Why did it take so long? PhL 2.11.14

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Part I: Analysis of the 21 weeks of work leading up to my first (2/10/14) Release.

Original lines doc was written Sept 1991 and is 107 pages long including contents pages. The new version written over five months in 2013 and 2014 is 341 pages long I think, so it grew by 200%.

Why did it take me 5 months (21 weeks = 147 days) to update and publish my Transmission Lines paper? The times quoted below include long hours proofing things after they were finalized.

[Calendar time was 162 days. But subtract :

5 days Kent visit
4 days Cherie visit
3 days Torrey trip with Dave in Nov
12 days Cod Trip total = 13 days 162-13= 149 days = 21 weeks]

1. Perhaps **2.5 weeks** can be ascribed to confusion about the **gauge**. I tried many approaches before finally stumbling onto the idea of using the dielectric region gauge in all regions, which resulted in a unified Helmholtz equation which applied to all regions. Only then could you talk about a solution in all regions.

King just did not provide much advice on this subject. It was not clear whether his King gauge was to be used separately in each region with separate μ,ε,σ constants for each region. King never allowed for different μ in dielectric and conductors, so that always added to the confusion. He also never displayed the right side of Helmholtz equations. With wrong gauges, I kept thinking there had to be diffraction at the boundaries as the effect of an interior current worked itself to the surface, using a conductor propagator, and then continued in the dielectric uses its different propagator. This problem went away when I could use the dielectric propagator in all regions. I could not find any source that clarified this issue. But I do think it is well clarified now in my document. This took a long time to clear up. I did have Stakgold support throughout this effort, the notion of a "region". This 2.5 week delay is why I refer to the gauge as a "can of worms" in my introduction.

2. Perhaps **1.5 weeks** was used up figuring out King's **$1/4\pi\xi$ factor**. Why was that ξ there? His only argument was that you just sort of arm-waved about ε becoming ξ in a conducting medium. I did two library trips on this. Only after much time went by did I realize that there are two different kinds of surface charge density and the ξ choice has to do with current boundary conditions. This was I think a pretty subtle issue, and it is now explained in much detail in lines doc with a clear capacitor example. Again, King just pulled it out of a hat in all his papers.

3. Maybe **1 week** can be associated with my original confusion about **"applied" currents and charges**. I realized that you had to have at least some kind of current on the right side of a Helmholtz equation in order to get a solution, and that was where my magical $\mathbf{J_a}$ came in, something that lived outside the Maxwell world as a kind of boundary condition. If you look at (1.3.21) region 1, you see there is no **J** source for the Helmholtz equation. How could you write a Helmholtz integral for region 1 if the equation has no source at all? So I put this $\mathbf{J_a}$ there in the original paper (I think). Later when the regions got unified into a single region R, then there *was* a source as in (1.3.23), and the need for $\mathbf{J_a}$ went away. The idea of $\mathbf{J_a}$ was that you use thin wires and you just forced this current in the wires. In retrospect, I think King only thought about the dielectric region 2, and then probably argued that J was in that region more or less for skin effect frequencies.

4. Maybe **2.5 weeks** is connected with the notion of adding in the **homo solutions** and with the **surface current trick**. Early on, I had no idea what boundary conditions looked like for A_z because I never did anything with an A_z in my entire life. I saw a flicker on the web one day, and then added this BC to my Chapter 1 list and that showed the way. I always had the round wire example where adding the $\mathbf{J_m}$ surface current made things work both inside and outside. I kept thinking that surface current $\mathbf{J_m}$ was supposed to be there as part of J, but this is not true, and that was an ongoing conflict. The J in Maxwell does not include mag currents. Eventually I realized it was just a trick to get the right homo adder solutions. I had tried many times to see why this trick worked, in terms of erasing the boundary, but I never had a tool that could prove the trick works. In the end, it was the Stakgold extra term method that provided the proof, and I have no idea how I realized that would work. I just tried it along the path and was surprised when it worked. I had no help on this entire subject from any source. It might be original research for all I know, but I am not making that claim in the doc. Probably someone else has done this in the last 175 years, I never looked hard in literature, I was just trying to get this paper "updated" and done. The work associated with this time item appears in Appendix B and Appendix G and in Section 4.12.

5. Maybe **1.5 weeks** went into the **Appendix D** (formerly Appendix 2.2) full solution of the round wire. My motivation for this huge digression was to see the relative sizes of E fields, so I could fill out those Tables in Chapter 3. Chapter 2 did not produce the smaller fields so did not give the answer. Once I found the E fields, I decided to add the B fields, and since I had no external verification, I had to have Maple verify everything in full detail. This appendix *did* exist as Appendix 2.2 in the original doc, with its partial wave expansion. I had in the original a low frequency limit which I got rid of. The original appendix was 9 pages, Appendix D is 36 pages, so it got 4 times longer!! Part of this time was on the $E_\varphi = 0$ condition mystery.

6. Maybe **1 weeks** was spent battling **Maple**, getting it to do what I wanted over the entire period.

7. Maybe **1.5 weeks** was involved in **reformulating the Chapter 4 expressions** for things like V(z) and W(z). In my original doc, I was at first confused about what β meant, and then I had the complete wrong expansion for small β (mine was for large β!) My entire Chapter 4 development in the original doc was just plain wrong in terms of statements of these expansions. I did have King help here with the small β limit. Interestingly, I think all the results of my original Chapter 4 were maintained, but now the derivation I think is correct instead of wrong. The need for Appendix 4.1 "support" went away.

8. Maybe **1 week** went into clarifying the whole **relationship between 3D and 2D** in many respects. The PDE, the Helmholtz propagators in 3D and 2D. This led to appendices H,I and J -- three of them!!

9. Maybe **1 week** went into a rewrite and **rethink of Chapter 5** on the transverse problem. I discovered the low-loss approximation very late in the game which led to the capacitor problem. Then solving the Capacitor Problem was much more complicated than I ever dreamed in the general case, which led to my discovery of the capacitance matrix. Here I did get external help from Smythe and a web source.

10. Maybe **1 week** on a rewrite of **Chapter 6** for the two round wires. Perga appeared here. I was confused by what set the overall scale of this solution, and I solved that by having a certain new "boundary condition" on any solution. This scale was glossed over in the original doc. I had no verification for my original claimed results. I did change the scale of the K used by a factor of 2, by the way. My results were expressed in a very clumsy way without ch^{-1} forms which make them simple. So this chapter got a complete rewrite, but of course the original Ch 6 had the right idea.

11. Maybe **1 week** to basically add "all of E&M theory" to chapter 1. This included both electric and magnetic media sub equations, many clarifying notes, all the integral forms, all the boundary conditions on the fields. NONE of this stuff was in the original paper.

12. Maybe **1/2 week** on the **complex functions** section 1.6, nothing like that in the original.

13. Maybe **1/2 week** into doing all the **Maple plots for Chapter 2**, none of them were there before!

14. Maybe **1 week** on amping up **Appendix C** (formerly Appendix 2.1) to include the rectangular wire and Kuester's stuff. I added the hollow pipe and thin flat wire sections here as well.

15. Maybe **1/2 week** clarifying the little sections about why **surface charge is thin** and why **no charge exists inside** dielectric and inside conductor. Major additions were done in these areas! Appendix 3.1 became Appendix E.

16. Maybe **1/2 week** rewriting the **Waveguides** Appendix F (formerly Appendix 3.2), removing irrelevant stuff and getting the relevant stuff done right with external verification.

17. Maybe **1 week** upgrading **Appendix A** (formerly Appendix 1.1), adding new pieces, correcting the language in the existing pieces. The structure stayed the same, but much was added and changes. Appendix 1.2 on the complex dielectric constant got deleted and that subject was merged in elsewhere.

18, Maybe **1/2 week** for adding the **network** appendix.

19. Maybe **1 week** for work associated with electrostatics **Appendix L**. The original "Jackson problem" which lost its relevance when the gauge stuff was cleared up. But I wanted to add the sphere problems here, just to have something on the dielectric electrostatics subject.

Summary of how the above adds up to 21 weeks.

weeks	subject

1	2.5	gauge, the can of worms
2	1.5	ξ factor, another can of worms
3	1	J_a issue, a red herring ghost item I invented
4	2.5	homo sols and surface currents
5	1.5	App D enhancements and E_φ
6	1	Maple battles
7	1.5	rewrite of all Chapter 4 expressions like V(z) and TLL
8	1	3D 2D details (3 appendices and more)
9	1	Chapter 5 rewrite
10	1	Chapter 6 rewrite
11	1	add all of EM theory to Chapter 1
12	1/2	complex functions section 1.6
13	1/2	Maple plots for Chapter 2
14	1	Appendix C upgrades including Kuester paper and email
15	1/2	thin surface charge, no charge in materials
16	1/2	waveguides Appendix F rewrite
17	1	Appendix A additions and rewriting
18	1/2	network Appendix K added
19	1	Appendix L added on electrostatic problems
	21	

So I guess in retrospect, it is not surprising it took so long. This baby is packed with stuff.

Part II: A little review of notes I wrote in 1991, -- ghosts that came back in 2014.

A Review of 1991 Paradox Documents

I recall from long ago (~ 22 years ago) how this King stuff always mystified me, as if something were missing or were not being explained right. This new lines doc shows that there really was stuff missing and not explained right after all.

In my old archive location, I see a few docs I wrote Sept 1991 about various mystery subjects. { I later found these in a binder as well }

Notes on B fields.doc

Here the ∇^2 symbol appears as a box squared, don't be confused. I am asking whether the Helmholtz equation for B applies inside wire. I can now quote

$$(\nabla^2 - \mu\varepsilon\,\partial_t^2)\mathbf{B} = -\mu\,\text{curl}\,\mathbf{J} \qquad (1.2.2)$$

and

$$\begin{aligned}
(\nabla^2 - \mu_1\varepsilon_1\,\partial_t^2)\mathbf{B} &= -\mu_1\,\text{curl}\,\mathbf{J}_1 && \text{// region 1} \qquad (1.3.35)\\
(\nabla^2 - \mu_2\varepsilon_2\,\partial_t^2)\mathbf{B} &= -\mu_2\,\text{curl}\,\mathbf{J}_2 && \text{// region 2}\\
(\nabla^2 - \mu_3\varepsilon_3\,\partial_t^2)\mathbf{B} &= -\mu_3\,\text{curl}\,\mathbf{J}_3 && \text{// region 3}
\end{aligned}$$

and then

$$\begin{aligned}
(\nabla^2 - \mu_1\varepsilon_1\,\partial_t^2 - \mu_1\sigma_1\partial_t)\mathbf{B} &= 0 && \text{// region 1} \qquad (1.3.36)\\
(\nabla^2 - \mu_2\varepsilon_2\,\partial_t^2 - \mu_2\sigma_2\partial_t)\mathbf{B} &= 0 && \text{// region 2}\\
(\nabla^2 - \mu_3\varepsilon_3\,\partial_t^2 - \mu_3\sigma_3\partial_t)\mathbf{B} &= 0 && \text{// region 3}
\end{aligned}$$

So yes, you *do* get a homo Helmholtz equation for **B** inside a wire, *if* you use the β^2 for the material inside that wire! So I think I have the answer to the question asked in this doc. This doc mentions "applied current" by the way! It permeated everything!

9.doc = The Gauge Equation Paradox 9.4.91

Here I interpret the King gauge in each region as using the parameters *of that region*. I find that divA takes a huge jump at the dielectric conductor boundary of a factor 10^6. This seems to suggest that A_z is discontinuous at the boundary. I am thinking there is an A_r which is discontinuous like E_r is. Yes, this gauge interpretation leads to problems, I agree now as then.

casalog 9.doc = BTS Casa Log on Transmission Line Theory Debug

This is a long 12 page "log" of problems I was having with all the King stuff. All those same problems resurfaced in 2013, but I think I have now resolved them all. It is amusing to see me suffering then exactly as I suffered now.

My first entry brings up the fact that I know that B is not always parallel to conductor surface, and this then means that A_z is not constant on a surface. In my current doc, this relates to Fig C.2 for the rectangular conductor. I showed that you have to go above some ω to get **E•B** = 0 at a surface so I hope that resolves this paradox of 1991. Nice to make the connection between B lines and A_z constant surfaces. I am calling King a liar about A_z constant on the surface, The Big Lie. (but I later retract!)

" My answer is that I am still willing to sacrifice all aspects of normal living in order to bring this to a positive conclusion. I keep thinking I am a few days from being done, but it keeps expanding into multi-weeks. A familiar cry." [think about the 145 days in 2013-2014!!]

So here I am soaked in this particular 1991 paradox which came back in 2014 to get me again!

" I am trying to get a wrap on my "book" on transmission line theory, but the whole structure keeps wobbling in very bad ways. Each day brings the collapse of certain "theories" and the rise of new ones, it is very hard to "test" anything. There is no workbench, all you can do is run theory tests to look for inconsistencies, and do simple model calculations."

" It seems that each day there is a 75% change in everything I think about this subject."

On Sept 4 I tried but failed to solve the round wire! Could only get E_z, stymied by vector Helmholtz.

I am wondering about whether radial charge pumping is real or not.

"(6) Big math discovery of the day was doing $\nabla^2\mathbf{E}$ on a vector quantity. Never in my entire physics life of perhaps 20 years did I ever attempt to solve such a thing in non-cartesians."

I have a "slipring model" as an alternative to radial charge pumping, but then it goes away.

On Sept 6 I seem to be doing Appendix D with the components other than E_z and getting results. I claim that Jim Ball suggested using divE = 0 to decouple the components!

" Now had a major change of view on A_Z = constant stuff today. I decided that it is reasonable to have grossly asymmetric J_Z , and yet still have A_Z = constant on the boundary."

" At least the bugaboo of "non-uniform J_Z implies $A_Z \neq$ constant" has a way to be bypassed. "

This log ranges from Sept 2 to Sept 10, 1991. It ends when I finished Appendix 2.2 which is the current Appendix D on fields in a round wire!

" So at 12 midnight I printed another App 2.2. This damn thing is finally done! "

Confusion in the.doc **Confusion in the Conductors** Sept 2, 1991

More comments on radial charge pumping and A_z at the conductor surface. I think this doc was written prior to all the log comments in the previous doc. The gauge condition is still causing me trouble. I don't think I ever arrived at the "region 1 gauge for all regions" conclusion in my 1991 efforts.

doubts chap 3 9.doc **A New Voyage through Chapter 3 Preliminaries**

I am marching through the sections of Chapter 3 as it was at that time. No date in this doc.

" Thus, A_Z is now <u>for sure</u> not constant on the surface! "

Then I start marching through Chapter 4.

" Section 4.4. But now W(z) will be W(x,y,z)!!! In this case, the K thing on the right of (3) is no longer independent of x,y, and L_e as defined is then not a constant. "

This just shows that if you give up W(z) = constant on cross section, the whole universe falls apart in terms of the transmission line equations. In my newer lines doc, I give three proofs A,B,C for the claim that A_z = constant on the surface, it is still a delicate issue!

Part III: Analysis of the 25 more calendar weeks of work leading to the 8/2/14 Release.

[Calendar time was 171 days. But subtract :

14 days Cod Lee trip in April
10 days end of May Kent/Torrey Mem day and other maintenance items
4 days Colorado trip (Fri-Mon)
12 days Cape Cod Lee trip in July total = 40 days 171-40 = 131 days = 19 weeks]

Well, Part I shows how I was so astounded it took me 21 weeks of work to get this transmission lines doc cleaned up for web publication. I certainly had no idea it was going to take me *another* 19 work weeks to get the job done!! So I guess I owe it to myself to see where all that time went.

The edit log provides a good history starting after the Feb release. Lines doc ended up being 500 pages long, compared to the 107 page 1991 doc, and the 341 page Feb 2014 release doc. Just the edit log is right now 195 pages long! The Feb release occurs in that log on page 122, which is about 62% through the log.

The first sign of trouble came on Feb 15, 3 days after release. How can Z_s be a constant on a conductor surface as I state in Chap 4? I was immensely confused by this issue.

Just to study this issue, I had to write Bipolar Doc [I claim this took 10 days] so I could learn about n(θ) for two cylinders and then get the moments η_m and somehow see if Z_s could really be constant. I pulled lines doc off the web on Feb 25! I then started into a long series of "repairs"/

- get use of φ and θ regularized through the doc
- App M on why A_t is small instead of arm waving (March 7)

I *then* discovered the massive ω → 0 asymmetry of J_z problem, and again, another HUGE sea of confusion about this. I am totally unsure whether J_z is symmetric at DC and was led astray but some guy Paul. So now I have *two huge problems*: Z_s = constant, and the ω→0 limit is wrong. [p 129 Elog]

- To *see* if J_z is really uniform at DC in a simple symmetric round wire, I had to invent the Radial Hall Effect which became App N. All the Drude stuff went in there, probably a whole week or more. Magnetic Ohm's Law explains regular Hall too, and then I wanted to flesh out all these App N matters so I did.
It is now March 30 or so. Hall stuff and App N was not installed until May 7 ! Maybe 2 weeks on Appendix N!

• I was then led to "eddy currents" as a way to *prove* that J_z should be symmetric at DC, but I nad no good source.

• Went off for a Cod trip, returning April 30.

• Write App P on eddy currents, a massive effort. Maybe 2 weeks on this!

I had a folder "lines overhaul" which contains lots of docs about how I am going to "overhaul" all these problems I am having in lines doc. Much more detail here than in the edit log. Threading my way through all this confusion was very time consuming! Lots of "paradoxes" to deal with. The whiteboard picture was drawn May 9.

• Massive rewriting of Chapter 3 on things like $A_z \neq$ constant on the surface. Even φ = constant is now uncertain!

• I then have to rewrite Chapter 4.

• May 13 I agonize about $\omega \rightarrow 0$ issue, because $n(\theta)$ really is hard wired to $J_z(\theta)$ and this is causing both my big problems: J_z asymmetry and $\omega = 0$ asym coming out of my model

• Chapter 6 gets new sections added after the summary table,

• At some point I ponder App O on mapping field lines, that must be a week in itself with various Maple problems and searching for old code stuff. I am back to editing the Facts in Chapter 3.

• The $\omega \rightarrow 0$ problem is studied in my "low frequency folder".

• Tried to do monster audio cable, but did not like it so omitted it.

• On May 18 I am writing new sections for App D on high and low ω limits. This topic existed in the original 1991, I took it out, and then I put it back with MUCH more detail.

• The Charge Pump BC is constantly being questioned, and on May 19 I thought once again it was collapsing. I am on and off the horse many times, daily.

• May 22 is a Torrey Mem Day trip, take out 8 days of no work. Then more on tail end of App D and Debye surface currents and where $n(\theta)$ comes from.

• June 4 I write Appendix O and I build the huge symbol index.

• Trip to Ft. Collins costs 5 days. Back June 9, Janet is moving to her rental this day.

• I refight the $\omega \rightarrow 0$ asym anomaly again and again, it never goes away, so I finally accept it. I try a reflection approach but that does not solve the J_z asym problem, so I give up on that. June 10, doing a massive proofing of the entire doc!!

• June 16 I do the Z_s averaging repair stuff. Now Z_s is better understood.

• June 17 telegrapher's equations.

• Back to finishing App P on Eddy currents.

• I then think around June 10 that I am done and I start another proofing cycle on all my new stuff.

•June 18 I think I may be there, final spell check. Got the headers reinstalled and checked. Do full pagination. Another shot at reflection goes nowhere.

• June 22 I start dealing with k(ω) and that as a loss model instead of some bad thing I had in Appendix D low ω limits.

• Clean up use of k and β symbols through doc.

• Update low loss Ch 5 section on June 24 or so.

• Last gasp: try to blame the ω→0 asym on the radial Hall effect, but no go.

• Wrote App Q around June 28/

•July 1 I start worrying about having a Belden appendix. I am then forced into the world of coax doc and trying to read my 1991 stuff there, another can of worms.

•July 5 add second part on Z_0 to App Q.

• Off to Cape Cod again with Belden hanging. Back on July 26.

• Did final 5 day push getting to right now Aug 1. Yeow.

Part IV. Oct 19 Release (the third)

• motivated by the ω→ 0 problem, added Ch 7 and lots of other changes.

Just for fun, here are some of things I learned or did during the 14 month lines doc ordeal. Many of these items come just from looking at the TOC!

• I did a very complete **review of E&M** with materials present, gathered everything into one place.

• **Derived** the mysterious King potential integral solutions

• Clarified the **complex** field notation

- Filled in on the **round wire** where Mattick left off

- Derived the **Transmission Line Equations** in full generality with **averaging** for fat conductors

- Showed how to generalize to **magnetic materials**, King never did that, no one has ever done that.

- Isolated the **Transverse Problem**

- Did soup to nuts for the **two cylinder** line. This includes writing Bipolar Doc!

- **Explained** why the $\omega \rightarrow 0$ limit is not valid

- Proved why you can find a **gauge** that does the things people always claim

- Did a **full general solution to the round wire**, I have never seen this done anywhere.

- Did lots of **DC inductance** calculations

- Did **Debye** thickness theory and some **waveguides** as well

- Various **vector potential examples** that you never see written up

- Clarified the whole subject of **propagators** in 2D and 3D

- Connected everything to the **network model** of App K.

- Did **conduction theory** in full detail, non quantum, including novel **radial Hall effect** that no-one has ever mentioned anywhere in the history of the world I suspect.

- Showed three ways to **plot field lines**, always a messy problem

- Did a huge section on **Eddy Currents** and **Proximity Effect**, with actual calculations

- Applied everything to **Belden cable** as an example

Perhaps each of the above 21 items took 3 weeks and it just added up.