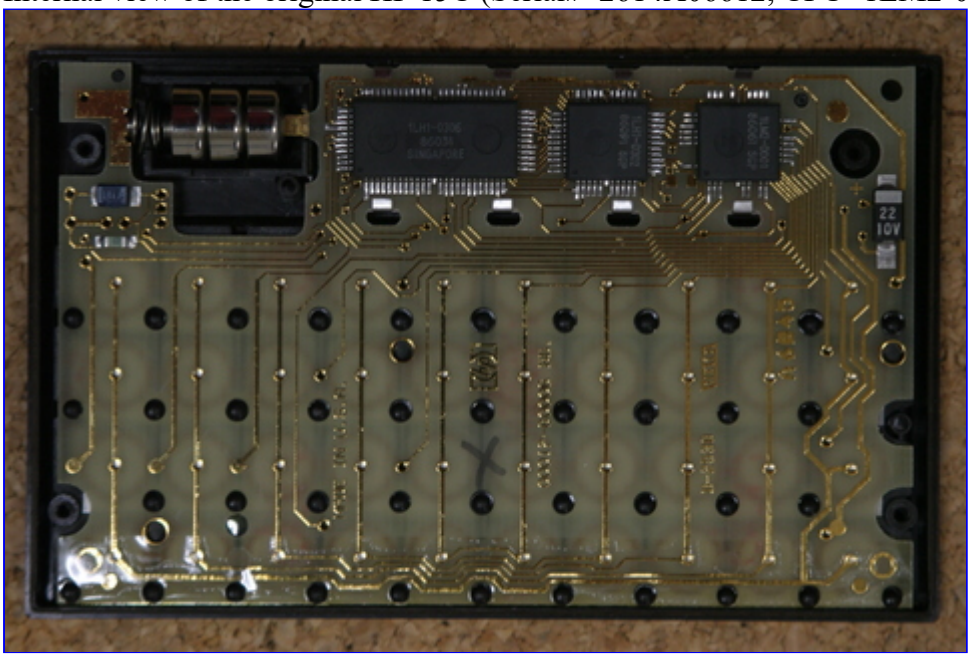
HP 15C - LC resonator replacement for triple speed 15C

Takayuki HOSODA
Oct. 12 2009

- Japanese edition is here.
- Please use the mirror site as well.

Triple speed modification (#2614A06612)

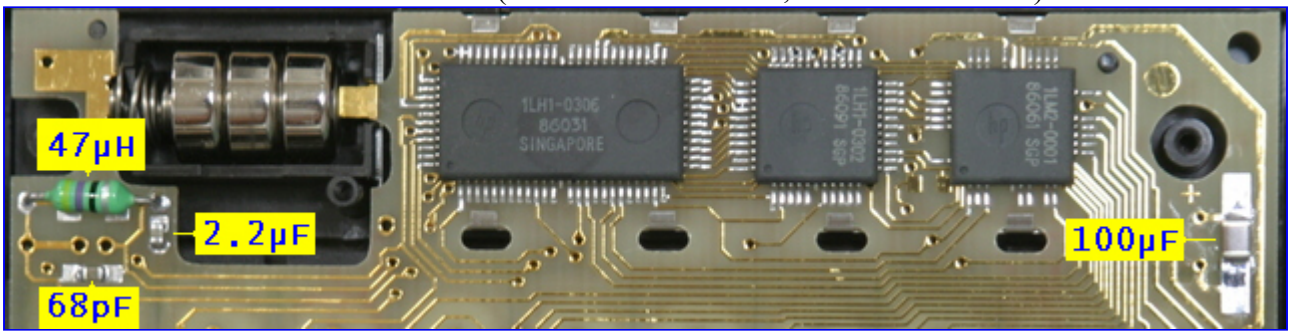
Internal view of the original HP 15C (Serial#=2614A06612, CPU=1LM2-0001)



Power supply current (T_a=26°C, $V_{battery}$=4.72V(SR44×3), f_{LC}=884kHz(original))

- I_{run}≈1.2mA
- I_{idle}≈27μA
- $I_{standby}$<0.1μA
- $I_{on\text{-}key}$≈2.7mA

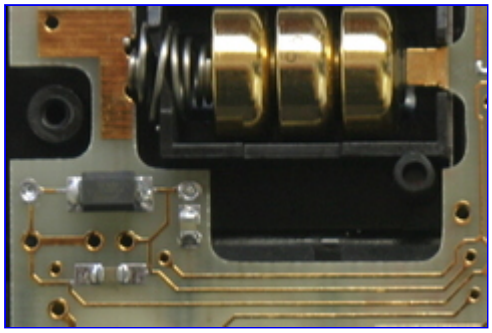
Internal view of the modified HP 15C (Serial#=2614A06612, CPU=1LM2-0001)



Parts replacement

- C_{osc}=180pF → 68pF

- L_{osc}=180μH(R_s=5.5Ω) → 47μH(R_s=1.5Ω)
  API Delevan S1812R-473K (Shielded, R_s=3.4Ω) is recommended for new modification.
  The resonator inductor and capacitor are chosen to obtain relatively high Q at resonant frequency of 2.8 MHz for stable oscillation.



LC resonant frequency of the LC resonator

L : Inductance	47	**[μH]**
f_0 : Self resonant frequency	15	**[MHz]**
f_m : L,Q measurement frequency (f_m)	2.52	**[MHz]**
Q_m : Quality factor at f_m	30	
R_s : Equivalent series resistance (at F_m) ≈		**[Ω]**
C_p : Parallel capacitance	68	**[pF]** → Fr ?
f_r : Resonant frequency ≈		**[MHz]** → Cp ?
Q_e : Estimated quality factor (at F_r) ≈		

Example of the electrical characteristics of the actual inductors
TDK, SMD Inductors For Signal Line(Wound) NLV Series NLV32

Inductance (μH)	Inductance tolerance	Q min.	Test frequency L,Q (MHz)	Self-resontant frequency (MHz)min.	DC resistance (Ω)max.	Rated current (mA)max.	Part No.
47	±5%	30	2.52	15	7	60	NLV32T-470J
180	±5%	20	0.796	7	17	60	NLV32T-181J

API Delevan, RF Inductors - Surface Mount - Shielded Surface Mount Inductors S1812 & S1812R Series

Inductance (μH)	Inductance tolerance	Q min.	Test frequency L,Q (MHz)	Self-resontant frequency (MHz)min.	DC resistance (Ω)max.	Rated current (mA)max.	Part No.
47	±10%	30	2.5	9	3.40	242	S1812R-473K
180	±10%	40	0.79	4.5	8.50	153	S1812R-184K

- C_{bypass}=22μF/10V/Ta → 100μF/6.3V/MLCC
  Large capacitance MLCC(Multi layer ceramic capacitor) is used for
  low impedance over wide temparature and frequency range for good bypassing,
  high capacitance for battery backup time at the stand-by current that might increase,
  and very low leakage current for long stand-by time.

Parts addition

A bypassing MLCC is added for stable operation, and expectingly to reduce EMI.

- Added a bypassing capacitor of 2.2μF/6.3V/MLCC next to the LC

Results (T_a=27°C, $V_{battery}$=4.7V, f_{LC})

The self-diagnostics-test ([ON]+[×]) passed 'till $V_{battery}$ dropped under 3.0V(T_a=27°C).
Low battery indicator turns on when $V_{battery}$≤3.5V

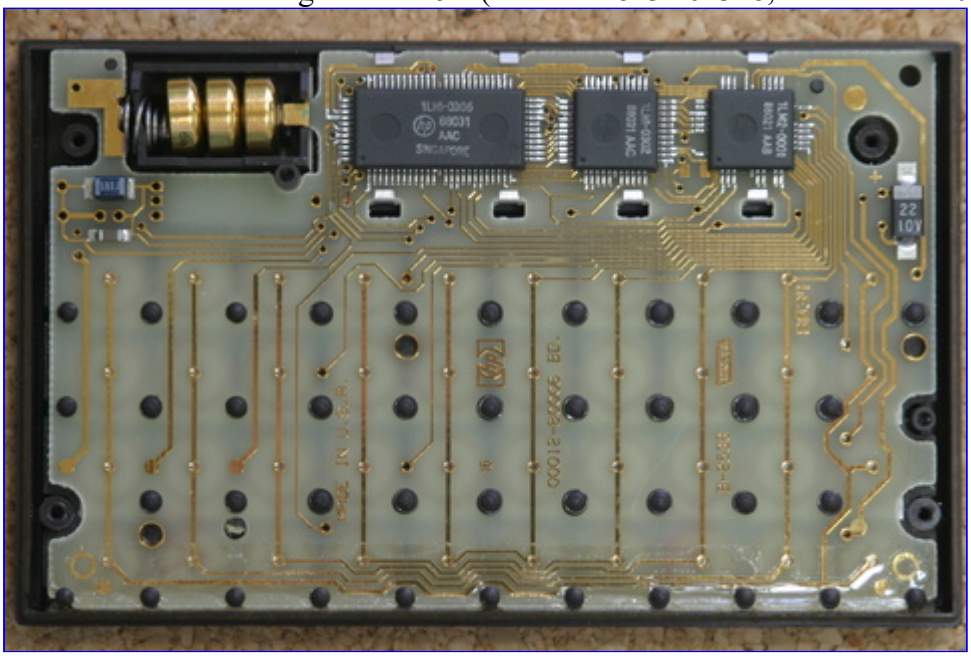
- $t_{diagnostic}$= 27s → 8.5s
- t_{ustrip}= 97s → 31s
- t_{nqueen}=(79m10s) → 25m5s

Power supply current (Ta=27°C, $V_{battery}$=4.5V(SR44×3), f_{LC}=2.8MHz)

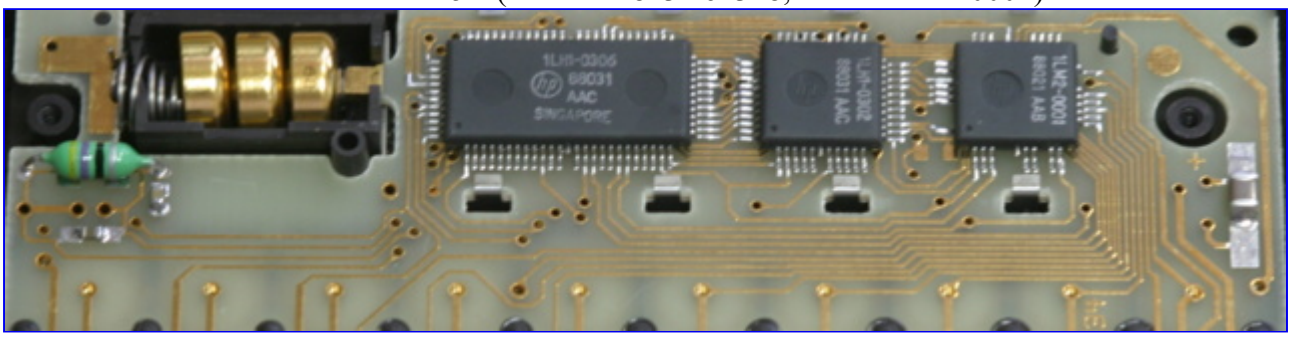
- I_{run}≈2.5mA,
- I_{idle}≈26μA,
- $I_{standby}$<0.1μA

Triple speed modification (#2813A62318)

Internal view of the original HP 15C (Serial#=2813A62318, CPU=1LM2-0001)



Internal view of the modified HP 15C (Serial#=2813A62318, CPU=1LM2-0001)



Parts replacement

- L_{osc}=180μH(R_s=5.5Ω) → 47μH(R_s=1.5Ω)
(API Delevan S1812R-473K (Shielded, R_s=3.5Ω) is recommended for new modification.)
- C_{osc}=180pF → 68pF
- C_{bypass}=22μF/10V/Ta → 100μF/6.3V/MLCC

Parts addition

- Added a bypassing capacitor of 10μF/6.3V/MLCC next to the LC

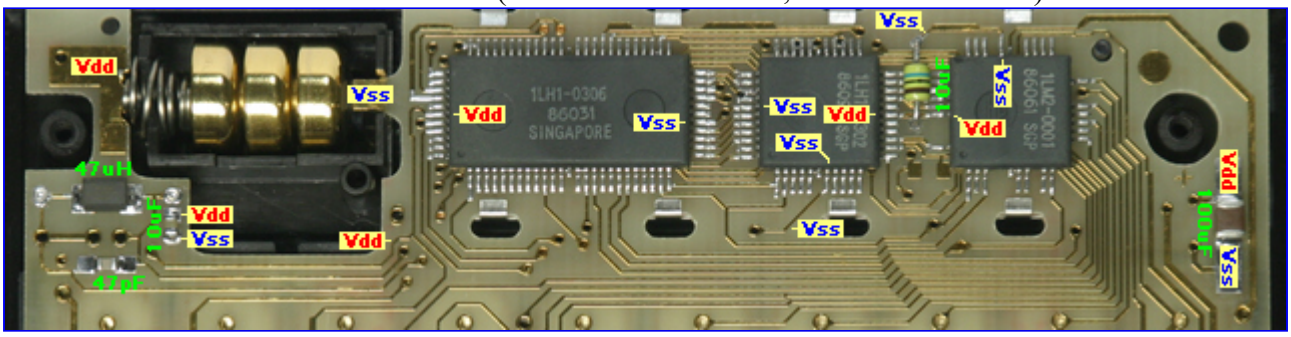
Results (T_a=27°C, $V_{battery}$=4.76V, f_{LC})

The self-diagnostics-test ([ON]+[×]) passed 'till $V_{battery}$ dropped under 2.9V(T_a=27°C).
Low battery indicator turns on when $V_{battery}$≤3.5V

- $t_{diagnostic}$= 27s → 8.5s
- t_{ustrip}= 97s → 31s
- t_{nqueen}=(79m10s) → 25m16s

Experimental modification for quad-speed 15C (#2813A62318)

Internal view of the modified HP 15C (Serial#=2813A62318, CPU=1LM2-0001)



Parts replacement

- L_{osc}=180μH(R_s=5.5Ω) → 47μH(API Delevan S1812R-473K, Shielded, R_s=3.5Ω)
- C_{osc}=180pF → 47pF (Taiyo-Yuden UMK212CH470J) | 33pF (Taiyo-Yuden UMK212CH330J) | 27pF (Taiyo-Yuden UMK212CH270J)
- C_{bypass}=22μF/10V/Ta → 100μF/6.3V/MLCC (TDK C3225JB0J107M)

Parts addition

- Added a bypassing capacitor next to the LC, 10μF/6.3V/MLCC (Murata, GRM21BB10J106KE01)
- Added a bypassing capacitor next to the CPU, 10μF/35V/MLCC (Taiyo-Yuden GP075F106Z-A-B Axial lead)

The self-diagnostics-test ([ON]+[×]) results at various voltage and LC conbination, and N-queens benchmark results.

T_a=27°C	Osillator inductor and capacitor						Comment
	47μH, 47pF		47μH, 33pF		47μH, 27pF		
$V_{battery}$	$I_{battery}$	Result	$I_{battery}$	Result	$I_{battery}$	Result	
4.7V	2.9mA	O.K.	3.2mA	O.K.	3.4mA	O.K.	Nominal voltage of SR44×3 at 20°C
3.8V	2.1mA	O.K.	2.4mA	O.K.	2.5mA	O.K.	Cut-off voltage of SR44×3 at -10°C
3.6V	2.0mA	O.K.	2.2mA	O.K.	2.5mA	O.K.	-
3.5V	1.9mA	O.K.	2.1mA	O.K.	2.2mA	O.K.	Low battery indicator turns on when $V_{battery}$ ≤ 3.5V
3.4V	1.9mA	O.K.	2.0mA	O.K.	-	FAIL	
3.3V	1.8mA	O.K.	-	FAIL	-	FAIL	
3.2V	1.7mA	O.K.	-	FAIL	-	FAIL	
3.1V	1.6mA	O.K.	-	FAIL	-	FAIL	
3.0V	-	FAIL	-	FAIL	-	FAIL	
2.7V							Cut-off voltage of LR44×3 at 20°C
$t_{N\text{-}queens}$	23m15s		20m30s		19m25s		$V_{battery}$=4.7V, T_a=27°C

Conclusion

The triple-speed-modified HP-15C with 1LM2 processor seems works well, and stable as far as you are using SR44 (Zink Silver Oxide) batteries.

The recommended parts value for the LC resonator are 47µH and 68pF so far.
At least one bypassing MLCC (Multi Layer Ceramic Capacitor) of its value from 1µF to 10µF should be added to the power line for stable operation.

SEE ALSO

- HP-15C Limited edition - Workaround for the high current spike
- DM-15CC - a real HP 15C emulator
- Online calculator - LCR - Resonant frequency of the LC resonator
- Upgrading the memory of the HP 42S to 32KB, Crystal resonator replacement for double speed 42S
- Reparing the hp32sII with faulty keypad

REFERENCE

- HP Voyager Calculator Speedup, Ken Sumrall
- HP-15C speed up, Gerson W. Barbosa
- Successful HP-11C speedup, Karl Schneider

APPENDIX - Program library

- Factr - Factor a positive integer
- Frac - Fractional approximation
- LCM/GCD - LCM and GCD of two positive integers
- LCR - Resonant frequency of a LC resonator
- µZw, µwZ - Synthesize/Analyze microstrip transmissionline
- RI - Rational interpolation
- Z→S - Impedance Z to S_{11} scattering parameter conversion

---

yokohama@finetune.co.jp