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TEST FACILITY FOR RELATIVISTIC BEAM PICKUPS*

J. Simpson, R. Konecny, S. L. Kramer, D. Suddeth
Argonne National Laboratory, Argonne, IL 60439

Introduction

Calibration of beam signal pickup devices is an important but frequently difficult activity associated with the construction of accelerator systems. This is especially true for pickups used in stochastic cooling systems. Here the sensitivity and phase as functions of beam position are frequently critical, fundamental parameters of the system design.

The most frequently used method for bench-calibration of pickup devices is that of passing a (usually thin) wire through the device. Electrical excitation of the wire, as a TEM line, simulates a beam and the transfer functions of the device is measured directly. As many people have discovered, this procedure can frequently lead to incorrect predictions of pickup response to particle beams. The reasons for the differences are not always obvious, but plausible explanations are: 1) that wires are incapable of exciting or permitting many modes in the pickup structure which real beams excite 2) that the interaction of the pickup device with the wire (e.g. large arrays of pickups such as independent striplines with outputs power added), produces unpredictable and unresolvable results.

These deficiencies have been eliminated in a facility at ANL which uses a relativistic electron beam to calibrate beam pickups. The facility is extensively used in the development of pickups, and is the primary calibration facility for pickups designed for the FNAL TeV-I antiproton source.

Method and Equipment

The Chemistry Division at Argonne National Laboratory operates a 20 MeV, L-band (1.3 GHz) electron linear accelerator[1] as part of its Radiation Chemistry Program. One very interesting mode of running this accelerator uses a subharmonic buncher to generate a single bunch of electrons with a pulse width τ<30 picoseconds wide, (see Fig. 1). The charge in a single pulse can reach 9×10^{-9} coulomb and the pulse rate is variable from 1 to 800 Hz.

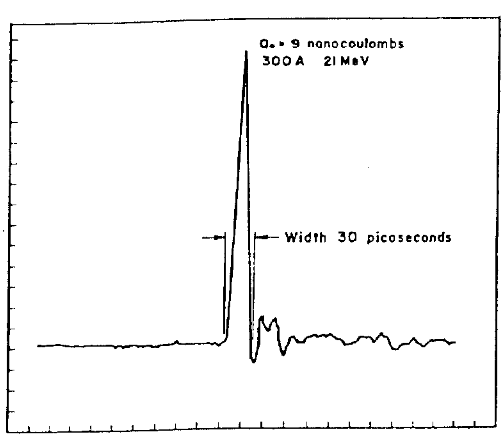

Fig. 1. Single bunch from ANL Linac

The small pulse width of the electron beam can be considered as a very broadband source which can be used to excite beam pickups. Considering the beam pulse as a delta function in time with charge Q and repetition frequency f_o, the current source is

$$I(f) = 2\,Q\,f_o \quad \text{amperes per Schottky band.}$$

The Schottky bands are spaced f_o apart up to infinite frequencies. Because the beam pulses are not point charges but have a finite width, τ, the components will have structure depending on the actual pulse shape. For three different pulse shapes the components are given by:

$$I(f) = 2\,Qf_o \left|\frac{\sin(\pi f\tau)}{\pi f\tau}\right| \quad \text{for square pulses} \quad (1a)$$

$$= 2\,Qf_o \left|\frac{\sin\frac{(\pi f\tau)}{2}}{\frac{\pi f\tau}{2}}\right|^2 \quad \text{for triangular pulses} \quad (1b)$$

$$= 2\,Qf_o \left|\frac{\cos(\pi f\tau)}{1-(2\tau f)^2}\right| \quad \text{for cosine pulses} \quad (1c)$$

These components are plotted in Fig. (2) for Q = 9 nanocoulomb, f_o = 800 Hz and τ = 30 psec. For cosine or triangular pulses the first zero of the excitation current is greater than 50 GHZ. Below 10 GHz the cosine and triangular currents are almost identical and both differ from the delta function current by less than 10%. Consequently, a reasonable approximation is to consider the current to be constant with magnitude 2 Qf_o per Shottky band for frequencies below 10 GHz.

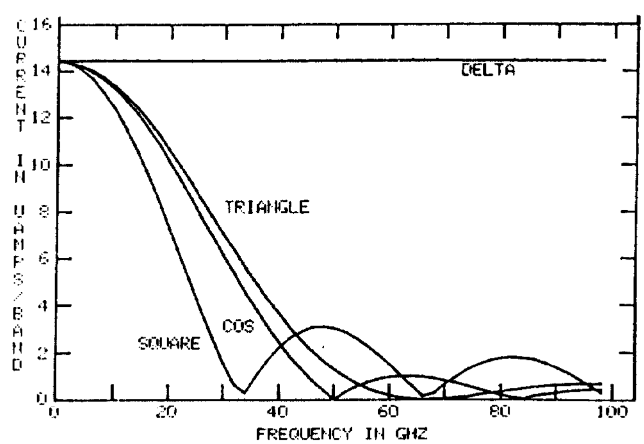

Fig. 2. Fourier compoents, f_o = 800 Hz, τ = 30 psec.

At an 800 Hz repetition rate, the measured time-averaged current is about 5 μamps. This may be and is often reduced by a factor of 20 (to reduce signal levels from pickups) by detuning the source and reducing the pulse repetition rate.

Beam from the linac can be delivered to two separate areas for pickup response tests. No direct connection is made to the linac vacuum system. Instead, the beam exits into the atmosphere through thin (2-0.001" Al) windows. The measured emittance of the beam after exiting a window is about 41π mrad-mm

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in each plane. In atmosphere, the beam spot grows from 0.5 cm diameter at the window to about 2.0 cm after a 35 cm drift. This divergence is acceptable for the tests of short devices or for devices for which having a small beam size isn't important.

A vacuum tank is available at one beam port for use when testing long pickups or pickup arrays. This vessel is 18 inches in diameter by 64 inches in length. A beam collimating and optics systems produces a nearly constant diameter beam (<0.5 cm) through the length of the tank. The emittance of the beam, and consequently the useful current, is reduced by a factor of 100 by the beam optics system. This is usually of no consequence because of the large signal available.

Pickup response can be measured by two methods: 1) spectrum analyzer and 2) Fourier analysis of the pulse response in the time domain. The spectrum analyzer technique is rather straight forward, except that the low duty cycle of the beam requires wide resolution bandwidths be used. Fig. (3) shows one such scan with an HP-8569A spectrum analyzer, measuring the response of a 750 MHz stripline pickup. This analyzer had a maximum resolution bandwidth of 3 KHz.

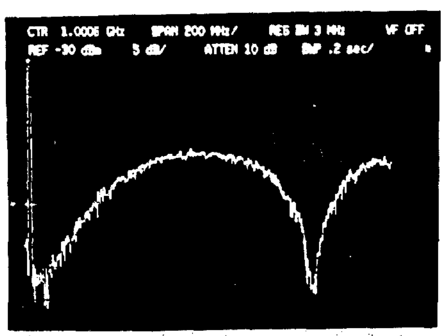

Fig. 3. Spectrum analyzer scan of a 750 MHz stripline signal. Horiz. scale is 0-3 GHz.

The technique which has proven most useful is Fourier analysis of the pickup pulse response. Figure (4) shows the equipment used to obtain a digital measurement of the voltage pulse from a pickup. This system consists of a Tektronix 568 oscilloscope with an 3S2 sampling unit and S4 sampling head. The time base is a 3T77A unit and is capable of giving 20 psec/div and 100 points/div, however the unit hasn't been used below 200 psec/div. The analog voltage and time base signals from the 568 scope are digitized by 12 bit ADC's and are available to an 8 bit microcomputer via the CAMAC dataway. A Fortran program has been written for the microcomputer which records a single trace of the sampled voltage signal on command from the operator. These data consist of 110 or 1100 voltage points equally spaced by a time interval Δt set by the 3T77A timebase unit. The 110 data points result from a 10 dot/div setting while the 1100 points result from a 100 dot/div setting of the 3T77A unit. During the time scan, a histogram of the charge per pulse from a beam Faraday cup is recorded and the average and rms value of the charge is printed out following the scan. This gives the operator a figure of merit of the accelerator operation during the scan. This is important because the voltage pulse is not normalized by the beam charge on a pulse by pulse basis. Typical rms variations in the beam charge per pulse are much less than 10%.

After the pulse scan has been digitized, the data are plotted for a visual comparison with the scope display. These data are then available for listing, for saving on disk, or for performing a Fourier analysis to yield the frequency and phase response of the pickup.

Figure (5) shows a pulse response on the Tektronix 568 scope as digitized by the above system. From the sharpness of the edges of the pulse and the smoothness of the data, these figures indicate pulse to pulse jitter and amplitude variations were well below a 10% level.

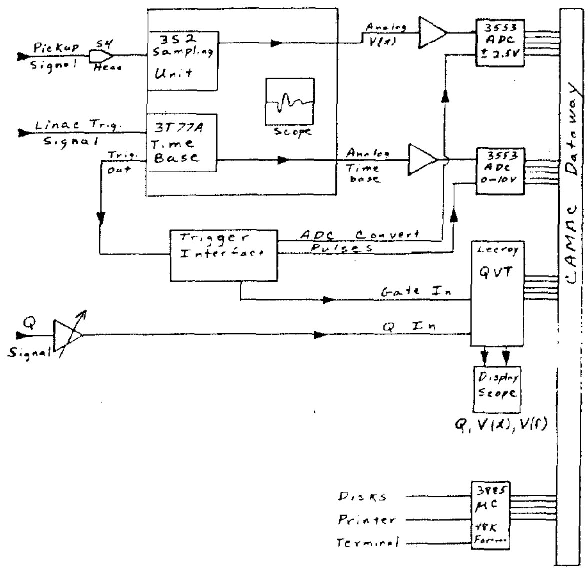

Fig. 4. Black diagram of data acquisition and analysis system

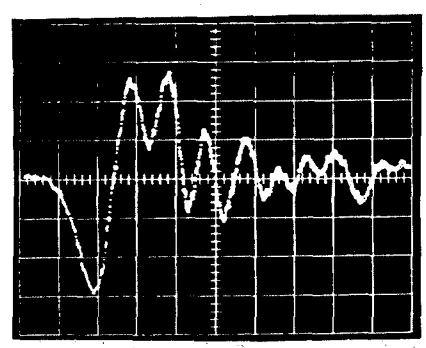

Fig. 5. Stripline response pulse as reconstructed from digitized data by the system (200 psec/cm).

II. Fourier Analysis Techniques

The Fourier analysis used in this system is a fast Fourier transform (FFT) which operates on base 2. The maximum number of input data points is 2^{10} = 1024 and the FFT for this data is performed in about 50 seconds.

The coupling impedance to the beam is computed by calculating the voltage response at the pickup

$$V_p(f) = A(f)\, B(f)\, |V_{fft}(f)| \qquad (5)$$

where

$A(f) = 10^{\frac{a}{20}}$ for a = signal attenuation in db.

$B(f) = \dfrac{V_{actual}(f)}{V_{measured}(f)}$ for S4 head and signal cable attenuation.

The coupling impedance is calculated by dividing the voltage response by the excitation current in the Δf frequency interval. The present program assumes the delta function current of $I(f) = 2\,Qf_o$ per band. Then the coupling impedance is calculated by

$$Z_c(f) = V_p(f)\, f_o/(2I_o \Delta f) \qquad (6)$$

where I_o is the measured, average beam current.

The program can plot on the QVT display the calculated quantities $|V_p(f)|$ or $Z_c(f)$ with or without the phase, ϕ in degrees. Figure (6) shows both $|V_p(f)|$ and ϕ plotted for the data in Fig. (5).

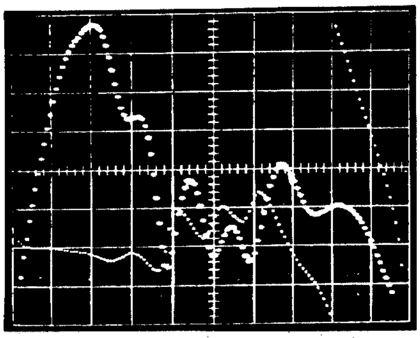

Fig. 6. FFT results for amplitude (heavy dots) and ϕ (light dots) response of stripline.

Tests of the Signal Processing Procedure

In order to gain confidence in the analysis procedure, pulser generated signals were fed into the system. The spectral analysis as computed by the system was compared to that produced by the same signal through a scanned, spectrum analyzer (HP-8554B). Because the pulser was unable to produce pulses much less than 10 nsec wide, the analysis was limited to $f_{max} < 500$ MHz. The only change from higher frequency analysis used with the electron beam is the time scale setting on the sampling oscilloscope.

Figure (7a) shows the pulses used to test the bipolar signal response. Fig. (7b) shows the scanned spectrum analyzer response to this pulse and Fig. (7c) shows the FFT for the same frequency interval performed with N = 512 data points. The resulting frequency interval is about 2 MHz per Fourier component. The two spectra are in excellent agreement with the ratio of peak heights agreeing to better than 10% (the spectrum analyzer data needed to be corrected for the noise floor which flattened the valleys of the spectra).

Absolute normalization of the Z_c cannot be easily compared in the previous measurement. However, a check can be made by measuring the average current in a unipolar pulse and using this to compute Z_c from Eq. (6). The peak coupling should yield $Z_c = 50\ \Omega$, and the measured value agreed to within 3%

Test with Real Pickups

The facility has already been used to evaluate a number of devices being developed at ANL and LBNL (for TEV-I) and at LANL (for FMIT). They include striplines, slot couplers, faraday cups, electrostatic pickups, beam transformers, and other specialized diagnostics.

The first prototype of a 16 stripline-pair, 1-2 GHz pickup module has just arrived at ANL for evaluation using the facility. Its measured characteristics will be used to "fine-tune" the stochastic cooling sytem design for the TEV-I anti-proton source.

Conclusion

The technique and facility described above provide a method of pickup response measurements unmatched by other means. It promises to be extremely useful in the development of state-of-the-art, high frequency pickup devices.

Acknowledgement

The authors thank G. Mavrogenes, G. Cox, and D. Ficht of the ANL Chemistry Division for their cooperation and efforts.

References

1. "High Change Picosecond Pulses with a Double Gap Subharmonic Buncher", G. Marvogenes, et. al, contributed paper N7, this conference.

(a)

(b)

(c)

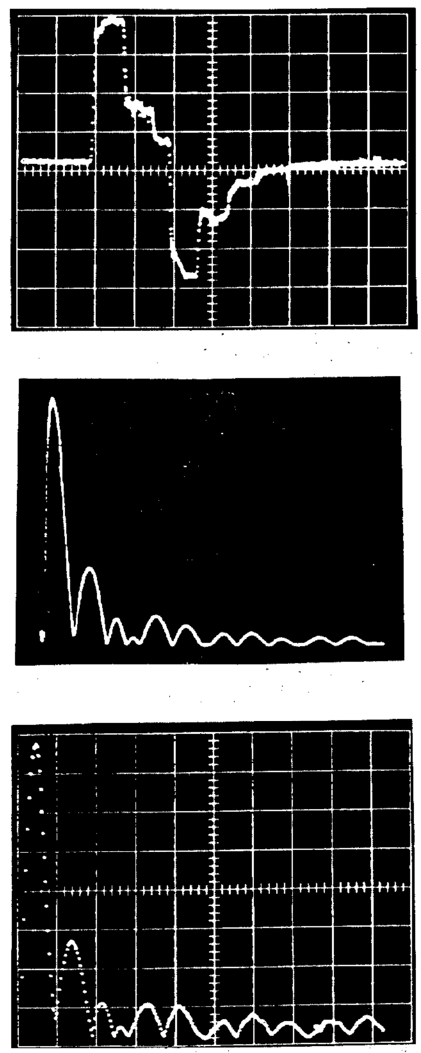

Fig. 7. Test pulse (a) and spectrum as observed by spectrum analyzer (b) and digital analysis system (c).