A Tutorial on Magic Numbers for High Definition Electronic Production

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Abstract

Numerical parameters for television systems must be selected to meet constraints imposed by the various disciplines of television: mechanics, analog and digital electronics, magnetics and even optics.

Television system parameters have sometimes been selected based on the technology of the day. For example, the FCC decided in 1953 to modify the frame rate of NTSC upon the introduction of colour. Although appropriate in a world without videotape recording, this decision did not adequately anticipate the development of technology. The burden of drop-frame timecode was unwittingly imposed: many television equipment designers and users still face the associated hassles on a daily basis, even twenty seven years later. The FCC leaves a heritage of magic numbers: 7, 11 and 13, the factors of 1001. The mystical — some say unlucky — properties of these particular numbers were well known in ancient times.

The magic of highly composite numbers and simple integer ratios allows implementation optimizations. For example the ratio $\frac{5\times7\times13}{2}$ between the line rate and subcarrier frequency of NTSC makes for fairly simple divider circuits. In PAL, similar integer ratios were lost when 25 Hz was added to the subcarrier frequency, leaving no prime factors between F_h and F_{sc}. This is a major nuisance to any equipment which generates a PAL signal, and this design decision has had consequences such as the delayed availability of new production equipment for PAL systems compared to NTSC.

In the early days of NTSC a “unit” was defined as $1/140$ of one volt. A unit is thus 7 $1/7$ mV: the extra $1/7$ was lost in the width of a scope trace in analog technology, but digital-to-analog converters have uniform steps across their range and the seventh of a volt is a big nuisance. CCIR Rec. 601 was established with 219 levels from black to white: the absence of a factor of two in this number (219=3×73) means that it is impossible to express 50% grey exactly, no matter how many bits are used.

So, we have thirty or so years of experience in selecting numerical parameters, with both good and bad results. This experience can be exploited to develop a rational HDEP standard.

The impact of digital computer technology on television systems is already substantial and in the next decade will become even more so. This suggests that the magic numbers of binary arithmetic be considered in the selection of standards. For example, framestore sizes relate well to RAM devices which have power-of-two capacities. “Mega,” in digital electronics actually 2^{10} or 1 048 576, is a magic number. A 1920×1080 framestore has just slightly less than two megapixels.

Simultaneously with computer technology influencing television systems, the economy of scale of consumer electronics — particularly television sets — causes the computer industry to take notice of the resulting high volumes and low costs. For example the 4:3 aspect ratio of all commercially available computer display tubes stems from consumer television. The 16:9 aspect ratio of HDTV will be the next magic aspect ratio number.

There are also some magic film numbers, for example, 24 frames per second. This number is especially important to ensure that HDEP standards interface easily to the film world.

Finally, it is especially important that emerging HDEP and ATV standards have a truly orthogonal sampling structure, that is, samples equally spaced vertically and horizontally. There is no perceptual basis for any other basic structure and the interchange of raster data with disciplines other than entertainment makes a strong justification for selection what is commonly called “square pixels.” This is the magic number, unity.

Introduction

The value of numbers with small factors has been recognized since ancient times. There are 24 hours in a day ($2^3\times3$), 60 minutes in an hour ($2^2\times3\times5$), 360 degrees in a circle ($2^3\times3^2\times5$) and 5280 feet in a mile ($2^5\times3\times5\times11$) because these numbers are products of small factors.

Composite numbers have utility in the design of machinery — both mechanical and electronic — because they offer a range of implementation possibilities. When building a set of gears to divide the once per minute rotation of the second hand of a clock to a once per hour rotation of the hour hand, the divisors of 60 ($2^2 \times 3 \times 5$) can be arranged in various ways depending on the circumstances of the design. If small gears are desirable then four gears with 2, 2, 3 and 5 teeth can be used. If two larger gears are indicated these can have 6 and 10 teeth, or 4 and 15 teeth. However if there were 59 minutes in an hour, since 59 is prime, there would only be one way to build the clock: a single gear with 59 teeth. This choice of the numerical value in a standard establishes the design possibilities for its implementation. The clock example applies in the domain of digital electronics, as well: there are many ways to build a divide-by-60 circuit, but not so many to build a divide-by-59 circuit.

Time and Frequency

Two-to-one interlace results when horizontal scan rate and vertical scan rate are related by an integer ratio with a denominator of two.

In NTSC the colour subcarrier frequency and the line rate are related by the simple integer ratio $^{455}/_{2}$. This relationship causes chrominance energy to be interleaved with luminance energy in the frequency domain.

PAL is based on the ratio $^{1135}/_{4}$. The odd-multiple-of-one-quarter relationship separates the luma and chroma spectra, as in NTSC, but combined with the line rate inversion of the V component of the subcarrier also separates the spectra of the two colour difference components. This in itself does not introduce any numerical problems.

However during the development of PAL the decision was made to add a +25 Hz offset to the subcarrier frequency, equivalent to one additional subcarrier cycle per frame. This offset destroyed the simple integer ratio between subcarrier and line rate: the ratio between subcarrier frequency and line rate in PAL became $\frac{1135}{4} + \frac{1}{625}$, or expressed in its simplest factors, $\frac{11 \times 64489}{2^2 \times 5^2}$. The prime factor 64489 is fairly impenetrable to digital techniques.

This design choice had an impact on the complexity of circuitry required to implement the system. The PAL designers concluded that the additional complexity was beneficial (in its reduction of the dreaded “Hanover bar” artifact), especially considering that no complexity was added to the receiver of the day. However in modern times this design choice imposes a severe penalty on digital circuits to implement PAL. Test signal generators that have no +25 Hz offset and generate a signal with coherent f_{SC} and f_H are ubiquitous despite their being not quite legal. The digital circuitry to generate the offset occupies perhaps 25 square inches of circuit board area. The unit volume of equipment that requires the offset is not sufficiently large to interest semiconductor manufacturers in designing an IC to perform the task.

Sampling Frequency

The CCIR Rec. 601 standard sampling frequency for digital video came into being through the numerical relationships between NTSC and PAL. One way to see this is to express $f_{H(525)}$ and $f_{H(625)}$ as a ratio of prime factors, then take the ratio:

line rate num.	denominator	numerator factors	denominator factors
15625	1	5 5 5 5 5 5	
2250000	143	2 2 2 2 3 3 5 5 5 5 5 5	11 13

The six factors of 5 are common, and the resulting ratio is $2^4 \times 3^2 : 11 \times 13$, or 144:143. Another way of deriving the ratio is to develop each rate from scratch: The numerical derivation is:

$$
\begin{array}{rcl}
\text{fH}(525/59.94) & : & \text{fH}(625/50) \\
525 \times \frac{60}{2} \times \frac{1000}{1001} & : & 625 \times \frac{50}{2} \\
7 \cdot 5^2 \cdot 3 \times \frac{5 \cdot 3 \cdot 2^2}{2} \times \frac{5^3 \cdot 2^3}{13 \cdot 11 \cdot 7} & : & 5^4 \times \frac{5^2 \cdot 2}{2} \\
3 \times 3 \times 2^3 & : & 13 \times 11 \\
144 & : & 143
\end{array}
$$

This calculation is much better suited to the manual cancelling-out of common factors than modern calculators; perhaps this explains why it took so long to identify.

The synthesis of the disparate 525 / 59.94 and 625 / 50 systems into a single (well, OK, dual) system took place by the only means possible given that frame and line rates were already fixed: common data rate. Some of us hope that because we do not have to contend with a vast installed base of equipment, we can select HDTV and ATV systems based on common image format rather than common data rate.

Rounding

We are used to expressing frequencies in decimal form, for example 3.58 MHz or even perhaps 3.579545 MHz. Invariably these representations are rounded; in fact the FCC standardized the nominal subcarrier value at 3.5795450000... even though the designers understood that the decimal fraction recurred.

To reveal the underlying ratios, it helps to state frequencies in their exact fractional form. The proper value of subcarrier frequency in NTSC is $3\frac{51}{88}$ MHz. Often we use a master clock of $14\frac{7}{11}$ MHz to generate sync and subcarrier in NTSC systems. There's those numbers 7 and 11 again.

A proposal being considered by WGSVS would base an exact definition of picture aspect ratio in a 525 / 59.94 system on a picture area with vertical extent of one scan line and horizontal extent of $\frac{1}{780}$ of the total line time. This proposal implies that square-pixel sampling of 525 / 59.94 would occur with a sampling frequency of $12\frac{2}{7}$ MHz. The proposal would create a three-member family of sampling structures for 525 / 59.94 (square pixel, CCIR 601, $4 \times f_{SC}$) with sampling frequencies in the integer ratio 30:33:35.

Some television standards in the past have standardized rounded values. For example, even though the NTSC designers computed the luminance coefficients of red, green and blue to be 0.299, 0.587 and 0.114 respectively, the EIA rounded these to 0.30, 0.59 and 0.11 when it wrote the standard for colour bars.

Further numerical confusion arises from the rounding of the U and V scaling factors for composite modulation (or the rounding of their reciprocals). The composite scaling factors (approximately 0.492 and 0.877) were computed to limit composite excursion to the range $-33\frac{1}{3}$ to $+133\frac{1}{3}$, but the computations were done with zero setup! Setting up an NTSC encoder to max out at $+133\frac{1}{3}$ actually generates a little too much chroma; the theoretical maximum chroma is at just over +131 IRE. Again these errors are relatively insignificant for analog systems, but the digital domain is quite exacting about these issues.

Another particularly bad case is the standard value of equalization pulse width, 2.3 µs, chosen by the FCC for 525 / 59.94 systems. This value should by design be half the normal sync width of 4.7 µs or ideally 2.35 µs. In 1953, analog circuitry was doing very well to get 0.1 µs pulse width accuracy. However modern sync generators are obliged to generate EQ pulse width that is *not* the ideal value, because to generate the theoretically correct value is out of spec! Users of the Fairchild and National MOS sync generator ICs suffered this problem for many years; for ease of implementation, they generated EQ half the width of sync.

A table at the end of this article shows the exact fractional values of some common television system parameters, along with their decimal approximations. Certainly in the days of analog circuitry the fractional values were not relevant to the implementation techniques then available, but digital circuits implement exact arithmetic and so the factoring of the values takes on great significance. Admittedly some of the numbers in the table appear more foreboding than they actually are; the lesson is that the 625/50 amplitude and scanning parameters, and the NTSC colour subcarrier parameters, are most rational. HDTV has already inherited the sensible 625/50 amplitude parameters, 700 mV from black to white instead of $^{37}\!/_{56}$ V! Let's hope that it will have sensible timing numbers as well.

Audio Example

Ideally, frame rate should be coherent with the standard sampling frequencies for digital audio, 44.1 kHz (exactly) for consumer equipment and 48 kHz for professional equipment. This condition is not met for 525/59.94 video; there are 1471.47 samples per frame at 44.1 kHz and 1601.6 samples at 48 kHz. These fractional sample periods cause major problems in the design of digital audio systems that work with video, particularly digital VTRs with digital audio capability. Film at 24 Hz is somewhat more fortunate, having 1838½ and 2000 samples per frame respectively; 625/50 video systems have integral sample counts (1764 and 1920) in both cases.

The following table shows the factors in the numerator and denominator of common frame rates and standard digital audio sampling rates:

frame rate: numerator	denominator	numerator factors	denominator factors
24	1	2 2 2 3	
25	1	5 5	
30000	1001	2 2 2 2 3 5 5 5 5	7 11 13
30	1	2 3 5	
audio f_S			
44100	1	2 2 3 3 5 5 7 7	
48000	1	2 2 2 2 2 2 2 3 5 5	

It is of interest to know the lowest sample rate that has an integral number of samples at various frame rates. A sampling rate with this property must possess all of the factors in each numerator above: in this case, that is $2^4 \times 3 \times 5^4$ or 30 kHz. Later I discuss a proposal for a 1250/72/1:1 HDTV display standard that has a line rate of 30 kHz. If 29.97 Hz were removed from the list, then any multiple of $2^3 \times 3 \times 5^2$, or 600 Hz, would have an integral number of samples per frame.

The C program included at the end of the article extracts prime factors.

The preceding sections have given examples of the importance of simple integer relationships in the design of television equipment, and examples of the difficulties that have been encountered in the past when the simple ratios have been lost. The remainder of this paper indicates where this experience can be used in the selection of system parameters for HDTV and ATV systems.

Digital Arithmetic and Storage

Analog-to-digital and digital-to-analog converters represent amplitudes as discrete, equally-spaced levels. The penalty of quantization error is imposed once at A-to-D time, and again at D-to-A time, but within the digital domain levels are represented perfectly.

If a particular analog quantity is to be represented accurately in the digital domain, then the coding should be chosen accordingly. As one example, it is useful in a digital television system if a video D-to-A converter can be used to insert sync on an analog output signal. If CCIR Rec. 601 levels are used for video, black at code 16 and white at code 219, the sync level does not fall at a luminance quantum and cannot be represented exactly. Of course sync can be added in the analog domain, or can be converted at a somewhat inaccurate level, but both of these cases the advantage of the digital circuitry are lost. By the way, computer graphics D-to-A converters have sync insertion circuitry, but the sync level is scaled for 0 to 255 black-to-white excursion, and the sync capability cannot be utilized with a CCIR Rec. 601 excursion of 16 to 235.

Because computer frame buffers are produced in large quantity, a wide variety of componentry — such as VRAMs, multiplexers, serializers and RAMDACs — is readily available. These components are economical because the amount of high-speed logic is kept to a minimum. One way to achieve a minimum of high-speed logic is to make the high-speed portions of the circuitry handle timing parameters that are powers of two. In high-end 1280-by-1024 graphics workstations divide-by-five circuits were used, but this entails some messy arithmetic. Nowadays the manufacturers of RAMDACs express a clear preference for divide-by-four and divide-by-eight multiplexing. This has implications for the design of raster standards for HDTV: waveform features such as sync width and samples per total line (S / TL) should be chosen to be divisible by as large a power of two as practicable, say 2^5 or 32.

Frame Rate

The standard film frame rate throughout the world, 24 Hz, is highly composite ($2^3 \times 3$) and therefore easy to work with.

There is a magic relationship between the film frame rate and the two predominant frame rates for television.

Playback where the film speed can be altered is constrained by the perceptibility of the speed change: slowing film by the fraction $^{1000}/_{1001}$ for 525 / 59.94 transmission is certainly imperceptible. Speeding it up by $^{25}/_{24}$ for 625 / 50 transmission is just on the threshold of perceptibility. By the way, perceptibility of aspect ratio error is also about 4%.

A different constraint obtains when true realtime operation is required: this is not relevant for film of course, but would come into effect for a 24 Hz production standard. Here the constraint is the motion artifacts introduced during frame rate conversion. After 3:2 pulldown, the small factor of $^{1000}/_{1001}$ requires that a frame adjustment be made once each $33^{11}/_{30}$ seconds. NHK and others have demonstrated that this low rate adjustment can be accommodated by equipment that buffers one or two frames and makes the adjustment during either a static scene or during very rapid motion; in either case the perceptibility is small.

For 625 / 50, there is no 3-2 pulldown process, but a frame adjustment is necessary once per second. This 1 Hz adjustment must be performed with great care because the human visual system is very sensitive to temporal artifacts in the range of 1 Hz.

Incidentally it is highly unlikely that the Hollywood film community will shift to a 30 Hz frame rate: to do so would make it very difficult for their product to be exhibited on European television.

ATV Transmission

Nearly all of the U.S. proponents of ATV transmission systems have chosen a 59.94 Hz field rate.

Zenith wishes to transmit the digital portion of its signal during the vertical blanking interval of the “victim” station that will be subject to its interference. I observe that this requirement can be met by any digital data that occupies an appropriate time slot, independent of its content. The other constraint is that the analog component of the signal be coherent with the line rate of the victim. This can be achieved in many ways, only one of which forces a production standard line rate of 3×NTSC. However admittedly if the target consumers for this equipment are in U.S. living rooms then a choice of 59.94 Hz is certainly the most economical in the short term.

General Instruments has proposed an all-digital solution, and is therefore completely free from the numerical constraints of 7, 11 and 13 in their choice of system parameters. In particular they could choose progressive transmission, square pixels and an arbitrary frame rate.

Europe seems to have pinned its ATV hopes on HD-MAC, and therefore seems destined to choose a 50 Hz basic frame rate for transmission.

Square Pixels

Outside of broadcast television, most electronic systems that deal with pictures have samples that are equally spaced horizontally and vertically, or *square pixels*.

Although in many particular application areas it would be quite feasible to select non-square sampling, to do so compromises the ease with which images can be exchanged. For example, high quality printers now commonly have 300 dots per inch, in both directions. In order to have access to hard copy printers, square samples must be used. It is possible to digitally resample an image to alter the pixel aspect ratio, but to do so takes a substantial amount of computing, in the order of eight multiply / add operation pairs per sample, and introduces resampling artifacts.

Virtually all modern computer displays have square pixels. Technology to integrate video with computing is having to face this fact. As one example, Philips / Signetics developed a digital NTSC / PAL decoder chip set for use in television receivers. This chip set utilizes a 13.5 MHz sampling frequency. Unfortunately the resulting pixels are non-square, so the devices cannot be effectively utilized in computers. Philips are working on a modified chip set, with square pixel sampling, for the computer industry.

There are also numerical reasons for square pixels. Geometry calculation can be performed at any aspect ratio but is obviously easiest with equal vertical and horizontal axis scaling. There is a famous algorithm in computer graphics that plots a circle on a display with square pixels. To plot a circle on a non-square format requires the equivalent of computing an ellipse. This is not a big challenge, but if non-square pixels confer no substantial benefit, and deter the interchange of pictures, why bother?

Image processing algorithms are greatly simplified by square pixels. For example the edge detectors and filter kernels of classic image processing (Prewitt, Sobel, Frei-Chen, Laplacian etc.).require square pixels; if non-square samples are processed by these operators, their results are anisotropic (*i.e.* the filter response is altered depending on the orientation of the image). Since these operators are essentially spatial differentiators, is the image is resampled prior to application of the filter, the error introduced by resampling will be magnified.

Example — A 72 Hz, 2-Megapixel Display Standard

I have made a proposal for a single worldwide HDTV production standard based on 24 Hz origination and 72 Hz display. This section discusses the choice of timing parameters for the 72 Hz display standard, as an example of the numerical relationships.

The timing parameters for this proposal meet the following constraints:

- The sampling frequency is a multiple of 13.5 MHz, for ease of integration with existing 525 / 59.94 and 625 / 50 digital television equipment.
- The number of frames per second is an exact integer.
- The total number of samples per line, number of active samples per line, and samples per sync pulse width are all multiples of 32, in order to utilize straightforward multiplexing techniques and commercial components.

To satisfy the constraint that the sampling frequency be a multiple of 13.5 MHz ($5^6 \times 3^3 \times 2^5$) with the chosen frame rate of 72 Hz ($3^2 \times 2^3$), the number of samples per total frame must be a multiple of their quotient 187 500 ($5^6 \times 3 \times 2^2$). To satisfy the additional desire to have a total sample count per line that is a multiple of 32, the sample rate needs to 13.5 MHz times some multiple of eight. If the sample count per total line were relaxed to multiples of 16, then the sample rate could be 13.5 MHz times a multiple of eight.

These constraints leave factors 5^6, 3^3, and 2 available to form the total line count. For a picture structure of 1920x1080, the total line count should be at least four percent in excess of 1080 lines to accommodate vertical retrace, that is, somewhat greater than 1123. The product of the factors 5^4 and 2 is 1250. A choice of 1250 total lines yields a line rate of exactly 90 kHz; this provides a vertical blanking interval of about 1.89 ms (about 15% overhead). 90 kHz evenly divides the standard consumer and professional digital audio sample rates.

The product of the remaining factors, 32 times $5^2 \times 3$, yields 2400 samples per total line (S / TL) for a sample rate of 216 MHz. The count of 2400 S / TL is exactly 25% in excess of 1920 samples per active line (S / AL), and corresponds to a horizontal blanking time of about 2.2 µs. This set of parameters yields exactly 3 000 000 sample periods per total frame.

What’s Different, and Why?

At the risk of being controversial, I conclude by presenting a table of 525 / NTSC and 625 / PAL parameters. Each of the rows in this table specifies a parameter whose value is completely independent of all of the other rows. I think a non-expert in the field would suspect that there are at least a few relatively frivolous differences. The nature of international standardization is such that the international document containing these parameters is framed as a CCIR “Report” which is non-binding, and not a “Recommendation.”

As an example of the impact of these parameters, it is quite unrealistic in the modern age to expect equipment manufacturers to mix up different batches of CRT phosphors for each side of the Atlantic.

Agreement was reached at the CCIR recently on a single worldwide chromaticity specification for HDTV, so that particular problem shows signs of being remedied, but no agreement whatsoever was reached on scanning parameters.

The challenge to designers of high definition electronic production standards today is to overcome the historical regionalism of television standards setting, and to establish systems that will serve the single world community.

Lines per Total Vertical (L/TV)	525	625
Field Rate	$\frac{60}{1.001}$	50
Picture:Sync Ratio	10:4	7:3
Setup	$\frac{3}{40}$	0
Equalization/Broad Pulse Count	6	5
Line Numbering starts at	field, 1^{st} EQ	frame, 1^{st} BR
Subcarrier Frequency	$227\frac{1}{2}\ f_H$	$\left[\frac{1135}{4}+\frac{1}{625}\right] f_H$
CIE x, y coord, red	.630, .340	.640, .330
CIE x, y coord, green	.310, .595	.290, .600
CIE x, y coord, blue	.155, .070	.150, .060
Assumed display gamma exponent	2.2	2.8

Factor.c *— This routine takes an argument y, and returns a zero-terminated array or its prime factors in r. The maximum result element count is one plus the count of bits in the argument. Poynton, 90/08/21.*

The array p210 contains integers that are used in turn as trial divisors. The array begins with 2, 3, 5 and 7; these are used in the first pass. The array continues with the integers between 11 and 211 [inclusive] that are relatively prime to 2, 3, 5 and 7. If factors remain after the first pass, and the square of the first trial divisor of the next pass is less than the current dividend, then the whole lot (starting with 11) is re-used, adding 210, and this process continues until termination.

Avoiding trial division by multiples of 3, 5, and 7 saves about half again as much work as avoiding only divisors that are even, at the expense of a few hundred bytes of storage.

Note that each of the trial divisors 11 through 211 is relatively prime to all of 2, 3, 5 and 7 but may be the product of factors larger than these. For example, 121 is 11^2. Although 121 is composite, and need not be a trial divisor in the first pass, there are numbers of the form 121+pass×210 that are prime, for example, 331 = 121+(1×210). These must be available as trial divisors in passes subsequent to the first. Fruitless but harmless divides by composite numbers such as these are performed as an expedient to avoid the complexity and storage that would be required to perform trial divides by primes only.

*The first pass starts with a trial divisor of two. Subsequent passes must include a trial divisor of 1+pass*210 (for example, 211 is prime). The trial divisor 211 is included as the last element of p210; it is the last divisor of each pass although intuitively it could be thought of as the first divisor of the next pass.*

```
factor (long y, long r[ ])
{
	int p210[ ] = {2, 3, 5, 7, 11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 37, 41, 43, 47, 53, 59, 61, 67, 71,
		73, 79, 83, 89, 97, 101, 103, 107, 109, 113, 121, 127, 131, 137, 139, 143, 149, 151, 157,
		163, 167, 169, 173, 179, 181, 187, 191, 193, 197, 199, 209, 211};

	long pass;                                          pass counter: 0, 210, 420, ...
	long curr, trial;                                   current dividend and trial divisor
	int n, p, psst;

	curr = y;                                           result in case arg illegal
	psst = 0;                                           starting trial divisor index: start with ‘2’’
	n = sizeof(p210) / sizeof(p210[0]);                 count of elements in p210 , better be 55!
	if (y > 2)                                          dismiss negative, zero, unity argument
		for (pass = 0; curr > pass∗pass; pass += 210)   squares test each pass
		{	for (p = psst; p < n; p++)                  include 2, 3, 5 and 7 first pass
			{	trial = pass + p210[p];                 get next trial divisor
				while (0 == curr % trial)               while remainder zero,
				{	*r++ = trial;                       save factor in result
					if (1 == (curr /= trial)) goto term;    pull out factor
				};
			};
			psst = 4;                                   starting divisor index, next pass
		};
	*r++ = curr;
term:
	*r++ = 0;                                           append terminating flag
}
```

Command shell for prime factor routine. Poynton 90/08/21.

Accept positive integer arguments, loop printing factors.

```
#include <stdio.h>
#include <limits.h>
main (int argc, char *argv[])
{
        long t, *r, res[CHAR_BIT * sizeof(long) + 1];
        while (--argc                                          for each argument ...
                &&  (1 == sscanf(++argv, "%ld", &t)))          convert
        {
                printf("%ld: ",t);                             print
                factor(t, res);                                factor, result to res[ ]
                r = res;
                while (*r)                                     loop printing factors 'til term flag
                        printf("%ld ", *r++);
                printf("\n");                                  append newline
        };
}
```

Prime Factors and Calculator Shortcuts

This table has, for each of a number of television system parameters, its exact value as a ratio of prime factors, its exact value as an integer with proper fraction, its exact value as a calculator shortcut (admittedly biased towards RPN), its value rounded to ten decimal digits, and its unit.

	prime ratio	proper fraction	shortcut	rounded to ten decimals	unit
CCIR Rec. 601 Parameters					
CCIR Y sampling period	$\frac{2^4\times5^3}{27}$	$74\frac{1}{27}$	$\frac{1}{.0135}$	$74.074\,074\,07^{+}$	ns
CCIR 8-bit Y quanta	3×73			219	
CCIR 8-bit C_B, C_R quanta	$2^5\times7$			224	
525 / 59.94 Parameters (7.5% setup)					
Sync amplitude			$\frac{2}{7}$	$0.285\,714\,285\,7^{+}$	V
Black-to-white excursion	$\frac{37}{2^3\times7}$		$\frac{37}{56}$	$0.660\,714\,285\,7^{+}$	V
Pedestal amplitude	$\frac{3}{2^3\times7}$		$\frac{3}{56}$	$0.053\,571\,428\,57^{+}$	V
Blanking-to-white excursion			$\frac{5}{7}$	$0.714\,285\,714\,3^{-}$	V
1 IRE unit	$\frac{2\times5^2}{7}$	$7\frac{1}{7}$	$\frac{1}{.14}$	$7.142\,857\,143^{-}$	mV
Frame period	$\frac{7\times11\times13}{2\times3\times5}$	$30\frac{11}{30}$	$\frac{1001}{30}$	$33.366\,666\,67^{-}$	ms
Field period	$\frac{7\times11\times13}{2^2\times3\times5}$	$16\frac{11}{15}$	$\frac{1001}{60}$	$16.683\,333\,33^{+}$	ms
Line period	$\frac{2^2\times11\times13}{3^2}$	$63\frac{5}{9}$	$\frac{572}{9}$	$63.555\,555\,56^{-}$	µs
525 / 59.94 NTSC (M) Parameters					
Subcarrier cycles per line			$\frac{455}{2}$	$227.5^{=}$	
Subcarrier period	$\frac{2^6\times5^2\times11}{3^2\times7}$	$279\frac{23}{63}$	$\frac{88}{.315}$	$279.365\,079\,4^{+}$	ns
Sample period (at $4\times f_{SC}$)	$\frac{2^4\times5^2\times11}{3^2\times7}$	$69\frac{53}{63}$	$\frac{22}{.315}$	$69.841\,269\,84^{+}$	ns

625 / 50 Parameters (zero setup)					
Sync amplitude				300	mV
Black-to-white, blanking-to-white excursion				700	mV
1 IRE unit				7	mV
Frame period				40	ms
Field period				20	ms
Line period				64	µs
625 / 50 PAL (B, G, H, I) Parameters					
Subcarrier cycles per line	$\frac{11\times 64489}{2^2\times 5^2}$	$283\frac{1879}{2500}$	$\frac{1135}{4}+\frac{1}{625}$	$283.7516^{=}$	
Subcarrier period	$\frac{2^{11}\times 5^7}{11\times 64489}$		$\frac{64}{.2837516}$	$225.549\ 389\ 0^{-}$	ns