

# A Numeric Compression Algorithm for the HP Prime Calculator

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## 1. History of the Algorithm

The VCR Plus+® Instant Programmer™ is a device for programming a video cassette recorder (VCR) using a short (1-8 digit) encrypted code published in a printed or online television grid listing. This code number, known as a PlusCode™, is converted via an algorithm to a channel number, date, start time and duration and substitutes for the user entering this same information.<sup>i</sup> This paper describes a procedure for encoding and decoding these 1-8 digit codes using an HP Prime. Since these codes are now obsolete, this information is for the purposes of mathematical and calculator research only. Please note the terms VCR Plus+®, Instant Programmer™, PlusCode™ and CallSet™ are all registered trademarks of Rovi Corporation, formerly Macrovision Solutions Corporation; successors to Gemstar-TV Guide International, Inc.<sup>ii</sup>

For background, the VCR Plus+® PlusCode™ was invented and patented by Dr. Henry C. Yuen and Dr. Daniel S. Kwoh<sup>iii</sup> as a way to simplify video cassette recorder (VCR) programming, which was, for some, a daunting task. Much like Samuel Morse, whose Morse code used the shortest combinations of dots and dashes for the most common letters, such as a single dot for 'e' and a single dash for 't', Yuen and Kwoh strove to make the most common start times, durations and channel numbers hash to the shortest numbers, while those programs having odd starting times, long durations and high channel numbers would be relegated to the 7- and 8-digit codes. Thus, a program on channel 2 at 7:30 P.M. for 30 minutes (perhaps a prime-time comedy show) might hash to a 2- or 3-digit code, while a show commencing at 3:00 A.M. on channel 150 for 6 hours (a very long infomercial?) might be listed as a 7- or 8-digit code.

Along the way, several compromises had to be made, because 8 digits allows for only 100,000,000 ( $10^8$ ) codes at maximum. Decisions had to be made on the maximum number of channels, start times, and durations, as well as accounting for the varying number of days in each month. Overall, there are allowances for 32 days per month (a nice power-of-2 number greater than the maximum 31 days in the longest months), as well as 288 possible starting times in a given day (every 5 minutes), two tiers of durations: 36 durations in 5-minute increments for programs lasting 3 hours or less, and 20 durations in 15-minute increments for programs from 3.25 to 8 hours in length, spread over 192 different channels. This produced a total of 32 days \* 288 start times \* 56 durations \* 192 channels = 99,090,432 codes, which is just under the 100 million codes possible using 8 digits or less.

The next step was to construct and weight the tables to produce a Huffman-style encoding that pushed the common channel/duration/start time combinations to the shortest codes, and the less popular combinations to the longer codes. In the HP Prime function entitled LIST in the program PLUS associated with this paper, the 192-element list L1 decodes and the list L2 encodes according to combinations of 48 half-hour incremental start times and four possible half-hour incremental durations with weighting included to give a rough placement of the most common starting times and program lengths. The other lists, L3 and L4 are used to scramble and unscramble the 7-and 8-digit codes, respectively, while L5 is used for assigning a name to a given channel number for additional reassurance to the user. In an actual VCR Plus+® Instant Programmer™, no such channel name is shown, only a channel number.

If the development had been left at this point, there would have been a static code for each date/channel/duration/start time combination each month. The code for a program on channel 3 at 6:00 P.M. for 1 hour on May 7th would be valid for that same program on June 7th, as well as May 7th the next year. This would make it too easy for publishers (and clever users) to guess the upcoming codes, and would likely make licensing the published codes unnecessary. Since the inventors did not want this, they added several layers of obfuscation to the original codes to make each month unique among 1200 months of a complete century starting March 1, 1989 and extending until February 28, 2089. They also used one encoding method for the 1-6 digit codes, and added a second technique for the 7-8 digit codes to further confuse would-be code guessers. In this way, Gemstar Development Corporation, the company which produced and distributed these codes, and which became Gemstar-TV Guide International, Inc. when it purchased TV Guide, Inc. in 1999, could control and license PlusCodes™ to various TV listing periodicals.

Several stand-alone models of Gemstar's VCR Plus+® Instant Programmer™ were manufactured and sold to the public, including the early "Patent Pending" VIP-8 and VIP-18, similar looking simple devices with an LCD display and a rectangular shape originally priced at \$59.95 with the ability to control both a cable box and a VCR. Later models included the clamshell design model VIP-18M with CallSet™, a built-in receiver allowing remote programming of the translation set between a local cable provider's channel numbers and the locally published channel designators by simply calling a 1-800 number and paying a \$4.95 fee to have the setup information transmitted through the phone. The most expensive model, the vertically designed CPS-1 or Control Tower™ could handle TV sets from more than 60 manufacturers, VCRs from over 100 different makers, and cable boxes made by more than 50 companies. VCR Plus+® tech was also incorporated into video cassette recorders from a multitude of manufacturers and built into both dedicated and general purpose remote controls, such as the Panasonic Light Tower.

PlusCodes™ hit their distribution peak somewhere in the late 1990s to the early 2000s. In one brochure from 1993, more than 500 newspapers were shown to be publishing the codes throughout the USA, but with the decline of VCRs in favor of Digital Video Recorders (DVRs), cable television networks with more than 192 channels, reduced newspaper circulation amid movement to the Internet, the conversion of broadcast television from analog to digital and the advent of on-demand streaming video by Netflix, Amazon Prime and Hulu, PlusCodes™ are now history. The codes have not been published in newspapers or TV Guide since May, 2010, and the only place they are still officially supported is at the website [www.vcrplus.com](http://www.vcrplus.com), where users can log in and request individual PlusCodes™.

## 2. The HP Prime Decoding and Encoding Programs

After entering 1-8 digit code in the HP Prime PLUS program subroutine entitled DECO, the code is passed to a small function called FUN1. Here, the PlusCode™ is "unmasked" by performing a series of repeated additions of the digits to form a unique new number. The new number is guaranteed to be the same length as the original code because the outer loop will repeat as long as the most significant digit of the resulting code is a zero. This process was described originally by Shirriff, Welch and Kinsman<sup>iv</sup> as mod-10 no-carry matrix multiplication using a decoding key of 68150631, but was later recognized to be the mod-10 remainders of 1 (1), 1+2 (3), 1+2+3 (6), 1+2+3+4 (0), ..., 1+2+3+4+5+6+7+8 (6) derived from looping<sup>v</sup>. Notice how the 1-8 digit code is parsed into an array by the FUN1 subroutine using only a single line: `n:=REVERSE(ASC(STRING(code))-48)`; and then reassembled using the HP Prime programming sequence: `RETURN EXPR(CHAR(REVERSE(n)+48))`; where 48 is used to convert values (0-9) between ASCII and binary.

After unmasking, the code is split into bottom 1 to 3 and top 0 to 5 digits. 1 is subtracted from the bottom 3 digits, the result is divided by 32 and 1 is added to give the day. The top 5 digits as well as the (bottom 3 digits – 1) mod-32 are sent to the mapping function MTOP (map top), which uses current year mod-16 and day, plus mod-10 no-carry matrix multiplication in the form of a loop to derive an offset value that is returned to the calling function for 1-6 digit numbers. For 7-8 digit values, table L3 is used for 7-digit and L4 for 8-digit numbers along with table L1 for both lengths to extract two digits from the top 4 or 5 digits of the number according to the positions indicated in L3 or L4, using those as a lookup into the L1 table, and then substituting the discovered digits from L1 back into the same positions in the original top 4-5 digits. This step is done several times until the top 4-5 digits are thoroughly scrambled.

Shuffling the bits is the next step, using the function SHUF, where the top 5 digits and remainder are sent in from MTOP and their bits rearranged to return time and channel codes. The HP Prime function BITAND was quite useful here. The function TWID (twiddle) uses the HP Prime's CASE/IF/ELSE/END command to take the time code as input and split it into start time and duration information, which are the final pieces of information returned to DECO. DECO now has code, year and month from input, and has calculated day, channel number, start time and program duration, which can then be displayed.

The ENCO function is similar to DECO, except everything is performed in the opposite direction. Year, month, day, start time, duration, and channel number are entered as input arguments, and those same values are returned along with the matching PlusCode™. The functions used are ITWD (inverse twiddle), ITLV (interleave), IMTP (inverse map top) and IFUN (inverse FUN1). These functions use mostly the same tables and techniques as their companion decoding functions, with the notable exception that IMTP uses table L2 rather than L1 to do an inverse mapping of the 192-position table to maintain speed.

### **3. The HP Prime User Menu Program**

Wrapped around the ENCO and DECO functions is a menu function called PLUS, which allows graphic entry and display of results of the encoding/decoding. PLUS sets HSeparator:=3 to eliminate any commas or decimal points interfering with codes and saves the reserved screen plotting and positioning variables for later restoration. The RGB command is used to choose some pleasant colors for foreground and background fields. CHOOSE puts up a choice box to let the user decide between DECODE (1) and ENCODE (2), and the 'when' function examines the value returned from CHOOSE to decide whether to call DECO or ENCO. Results are returned in an array called n, split up and formatted correctly, then displayed in a series of boxes using the RECT command with positioning and color information along with labels via the TEXTOUT command. FREEZE stops the screen so the user can read the information and restart if desired. A bit of experimentation was required to get the RECT command to position the boxes correctly, and to make TEXTOUT put the labels and other output information in the proper locations relative to the boxes.

Values for reserved variables Xmin, Xmax, Ymin and Ymax define the screen plotting and positioning. Depending upon the HP Prime application chosen immediately before running the PLUS program, these values may vary. For example, for Function Plot, Xmin=-15.9, Xmax=15.9, Ymin=-10.9, Ymax=10.9 and for Sequence Plot, Xmin=-1.8, Xmax=30, Ymin=-1.8, Ymax=20. It was necessary for predictability in where the input and output text boxes for PLUS would appear to set these variables to known values beforehand, so Xmin is set to 1, Xmax to 319, Ymin to 1 and Ymax to 219 to directly address a 320 x 220 pixel screen. The values for the prior plotting and positioning variables are saved as x1, x2, y1 and y2 at the beginning of PLUS and are restored at the end of that routine after the FREEZE command has shown the text output.

## 4. How to Run the Program

To run the program, after going to the Program menu and using the 4-point selector button to position the blue band over the program named PLUS, press the "Run" button in the lower right corner of the screen. Select PLUS from the "Choose Prog Function" menu. From the Choose menu, select either Decode or Encode. For Decode, you are asked to enter the Year (1989-2089), a Month (1-12), and a Code (1-99999999), clicking OK after each value is entered, and once more after all values have been confirmed. The display then shows labeled values of Code, Date (with day of the week abbreviated), Start time (plus AM or PM), Finish time (plus AM or PM), Length in hours and minutes, and Channel number and designation. For example, Year=2015, Month=9 and Code=12345678 yields Monday, 9/21/2015 Starting 2:10 AM, Finish 2:35 AM, Length 0 hr 25 min, Channel 96 - PAL. Hit Enter key to return to the Program Catalog. You can change the channel designation if you wish at any time by adjusting L5:={"WXXA1","WXXB2","WXXC3",...}; under the LIST() function in the appropriate position. You can use the HP Prime LIST key (SHIFT-7) to examine L5 after it has been created to see what name sits in the numbered slot you wish to replace. For example, slot 37 = "DSC", so replace "DSC" in the LIST function in the line starting L5:={"WXXA1","WXXB2","WXXC3",...}; with your desired channel name.

If you choose to Encode instead of Decode in the procedure above, you will be asked to enter a Year (1989-2089), a Month (1-12), a Day (1-31), a Start time (HHMM = 2-digit hour followed by 2-digit minute in 24-hour format from 0-2355), program Length (HMM from 5 to 800) and Channel (1-192). For example, entering Year=2015, Month=9, Day=21, Start=210, Length=25 and Channel=96 gives identical output information as in the previous paragraph. Please note that Length is in HMM format, not minutes alone, so 120 entered in that field would be 1 hour and 20 minutes (80 minutes), not 120 minutes.

It is possible that you might encounter an error when decoding, as about 4% of the address range is invalid. These might produce a Day of 32 or a duration greater than 8 hours, for example, where on the original VCR Plus+® an error statement such as Err: DATE or Err: CODE might be shown. Similarly, it might be possible to encode something like September 31st, and decode the same, where on a real VCR Plus+® device that generated code would produce an error. This program does some rudimentary error checking, such as keeping channel numbers, starting times and program lengths within known boundaries, as well as rounding starting times to the nearest 5 minutes and lengths of 3 hours or less to the nearest 5 minutes or program lengths of greater than 3 hours and less than 8 hours to the nearest 15 minutes, but a valid date/channel/start/length combination should produce a working code and vice-versa. Note also that if you enter a code on a real device, and the date has been set later than the date of the show to be recorded, that another date/channel/start/length will be generated from the following month. For example, if you have a VCR Plus+® set to September 26th, 2015 and you enter 12345678, you will see a date of 10/21/2015, a start time of 2:40 P.M., duration of 2 hours and 25 minutes on channel 180 rather than the information in the previous paragraphs, just as if you had entered Year=2015, Month=10, Code=12345678 into the Decode choice within the PLUS program.

No attempt has been made in the program to cover the translation of cable box channels to local listings, as this feature can be accomplished easily by encoding the translated channel number directly. A three hour time shift available in the VCR Plus+® Instant Programmer™ has also not been implemented for the same reason. And, of course, sending coded signals to a VCR, cable box or TV would be beyond the capabilities of the HP Prime without external hardware, and is not particularly germane to the algorithm.

## 5. Final Thoughts

A previous attempt was made to put this algorithm on an HP-50G calculator, but the results were rather slow and somewhat difficult to run correctly without external help. The HP Prime program PLUS and its internal functions were written based on a public-domain program called `vcrpp1.c`<sup>vi</sup> originally made in C programming language, a copy of which I have included along with a second version, `vcrpp2.c` containing some corrections for the high channels. The mechanics of the algorithms can be further explored through this program or via the Shirriff, Welch and Kinsman paper and follow-up notes listed in the reference section if desired. The patent documents for US Patent 5,335,079 contain some interesting diagrams and explanations. The routines described in the preceding paragraphs are included in the HP Prime program as EXPORT functions, so you can call any one of them from the Home screen or from your program by using its name and passing in the correct arguments. For example, at Home, typing `DOTW(9,26,2015)` would return the output value "SAT". As well, program functions can be explored by selecting each directly from the PLUS "Choose Prog Option" menu after starting the PLUS program. The HP Prime programming language will automatically prompt for all the arguments it needs to run using labeled boxes, and will return any value(s) normally returned from that function as a list surrounded by curly braces prefaced by the name of the function. Just remember to move between input boxes with either the Enter key or by pressing the soft OK box at the lower right side of the screen, and press one more Enter or OK to run the function and obtain the output list. Inside the program, the decoding sequence is `code -> DECO -> FUN1 -> MTOP -> SHUF -> TWID -> date/start/channel/length`. Encoding sequence is `date/start/channel/length -> ENCO -> ITWD -> ITLV -> IMTP -> IFUN -> code`.

The functions within the PLUS program have been written so that they are "mirror images" of each other, and the output of one can be used as input to the other in order to quickly regression test each pair of functions. The function pairs are DECO & ENCO, FUN1 & IFUN, MTOP & IMTP, SHUF & ITLV and TWID & ITWD. Thus, calling `TWID(12345)` from the Home or CAS command line yields {230,135} and the function `ITWD(230, 135)` gives 12345 as a result. Similarly, function `FUN1(IFUN(12345678))` returns 12345678. Of course, there are no mirror images for DOTW (Day of the Week) or LIST (create lists L1-L5).

A couple of secrets were found while playing around with a real VCR Plus+<sup>®</sup> device. First, if you enter and erase more than about 200 codes within a short amount of time, the device will lock up on you and only removing the batteries for a long time (or shorting a certain internal capacitor) will bring the unit back to life. In the case of too many codes, the error code Err: MEMORY FULL came up, and you are out of luck for a while. Second, there is an entire separate section of codes set up for 1 day of same-day use only. These 10 million codes with starting digit of 0 do not have to worry about a day being input, so a factor of 32 could be used for other purposes. Further research is needed, as these codes have not been explored to their full range of possibilities, nor is their encoding/decoding system known at this time.

The various VCR Plus+<sup>®</sup> devices, which wait patiently after having the codes entered to send out a signal to your VCR to start recording at the given time appear on eBay and at thrift stores and garage sales every now and then for a few dollars, and just like the older calculators that might not do as much as today's models, but are still very collectible, they are an interesting relic of technological progress. And, like the calculators of long ago, they still hold some interesting mysteries waiting to be explored.

## References:

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- <sup>ii</sup> Wikipedia “Gemstar-TV Guide International” [http://en.wikipedia.org/wiki/Gemstar-TV\\_Guide\\_International](http://en.wikipedia.org/wiki/Gemstar-TV_Guide_International)
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- <sup>iv</sup> K. Shirriff, C. Welch, A. Kinsman “Decoding a VCR Controller Code” Cryptologia, 16(3), July 1992, pp 227-234.
- <sup>v</sup> K. Shirriff “VCR Controller Code: Additional Notes” <http://files.righto.com/papers/vcr1.html>
- <sup>vi</sup> Anonymous “VCRPlus+ Encoding, Decoding and Regression Test Code” <http://www.cs.cmu.edu/~dst/VCRPlus/>