Problem “Resonating modes”

Presented by Belarusian team
Resonating modes
Place a mobile phone inside a metallic container with a hole in it. Investigate under what conditions the mobile phone starts to ring after calling it.
Plan of investigations:
1. To make clear the main principles of the mobile communications;
2. To make sure what the signal is, and what parameters it has.
3. To investigate, how the conducting metal border influences the electromagnetic wave;
4. To research the electromagnetic field in the boxes of some primitive shapes;
5. To find, on which conditions the hole lets the wave pass through.
6. To find the best conditions for the phone to ring.
These 375 Channels are used for uplink from cell phone to cell tower.

GSM 900
890 MHz – 960 MHz

GSM 850
824 MHz – 894 MHz

GSM 1800
1710 MHz – 1880 MHz

GSM 1900
1850 MHz – 1990 MHz

Frequencies and standards

N = 750

Δν = 200 KHz

Resonating modes
How does the phone ring?

- **Uplink**
- **Downlink**
- The phone rings
Signal parameters

Resonating modes
Amplitude, polarization & wavelength (frequency)
Timbre

Resonating modes
Fields near the surface of a good, but not perfect, conductor. For $\xi > 0$, the dashed curves show the envelope of the damped oscillations of $H_c$ (8.9).
Experimental Unit 1: Standing wave

A high frequency generator

Dipole antenna connected to a Voltmeter

Metal screen

20 sm

0

U~

V

Resonating modes
Standing wave

\[ \nu = 3.4 \text{GHz} \]
Resonant cavity

\[ \vec{E}_{\text{max}} \]

Resonating modes
Square resonating cavity

\[ \lambda = \frac{2L}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{L}\right)^2}} \]
Field distribution

\[ E(z) = \text{const} \]

B in the normal section is vortex
Experimental Unit 2. Square cavity

\[ a = 6.5\, sm \]
\[ b = 12\, sm \]
\[ L_{\text{max}} = 25\, sm \]
Experiment №2

\( \nu = 0.9 \text{GHz} \)
Cylindrical resonating cavity 1

**TM oscillations:**

\[
\omega_{mnp} = \frac{1 \cdot c}{\sqrt{\mu \varepsilon}} \sqrt{\frac{x_{mn}^2}{R^2} + \frac{p^2 \pi^2}{d^2}}
\]

\(x_{mn}\) is the \(n\)th root of the equation, \(J_m(x) = 0\).

\(m=0,1,2...\) \(n=1,2,3...\) \(p=0,1,2...\)

**Lowest mode:**

\[
m = 0, n = 1, p = 0
\]

\[
\omega_{010} = \frac{2.405 \cdot c}{\sqrt{\mu \varepsilon} \cdot R}
\]
Field in cylindrical cavity

\[ \frac{\Delta E}{\Delta r} > 0 \]
Experimental Unit 3. TM oscillations

- $R = 6.5 \text{sm}$
- $h_{\text{max}} = 20 \text{sm}$
- We changed height and measured the minimum length of the hole
  
  $d_{\text{min}} = \text{const} = 27 \text{mm}$
Cylindrical resonating cavity 2

**TE oscillations:**

\[ \omega_{mnp} = \frac{c}{\sqrt{\mu \epsilon}} \left( \frac{x_{mn}^2}{R^2} + \frac{p^2 \pi^2}{d^2} \right)^{1/2} \]

\[ m=0,1,2... \quad n=1,2,3... \quad p=1,2,3... \]

**Lowest mode:**

\[ m = 1, \quad n = 1, \quad p = 1 \]

\[ \omega_{111} = \frac{1.841c}{\sqrt{\mu \epsilon R}} \left( 1 + 2.912 \frac{R^2}{d^2} \right)^{1/2} \]
Field in cylindrical cavity
Experimental Unit 4. TE oscillations

\[ R = 9.5\, sm \]
\[ h_{\text{max}} = 25\, sm \]

We also changed height and measured the minimum length of the hole
Experiment №4. TE oscillations

\[ \nu = 1.8 \text{GHz} \]
Part 2: Hole radiation
The slot and currents
Round hole
Experimental Unit №5. Holes
Experiment №5. Holes

$\nu = 3.4\text{GHz}$
Part 3: Phone position
Resonating modes

Antenna types

Cell phone antennas

- Whip antenna: Isn’t tuned quite to resonance
- Planar antenna: Is tuned to resonance → changes field distribution a lot
Phone position
Box position

Resonating modes
Conclusions: What should we do for the phone to ring

• Find a metal box for which the resonance on specified frequency may occur;
• Put the phone into the antinode of standing electromagnetic wave;
• Make a slot near the antinode. Length of the node must be equal to half wave length. It must be normal to vector E;
• Place the box in such way, that the slot will be parallel with the ground and will face the cell tower;
Summary:
The four main factors which the quality of a signal depends on are:
1. The box shape
2. The hole length and position
3. The phone position
4. The box position
We need to keep amplitude as high as possible and all other signal features unchanged for the phone to ring.
Literature:

Wikipedia: Field test mode.
Wikipedia: Timing advance.
Wikipedia: Received signal strength indication.
Wikipedia: Time division multiple access.
Wikipedia: Telecommunications link.
Frequency hopping on GSM networks. CDMA vs. TDMA.
Steve Punter's Southern Ontario Cell Phone Page.
(http://www.arcx.com/)
Jackson J.D. Classical electrodynamics
Feynman's lecions 6: Electrodynamics
Thanks for your attention!
$J_\nu(x_{\nu n}) = 0 \quad (n = 1, 2, 3, \ldots)$

$\nu = 0, \quad x_{0n} = 2.405, 5.520, 8.654, \ldots$

$\nu = 1, \quad x_{1n} = 3.832, 7.016, 10.173, \ldots$

$\nu = 2, \quad x_{2n} = 5.136, 8.417, 11.620, \ldots$
Roots of $J'_m(x) = 0$

$m = 0$: $x'_{0n} = 3.832, 7.016, 10.173, \ldots$

$m = 1$: $x'_{1n} = 1.841, 5.331, 8.536, \ldots$

$m = 2$: $x'_{2n} = 3.054, 6.706, 9.970, \ldots$

$m = 3$: $x'_{3n} = 4.201, 8.015, 11.336, \ldots$
Diffraction

\[ r_0 = \sqrt{\lambda b} \]

\[ r_0 \approx 10 \text{sm} \]