. The dirt in the specular map contains the appropriate F0 value for dielectric. In this case, I am using 0.04 or 4%.

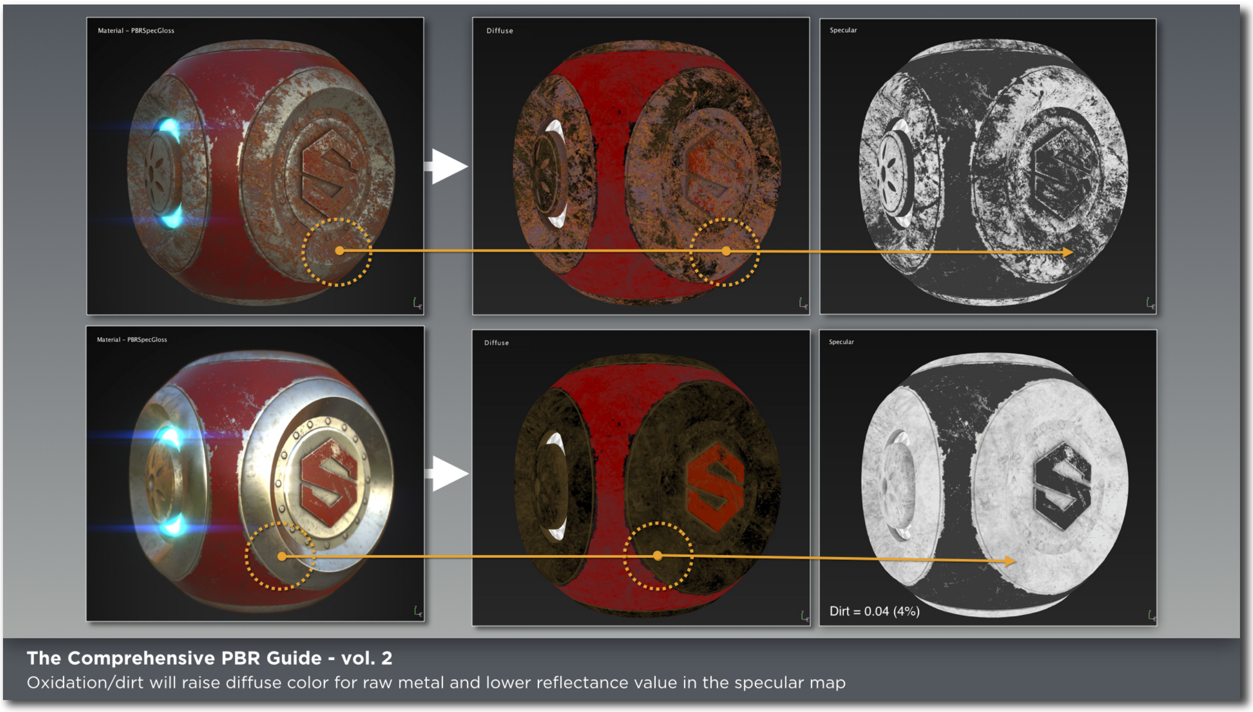


Figure 24

Dielectric

The F0 for dielectric materials is authored in the specular map as well. Here you have full control over the F0 value, however, it is important to use the correct data. As we discussed in Volume one, non-metals (insulators/dielectrics) are poor conductors of electricity. The refracted light is scattered and/or absorbed (often re-emerging from the surface) and thus they reflect a much smaller amount of light than metals. We stated that the value for common dielectrics would be around 2-5% based on the F0 as computed by the index of refraction (IOR). With the exception of gemstones, the F0 can be within the 0.02-0.05 (linear) range for common dielectric materials as shown in figure 25. In terms of sRGB, we are looking at a scale of values between 40-75 sRGB, which overlap the linear 0.02-0.05 (2-5%) range.

If you can't find an IOR value for a specific material, you can use 4% (0.04 - plastic). Gemstones are an exception and they have a range of 0.05-0.17 (linear) as was shown in figure 21. In the metal workflow, the shader is mapped to a range of 0.0-0.08 (linear) when using the specularLevel channel as zero is needed to represent air as shown in figure 25.

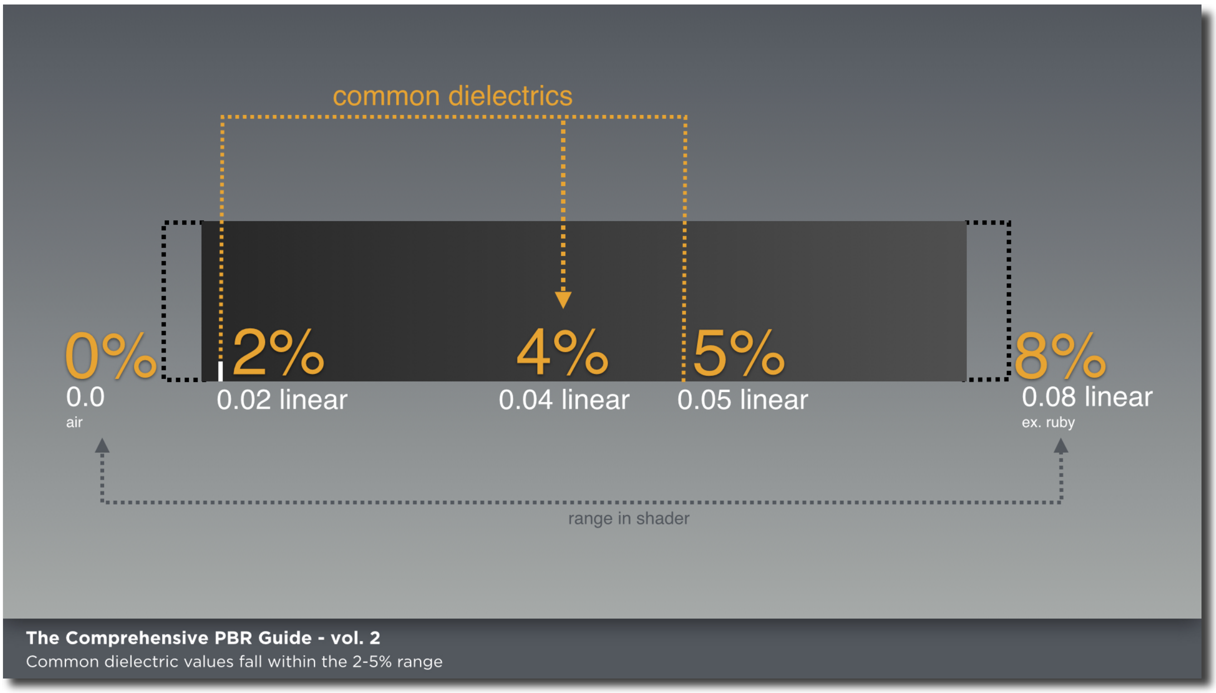


Figure 25

Conversions from sRGB to linear were done using the gamma 2.2 approximation. See linear space rendering in Vol.1 for more details.

1. Specular map contains F0 for dielectrics and the reflectance value for raw metal.
2. Dielectrics reflect a smaller amount of light than metals. The value for common dielectrics would be around 2-5% and in terms of sRGB, the values should be between sRGB 40-75, which overlaps 0.02-0.05 (linear) range.
3. Common gemstones fall within the 0.05-0.17 (linear) range.
4. Common liquids fall within the 0.02-0.04 (linear) range.
5. The reflectance value for raw metal is going to be high in the range of 70-100% specular, which we can map to 180-255 sRGB.
6. If you can't find an IOR value for a specific material, you can use 4% (0.04 - plastic).

Glossiness (Grayscale - Linear)

The glossiness map describes the surface irregularities that cause light diffusion as shown in figure 26. In this map, black (0.0) represents a rough surface and white (1.0) represents a smooth surface. It is the inverse to the roughness map in the metal/roughness workflow. This map has the same artistic guidelines as we covered in the roughness section above.

Describes the surface irregularities that cause light diffusion

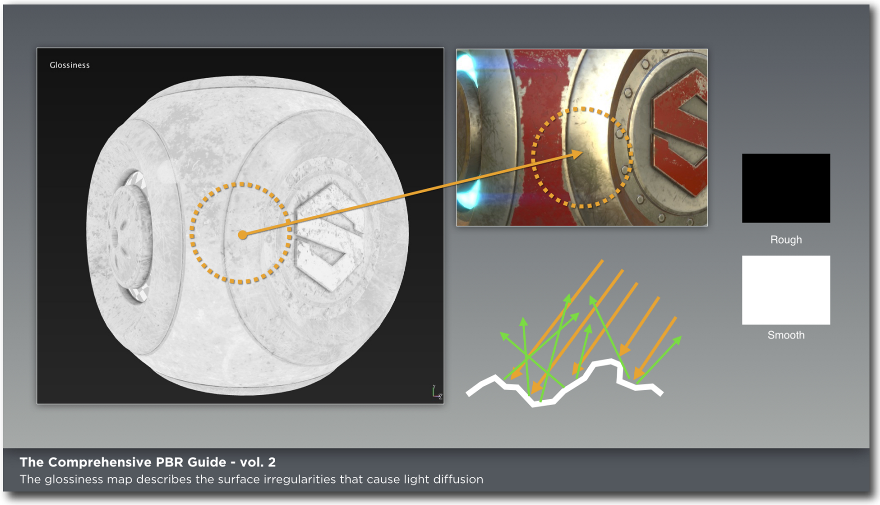


Figure 26

Creation Guidelines

1. Be creative and tell a visual story about the surface.

Resolution and Texel Density

We discussed earlier how edge artifacts could appear in both workflows. This was discussed in-depth in the metal/roughness section, as the edge artifacts are more apparent in that workflow. It was also mentioned that with specular/glossiness, the diffuse map contains black since raw metal has no diffuse color. The black value is interpolated with the non-metal diffuse color, which produces a black fringe as shown again in figure 27.

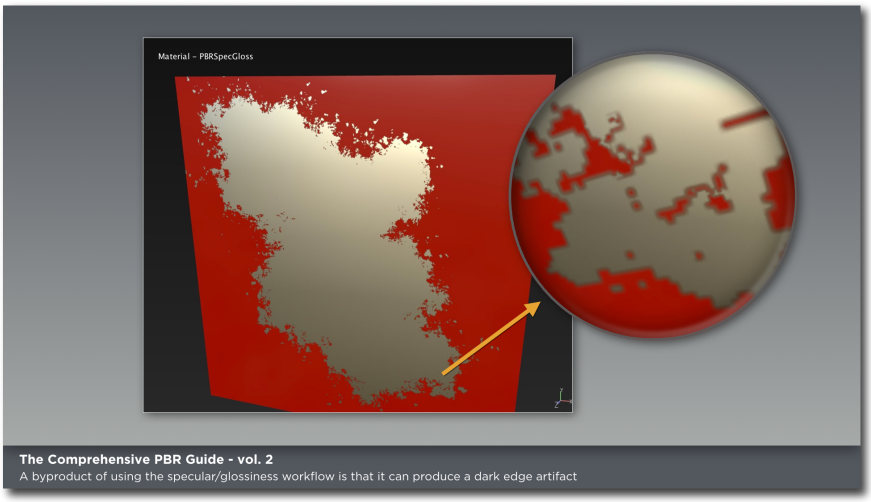


Figure 27

Here I will reiterate that the document resolution and texel density have a direct impact on the visibility of edge artifacts. For example, if you use a hard edge brush to create the transitional areas between metal and non-metal, a low document resolution will still soften the edge and thus exacerbate the artifact. This low-resolution issue is also caused by UVs that are not scaled to provide an adequate texel density compared to the document resolution. Providing a good texel density for UVs is the best method to control this issue as shown again in figure 28.

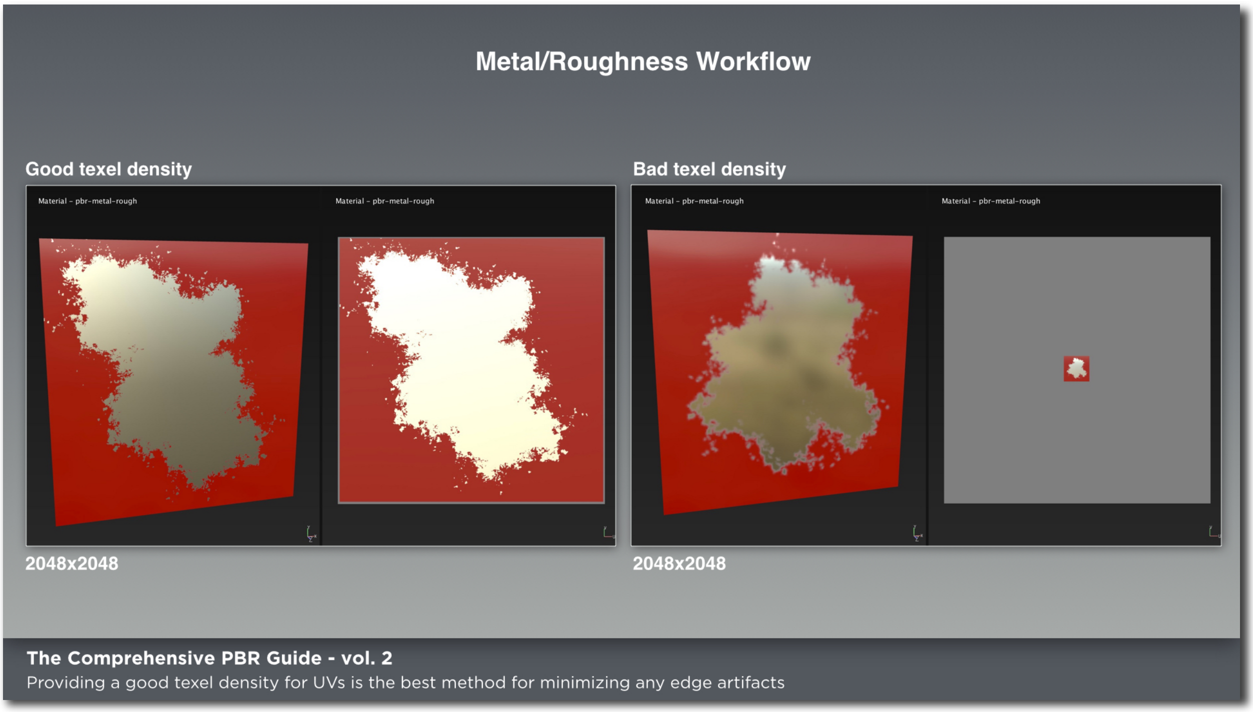


Figure 28

The document resolution and texel density have a direct impact on the visibility of edge artifacts

Creation Guidelines

1. Texel density and resolution impact the black fringe that can appear in the specular/glossiness workflow. Be sure that your UVs provide an adequate density to match the document resolution to minimize artifacts.

Pros and Cons of the Specular/Glossiness Worflow

Pros

1. Edge artifacts are less apparent.

2. Control over dielectric F0 in the specular map.

Cons

1. Because the specular map provides control over dielectric F0, it can be more susceptible to incorrect values being used. It is possible to break the law of conservation if it is not handled correctly in the shader.

2. Utilizes more texture memory with an additional RGB map.

3. Can be more confusing as it uses similar terminology to traditional workflows but requires different data. Also it requires more knowledge of physically based guidelines e.g. correct F0 for dielectrics, black for raw metal diffuse color and possible energy conservation if not handled in the shader.

Video walkthrough available at http://www.allegorithmic.com/pbr-guide

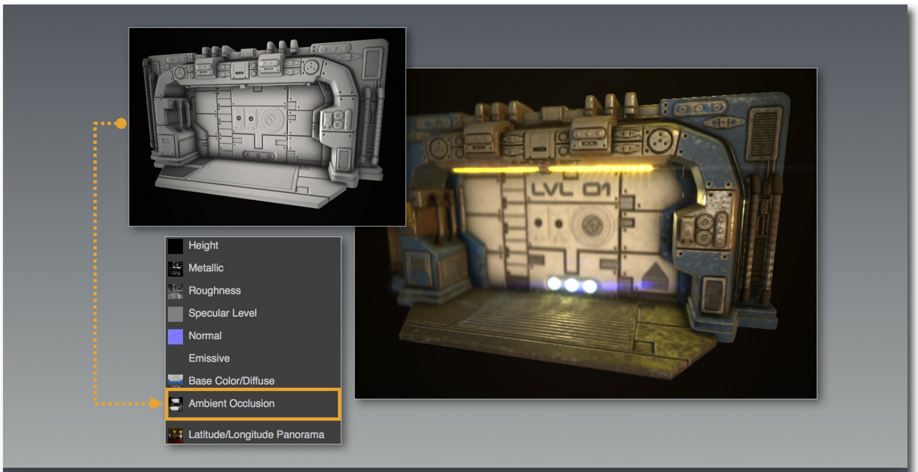
Maps common to both workflows

Ambient Occlusion

The ambient occlusion (AO) map defines how much of the ambient environment lighting is accessible to a surface point. It only affects the diffuse contribution and should not occlude the specular contribution. Some engines such as Unreal Engine 4 have an option for screen space reflection to simulate local reflections. The best combination is to use AO with screen space reflections.

In Substance PBR shaders, the ambient lighting (generated by the environment map) is multiplied by the AO. The AO map is supplied by a texture sampler in the PBR shader and is an optional channel as shown in figure 29. The AO should not be baked into texture maps, but only supplied as its own channel to the shader.

AO only affects the diffuse contribution and should not occlude the specular contribution

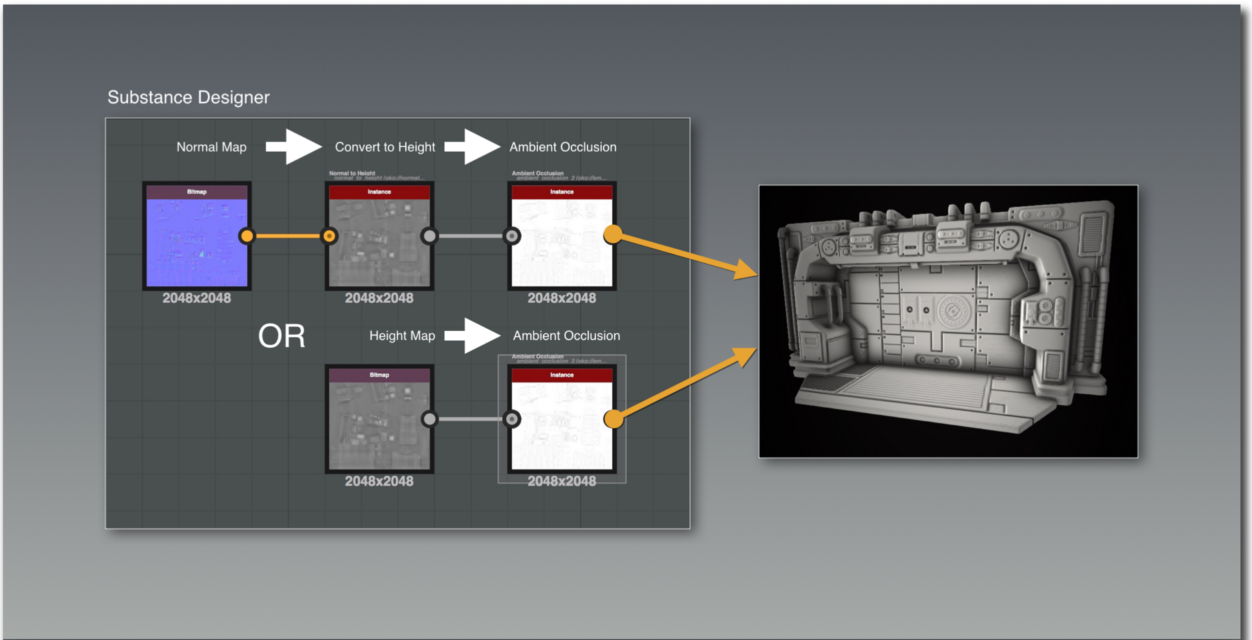


The Comprehensive PBR Guide - vol. 2
The AO should not be baked into texture maps, but only supplied as its own channel to the shader

Figure 29

Creating Ambient Occlusion

In Substance Designer, AO can be baked from a mesh or converted from a normal map using the integrated baking toolset. In addition, there is an ambient occlusion node for converting height to AO as shown in figure 30. Bitmap2Material can be used to generate AO from a source image as shown in figure 31.



The Comprehensive PBR Guide - vol. 2
Ambient Occlusion node for converting normal or height to AO

Figure 30

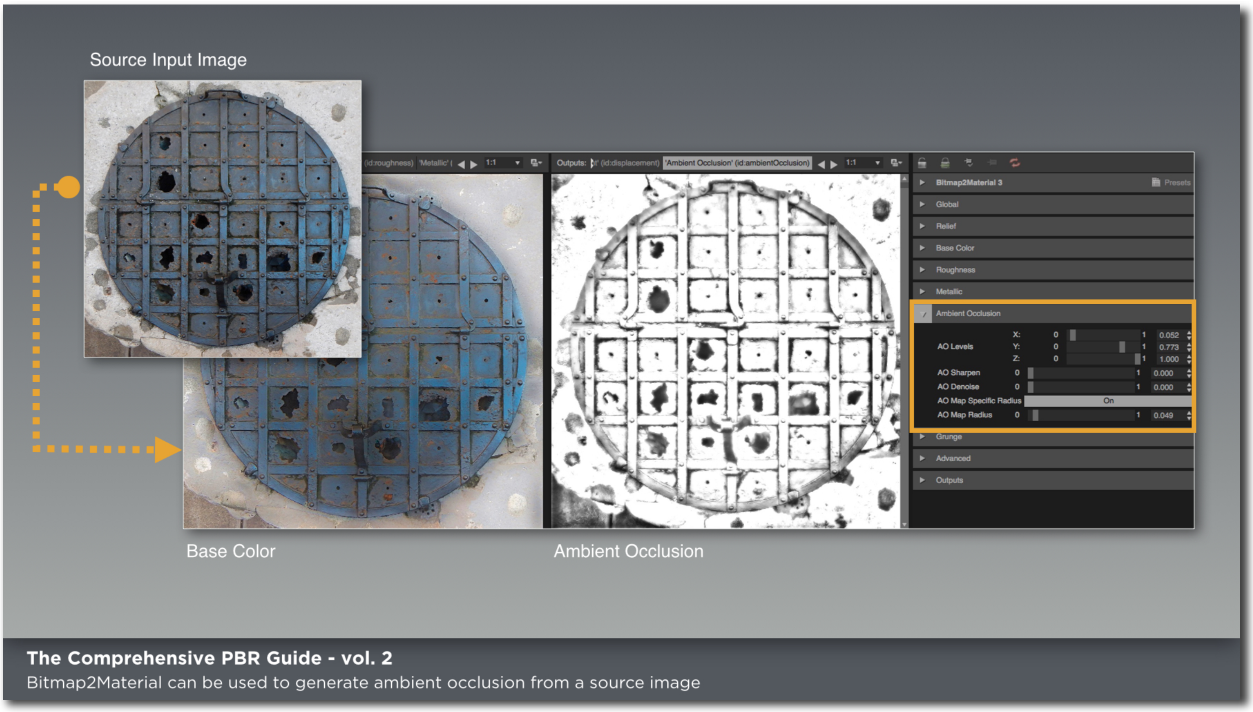


Figure 31

Height

A height map is often used for displacement in rendering and with PBR, it can be used for parallax mapping which helps to add more apparent depth and thus greater realism to normal and bump mapping as shown in figure 32. Substance Designer uses the relief mapping parallax algorithm. The height is supplied by a texture sampler in the PBR shader and is also an option channel. In Substance Designer, the effect can be controlled using the relief parameter on the shader as also shown in figure 32.

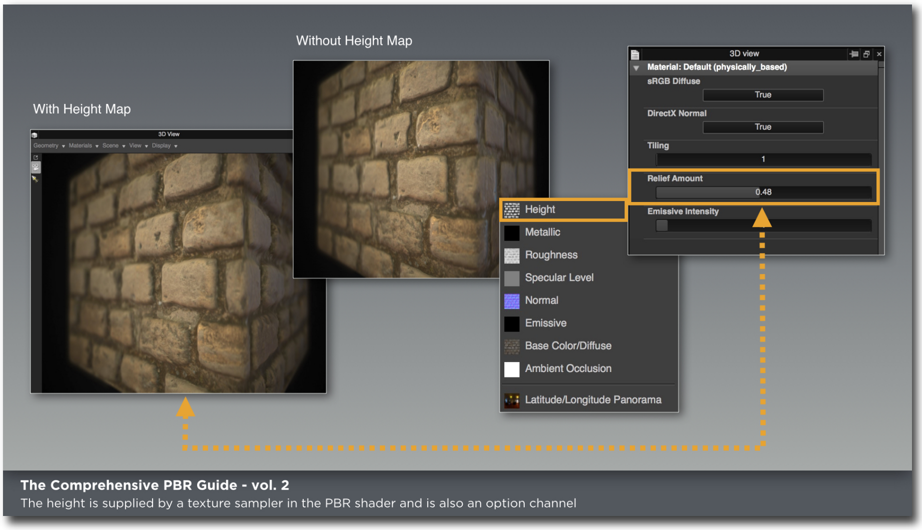


Figure 32

Height can be used for parallax mapping which helps to add more apparent depth and thus greater realism

Creating Height

Similar to AO, height can be baked in Substance Designer from a mesh using the integrated baking toolset. In addition, there is a normal to height node for converting height from a normal map as shown in figure 33. Bitmap2Material can be used to generate height from a source image as shown in figure 34. You can even paint height data using vector or bitmap painting tools in Substance Designer. However, the best method for painting height is by using Substance Painter to paint detail directly on the 3D mesh as shown in figure 35.

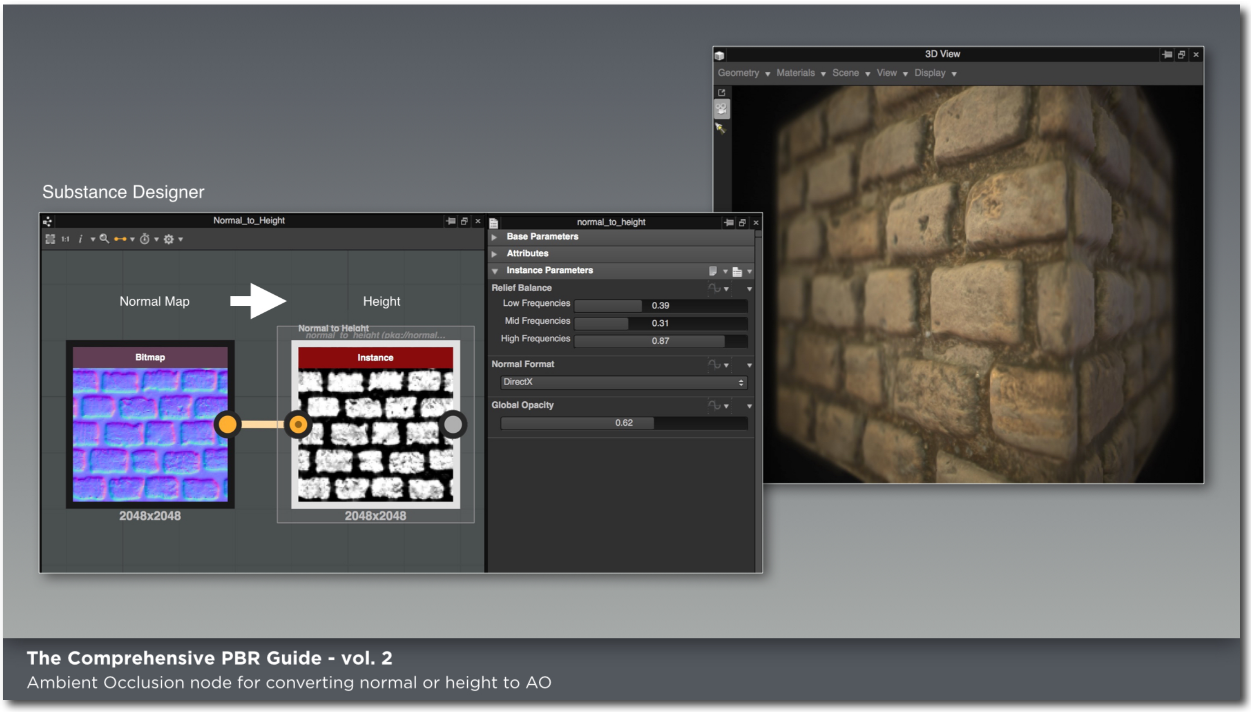


Figure 33

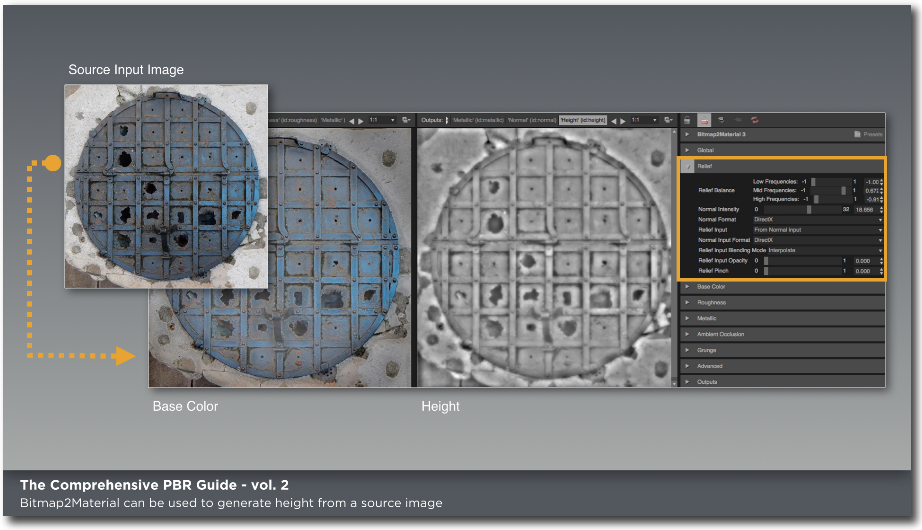


Figure 34

Bitmap2Material can be used to generate height from a source image

Height can be painted in Substance Painter

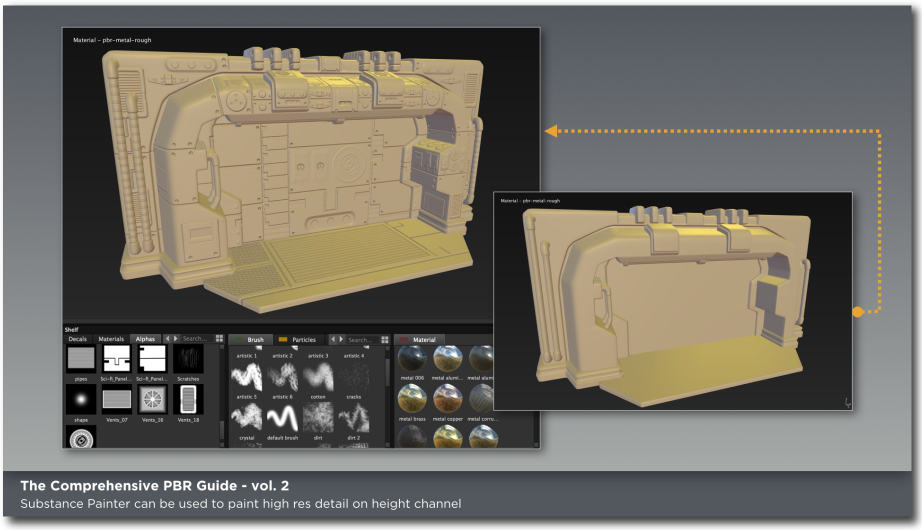


Figure 35

Normal

The normal map is used to simulate surface detail and its usage is the same in PBR as it is in non-PBR workflows. However, since the normal map simulates surface detail, it can be beneficial to have the surface details from the normal map also affect the roughness or glossiness maps as well.

Creating Normal

A normal map can be baked in Substance Designer from a mesh using the integrated baking toolset. In addition, there is a normal node for converting height into a normal map as shown in figure 36. Bitmap2Material can be used to generate a normal from a source image as shown in figure 37. You can paint height data using vector or bitmap painting tools in Substance Designer and convert them to normal data using the normal node. Height data painted in Substance Painter can be exported as a normal map and you can paint normal data direclty as well.

Normals can be baked or converted using the Substance toolset

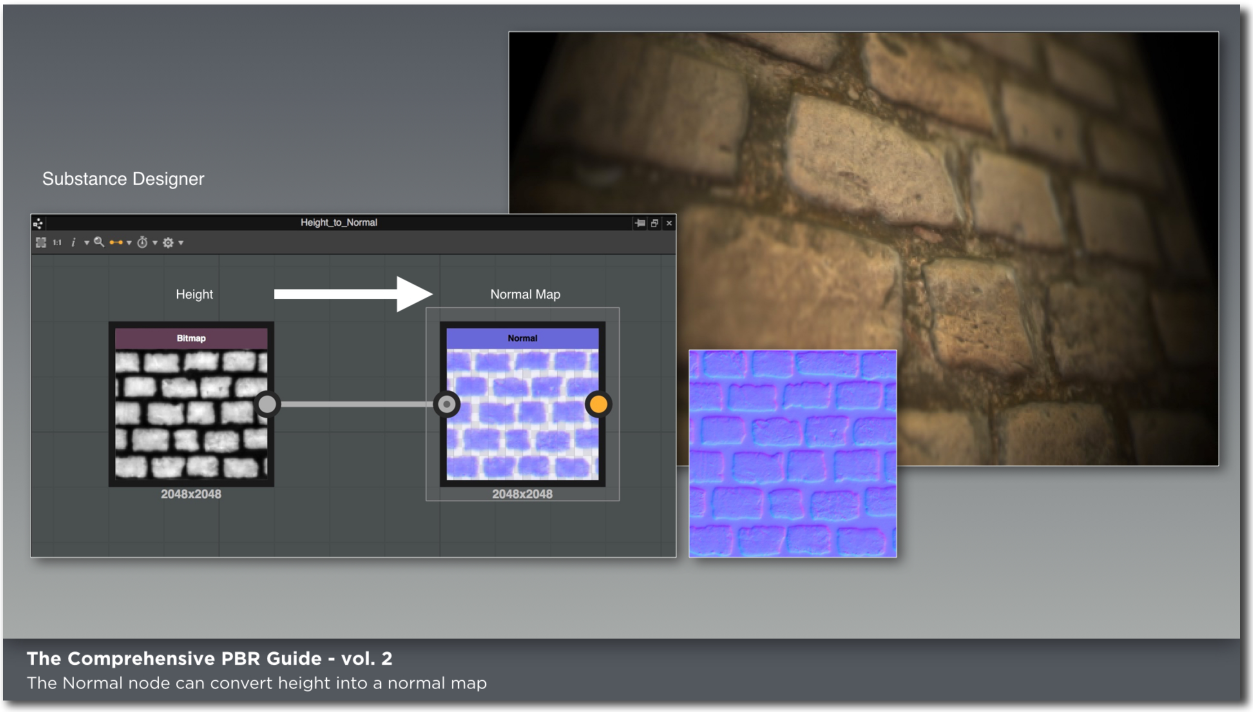


Figure 36

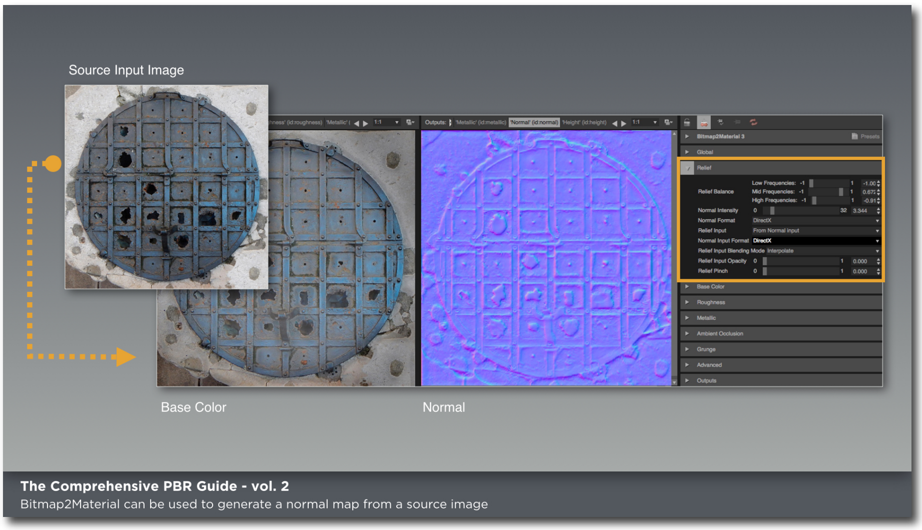


Figure 37

Bitmap2Material can be used to generate normal from a source image

Substance PBR Utilities

In this section, we will discuss several Substance utilities that can help with authoring PBR textures and setting correct reflectance values. The utilities are divided into sections based on materials, correction and values. These nodes were built based on the principles and concepts covered in this guide.

Materials

Bitmap2Material 3

B2M 3 is a standalone app (Indie/Pro) or packaged Substance material (Pro Only) that creates PBR maps for metal/roughness or specular/glossiness workflows from a single source image input. It can create tileable maps and excels at creating albedo (using its light cancelation functions), normal and height maps. It is a great utility for creating base textures for materials as shown in figure 38.

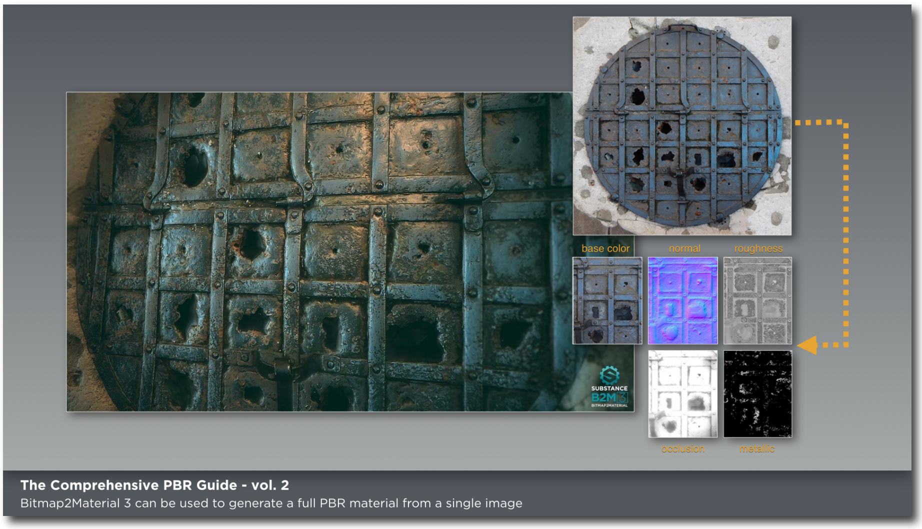


Figure 38

PBR Base Material

This node is a utility for creating a full base material and can be found in the Substance Designer Library under Filters>PBR Utilities as shown in figure 39. It supports both metal/roughness and specular/glossiness workflows. It provides common presets for raw metal materials and also allows you to set the dielectric albedo if creating a non-metal. There are controls for roughness and glossiness depending on the workflow, which also have a grunge amount option. Alternatively, you can choose to add custom map inputs which works well if you are importing base maps created in Substance Painter. Using this method, you can quickly create a material node that can be blended with other materials.

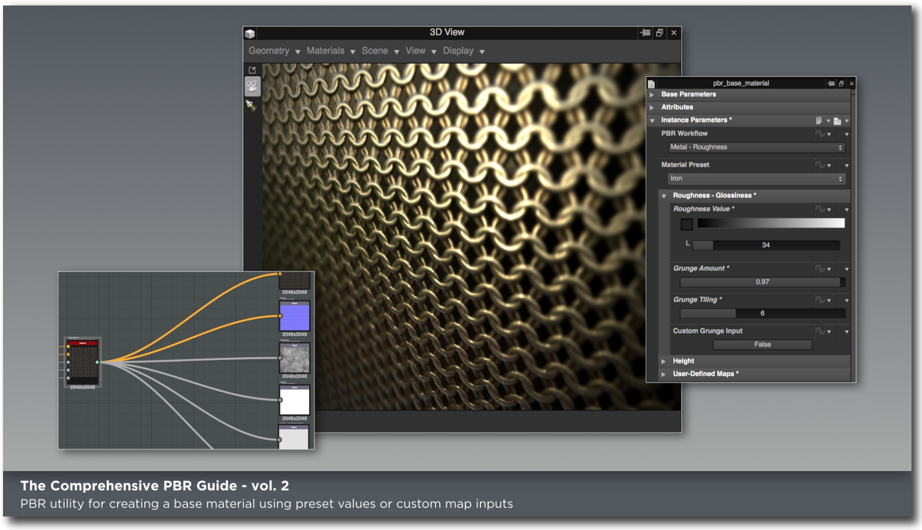


Figure 39

Video walkthrough available at http://www.allegorithmic.com/pbr-guide

PBR Substance Materials

Substance Designer and Substance Painter ship with PBR calibrated materials. They are a combination of procedural, hand painted and photo generated materials compiled into the Substance format. As Substance materials, they can have the benefit of being dynamic with various parameters for controlling different aspects of the texture. They provide a fast and efficient method for working with PBR content without having to author the maps from scratch.

In Substance Designer, the Substances can be found in the Library under PBR Materials. There is also a set of hand-painted PBR materials provided by Gametextures.com. You can download the extra Gametextures.com PBR Substances from your Allegorithmic account.

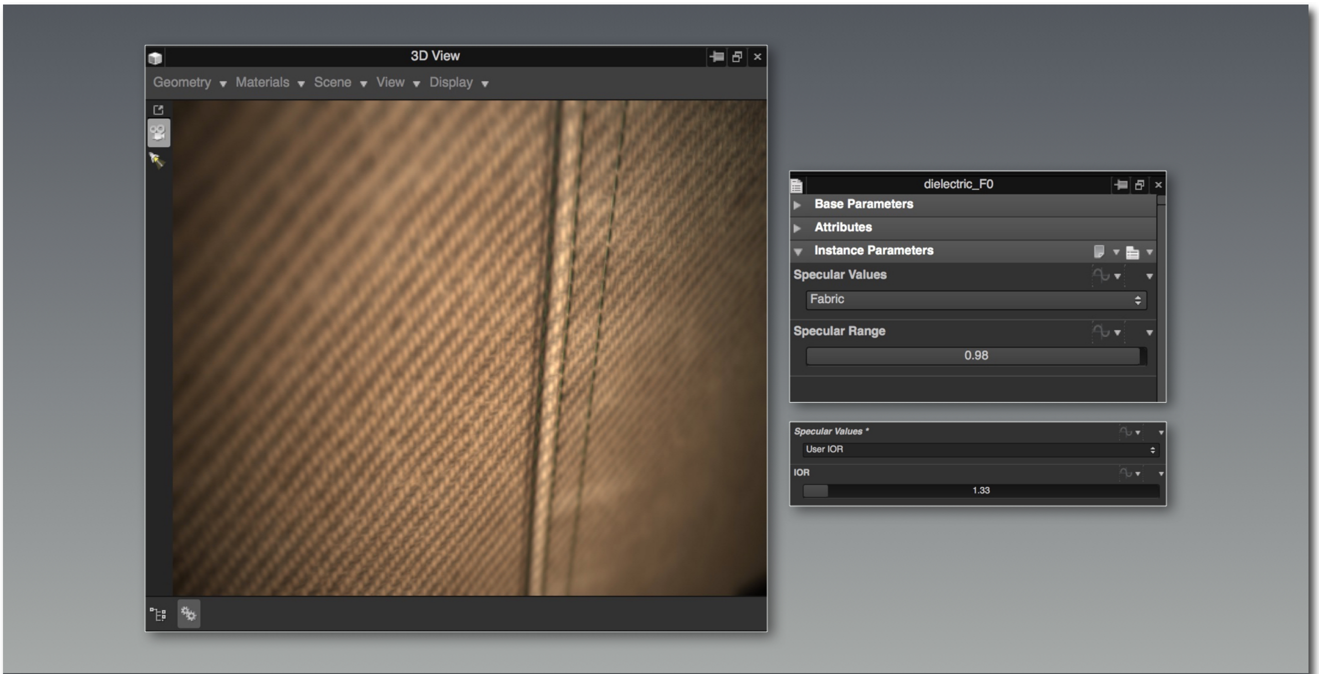
In Substance Painter, the Substances are found in the Material tab on the Shelf. There is also a set of materials from Gametextures.com as well. The Gametextures.com materials can be downloaded from your Allegorithmic account and installed to the Material tab.

In addition to the content provided with Substance Designer and Substance Painter, the Substance Database contains a vast amount of PBR calibrated materials, which also are a combination of procedural, hand painted and photo generated materials compiled into the Substance format.

Reflectance Values

Dielectric F0

This node outputs F0 values for common dielectric materials as shown in figure 40. You can choose from preset values and it also has an IOR input field that takes an IOR and computes the F0 value. It was designed for dielectric materials and can be used with the specular/glossiness workflow.



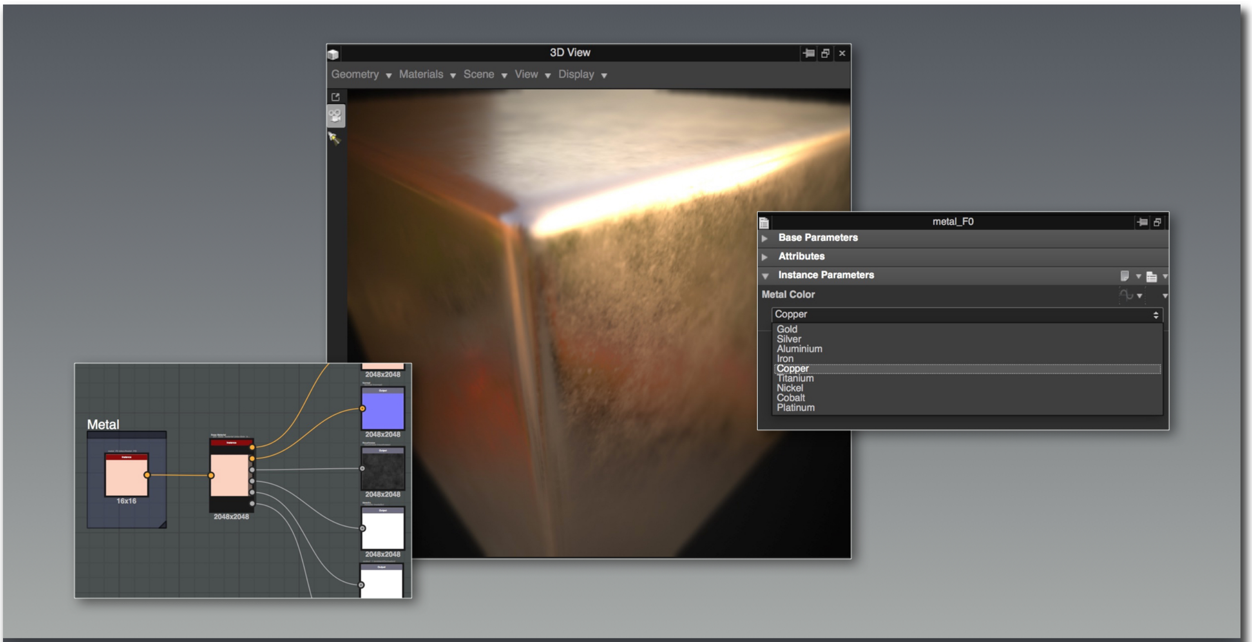
The Comprehensive PBR Guide - vol. 2
PBR utility for computing dielectric F0 values using presets or a custom IOR

Figure 40

Video walkthrough available at http://www.allegorithmic.com/pbr-guide

Metal Reflectance

This node outputs reflectance values for common raw metal materials and it can be found in the Substance Designer Library under Filters>PBR. You can choose from several preset metal values as shown in figure 41.



The Comprehensive PBR Guide - vol. 2
PBR utility containing presets for metal reflectance values

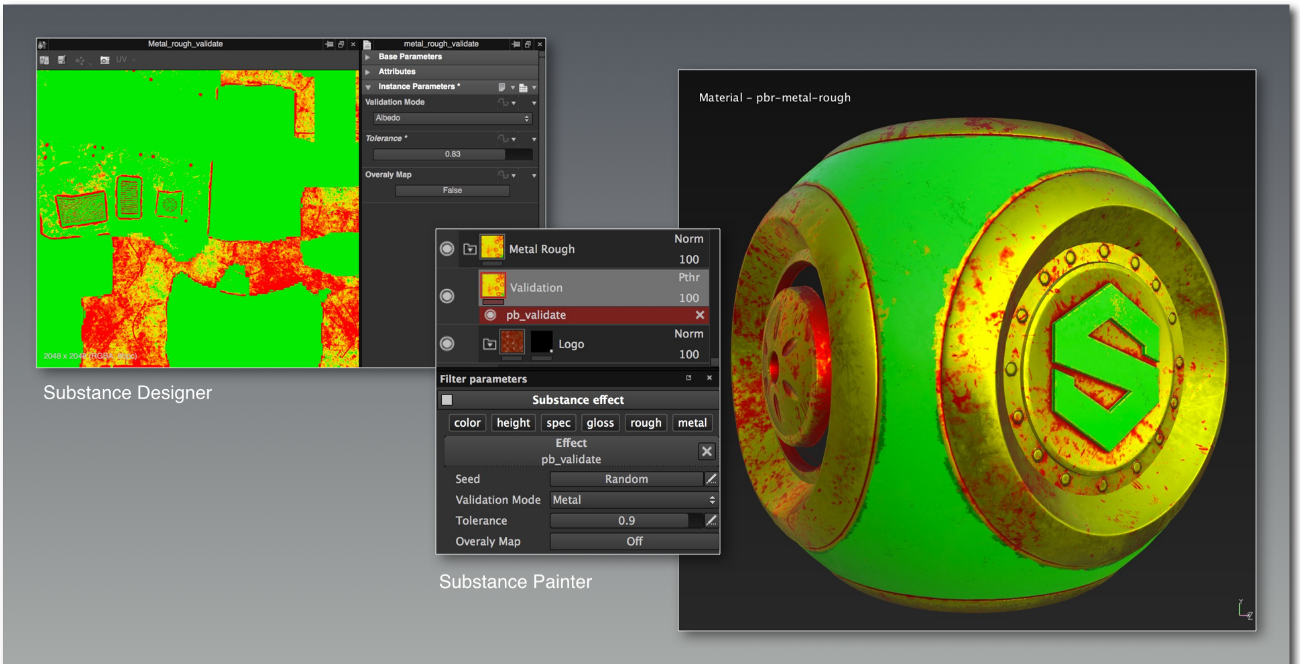
Figure 41

Video walkthrough available at http://www.allegorithmic.com/pbr-guide

Correction

PBR Metal/Roughness Validate

This node is designed to work with the metal/roughness workflow and is a utility which checks for incorrect values for the base color and metal maps as shown in figure 42. It can be found in the Substance Designer Library under Filters>PBR and the node outputs a heat map moving from red->yellow->green where red is incorrect and green/yellow is correct. With metal, it checks the corresponding F0 values in the base color for areas indicated as metal in the metallic map (greater than 235 sRGB). The heat map displays the range in which the F0 range may be too low. For the albedo, it checks to see if dielectric brightness ranges are correct.



The Comprehensive PBR Guide - vol. 2
PBR utility that checks ranges for albedo and metal and outputs heat map

Figure 42

Video walkthrough available at http://www.allegorithmic.com/pbr-guide

PBR Safe Color

This node corrects values in the base color or diffuse maps as shown in figure 43. It makes sure that values fall within the corrected brightness ranges for dielectrics. It can be found in Substance Designer's Library under PBR Utilities.

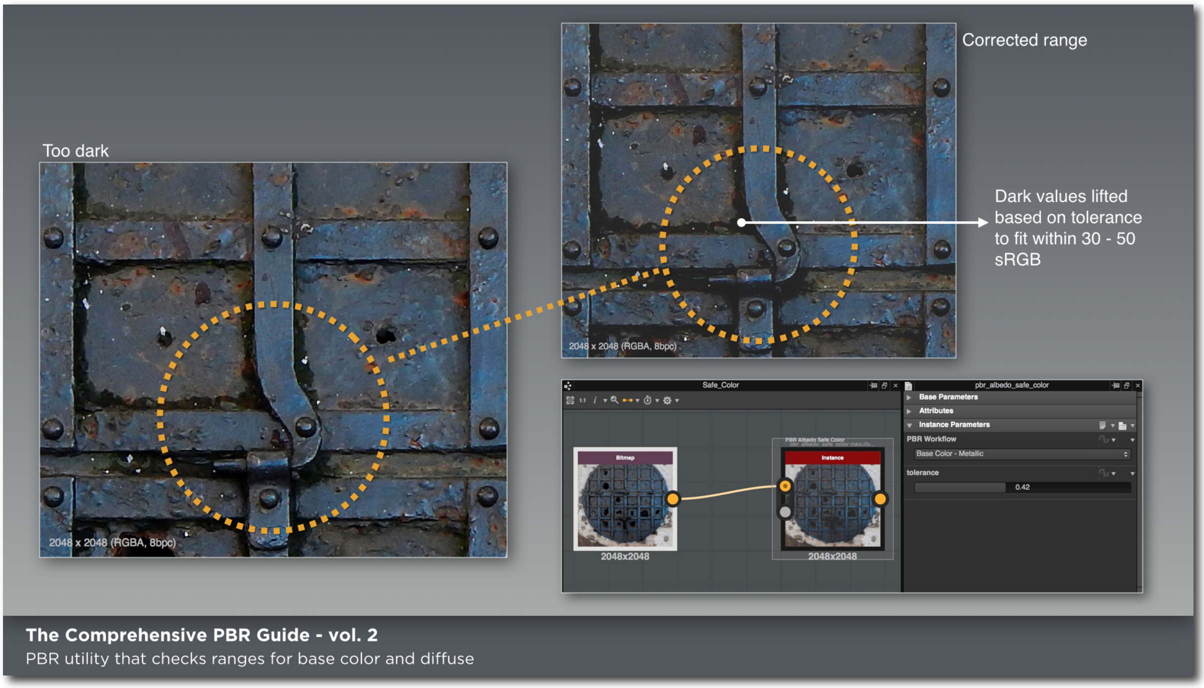


Figure 43

Video walkthrough available at http://www.allegorithmic.com/pbr-guide

Conversion

BaseColor_metallic_roughness_to_diffuse_specular_glossiness

This node converts maps from the metal/roughness workflow to specular/glossiness as shown in figure 44. It can be found in Substance Designer's Library under PBR Utilities.

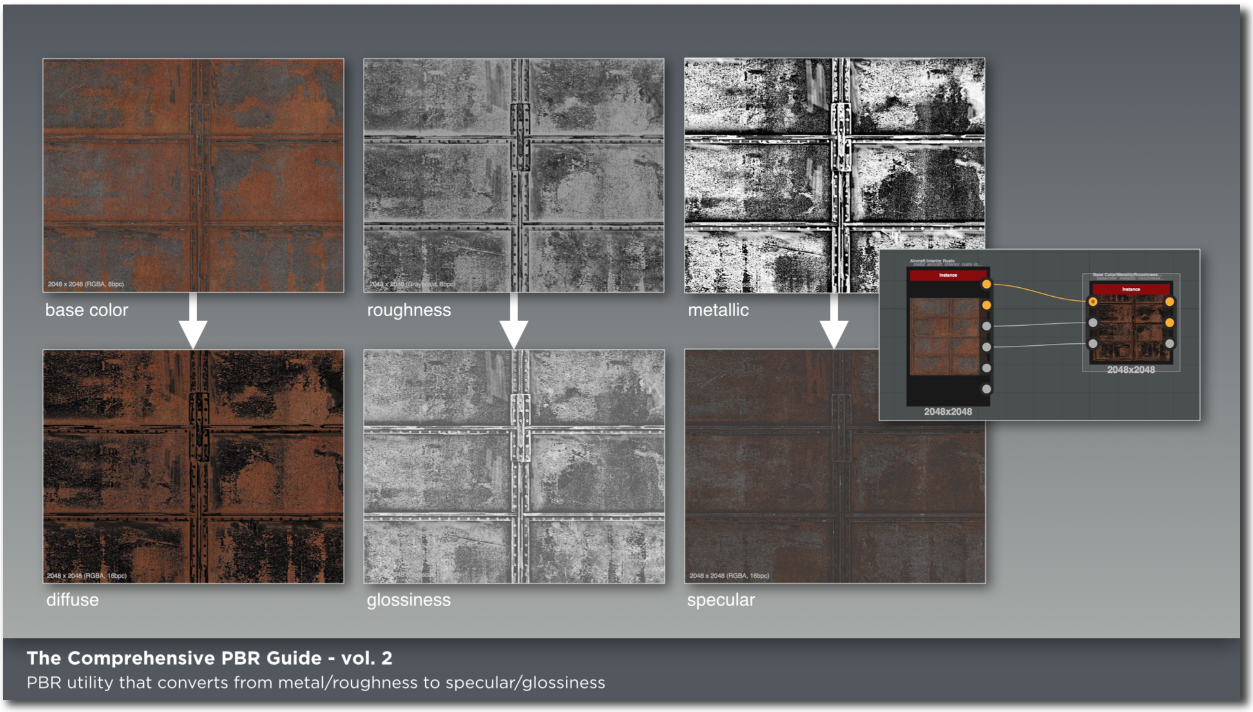


Figure 44

Appendix - Charts

Is the surface metal?

It can be helpful to break down a surface into the metal or non-metal categories. I will often begin the texturing process by first examining the material and asking myself if what I am creating is metal or not. Through this inquiry, you can derive some guidelines for the texturing process as we have covered in this Volume and as shown in figures 45 and 46. Figure 45 is using the metal/roughness workflow and figure 46 is specular/glossiness.

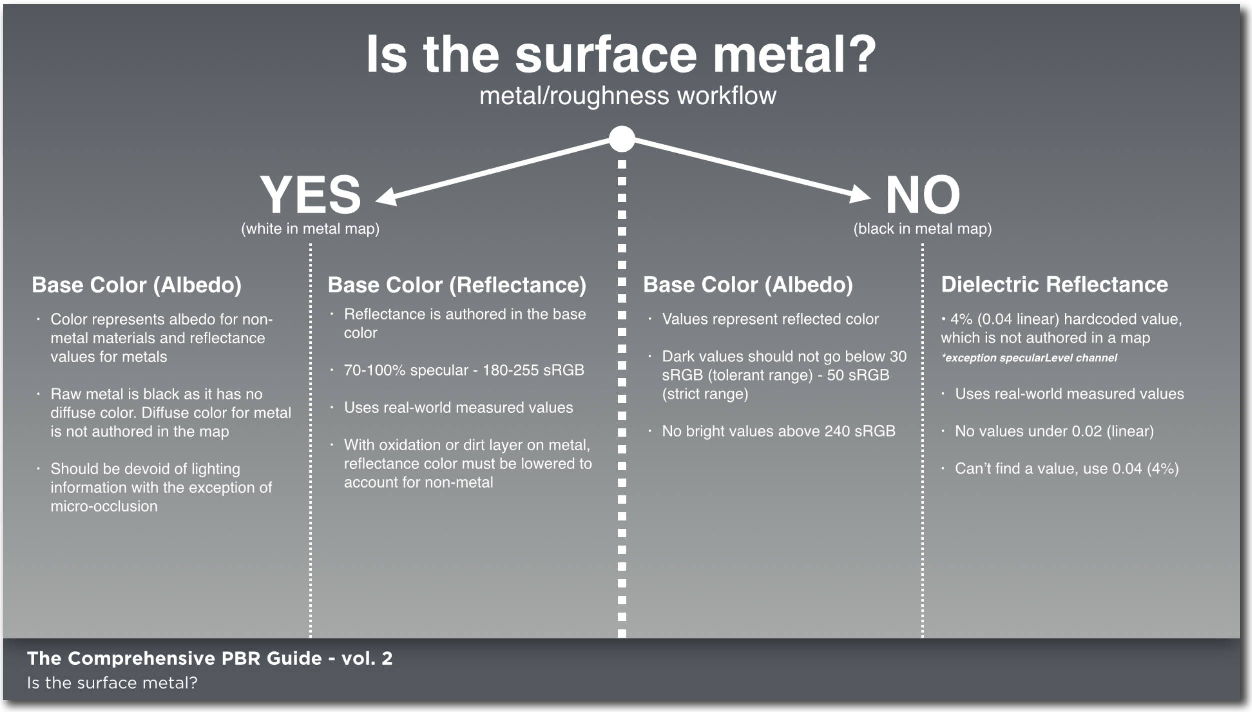


Figure 45

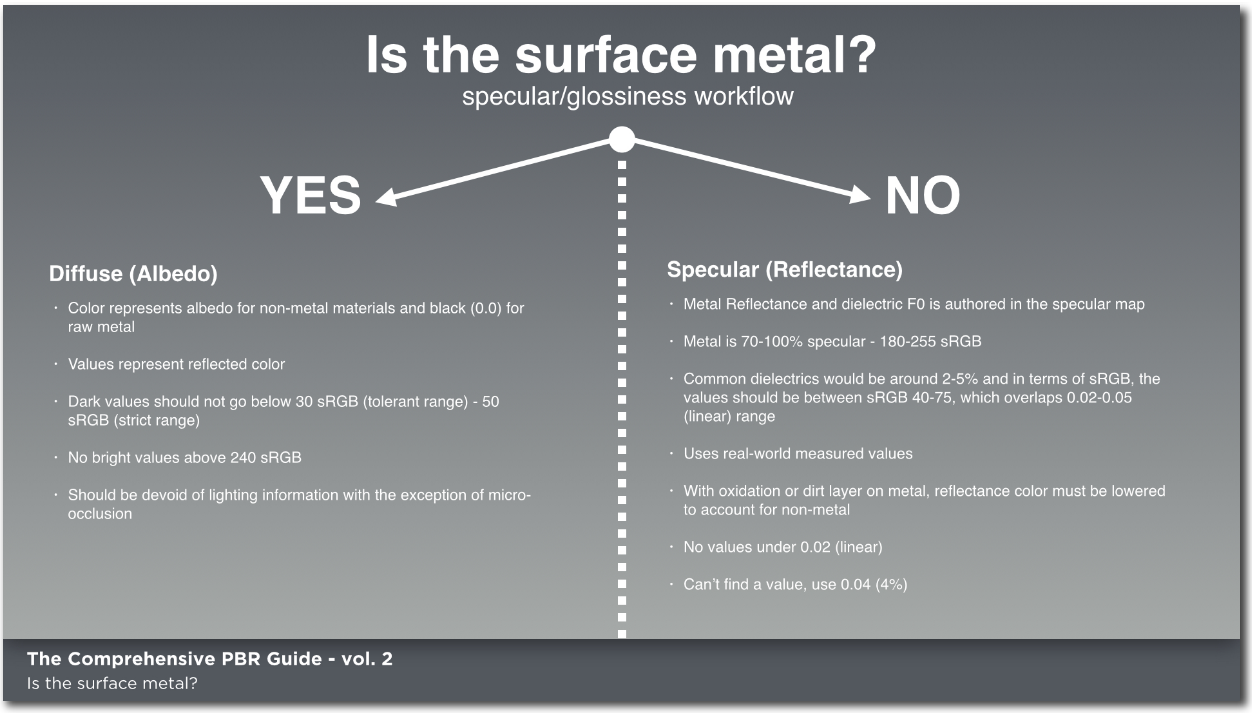


Figure 46

Reflectance Values

Figure 47 shows the F0 ranges for dielectrics. Dielectrics reflect a smaller amount of light than metals. The value for common dielectrics would be around 2-5% and in terms of sRGB, the values should be between sRGB 40-75, which overlaps 0.02-0.05 (linear) range. In figure 48, you can see both dielectric F0 and metal reflectance values. With metals, the specular range is within 70-100% and maps to the sRGB values of 180-255.

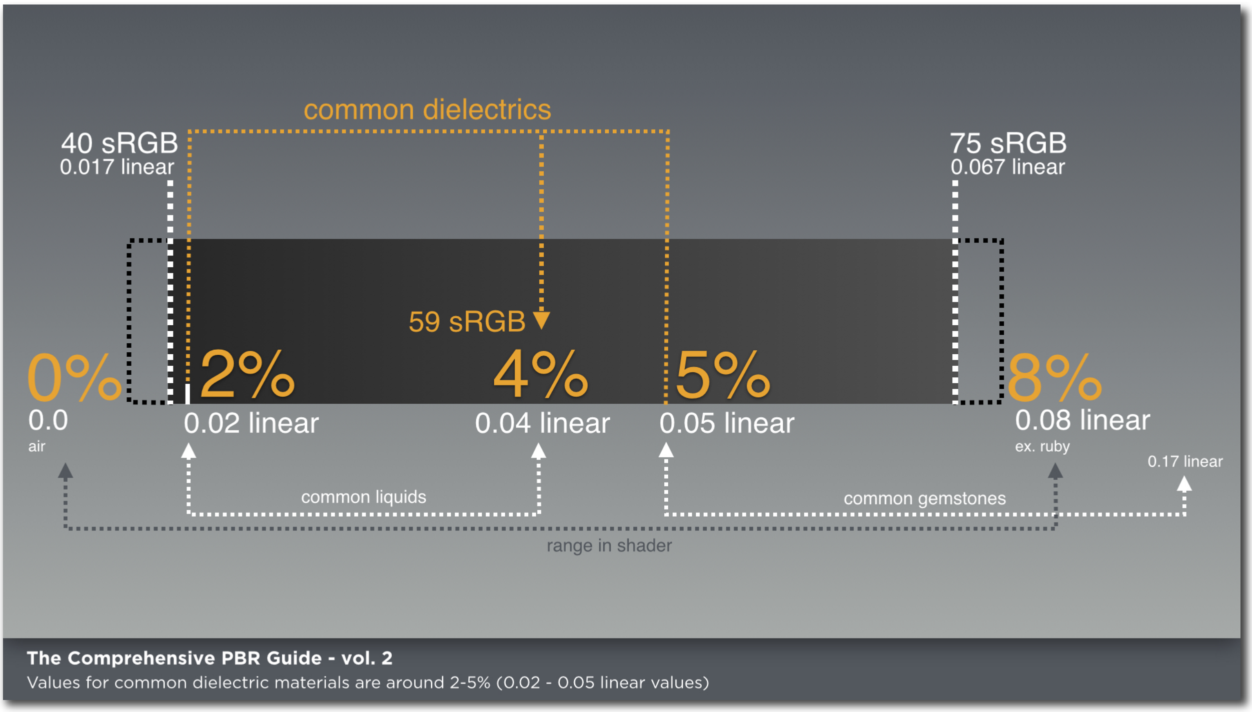


Figure 47

Conversions from sRGB to linear were done using the gamma 2.2 approximation. See linear space rendering in Vol.1 for more details.

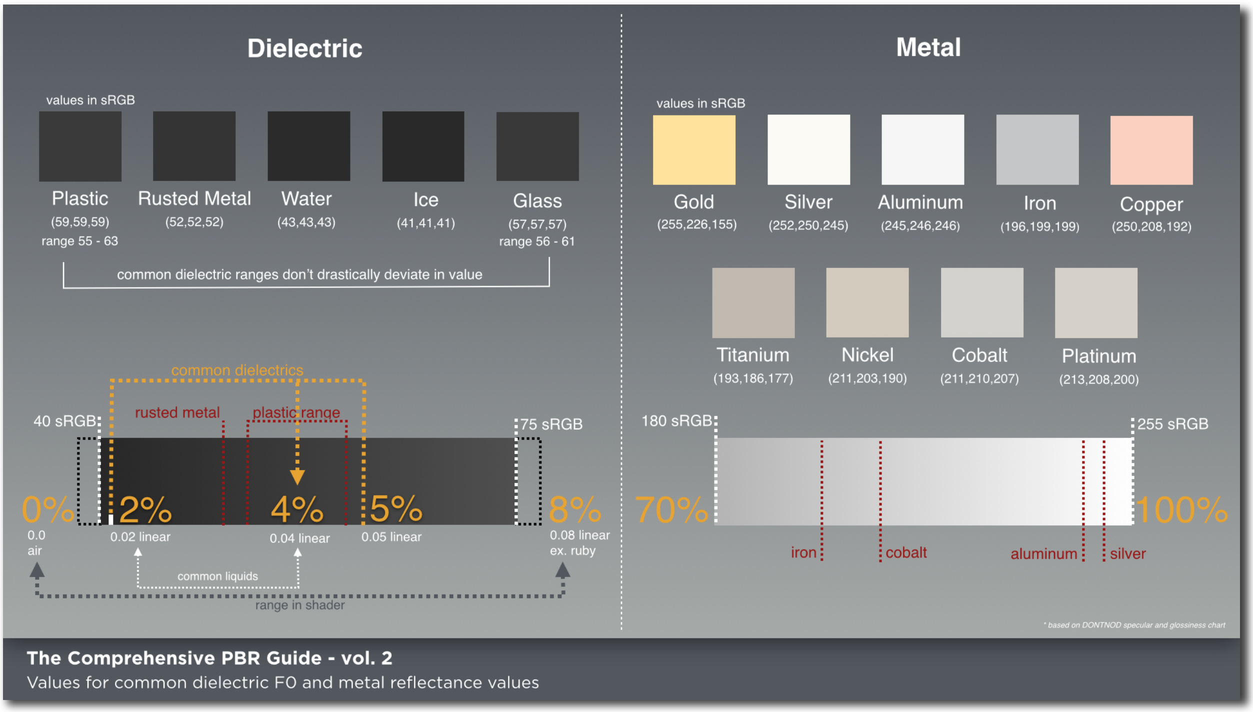


Figure 48

Conversions from sRGB to linear were done using the gamma 2.2 approximation. See linear space rendering in Vol.1 for more details.

Correct/Incorrect Comparisons

In figure 49, you can see an example of maps created correctly and incorrectly using the metal/roughness workflow. The dirt and paint dielectric layers have too dark of an albedo value and the dirt is marked as raw metal in the metallic map. Also, the metal reflectance value is set too low in the base color as it doesn't reflect the 70-100% specular range.

In figure 50, you can see an example of maps created correctly and incorrectly using the specular/glossiness workflow. All of the raw metal has too bright of a value in the diffuse map. It should be black. The dielectric paint and dirt layers have too dark of an albedo value in the diffuse map. The dirt layer has too bright of an F0 in the specular map. The dirt F0 doesn't match the range for dielectrics.

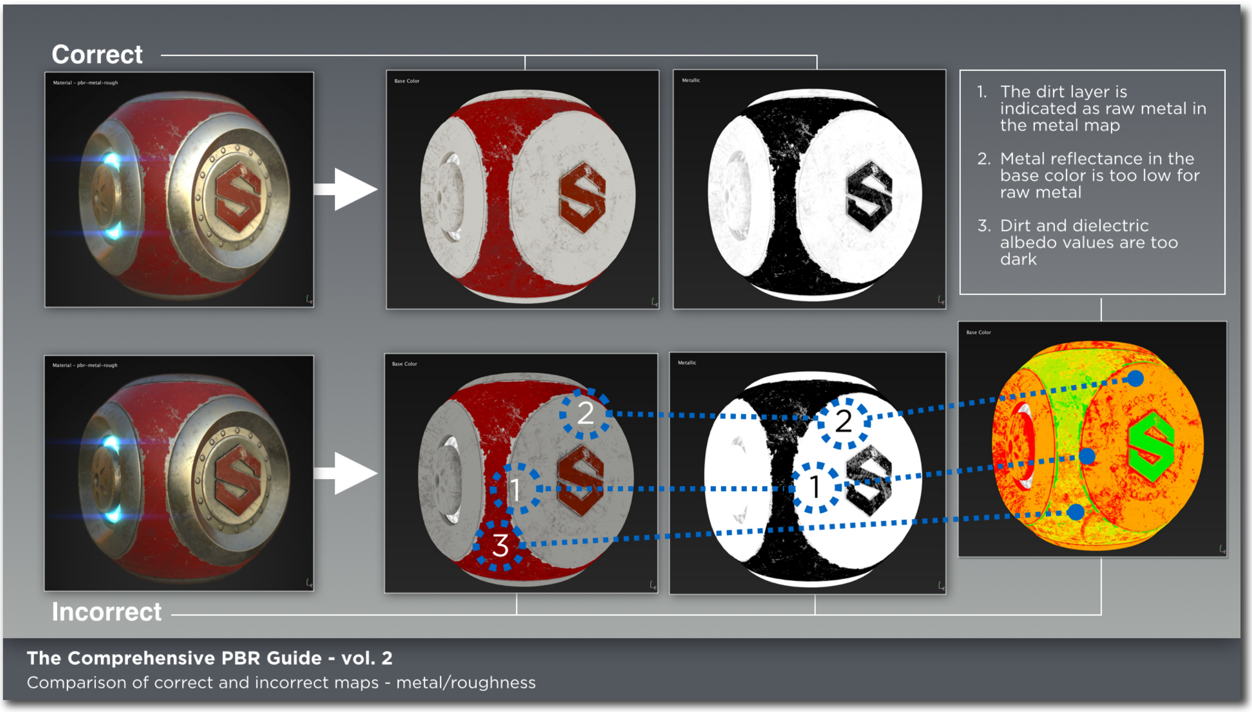


Figure 49

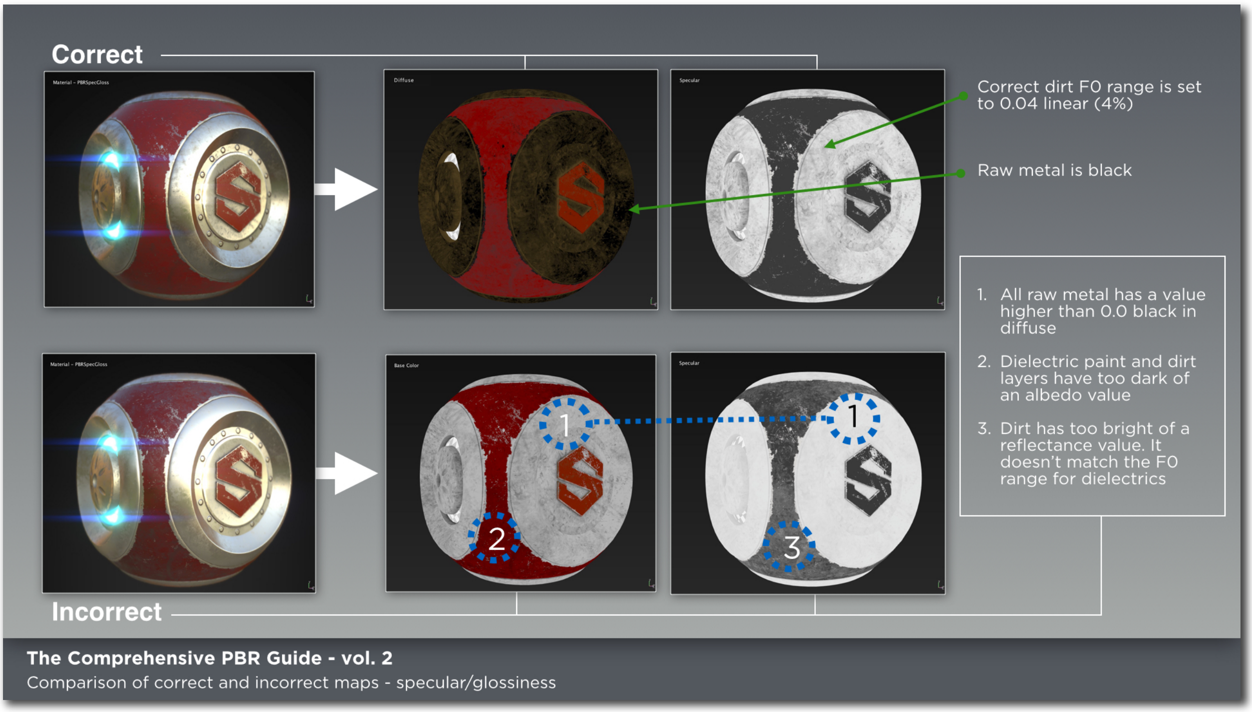


Figure 50

Allegorithmic develops the new generation of 3D texturing software: Substance Painter, Substance Designer and Bitmap2Material. With most AAA game studios using these tools, Substance has become the standard for creating next-generation PBR (Physically Based Rendering) assets.

For more information on Substance, please visit our website at
www.allegorithmic.com

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