Analysis of the Tuggle Front End – Part III

As a first approximation, the 3dB bandwidth of the antenna-ground-lossy tuner system under matched load conditions can be computed assuming that the L_1-C tank behaves as an equivalent constant inductance Leq in the 3dB passband, this inductance being in series with the rest of the circuit. However, this approach leads to large errors in the results, as suggested by a SPICE circuit simulation.

A precise model for accurate bandwidth computation is shown in Fig.1.a below. R_T is the net RF resistance in parallel with the L_1-C tank at $\omega = \omega_r$, as found in part II of our study. Ground losses Rg and antenna radiation resistance r_a are accounted for by r. However, calculations on this circuit are rather tedious. Simulation shows that the circuit depicted in Fig.1.b can be alternatively employed for bandwidth computation with equivalent results to those given by the circuit of Fig.1.a. Here, Re = $2Rs_1$ (please refer to part II). Circuit calculations in this case are much more simple.

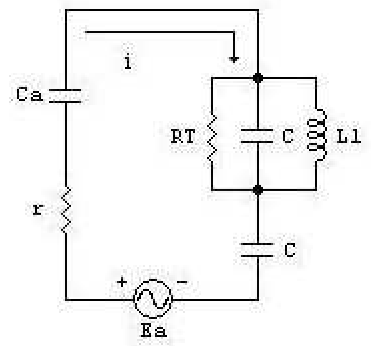

Fig.1.a Equivalent circuit for accurate 3dB bandwidth calculation

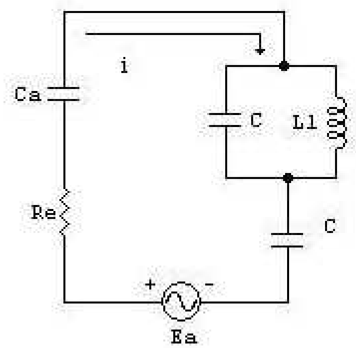

Fig.1.b Alternative circuit for bandwidth calculation as suggested by simulation

<u>Simulation results</u>

Figures 2.a through 2.f illustrate simulation results for circuit of Fig.1.a at resonance frequencies of 530kHz, 1MHz and 1.7MHz. Assumed values for r and Ca are 30 ohms and 200pF, respectively. The values for R_T are those obtained when the secondary load R_2 is impedance matched to the primary side (please refer to part II). Notch frequencies occurring above resonance can be observed on the graphics. The Y axis represents voltage across r in decibels with Ea being a 1volt-amplitude unmodulated carrier.

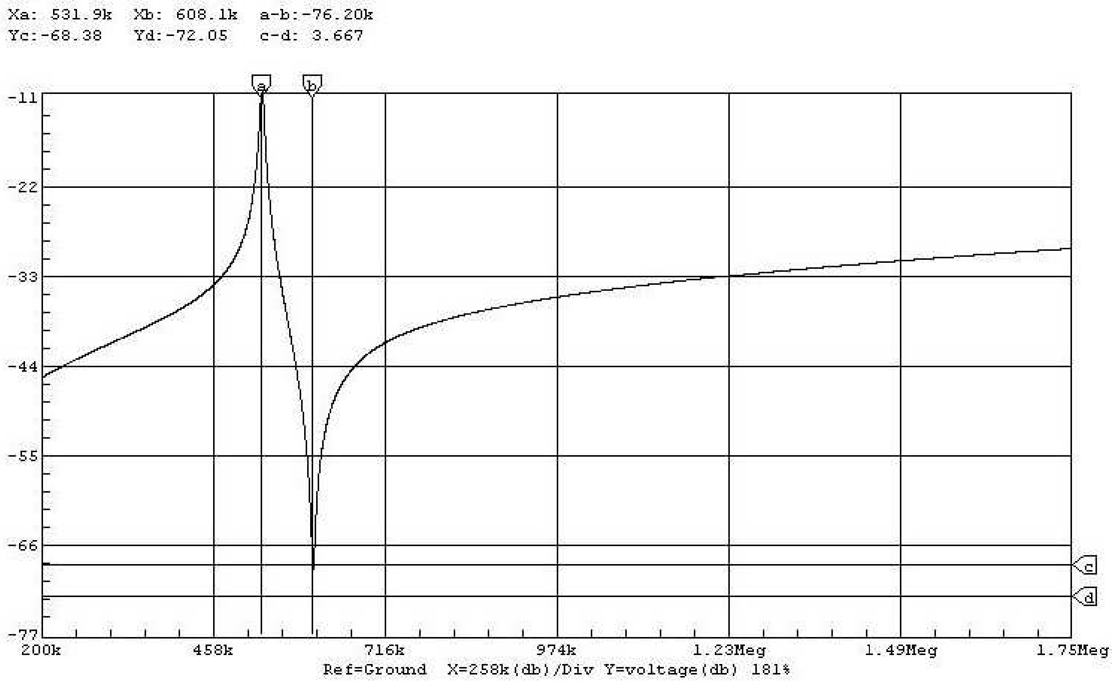

Fig.2.a Frequency response of circuit of Fig.1.a
when resonance is adjusted to 530kHz

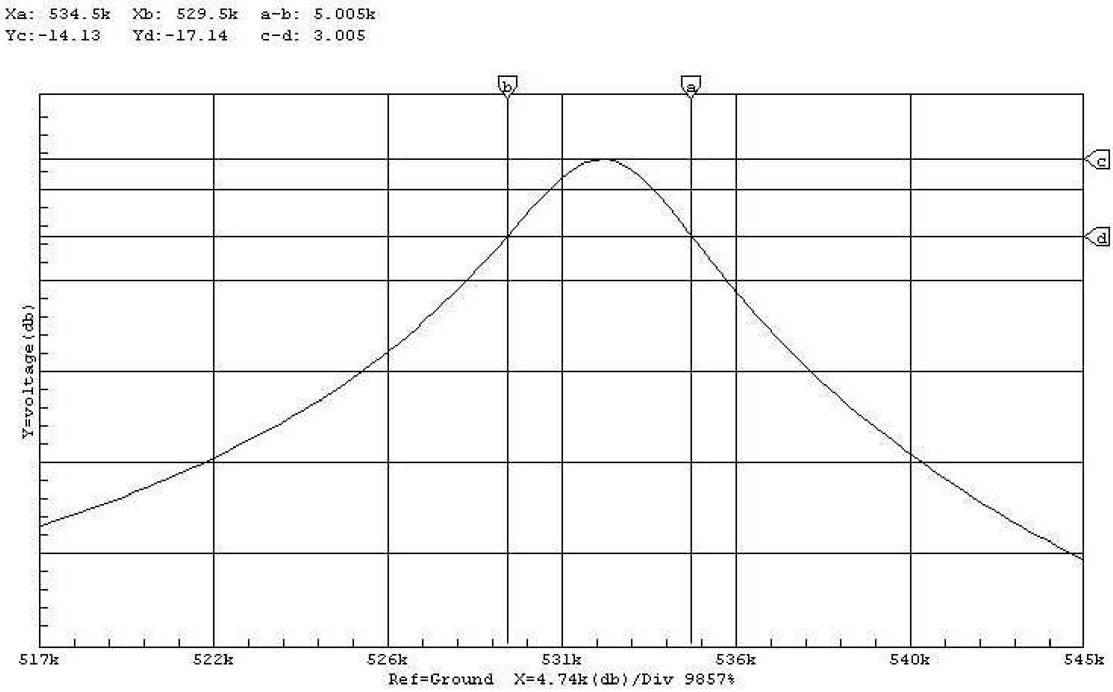

Fig.2.b 3dB bandwidth for a nominal
resonance frequency of 530kHz is 5.005kHz.
Actually, the resonance frequency is 532kHz.

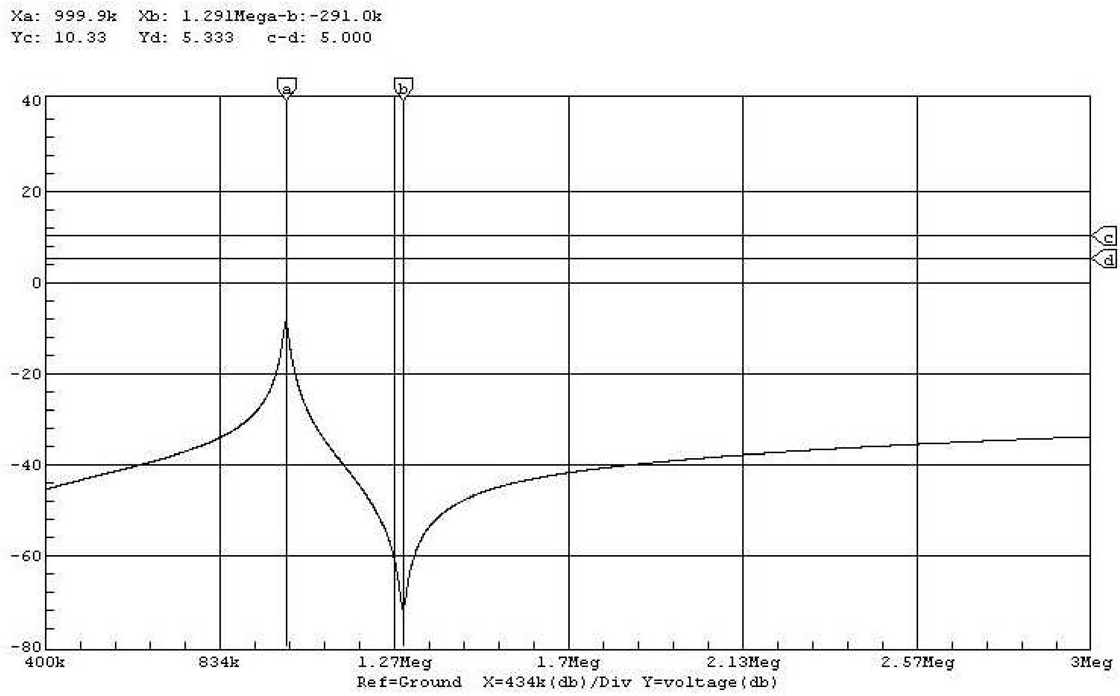

Fig.2.c Frequency response of circuit of Fig.1.a
when resonance is adjusted to 1MHz

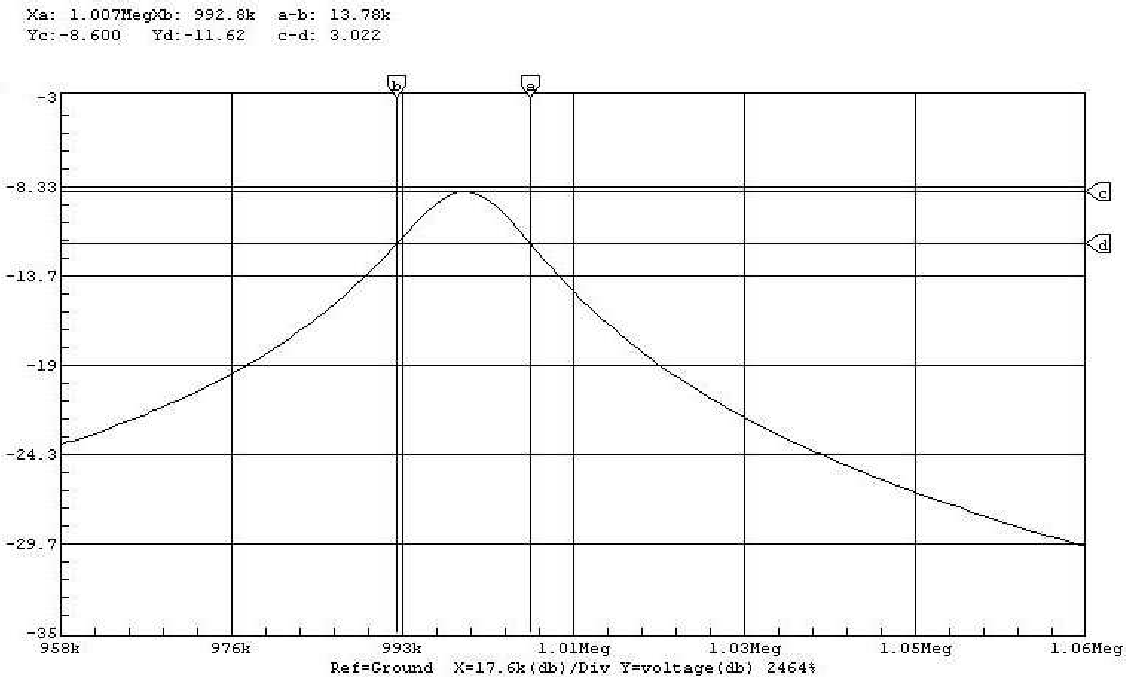

Fig.2.d 3dB Bandwidth for a resonance
frequency of 1MHz is 13.78kHz

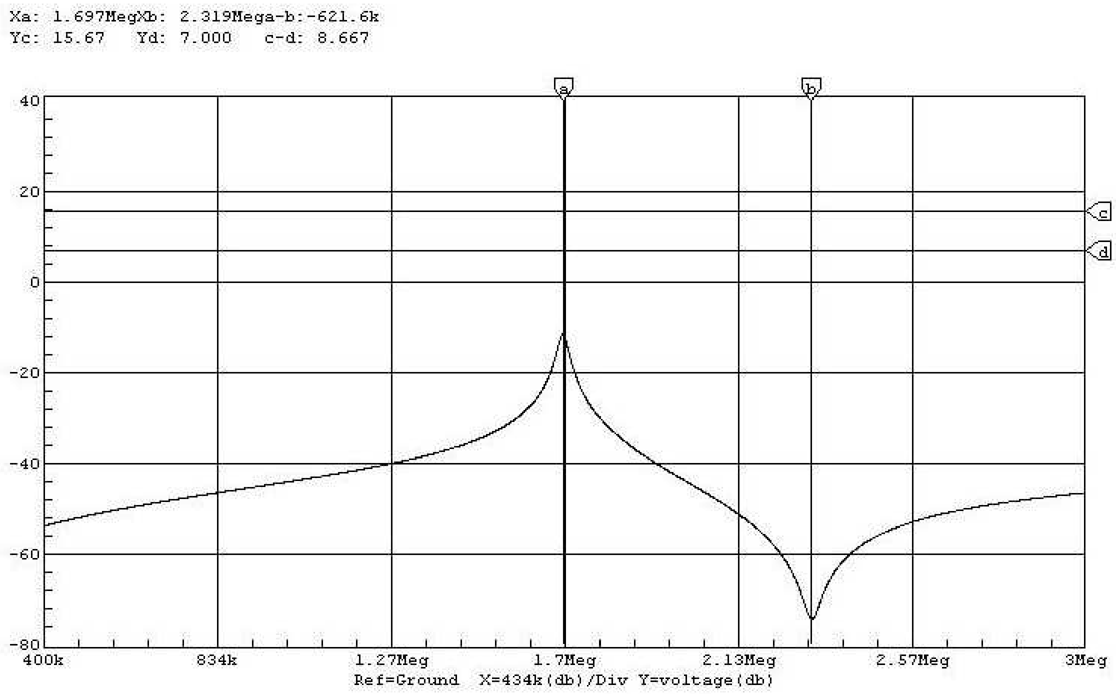

Fig.2.e Frequency response of circuit of Fig.1.a
when resonance is adjusted to 1.7MHz

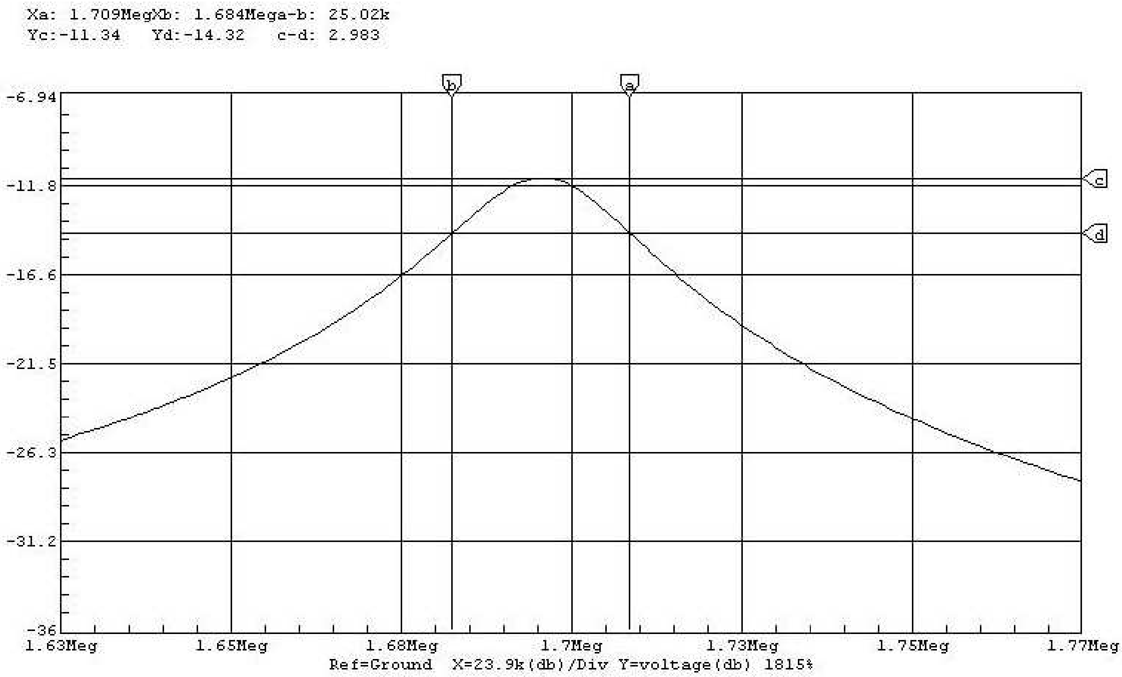

Fig.2.f 3dB bandwidth for a resonance frequency of
1.7MHz is 25.02kHz

Figures 3.a through 3.f show simulation results for circuit of Fig.1.b at resonance frequencies also of 530kHz, 1MHz and 1.7MHz. Again, r = 30 ohms and Ca = 200pF. Re = $2Rs_1$, and it can be easily shown that:

$$R_{s1} = r\left(1 + \frac{A}{R_P}\right)$$

The Y axis on the graphics represents voltage across Re in decibels, with Ea being a 1 volt-amplitude unmodulated carrier.

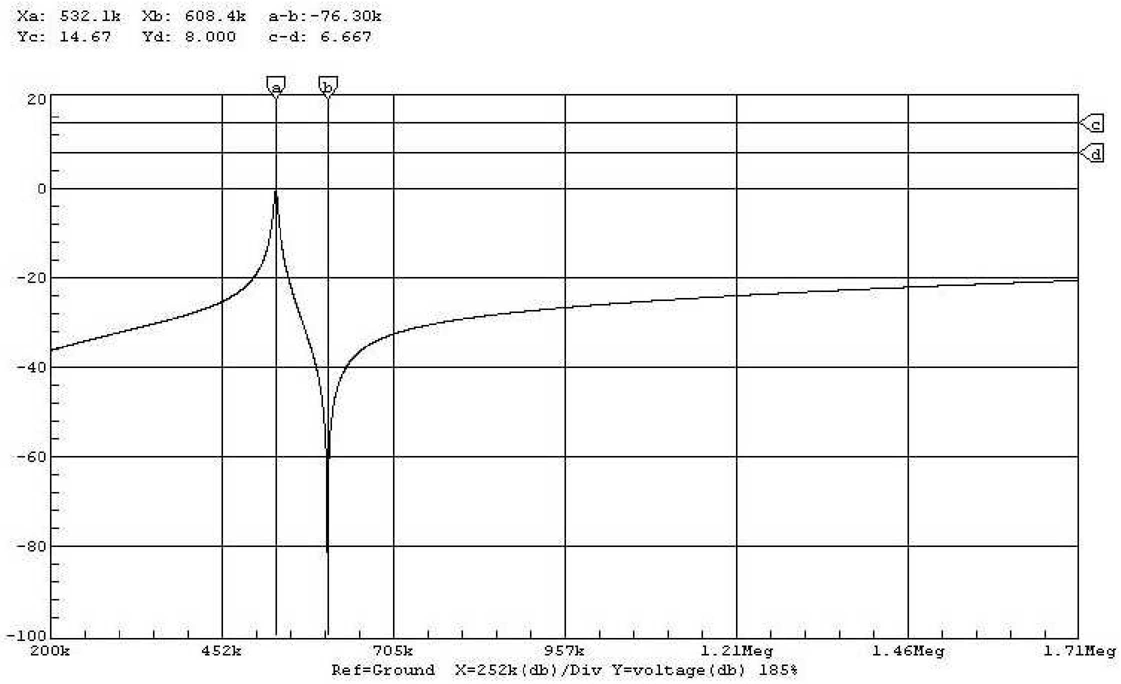

Fig.3.a Frequency response for circuit of Fig. 1.b
when resonance is adjusted to 530kHz

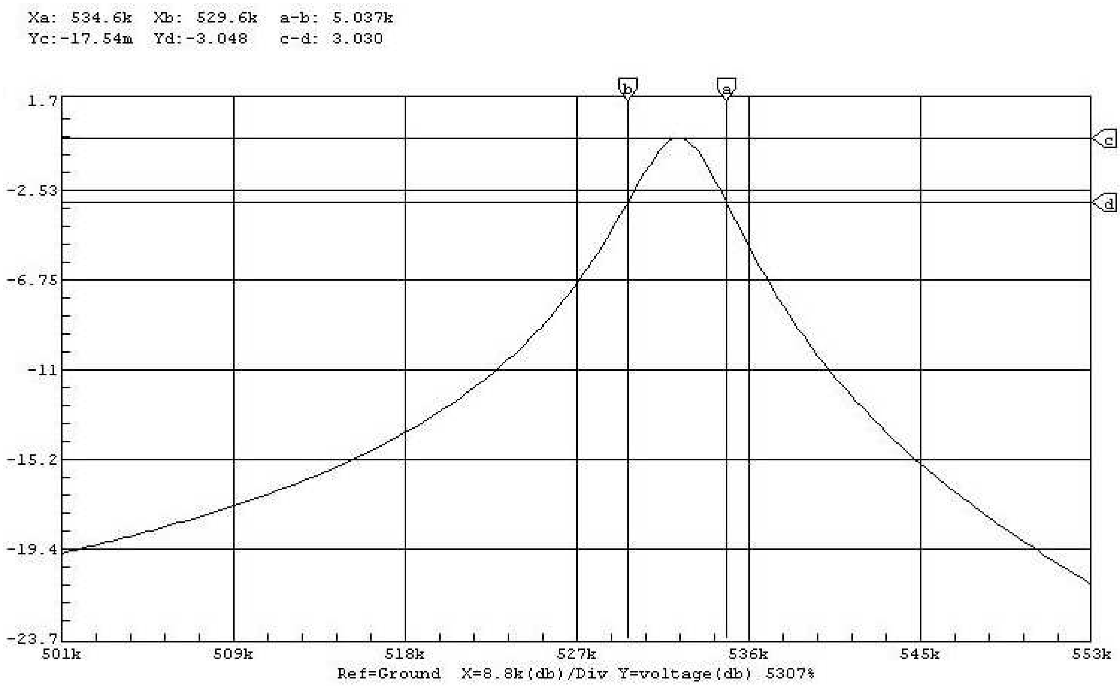

Fig.3.b 3dB bandwidth for a resonance frequency of 530kHz is 5.037kHz

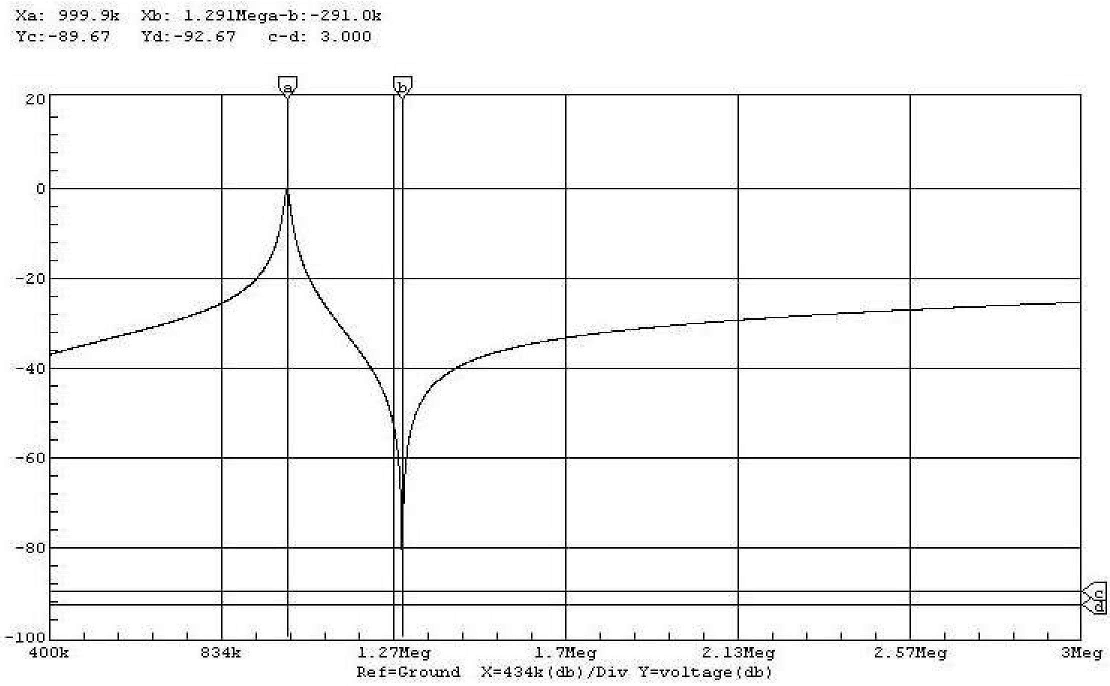

Fig.3.c Frequency response for circuit of Fig.1.b when resonance is adjusted to 1MHz

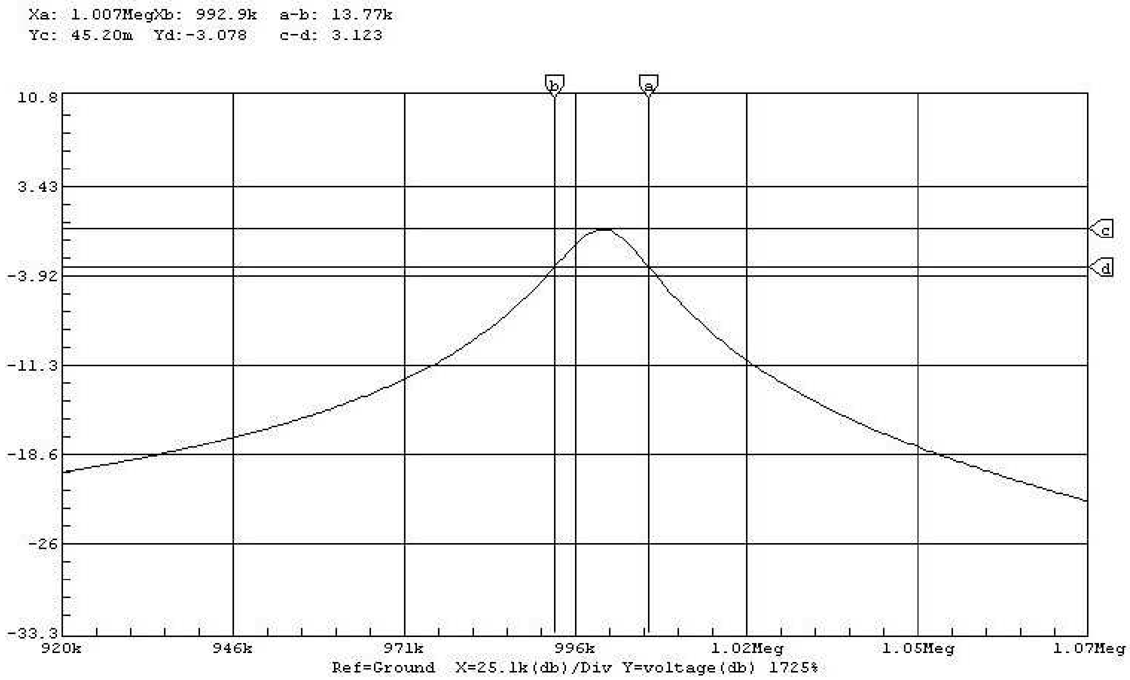

Fig.3.d 3dB bandwidth for a resonance frequency of 1MHz is 13.77kHz

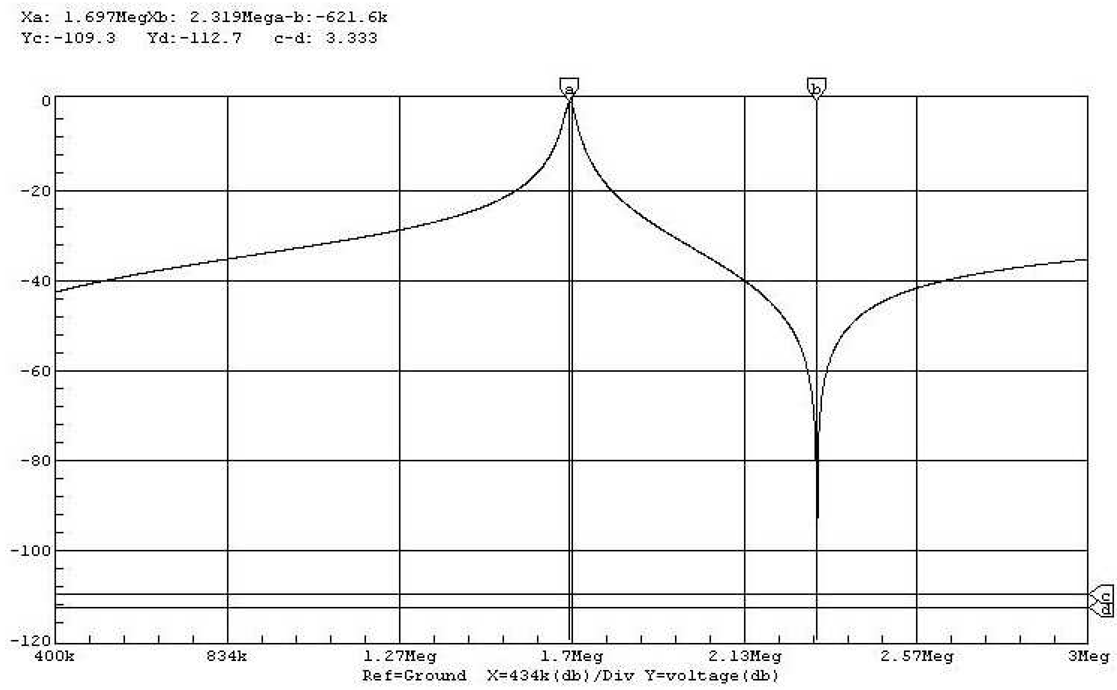

Fig.3.e Frequency response for circuit of Fig.1.b when resonance is adjusted to 1.7MHz

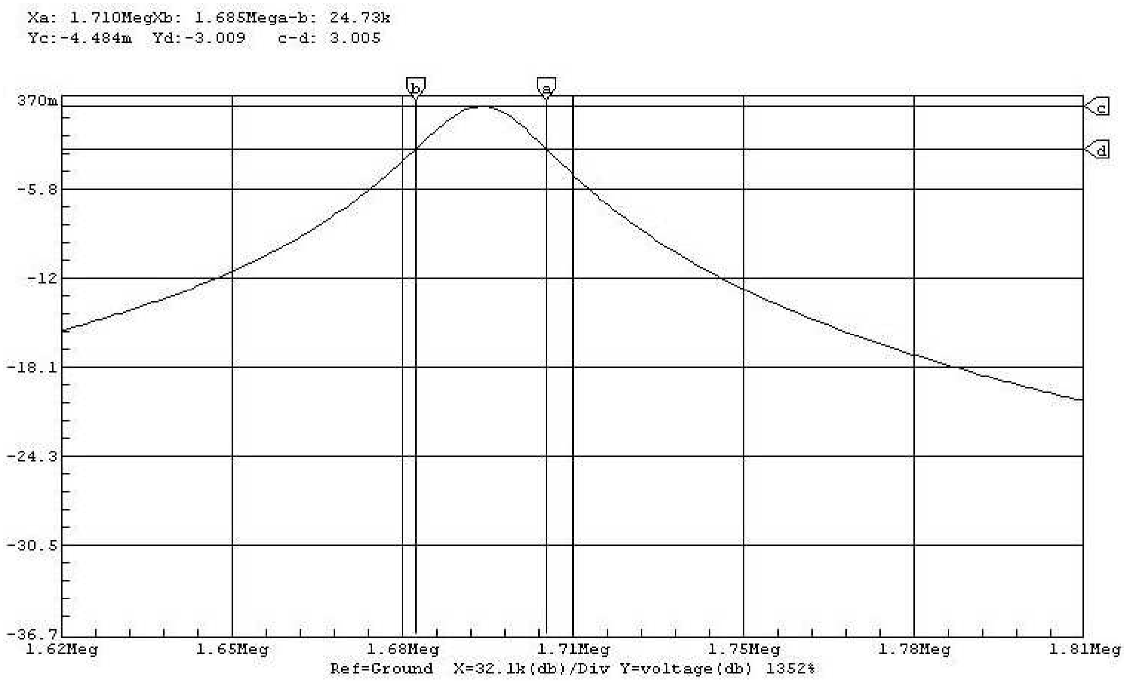

Fig.3.f 3dB bandwidth for a resonance frequency of 1.7MHz is 24.73kHz

3dB bandwidth calculations

We shall now proceed to calculate the 3dB bandwidth of circuit of Fig.1.b.
Mesh current is given by:

$$I = \frac{E_a}{R_e + j\left(\frac{\omega L_1}{1-\omega^2 L_1 C} - \frac{1}{\omega C_T}\right)}$$

where:

$$C_T = \frac{CaC}{Ca + C}$$

The amplitude-frequency relationship for I is determined by:

$$I(\omega) = \frac{E_a}{\sqrt{R_e^{\,2} + \left(\frac{\omega L_1}{1-\omega^2 L_1 C} - \frac{1}{\omega C_T}\right)^2}}$$

At the -3dB points:

$$I(\omega) = \frac{E_a}{\sqrt{2} R_e}$$

The corresponding frequencies must satisfy the equation:

$$R_e^{\ 2} + \left(\frac{\omega L_1}{1-\omega^2 L_1 C} - \frac{1}{\omega C_T} \right)^2 = 2R_e^{\ 2}$$

or:

$$\frac{\omega L_1}{1-\omega^2 L_1 C} - \frac{1}{\omega C_T} = \pm R_e \qquad \ldots(1)$$

Let ω_r be the resonant frequency and $\omega = \omega_r + \Delta\omega$ the frequency at a –3dB point on the amplitude curve. The left hand member of eq. (1) can be written as:

$$\frac{\omega^2 L_1 (C_T + C) - 1}{(1-\omega^2 L_1 C)\omega C_T} = \frac{(\omega_r^{\ 2} + 2\omega_r \Delta\omega)(C_T + C)L_1 - 1}{(1-(\omega_r^{\ 2} + 2\omega_r \Delta\omega)L_1 C)\omega_r C_T}$$

with the following approximations:

$$(\omega_r + \Delta\omega)C_T \approx \omega_r C_T$$

$$(\omega_r + \Delta\omega)^2 = \omega_r^{\ 2} + 2\omega_r \Delta\omega + \Delta\omega^2 \approx \omega_r^{\ 2} + 2\omega_r \Delta\omega$$

Then:

$$\frac{\omega_r^{\ 2} L_1 (C_T + C) + 2\omega_r (C_T + C) L_1 \Delta\omega - 1}{(1-\omega_r^{\ 2} L_1 C - 2\omega_r L_1 C \Delta\omega)\omega_r C_T} = \pm R_e$$

or:

$$\frac{2\omega_r (C_T + C) L_1 \Delta\omega}{\left(\frac{Ca}{2Ca + C} \right) - 2\omega_r L_1 C \Delta\omega} = \pm \omega_r C_T R_e$$

which simplifies to:

$$2L_1 [C_T + C(1 \pm \omega_r C_T R_e)]\Delta\omega = \pm C_T R_e \left(\frac{Ca}{2Ca + C} \right)$$

Now, if $\omega_r C_T R_e << 1$, then:

$$2\Delta\omega = \pm \frac{R_e}{L_1} \left(\frac{C_T}{C_T + C} \right) \left(\frac{Ca}{2Ca + C} \right)$$

this is:

$$\Delta\omega = \pm\frac{R_e}{2L_1}\left(\frac{Ca}{2Ca+C}\right)\left(\frac{Ca}{2Ca+C}\right)$$

$$= \pm\frac{R_{s1}}{L_{eq}}\left(\frac{Ca}{2Ca+C}\right) \qquad \ldots(2)$$

From part II of our study we can obtain the following expression for R_{s1}:

$$R_{s1} = r\left(1+\frac{A}{R_P}\right)$$

Then, the 3dB bandwidth is given by:

$$BW = 2\Delta\omega = 2r\left(1+\frac{A}{R_P}\right)\left(\frac{1}{L_1\left(2+\frac{C}{Ca}\right)}\right)\left(\frac{Ca}{2Ca+C}\right) \qquad \ldots(3)$$

in radians per second.

Next, we shall compute the bandwidths at three frequencies: 530kHz, 1MHz and 1.7MHz. Results are tabulated below.

Freq.(kHz)	BW (kHz)	Q	R_P (kΩ)	A (kΩ)	C (pF)	Ca (pF)	r (Ω)	L_1 (uH)
530	5.004	105.9	354.32	155.50	450	200	30	152
1000	13.47	74.24	558.7	190	100	200	30	152
1700	24.83	68.49	487.072	406.8	31	200	30	152

Results for BW are very close to those obtained from simulation of circuit of Fig.1.b.

Ramon Vargas Patron
rvargas@inictel.gob.pe
Lima-Peru, South America
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