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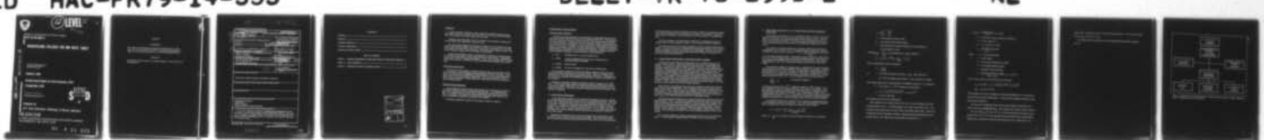

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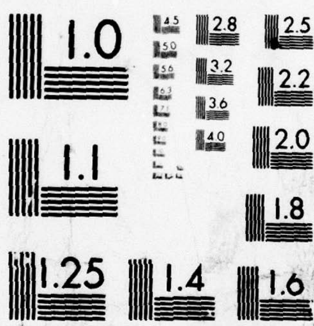
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Research and Development Technical Report
DELET-TR-78-2991-2

NANOSECOND PULSERS FOR MM WAVE TUBES

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HUGHES AIRCRAFT COMPANY
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February 1980

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The AVG avalanche transistor ~~manufactured by Raytheon~~ has been selected as the switching element for the nanosecond pulsers. Still open for consideration is a high voltage (400V) VMOS FET that ~~Siliconix~~ will be ~~make~~ available ~~to Hughes~~ shortly for evaluation of that device operating in avalanche mode.

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SUMMARY

A nine stage Marx modulator circuit using AVG avalanche transistors was fabricated and tested. Current rise time of 0.8 to 0.9 ns was achieved working into a 50Ω resistive load with a peak current of 20A.

Impedance matching within the Marx circuitry was required to minimize the adverse effect from reflections on the rise time.

The above Marx modulator with groups of 2N6661 FET or 2N2219A BJT indicated no appreciable change in the current rise time at a voltage level of one-half the previous case using AVG transistors. The lower output voltage was due to the lower avalanche voltage (130V) of the 2N6661 and 2N2219A.

In the previous interim report, an approach was outlined for the development of a voltage probe needed to support this program's pulser design. Subsequently, several test circuits have been investigated. A 2kV, 1000:1 divider probe has been fabricated and tested. Calibration of this probe has been attempted and is continuing.

PROGRAM OBJECTIVES

The efforts of the program as stated in the first report are directed towards the development of three separate nanosecond pulsers for MM wave tubes. Presently, the specific goal is fulfilling the requirements of Task A, implementing the Marx circuit with AVG avalanche transistors. Later in the program, when the device becomes available, a high voltage FET may replace the AVG transistor as the switching element.

PROGRAM ORGANIZATION

Several additional personnel have been brought onto the nanosecond project to meet the anticipated technical challenges of the program. The technical areas that will be reinforced are in microwave techniques and semiconductor devices. Also, a consultant with expertise in transformer design has been retained to develop the magnetic components required for this program.

A detailed organization outline of the program is shown in Figure 1.

NANOSECOND PULSER DESIGN

Switching Device Selection

The AVG avalanche transistor was selected as the switching element for the nanosecond pulser over the 2N2219A BJT and 2N6661 VMOS FET. Commensurate rise times were achieved when the three devices were incorporated in the Marx circuit configuration. Because of the lower avalanche voltage of the 2N2219A and the 2N6661 (≈ 130V) as compared to the AVG unit (230V), approximately double the number of 2N2219A's or 2N6661's would be required in a Marx circuit to generate a given output voltage using the AVG avalanche transistor. Raytheon has made and delivered several variations of the standard AVG avalanche transistor using different assembly techniques to minimize emitter series inductance.

- AVG — Standard AVG, 1.0 mil Au bonding wire.
- AVGX — 1.0 mil Au bonding wire, die close to emitter post to shorting bonding wire length.
- AVGZX — Same as above
- AVGBX — 1.5 mil Au bonding wire, die close to emitter post.

No discernible change in rise time of the Marx modulator output was noted using the various above groups of avalanche devices. This was probably due to masking of the AVG lead inductance by other circuit parameters. Investigation of the circuit and evaluation of the different modifications to the AVG transistor will be continued.

Siliconix is planning to release in early July a 400V 1Ω R_{DON} @ 10A VMOS FET. If tests of the device indicate favorable avalanche characteristics similar to that of the 2N6661 VMOS FET, this VMOS FET may very well replace the AVG avalanche transistor. The decision must be deferred until the unit becomes available and is evaluated.

A. Switch Module Development

A nine stage Marx modulator circuit using AVG transistor similar in configuration to that illustrated in the previous report was fabricated and tested. Rise time of the output current between 0.8 and 0.9 ns was achieved working into a 50Ω load at 20A peak. Impedance matching the output load and the first stage of the Marx modulator was required to reduce the rise time from 4 to 5 ns range to approximately 1.25 to 1.5 ns. Further improvements to 0.8 → 0.9 ns region was realized by adding a RC network between collector and emitters and emitter to ground of each switch stage.

Impedance matching the input to the output imposes the requirement of twice the output voltage to appear across the switch module. With each switch device (AVG transistor) delivering approximately 200V @ 20A, nine to ten AVG transistors will be required for a 1000V output into a 50Ω load. Efforts to increase the voltage and current capabilities of the individual switch stage is in progress. Improved switch layout to minimize circuit inductance may be one means to accomplish this task.

The Marx modulator previously discussed will be reconfigured to meet the negative output voltage required in Task A. The circuitry is shown in Figure 2.

The turn off circuitry for the Marx modulator switch is presently under development. The Marx type circuit configuration and the requirement of a fast fall time makes the design of the turn off circuitry quite formidable. However, several alternative methods are under consideration and as the designs are firmed up, the unit will be fabricated and tested.

B. Voltage Divider Development for Nanosecond Pulser Program

The first step toward the probe development was to evaluate components in various divider circuits. These were elementary resistive and capacitive type dividers. A capacitive divider was built in microstrip form. This exhibited an attenuation factor far in excess of that predicted. The stray shunt capacitance was excessive. The ground plane was removed 1/4 inch away from the circuit. This improved the predictability of the divider significantly. Consequently, and for shielding reasons, the probe was constructed as a coaxial line with a planar center conductor. This allowed close prediction of distributed inductance and capacitance due to ground proximity. By varying the characteristic impedance of the coaxial probe, the divider ratio became predictable and the first prototype design became possible. Figure 3 shows an equivalent circuit of the prototype divider. It currently has a ratio of 1140:1 and 2kV peak voltage capability.

Pulse voltage measurements are made using a Tektronix Model 7904 oscilloscope using a S-3A sampling head. This sampling system has an integral high impedance probe input. The new probe was, therefore, designed to interface with the S-3A probe tip. This made the probe incompatible with 50 ohm input systems. It is planned to design a second probe prototype specifically for use with 50 ohm systems, such as the Tektronix Model 7904 with S-4 sampling system.

Probe compensation/calibration was accomplished using a Tektronix Model 109 pulse generator. This is a reed pulser specified at less than 250ps rise time and 750 Hz repetition rate. Maximum amplitude is (with external power supply) 300 v. Initial probe compensation was done using a 250 MHz bandwidth oscilloscope. Although rise time limited, this allowed fundamental probe compensation. Results showed a 15% overshoot in the response. The elimination of this anomoly is continuing. Probe testing has indicated a rise time capability between .5 and 1 nanosecond.

It is currently planned to continue compensation efforts on the first prototype probe. A second probe is being designed to interface with 50 ohm systems.

C. High Voltage, High Current 0.1 ns Voltage Rise Time Pulse Transformer Development

The ultimate requirement is a 0.1 ns voltage rise time to 13 K.V. into $\approx$ 30 pf capacitor load and a 0.2 ns fall time for pulse widths from 2 to 100 ns. For purposes of development, the immediate objective was to build and test a 1000V to 3000V step-up pulse transformer. For test purposes the voltage source will be a 1000V charged capacitor to be switched to the transformer primary as a power source.

The problem in the above objective is to charge a scaled down capacitor of approximately 10 pf to 3000V in 0.10 ns through the pulse transformer. The approximate average current is given by $I = \Delta VC/t = \frac{3000 \times 10 \times 10^{-12}}{10^{-10}} = 300A$ which is the secondary average current. The primary current would be 3 x 300A = 900A for 0.1 ns. The estimated current would also be higher because of the addition of the transformer distributed capacity (referred to the secondary). Thus, if this added capacity is also 10 pf, the average charging current would be required to double.

Along with the transformer response time, a suitable type of copper conductor for the primary and secondary windings of the transformer is required. At the frequency inherent in a 0.1 n sec. rise time, the skin depth of copper would be less than about 80×10^{-6} inches into the surface. With current requirements of the order of 1800A for the primary and 600A for the secondary, even fine Litz wire will absorb too much IR drop. Litz wire of 80 strands of #48 wire would have its:

$$\frac{R_{AC}}{R_{DC}} = 93 \quad \text{at the subject frequency.}$$

A thin deposit of about $180 \times 10^{-6''}$ of deposited copper on .0005" kapton (1' x 1') was obtained from Fortin Company of Sylmar in Los Angeles as a sample. With a skin penetration of about 80μ inches from each surface, the ac resistance will not be significantly higher than dc resistance. For a transformer of about 1.25" in winding length a strip width of 1.1" of two sheets of the subject copper will be bonded together for the primary. For the secondaries four sheets will be bonded together. Conductors of about 0.015" wide x four sheets thick will be cut for the secondary.

To calculate the tranformer response time a calculation of leakage inductance L and distributed capacity C is necessary. For a step-up transformer energized from a voltage source, the front edge of the wavefront output voltage

$$V_o = E_1 r \left[1 - \frac{e^{-mt} \left(\sin Nt + \tan^{-1} \frac{N}{m}\right)}{N\sqrt{LC}}\right]$$

where: $m = \frac{R}{2L}$; R is the effective copper resistance referred to the secondary

$$N = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

r = the transformer step-up ratio

E_1 = the primary source input voltage

C = the total effective capacity referred to the secondary N_2 (this includes the load)

Assuming $\frac{1}{LC} >> \frac{R^2}{4L^2}$, the expression for V_o above reduces to

$$V_o = E_1 r \left[1 - e^{-mt} \sin\left(\frac{t}{\sqrt{LC}} + \frac{\pi}{2}\right)\right]$$

This is a damped sine wave of frequency

$$F = \frac{1}{2\pi\sqrt{LC}}$$

At $t = \frac{\pi}{2}\sqrt{LC}$, the output V_o will be $V_o = E_1 r$. The rise time is

$= \frac{\pi}{2}\sqrt{LC}$ (the output would reach $V_o = 2E_1 r$, unless it is clipped with a high voltage zener of designed with a "despiking" network. If, for example,

C = 20 pF and L 2×10^{-9} H (refer to the secondary)

$$t_r = 1.57\sqrt{2 \times 10^{-9} \times 20 \times 10^{-12}} = 3.14 \times 10^{-10}$$

$= 0.314$ ns rise time

To calculate L and C for the transformer:

The transformer core chosen will be 1/4" x 1/4" in cross sectional area with a window length of 1.24". A winding length of 1.1" wide x two sheets of foil. The secondary will be three turns of 0.015" wide x four sheets thick of foil. Three such secondaries will be connected in parallel. Between primary and secondary the insulation will be .005" teflon with a low dielectric constant of K = 2.

$$C_e/\text{sec} = \frac{0.225 \times A \times K}{d \times 3} \text{ pF} \quad \text{where}$$

$A = 0.0585 \text{ in}^2$, area of secondary opposite N_1

$d = 0.005''$ teflon; $K = 2$

$C_e = 3 \times 1.755 \text{ pF} = 5.26 \text{ pF}$

$$L = \frac{10.6\, N^2 1\, (2\, nc + a) H}{10^9\, b}$$

where $n = 1$, for no interleaving

$c = 0.005''$ teflon

$a = 0.014$ total coil build-up in inches

$b =$ coil winding length in inches

$1 =$ average coil turn in inches

$$L = \frac{10.6 \times 9 \times 1.3'' \,(.01 = .014)}{10^9 \times 1.1 \text{ in.}} = 2.7 \times 10^{-9} \text{ H}$$

From F and t_r above, the rise time with a 10 pF load

$$T_R = \frac{\pi}{2} \sqrt{LC} = 1.57 \sqrt{15.26 \times 10^{-12} \times 2.7 \times 10^{-9}}$$

$$T_R = 0.318 \times 10^{-9} \text{ sec.}$$

The resulting rise time is contingent on having little additional L & C in the input and output leads (short twisted leads). It also assumes negligible inductance in the power source capacitor.

To test such a transformer there will be some problems encounted to get a source with such a high $\frac{di}{dt}$ capability. This aspect of the problem is under study too.

The rise time T_R of 0.318×10^{-9} sec. can be improved upon by using a transformer with a 1/8" x 1/8" cross sectional area and with the same winding length, though such a transformer would only have enough volt-sec. capacity for 15 ns pulse width. The factors L and A would each be reduced by 2. The rise time would be cut to $T_R = 0.159 \times 10^{-9}$ sec.

Fabrication of this transformer will be completed during the next reporting period.

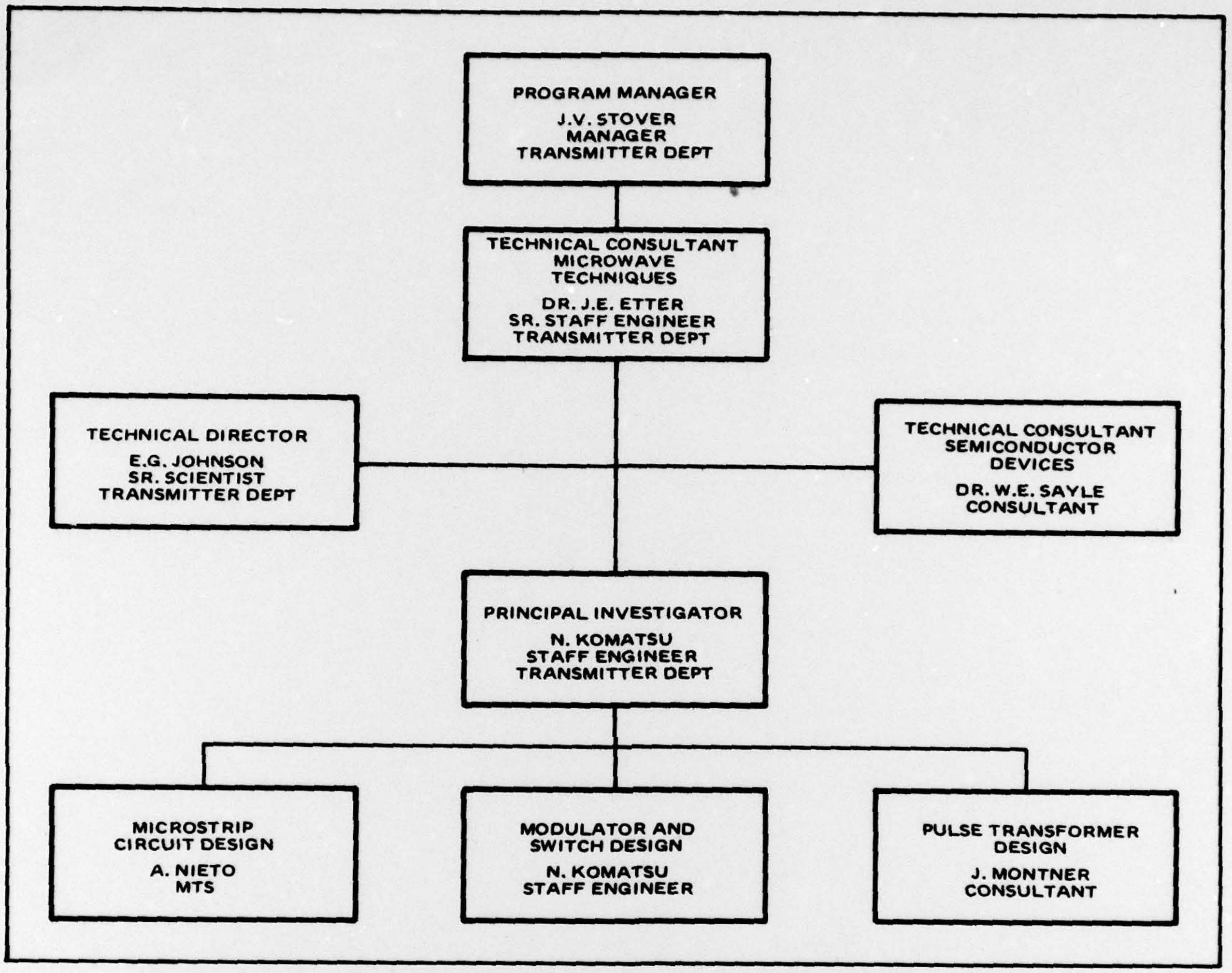

Figure 1. Organization of Nanosecond Pulser for MM Wave Tubes Program at Hughes Illustrating Upper Management Interest in the Program

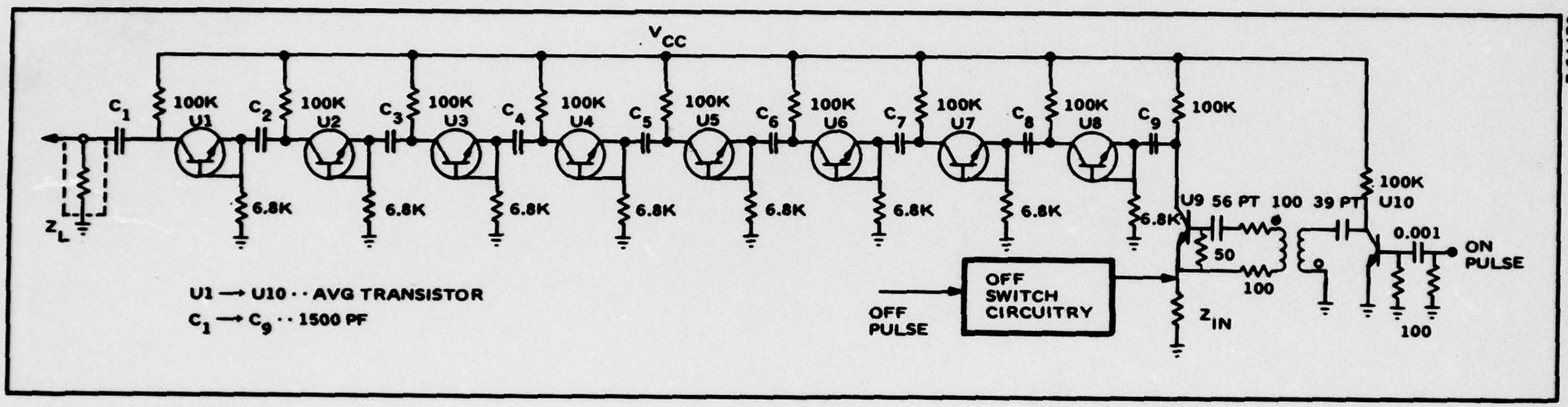

Figure 2. Marx Modulator

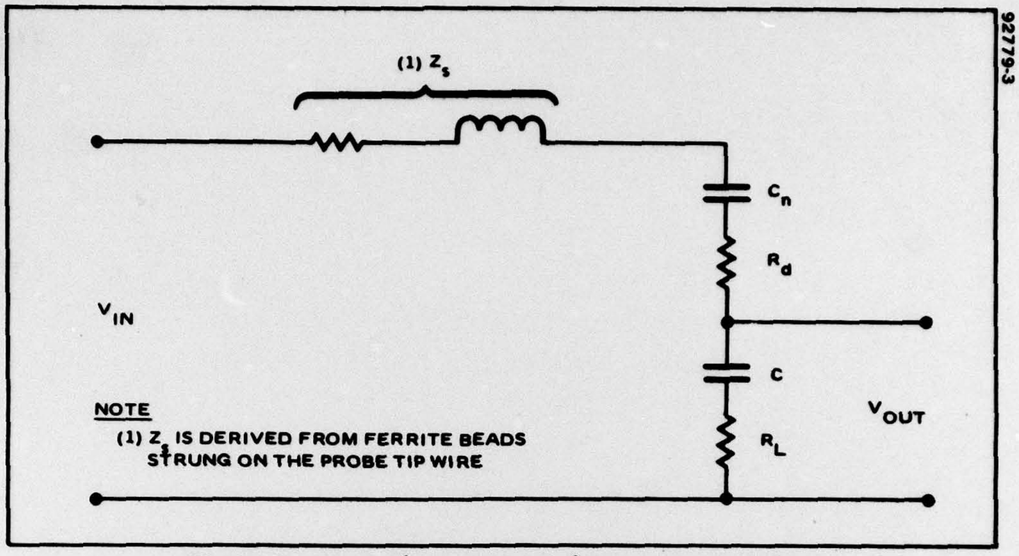

Figure 3. Equivalent Circuit of Prototype Divider

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