The Bandwidth of a Transistorised Active Antenna

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A single stage transistor amplifier antenna is claimed to exhibit the property of wide bandwidth. This is conventionally attributed to the addition of the resistive parameters by the active device. This does not appear to be very correct. A different explanation is suggested on the basis of transistor circuit concepts.

LITERATURE[1,2,3] reports possible use of active integrated short antennas over wide range of frequencies (100 KHz. to 1GHz). One of the claims of these short integrated antennas is their wide band behaviour. The reason for this behaviour is attributed[4] to the higher resistive component in the input impedance of the active antenna as compared to that of the equivalent passive antenna.

It is felt that this explanation is not sufficient to account for the relevant experimental results. This is brought out by simple calculations presented here. A slightly different interpretation is suggested on the basis of transistor circuit concepts.

CONSIDERATION OF AN ANTENNA STRUCTURE

A SIA (Subminiature Integrated Antenna) structure reported in literature[1] may conveniently be taken for consideration. Fig. 1(a) shows the structure while Fig. 1(b) shows the corresponding equivalent circuits adopted for the analysis. An assumption has been made[1] for the sake of a simplified analysis that the effect of the rod H3 may conveniently be ignored and that the 'electric and magnetic' reception by the radiators can be simulated by a single generator as shown in the figure.

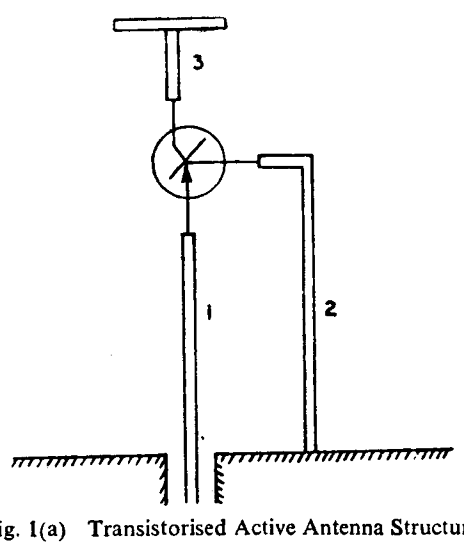

Fig. 1(a) Transistorised Active Antenna Structure

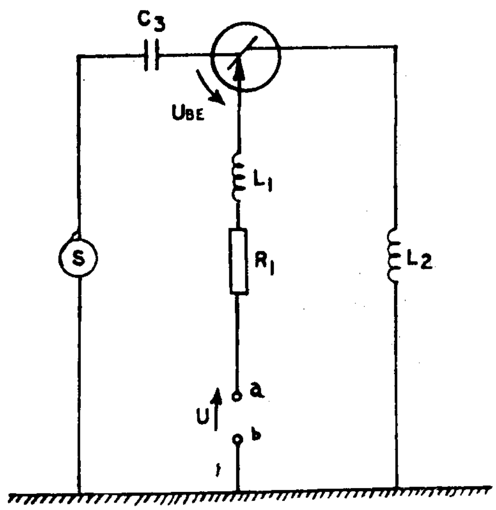

Fig. 1(b) Equivalent circuit

An expression for the input impedance at the feed points (a, b) can be derived as in equation 1(a). If the operating current gain of the active device is sufficiently high and the portion H3 of the radiator is significantly small in length as is usually the case, the terms R3/(1+β) and L3/(1+β) may be neglected as that any loss of generality. When this is done, the expression for the input impedance at the feed point for the SIA structure under consideration reduces to equation 1(b). Thus,

$$\text{Zin} = \frac{1}{jw\,C_3(\beta+1)} + jw\left(L_1 + \frac{L_3}{\beta+1}\right) + \left(R_1 + \frac{R_3}{\beta+1} + R_{21}\right) \quad ..1(\text{a})$$

where, $R_{21} = \frac{V_{be}}{I_e} = \frac{1}{Y_{21}}$ = reciprocal transconductance

as defined in literature[4].

and, after neglecting the terms as discussed above.

$$\text{Zin} = (R_1 + R_{21}) + j\left[wL_1 - \frac{1}{wC_3(\beta+1)}\right] \quad ..1(\text{b})$$

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BANDWIDTH CONSIDERATION

Equation 1(b) can now be examined for bandwidth on the basis of the explanation suggested in literature. An approximate quantitative estimation for the equivalent capacitance, inductance and radiation resistance of the three constituting rods in the SIA can be done with the help of following equations[5] viz :

The average impedance of a circular antenna rod is given by

$$Z_{av} = 60 \left[\text{Log} \left(\frac{h}{a} \right) - 1 \right] \qquad \ldots(2)$$

where, h—length of the antenna element.
a—diameter of the rod.

Equivalent inductance of the antenna rod is given by

$$L_{eq} = \frac{Z_{av} \, x \, h}{C} \qquad \ldots(3)$$

When C is the velocity of the electromagnetic waves on the surface of the conductor.

The equivalent capacitance of the radiating element is given by

$$C_{eq} = \frac{h}{Z_{av} \times C}$$

$C = 3 \times 10^{10}$ cm/sec.

Assuming that the SIA has a perfect earth. Simulation, the radiation resistance of the radiators may be obtained approximately as

$$R_{eq} = 40 \times \pi^2 \left(\frac{h}{\lambda} \right)^2 \qquad \ldots(5)$$

Values of the antenna parameters for the three radiating rods using equations (3)—(5) are shown in Table 1.

The values of the relevant parameters of the active device for the three bias points used (viz. 1 *mA*, 2 *mA*, 3 *mA* collector current) are shown in Table—2.

If we now accept the explanation suggested in literature, viz 'The bandwidth of the transistorized radiator is far higher than the bandwidth of the passive radiator, because the resistive component of Zin is higher and the capacitance C_3 is multiplied by $(1+\beta)$ ....', we finish with the results far lower than those obtained experimentally. The values of BW calculated and those obtained experimentally for the SIA of Fig. 1 are shown in Table-3.

Even a cursory glance at table 3 reveals that the phenomenon of 'fantastic' bandwidth of the SIA can not be explained by the explanation suggested in literature.

TABLE 1

Rod	L_{eq} µH	C_{eq} pf	R_{eq} Ohm
1	0.39	7.1	0.07
2	0.44	6.2	0.20
3	0.08	1.4	0.03

*Includes top capacitance of 10 pf.

TABLE 2

I_c mA	β	R_{21} Ohm	f MHz
1	22.5	26.3	700
2	44.5	14.7	700
3	52	10.4	700

TABLE 3

IC mA	BW Calculated (MHz)	BW Experimental (MHz)
1	2.49	>28 MHz.
2	2.67	>28 MHz.
3	2.21	>28 MHz.

POSSIBLE EXPLANATION

The equivalent circuit of Fig. 1(b) can be looked upon as a transistor equivalent circuit. The active device in the circuit is presented with impedances in the input and output which are extremely small. As such the active device in the SIA is operating in the near short circuit conditions. As such the bandwidth over which a constant current gain is obtained is given by[6]

$$w_h - w_l \doteqdot \frac{wT}{Ai}$$

Where Ai is the mid band current gain. In the present structure the voltage gain is less than or near unity. Hence the powergain bandwidth for the SIA would be

$$(w_h - w_l) \doteqdot \frac{wT}{G_o} \qquad \ldots(7)$$

Where G_o is the mid band power gain. Using an ideal voltage gain of unity for 1 mA case and actual operating β of 22.5 the maximum possible power gain for 1 mA bias is $G_o = 23.5$. The values of G_o for 2 mA and 3mA are obtained on a relative basis from actual experimental values of respectively 22.6 dBs, 24.75 dBs and 25.85 dBs are obtained below :

The values of possible bandwidth are given in Table-4 are obtained on the basis of the assumption of near unity voltage gain in the structure. This condition may not be fulfilled in the actual case, which will result into further extension of the bandwidth.

TABLE 4

IC mA	G_0	BW MHz
1	23.5	29.78
2	39.4	17.87
3	49.35	14.18

In another case[7] when actual power gain of the active device having f_T of 1300 MHz was experimentally found out to be 22, equation (7) above gives

$$BW = \frac{1300}{22} = 59.07 \text{ MHz}$$

which agrees very well with the experimental results.

FURTHER DISCUSSION OF BAND WIDTH

Equation (7) above has been derived on the basis of a limiting current gain and voltage gain basis. This may give an impression that it is true only in case of common collector configuration, *i.e.*, when base is the input terminal and emitter is the output terminal.

A similar result can be obtained in common base case, *i.e.*, when emitter is the input terminal and collector is the output terminal, we have[8]

$$BW \leqslant \frac{f_T}{A_v}$$

Where A_v is the voltage gain. The current gain α, in this case is near unity.

$$\text{Hence } BW \leqslant \frac{f_T}{G_0}$$

In the case of common emitter, *i.e.*, when the base is the input terminal and collector is the output terminal, the short circuit limiting current gain is still given by eq. (6). If A_v is the operating voltage gain, then

$$BW \leqslant \frac{f_T}{G_0} A_v \qquad ..(9)$$

Equations (7) and (9) give only the limiting values of BW which can be realised in the case of transistorised SIA. As, however, the equivalent impedance values of the radiating rods increase with increasing operating frequency, the actual gain obtained from SIA will differ and will correspondingly affect the bandwidth performance.

CONCLUSION

Some workers have varified experimentally about a wider bandwidth of a short integrated active antenna is conventionally believed due to the addition of resistive parameters of the active device and, in some cases, because of multiplied capacitive effect in the input circuit. It is shown in the foregoing discussion that it does not account for the larger bandwidth actually obtained.

An explanation has been suggested here on the basis of the fact that an active device (transistor) is presented with very low input and output impedances in the SIA structure. Under the situation the transistor is operating in near short circuit conditions and is capable of giving constant gain over several decades of frequency so long as the operating frequency is sufficiently below the cut-off frequency.

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