ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB348

# PORTABLE 2.5 MeV X-BAND LINEAR ACCELERATOR STRUCTURE

A. V. Mishin, M. Denney, S. Proskin, D. Fischer, Varex Imaging Corporation, Salt Lake City, USA
K. Brown, N. P. Hanson, J. Stammetti, Varex Imaging Corporation, Las Vegas, USA

*Abstract*

Two versions of 2.5 MeV X-Band linear accelerator have been designed and tested. The first is a traditional single input linac, and the other one is a dual input, two-section linac with power input through a 3-dB coupler. The linac is designed for a portable linac system, which can be used for security screening, non-destructive testing, medical and industrial CT, and, perhaps, some other applications.

## LINACS FOR SECURITY AND NDT

Multiple applications utilizing linacs and other X-ray sources require reduction of their size and weight, and the latter becomes most important when the source dimensions heavily influence mass of the radiation shielding housing, especially for mobile applications in security and non-destructive testing (NDT), or some other similar cases. It is known that radial dimensions of the Accelerator Beam Centerline (ABC) [1] are proportional to the RF source wavelength and define X-band ABC to be approximately three times smaller in radial dimensions than the similar S-band linac (see Fig. 1 for a comparison).

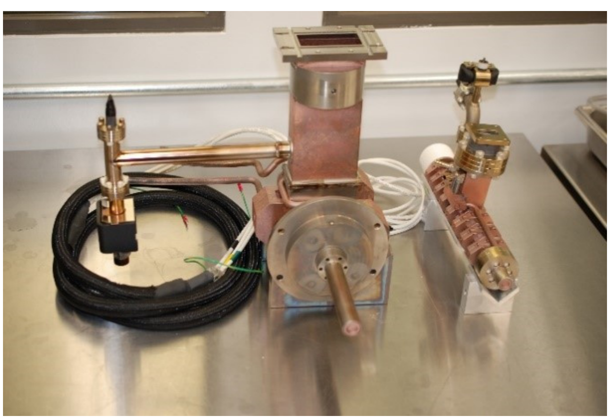

Figure 1: 3 MeV S-Band and 3 MeV X-Band ABC (at the correlated RF power settings). Note difference in radial dimensions for the two ABCs.

The customers and designers usually think of X-band linacs as of much lower power and dose rate units, and, sometimes, unreliable machines compared to the S-band linacs operating at the same energy, mostly, due to historical lack of available powerful and reliable X-band magnetrons and their high cost, but lately, the advances in the X-Band RF sources as well as design quality for the X-Band ABC we introduced shaken these common views. In addition, the available X-Band ABC and X-Band magnetrons ensure that such linacs meet the requirements for mobile security scanners, for example.

We have designed and fully qualified two linear ABCs – one is a traditional, single section accelerator ABC-1.8-X-X, originally designed for a small, 350 kW magnetron, shown in Fig. 2, and the other one – ABC-2.5-X-X-DI (Fig. 3), a dual section linac with power input through a power splitter with attenuation ratio close to 3 dB, similar in length and in all other characteristics to the single input ABC, shown in Fig. 2.

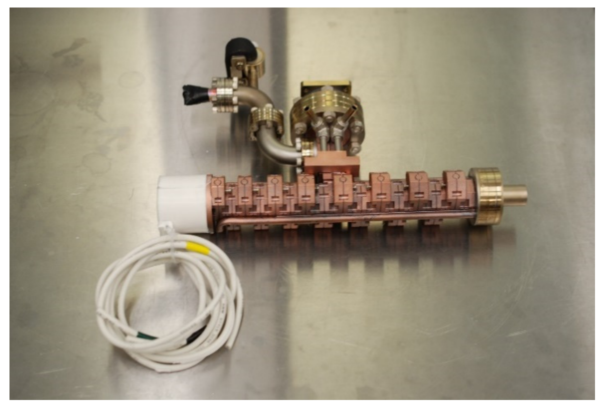

Figure 2: Single section X-band ABC, designed to operate at 1.8 MeV and at 2.5 MeV at 350 kW and 700 kW RF power input, correspondingly.

Figure 3: Two section X-band ABC, designed to operate at 2.5 MeV and dose rate up to 50 R/min @1 m from target.

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The technique of two uncoupled sections run through a symmetrical 3-dB splitter was described by Victor Vaguine [2] and Eiji Tanabe, and it has been used in other systems, for example, in a compact, high gradient medical linac, later described by Getka in [3].

Both ABCs were high-power tested at the same input power of approximately 700 kW, using the same magnetron, we have recently purchased.

A linac system for operation at the customer requested 2.5 MeV energy and dose rate of 10 R/min @ 1 m is under development at Varex Imaging, and will shortly be assembled, high power tested, and shipped to our customer. We are proud to have exceeded the required specifications from the first try. In course of designing the dual input linac, we predicted and then confirmed the final answer to a question regarding the phase shift between the ports 2 and 4 feeding the two linac sections in this case, which has been defined and debated in earlier publications [4-6].

## SINGLE SECTION LINEAR ABC TEST RESULTS

The 1.8 MeV section has been designed as a replacement of a Varian produced X-Band guide for an affordable linac system operating at energy of less than 2 MeV, which does not require an export control license. The latter substantially broadens worldwide market for this linac. The linac was designed to utilize a small magnetron operating at 350 kW peak RF power. This is a relatively low output, yet a very useful linac, which may be used for multiple practical applications in both security and NDT. The first ABC has been designed, built and tested in 2017, and it was the first new linac model we have designed at Varex after the acquisition, and, in addition, it was the first ABC we certified for production. Three prototypes have been built, and all demonstrated excellent performance, producing the expected parameters: maximum energy of <2 MeV (contingent on RF power input), with loaded nominal energy of 1.8±0.1 MeV, nominal dose rate of 13±2 Rad/min. The ABC-1.8-X-X is equipped with a triode electron gun and demonstrated a spot size of 1.0±0.2 mm, measured later. As an example, we present the 3rd built unit operating characteristics in Fig. 4. Please note the exceptional match between experimental and theoretical data. Once we received a request from our major customer to deliver a 2.5 MeV system, indeed, it was very tempting to test this ABC with a higher RF power magnetron (700-800 kW, approximately 2 times the design power of 350 kW) and see if it will deliver the required specifications, which we expected, based on simple input RF power scaling considerations and beam optics calculations, see Fig. 5.

In the latter case #2, a circulator will have to remain in the RF circuit. Note that this design is substantially more compact, than the one we used many years ago on the unit for intraoperative radiation therapy [7].

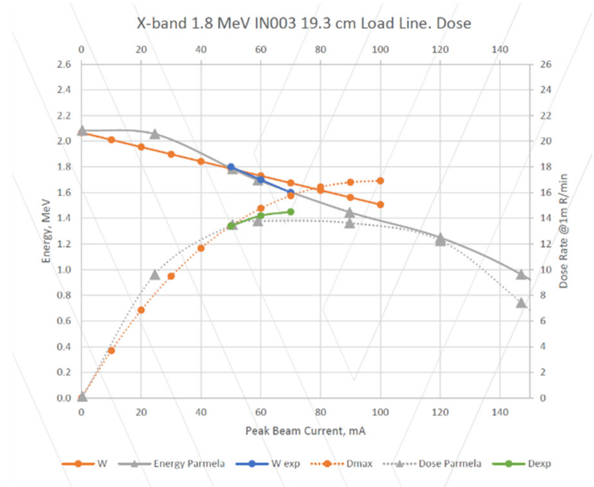


Figure 4: ABC-1.8-X-X design and experimental results using 350 kW peak RF power magnetron.

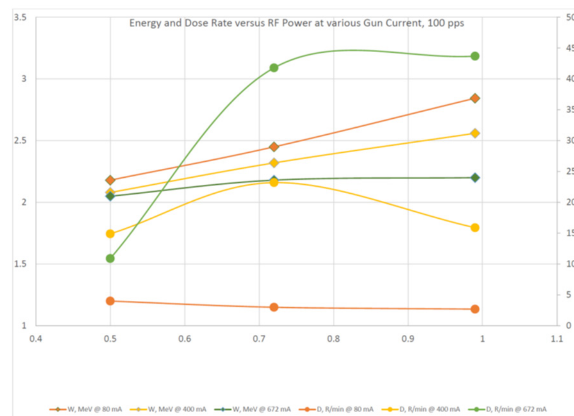


Figure 5: ABC-1.8-X-X test results with higher power magnetron, at 100 PPS in a range of injected current.

## TWO SECTION, DUAL INPUT THROUGH 3-DB DIVIDER ABC TEST RESULTS

We decided to design a two-section ABC with a dual input through a 3-dB coupler, *a la Vaguine and Tanabe.* As any design, it has its own advantages and disadvantages, but the most attractive potential advantages of the selected approach are as follows:

1. Elimination of the circulator in the most simple, non-regulated power and energy configuration, and, therefore, reduction of the overall unit cost. This is important in the modern business, when we experience a lot of pressure from our customers to reduce our price.
2. Addition of the phase or phase-and-power regulator into the second arm, which would allow a very effective broad energy regulation, essentially in full range from virtually "zero" to a maximum energy.

We have successfully tuned all elements of the RF circuit and built the first prototype of the 2.5 MeV unit, which has been tested by our Varex team in Las Vegas, with our inputs from Salt Lake City.

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB348



The test results were quite satisfying, even better than that obtained with the single input guide and shown in Figs. 6 and 7, below.

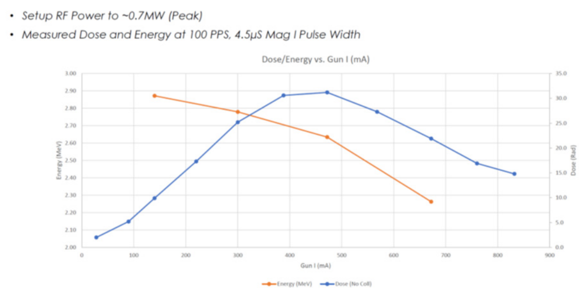


Figure 6: ABC-2.5-X-X-DI test results measured with 4.5 µs pulse, at 100 PPS.

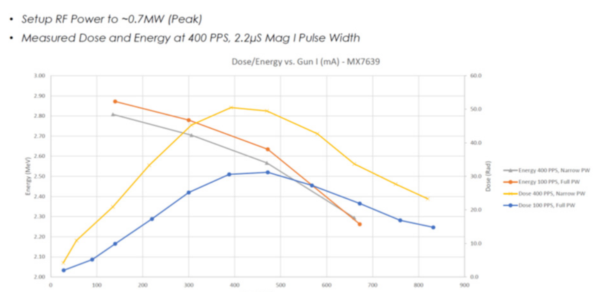


Figure 7: ABC-2.5-X-X-DI test results measured with 2.2 µs pulse, at 400 PPS.

After the first round of testing, we made some minor improvements to the first prototype, improving its cooling and tuning.

## CONCLUSION

We have designed, built, and high-power tested two versions of the 2.5 MeV linear accelerator beam centerlines, both usable for the corresponding linear accelerator system, with slightly different features. The single section traditional design has been tested in a broad range of input power and demonstrated excellent performance, delivering a mm-spot on the target. The symmetrical two-section, dual input through 3 dB coupler design worked very well, and it has a potential for further improvement and cost reduction, or for broad energy and dose regulation, easy low-dose operation, thanks to the triode (gridded) electron gun.

## ACKNOWLEDGEMENTS

It was not possible to list all the contributors to this project due to limited space allowed for this publication. While not all the employees who contributed to this project are listed as co-authors, we will mention their names in the presentation. Special thanks to John Roylance and Loren Young, our mechanical designers, for their invaluable contributions; our physicists Rich LaFave and Mike Perkins for their support, also to all John Stammetti's team in Las Vegas. This work also is a result and continuation of many pre-existing efforts [7-12], and we thank our mentors, colleagues, peers, and Varex management for their contributions and continuing support.

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