WIDE-BAND DIFFERENTIAL AMPLIFIER WITH GAIN CONTROL (ANALOG DIVISION) FOR THE CPS COMPACT PU STATIONS (IMPROVED VERSION OF MFS 2848)

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PS/6635
An early version of this amplifier has been described last year \(^1\). The present more final version has been improved mainly with respect to noise, cross talk, and max. output signal. 8 PU stations have been equipped with this amplifier for operational tests.

Three of these differential amplifiers are connected to the PU station head amplifier (MPS 2847) outputs. Two of them amplify the radial and vertical difference signals, the other amplifies the sum signal.

1. **General description of the amplifier**

   The bandwidth (-3 db) of the differential amplifier is 1.2 kHz to 50 MHz. The Common Mode Rejection within this bandwidth is greater than 56 db. The gain can be varied in a wide range (approximately 5 : 1000) by remote control. The bandwidth for gain = 1000 is 10 MHz. For a constant bandwidth of 50 MHz the gain can be varied 8 : 80 (1 : 10).

   Within this range the gain is inversely proportional to an applied signal. This permits dividing of the difference signal by the sum signal (in order to get the beam position independent of the beam intensity).

   This amplifier can be considered as a wide band differential amplifier plus a modulator with a hyperbolic characteristic. It could be used in servo-mechanisms and regulating systems where a HF level should be monitored.

2. **Requirements**

   The requirements for this amplifier are the same as those quoted in \(^1\) except the following points:

   1.) The output noise should be \(\leq 4 \text{mV}_p\) for a gain of 25 db and 50 MHz bandwidth.

   2.) The maximum output voltage should be \(\pm 2 \text{V}_p\).

   3.) The cross talk from the sum input to the output
should be \(< 10 \text{ mV}\) for a variation of the INCH-
resistance \(R_{\text{INCH}} = 330 \times 33 \Omega \left(\tau_r = 8 \text{ ns}\right)\).

4.) The division error \(\frac{\Delta U}{U_s}\) should be \(< 3\%\) for a
dynamic range of the sum signal \(U_s : 1 \div 10\).

5.) The delay between sum signal and inch-response
should be \(< 200 \text{ ns}\).

3. Discussion of the circuit
(see drawing No. KPS-RP 2846-RF 8-2)

3.1 Differential amplifier

The first differential stage with its wide band
balancing network is discussed in 1). After having passed
this stage, the signals are amplified in the second diffe-
rential stage.

The two emitters of the INCH 3 N 87 are connected
to the collectors of this stage by \(R_{10} = 100 \Omega\) and \(C_{10} = 1 \mu\text{F}\).
\(R_{10}\) suppresses HF oscillations, and \(C_{10}\) and \(C_{11}\) insulate the
emitters of the INCH from DC potentials. A control of the
inter-emitter resistance \(R_{\text{EE}}\) permits the division (see 1).

Behind the integrated chopper transistor 3N87, the
signals enter into a 3 stage differential amplifier with a
voltage gain of about 40. In order to have a high load impe-
dance for the proceeding stage, a Darlington circuit was chosen
for the output stage. The output impedance is determined mainly
by the collector resistance \(R_{11}\). This means \(R_{\text{out}} \approx 270\).

3.2 Control circuit for the INCH

The emitter 1 – emitter 2 resistance \(R_{\text{EE}}\) of the INCH
is controlled by the base current \(I_B\). The collector of the
transistor \(T_1\) is connected to the base of the INCH (point X).
\(T_1\) converts the sum input voltage source into a constant current
source.
If the FU sum signal should be used for automatic control, it must be clamped in order to restore the DC component (see 2).

The base of \( T_1 \) is biased by the potentiometer \( P_{10} \) so that the emitter DC of \( T_1 \) voltage is zero. This means no current flows through \( R_{14} \) when relay \( Z \) is excited. So the collector bias current of \( T_1 \) is independent of the internal resistance of the source which is connected to the sum input.

The parallel branches \( P_{11} + D_2 \parallel P_{12} + D_3 + D_4 \) serve to compensate the inaccuracy of the \( 1/I_B \) function of the INCH

\[
R_{EE} \approx K' \cdot \frac{1}{I_B}
\]

so that

\[
R_{EE} = K \frac{1}{U_s}
\]

\( K, K' \) = constants

\( U_s \) = sum signal

\( R_{EE} \) = emitter 1 - emitter 2 resistance \( \) of the INCH

\( I_B \) = base current

With potentiometer \( P_{13} \) the division circuit can be adjusted so that \( R = 30 \, \Omega \) for a sum signal \( U_s = 1 \, V \) \( (K = 30 \, \Omega \cdot V) \).

The working point of the INCH \( (I_B) \) can be adjusted at the gain control input by remote control \( (0 \div +15 \, V) \).

A negative base current stop of the INCH has a longer response time than a positive one. The circuit with \( T_2', T_3', C_{12}, C_{14} \) and \( P_{16} \) serves to accelerate the INCH response for
negative sides of the sum input pulse. Differentiated signals of the sum input pulse appear on the emitters of T₂ and T₃. The negative spike causes a collector current at T₂ which discharges the capacity between base of the INCH and ground. The positive spike blocks transistor T₂ and opens T₃. So the differentiation time constants for positive and negative signals are approximately equal. The time constants can be adjusted by P₁₄ and P₁₆. The INCH time response becomes ≤200 ns for negative and positive modulation (see fig. 4).

In the case that no automatic division is desired, the circuit drawn with dashed lines can be eliminated. The gain of the amplifier is then still adjustable by remote control.

The plug-in unit of the amplifier is shown in fig. 5.

4. Features

16 of these amplifiers have been manufactured and adjusted to meet the following parameters and tolerances:

- Input impedance: 75 Ω
- Max. common mode input signal: 3 Vpp
- Output impedance: ~270 Ω
- Nominal output signal: ±2 Vp

Nominal output load (the following values are obtained with 75 Ω load):

- Max. voltage gain (rₑₑ = ∞) with fₘₐₓ (-3 db): 1000 (60 db)
- Nominal voltage gain (rₑₑ = 20 → 200JL) with fₘₐₓ (-3 db) see fig. 1 and 2): 8 → 80 (18 → 38 db)
- Minimum voltage gain rₑₑ ∼ 10 Ω with fₘₐₓ (-3 db): 5 (14 db)
- Lower frequency limit (-3 db): 1.2 kHz
- Common Mode Rejection (CMR) for 1.2 kHz < f < 50 MHz: > 56 db
linearity of \( \frac{U_{\text{out}}}{U_{\text{in}}} \)

\[
\begin{align*}
-1.5 \text{ V} &< U_{\text{out}} < 1.5 \text{ V} &<1.5 \% \\
-2 \text{ V} &< U_{\text{out}} < 2 \text{ V} &< 3 \%
\end{align*}
\]

error of constance \( \mathcal{C} = f \left( \frac{U_0}{U_s} \right) \)

\[ \approx 3 \% \]

for \( \frac{U_{\text{max}}}{U_{\text{min}}} = \frac{1 \text{ V}}{0.1 \text{ V}} = 10 \) (see fig. 3)

output noise \( f_{\text{max}} = 50 \text{ MHz}, R_{\text{EE}} = 50 \Omega \)

\[ 4 \text{ mV}_{\text{pp}} \]

max. signal to noise ratio 60 db

cross talk (sum input to diff. output) \(< 7 \text{ mV} \)

for jump of \( R_{\text{EE}} = 330 \) to \( 27 \Omega \) with risetime \( \tau_r = 8 \text{ ns} \)

delay between sum input signal \( U_s \) and INCH response (see fig. 4)

\[ < 200 \text{ ns} \]

fixed attenuation by relay 1 : 10

*) With the PU signals from the proton bunches, the error of the automatic division was found in the order of \( \pm 20 \% \) (see fig. 6).

**Power supply requirements**

for 1 amplifier:

\[ U_1 = -150 \text{ V} \pm 1 \% \]
\[ I_1 \approx 60 \text{ mA} \]
\[ U_2 = +30 \text{ V} \pm 1 \% \]
\[ I_2 \approx 100 \text{ mA} \]
\[ U_3 = -6 \text{ V} \pm 1 \% \]
\[ I_3 \approx 5 \text{ mA} \]

for the relays:

\[ i_{Z_1Z_2} = 39 \pm 1 \text{ mA} \]
\[ U_{Z_1Z_2} \approx 3 \text{ V} \]
\[ i_{Z_3} = 39 \pm 1 \text{ mA} \]
\[ U_{Z_3} \approx 1.5 \text{ V} \]
Acknowledgements

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References

1) G. Schneider : A Wide Band Differential Amplifier with Analog Division for the CPS Compact P.U. Stations MPS/Int. RF 67-7

2) D. Boussard : Amplificateur de somme et redresseur rapide MPS 2849 RF 1 MPS/SR/Note/68-11

Distribution: open
FIG. 4
Fig. 5 - Controlled Wide Band Differential Amplifier EPS 2348
from PU-Station 90
without division

radial $\Delta R$ 0.2 V/cm

sum $S$ 0.5 V/cm

$\rightarrow$ 2 ms/cm

from PU-Station 97
with automatic division

$\frac{\Delta R}{S}$ 0.2 V/cm

$S$ 0.5 V/cm

$\rightarrow$ 2 ms/cm

(The beam was lost on target 84 in position - 5 cm)

FIG. 6