

## EFFECTIVE SPILL LENGTH MONITOR

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For many AGS users the figure of merit for AGS performance is

$$R = \frac{\text{protons delivered per pulse}}{\text{cycle time}}$$

This is equivalent to delivered beam current. On the other hand, many experiments in the slow extracted beam are sensitive to an entirely different figure of merit

$$R' = \frac{\text{effective spill length}}{\text{cycle time}}$$

The effective spill length depends on the total length of the slow spill and also on its "smoothness" or time uniformity. Instead of effective spill length, we may define a spill duty factor as

$$DF = \text{spill duty factor} = \frac{\text{effective spill length}}{\text{total spill length}}$$

We might consider the total spill length to be  $t_2 - t_1$ , where  $t_1$  is the earliest time that beam can be extracted and  $t_2$  is the start of Siemens invert; this defines the maximum spill length possible. The spill duty factor is 100% for an ideal beam with no time structure and less than 100% for real beams.

If we let  $f(t)$  be the beam current as a function of time, then the effective spill length is given by

$$t_{\text{EFSP}} = \left[ \int_{t_1}^{t_2} f(t) dt \right]^2 / \int_{t_1}^{t_2} [f(t)]^2 dt \quad (1)$$

A number of examples of time structure, and their effect on spill duty factor, are illustrated in Fig. 1. Several of these cases apply to the AGS. Case 1 applies because the spill does not always fill the entire time available. If we try to avoid Case 1, then Case 2 (spike at the end of the spill) may develop. In addition, the AGS slow extracted beam can be bunched as in Case 4 because of interaction of the beam with the RF cavities; even though the RF drive is off, the beam current induces a cavity voltage that rebunches the beam. Finally, there is a slow (5 - 1000 Hz) amplitude modulation of the spill with components like that shown in Case 5, caused by power supply ripple, by oscillations in the spill servo and by "lumpiness" in the beam energy distribution. This "lumpiness" is related in turn to rebunching effects in the cavities, leading to a connection between slow structure and RF structure.

Under optimum conditions, the AGS spill duty factor is approximately 90%, but it is sometimes considerably worse. To help maintain optimum operation, a monitor is needed. To get such a monitor, the circuit of Fig. 2 has been set up. This circuit measures an approximation to Eq. (1) by counting accidental coincidences between a signal from a scintillation counter telescope that views one of the targets and the same signal delayed. Depending on operating conditions, the counts from any of three target telescopes may be used.

Since the synchrotron frequency is small compared to the rotation frequency, a time delay equal to the rotation period  $t_R$  may be used in Fig. 2. The result is exactly equivalent to looking at accidental coincidences between two different telescopes that are in time with each other. The necessary delay is

$$t_R = \frac{2\pi r_0}{c} \sqrt{1 + \frac{m^2}{p^2}} = 2690 \text{ nsec}$$

where  $r_0$  is the radius of the AGS (128.458 m),  $m$  is the proton mass,  $c$  is the velocity of light and  $P = 29 \text{ GeV}/c$  is the momentum. The  $29 \text{ GeV}/c$  value is in error by no more than 30 nsec down to  $P = 15 \text{ GeV}/c$ .

A delay of only one RF period, or about 1/12 of the rotation period, is not adequate because of the rebunching occurs at not only the twelfth but also at other harmonics of the rotation frequency, and this harmonic mix

changes with operating conditions so that misleading results could be obtained.

The effective spill length is calculated for each pulse by the AGS control computer in the SEB monitoring program "CLYDE" and is displayed on the SEB general page. The formula used is

$$t_{\text{EFSP}} = \text{EFSP} \times 10^{-9} \times (\text{EFSP1})^2 / \text{EFSP2} \quad (2)$$

where EFSP1 and EFSP2 are the single and coincidence counts from Fig. 2 and EFSP is a constant which corresponds to the resolving time in nsec of the coincidence circuit. This resolving time depends on the pulse widths of the discriminators that drive the coincidence unit and these widths are determined by shorted delay lines, which give fixed and stable widths. The resolving time was measured to be 54 nsec, corresponding to EFSP = 54.

In a test, the circuit was fed by pulses from a random pulse generator and the indicated time from Eq. (2) was equal to the scaler gate time (called TEFSP in the computer program) to within 5 percent up to a singles counting rate of 0.4 MHz. At 0.1 MHz and above the statistical fluctuation from pulse to pulse is less than 4%. Therefore, for best results, the circuit should be connected to a telescope with an average counting rate, during the beam spill, of 0.1 to 0.4 MHz. A second point to keep in mind is that the effective spill value obtained may vary from telescope to telescope if there are magnet ripple or steering variations that give a time modulation to the proton targeting at the various stations.

Provided one takes account of the caveats in the previous paragraph, the computer display of EFSP provides a quantitative measure that responds to RF structure, ripple and other spill effects in exactly the same way as an experimenter's apparatus.

For diagnostic purposes, some additional circuitry that responds to RF structure only has been provided. A time-to-amplitude-converter and multi-channel analyzer, shown in Fig. 2, give a digital display in the control room of the rebunching. An example is shown in Fig. 3. The amount of modulation in this display depends on the amount of rebunching, and the beat pattern shows that rebunching occurs on more than one harmonic. This display requires several AGS pulses to accumulate useful information, so a control of the accumulation period is provided in the control room. In addition, to give a

single number that measures rebunching effects on a pulse-by-pulse basis, a coincidence circuit and scaler EFSP3 are provided to measure the rate of coincidences between the telescope and itself with a delay of approximately  $(23/24)t_R$ . The computer calculates the quantity

$$\text{SPLRF} = \text{EFSP3/EFSP2} \tag{3}$$

which is 100% for an unbunched beam and less than 100% when bunching is present. This quantity corresponds roughly to the valley-to-peak ratio in the multichannel analyzer display, Fig. 3.

Both the multichannel analyzer display and the quantity SPLRF tend to understate the amount of bunching present because they depend on the convolution of the bunch shape with itself. For example, with 100% bunching as in Fig. 1, Case 4, we have SPLRF = 69%.

The equipment was installed and integrated into the AGS systems by E. Gill and S. Naase

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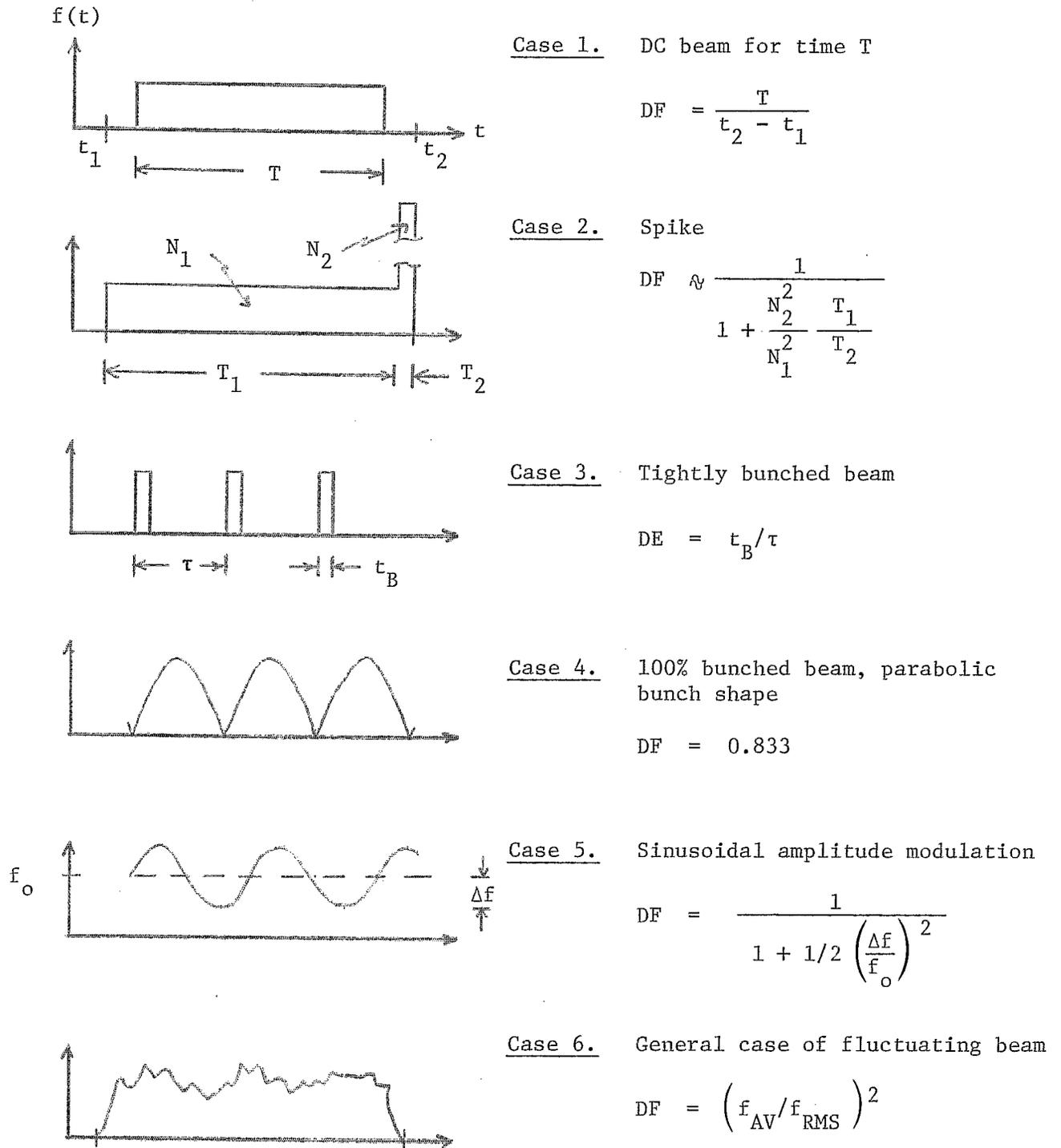
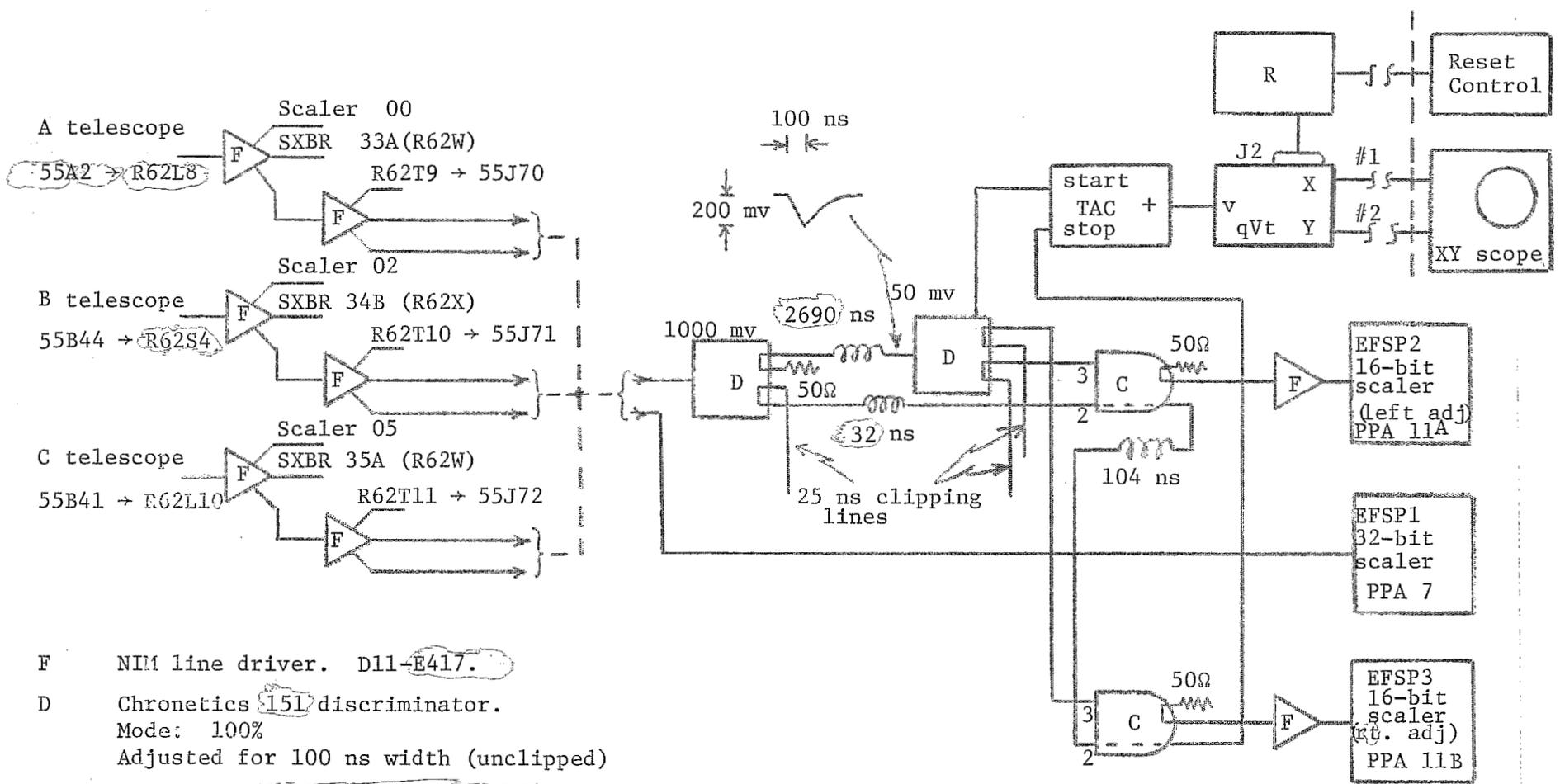


Figure 1 - Examples of spill time structure and its effect on spill duty factor.



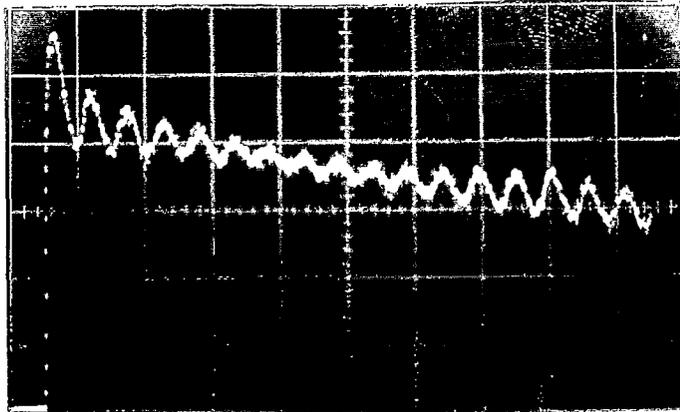
- F NIM line driver. D11-E417.
- D Chronetics 151 discriminator.  
Mode: 100%  
Adjusted for 100 ns width (unclipped)
- C Chronetics 152 logic unit.  
Mode: AND  
Adjusted for 100 ns width.
- TAC EGG TH200A time to amplitude convertor. Modified for 4 μsec full scale. Width: 2 μsec.
- qVt LeCroy 3001 multichannel analyzer. Width: max. Thresh: max.
- R qVt reset controller. D11-634-2

- #1 R62AG7 → R25S14
- #2 R62AG8 → R25S15

D11-E635-3  
4 April, 1980

Figure 2 - Effective spill monitor circuit.

(a)



(b)

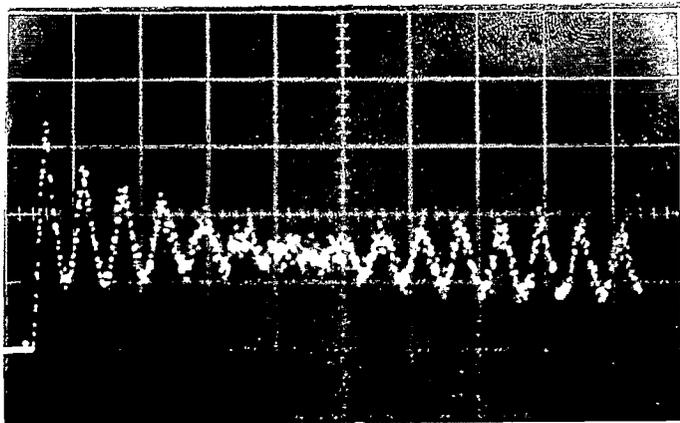


Figure 3 - Multichannel analyzer displays of extracted beam RF structure. Horizontal scale:  $0.42 \mu\text{sec}/\text{box}$ . Conditions:  $\text{CBM} = 6 \times 10^{12}$ . Spill length: 1.15 sec.

(a) At optimum settings; EFSP = 1.05 sec, DF = 92%.

(b) With off-frequency bias mistuned; EFSP = 0.70 sec, DF = 61%.