Oscillator Design… 1

- *The beauty of oscillator options for high voltage systems is truly in the eye of the beholder/user.*
- *The most important criteria for the selection of an approach is confidence in the stability and reliability of the design choice.*
  - ***Power range and application.***
  - ***Sine vs. Square vs. Flyback.***
  - ***Driven vs. Self-Oscillating.***
  - ***Frequency synchronization.***
- *When considering an oscillator design, it is important to see the oscillator and transformer as coupled system with respect to performance and reliability.*

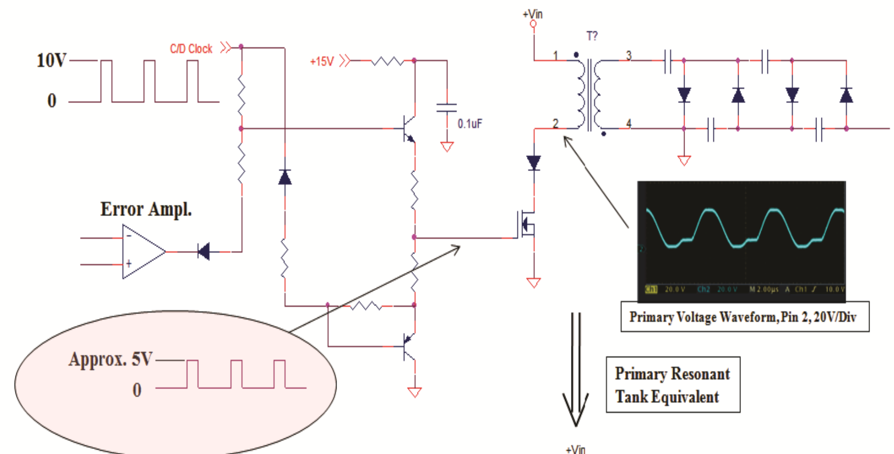
Oscillator Design… 2

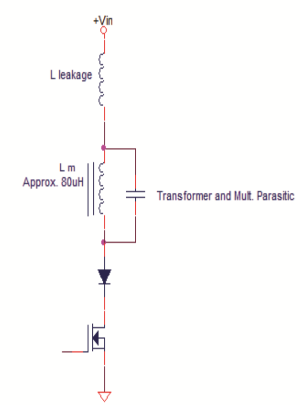
- *Many designs have moved to driven systems since easier to design and understand. Frequency synchronization is also simpler when demanded by the application or to manage multiple oscillators within the system.*
- *Although more complex, driven systems, if correctly implemented, have an excellent flight history.*
- *With the permission of the designers, I will do a quick description of two types developed by GSFC (Ruitberg et al.) and SwRI (Casey et al.), each with more than 20 years of flight development history.*
- *Note that both design approaches are also tied to a specific magnetic design and qualified manufacturing process.* ***You must implement both matched to the application in order to achieve a reliable system.***

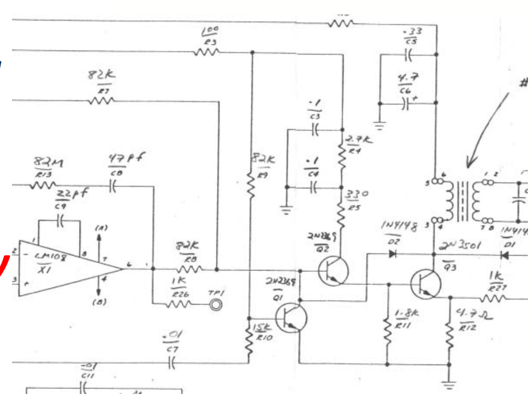
Oscillator Design… *GSFC Design Approach 3*

- *The GSFC design uses a 25% drive duty cycle that can be synchronized using a PLL.*
- *The oscillator is designed to be primary resonant.*
- *Control of the system gain is achieved via linear control of the gate voltage on the MosFet drive stage.*
- *The design requires a special transformer that will be discussed later.*

My notes show a similar secondary resonant design developed by Rosenbauer in the 1970's for ISEE.

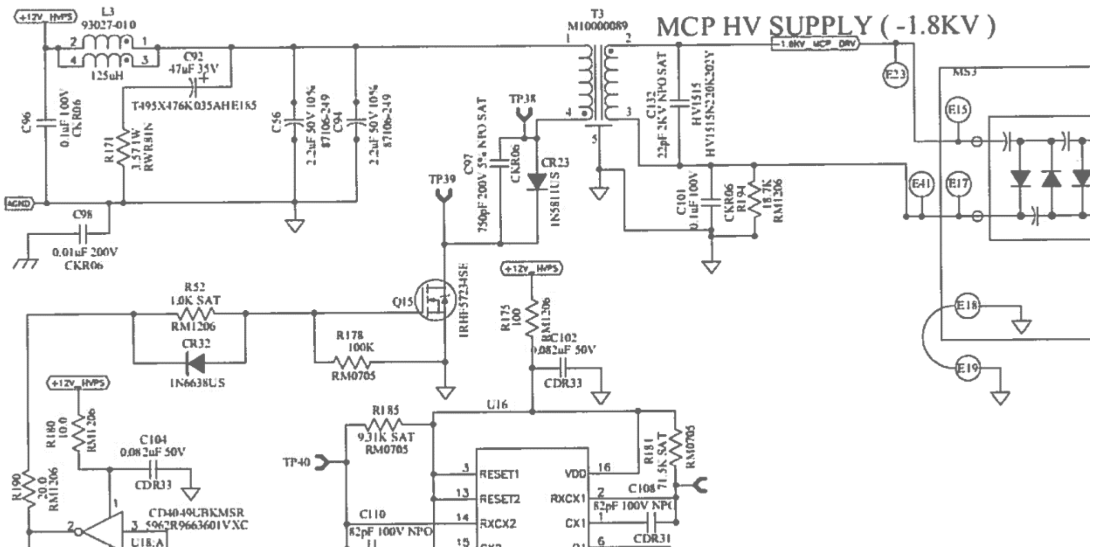






Oscillator Design… *SwRI Design Approach 4*

- ***The SwRI design is similar in drive approach to the GSFC design but uses a triggerable multi-vibrator to manage the duty cycle and achieve regulation.***
- ***The oscillator is also designed to be secondary resonant.***

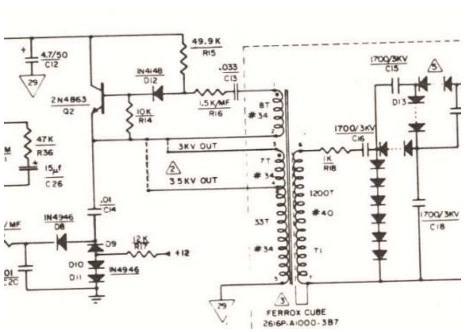


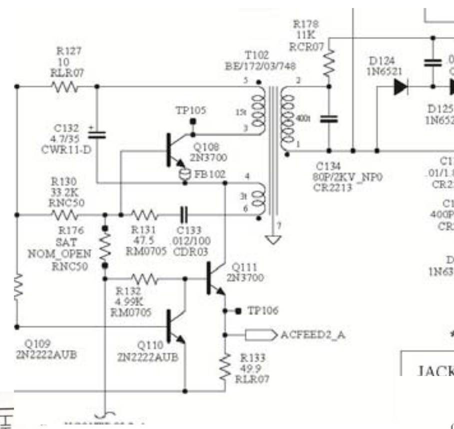
Oscillator Design… 5

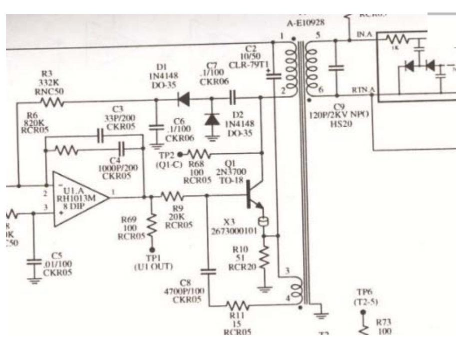
- *I prefer self-resonant oscillators since they are much simpler, more robust, immune to aging effects and lower noise.*
- *2 basic oscillator types have been evolved over the past 35 years.*
- *Type 1 is a single transistor gain controlled amplifier for low power applications in the <1 watt range. There is a 40 year story of its evolution!*
- *The Type 2 design is actually based on a Ruitberg current-fed push-pull oscillator than can operate efficiently in applications up to 6+ watts. The Type 2 evolution story is only 35 years!*
- *Both designs being self-resonant are functionally intertwined with their associated magnetic devices.*

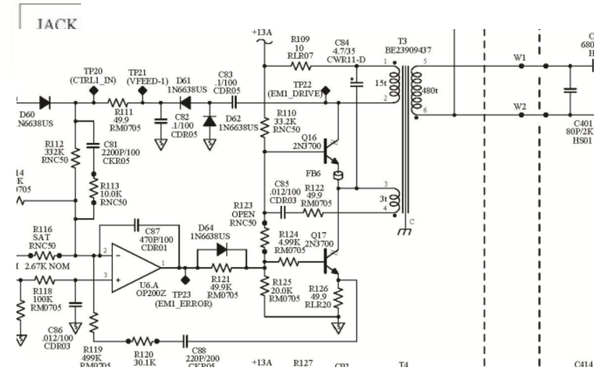
Oscillator Design… *Single-Ended 6*

The 40 year story of the low power oscillator starts with the AE mission in an unbroken string through DE – Galileo – Cassini- IMAGE - AIM all the way to SAM and MAVEN.





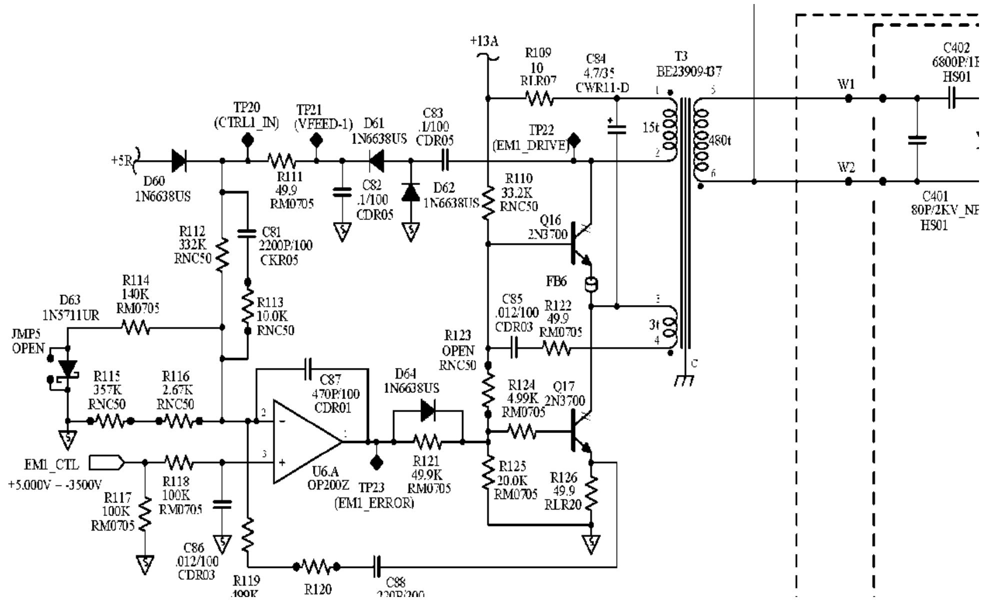




Developed by S. Battel and J. Maurer (at the University of Michigan) in the mid-1970's, this circuit was first used on the Dynamics Explorer and Galileo missions and has subsequently flown in 36 applications on 11 missions including Cassini and Huygens. The design show uses primary feedback without a connection to the secondary.

Oscillator Design… *Single-Ended 7*

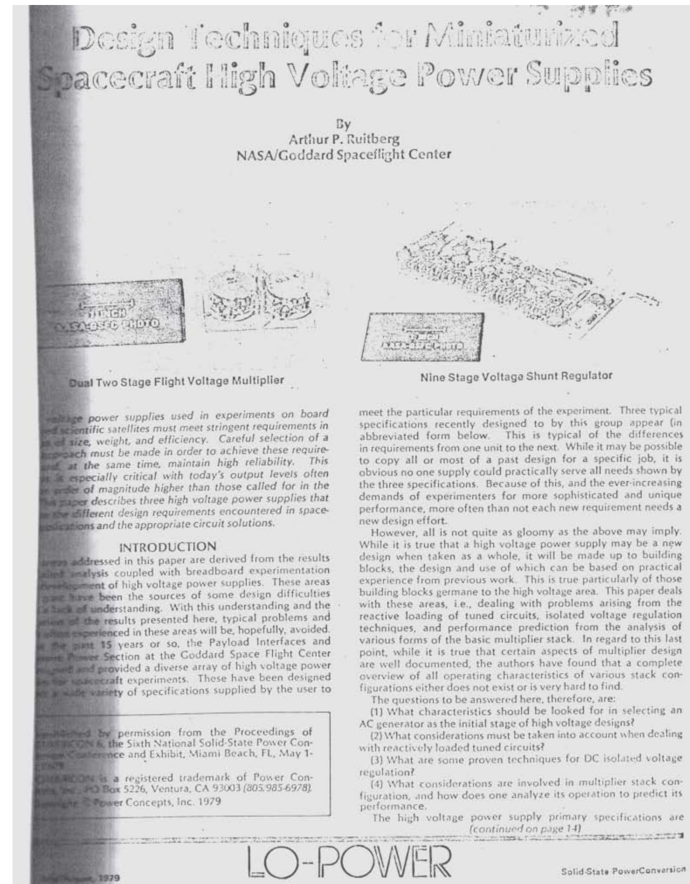
- ***The basic low power oscillator used for most designs is capable of operating down to 5 volts with start-up at less than 1 volt.***
- ***Oscillator is a single-transistor self-resonant Hartley-Armstrong derivative using a resonant secondary.***
- ***Develops a harmonically pure sine wave output and is essentially immune to radiation and temperature induced gain reduction in the drive circuit.***
- ***Inherently very low power through the using a dual feedback loop with AC coupled "tickler" feedback combined with proportional cascode control of the DC current drive to set the operating point.***



The "Ruitberg" oscillator described in 1979 was modified by S. Battel at Lockheed in the early 1980's to incorporate the use of Darlington drive transistors for higher efficiency and wider dynamic range. It has been used in 18 applications on 12 missions including Cassini, SOHO, IMAGE, FUSE, GALEX, HST and Mars-Phoenix.

Oscillator Design… *Current-Fed Push-Pull 8*

- ***The basic medium power push-pull oscillator used for most designs is capable of operating down to 5 volts with start-up at less than 2 volts. Best operation in regulated applications occurs when operated at 8 volts or higher.***
- ***Oscillator is a current-fed push-pull self-resonant design using a resonant primary and loosely coupled secondary.***
- ***Develops a harmonically pure sine wave output and is basically immune to radiation and temperature induced gain reduction in the drive circuit.***



Design Techniques for Miniaturized Spacecraft High Voltage Power Supplies

By
Arthur P. Ruitberg
NASA/Goddard Spaceflight Center

Dual Two Stage Flight Voltage Multiplier

Nine Stage Voltage Shunt Regulator

…power supplies used in experiments on board …scientific satellites must meet stringent requirements in … size, weight, and efficiency. Careful selection of a … must be made in order to achieve these requirements … at the same time, maintain high reliability. This … especially critical with today's output levels often … of magnitude higher than those called for in the … paper describes three high voltage power supplies that … different design requirements encountered in space… and the appropriate circuit solutions.

INTRODUCTION

…addressed in this paper are derived from the results … analysis coupled with breadboard experimentation … of high voltage power supplies. These areas … been the sources of some design difficulties … understanding. With this understanding and the … results presented here, typical problems and … experienced in these areas will be, hopefully, avoided. … 15 years or so, the Payload Interfaces and … Section at the Goddard Space Flight Center … provided a diverse array of high voltage power … experiments. These have been designed … variety of specifications supplied by the user to meet the particular requirements of the experiment. Three typical specifications recently designed to by this group appear (in abbreviated form below. This is typical of the differences in requirements from one unit to the next. While it may be possible to copy all or most of a past design for a specific job, it is obvious no one supply could practically serve all needs shown by the three specifications. Because of this, and the ever-increasing demands of experimenters for more sophisticated and unique performance, more often than not each new requirement needs a new design effort.

However, all is not quite as gloomy as the above may imply. While it is true that a high voltage power supply may be a new design when taken as a whole, it will be made up to building blocks, the design and use of which can be based on practical experience from previous work. This is true particularly of those building blocks germane to the high voltage area. This paper deals with these areas, i.e., dealing with problems arising from the reactive loading of tuned circuits, isolated voltage regulation techniques, and performance prediction from the analysis of various forms of the basic multiplier stack. In regard to this last point, while it is true that certain aspects of multiplier design are well documented, the authors have found that a complete overview of all operating characteristics of various stack configurations either does not exist or is very hard to find.

The questions to be answered here, therefore, are:

(1) What characteristics should be looked for in selecting an AC generator as the initial stage of high voltage designs?

(2) What considerations must be taken into account when dealing with reactively loaded tuned circuits?

(3) What are some proven techniques for DC isolated voltage regulation?

(4) What considerations are involved in multiplier stack configuration, and how does one analyze its operation to predict its performance.

The high voltage power supply primary specifications are

(continued on page 14)

… permission from the Proceedings of … 6, the Sixth National Solid-State Power Con… Conference and Exhibit, Miami Beach, FL, May 1-… 1979
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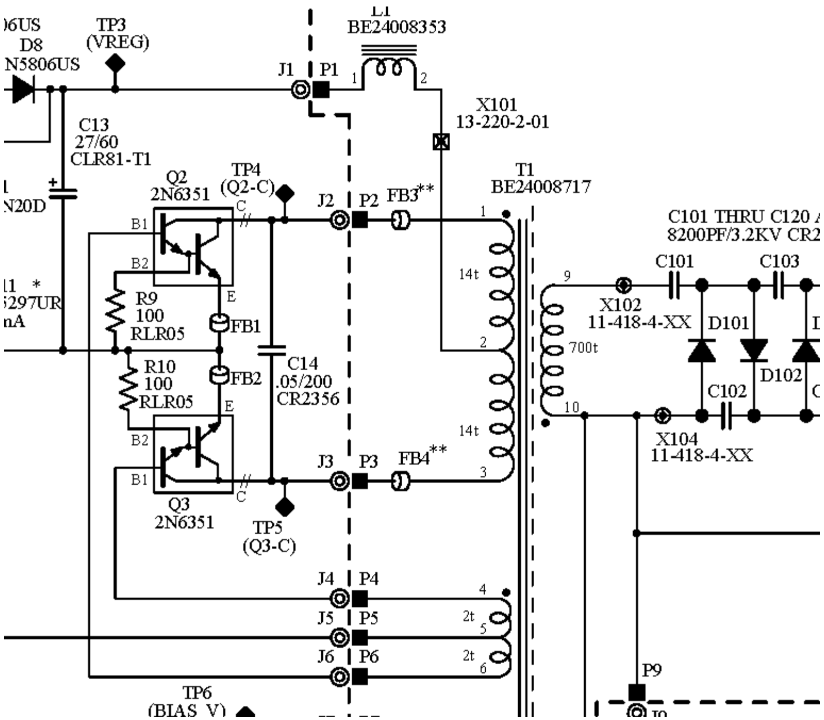
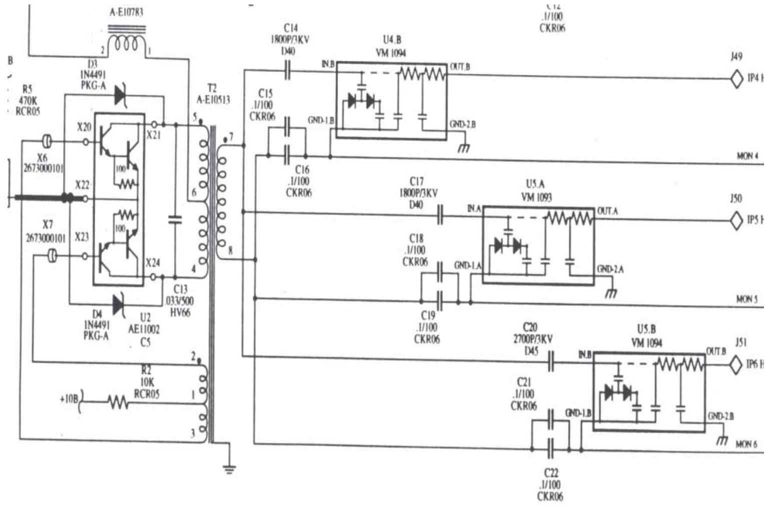
Oscillator Design… *Current-Fed Push-Pull 9*

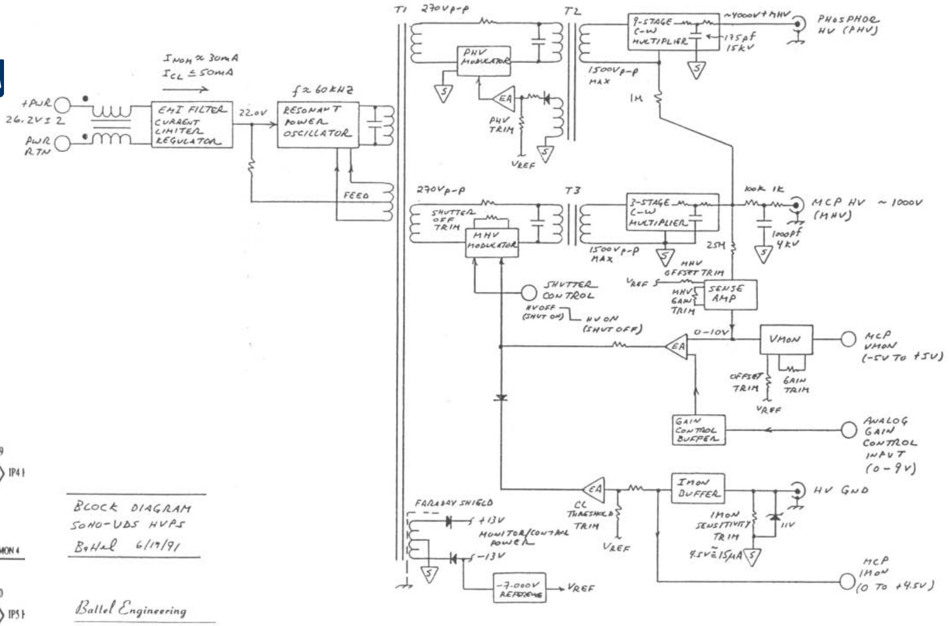
- ***Design required both a transformer and a resonating inductor although both can be stacked into a single assembly.***
- ***Aside from simplicity and efficiency over a wide dynamic range, 3 major advantages of this oscillator approach are scalability, the boosted drive voltage at the center-tap to 1.57 time the supply voltage, ability to use primary resonance.***
- ***Circuit also has low ripple current and is very quiet if properly designed and shielded.***



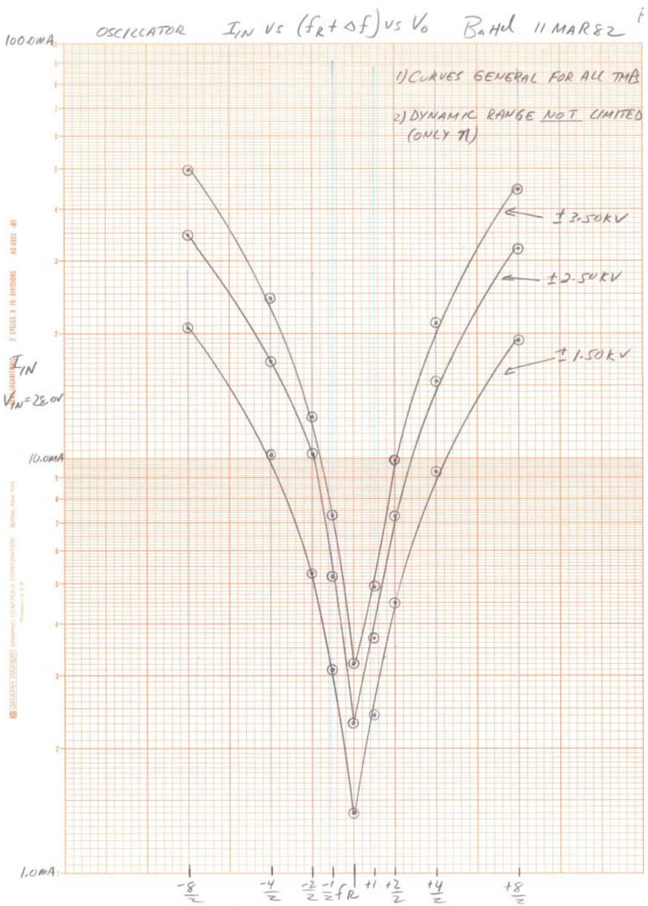
Oscillator Design… *Current-Fed Push-Pull 10*

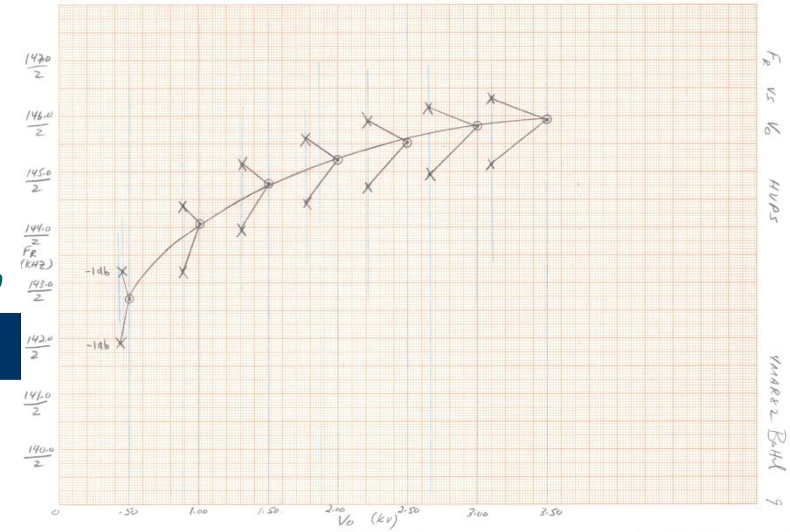
- ***The push-pull design's dynamic range and stability under wide loads also makes it useful in applications with multiple secondary outputs.***

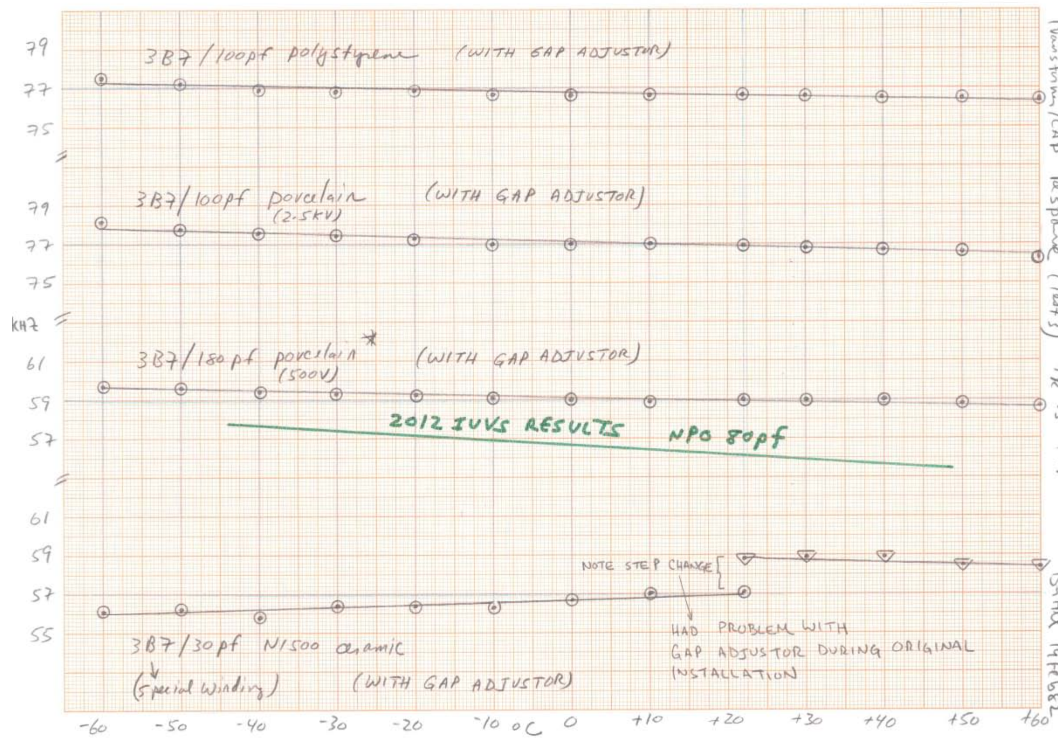




Oscillator Frequency Stability…

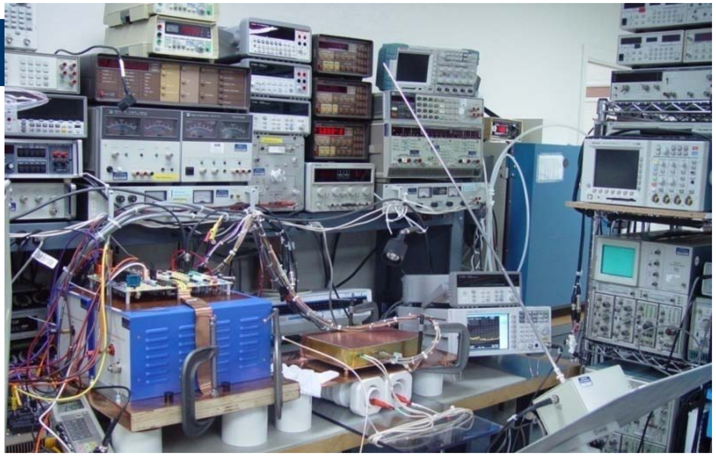


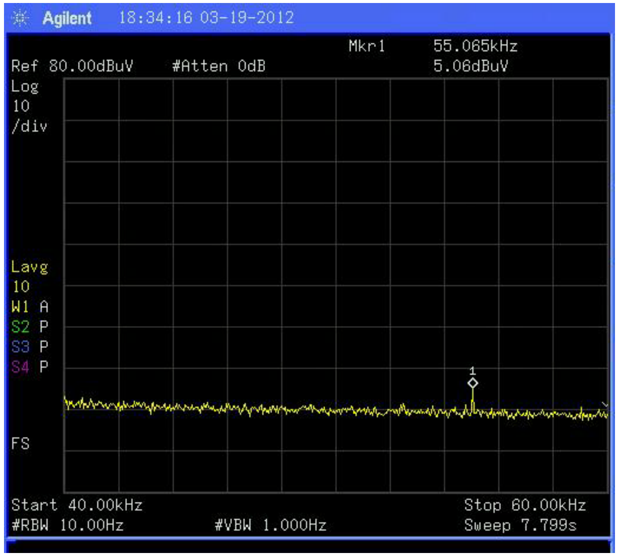




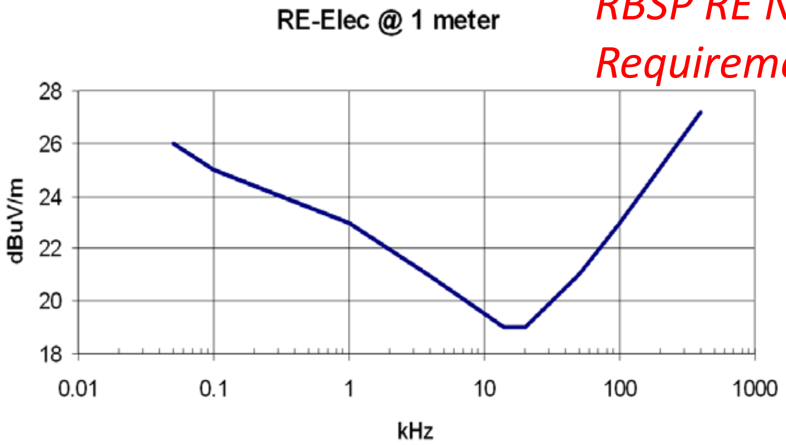
The Oscillator Noise Story… 1

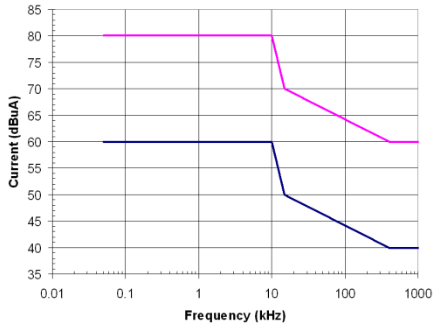
Self-Oscillating systems are harmonically pure and actually quieter than driven and/or synchronized systems. The measured E-Field value for MAVEN unit is 5.06 dBuV/m.





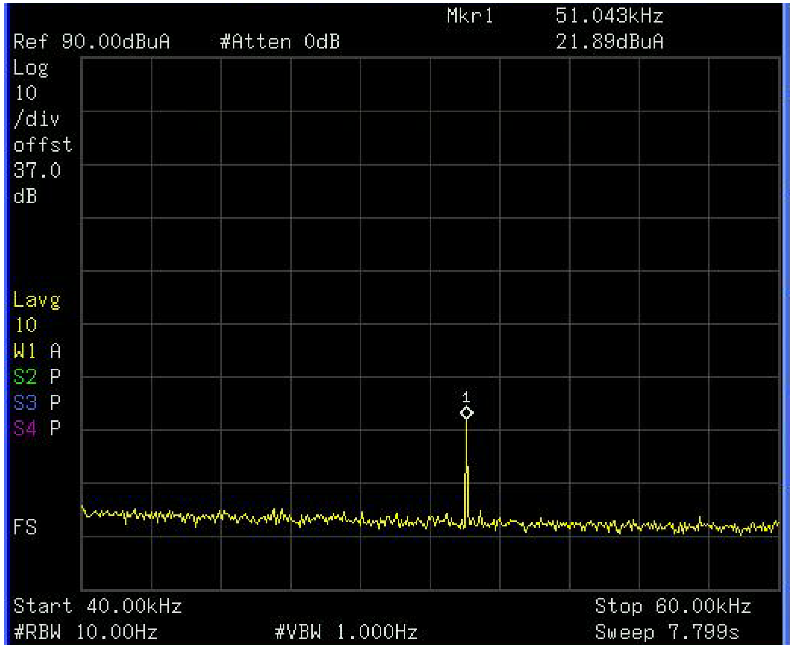
RBSP RE Noise Requirement



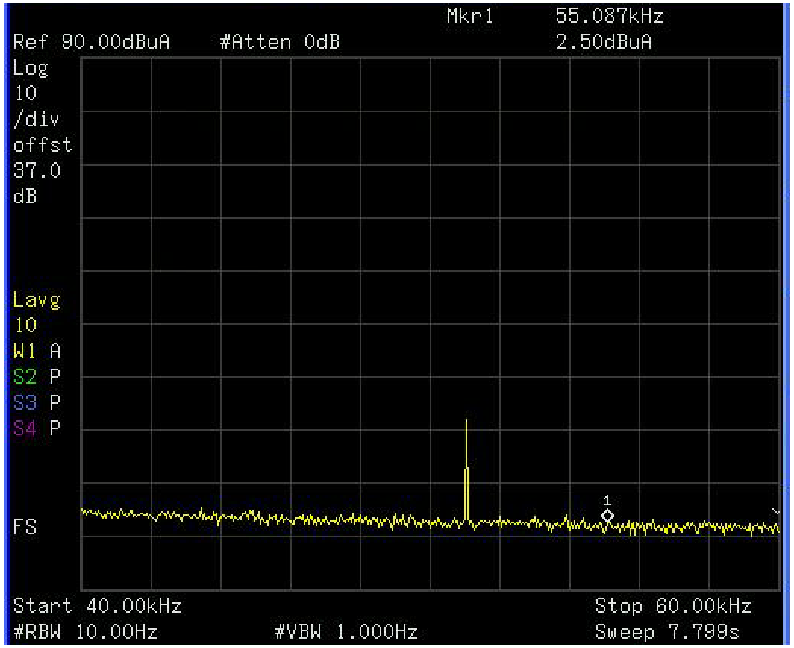


RBSP C-M Noise Requirement

The Oscillator Noise Story… 2



CE-01 C-M MAVEN measurement with LVPS on and HVPS off = 21.9 dBuA



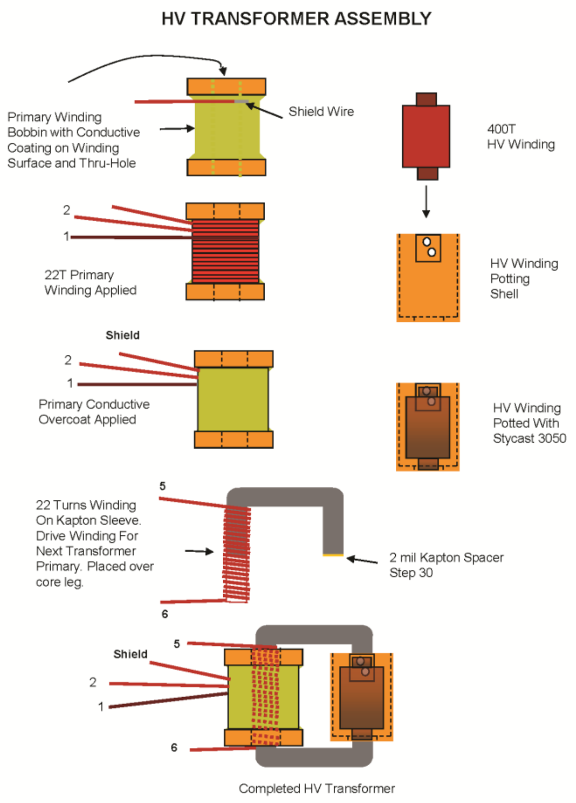
CE-01 C-M measurement with LVPS on and HVPS on- not measurable at HVPS oscillator frequency.

Magnetics Overview…

- *Magnetics are typically the design limiter on high voltage power supply designs.*
  - ***Most vendor sensitive element.***
  - ***Most expensive element.***
  - ***Least stress-controlled element.***
  - ***Most process and material sensitive element***
- *I try to use standardized designs in each type of oscillator application that have evolved into trusted elements through a long history of testing, process improvements and flight experience.*
  - ***Processes and manufacturing continuity for 30+ years.***
  - ***Have developed my own qualification and screening capability.***
- *One helpful thing about a transformer is that it can be tested to failure using accelerated methods.*

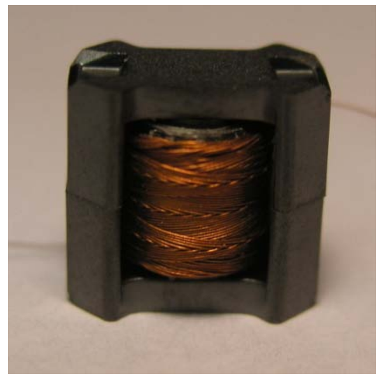
Ruitberg Lattice Wound Transformer… 1

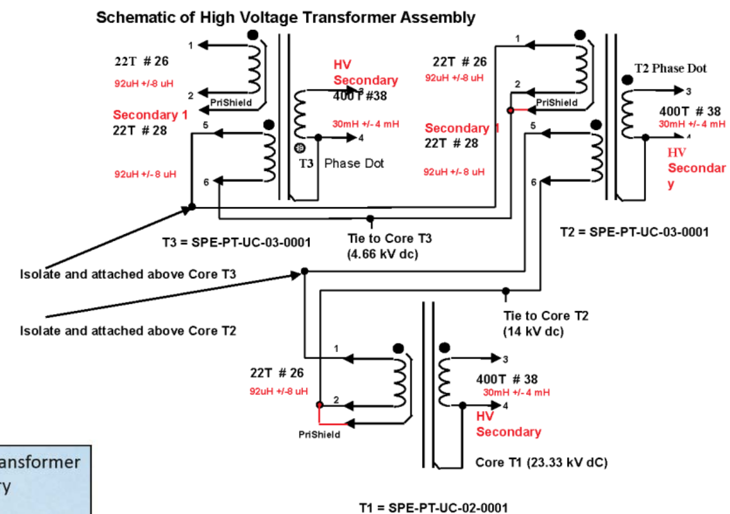
- *WINDING IS SELF SUPPORTING. NO BOBBINS OR INNER INSULATION LAYERS REQUIRED.*
- *ADJACENT WINDING TO WINDING VOLTAGE CAN BE PRECISELY CONTROLLED IN LATTICE STYLE CONSTRUCTION.*
- *WINDING PITCH CAN BE VARIED TO ADJUST INTERWINDING SPACING (AND ASSOCIATED PARASITIC CAPACITANCE.)*
- *WINDING PARASITIC PROPERTIES VERY REPEATABLE.*
- *TECHNIQUE LESS PRONE TO OPERATOR ERROR THAN MANUAL METHODS.*
- *BARRIER-FREE CONSTRUCTION AND LARGE INTERWINDING SPACING ALLOWS FOR VOID-FREE SOLID ENCAPSULATION. TRANSFORMER CORE AND PRIMARY WINDING LEFT UNPOTTED.*

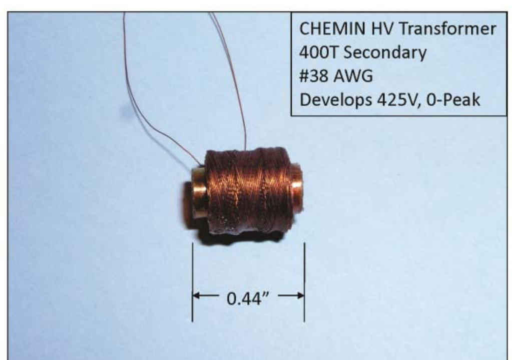


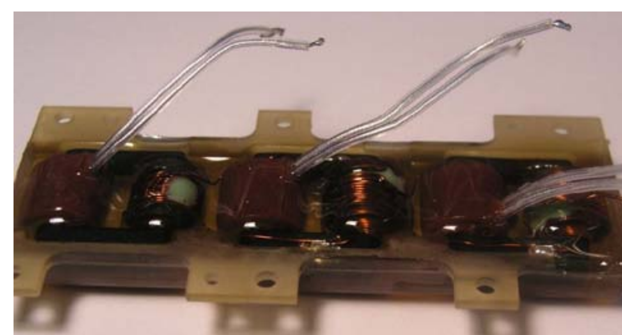
Ruitberg Lattice Wound Transformer… 2

- ***IN MANY APPLICATIONS, LATTICE HV WINDING CAN BE USED "UNPOTTED."***
- ***ALSO, VERY COMPATIBLE WITH PARYLENE COATING. PARYLENE WILL COMPLELETY PENETRATE WINDING AND MECHANICALLY " LOCK" WINDINGS TOGETHER, VOID FREE.***

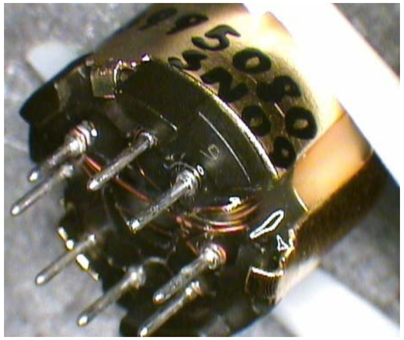




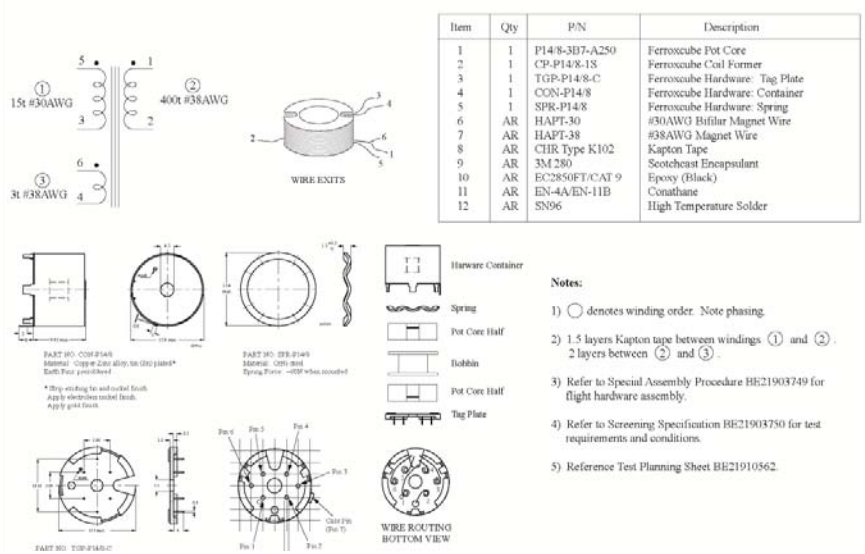




Resonant Transformer Construction… 1



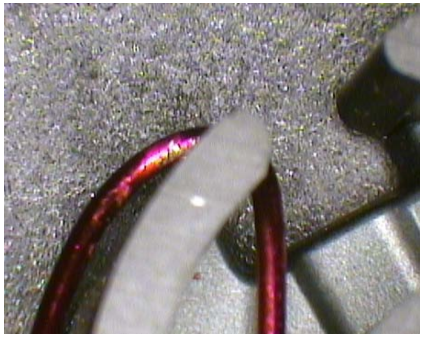
- *"Standard" transformer designs for most high voltage oscillators use gapped potcore magnetics and standard spring mounting hardware to allow a -55C to +120C processing temperature range.*
- *Typically use Ferroxcube 3B7 material due to relatively linear temperature coefficient.*
- *Cores should be carefully inspected and diamond filed to smooth sharp edges. Do not scratch, drop or chip cores during handling or use one that have cracks or chipouts.*
- *Cans should be stripped and gold plated.*
- *Windings should be implemented to minimize internal gradients.*



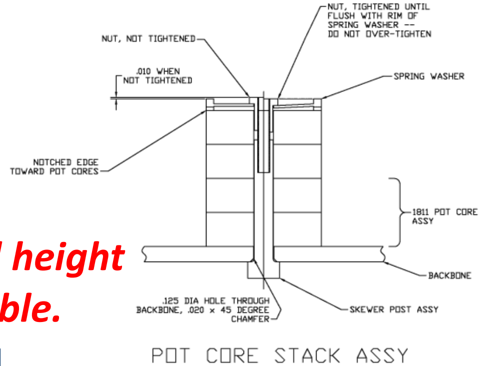
Item	Qty	P/N	Description
1	1	P14/8-3B7-A250	Ferroxcube Pot Core
2	1	CP-P14/8-1S	Ferroxcube Coil Former
3	1	TGP-P14/8-C	Ferroxcube Hardware: Tag Plate
4	1	CON-P14/8	Ferroxcube Hardware: Container
5	1	SPR-P14/8	Ferroxcube Hardware: Spring
6	AR	HAPT-30	#30AWG Bifilar Magnet Wire
7	AR	HAPT-38	#38AWG Magnet Wire
8	AR	CHR Type K102	Kapton Tape
9	AR	3M 280	Scotchcast Encapsulant
10	AR	EC2850FT/CAT 9	Epoxy (Black)
11	AR	EN-4A/EN-11B	Conathane
12	AR	SN96	High Temperature Solder

Notes:

1) ◯ denotes winding order. Note phasing.
2) 1.5 layers Kapton tape between windings ① and ②. 2 layers between ② and ③.
3) Refer to Special Assembly Procedure BE21903749 for flight hardware assembly.
4) Refer to Screening Specification BE21903750 for test requirements and conditions.
5) Reference Test Planning Sheet BE21910562.

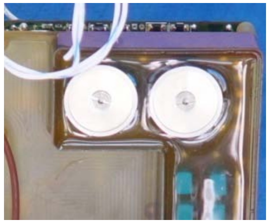


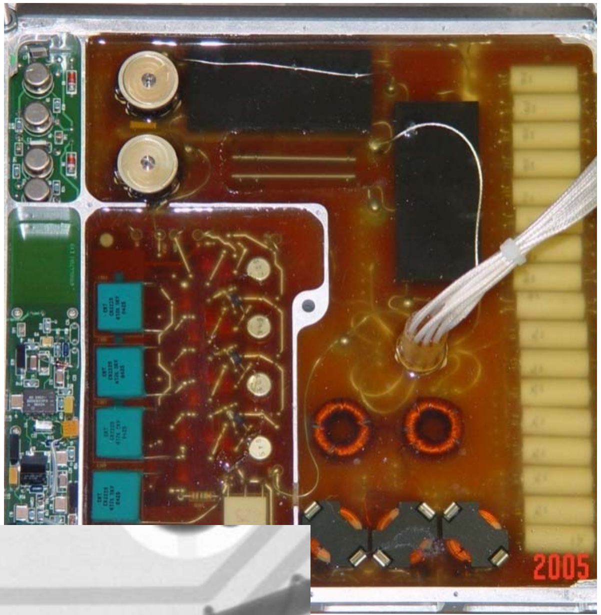
Resonant Transformer Construction… 2

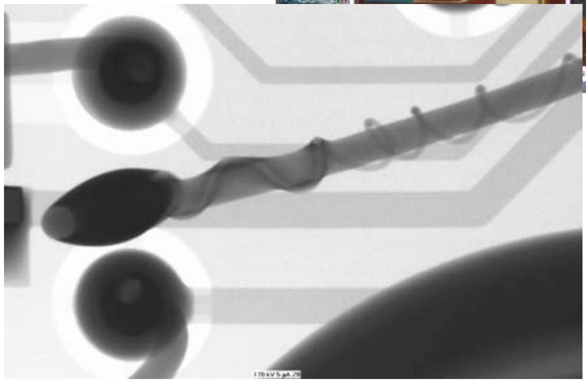


A single height or dual height stacked design is possible.

- *Designs intended to be potted (such as Mars applications) are implemented using a "Hertzberg Spring" that has controlled mechanical properties matched to the core thermal expansion properties.*
- *RM cores with standard clamps have also been qualified less critical resonant or non-resonant applications where the operating properties are less critical. Note that they are not fully shielded as are potcores.*
- *Routing and soldering of fine wires smaller than 34 AWG is much more critical when the transformer is potted.*

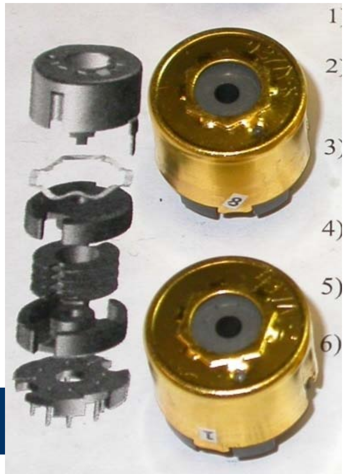






40 MINUTE LUNCH

Magnetics Design and Manufacture… 1

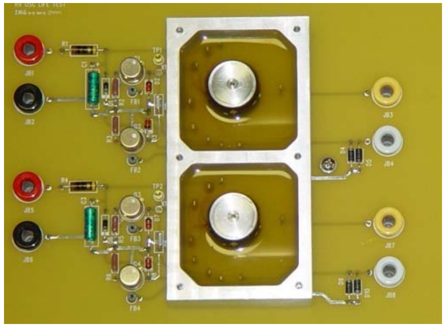


- *Once you achieve a proven and qualified design for a resonant transformer, each application comes down to a choice of core size, gap choice, primary winding turns and secondary step-up ratio.*
- *Proven potcore sizes are 1408, 1811, 2213 and 2616 with 1811 being the preferred starting point for most low power and medium power designs. In higher step-up applications, a 2213 core gives more room for larger wires and managing spacing. For higher power (up to 6-8 watts) a 2616 core is preferred although the resonant characteristics require a little more management.*
- *For most applications a transformer works best with around 1 volt per turn on the primary. Secondary turns up to 750 have been successful with output voltages as high as 1250 volts peak.*
- *With lower voltages (~450 volts peak) coupling and efficiency are best with the windings layered on top or each other. Above that voltage, custom split bobbins made of Ultem are typically used.*

Magnetics Design and Manufacture… 2

- *The resonant frequency "sweet spot" tends to be in the range of 40 kHz in higher power applications and 55 kHz to 80 kHz in lower power applications depending on the turns ratio and parasitic capacitance. In general, the driver on frequency is the size of the tank capacitor with the frequency chosen to eliminate higher frequency resonances.*
- *In nearly all applications resonant designs, if properly constructed, result in very little heat rise within the device. In most cases the temperature rise is less than 5C.*
- *Process control is essential in low volume production manufacturing spread over many years. The manufacturing technicians have not changed in almost 30 years of production. Procedures evolve based on engineering results, discoveries, material changes AND feedback from the technicians.*

Magnetics Design and Manufacture… 3



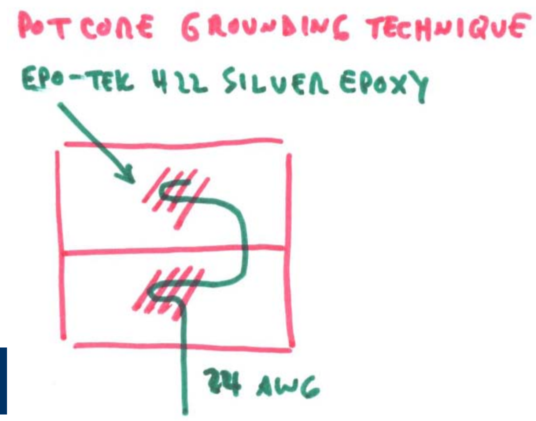
- Design, manufacturing and test are fundamentally based on 981 criteria but have been adapted to achieve high voltage reliability. Most important (and a great advantage) in resonant designs is to test using a simple oscillator circuit similar to the flight application.
- Generally, I test magnetics from -55C to +100C operating in the resonant circuit. Note that REAL operating applications are generally limited to +70C due to limitations on potting materials and coatings.
- Faraday shields within the transformer are possible but tend to add complexity and reduce reliability. They can be helpful, however, in some designs by allowing for better field control between windings.

Magnetics Design and Manufacture… 4

- *Special bobbins are also possible to manage the construction and internal fields. Except for split bobbins, I tend to avoid complicated assemblies but nested Ultem cores, gold plating and other techniques are certainly possible and have been successful.*

- *Wire sizing has a big impact on the E-field. In general, the wire-wire voltage and layer-layer voltages can be controlled by how the windings are constructed. However, the wire egress and transition segment are a challenge that must be managed.*
- *In general breakdown in air is a good indicator of the effective electric field around the wire. Thus, if you can operate with the bare wire in air you are likely to be sized okay. In nearly all practical cases 36 AWG works okay up to 1200 volts peak. Splicing or spiral wrapping at the point of egress can improve on these numbers.*

Magnetics Design and Manufacture… 5



- *Core grounding occurs automatically when a core is mounted in a standard can (assuming the can grounding pin is used) but grounding is not guaranteed when other mounting schemes are used. There are also floating applications where the core is not at ground potential. In these cases, if the core is properly abraded, a hair pin 24 AWG wire can be attached to each core half using silver epoxy.*
- *As noted previously, special care must be taken to make sure that there is no tin plating on the cans or on other parts. The magnetic materials we use are fundamentally commercial parts so they are cheap but also subject to manufacturing "improvements" and RoHS requirements.*

Magnet Wire Considerations… 1

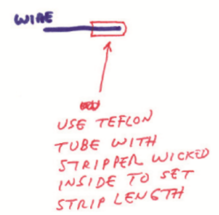
- *There are several types of magnet wire and many people try to go for the heaviest built (H4) and highest temperature (220C) under the largely false assumption that these characteristics increase reliability. The assumption turns out to be fundamentally true in motors and transformers operating at very hot temperatures but not for small high voltage wires operating as low temperatures.*
- *For greatest process uniformity and best wire lay-up of small wires, I prefer HAPT (Heavy Armored Poly-Thermaleze) which is a dual coated wire consisting of a base coat of cross-linked modified polyester resin and a top coat of amide-imide polymer.*
- *I usually procure from MWS Wire Industries using the JW 1177/12B CL-180 H2 spec. There are other manufacturers but I have 30 years of experience working with MWS and they have always delivered a good product at a fair cost.*

Magnet Wire Considerations… 2

- *MWS mostly re-spools Essex wire for standard applications like HAPT so make sure to ask them to provide material less than 1 year old. I have had not problem recertifying wire more than 1 year old if it has been stored in a cool dry place but I always try to use new wire for each mission.*
- *Magnet wire insulation may be crazed or otherwise degraded by exposure to polar solvents (such as water or alcohol). As well, acrylic adhesive dissolves in alcohol and many epoxy bonds may be damaged by even short exposure (>1 min) to trichloroethane vapors.*
- *Due to crazing problems, alcohol or other solvents should be used locally and controlled procedurally with respect to* ***where and how****. Any time solvents are used,* ***an annealing step shall follow afterwards unless otherwise specified. This annealing step consists of baking at 120C (do not exceed 128C) for 1 hour.***

Magnet Wire Considerations… 3

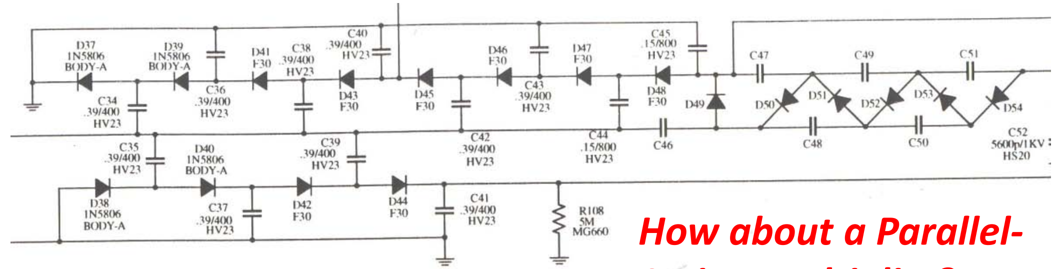
48	Trim wire to allow for a transition to the stripped section of wire. Strip the wire insulation using InsulStrip acid allowing for 4 turns of wrap at the point of soldering. Use Teflon tubing to hold the acid and set the strip length. Apply stripper multiple times until the wires are fully stripped.
49	Thoroughly wipe off acid with moistened swab followed with IPA or ethyl alcohol swab rinse.



Using InsulStrip

- *I prefer 3M 281 Scotchcast epoxy for bobbin impregnation due its low viscosity and excellent penetration in combination with its good thermal shock characteristics over the temperature range of -65C to +150C. Standard outgassing tests tend to show it a little above the 0.1% CVCM spec but the transformer hot temperature post-cure processing results in-spec outgassing.*
- *Stripping of fine magnet wires is always a challenge. Over many years and many attempts to find alternatives to chemical stripping,* ***Ambion "InsulStrip" gel*** (AMBION CORPORATION, *NAUGATUCK , CT) remains the method of choice for the tougher magnet wire coatings. . This stuff is very dangerous so make sure to prepare properly and handle safely.*
- *For solder terminations on pins that will be re-soldered to a PC board, you want to use a higher temperature solder (I prefer Sn96) that will not re-melt during the later installation process. Note that it has a gray appearance that tends to confuse inspectors so you want to make sure the inspection criteria are clearly noted in the processing procedure.*

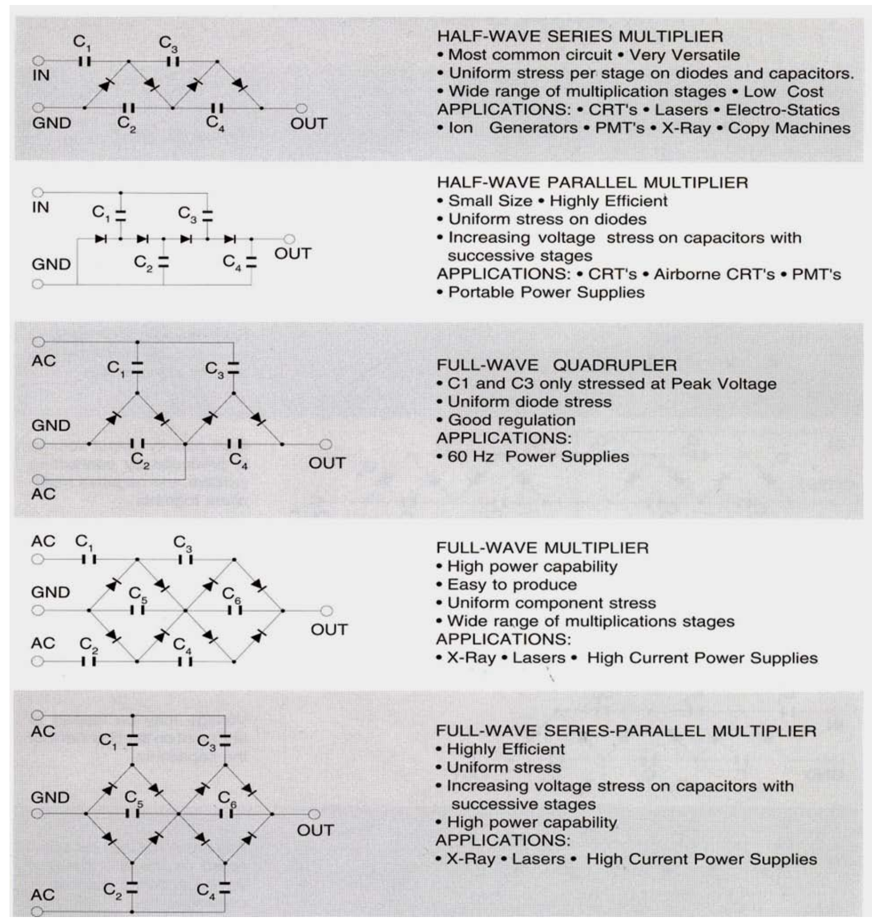
High Voltage Multiplier Design… 1



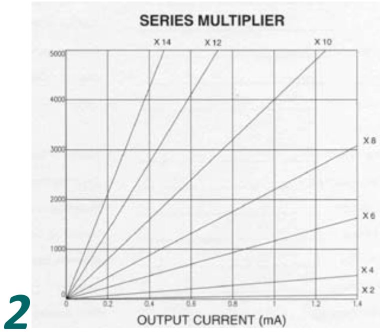
How about a Parallel-Series Multiplier?

Figure provided courtesy of Voltage Multipliers Inc.

- *Most designers prefer a half-wave Cockroft-Walton voltage multiplier (proper name is actually a Greinacher cascade) implementation because of its simplicity and equal voltage per stage.*
- *There are many types of half-wave and full-wave designs each possessing advantages and dis-advantages. Parallel multipliers are more efficient but require higher voltages for progressive stages.*



High Voltage Multiplier Design… 2



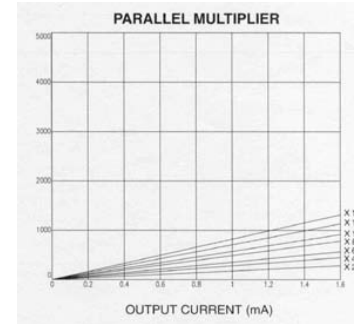
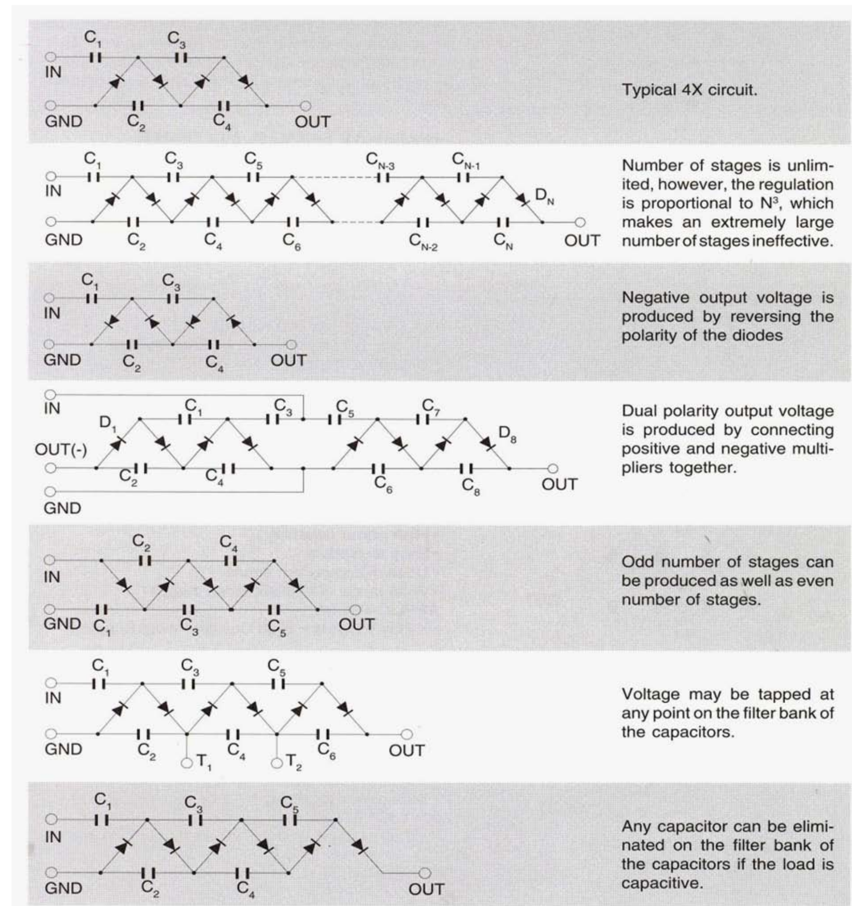


Figure provided courtesy of Voltage Multipliers Inc.

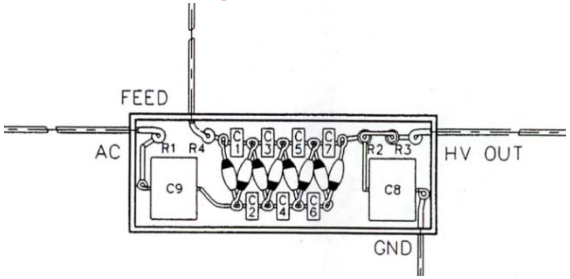
- *The key to understanding a multiplier is to recognize the problem of charge transfer per stage.*
- *A series multiplier must move all of the charge through every stage while a parallel design injects along the length of the stack.*
- *In the end the size due to the CV constraint is about the same for each type but the voltage loss is less on a parallel design.*
- *Designs can be optimized by using larger capacitors and/or progressive staging to limit the loss per stage.*

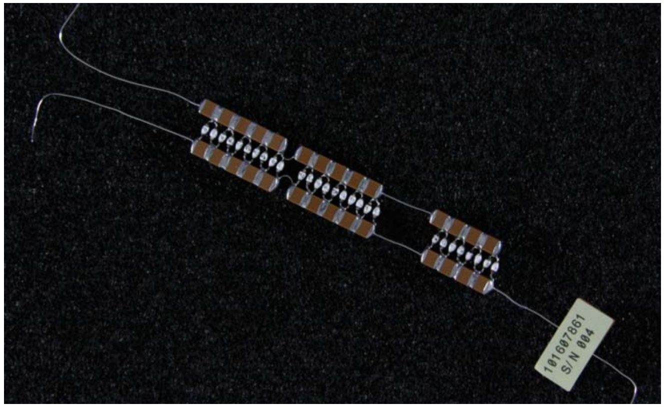


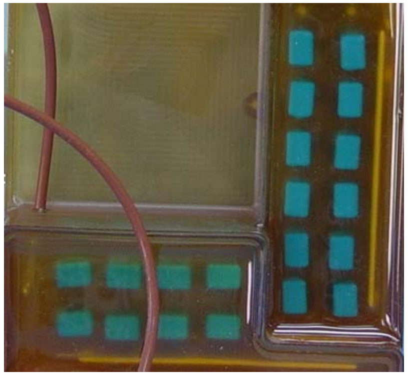
High Voltage Multiplier Design… 3

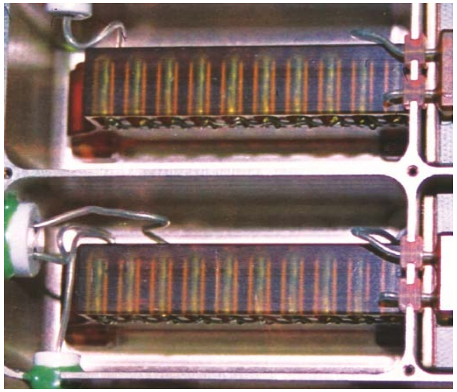
With thanks to VMI, SwRI and Art Ruitberg

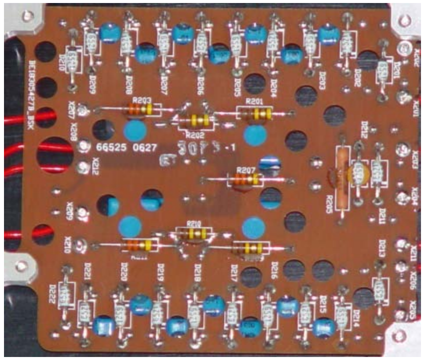
Multipliers can be made in all shapes, sizes and ratings using many different assembly methods.





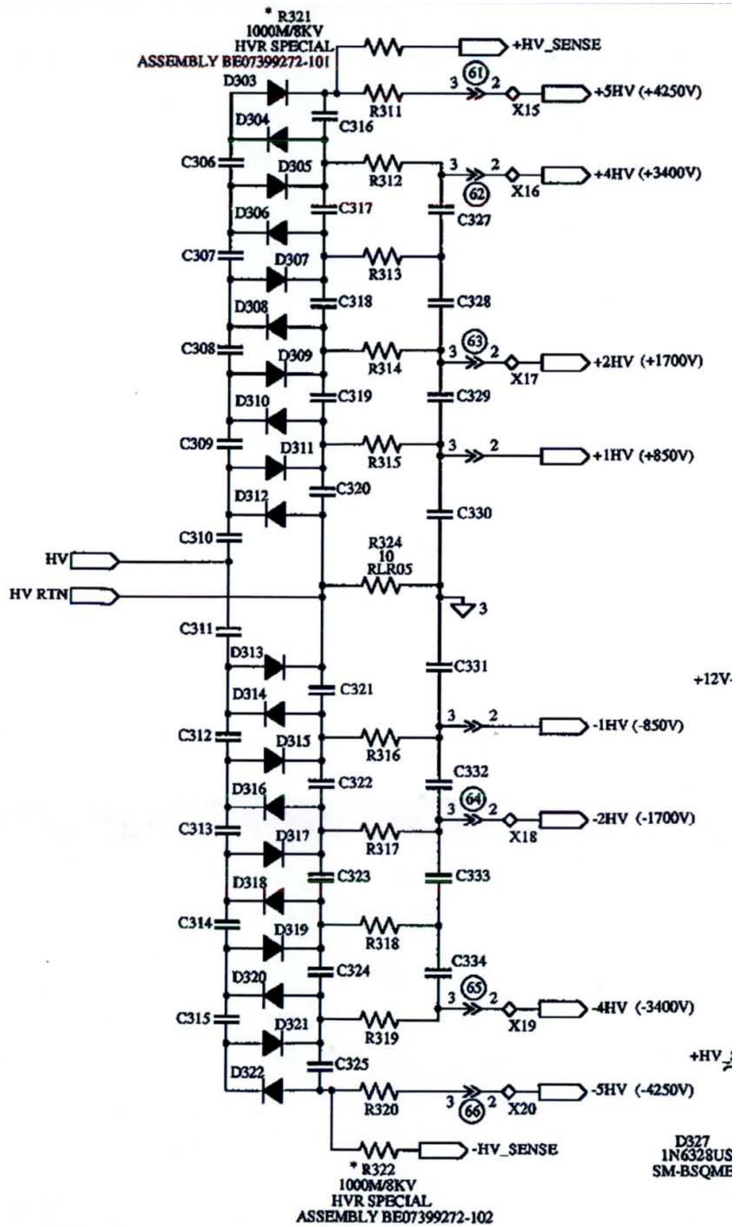






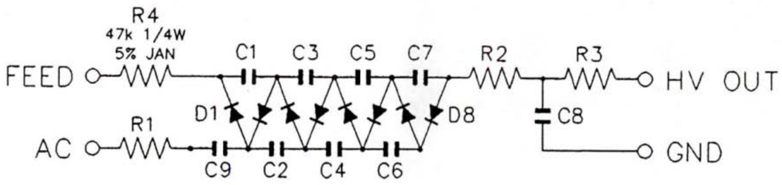
High Voltage Multiplier Design… 4

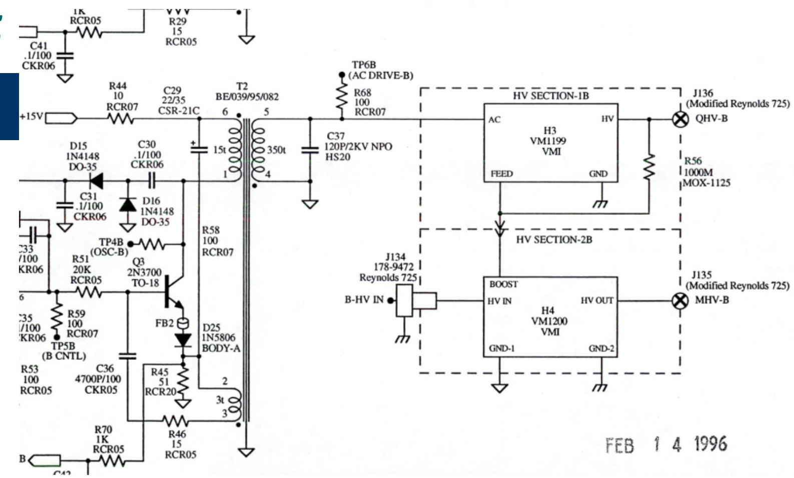
- *In "bulk supply" where the voltage on the overall stack is held relatively constant, **voltage taps** can be implemented.*
- *Depending on the bulk application and regulation requirements, it is also possible to regulate the stack of one of the lower taps with the benefit of requiring a lower voltage rating on the feedback resistor.*
- *As will be discussed later, it is also possible to use a lower tap for AC feed-forward in the control loop.*

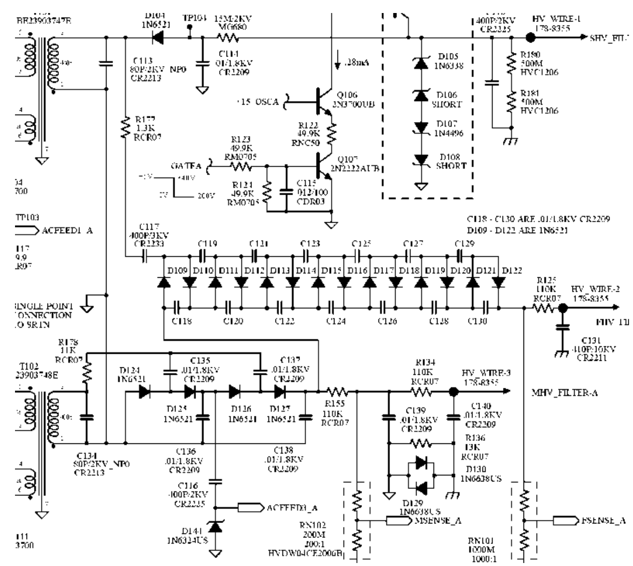


High Voltage Multiplier Design… 5

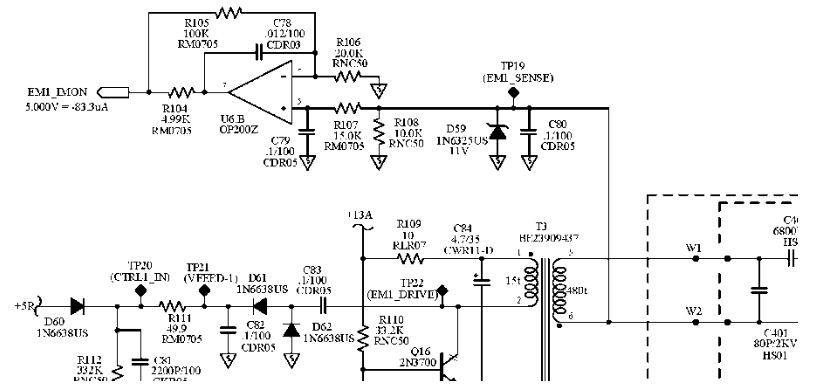
- *You have seen that transformers can be stacked in specialized applications.*
- *Multipliers can be AC coupled and stacked as well.*
- *In noise-sensitive applications it is usually helpful to implement shields to isolate the multiplier from the output filter.*
- *Remember that multipliers exhibit light sensitivity and can become leaky if they do not have an opaque cover.*



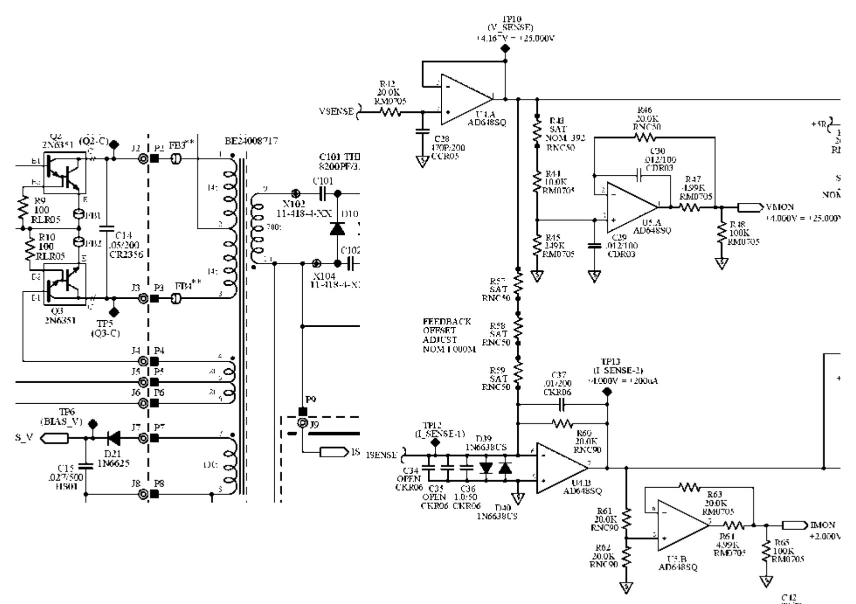




Current and Voltage Monitor Approaches… 1

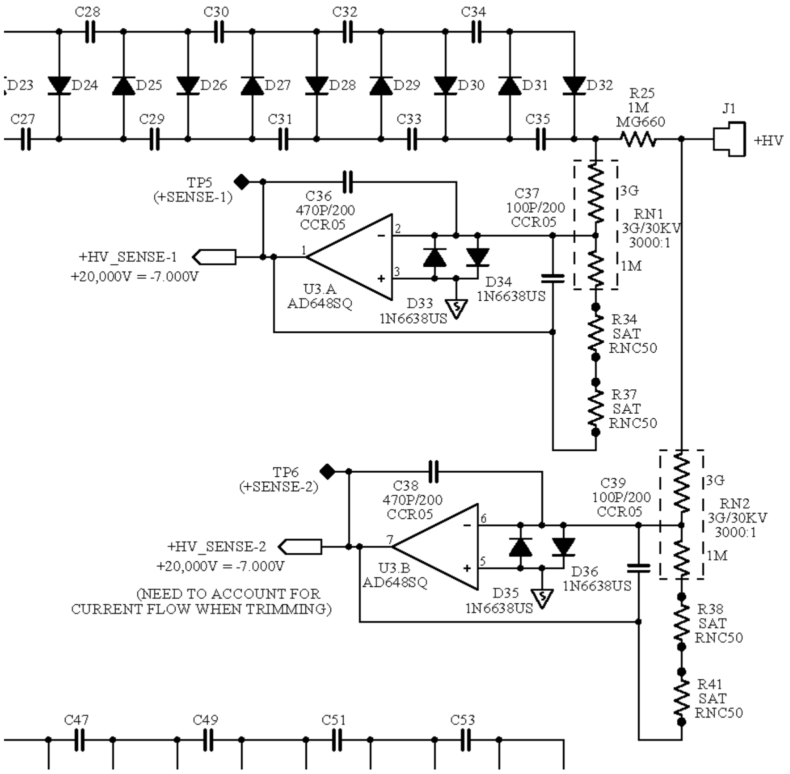


- *The 2 key rule of designing monitors is first, “do no harm” and second, keep it simple.*
- *A properly designed monitor should never affect the main circuit function or add a failure mode to that function.*
- *For current monitors, I always prefer a ground-leg approach where the current is sensed at the return point of the monitor. ALWAYS include clamping protection on the input that accommodates a fault condition.*
- *Feedback current can also be corrected for by coupling the voltage and current monitors.*



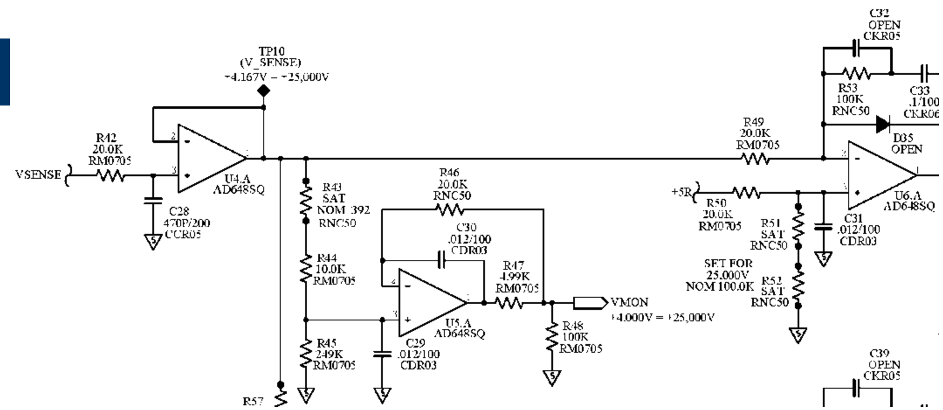
Current and Voltage Monitor Approaches… 2

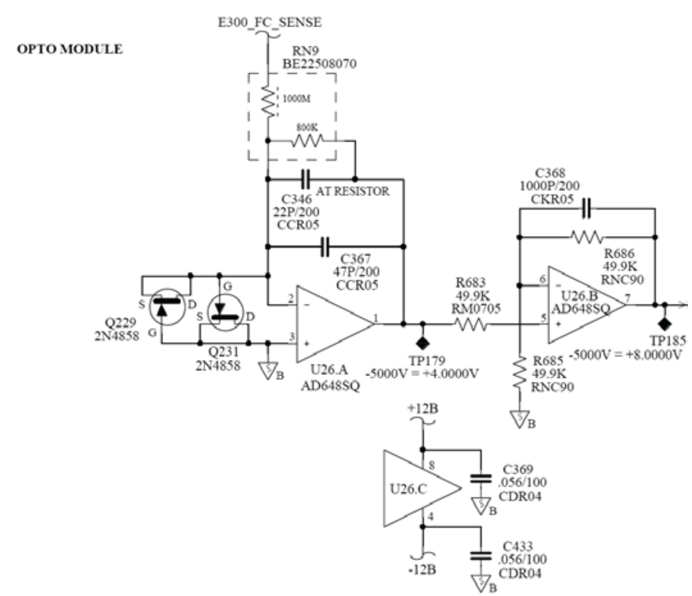
- *High-side current monitors generally add risk and complexity due to the need to sample parallel voltage outputs across a sense resistor.*
- *When designing a high side monitor work hard to get sense resistors that are matched for resistance as well as for Tc and Tc of Vc. It also helps if you only need to match at the operating point over a narrow voltage range.*
- *It is also worth noting that in many application the primary side input current is very closely coupled to the output current.*



Current and Voltage Monitor Approaches… 3

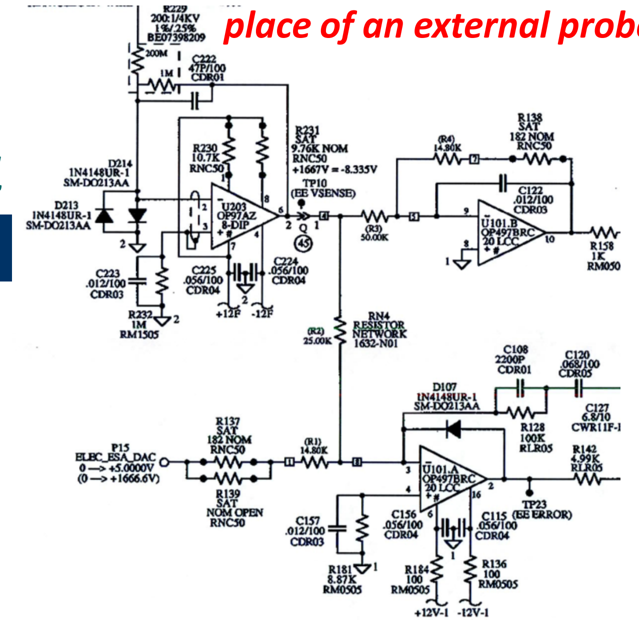
- *Voltage monitors also have their challenges, especially if linearity, accuracy and speed are required over a wide voltage range and/or temperature range.*
- *The challenge is made greater in cases where the feedback system and monitor are inter-connected since there is a trade between power dissipation and bandwidth that must be managed.*
- *Although a little more complicated, I generally prefer to use a higher impedance with a sense amplifier followed by a separate monitor amplifier and error amplifier.*



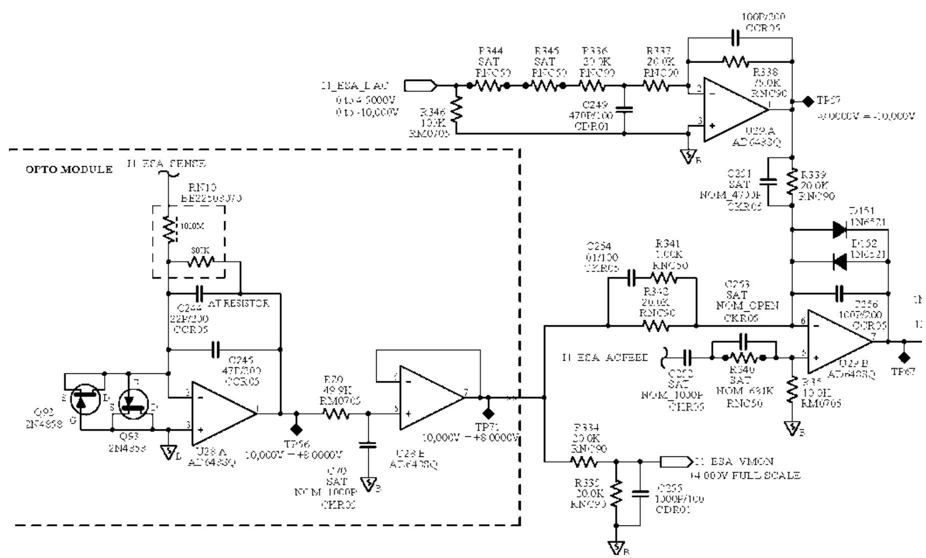


Feedback and Sense Amp Methods… 1

If you trust the sense amp, once it is calibrated you can use it for many tests in place of an external probe.

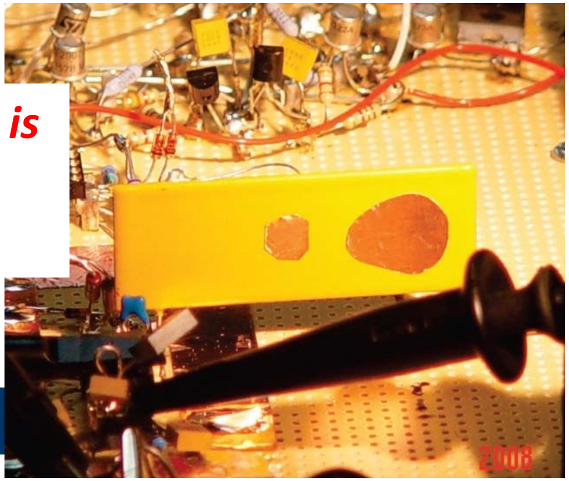


- *Following from the monitor discussion, using a sense amplifier allows matching the feedback resistor to the unique requirements of the monitor and error amplifier.*
- *Loading considerations are also important depending on power, speed and accuracy requirements.*
- *Make sure that the sense amplifier has arc protection.*
- *Feed-forward and Speed-up methods should be integral to the design approach.*
- *V/10 or some means of reduced voltage testing is should also be considered.*



Feedback and Sense Amp Methods… 2

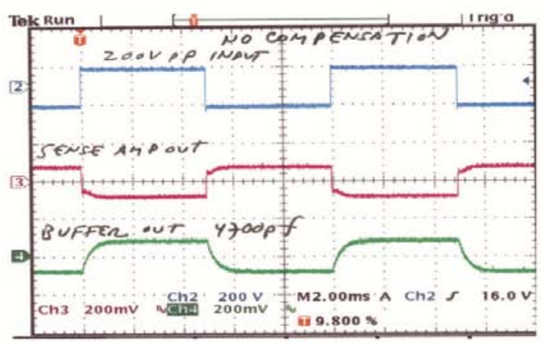
The resistor shown is operating at 10 kV.



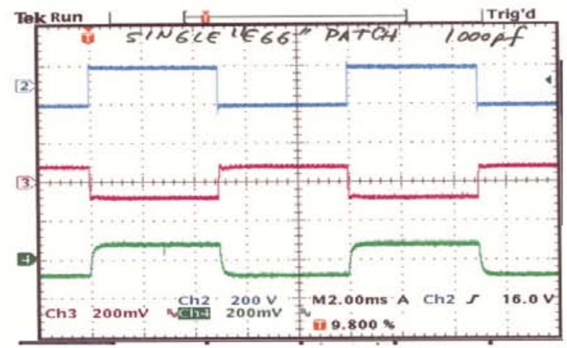
- *For high speed applications, some means of overcoming the distributed capacitance of the sense resistor is generally required unless the resistor is made an unrealistically low value.*
- *The traditional speed-up approaches, are to use a capacitor to bypass the resistor or use a series of resistors that can be impedance matched. Unfortunately, both methods add complexity and can degrade reliability.*
- *An alternate approach that is usable with flat high voltage resistors is **the "egg" method** where patches are attached to back side of the alumina.*
- *It can be seen on the next page, that it is possible through a bit of trial and error to effectively match the distributed impedance of the sense resistor in a way that corrects the response.*
- *Ohmcraft indicates that it should be possible to mask on a backside semiconductive coating that can match the "egg" response.*

Feedback and Sense Amp Methods… 3

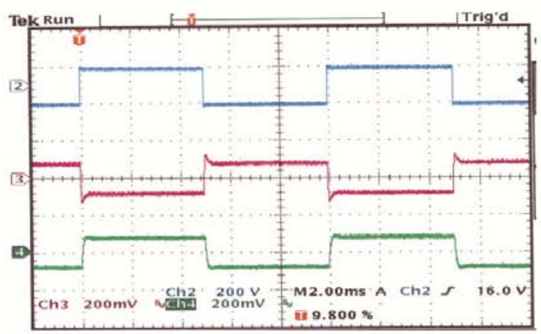
Progressive adjustment of phase response in using a wideband 200 volt peak-to-peak signal injected by a Krohn-Hite 7500 power amplifier.



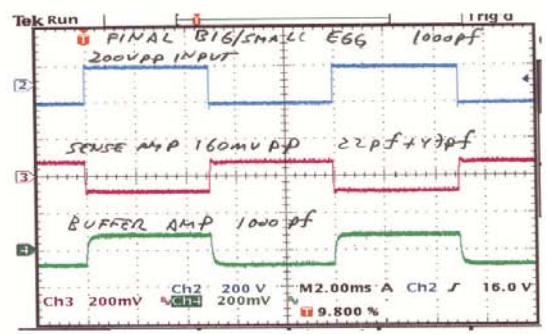
PIC5- Uncompensated
4700 pf on Buffer Amp (DN227)



PIC6- Single Patch
1000 pf on Buffer Amp (DN232)



PIC7- "Double Egg" Patches
1000 pf on Buffer Amp (DN233)



PIC8- Final "Big Egg–Small Egg"
Compensation; 1000 pf on Buffer Amp
22pf + 47pf on Resistor (DN234)