REPORT OF TRIP TO ROME, NEW YORK, LINCOLN LABS and POLYTECHNIC INSTITUTE OF BROOKLYN

Re: Possibilities or Present Knowledge of High-Power Modulators

A brief summary of the results of this trip can be quoted as follows: Very little if anything is known of modulators in the power level range in which we are interested for M. Specifically, no such modulators are in use at present by anybody and certainly no life information is available.

The general concensus of opinion appears to be that the hydrogen thyratron will probably not be a satisfactory switch from standpoint of life. A study program with General Electric supported by Evans Signal Laboratory is still years from producing a tube which would adequately cover the power levels which we are interested in. Since this program was started at least two years ago, it appears improbable that another hydrogen thyratron manufacturer could in six months develop a tube which would do exactly what we want and have a very long life.

The best approach from the standpoint of single switch at present appears to be the mercury ignitron. Several ignitron sets are in use at present at power levels which are less than what we require from the standpoint of peak power, but very much higher than what we require from a standpoint of average power. Life experience with these ignitrons has been very good up to now. Either these or similar ignitrons should be in our hands after the paper work has cleared away to transfer them from Livermore to Stanford, and I strongly suggest that the first order of business will be to investigate these ignitrons from the standpoint of deionization time and firing jitter.

At present the voltage rating of ignitrons is not high enough to satisfy our requirements. Experience with ignitrons in crowbar circuits and the like has indicated that they can indeed hold off voltages in excess of 50 kv. Whether this will still be correct for our application or not is not certain.

Another possibility is the use of magnetic modulators. Disregarding the cost for the present time, the main disadvantage of the magnetic modulator appears to be the fact that no high-power magnetic modulator has been built yet. A 2-megawatt peak magnetic modulator is in operation at MRI (Microwave Research Institute of Polytechnic Institute of Brooklyn). This machine has been running for at least a year or two and is a developmental type of equipment. A very definite statement was made repeatedly by Dr. E. J. Smith in charge of magnetic modulator research at MRI to the effect that the jitter normally encountered in magnetic modulators is caused not by the magnetic switch itself but by irregularities in the initial wave shape applied to the modulator.

It appears also that a hybrid modulator might be worth investigating. This would consist essentially of a one-stage magnetic switch. A low voltage long pulse initial stage would probably utilize an ignitron (again assuming that both the jitter and de-ionization time criteria can be satisfied). A voltage step-up can be obtained in the magnetic switch so that starting from 10 kv dc, it should be possible to charge up a network to 60 kv. From the standpoint of reliability, this particular system would probably be almost ideal since under these conditions we are now using ignitrons under operating characteristics for which there is a lot of data available. As I said before, cost has been disregarded in this present statement and it appears that the cost of the 1 magnetic switch or transformer might exceed $5,000 and possibly even $10,000.

Obviously we should also not neglect work on single spark gaps, either the simple gaps such as we are using with view to improving the de-ionization time or gaps similar to those that we have learned about either from Baker, UCRL, or from Livermore, or from Los Alamos. The possibility of using hard tube modulators appears extremely dim. The best probable hard tube characteristics available within a few years would be a hold-off voltage of about 65 kv, a peak current of about 700 amperes, and a heater power of about 2-1/2 kilowatts. The drive power for these tubes would be at least 10 percent (this 10 percent is the estimate of the tube manufacturer) of the peak output power which means we need another 10-megawatt modulator to drive the final stages of the 70-megawatt modulator of which we are now talking. I would personally recommend at this time that the hard tube should be no longer considered for our application. The 10 percent drive and 10 percent plate drop loss automatically implies that the efficiency of the modulator is going to be extremely low compared to what can be achieved with line-type modulators.

Considering efficiency, the magnetic modulator also is at a disadvantage compared to the simple line-type soft tube switch modulator. Whether or not this will turn out to be the most important factor I am not in a position to state now.

Following are some of the notes which I took during this trip.

July 14 - RADC - Wiejeck
Beard

also B. Bernstein } Central Electronics Mfrs., Denville, N.J.
K. Rusinaiv }

We discussed the following possible switches: hard tube, spark gap, magnetic modulator, thyratron, and ignitron. At lunch, I discussed our general modulator requirements and obtained the following information on tentative specifications of hard tube switch being developed for RADC.

Peak plate voltage	65 kv
Peak plate current	750 A
Peak cathode current	1000 A
Duty	.01
Pulse width	25 µsec
Heater power	≃ 2.5 kw
Drive ~ 10 percent maybe: possibly higher	
Voltage drop	6.5 to 7.5 kv
Clippers and rectifiers up to 80 kv, 7 A rms, 150 A peak	

Note that this tube is still in the development stage, and will probably not be ready for about 18 months. It will use either a matrix-type or dispenser-type cathode. To be reasonably conservative, it would take two in parallel to operate at our peak power level, although average power is much higher than we need. Note also that the probable maximum efficiency of the switching circuit is 80 percent, and that the probable cathode power for two tubes is 5 kw, making for a very inefficient modulator.

Price is, of course, unknown, so that unless an extremely long life can be guaranteed, this approach does not look promising. The possible sources of hard tubes are RCA (used in Westinghouse equipment), and giving voltage breakdown (ageing) problems at 65 kv, and Eimac - no information at this time.

Spark Gaps - We probably know as much (or as little) as anybody else - should be a good device if all else fails.

Magnetic Modulators - should get more information from Smith at Polytechnic Institute of Brooklyn. There are apparently tricks to use 3 phase input, and some combinations of magnetic and hard tube switching to give preferred flexibility.

H^2 Thyratrons. The 1257 may achieve a life of 1000 hours at or near full rating. Not enough is known about the 1257B to make any statements on final ratings or life. The problem is usually gas cleanup, and complicated sensing circuits to control capsule voltage so that two can be run in parallel.

The Evans-G.E. program has so far produced the Z-5069 - which has cathode life problems, and two phase II tubes (50 kv, 2000 A). No tests to full power on phase II for lack of video load. Minimum of 1 year before information on performance and beginning of pre-production. Phase III tubes (100 kv, 2000 amps) would be lovely for our application, but will most probably not be ready in time. Also, there are still some life problems. (Table II - Tube Ratings for Phase II and Phase III, attached.)

In any case, RADC is getting discouraged with H^2 thyratron program, and intends to discontinue support of the G.E.-Evans venture. They may instead support some solid-state investigations. Whatever results would be too late for our purpose.

Ignitrons. Although not operated near our proposed conditions, service data on ignitrons appears very promising. GL5630 has been in operation 2-1/2 years in 3 radar sets operating at about 20 kv, 400 amps., .06 duty. A GL 6228 is operating at about 1/2 our peak power, 15 times average power of our requirements. The probable stumbling blocks are jitter and rep. rates. For further information and discussions, see George Harding, G. E. Syracuse, Bldg. 15, GRanite 6-4411, Ext. 3251. Other possible sources are Westinghouse and National Electronics, Geneva, Illinois.

July 15 - Visit to R. Butman, Lincoln Labs.

Very little is known about switch or modulator problems in our power range: most high-power modulators are at lower peak, higher average than our requirements. Lincoln has been toying with the idea of a 100 Mw peak, 1 Mw average modulator. Would probably use ignitrons (low rep. rate). They have one set under construction using 6 Z5069 H^2 thyratrons, three networks, two thyratrons in series from each network. They would not recommend this for reliability.

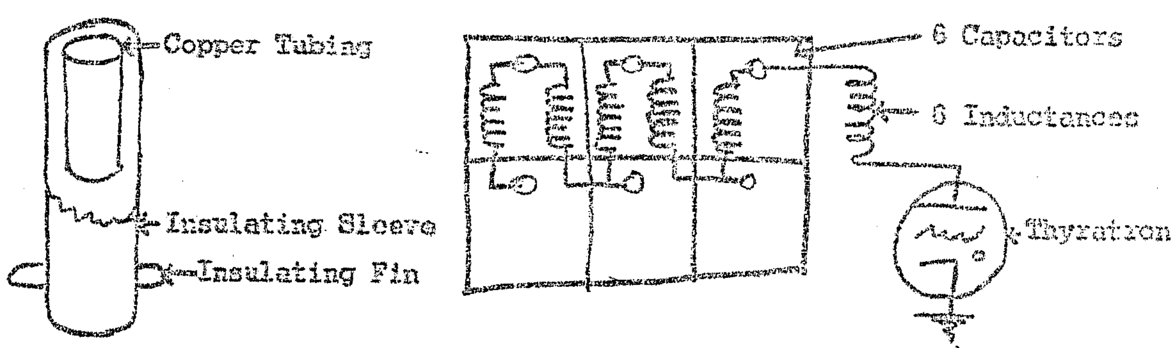
Their latest thinking for high power is to investigate ignitrons. However, there is no jitter or de-ionization time information. Butman believes somebody quoted jitter time of less than .1 µsec for some ignitrons such as the Z 5233 or Z 5234.

On some other problems:

1. Reliability studies are non-existent.

2. We will receive instrumentation specs on AN-FPS 18 radar-designed for unattended operation.

3. Phase modulation at the top of the pulse with a line-type modulator and a VA 821 can be brought down to about 10° peak to peak. This is measured by a Sperry Microline Model 337C rf mixer. Under these conditions the ripple on top of the voltage pulse is barely visible. Ripple and phase modulation are adjusted by individual tuning of network inductances. No mutual coupling in usual way. Physical layout as shown below. Each inductance is about 15 turns of 1/4" tubing on 2" diameter, 1/4" spacing. Tuning by copper tubing in insulating sleeve (1/8" thick) screwed in and out of coils.



As far as notes on the magnetic modulators, I am enclosing in this brief report the conclusions of a report by Dr. E. J. Smith, published in July 1957 on the topic of magnetic modulators. I would also like to comment on the fact that we have not followed up the work on high-power modulators as closely as we probably should have, and I believe one should immediately procure the following bits of information.

1. The Proceedings of the 5th Symposium on Hydrogen Thyratrons and Modulators, held at Fort Monmouth, New Jersey on May 20-21-22, 1958. The General Electric Company were this time discussing the possibilities of using

mercury pool cathode tubes (ignitrons) and E. A. Baum and H. E. Zubers have an article on page 171 of these Proceedings. In this article they quote that the jitter of a mercury ignitron with proper grid control can be cut down to .02 microseconds.

2. A book by Craggs and Meek on High Voltage Laboratory Techniques, published by Butterworths Scientific Publications, 88 Kingsway, W.C. 2 London (1954), relates the experience of the British in using high-power mercury switches for modulators.

On July 23 I had a visit from Mr. Zinn of Evans Signal Laboratories, who are supporting the high-power thyratron work at G. E. Zinn is quite optimistic that a single Phase I tube would be adequate for operation in the M modulator, even though the ratings indicate less peak and average power than we require. Anode and grid structure of the Phase I tube is the same as Phase II but the average current is approximately one-half, limited by cathode size. Zinn is rather confident that the life of a high-power thyratron can exceed several thousand hours once the tube is in production. Evans would be happy to collaborate with us in testing program for our application.

J. V. Lebacqz
July 24, 1959

STUDIES OF PULSE-TYPE

MAGNETIC MODULATORS - A SUMMARY

E. J. Smith

for

ROME AIR DEVELOPMENT CENTER

II. Conclusions

The following conclusions are based upon the experimental work with the low and high-power model magnetic modulators which employed square-loop reactor cores.

1. The design procedure for the modulator line with a linear resistive load yields good results in terms of output power, pulse rise time, and line efficiency. Stage efficiencies in the range 0.85 to 0.95 can be achieved.

2. The method for handling the effect of core loss appears to be satisfactory. The effective value of saturated iron permeability (μ_m) also appears adequate for most practical design purposes, on the basis of test results of the two model modulators designed according to the described procedure. However, it would be desirable to obtain permeability measurements on a much greater number of core samples to determine truly average values and also to ascertain the expected variations in samples of the several commercially available types of 50-50 N_i-Fe, square-loop takes.

3. The analysis and design procedure for the pulse-clipping circuit has been found to be essentially valid. Flat-topped current pulses of low-distortion were obtained for pulses of six microseconds duration; but for pulses of shorter duration (i.e., one microsecond) the distortion was found to increase rapidly. The increase of pulse distortion with decrease in pulse duration is due to: greater core loss per unit v olume, increased importance of stray and winding capacitance, and the influence of magnetic lags due to domain effects. The magnetic pulse-clipping technique would appear to be of greatest usefulness where the pulse duration is greater than say five microseconds; the application on this technique to the shaping of very broad pulses should be investigated further. However, the magnetic pulse-clipping technique is not as generally useful for obtaining pulses of continuously variable pulse width as was originally thought, because, while the pulse width can be varied by means of an adjustable bias control, the efficiency of energy transfer is generally high for only a small range of bias adjustment (i.e., values of g). Therefore, the pulse width can be varied over only a small range by means of the bias control, if high transfer efficiency is to be maintained. If variable pulse-width operation is to be employed, a separate shunting reactor is desirable to provide rapid current and voltage pulse decay for all adjustments.

4. The bias power for the pulse-clipping method should not exceed ten percent of the input power to the line. The method requires a-c excitation for practical reasons and is useful only for all-magnetic modulator lines which operate from an alternator with a p.r.f. equal to the alternator frequency.

5. The overall design procedure has been tested with a biased-diode load and found to be satisfactory. However, reverse shunting diodes were found necess-

ary to prevent large oscillations when the biased-diode load was connected. Some tests made with linear resistive and shunt reactor damping gave encouraging results but the investigations were not continued far enough to reach definite conclusions; these methods might profitably be studied in greater detail.

6. The design and construction of a high-power (two-megawatt) magnetic modulator was shown to be quite practical. In particular, the design procedure and techniques developed on the basis of low-power models were applied successfully to the high-power model. Still higher-power modulator lines appear to be entirely practical; the ultimate limit on the modulator rating might be expected to be imposed by: the heat dissipating ability of the 'n'th line reactor, availability of large reactors constructed from thin square-loop tapes, and insulation problems associated with the winding of high-voltage coils on the toroidal cores.

7. Negative pulses of appreciable amplitude (and sometimes smaller positive pulses also) appear between successive primary load pulses. These secondary pulses are associated with flux reset in the pulse transformer and the line reactors, and are dependent upon the bias settings of all of the reactors. An optimum setting of the biases results in a best output condition with respect to minimum interpulse distortion. A more thorough investigation of the flux reset mechanism in the entire line will undoubtedly lead to profitable results in terms of minimizing or eliminating this distortion.

Table II - Tube Ratings for Phase II and Phase III

	Phase II	Phase III
Peak Forward Voltage (A) (kilovolts)	50	100
Peak Pulse Current (B) (amperes)	2000	2000
Pulse Repetition Rate (C) (pulses per second)	4000	4000
Average Current (amperes direct current)	8.0	8.0
Plate Dissipation Factor (A x B x C) 10^{-9}	400	400
Initial Inverse Voltage (kilovolts)	2.5 minimum 15.0 maximum	5 minimum 30 maximum
Rate of Rise of Current (amperes per microsecond)	20,000	20,000
Time Jitter (microseconds)	0.005	0.005
Minimum Life (hours)	500	500
Average Power Output (kilowatts)	200	400