SMPTE RP 2077:2013

SMPTE RECOMMENDED PRACTICE

Full-Range Image Mapping

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Foreword

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SMPTE RP 2077 was prepared by Technology Committee 10E.

Intellectual Property

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Introduction

This section is entirely informative and does not form an integral part of this Engineering Document.

Each pixel in a digital image is commonly encoded as a triplet of n-bit binary words — see, for instance, SMPTE ST 125, SMPTE ST 274 and ST SMPTE 296 for the process by which such encoding is generated.

In a full-range digital image, the code values of the reference black and white triplets are the minimum and maximum values that can be encoded by an n-bit unsigned binary integer, (0, 0, 0) and (2^n – 1, 2^n – 1, 2^n – 1) respectively, i.e. the "full range" of code values.

This specification defines mappings allowing source full-range images to be carried by (i) digital interfaces that rely upon protected values, e.g. for synchronization, and (ii) narrow-range digital image formats where the full-range of code values is not utilized for the range between reference black and white[1]. These mappings can be used to devise methods to interoperate with analog workflows, but those methods are outside the scope of this document.

On digital interfaces that rely upon protected values, a small number of code values are prohibited from appearing in triplets. For instance, the 10-bit interface defined in SMPTE ST 292-1 protects code values outside the range [4,1019].

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[1] The terms "reference black" and "reference white" have the same meanings herein as in SMPTE ST 125, SMPTE ST 274 and SMPTE ST 296, which state "picture information shall be linearly represented by red, green and blue tristimulus values (RGB), lying in the range 0 (reference black) to 1 (reference white)".

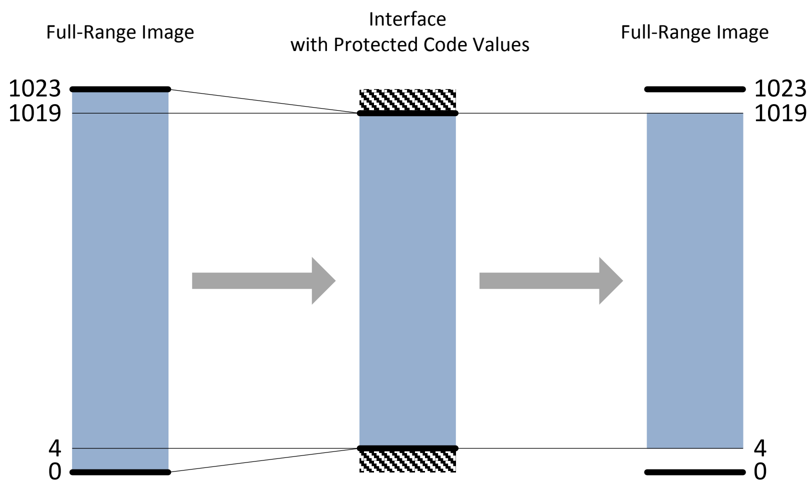

Figure 1 – Full-Range Image Mapping over an Interface that Rely upon Protected Code Values

In this first scenario, Section 4.1 specifies that, given a full-range image as input, code values falling within the protected range are clipped to the closest permitted value without any scaling. As illustrated in Figure 1, no additional processing is required if the resulting narrow-range image is mapped back to full-range at a later time, but the resulting full-range image will be missing any code value clipped by the initial mapping to the digital interface.

In narrow-range digital image formats, the reference black and white triplets, (R_{BLACK}, R_{BLACK}, R_{BLACK}) and (R_{WHITE}, R_{WHITE}, R_{WHITE}) respectively, are specified with $R_{BLACK} > 0$ and $R_{WHITE} < 2^n - 1$. For instance, as illustrated in Figure, the reference black and white triplets of a 8-bit R'G'B' image encoded as specified in SMPTE ST 125, SMPTE ST 274 and SMPTE ST 296 are equal to (16, 16, 16) and (235, 235, 235), respectively. In other words, while reference black and reference white are the same color in both narrow-range and full-range images, their respective encoded values are different.

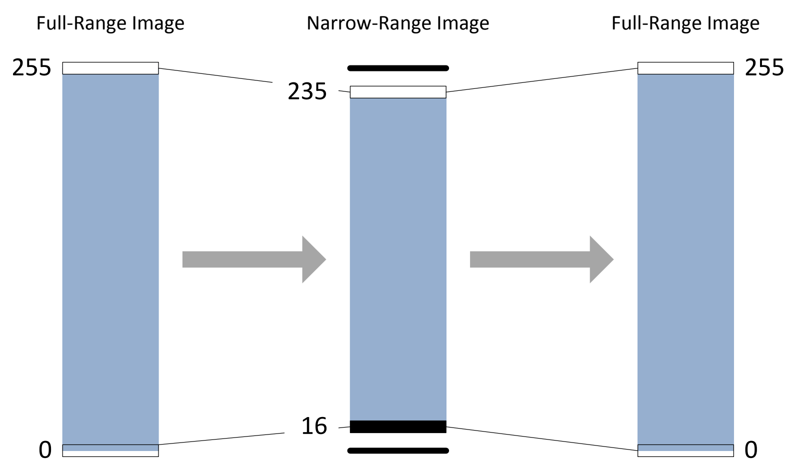

Figure 2 – Mapping a Full-range Image to and from a Narrow-Range Image

In this second scenario, Section 6 specifies that the full-range image code values be scaled to the reference black to white range of the narrow-range image format. If a full-range image mapped to narrow-range needs to be mapped back to full-range, the specification defines a second mapping such that, once a full-range value has been mapped to a narrow-range value (and quantization information lost), no further information is lost if the mapping is repeated.

This second mapping is not generally applicable to mapping from narrow-range images to full-range images since code values outside the range from reference black to white are simply clipped. For instance, any code value larger than 235 in an 8-bit studio range image is clipped to 235. This can result, for instance, in a change in the hue of pixels containing such code values. If a narrow-range image contains code values outside the range from reference black to white and such behavior is not desired, then another mapping, outside the scope of this specification, can be applied. The separate practices of using full-range image versus narrow-range image originate from the worlds of computer graphics and video, respectively. In the process of converging the practices and mapping between them, users are cautioned to be aware of the compromises that can result.

Narrow-range, as defined herein, encompass a number of commonly used terms such broadcast range, SMPTE range, nominal range, reduced range, head range, video range, standard range, etc.

1 Scope

This Recommended Practice defines mappings of full-range digital images to and from (i) digital image formats and interfaces that rely upon protected values, e.g. for synchronization, and (ii) narrow-range digital image formats and interfaces where the full-range of code values is not utilized for the range between reference black and white. These mappings are not generally applicable to mapping of source narrow-range images, e.g. studio range images, to full-range images.

2 Conformance Notation

Normative text is text that describes elements of the design that are indispensable or contains the conformance language keywords: "shall", "should", or "may". Informative text is text that is potentially helpful to the user, but not indispensable, and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

All text in this document is, by default, normative, except: the Introduction, any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:”

The keywords "shall" and "shall not" indicate requirements strictly to be followed in order to conform to the document and from which no deviation is permitted.

The keywords, "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

The keyword “reserved” indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword “forbidden” indicates “reserved” and in addition indicates that the provision will never be defined in the future.

A conformant implementation according to this document is one that includes all mandatory provisions ("shall") and, if implemented, all recommended provisions ("should") as described. A conformant implementation need not implement optional provisions ("may") and need not implement them as described.

Unless otherwise specified, the order of precedence of the types of normative information in this document shall be as follows: Normative prose shall be the authoritative definition; Tables shall be next; followed by formal languages; then figures; and then any other language forms.

3 Normative References

The following standards contain provisions which, through reference in this text, constitute provisions of this recommended practice. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this recommended practice are encouraged to investigate the possibility of applying the most recent edition of the standards indicated below.

There are no normative references.

4 Terms and Definitions

4.1 Full-Range Image

A full-range image consists of a collection of pixels, each being quantized using a triplet of *n*-bit unsigned integer words, where the triplets (0,0,0) and (2^n - 1, 2^n - 1, 2^n - 1) correspond to reference black and reference white, respectively. Table 1 lists reference black and white triplets for example bit depths.

Table 1 – Reference black and white triplets for example bit depths (Informative)

Bit Depth	*Reference Black*	*Reference White*
8	(0,0,0)	(255, 255, 255)
10	(0,0,0)	(1023, 1023, 1023)
12	(0,0,0)	(4095, 4095, 4095)

Note: Images for which not all pixels consist of triplets of words, e.g. images that use 4:2:2 sampling as defined in SMPTE ST 274, are not full-range images.

4.2 Narrow-Range Image

A narrow-range image consists of a collection of pixels, each being quantized using a triplet of *n*-bit integer words, where the black and white reference triplets are, respectively, (R_{BLACK}, R_{BLACK}, R_{BLACK}) and (R_{WHITE}, R_{WHITE}, R_{WHITE}), respectively, where $0 < R_{BLACK} < R_{WHITE} < 2^n - 1$.

5 Mapping to Interfaces and Formats that Rely upon Protected Code Values

The following shall apply when mapping a full-range image to a format or interface that (i) uses triplets of the same bit length, (ii) uses the same black and white reference triplets and (iii) defines protected code values that cannot be used so that only code values in the range [CV_{LOW}, CV_{HIGH}] are permitted.

The function $M_{full \rightarrow permitted}$ ("map from full-range to permitted range") shall map a code value CV_{FULL} from a full-range image to a code value CV_P on the interface or format according to

$$M_{full \rightarrow permitted} : CV_{FULL} \rightarrow CV_P = \text{clamp}(CV_{LOW}, CV_{HIGH}, CV_{FULL}) \,, \quad (1)$$

where

$$\text{clamp}(a, b, x) = \begin{cases} x, \text{ if } x \in [a, b] \\ a \text{ if } x < a \\ b \text{ if } x > b \end{cases}$$

The function $M_{permitted \rightarrow full}$ ("map from permitted range to full-range") shall map a code value CV_P on the interface or format to a code value CV_{FULL} for the full-range image according to

$$M_{permitted \rightarrow full} : CV_P \rightarrow CV_{FULL} = CV_P \quad (2)$$

Note: Any information in a full-range image encoded using code values outside the range [CV_{LOW}, CV_{HIGH}] is lost in this mapping. Equivalently, full-range images sourced from an interface or format with protected code values will not contain code values outside the range [CV_{LOW}, CV_{HIGH}].

Annex B contains an illustrative mapping to and from a 10-bit interface with $CV_{LOW} = 4$ and $CV_{HIGH} = 1019$.

6 Mapping to Interfaces and Formats with Narrow-Range Image

The following applies when mapping a full-range image to a format or interface that uses narrow-range images of the same bit length *n.*

The function $M_{full \rightarrow narrow}$ ("map from full-range to narrow-range") shall map a code value CV_{FULL} from a full-range image to a narrow-range code value CV_N on the interface or format according to:

$$M_{full \rightarrow narrow}: CV_{FULL} \rightarrow CV_N = \text{floor}\ (\ 0.5 + CV_{FULL}\ /\ (2^n - 1) \cdot (R_{WHITE} - R_{BLACK}) + R_{BLACK}), \qquad (3)$$

where floor(x) is equal to the largest integer not greater than x.

The function $M_{narrow \rightarrow full}$ ("map from narrow-range to full-range") shall map a code value CV_N from the interface or format to a full-range code value CV_{FULL} according to

$$M_{narrow \rightarrow full}: CV_N \rightarrow CV_{FULL} = \text{floor}\ (\ 0.5 + \text{clamp}\ (\ 0.0, 1.0, (CV_N - R_{BLACK})\ /\ (R_{WHITE} - R_{BLACK})\ )\ \cdot (2^n - 1)\ )\ , \qquad (4)$$

where floor(x) and clamp(a, b, x) use the same definitions as in the previous section.

Notes:

1 floor(0.5 + x) expresses rounding of positive x to the nearest integer.

2 No slopes, curves, knee or shoulder are specified at the top and bottom of the mapping interval.

3 The pair of equations above are constructed such that $M_{full \rightarrow narrow}(M_{narrow \rightarrow full}(M_{full \rightarrow narrow}(x))) = M_{full \rightarrow narrow}(x)$, i.e. once a full-range value has been mapped to a narrow-range value (and quantization information necessarily lost), no further information is lost if the mapping is repeated.

4 CV_N in Equation (4) can be smaller than R_{BLACK} or larger than R_{WHITE}, but any information outside the range [R_{BLACK}, R_{WHITE}] is lost when mapping from narrow-range to full-range using $M_{narrow \rightarrow full}$, i.e. $M_{narrow \rightarrow full}$ clips code-values outside the range [R_{BLACK}, R_{WHITE}]. If such clipping is not desired, code values outside the range [R_{BLACK}, R_{WHITE}] can be mapped to the range [R_{BLACK}, R_{WHITE}] prior to applying C_{NF}, using a mapping outside the scope of this specification.

5 The $M_{full \rightarrow narrow}$ and $M_{full \rightarrow permitted}$ mappings are not commutative. If an interface or format uses both protected values and narrow-range image, then the $M_{full \rightarrow narrow}$ mapping is applied first since the $M_{full \rightarrow permitted}$ mapping applies only to interfaces and formats with white and black reference code values equal to that of full-range. Conversely, the inverse functions are applied in the opposite order, i.e., the $M_{permitted \rightarrow full}$ mapping is applied first, followed by $M_{narrow \rightarrow full}$.

Annex C contains example mappings according to Equations (3) and (4), for both 8-bit (R_{BLACK} = 16 and R_{WHITE} = 235) and 10-bit images (R_{BLACK} = 64 and R_{WHITE} = 940).

Annex A Bibliography (Informative)

Note: All references in this document to other SMPTE documents use the current numbering style (e.g. SMPTE ST 274:2008) although, during a transitional phase, the document as published (printed or PDF) may bear an older designation (such as SMPTE 274M-2008). Documents with the same root number (e.g. 274) and publication year (e.g. 2008) are functionally identical.

SMPTE ST 125:2013, SDTV Component Video Signal Coding 4:4:4 and 4:2:2 for 13.5 MHz and 18 MHz Systems

SMPTE ST 274:2008, Television — 1920 x 1080 Image Sample Structure, Digital Representation and Digital Timing Reference Sequences for Multiple Picture Rates

SMPTE ST 292-1:2012, 1.5 Gb/s Signal/Data Serial Interface

SMPTE ST 296:2012, 1280 x 720 Progressive Image 4:2:2 and 4:4:4 Sample Structure — Analog and Digital Representation and Analog Interface

SMPTE RP 291-2:2013, Ancillary Data Space Use — 4:2:2 SDTV and HDTV Component Systems and 4:2:2 2048 x 1080 Production Image Formats

Annex B Mapping to and from a 10-Bit Interface that Relies upon Protected Code Values (Informative)

The following illustrates the mapping of a 10-bit full-range image to and from a 10-bit interface that relies upon protected code values [0, 3] ∪ [1020,1023], using the $M_{full \rightarrow permitted}$ and $M_{permitted \rightarrow full}$ mappings, respectively.

The same protected code values are, for instance, used by the digital interface specified in SMPTE ST 292-1.

Table B.1 – Mapping code values from a full-range image (CV_{FULL}) to a 10-bit interface (CV_P) that rely upon protected code values

CV_{FULL}	CV_P
0	4
1	4
2	4
3	4
4	4
5	5
⋮	⋮
127	127
128	128
⋮	⋮
1018	1018
1019	1019
1020	1019
1021	1019
1022	1019
1023	1019

Table B.2 – Mapping from a 10-bit interface (CV_P) that rely upon protected code values to a full-range image (CV_{FULL})

CV_P	CV_{FULL}
4	4
5	5
6	6
⋮	⋮
127	127
128	128
⋮	⋮
1017	1017
1018	1018
1019	1019

Annex C Example Mappings to and from a Format with Narrow-Range Image (Informative)

The following tables illustrate the mapping of code values for a full-range image to and from code values for narrow-range image, using the $M_{full \rightarrow narrow}$ and $M_{narrow \rightarrow full}$ mappings, respectively. The black and white reference triplets used in these examples are those used, for instance, in the R'G'B' digital representation specified in SMPTE ST 274.

As indicated in Section 6, Table C.2 and Table C.4 perform a mapping from narrow-range to full-range in which code values below reference black and above reference white are lost. If conservation of these values is required, another mapping can be used.

Table C.1 – Mapping code values from a 8-bit full-range image (CV_{FULL}) to an 8-bit image (CV_N) with black reference triplet (16, 16, 16) and white reference triplet (235, 235, 235)

CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N
0	16	32	43	64	71	96	98	128	126	160	153	192	181	224	208
1	17	33	44	65	72	97	99	129	127	161	154	193	182	225	209
2	18	34	45	66	73	98	100	130	128	162	155	194	183	226	210
3	19	35	46	67	74	99	101	131	129	163	156	195	183	227	211
4	19	36	47	68	74	100	102	132	129	164	157	196	184	228	212
5	20	37	48	69	75	101	103	133	130	165	158	197	185	229	213
6	21	38	49	70	76	102	104	134	131	166	159	198	186	230	214
7	22	39	49	71	77	103	104	135	132	167	159	199	187	231	214
8	23	40	50	72	78	104	105	136	133	168	160	200	188	232	215
9	24	41	51	73	79	105	106	137	134	169	161	201	189	233	216
10	25	42	52	74	80	106	107	138	135	170	162	202	189	234	217
11	25	43	53	75	80	107	108	139	135	171	163	203	190	235	218
12	26	44	54	76	81	108	109	140	136	172	164	204	191	236	219
13	27	45	55	77	82	109	110	141	137	173	165	205	192	237	220
14	28	46	56	78	83	110	110	142	138	174	165	206	193	238	220
15	29	47	56	79	84	111	111	143	139	175	166	207	194	239	221
16	30	48	57	80	85	112	112	144	140	176	167	208	195	240	222
17	31	49	58	81	86	113	113	145	141	177	168	209	195	241	223
18	31	50	59	82	86	114	114	146	141	178	169	210	196	242	224
19	32	51	60	83	87	115	115	147	142	179	170	211	197	243	225
20	33	52	61	84	88	116	116	148	143	180	171	212	198	244	226
21	34	53	62	85	89	117	116	149	144	181	171	213	199	245	226
22	35	54	62	86	90	118	117	150	145	182	172	214	200	246	227
23	36	55	63	87	91	119	118	151	146	183	173	215	201	247	228
24	37	56	64	88	92	120	119	152	147	184	174	216	202	248	229
25	37	57	65	89	92	121	120	153	147	185	175	217	202	249	230
26	38	58	66	90	93	122	121	154	148	186	176	218	203	250	231
27	39	59	67	91	94	123	122	155	149	187	177	219	204	251	232
28	40	60	68	92	95	124	122	156	150	188	177	220	205	252	232
29	41	61	68	93	96	125	123	157	151	189	178	221	206	253	233
30	42	62	69	94	97	126	124	158	152	190	179	222	207	254	234
31	43	63	70	95	98	127	125	159	153	191	180	223	208	255	235

Table C.2 – Mapping code values from an 8-bit image (CV_N) with black reference triplet (16, 16, 16) and white reference triplet (235, 235, 235) to an 8-bit full-range image (CV_{FULL})

CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}
0	0	32	19	64	56	96	93	128	130	160	168	192	205	224	242
1	0	33	20	65	57	97	94	129	132	161	169	193	206	225	243
2	0	34	21	66	58	98	95	130	133	162	170	194	207	226	245
3	0	35	22	67	59	99	97	131	134	163	171	195	208	227	246
4	0	36	23	68	61	100	98	132	135	164	172	196	210	228	247
5	0	37	24	69	62	101	99	133	136	165	173	197	211	229	248
6	0	38	26	70	63	102	100	134	137	166	175	198	212	230	249
7	0	39	27	71	64	103	101	135	139	167	176	199	213	231	250
8	0	40	28	72	65	104	102	136	140	168	177	200	214	232	252
9	0	41	29	73	66	105	104	137	141	169	178	201	215	233	253
10	0	42	30	74	68	106	105	138	142	170	179	202	217	234	254
11	0	43	31	75	69	107	106	139	143	171	180	203	218	235	255
12	0	44	33	76	70	108	107	140	144	172	182	204	219	236	255
13	0	45	34	77	71	109	108	141	146	173	183	205	220	237	255
14	0	46	35	78	72	110	109	142	147	174	184	206	221	238	255
15	0	47	36	79	73	111	111	143	148	175	185	207	222	239	255
16	0	48	37	80	75	112	112	144	149	176	186	208	224	240	255
17	1	49	38	81	76	113	113	145	150	177	187	209	225	241	255
18	2	50	40	82	77	114	114	146	151	178	189	210	226	242	255
19	3	51	41	83	78	115	115	147	153	179	190	211	227	243	255
20	5	52	42	84	79	116	116	148	154	180	191	212	228	244	255
21	6	53	43	85	80	117	118	149	155	181	192	213	229	245	255
22	7	54	44	86	82	118	119	150	156	182	193	214	231	246	255
23	8	55	45	87	83	119	120	151	157	183	194	215	232	247	255
24	9	56	47	88	84	120	121	152	158	184	196	216	233	248	255
25	10	57	48	89	85	121	122	153	160	185	197	217	234	249	255
26	12	58	49	90	86	122	123	154	161	186	198	218	235	250	255
27	13	59	50	91	87	123	125	155	162	187	199	219	236	251	255
28	14	60	51	92	88	124	126	156	163	188	200	220	238	252	255
29	15	61	52	93	90	125	127	157	164	189	201	221	239	253	255
30	16	62	54	94	91	126	128	158	165	190	203	222	240	254	255
31	17	63	55	95	92	127	129	159	167	191	204	223	241	255	255

Table C.3 – Mapping code values from a 10-bit full-range image (CV_{FULL}) to a 10-bit image (CV_N) with black reference triplet (64, 64, 64) and white reference triplet (940, 940, 940).

CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N
0	64	128	174	256	283	384	393	512	502	640	612	768	722	896	831
1	65	129	174	257	284	385	394	513	503	641	613	769	722	897	832
2	66	130	175	258	285	386	395	514	504	642	614	770	723	898	833
3	67	131	176	259	286	387	395	515	505	643	615	771	724	899	834
4	67	132	177	260	287	388	396	516	506	644	615	772	725	900	835
5	68	133	178	261	287	389	397	517	507	645	616	773	726	901	836
6	69	134	179	262	288	390	398	518	508	646	617	774	727	902	836
7	70	135	180	263	289	391	399	519	508	647	618	775	728	903	837
8	71	136	180	264	290	392	400	520	509	648	619	776	728	904	838
9	72	137	181	265	291	393	401	521	510	649	620	777	729	905	839
10	73	138	182	266	292	394	401	522	511	650	621	778	730	906	840
11	73	139	183	267	293	395	402	523	512	651	621	779	731	907	841
12	74	140	184	268	293	396	403	524	513	652	622	780	732	908	842
13	75	141	185	269	294	397	404	525	514	653	623	781	733	909	842
14	76	142	186	270	295	398	405	526	514	654	624	782	734	910	843
15	77	143	186	271	296	399	406	527	515	655	625	783	734	911	844
16	78	144	187	272	297	400	407	528	516	656	626	784	735	912	845
17	79	145	188	273	298	401	407	529	517	657	627	785	736	913	846
18	79	146	189	274	299	402	408	530	518	658	627	786	737	914	847
19	80	147	190	275	299	403	409	531	519	659	628	787	738	915	848
20	81	148	191	276	300	404	410	532	520	660	629	788	739	916	848
21	82	149	192	277	301	405	411	533	520	661	630	789	740	917	849
22	83	150	192	278	302	406	412	534	521	662	631	790	740	918	850
23	84	151	193	279	303	407	413	535	522	663	632	791	741	919	851
24	85	152	194	280	304	408	413	536	523	664	633	792	742	920	852
25	85	153	195	281	305	409	414	537	524	665	633	793	743	921	853
26	86	154	196	282	305	410	415	538	525	666	634	794	744	922	854
27	87	155	197	283	306	411	416	539	526	667	635	795	745	923	854
28	88	156	198	284	307	412	417	540	526	668	636	796	746	924	855
29	89	157	198	285	308	413	418	541	527	669	637	797	746	925	856
30	90	158	199	286	309	414	419	542	528	670	638	798	747	926	857
31	91	159	200	287	310	415	419	543	529	671	639	799	748	927	858
32	91	160	201	288	311	416	420	544	530	672	639	800	749	928	859
33	92	161	202	289	311	417	421	545	531	673	640	801	750	929	860
34	93	162	203	290	312	418	422	546	532	674	641	802	751	930	860
35	94	163	204	291	313	419	423	547	532	675	642	803	752	931	861
36	95	164	204	292	314	420	424	548	533	676	643	804	752	932	862
37	96	165	205	293	315	421	425	549	534	677	644	805	753	933	863
38	97	166	206	294	316	422	425	550	535	678	645	806	754	934	864

CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N
39	97	167	207	295	317	423	426	551	536	679	645	807	755	935	865
40	98	168	208	296	317	424	427	552	537	680	646	808	756	936	866
41	99	169	209	297	318	425	428	553	538	681	647	809	757	937	866
42	100	170	210	298	319	426	429	554	538	682	648	810	758	938	867
43	101	171	210	299	320	427	430	555	539	683	649	811	758	939	868
44	102	172	211	300	321	428	430	556	540	684	650	812	759	940	869
45	103	173	212	301	322	429	431	557	541	685	651	813	760	941	870
46	103	174	213	302	323	430	432	558	542	686	651	814	761	942	871
47	104	175	214	303	323	431	433	559	543	687	652	815	762	943	871
48	105	176	215	304	324	432	434	560	544	688	653	816	763	944	872
49	106	177	216	305	325	433	435	561	544	689	654	817	764	945	873
50	107	178	216	306	326	434	436	562	545	690	655	818	764	946	874
51	108	179	217	307	327	435	436	563	546	691	656	819	765	947	875
52	109	180	218	308	328	436	437	564	547	692	657	820	766	948	876
53	109	181	219	309	329	437	438	565	548	693	657	821	767	949	877
54	110	182	220	310	329	438	439	566	549	694	658	822	768	950	877
55	111	183	221	311	330	439	440	567	550	695	659	823	769	951	878
56	112	184	222	312	331	440	441	568	550	696	660	824	770	952	879
57	113	185	222	313	332	441	442	569	551	697	661	825	770	953	880
58	114	186	223	314	333	442	442	570	552	698	662	826	771	954	881
59	115	187	224	315	334	443	443	571	553	699	663	827	772	955	882
60	115	188	225	316	335	444	444	572	554	700	663	828	773	956	883
61	116	189	226	317	335	445	445	573	555	701	664	829	774	957	883
62	117	190	227	318	336	446	446	574	556	702	665	830	775	958	884
63	118	191	228	319	337	447	447	575	556	703	666	831	776	959	885
64	119	192	228	320	338	448	448	576	557	704	667	832	776	960	886
65	120	193	229	321	339	449	448	577	558	705	668	833	777	961	887
66	121	194	230	322	340	450	449	578	559	706	669	834	778	962	888
67	121	195	231	323	341	451	450	579	560	707	669	835	779	963	889
68	122	196	232	324	341	452	451	580	561	708	670	836	780	964	889
69	123	197	233	325	342	453	452	581	562	709	671	837	781	965	890
70	124	198	234	326	343	454	453	582	562	710	672	838	782	966	891
71	125	199	234	327	344	455	454	583	563	711	673	839	782	967	892
72	126	200	235	328	345	456	454	584	564	712	674	840	783	968	893
73	127	201	236	329	346	457	455	585	565	713	675	841	784	969	894
74	127	202	237	330	347	458	456	586	566	714	675	842	785	970	895
75	128	203	238	331	347	459	457	587	567	715	676	843	786	971	895
76	129	204	239	332	348	460	458	588	568	716	677	844	787	972	896
77	130	205	240	333	349	461	459	589	568	717	678	845	788	973	897
78	131	206	240	334	350	462	460	590	569	718	679	846	788	974	898
79	132	207	241	335	351	463	460	591	570	719	680	847	789	975	899
80	133	208	242	336	352	464	461	592	571	720	681	848	790	976	900

CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N
81	133	209	243	337	353	465	462	593	572	721	681	849	791	977	901
82	134	210	244	338	353	466	463	594	573	722	682	850	792	978	901
83	135	211	245	339	354	467	464	595	574	723	683	851	793	979	902
84	136	212	246	340	355	468	465	596	574	724	684	852	794	980	903
85	137	213	246	341	356	469	466	597	575	725	685	853	794	981	904
86	138	214	247	342	357	470	466	598	576	726	686	854	795	982	905
87	138	215	248	343	358	471	467	599	577	727	687	855	796	983	906
88	139	216	249	344	359	472	468	600	578	728	687	856	797	984	907
89	140	217	250	345	359	473	469	601	579	729	688	857	798	985	907
90	141	218	251	346	360	474	470	602	579	730	689	858	799	986	908
91	142	219	252	347	361	475	471	603	580	731	690	859	800	987	909
92	143	220	252	348	362	476	472	604	581	732	691	860	800	988	910
93	144	221	253	349	363	477	472	605	582	733	692	861	801	989	911
94	144	222	254	350	364	478	473	606	583	734	693	862	802	990	912
95	145	223	255	351	365	479	474	607	584	735	693	863	803	991	913
96	146	224	256	352	365	480	475	608	585	736	694	864	804	992	913
97	147	225	257	353	366	481	476	609	585	737	695	865	805	993	914
98	148	226	258	354	367	482	477	610	586	738	696	866	806	994	915
99	149	227	258	355	368	483	478	611	587	739	697	867	806	995	916
100	150	228	259	356	369	484	478	612	588	740	698	868	807	996	917
101	150	229	260	357	370	485	479	613	589	741	699	869	808	997	918
102	151	230	261	358	371	486	480	614	590	742	699	870	809	998	919
103	152	231	262	359	371	487	481	615	591	743	700	871	810	999	919
104	153	232	263	360	372	488	482	616	591	744	701	872	811	1000	920
105	154	233	264	361	373	489	483	617	592	745	702	873	812	1001	921
106	155	234	264	362	374	490	484	618	593	746	703	874	812	1002	922
107	156	235	265	363	375	491	484	619	594	747	704	875	813	1003	923
108	156	236	266	364	376	492	485	620	595	748	705	876	814	1004	924
109	157	237	267	365	377	493	486	621	596	749	705	877	815	1005	925
110	158	238	268	366	377	494	487	622	597	750	706	878	816	1006	925
111	159	239	269	367	378	495	488	623	597	751	707	879	817	1007	926
112	160	240	270	368	379	496	489	624	598	752	708	880	818	1008	927
113	161	241	270	369	380	497	490	625	599	753	709	881	818	1009	928
114	162	242	271	370	381	498	490	626	600	754	710	882	819	1010	929
115	162	243	272	371	382	499	491	627	601	755	711	883	820	1011	930
116	163	244	273	372	383	500	492	628	602	756	711	884	821	1012	931
117	164	245	274	373	383	501	493	629	603	757	712	885	822	1013	931
118	165	246	275	374	384	502	494	630	603	758	713	886	823	1014	932
119	166	247	276	375	385	503	495	631	604	759	714	887	824	1015	933
120	167	248	276	376	386	504	496	632	605	760	715	888	824	1016	934
121	168	249	277	377	387	505	496	633	606	761	716	889	825	1017	935
122	168	250	278	378	388	506	497	634	607	762	717	890	826	1018	936

CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N
123	169	251	279	379	389	507	498	635	608	763	717	891	827	1019	937
124	170	252	280	380	389	508	499	636	609	764	718	892	828	1020	937
125	171	253	281	381	390	509	500	637	609	765	719	893	829	1021	938
126	172	254	282	382	391	510	501	638	610	766	720	894	830	1022	939
127	173	255	282	383	392	511	502	639	611	767	721	895	830	1023	940

Table C.4 – Mapping code values from a 10-bit image (CV_N) with black reference triplet (64, 64, 64) and white reference triplet (940, 940, 940) to a 10-bit full-range image (CV_{FULL})

CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}
0	0	128	75	256	224	384	374	512	523	640	673	768	822	896	972
1	0	129	76	257	225	385	375	513	524	641	674	769	823	897	973
2	0	130	77	258	227	386	376	514	526	642	675	770	824	898	974
3	0	131	78	259	228	387	377	515	527	643	676	771	826	899	975
4	0	132	79	260	229	388	378	516	528	644	677	772	827	900	976
5	0	133	81	261	230	389	380	517	529	645	678	773	828	901	977
6	0	134	82	262	231	390	381	518	530	646	680	774	829	902	979
7	0	135	83	263	232	391	382	519	531	647	681	775	830	903	980
8	0	136	84	264	234	392	383	520	533	648	682	776	831	904	981
9	0	137	85	265	235	393	384	521	534	649	683	777	833	905	982
10	0	138	86	266	236	394	385	522	535	650	684	778	834	906	983
11	0	139	88	267	237	395	387	523	536	651	686	779	835	907	984
12	0	140	89	268	238	396	388	524	537	652	687	780	836	908	986
13	0	141	90	269	239	397	389	525	538	653	688	781	837	909	987
14	0	142	91	270	241	398	390	526	540	654	689	782	838	910	988
15	0	143	92	271	242	399	391	527	541	655	690	783	840	911	989
16	0	144	93	272	243	400	392	528	542	656	691	784	841	912	990
17	0	145	95	273	244	401	394	529	543	657	693	785	842	913	991
18	0	146	96	274	245	402	395	530	544	658	694	786	843	914	993
19	0	147	97	275	246	403	396	531	545	659	695	787	844	915	994
20	0	148	98	276	248	404	397	532	547	660	696	788	845	916	995
21	0	149	99	277	249	405	398	533	548	661	697	789	847	917	996
22	0	150	100	278	250	406	399	534	549	662	698	790	848	918	997
23	0	151	102	279	251	407	401	535	550	663	700	791	849	919	998
24	0	152	103	280	252	408	402	536	551	664	701	792	850	920	1000
25	0	153	104	281	253	409	403	537	552	665	702	793	851	921	1001
26	0	154	105	282	255	410	404	538	554	666	703	794	853	922	1002
27	0	155	106	283	256	411	405	539	555	667	704	795	854	923	1003
28	0	156	107	284	257	412	406	540	556	668	705	796	855	924	1004

CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}
29	0	157	109	285	258	413	408	541	557	669	707	797	856	925	1005
30	0	158	110	286	259	414	409	542	558	670	708	798	857	926	1007
31	0	159	111	287	260	415	410	543	559	671	709	799	858	927	1008
32	0	160	112	288	262	416	411	544	561	672	710	800	860	928	1009
33	0	161	113	289	263	417	412	545	562	673	711	801	861	929	1010
34	0	162	114	290	264	418	413	546	563	674	712	802	862	930	1011
35	0	163	116	291	265	419	415	547	564	675	714	803	863	931	1012
36	0	164	117	292	266	420	416	548	565	676	715	804	864	932	1014
37	0	165	118	293	267	421	417	549	566	677	716	805	865	933	1015
38	0	166	119	294	269	422	418	550	568	678	717	806	867	934	1016
39	0	167	120	295	270	423	419	551	569	679	718	807	868	935	1017
40	0	168	121	296	271	424	420	552	570	680	719	808	869	936	1018
41	0	169	123	297	272	425	422	553	571	681	721	809	870	937	1019
42	0	170	124	298	273	426	423	554	572	682	722	810	871	938	1021
43	0	171	125	299	274	427	424	555	573	683	723	811	872	939	1022
44	0	172	126	300	276	428	425	556	575	684	724	812	874	940	1023
45	0	173	127	301	277	429	426	557	576	685	725	813	875	941	1023
46	0	174	128	302	278	430	427	558	577	686	726	814	876	942	1023
47	0	175	130	303	279	431	429	559	578	687	728	815	877	943	1023
48	0	176	131	304	280	432	430	560	579	688	729	816	878	944	1023
49	0	177	132	305	281	433	431	561	580	689	730	817	879	945	1023
50	0	178	133	306	283	434	432	562	582	690	731	818	881	946	1023
51	0	179	134	307	284	435	433	563	583	691	732	819	882	947	1023
52	0	180	135	308	285	436	434	564	584	692	733	820	883	948	1023
53	0	181	137	309	286	437	436	565	585	693	735	821	884	949	1023
54	0	182	138	310	287	438	437	566	586	694	736	822	885	950	1023
55	0	183	139	311	288	439	438	567	587	695	737	823	886	951	1023
56	0	184	140	312	290	440	439	568	589	696	738	824	888	952	1023
57	0	185	141	313	291	441	440	569	590	697	739	825	889	953	1023
58	0	186	142	314	292	442	441	570	591	698	740	826	890	954	1023
59	0	187	144	315	293	443	443	571	592	699	742	827	891	955	1023
60	0	188	145	316	294	444	444	572	593	700	743	828	892	956	1023
61	0	189	146	317	295	445	445	573	594	701	744	829	893	957	1023
62	0	190	147	318	297	446	446	574	596	702	745	830	895	958	1023
63	0	191	148	319	298	447	447	575	597	703	746	831	896	959	1023
64	0	192	149	320	299	448	448	576	598	704	747	832	897	960	1023
65	1	193	151	321	300	449	450	577	599	705	749	833	898	961	1023
66	2	194	152	322	301	450	451	578	600	706	750	834	899	962	1023
67	4	195	153	323	302	451	452	579	601	707	751	835	900	963	1023
68	5	196	154	324	304	452	453	580	603	708	752	836	902	964	1023
69	6	197	155	325	305	453	454	581	604	709	753	837	903	965	1023

CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}
70	7	198	156	326	306	454	455	582	605	710	754	838	904	966	1023
71	8	199	158	327	307	455	457	583	606	711	756	839	905	967	1023
72	9	200	159	328	308	456	458	584	607	712	757	840	906	968	1023
73	11	201	160	329	309	457	459	585	608	713	758	841	907	969	1023
74	12	202	161	330	311	458	460	586	610	714	759	842	909	970	1023
75	13	203	162	331	312	459	461	587	611	715	760	843	910	971	1023
76	14	204	163	332	313	460	462	588	612	716	761	844	911	972	1023
77	15	205	165	333	314	461	464	589	613	717	763	845	912	973	1023
78	16	206	166	334	315	462	465	590	614	718	764	846	913	974	1023
79	18	207	167	335	316	463	466	591	615	719	765	847	914	975	1023
80	19	208	168	336	318	464	467	592	617	720	766	848	916	976	1023
81	20	209	169	337	319	465	468	593	618	721	767	849	917	977	1023
82	21	210	171	338	320	466	469	594	619	722	768	850	918	978	1023
83	22	211	172	339	321	467	471	595	620	723	770	851	919	979	1023
84	23	212	173	340	322	468	472	596	621	724	771	852	920	980	1023
85	25	213	174	341	323	469	473	597	622	725	772	853	921	981	1023
86	26	214	175	342	325	470	474	598	624	726	773	854	923	982	1023
87	27	215	176	343	326	471	475	599	625	727	774	855	924	983	1023
88	28	216	178	344	327	472	476	600	626	728	775	856	925	984	1023
89	29	217	179	345	328	473	478	601	627	729	777	857	926	985	1023
90	30	218	180	346	329	474	479	602	628	730	778	858	927	986	1023
91	32	219	181	347	330	475	480	603	629	731	779	859	928	987	1023
92	33	220	182	348	332	476	481	604	631	732	780	860	930	988	1023
93	34	221	183	349	333	477	482	605	632	733	781	861	931	989	1023
94	35	222	185	350	334	478	483	606	633	734	782	862	932	990	1023
95	36	223	186	351	335	479	485	607	634	735	784	863	933	991	1023
96	37	224	187	352	336	480	486	608	635	736	785	864	934	992	1023
97	39	225	188	353	337	481	487	609	636	737	786	865	935	993	1023
98	40	226	189	354	339	482	488	610	638	738	787	866	937	994	1023
99	41	227	190	355	340	483	489	611	639	739	788	867	938	995	1023
100	42	228	192	356	341	484	490	612	640	740	789	868	939	996	1023
101	43	229	193	357	342	485	492	613	641	741	791	869	940	997	1023
102	44	230	194	358	343	486	493	614	642	742	792	870	941	998	1023
103	46	231	195	359	345	487	494	615	643	743	793	871	942	999	1023
104	47	232	196	360	346	488	495	616	645	744	794	872	944	1000	1023
105	48	233	197	361	347	489	496	617	646	745	795	873	945	1001	1023
106	49	234	199	362	348	490	497	618	647	746	796	874	946	1002	1023
107	50	235	200	363	349	491	499	619	648	747	798	875	947	1003	1023
108	51	236	201	364	350	492	500	620	649	748	799	876	948	1004	1023
109	53	237	202	365	352	493	501	621	650	749	800	877	949	1005	1023
110	54	238	203	366	353	494	502	622	652	750	801	878	951	1006	1023
111	55	239	204	367	354	495	503	623	653	751	802	879	952	1007	1023

CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}	CV_N	CV_{FULL}
112	56	240	206	368	355	496	504	624	654	752	803	880	953	1008	1023
113	57	241	207	369	356	497	506	625	655	753	805	881	954	1009	1023
114	58	242	208	370	357	498	507	626	656	754	806	882	955	1010	1023
115	60	243	209	371	359	499	508	627	657	755	807	883	956	1011	1023
116	61	244	210	372	360	500	509	628	659	756	808	884	958	1012	1023
117	62	245	211	373	361	501	510	629	660	757	809	885	959	1013	1023
118	63	246	213	374	362	502	512	630	661	758	810	886	960	1014	1023
119	64	247	214	375	363	503	513	631	662	759	812	887	961	1015	1023
120	65	248	215	376	364	504	514	632	663	760	813	888	962	1016	1023
121	67	249	216	377	366	505	515	633	664	761	814	889	963	1017	1023
122	68	250	217	378	367	506	516	634	666	762	815	890	965	1018	1023
123	69	251	218	379	368	507	517	635	667	763	816	891	966	1019	1023
124	70	252	220	380	369	508	519	636	668	764	817	892	967	1020	1023
125	71	253	221	381	370	509	520	637	669	765	819	893	968	1021	1023
126	72	254	222	382	371	510	521	638	670	766	820	894	969	1022	1023
127	74	255	223	383	373	511	522	639	671	767	821	895	970	1023	1023