Forward ECAL FEB power and DC/DC work towards that

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2/15/2024 ePIC DAQ/Electronics meeting

fwd ECAL FEB power requirements

- 468 FEB in all
- water cooled (about 4 W / FEB)
  - power losses conducted into PCB & water cooling are not so important, although of course we do want to minimize
  - main goal is to reduce cable size and power losses in cables (or elsewhere) that ultimately get into airspace & SiPM boards
- SiPM signals very small (15 MeV ≈ 90 μV), but very low impedance / not easily disturbed
  - EMI risks from DC/DC circuits are moderate – with care we can easily avoid troubles
- radiation tolerance: 3×10^{11} n/cm^2 (1 MeV eq.)
- load voltage & current estimates:

voltage	current	uses	scheme
+52 V	<32 mA (TBD)	SiPM bias regulators	external
+3.3 V	240 mA	preamps, ADC driver, etc.	LDO from external, or local buck
+2.5 V	small	FPGA	LDO from +3.3 V
+1.8 V	1.2 A	ADC's	local buck from +15 V external
+1.0 V	200 mA (TBD)	FPGA	LDO from +1.8 V
−1.5 V	100 mA	preamps	LDO from external

today's focus

DC/DC chip selection considerations

(for the fwd ECAL 1.8 V 1.2 A load case, for the sake of discussion)

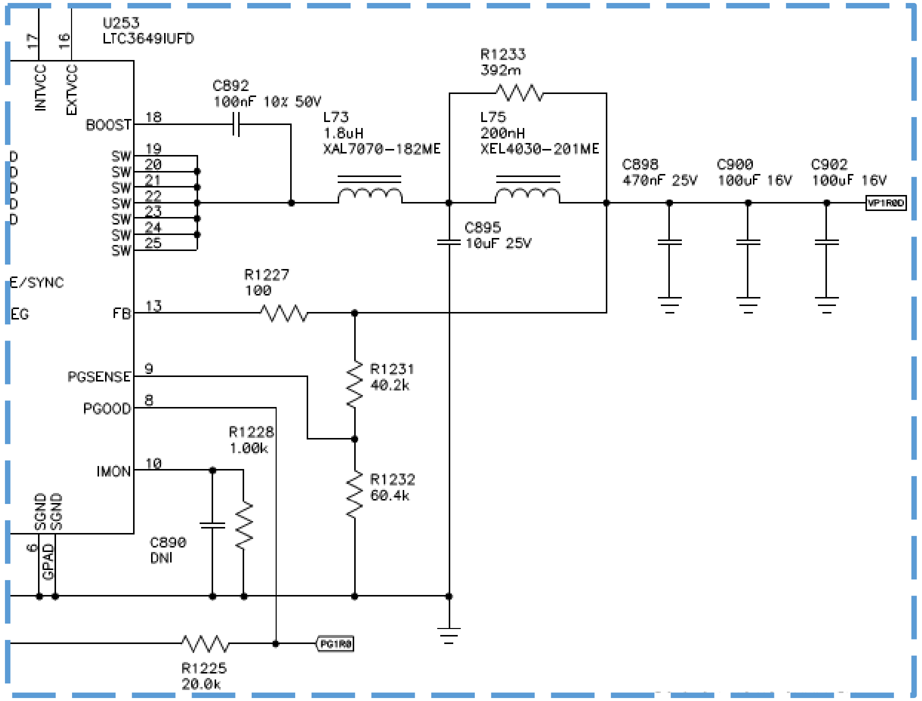
- so called "synchronous buck" (low side switch FET, not diode), for decent efficiency at V_{OUT} <2 V
- f_{SW} ≥2 MHz capability, for practical air-core inductor
- internal switch FET's, for compact, simple, lower EMI board design
- I_{OUT} capability 1.5 to 4 A
  - *too much is not good*: capacitance of switches wastes power, and low current sense gain means either noisy operation or comparatively high inductor ripple current (which wastes power and raises EMI risks)
- V_{IN} capability ≥12 V, as high as possible up to ~48 V would be interesting
  - In practice, efficiency suffers at higher V_{IN} and (generally speaking) with higher $V_{IN,MAX}$ capability. But **input current reduction**, not efficiency of the DC/DC, **is the priority goal**. (Assuming board cooling is "easy".)
  - For many parts on market, especially ones with simple peak current control, the minimum on-time seriously limits V_{IN} under the constraint of low V_{OUT} and high frequency
- customizable loop gain, i.e., a COMP/ITH pin or equivalent, is best
  - besides enabling optimal noise and transient response, this can be used to decrease output ripple 5×
  - unfortunately, in the name of simplifying the application circuit and the design process, more than half of modern small DC/DC chips have internally fixed loop gain ☹
- Of course we want high efficiency, although power loss well coupled to cooling water is not really a big concern
- Ability to use external reference voltage, simply, *might be helpful for radiation tolerance*

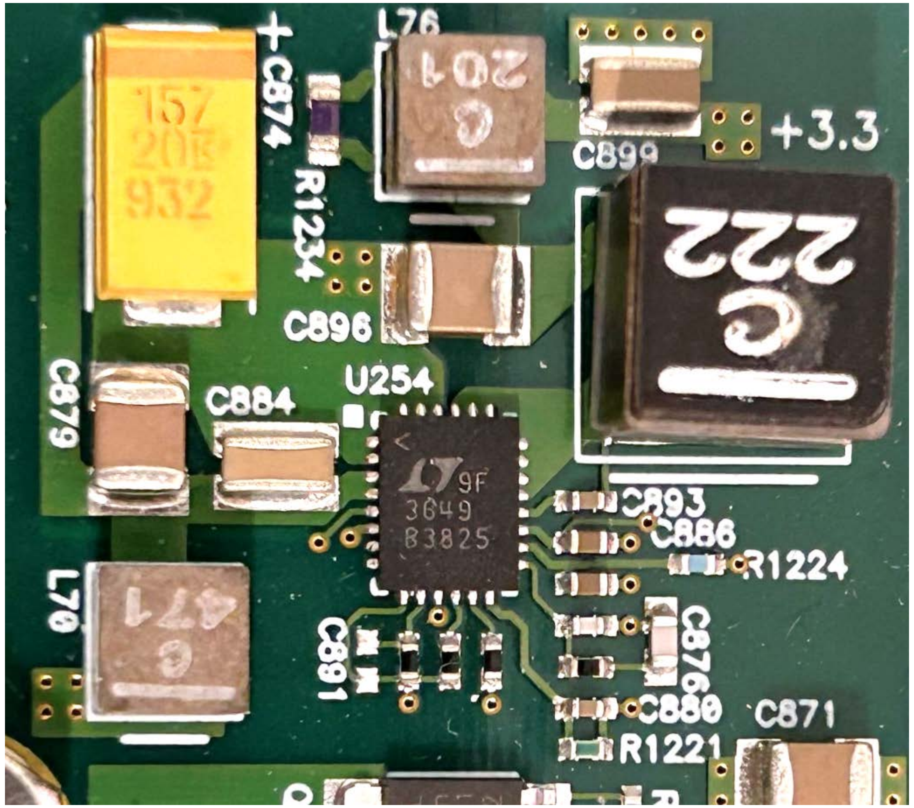
Candidate DC/DC chips

(again, for the fwd ECAL 1.8 V 1.2 A load case, for the sake of discussion)

P/N	$I_{OUT,MAX}$, A	$V_{IN,MAX}$, V @ 1.8 V out, 2 MHz	f_{SW} range, MHz	control topology	comments
LTC3600	1.5	15	0.2 – 4.0	valley current	eval board in hand; direct external ref possible
LTC3601	1.5	15	0.8 – 4.0	valley current	~~eval board in hand~~ (blown); high high frequency efficiency claimed
LTC3626	2.5	20	0.5 – 3.0	valley current	eval board on order
LT8622SA	2.0	18	0.3 – 6.0	?	NDA needed (working on it); direct external ref possible
TPS543320	3.0	18	0.5 – 2.2	emulated peak I_L	>85% efficiency at 1.8 V 1 A 1.5 MHz (w/ iron powder inductor)
other COTS … ?					
bPOL12V	4.0	11 (maybe 12)	1.0 – 3.0	peak current	eval board in hand; availability concerns; rad hard
bPOL48V + EPC2152	15 (GaN)	22.5	0.5 – 3.0	duty cycle	external FET; loop gain constrained; rad hard

A point about output ripple/noise and control loop





a layout example
(HELIX TOF readout board, G. Visser)

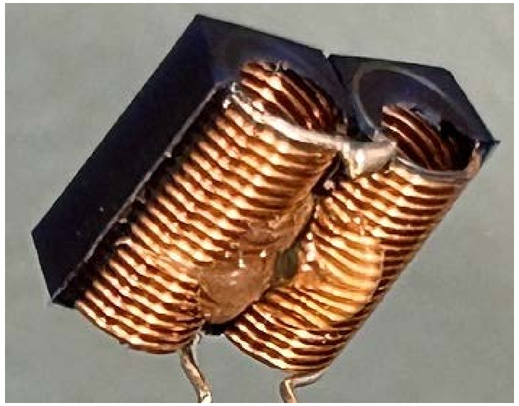
An ideal way to keep conducted noise on output to a minimum is to use 2nd order circuit. Basically, the output filter is absorbed into the control loop. Voltage drop on output filter is regulated out.

Of course, a simple standard buck regulator can be used with an output filter outside the loop. This is just “better” but not the only way.

Phase shift changes significantly → loop gain needs to be different if you do this – “standard” loop gain won’t work… Needs external compensation components to tweak.

inductors

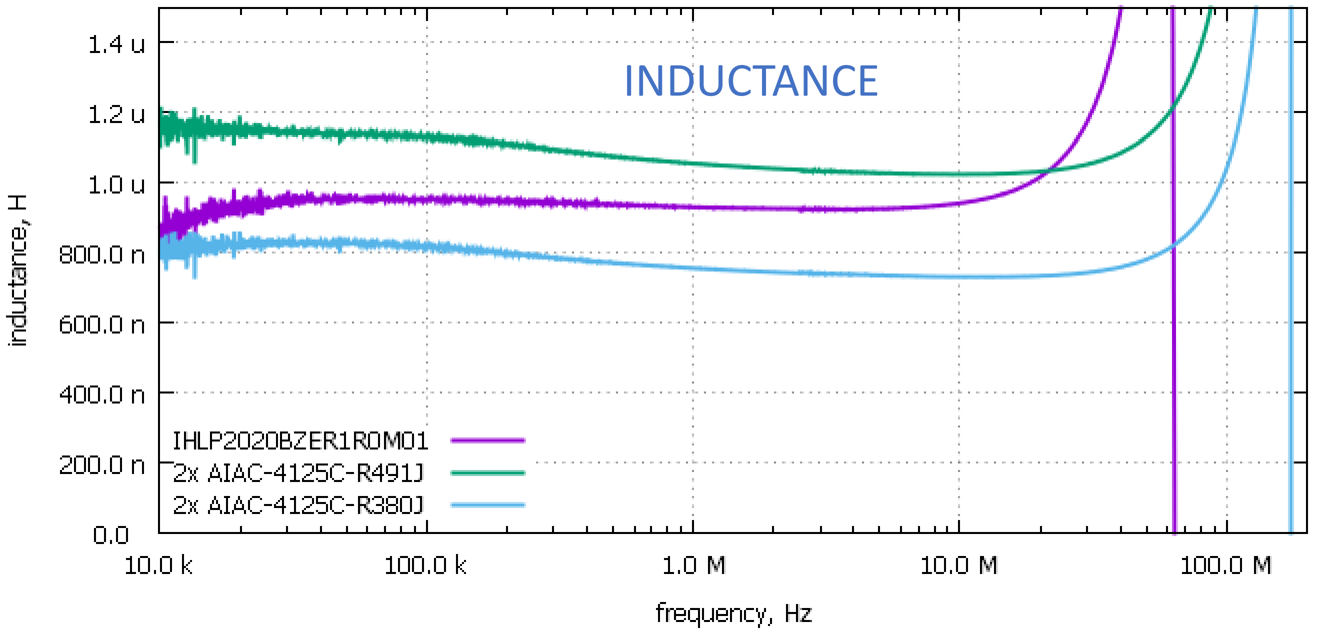
There are a few styles of air-core inductor to choose from. We need something compact, cheap, perhaps COTS, and with low stray magnetic field.

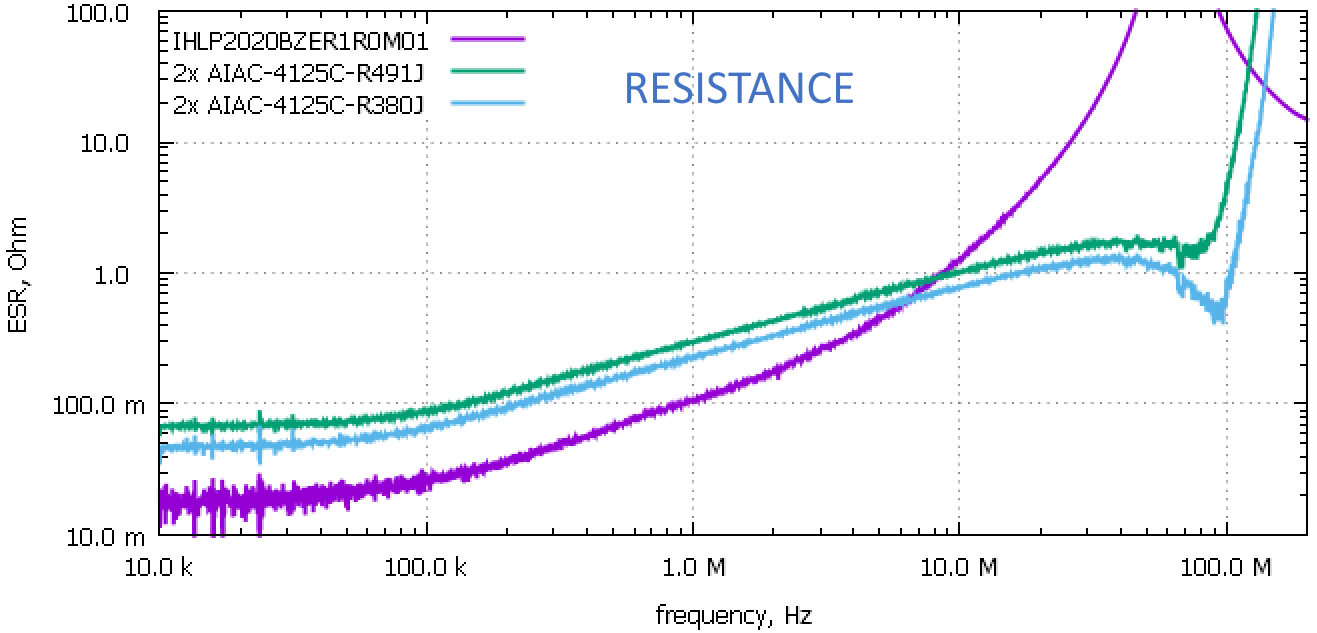


A copper shield is probably needed in any case. Shield might be a 2nd PCB as mezzanine (incorporating other functions besides shielding).

Solenoid: cheap/COTS but large stray field
Toroid: excellent low stray field, expensive to wind
Integrated toroid in PCB: large, needs thick PCB, resistance is high
Two solenoids adjacent anti-parallel: cheap/COTS yet lower stray field → proposed scheme

Abracon AIAC-4125C series ought to work well for <3.5 A load applications. Measured inductance and ESR (and SRF) looks excellent. DCR only 2 – 3 × that of iron powder inductors. Worked well in LTC3601 and LTC3600 tests!

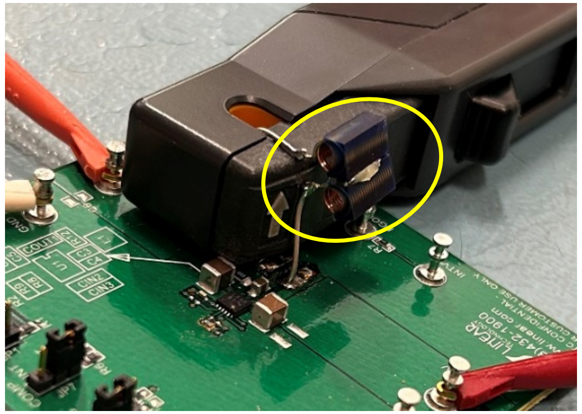


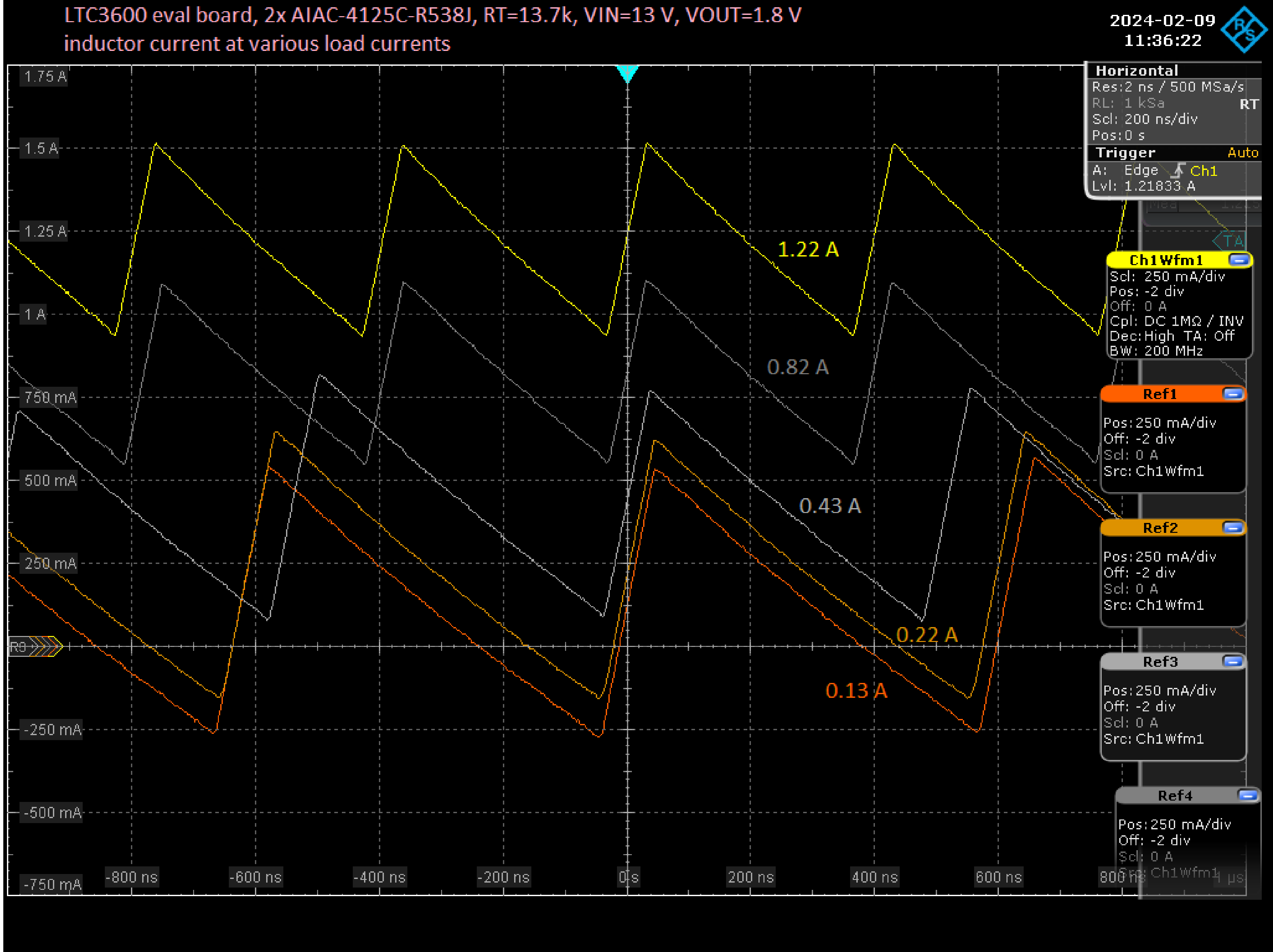


Shield tested: As expected, it reduces inductance a little. ESR unaffected. Won’t be a problem…

Direct measurement of inductor current at various loads:

- Nothing unusual, the air core inductor performs perfectly normally.
- Incidentally though, the LTC3600 lowers its frequency at light load.
- A quirk to be kept in mind, especially for loop gain design. No real problem.

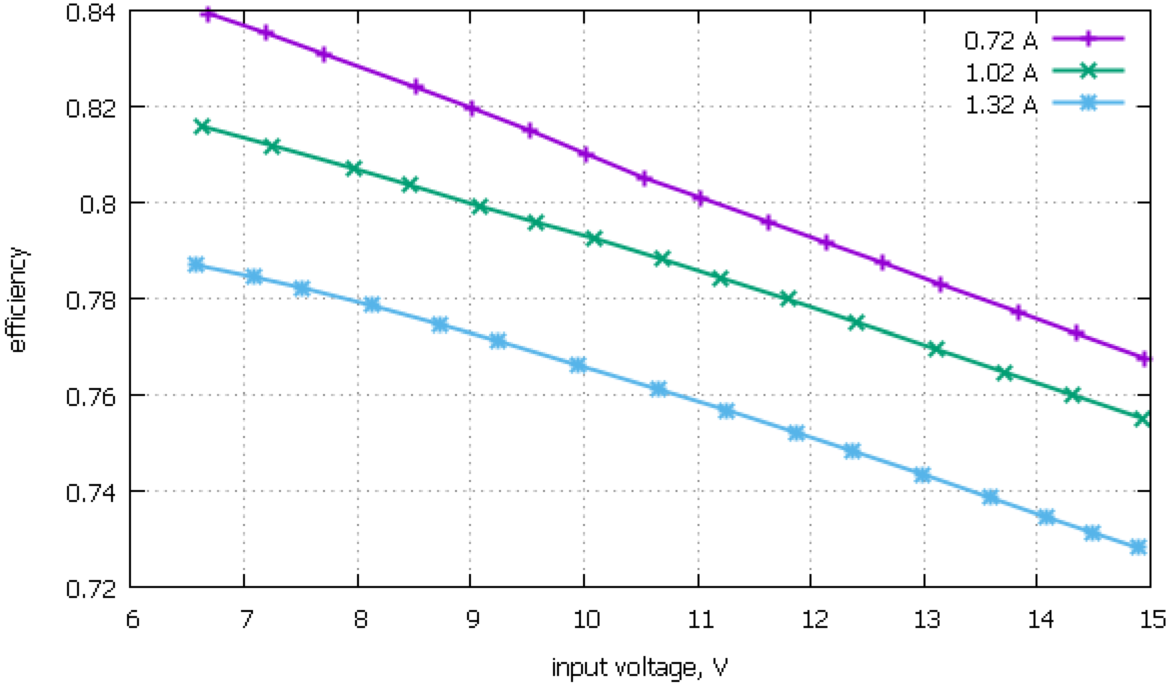




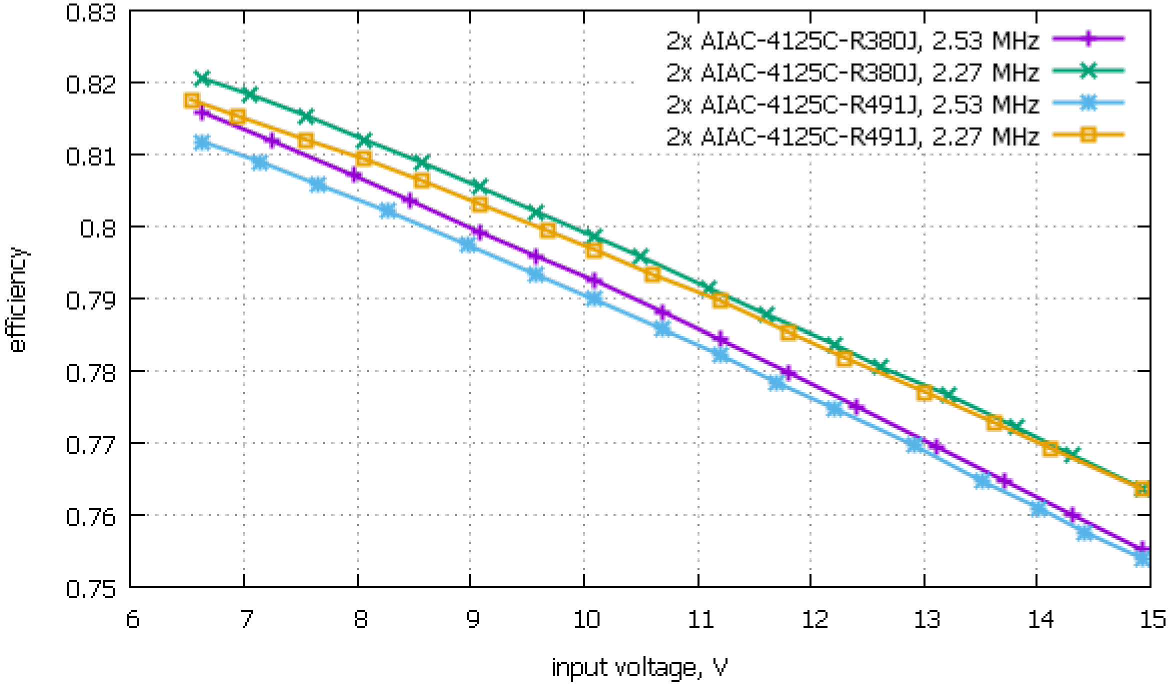
LTC3600 efficiency measurements w/ air-core inductors

1.8 V out

2x AIAC-4125C-R380J inductor, 2.54 MHz, various loads

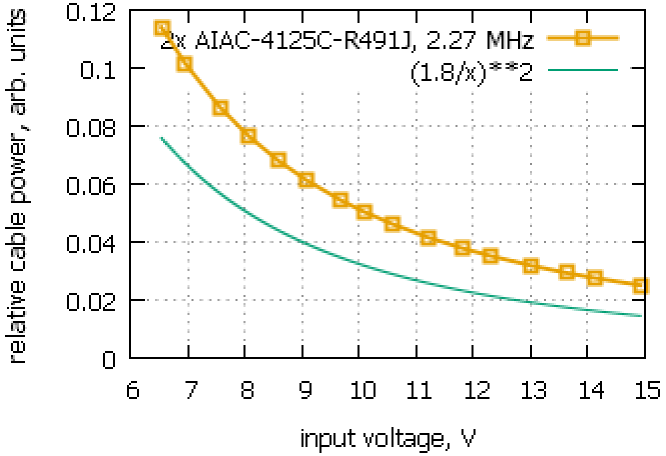


1.02 A load, various inductors & frequencies



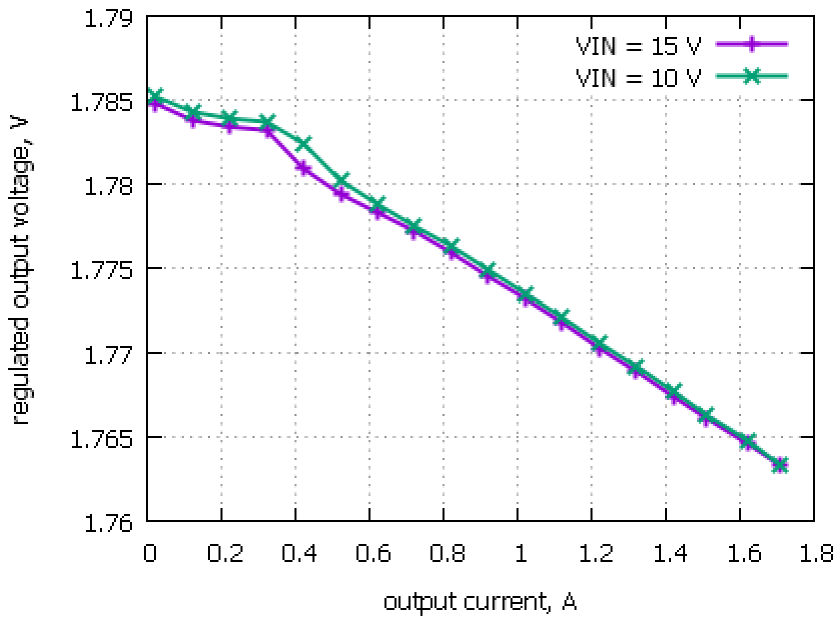
efficiency is reasonable
(of course room for improvement)

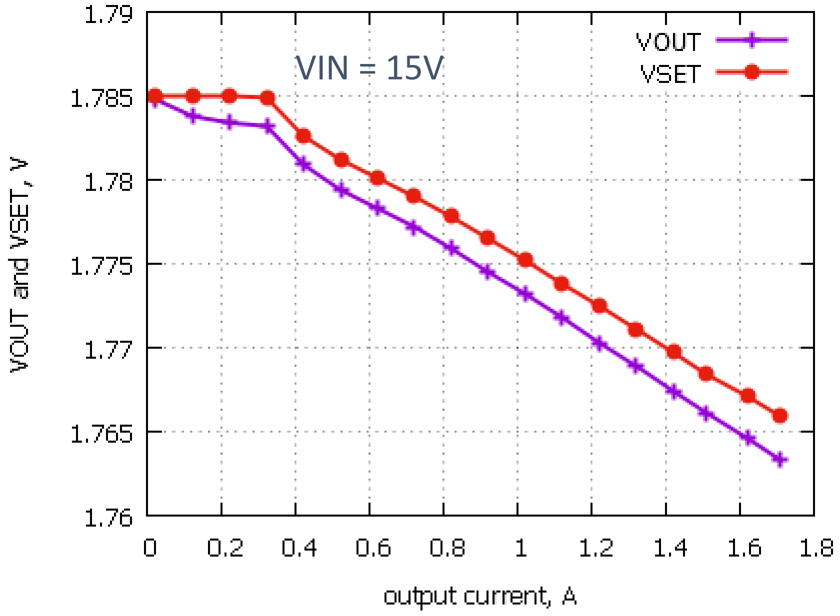
relative cable power,
this circuit & 100% efficient,
@ constant cable resistance



LTC3600 – other evaluations

- output ripple (on eval board): 40 mV p-p, *see backup slides*
  - certainly unacceptable
  - but just as certainly improvable with a better board design and I/O filters added – <2 mV p-p should be achievable
- output noise and subharmonics (everything <85% of f_{SW}): 125 µV rms
  - *this is really excellent, about the best I've ever seen*
  - very important – low frequency noise 'impossible' to filter
- output regulation: relatively poor ~1%
  - probably, we don't really care, our load is ~constant
  - anyway the trouble seems to be in the reference voltage, which could be overridden externally



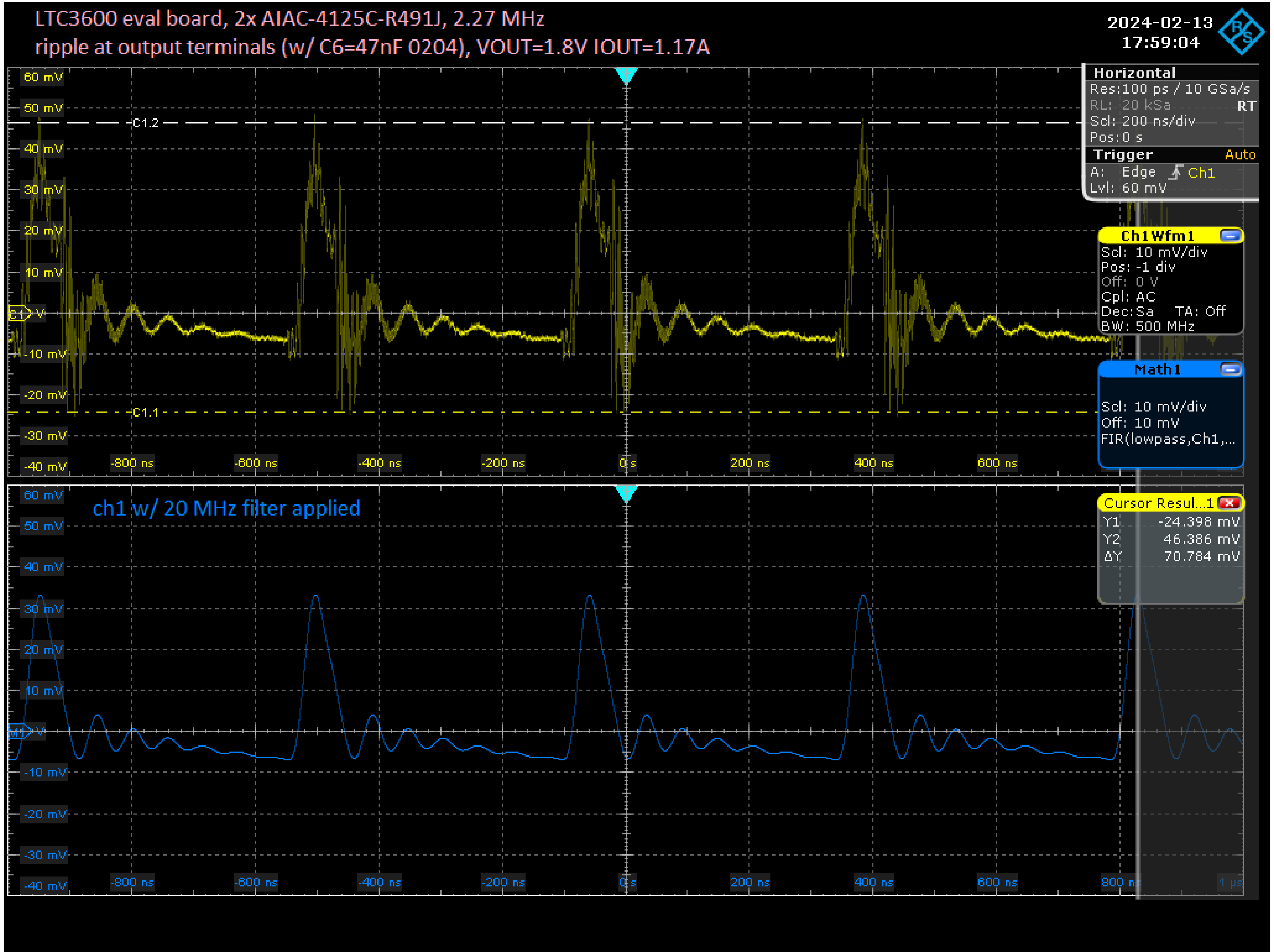


conclusions

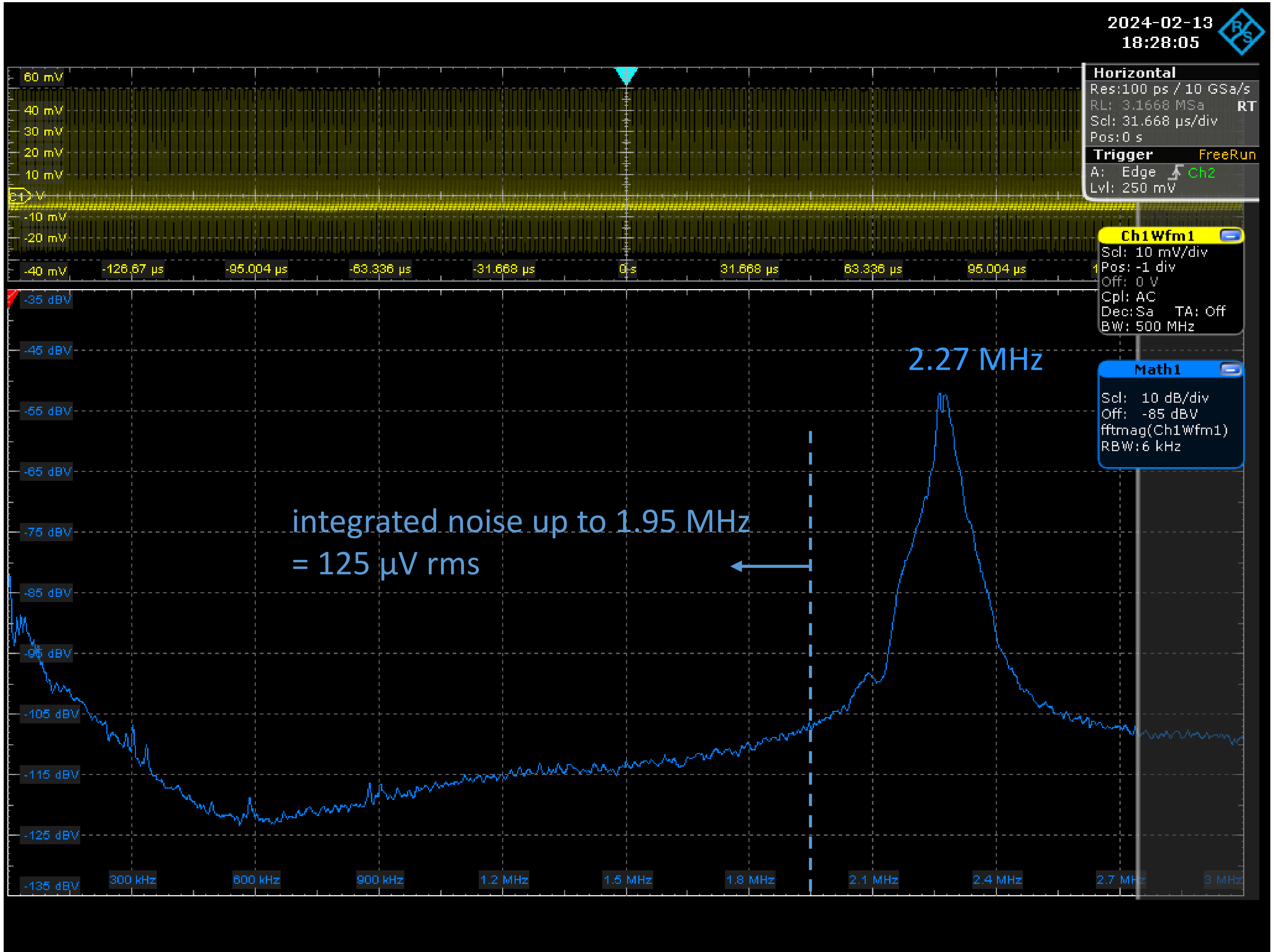
- validated all aspects of LTC3600, except radiation (and magnetic field)
  - looks good for up to 1.5 A applications, although efficiency not excellent
- *I would like to get this eval board into radiation test as soon as feasible…* (help…?)
- I think we have a good, low cost, small size solution for air core inductors for this current range
- will also evaluate at least the LTC3626 and TPS543320
- bPOL12V can be considered, if we are comfortable with availability
  - 11 V input range is not ideal though

backup – some details for reference, in case anyone finds something useful

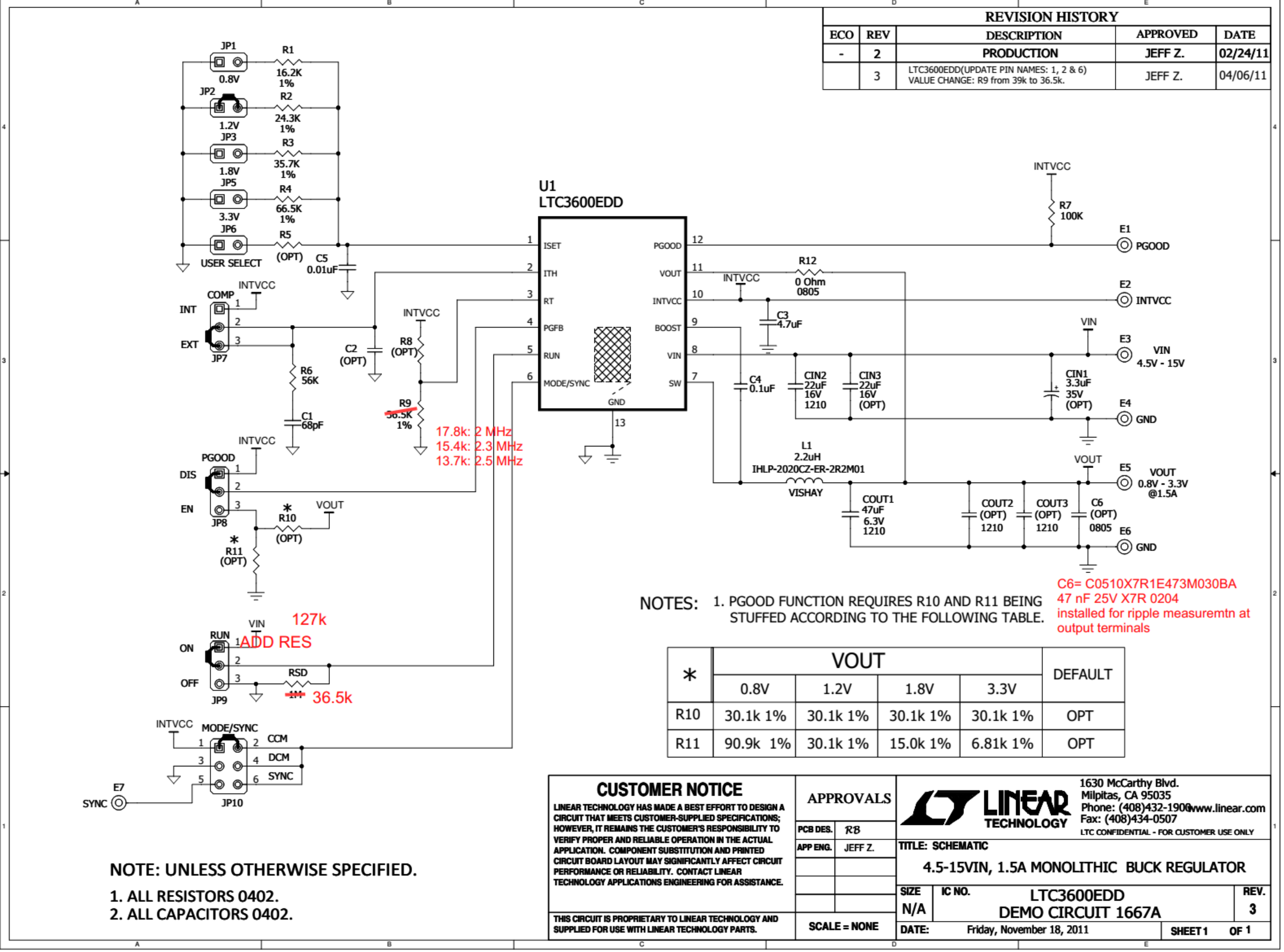
LTC3600 eval board output ripple: 40 mV p-p @ 20 MHz BW, 70 mV p-p @ 500 MHz BW



LTC3600 eval board output spectrum: clean, no subharmonics, low noise



ripple/noise measurement



REVISION HISTORY

ECO	REV	DESCRIPTION	APPROVED	DATE
-	2	PRODUCTION	JEFF Z.	02/24/11
	3	LTC3600EDD(UPDATE PIN NAMES: 1, 2 & 6) VALUE CHANGE: R9 from 39k to 36.5k.	JEFF Z.	04/06/11

NOTES: 1. PGOOD FUNCTION REQUIRES R10 AND R11 BEING STUFFED ACCORDING TO THE FOLLOWING TABLE.

*	VOUT				DEFAULT
	0.8V	1.2V	1.8V	3.3V	
R10	30.1k 1%	30.1k 1%	30.1k 1%	30.1k 1%	OPT
R11	90.9k 1%	30.1k 1%	15.0k 1%	6.81k 1%	OPT

NOTE: UNLESS OTHERWISE SPECIFIED.

1. ALL RESISTORS 0402.
2. ALL CAPACITORS 0402.

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THIS CIRCUIT IS PROPRIETARY TO LINEAR TECHNOLOGY AND SUPPLIED FOR USE WITH LINEAR TECHNOLOGY PARTS.

APPROVALS	
PCB DES.	RB
APP ENG.	JEFF Z.

SCALE = NONE

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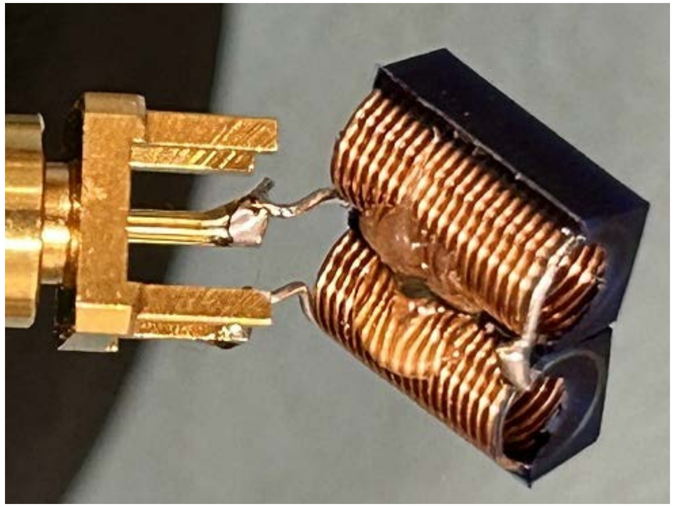
TITLE: SCHEMATIC
4.5-15VIN, 1.5A MONOLITHIC BUCK REGULATOR

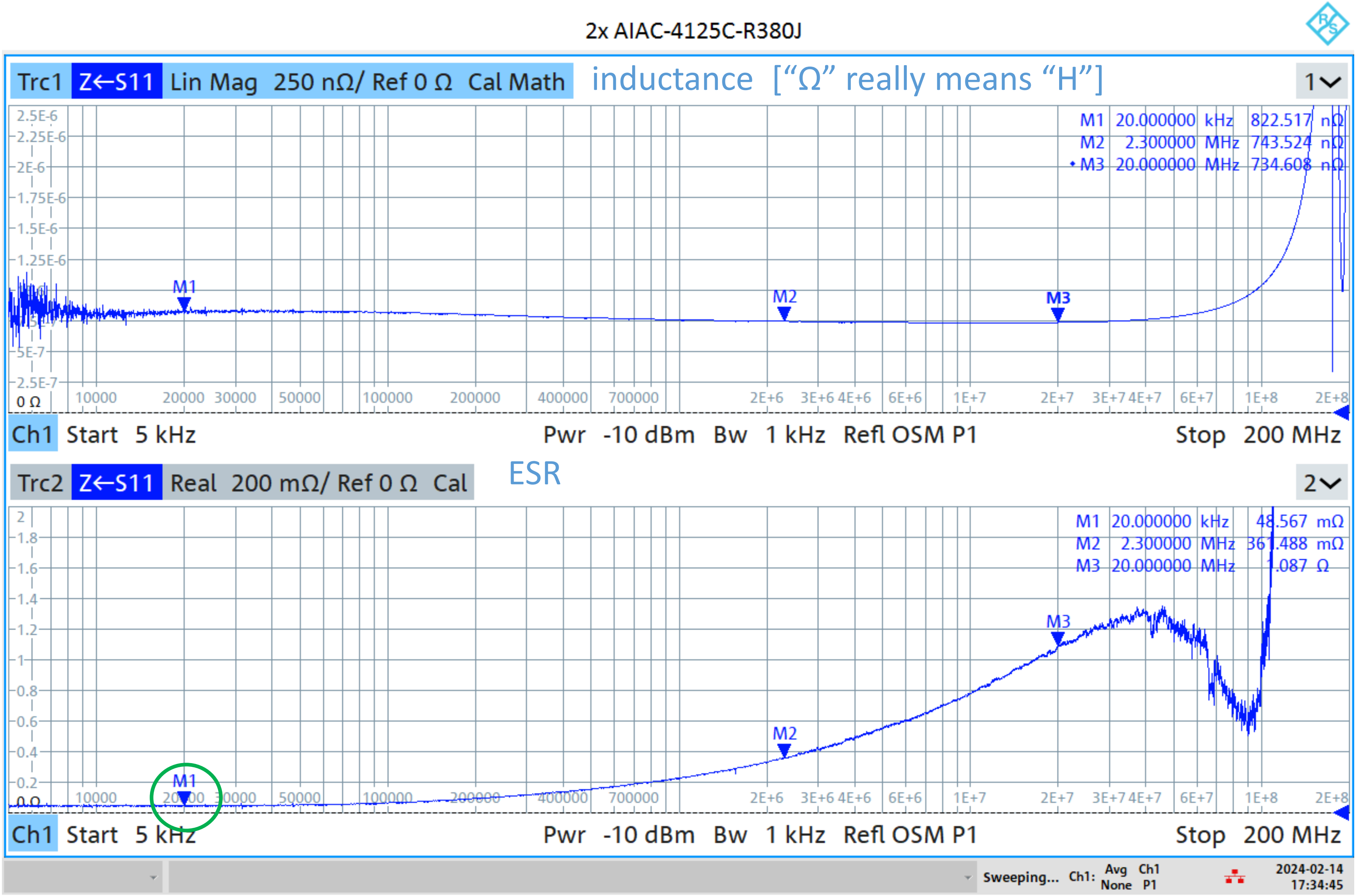
SIZE	IC NO.	REV.
N/A	LTC3600EDD DEMO CIRCUIT 1667A	3

DATE: Friday, November 18, 2011 SHEET 1 OF 1

inductor measurements

S11 measurement with network analyzer
(of course ASSUMES inductor is linear – for air core it is, for iron core approximately so)





low frequency ESR is just the DC resistance – good agreement with DMM measurement

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